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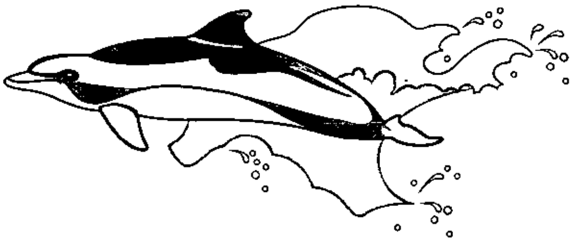

Marine Science and Technology
for
Environmental Sustainability

13,14 and 15 April 2005

Organised by the
School of Marine Science and Technology,
University of Newcastle upon Tyne
jointly with the
EU EcoDock Project
and the
EU POP&C Project

UNIVERSITY OF
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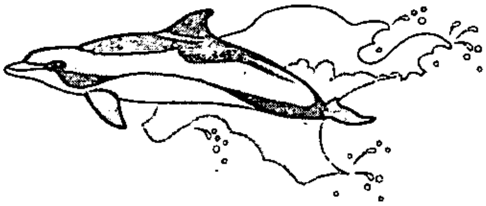

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PREFACE

3rd International Conference on Marine Science and Technology for Environmental Sustainability

This volume contains the papers presented at the 3rd International Conference on Marine Science and Technology for Environmental Sustainability. The conference was organised by the School of Marine Science and Technology, University of Newcastle upon Tyne, in conjunction with the EU EcoDock and POP&C projects.

The EcoDock is a project within the 6th Framework Programme. During the last 5 years marine coating processes have changed due to advanced material developments, changed production systems and international regulations. Marine coating is not just a very complex technology area due to a large variety of production parameters but also because different industrial parties are involved with competing objectives. Ship owner, shipyard, marine paint supplier, classification societies and public authorities have different intentions during the life cycle of a ship. The overall objectives of EcoDock are in this context:

- to improve the performance of marine coatings during the lifetime of a ship,
- to reduce environmental impact of marine coatings during the ship life cycle,
- to provide independent assessment of marine coating systems with regard to the above mentioned categories,
- to establish a European communication platform in order to stimulate the information exchange of the parties involved,
- to speed up the application of advanced environmentally friendly materials and production processes in ship new building, repair and operation.

The POP&C project (**Po**llution **P**revention and **C**ontrol Safe Transportation of Hazardous Goods by Tankers) is a three-year research project which started on the 1st January 2004 under the Growth Programme of the 6th Framework Programme. The support is given under the scheme STREP, Contract No. FP6-PLT-506193. POP&C proposes to deliver a framework and suitable tools for a methodological assessment of risk to be undertaken to provide a rational basis for making decisions pertaining to the design, operation and regulation of oil tankers. Such support can be used to make more informed decisions, which in turn will contribute to reducing the likelihood and severity of future oil spills.

Prof. Atilla Incecik
Chairman, ENSUS 2005 Conference
School of Marine Science and Technology

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3rd International Conference on Marine Science and Technology for Environmental Sustainability

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3rd International Conference on Marine Science and Technology for Environmental Sustainability

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Special thanks are of course due to the authors, delegates and chairpersons; without whom this Conference could not take place.

CRITICAL REVIEW OF AFRAMAX TANKERS INCIDENTS

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ABSTRACT

The paper presents detailed results of a comprehensive analysis pertaining to AFRAMAX tanker incidents occurred in the last 25 years, enabling a thorough review of accidental database information, the identification of significant trends with respect to the impact of ship design, of human and a variety of other factors and the drawing of conclusions on AFRAMAX tanker incidents and of tankers in general, for further exploitation.

1. Introduction

A rational database of AFRAMAX tankers was set up in the framework of the EU funded project POP&C [1] to enable the full exploitation of the raw incidental data compiled and which was commercially available by Lloyd's Marine Information Service (LMIS) [2]. The textual information presented in the incidental data were re-analysed by a team of the POP&C project partners and were introduced in the newly developed database to produce appropriate incidental statistics.

The analysis was mainly focused on six major incident/accident categories, namely Non-Accidental Structural Failure, Collision, Contact, Grounding, Fire, and Explosion. Whilst, on one hand, the analysis made an attempt to identify basic events leading to these major casualty categories, on the other hand, factors related to consequences such as the degree of incidents' severity, event location and ship operating condition at the time of incident, loss of watertight integrity, weather impact, loss of life/injury, oil spill occurrence and the final outcome of incidents were also investigated.

2. Marine Accidents

Although the ship appears by statistics to be the safest mode of transportation, marine incidents always happened and will continue to. The prime concern of ship safety is not to totally eliminate the incidents/accidents, because the probability of occurrence always exists, but to minimise the probability of occurrence and to mitigate the serious consequences of an incident/accident. Investigations into some tragic tanker and other ship accidents have provided an in-depth knowledge and experience to change the safety regime in the past years. Significant outcomes of some catastrophic casualties that were investigated, led to improvements of IMO's regulatory framework and eventually of marine safety and operation.

As far as the Tanker Fleet is concerned, some serious casualties led to the adoption of new regulations or/and amendments of the existing ones. Some spectacular tanker casualties are stated below:

- The grounding of "Torrey Canyon", in 1967, led to the biggest marine pollution in history at that time. The results of this investigation contributed to MARPOL 1973, STCW 1978 and SOLAS 1974 (fire safety provisions for tankers).
- The grounding of "Argo Merchant", in 1976, contributed to the development of Protocol 1978 of MARPOL.
- The grounding of "Amoco Cadiz", in 1978, led to the implementation of MARPOL 1978 Protocol.
- The "Exxon Valdez" casualty, in 1989, led to the adoption of the first regional agreement (application in US waters), OPA 90.
- The "Erika" disaster, in 1999, contributed to the revision of MARPOL 73/78 (Reg. 13G) which regulated a new phase-out for single hull tankers (MEPC - IMO). Furthermore, this particular accident led the European Union to the adoption of the ERIKA I and ERIKA II EU Marine Resolutions.
- Following the "Prestige" accident in 2002, the European Union adopted Regulation 1726/2003 (accelerated single hull tanker phase-out, carriage of heavy grade oils in double hull tankers, enhanced hull condition assessment). This regulation took effect within EU on 21 October 2003. The IMO's Marine Environment Protection Committee (MEPC) adopted amendments to Regulation 13G and produced Regulation 13H to Annex I of MARPOL on 4 December 2003 [Resolution MEPC.111(50) and Resolution MEPC.112(50)].

3. Methodology of work

3.1 Source of Data

The basic information was a comprehensive set of incidental records, provided by INTERTANKO [3] who had originally obtained most of this data from LMIS Ltd [2], concerning all subtypes and sizes of tankers and covering the period 1978 to early 2004.
Since the POP&C project has used the AFRAMAX size tankers to demonstrate the applicability of the developed risk based methodology, the analysis of past incidents was also focused on records pertaining to AFRAMAX tankers. The selection of the particular tanker ship size, namely AFRAMAX, was based on DWT size segment 80,000 – 119,999. In addition to the size, the basic AFRAMAX subtypes were also selected, namely Oil Tankers, Crude Tankers, Shuttle Tankers, Product Carriers and Chemical/Oil Tankers. OBOs and chemical tankers were excluded from the analysis since these tanker subtypes have special design features and layout, which are not representative of the whole AFRAMAX class of tankers. Out of all the available records, 1294 incident records were finally extracted with respect to size and particular tanker subtypes covering the period 1978 to early 2004.

The existing information of the initial records covered the followings:

- Ship basic characteristics (LR/IMO Number, Ship Name, Ship Type, Built Year and DWT)
- Type of incident according to LMIS coding, namely "Hull & Machinery", "Collision", "Grounding", "Fire/Explosion" and "Miscellaneous".
- Year and Location (MARSDEN grid) of incidents' occurrence.
- Degree of severity of each incident, according to LMIS coding.
- Basic information concerning environmental pollution (quantity and units).
- Number of killed and missing persons and the case of Dead ship condition.
- Complementary texts with raw description of the incident concerning the causes, the ship operating condition at the time of incident, the location, environmental pollution and the outcome of the incident concerning the resulting ship's condition.

3.2 POP&C Database

The initial selected records were imported into a database designed by NTUA-SDL to enable a comprehensive analysis of the data. The POP&C Tanker Incidents Database has been set-up in MS ACCESS 2000 format and can run at any PC computer employing MS Office 2000 (or later versions) [4].

The database was further developed in order to register the information of the complementary texts in a proper manner (using checklists, pull-down menus, etc.) so that the information could be easily retrieved and systematically analysed. The registered information was constructed such that the POP&C Risk Contribution Fault Trees (FTs) and Event Trees (ETs) developed by the project could be populated partially or completely. Synoptically, the following considerations were included into the new version:

- New major categories of incident types were predefined, namely: Non-Accidental Structural Failure, Collision, Contact, Grounding, Fire, Explosion, Failure of Hull Fittings, Machinery Failure and Unknown Reasons.
- Each incident category was further described by subcategories or/and descriptions of causes and exact ship's location. Basically, the following considerations were defined in order to follow the POP&C Risk Contribution Fault-Trees.
    1. Non-Accidental Structural Failure occurrence: due to "Structural degradation", due to "poor design/construction" or due to "excessive loading".
    2. Collision occurrence because of: "failure to supervise route" or "failure of avoidance manoeuvring".
    3. Contact: "contact with floating object" or "contact with fixed installation".
    4. Grounding: "Drift Grounding" or "Powered Grounding".
    5. Fire: as initiative event due to "internal source", "external source" (piracy, spread of fire from other ship) or due to "atmospheric conditions" (lightning) along with further description on ship's main location and ignition source.
    6. Explosion: as initiative event in cargo /slop tank, in aft area, on deck or in ballast tank/void spaces, along with ignition source information.
- Enhanced oil spill information concerning the location, proximity to shore, total oil spill quantity and the amount recovered.
- Information on fatalities/ injuries, namely: number of serious injuries, non-serious injuries, fatalities and missing persons.
- Definition of event location and ship's operating condition according to IMO relevant descriptions [5]. Basic information on the environmental condition at the time of incident.
- Outcome of incident with respect to the ship's condition after the incident such as: "Remains Afloat", "Total Loss", "Sailed by her means" or "Towed Away", "Loss of watertight integrity", "Minor" or "Major" Repairs, "Sold for Demolition", "Broken Up", "No Damage Reported or Sustained".
- Finally, information regarding the hull type of ships involved in the incidents was provided by Lloyds Register [6] and was input to the database.

3.3 Population of POP&C Database

The process of populating the POP&C database was carried out by the authors. Each partner organisation undertook the task of studying the accompanying complementary textual information for each incidental record and entering the relevant information in the format specified above. Because of the fuzzy character of the majority of the available information of the incidental records and also for ensuring the non-biased assessment of the incidental records to the extent feasible, a second round review of all records was conducted, by exchanging the records between the analysts. It should be noted that when the raw record data were poor, requesting the personal judgement of the analysts for proper population of the database, a slightly different degree of 'strictness' was observed in relation to the assumptions made. The final control and assessment of all database input as well as the analysis of data [7] was the responsibility of the database developer.

4. Review of Results

The overall distribution of the initial 1294 records pertaining to AFRAMAX tankers, after the POP&C population process, is presented in Table 1.

Since the scope of POP&C project is to evaluate incidents that led directly to ship's loss of watertight integrity (LOWI), the analysis of data was focused on the six major incident types, namely Non-Accidental Structural Failure, Collision, Contact, Grounding, Fire, and Explosion incidents.

Although significant proportion of the incidents were due to Machinery Failure and Failure of Hull Fitting (26% and 11% respectively), these particular categories were not considered in the analysis because they do not lead directly to loss of watertight integrity. When incidents in the above categories subsequently result in grounding, contact, etc, they are accounted for in the appropriate resulting event categories. Also, incidents characterised by Unknown Reasons were also excluded because of their insufficient information.

Table 1 – Distribution of major incident types according to POP&C analysts, Covered period 1978 to early 2004

POP&C Incident Type	No. of Incidents	All Categories Percentage		Six major types Percentage
Collision	233	18%		29%
Grounding	194	15%		25%
Contact	126	10%		16%
Non-accidental Structural Failure	121	9%		15%
Fire	79	6%		10%
Explosion	39	3%		5%
Total of six major types	***792***			***100%***
Machinery Failure	337	26%		
Failure of Hull Fittings	137	11%		
Unknown Reasons	28	2%		
	1294	**100%**		

With respect to the whole analysis process and the given statistics of accidents, it is noted that records with partly missing relevant information, indicated as "unknown" in the original LMIS taxonomy, were not separately classified, but embedded in records with known information, except for the category 'unknown reasons', that was kept separate from the others.

4.1 Review of Non-Accidental Structural Failure incidents

In total, 121 incidents were caused by Non-Accidental Structural Failure (see Table 1). *Structural Degradation* was found in 17% of the particular sample, 66% was as a result of *Excessive Loading* and 17% was due to *Poor Design/Construction.*

Event Location and Ship operating condition

The majority of Non-Accidental Structural Failure incidents were found to have taken place in Open Sea. Specifically;

- 68% took place in Open Sea
- 18% took place at Berth
- 9% took place at Port and Port Approach
- 3% took place in Coastal Waters, 1% in River and 1% at Anchorage.

At the time of the Non-Accidental Structural Failure incidents, ships were under the following operating conditions:
75% were En-route, 18% were: Discharging (9%), Loading (5%) & Ballasting (4%), 4% were: at Berth (3%) or in Port (1%) and 3% were: Manoeuvring (1%), Towed (1%) or Mooring (1%).

Environmental Condition at the time of incident
39% (47 incidents) of the Non-Accidental Structural Failure incidents were affected by heavy weather conditions.

Oil Pollution
84% (102 incidents) of the Non-Accidental Structural Failure incidents did not lead to environmental pollution. With respect to the incidents that caused pollution, the following conclusions can be drawn: 37% took place in Open Sea, 37% took place at Berth, 13% took place at Port and 13% during Port Approaching

Outcome of incident
- In 9% of the Non-Accidental Structural Failure incidents, no damage, if any, was reported.
- 27% sustained damage requiring minor repairs.
- 61% of the Non-Accidental Structural Failure incidents led to major repairs to ships.
- 3% led to the vessel's total loss (Total loss, Sold for Demolition & Broken Up).

4.2 Review of Collision incidents

In total, 233 incidents were caused by collision (see Table 1). In 80% of the collision incidents, the ship had failed to do an *Avoidance Maneuver* and in the rest of the cases the ship's crew had failed to *Supervise Route.*

Event Location & Ship operating condition
The majority of collision incidents were found to have taken place within confined waters, namely Coastal, Restricted Waters, Port, Berth and Anchorage. This could be expected due to the fact that these places have heavy traffic rate. More specifically,
- 40% took place either in Port (19%), or at Anchorage (12%), or at Berth (7%) or during Port Approach (2%).
- 36% took place in Coastal (33%) and Restricted Waters (3%).
- 13% took place in Open Sea.
- 10% took place in Canals (2%), Rivers (7%) or Inland waters (1%).
- 1% took place at Drydock.

At the time of the collision incidents, the following holds for the operating condition:
63% were En-route, 15% were: at Berth (6%), Anchoring (5%), Towed (2%) or Mooring (2%), 11% of the collision incidents happened during Manoeuvring, 10% took place during Discharging (8%), Bunkering (1%) and Loading (1%) and 1% was Under Repair.

Environmental Condition at the time of incident
Only 6% (14 incidents) were affected by heavy weather conditions.

Oil Pollution

96% (223 incidents) of the collision incidents did not lead to environmental pollution. With respect to the few incidents (10) that caused oil pollution, the following conclusions could be drawn (bearing in mind however the very small size of the statistical sample here):
56% took place in Coastal Waters, 22% took place at Port, 11% took place in Anchorage and 11% was in Open Sea.
In relation to the event location, environmental pollution caused by collision incidents, occurred primarily in confined waters.

Outcome of incident

- In 30% of the collision incidents, no damage, if any, was reported.
- 59% sustained damages requiring minor repairs or no damage at all.
- 11% of the incidents led to major repairs to ships.

4.3 Review of Contact incidents

In total, 126 incidents were caused by Contact, Table 1. Almost half (45%) of the contact incidents refer to *contact with a floating object* and the rest (55%) *to contact with a fixed installation.*
Concerning *contact with floating object,* in 64% of the cases, *the object was detected but it could not be avoided,* because of either *Manoeuvring Avoidance Error* (33%) or *Steering System Failure* (67%). In the rest of the cases (36%), *the object was simply not detected.*
Regarding the incidents involved in *contact with fixed installation,* in almost all cases (97% of the particular incidents) the *object was detected but it could not be avoided,* due to *Manoeuvring Avoidance Error* (82%), due to *Steering System Failure* (9%) or due to *Bad Environmental Condition* (9%).

Event Location and Ship operating condition

Contact incidents occurred primarily in confined waters, as could be expected due to the nature of the incident, like Collision incidents. Specifically,

- 37% took place at Port (36%) or during Port Approach (1%)
- 23% took place in Coastal (20%) or Restricted Waters (3%)
- 16% took place at Berth
- 13% took place in Rivers (9%), Canals (3%) or Inland waters (1%)
- 7% took place in Open Sea
- 4% took place at Drydock (3%) & Shipyard (1%).

At the time of the contact incidents, the following holds for the operating conditions:
48% were En-route, 36% took place during Manoeuvring and 16% were at Berth (8%), while Towed (3%), Mooring (3%), at Port (1%) or while Discharging (1%).

Environmental Condition at the time of incident

Only 2% (3 incidents) of the contact incidents were affected by heavy weather conditions.

Oil Pollution

89% (112 incidents) of the contact incidents did not lead to environmental pollution. With respect to the 14 incidents that caused pollution, the followings statistics apply:
51% took place in Port, 14% took place in Rivers, 14% took place in Coastal Waters, 7% took place in Canals, 7% took place at Berth and 7% took place in Open Sea.

In relation to the event location, environmental pollution caused by contact incidents, occurred primarily in confined waters (as is the case for collision incidents).

Outcome of incident

- In 16% of the contact incidents, no damage, if any, was reported
- 74% sustained damages requiring minor repairs or no damage at all
- 10% of the incidents led to major repairs.

4.4 Review of Grounding incidents

In total, 194 incidents were caused by Grounding, Table 1. The majority (90%) of the grounding incidents were characterised as *Powered grounding* and the remaining 10% as *Drift grounding.*
In *Powered grounding* incidents, 83% were attributed to *"Squat Effect". Drift groundings* were caused due to *loss of propulsion* (40%), whereas the remaining 60% were due to *loss of steering.*

Event Location and Ship operating condition
Grounding incidents primarily took place in shallow waters.

- 33% took place in Coastal Waters
- 28% took place in Rivers and Inland Waters
- 21% took place in Canals
- 14% took place at Port and Port Approaches
- 3% were at Anchorage (2%) or Berth (1%), and
- 1% took place in Open Sea.

At the time of the grounding incidents, the following holds for the operating conditions:
90% were En-route, 4% were during Anchoring, 4% were at Berth (2%) or in Port (2%), 1% was during Discharging and 1% was while being Towed.

Environmental Condition at the time of incident
Only 8% (16 incidents) were affected by heavy weather conditions.

Oil Pollution
91% (176 incidents) of the grounding incidents did not lead to environmental pollution.
With respect to the 18 incidents that caused pollution, the following statistics apply based on this limited sample size: 28% took place in Coastal Waters, 24% took place in Rivers, 12% took place at Ports, 12% took place in Canals, 12% took place in Open Sea, 6% took place at Berth, and 6% took place during Port Approach.
In relation to the event location, environmental pollution caused by grounding incidents occurred primarily in shallow waters that are close to the land.

Outcome of incident

- In 37% of the grounding incidents, no damage, if any, was reported
- 42% sustained damages requiring minor repairs or no damage at all
- 16% of the incidents led to major repairs to ships
- 4% were sold for Demolition and Broken Up
- 1% was Total Loss/ Capsize.

4.5 Review of Fire incidents

In the LMIS database Fire and Explosions are considered as a single category. Upon examination of the location and also consequences of the fire and explosion incidents, there was a clear difference between the two. Therefore, it was decided to investigate these incidents separately.

In total, 79 incidents were caused by Fire, Table 1. Based on the analysis of POP&C database, in 4% of the investigated fire incidents, an explosion followed as a second major event.
As far as the nature of the source is concerned, the great majority (97%) were caused by *"Internal Source"* and the remaining 3% by *"External Source"*.
Regarding the incidents for which Fire was caused by *"Internal Source"*, the following can be indicated: 83% took place in ship's Aft Area, 16% took place in Cargo/ Slop tanks and 1% took place in Ballast Tanks/Void Spaces.

Focusing on the incidents which occurred in the *ships' Aft Area*:

- in 83% of these incidents, the fire started in the area of Machinery Spaces, below the main deck namely:
    - the fire started from the *Engine Room* in 83% of the incidents
    - the fire started from the *Pump Room* in 17% of the incidents
- in 17% of the incidents in ship's aft area the fire started *On Superstructure.*

Focusing on the fire incidents initiated *On Superstructure,* 83% of them started in Accommodation area, whereas the remaining 17% started in Bridge area.

Given the small sample of information concerning the Ignition Source (34 incidents), the following distribution is given: 43% were due to *Hot Works,* 24% were due to *Electrical Faults,* 18% were due to *Equipment Failure,* 9% were due to *Remains of Crude Oil,* 3% (i.e. 1 incident) were due to *Prohibited Transfer* of crude oil to bunkers and 3% were due to *Heating Equipment* (Boiler & Preheater).

Event Location and Ship operating condition

Many fire incidents occurred in Port and Port Approaches. Also, a considerable percentage was found to have taken place in non-confined waters (Open Sea).

- 44% took place in Port (41%) & Port Approaches (3%)
- 23% took place in Open Sea
- 11% took place in Coastal Waters
- 15% took place in Shipyard (11%) or Drydock (4%)
- 5% took place at Berth, and
- 2% took place in Canals (1%) and Rivers (1%).

At the time of the "Fire" incidents, the following holds for the operating conditions:
45% were En-route, 28% were Under Repair (26%) or during Ship's Construction (2%), 11% were at Berth, 9% were during Discharging (7%) or Bunkering (2%), and 7% took place while Mooring.

Environmental Condition at the time of incident

Only 3% (2 incidents) of fire incidents were directly affected by the heavy weather conditions.

Oil Pollution

Only 1 incident led to oil pollution to the environment while the vessel was *At Berth*; the fire started in *Engine Room.*

Outcome of incident

- In 38% of the "Fire" incidents, no damage, if any, was reported
- 43% sustained minor repairs (39%) or no damage at all (4%)
- 15% of the incidents led to major repairs to the ship
- 4% were sold for demolition (1%) or to be broken up (3%).

4.5.1 Review of fire incidents initiated in Engine Room

Focusing on the fire incidents initiated in the *Engine Room,*

- 39% of the incidents had a serious degree of severity, 3% led to ship's total loss and 58% of the incidents had a non-serious degree of severity. The above percentages indicate that Fire incidents caused in the area of Engine Room need special attention as they often lead to severe consequences.
- In relation to the Ignition Source (information on 12 incidents): 50% of the incidents were due to *Electrical Faults* (6 incidents), 25% due to *Equipment Failure* (3 incidents), 8% due to *Heating Equipment* (1 incident), 8% due to *Prohibited Transfer* of crude oil to bunkers (1 incident) and 8% due to *Hot Works* (1 incident).
- In 3%, explosion followed as a second major event.

It should be noted however that the basis of all the above percentages are small numbers.

Event Location and Ship operating condition

- 36% took place in Port (30%) or Port Approaches (6%)
- 30% took place in Open Sea
- 22% took place in Coastal Waters
- 9% took place at Berth (6%) or in Shipyard (3%), and
- 3% were in Rivers.

At the time of the fire incidents initiated in Engine Room, the following holds for the operating conditions: 72% were En-route, 12% were at Berth, 12% took place during Discharging or Bunkering, and 4% took place when the vessel was under construction/repair

Outcome of incident

- In 47% of the fire incidents initiated in Engine Room, no damage was reported.
- 30% of the incidents sustained minor damages
- 20% of the incidents led to major repairs
- in 3% of the incidents, ship was broken up.

4.5.2 Review of fire incidents initiated in Cargo/ Slop Tanks (12 incidents)

Focusing on the area of *Cargo/ Slop tanks,*

- Only in one (1) incident, the fire was followed by an explosion.
- All of the particular incidents had non-serious degree of severity.
- The majority (10 out of 12) of the particular incidents were caused due to *"Hot Works"*.

Event Location and Ship operating condition

- 75% took place in Shipyards & Drydock
- 17% took place in Port, and
- 8% took place at Berth

At the time of the fire incidents initiated in Cargo/ Slop Tanks, the following data can be mentioned: 83% was under repair and 17% was at Berth.

The event location, as well as the ship operating condition at the time of incident, indicates that these incidents were mainly caused by human error.

Outcome of incident

- In 25% of the fire incidents initiated in *Cargo/ Slop tanks*, no damage, if any, was reported.
- in 25% of these incidents, no damage was sustained.
- 50% of the fire incidents initiated *Cargo/ Slop tanks* sustained damages requiring minor repairs.

4.6 Review of Explosion incidents

In total, 39 incidents were caused by Explosion, Table 1. Based on the analysis of the database, in 41% of the investigated explosion incidents, fire followed as a second major event.
Concerning the location of the initiation of the explosion incidents, the great majority (62%) started in the ship's *Aft Area,* 24% in the *Cargo / Slop Tanks,* 11% *on Deck* and 3% in ship's *Ballast Tanks / Void Spaces.*

Given the small sample of information concerning the Ignition Source (9 incidents), the following distribution is given: 56% were due to *Hot Works*, 22% were due to *Electrical Faults,* and 22% were due to *Electrostatic Charges.*

Event Location and Ship operating condition
A considerable percentage of the Explosion incidents occurred outside confined waters as well as a considerable percentage of occurrences taking place at Port. Specifically

- 40% took place in Open Sea and Archipelagos
- 35% took place in Port
- 14% were in Shipyard (11%) or Drydock (3%)
- 5% took place in Coastal Waters
- 3% were at Anchorage and 3% in Rivers.

At the time of the explosion incidents, the following holds for the operating conditions:
43% were En-route, 33% were Under Repair, 14% were in Port (7%) or during Anchoring (7%), and 10% took place during Discharging.

Environmental Condition at the time of incident
There is no indication that weather had an impact on the particular incidents.

Oil Pollution
5% of the explosion incidents (2 incidents) led to environmental pollution.

Outcome of incident

- In 30% of the explosion incidents, no damage, if any, was reported.
- 31% sustained damages requiring minor repairs or no damage at all
- 18% of the incidents led to major repairs to the ship
- 13% were sold for demolition and were broken up, and
- 8% were Total Loss/ Capsize.

4.6.1 Review of explosion incidents initiated in Cargo/ Slop Tanks

Focusing on the area of *Cargo/ Slop tanks where there are 9 incidents recorded:*

- 1 incident happened during tank cleaning.
- 1 incident happened although tanks were degassed.

4.6.2 Review of explosion incidents initiated in Aft Area

Focusing on the incidents initiated in *the Aft Area* the following can be stated:

65% of the incidents started in Engine Room, 20% started in Boiler Room, and 15% started in Pump Room.

5. Discussion

5.1 Incident Categories

Fig. 1 presents the distribution of all incident categories for the range of years 1978-2003, as derived from the POP&C Database, (see also Table 2).

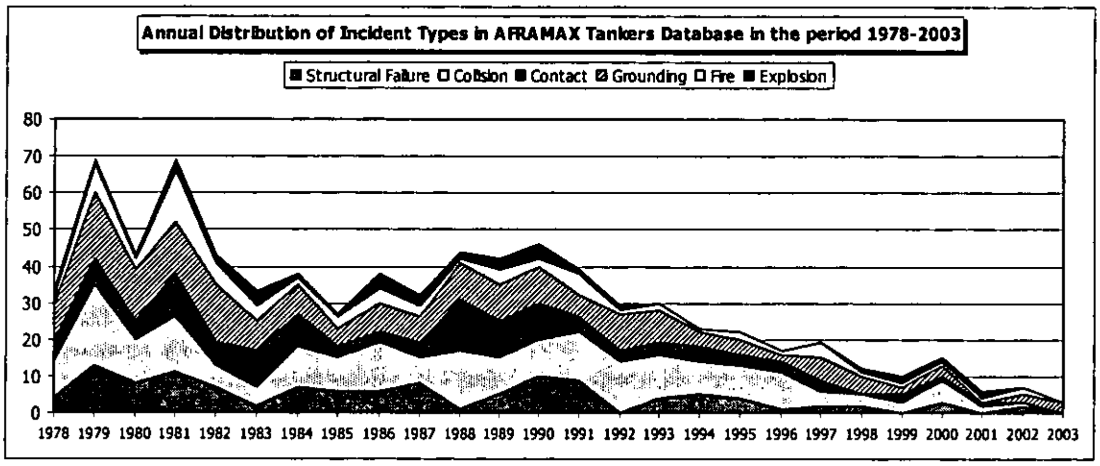


Fig. 1 – Distribution of major incident types, POP&C Database, period 1978 – 2003.

Table 2 - Number of incidents, POP&C Database, period 1978 – 2003

Year	Number of incidents, POP&C Database, period 1978 - 2003						Sum
	Structural Failure	Collision	Contact	Grounding	Fire	Explosion	
1978	4	10	5	10	2	2	33
1979	13	22	7	18	8	1	69
1980	8	12	5	14	3	1	43
1981	11	15	12	14	14	3	69
1982	7	6	6	16	6	2	43
1983	2	5	10	8	4	4	33
1984	7	11	9	8	2	1	38
1985	6	9	3	5	3	1	27
1986	6	13	3	8	4	4	38
1987	8	7	4	7	3	3	32
1988	1	16	14	10	1	2	44
1989	5	10	10	10	4	3	42
1990	10	10	10	10	2	4	46
1991	9	13	4	6	6	1	39
1992	0	14	3	10	1	1	29
1993	4	12	3	9	2	0	30
1994	5	9	4	4	1	0	23
1995	4	9	3	4	2	0	22
1996	1	10	3	2	1	0	17
1997	2	4	3	6	4	0	19
1998	2	3	0	5	1	1	12
1999	0	3	2	2	1	2	10
2000	3	6	1	3	1	1	15

2001	0	2	1	0	1	2	6
2002	2	1	0	2	2	0	7
2003	0	0	0	3	0	0	3
	120	*232*	*125*	*194*	*79*	*39*	*789*

As can be seen from the table, an increase of incidents is noted in years 1979 and 1981, as well as within the period 1988-1991. Afterwards, there is a clear tendency of reduced numbers of incidents for all incident categories presented, particularly after the early 90ties. This could be attributed to the adoption and implementation of enhanced regulations concerning ship's safety and pollution (e.g. OPA 90, MARPOL), as well as operation, and also to the increased safety awareness and safety culture amongst ship owners and operators.

5.2 AFRAMAX tankers vs. All Tankers

Fig. 2 presents the number of incidents concerning AFRAMAX tankers within the period 1980-2003 (POP&C database), as well as the total number of incidents for All Tankers (Source: INTERTANKO) for the same time period. Actually no data for all tankers were available for pre-80.

It is noted that the initial LMIS incident category "Hull & Machinery" (Fig. 2: 6735 incidents) is herein compared with the three (3) relevant POP&C incident categories, namely "Failure of Hull Fitting", "Non-Accidental Structural Failure" and "Machinery Failure" (Fig. 2: 501 incidents). Similarly, the unified LMIS category "Fire and Explosion" is compared with the sum of POP&C categories "Fire" and "Explosion".

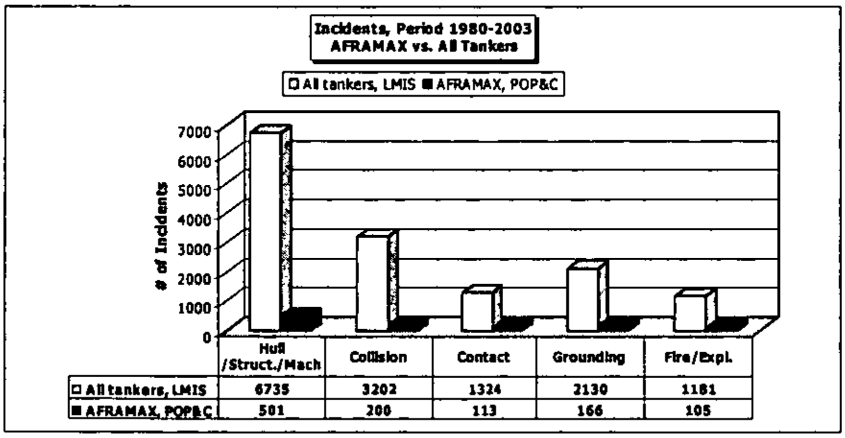


Fig. 2 – AFRAMAX vs. All Tankers, number of incidents per incident type

Incidents of AFRAMAX tankers correspond to 6.3-8.9 % of incidents of all tankers, Table 3, depending on the type of incident. The upper percentage (8.9%) refers to the Fire & Explosion Incidents and the lower one to Collision Incidents.

Table 3 - AFRAMAX vs. All Tankers, Period 1980-2003

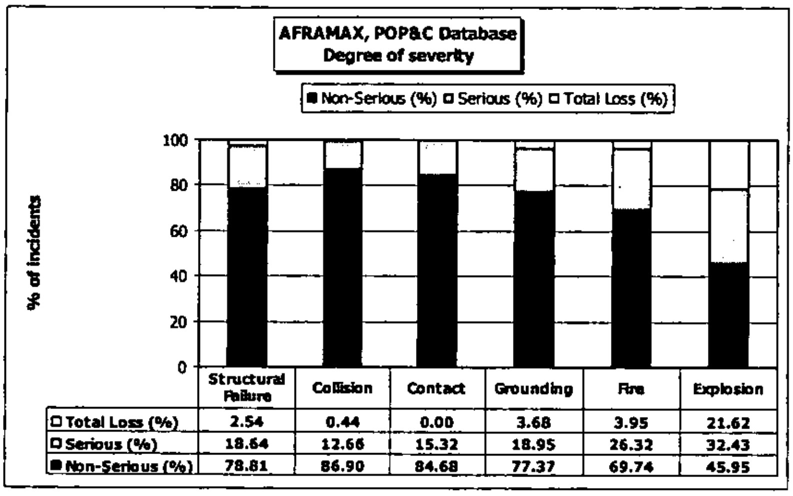
Incident Type	**AFRAMAX incidents as a % of all tanker incidents (Fig. 2)**	**Number that corresponds to the 19% of incidents of All Tankers involved**	**Actual # of AFRAMAX incidents**
Hull/Struct/Machinery	7.4	[6735*0.19] = 1280	501
Collision	6.3	[3202*0.19] = 608	200
Contact	8.5	[1324*0.19] = 252	113
Grounding	7.8	[2130*0.19] = 405	166
Fire/Explosion	8.9	[1181*0.19] = 224	105

The AFRAMAX Fleet corresponds to about 19% of the Total Tanker Fleet. This percentage is computed as the average value of the operating fleet within the period 1980-2003. From the last two columns of Table 3, it is evident that with respect to the ship size categorisation; the number of incidents that AFRAMAX tankers were involved is relatively low for the part of fleet they present.

5.3 Degree of severity[1]

The following results are considered of major importance, Fig. 3:

- 19% of Non-Accidental Structural Failure incidents are characterised by serious degree of severity.
- 13-15 % of Collision and Contact incidents have serious degree of severity and the case of ship's loss could be considered as negligible.
- 19% of Grounding incidents are characterised as serious and in 4% of the particular incidents the ship was lost.
- 26% of Fire incidents are considered serious and in 4% of the particular incidents the ship was lost. Based on this consideration, ***Fire Incidents are characterised as the second most severe incident event, regarding this type of tankers.***
- ***Explosion is the most severe incident event*** due to the fact that more than half of the explosion incidents are characterised by serious consequences (32 % had serious degree of severity and 22% led to ship's total loss, in total amounting to 54%).



	Structural Failure	Collision	Contact	Grounding	Fire	Explosion
□ Total Loss (%)	2.54	0.44	0.00	3.68	3.95	21.62
□ Serious (%)	18.64	12.66	15.32	18.95	26.32	32.43
■ Non-Serious (%)	78.81	86.90	84.68	77.37	69.74	45.95

Fig. 3 – AFRAMAX incidents, degree of severity, POP&C database

5.4 Ship's Loss of Watertight Integrity (LOWI)

Fig. 4 presents the number of incidents, per incident type, where Loss of Watertight Integrity has occurred.

The large percentage of incidents (29.8%) that underwent LOWI occurred due to Non-Accidental Structural Failure. LOWI occurred in between 17 to 24 percent of incidents in relation to Grounding, Contact and Collision incidents. Whilst only in 13% of Explosion incidents LOWI occurred, the occurrence of LOWI is considered almost negligible in Fire Incidents.

With respect to the ship's loss of watertight integrity, Non-Accidental Structural Failure incidents are the most severe incident event.

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[1] According to LMIS coding

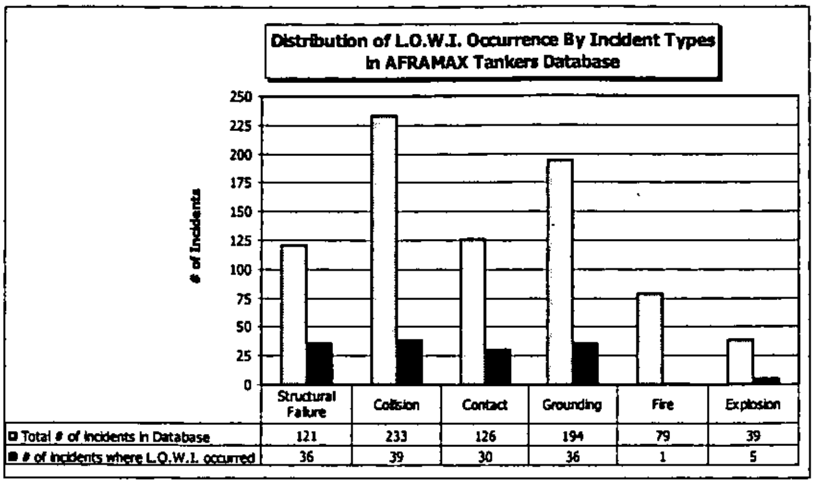

Fig. 4 – AFRAMAX incidents, L.O.W.I., POP&C database

5.5 Weather Impact

Fig. 5 shows the number of incidents where the environmental conditions had an impact on the incident noting the followings:

In 39% of the Non-Accidental Structural Failure incidents, the environmental condition appears to be a contributing factor to the incident. Comparing the data for the other incident types, it could be concluded that the Non-Accidental Structural Failure incidents are often caused (or at least, triggered) by bad weather, in contrast to the other incident categories for which the weather is much less of a contributory factor.

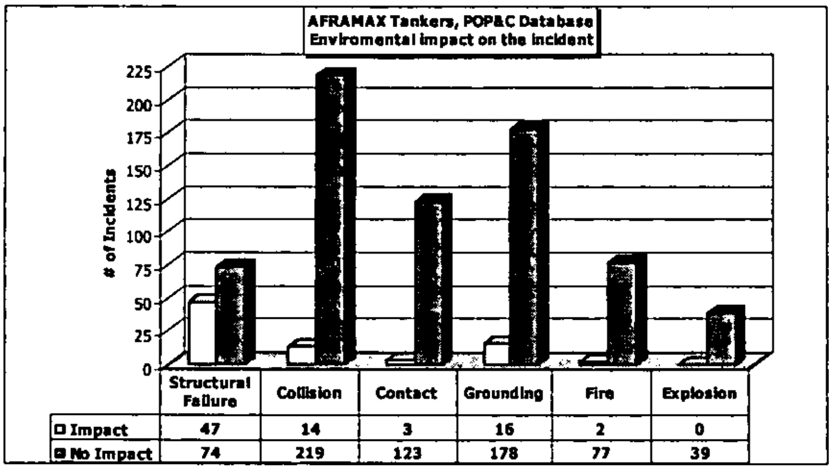

Fig. 5 – AFRAMAX incidents, Weather Impact, POP&C database

5.6 Oil Pollution Quantity

Fig. 6 presents the total oil spill quantity in tonnes, as derived from the POP&C database per incident type.

With respect to the oil spill quantity, Grounding incidents gave the larger total oil pollution quantity (see Fig.6 and Table 4). The highest number of incidents causing environmental pollution arises from Non-Accidental Structural Failure. The severity of the Explosion incidents is once again highlighted. For example, two Explosion incidents led to more pollution than nineteen Non-Accidental Structural Failure incidents.

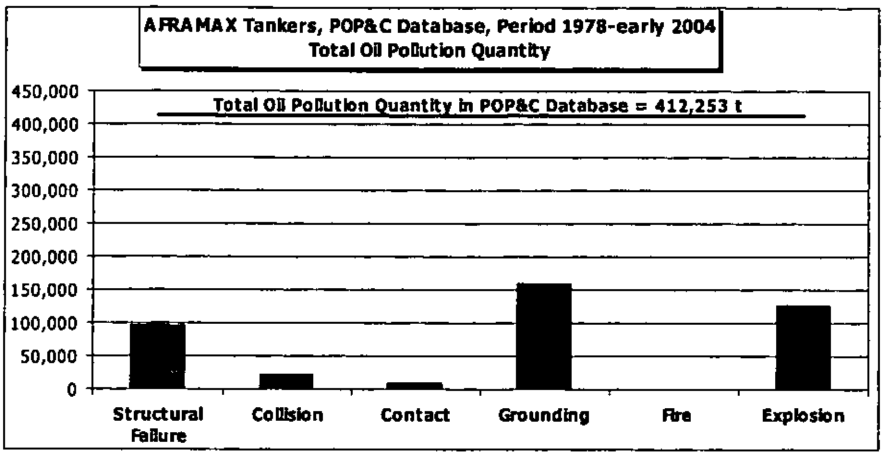

Fig. 6 - Oil spill quantity in tonnes, AFRAMAX tankers, POP&C database

Table 4 - Incident Categories vs. Pollution Quantity, period 1978-early 2004

Incident Type	Number of Incidents	Number of incidents causing pollution	Number of incidents w/o pollution	% of incidents with Oil Spilt	Total Oil Pollution Quantity per incident type, t	% of oil spill quantity, per incident type
Structural Failure	121	19	102	15.70	96,370	23.38
Contact	126	14	112	11.11	7,878	1.91
Collision	233	10	223	4.29	20,934	5.08
Grounding	194	18	176	9.28	158,869	38.54
Fire	79	1	78	1.27	676	0.16
Explosion	39	2	37	5.13	126,260	30.63
Total Oil Pollution Quantity in POP&C Database, t					*412,253*	

Note that only 0.3% of total oil pollution quantity is coming from the other non-studied incident categories (i.e. categories of Machinery Failure, Failure of Hull Fitting and Unknown Reasons).

5.7 Injuries and Fatalities

There are no records of fatalities and injuries for the Non Accidental Structural Failure, Grounding and Contact incidents.

Regarding Collision incidents, the total number of fatalities amounts to 25 persons and the number of injuries is 2 persons.

In Explosion incidents, twenty-two (22) fatalities were recorded and four (4) persons were injured.

In the case of Fire incidents, there were 22 fatalities and 27 injuries.

The consequences in terms of safety of life confirm the severity of the explosion and fire incidents.

5.8 Quality of Data in Incident Databases

Accident databases such as the one utilized by POP&C are potentially important tools for gauging the safety and the environmental performance of the industry. They can be used to guide the regulatory process so that the regulations that are being produced may be focused so as to address the weakest links in the safety and environmental prevention chain, and also they can be used to provide alerts for areas of design, operation and training which may be in need of additional attention or of a new approach.

Whereas the recognition of the potential value of marine accident databases is not new, the databases that currently exist suffer from two basic and serious weaknesses that greatly diminish our ability to utilize this data. These two problems were faced by the analysts of the POP&C project, and whereas they could not be resolved within this project, the experience gained is certainly worthy of dissemination because until these problems start being resolved, accident data will remain mostly underutilized.

It might be argued that a lot of maritime accident records already exist in the public domain in the form of commercially available casualty databases (examples are: the old LMIS database, the LR-Fairplay database, and the Lloyd's Marine Intelligence Unit database). Whereas these international databases contain a plethora of records of shipping casualties (and a plethora of records are certainly needed in order to arrive at statistically meaningful conclusions), they all tend to suffer greatly from the fact that the source of their information is more often than not, non- technical. And anyone who has worked with such data will probably confirm this serious limitation.

The second stumbling block to the utilisation of accident data arises from the way the information is categorised. Accidents are assigned a single category, such as Collision, Grounding, Fire/Explosion, Hull & Machinery etc. This one-dimensional categorisation ignores the basic fact that accidents are sequences of undesirable events, each of these having their own probability profile, as for example a fire can lead to loss of power or steering, which in turn can lead to grounding. Using a single code to define an accident takes away vital information for any subsequent analysis and in the days of computers is an unnecessary restriction. It should therefore be evident that accident categorisation (accident taxonomy) is in need of a rethink and a restructure.

6. Acknowledgements

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The European Community and the authors shall not in any way be liable or responsible for the use of any such knowledge, information or data, or of the consequences thereof.

7. References

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A RATIONAL RISK BASED APPROACH FOR DESIGN AND OPERATION OF TANKERS

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The European Commission provided funding for a 3-year project entitled "Pollution Prevention and Control – Safe Transportation of Hazardous Goods by Tankers" (POP&C) under Framework Programme 6 (FP6), which started in January 2004. The POP&C project aims to develop a framework and first-principles tools for a methodological assessment of risk, which could then form a rational basis for making decisions pertaining to design, operation and regulation of oil tankers.

In this paper, the main philosophy behind the POP&C project is discussed and the basics of the proposed methodology detailed and explained. To demonstrate the methodology adopted, the Aframax class of tankers is considered. Six casualty categories, namely collision, contact, grounding, structural failure, fire and explosions were identified as the key hazards leading to loss of watertight integrity.

A key to risk assessment methodology is to account for the consequences of main hazards accurately. Consequences for tanker accidents comprise loss of lives / serious injuries, loss of property and, most importantly for oil tankers, damage to environment. The methodology to be adopted for determining consequences due to environmental damage (oil outflow and its impact to the environment) is also discussed.

1. Introduction

Since the early 90s tanker design and operations have seen significant changes with the introduction of stricter international regulations resulting in considerable improvements in the safety record of the tanker industry. Despite these improvements, the two recent accidents *Erika* (1999) and *Prestige* (2002), with their heavy oil cargoes caused extensive pollution on European shores. The implications (political, social and economic) of these two accidents resulted in the consideration of an accelerated phase-out of single hull tankers by the EU [1], which eventually led to an internationally agreed accelerated phase out schedule [2]. At the same time, the Condition Assessment Scheme (CAS) for single hull tankers was introduced as a means of verifying that their structural integrity is maintained to the required standards for the remainder of their reduced life.

In the context of European Union, sea transportation is a key element in developing sustainable surface transportation in Europe. Considering that tankers carry close to 40% of the world seaborne trade - Europe having a good share of this trade - safe shipping in general, and in particular safe transportation of hazardous goods by tankers is one pre-requisite to reducing environmental impact on Europe's coastline. Leading by example, the European Commission provided funding for a 3-year project entitled "Pollution Prevention and Control – Safe Transportation of Hazardous Goods by Tankers" (POP&C) under Framework Programme 6 (FP6), which started in January 2004 [3].

The development of a framework and first-principles tools for a methodological assessment of risk, which could then form a rational basis for making decisions pertaining to design, operation and regulation of oil tankers has been the main aim of the POP&C project. Such rational assessment methodology can be used to make more informed decisions, which will in turn contribute to reducing the likelihood and severity of future oil spills. The project has brought together 15 organisations with expertise in maritime safety covering design, construction, classification, and operational aspects of the maritime sector in Europe.

This paper aims to present the main philosophy behind the POP&C project and to detail and explain the basics of the proposed methodology. To demonstrate the methodology adopted, the Aframax class of tankers has been considered. Six casualty categories (namely collision, contact, grounding, structural failure, fire and explosions) have been identified as the key hazards leading to loss of watertight integrity and were used as the basis to the analysis of the LMIS tanker accidents' database covering a period between 1978 and 2003. In this respect, a HAZID analysis was carried out based on expert judgement. The analysis yielded interesting conclusions and provided useful data for the validation/calibration of numerical tools under development as part of the risk model adopted. It is not intended to discuss in detail the results of both analyses in this paper, but simply to present in brief the progress made thus far.

Consequences of tanker accidents comprise loss of lives / serious injuries, loss of property and, most importantly for oil tankers, damage to the environment. The methodology to be adopted for determining consequences due to environmental damage (oil outflow and impact to the environment) is also discussed.

2. Pollution Prevention and Control Methodology

The pollution prevention and control methodology is described in Figure 1. The key components of the pollution prevention and control framework are explained in the following sections.

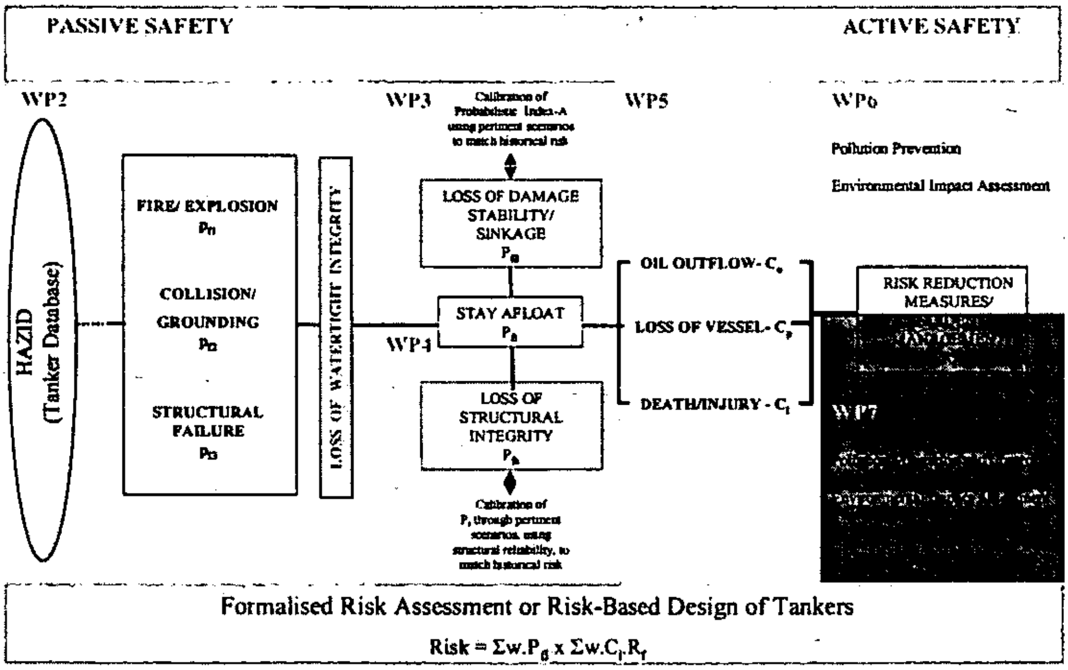

Figure 1 - The Risk based pollution prevention and control framework.

2.1. Hazard Identification (HAZID) and Ranking

The primary purpose of Hazard Identification and Ranking process is to identify main hazards that lead to a vessel's loss of watertight integrity and consequently cause pollution and environmental damage. The study made use of accident statistics and fault tree / event tree analysis to determine their probability of occurrence. This was achieved by:

- considering a representative sector of the tanker fleet covering a wide range in size and trade, operating worldwide, and sampled to form a database;
- defining a suitable methodology for hazard identification and ranking;
- identifying hazards potentially leading to loss of watertight integrity and consequently likely to cause pollution and environmental damage, and detailing them further.
- ranking the hazards according to the method defined previously;
- determining the associated risks against the hazards and identifying and selecting the most critical scenarios.

A database with a representative number of tankers specified to be of AFRAMAX size (80,000 to 119,999 deadweight tonnes) with pertinent information on casualties and technical ship characteristics covering a wide range of representative tankers operating within worldwide waters was compiled [4]. The database included accident/incident records that were elaborated to produce appropriate accident statistics. Where possible, relationships between these statistics and particular tanker characteristics were developed. The database included approximately 1300 incidents (all recorded accidents/incidents by LMIS on AFRAMAX tankers between 1978 and 2003). A comprehensive analysis of the incident/accident records of the POP&C database was performed enabling a thorough review of the information in hand, the identification of significant trends with respect to the impact of ship design, of human and a variety of other factors and the drawing of conclusions on tanker incidents/accidents for further exploitation.

To carry out the HAZID analysis, the project identified that the focus should be on the hazards that can potentially lead to **L**oss **O**f **W**atertight **I**ntegrity (LOWI). "LOWI" means loss of **hull integrity** (and not necessarily integrity of cargo containment) as the project is more focused on stability and structural questions, which can potentially lead to severe consequences including oil pollution. Hazards leading to oil pollution but do not involve the loss of watertight integrity of the ship were excluded from the scope of the study. That is to say, hull fittings' failures (e.g. piping and valve failures, or hose failures) or failures resulting from operational procedures (such as loading/unloading or bunkering) were not considered to be within the scope of the project even though they might lead to cases of pollution.

A number of methods may be utilised for hazard identification and ranking. The following mainstream techniques are used in the maritime field of risk analysis studies: What-If Analysis, What-If/Checklist Analysis, Hazard and Operability Analysis, Failure Modes and Effects Analysis, Fault Tree Analysis, Event Tree Analysis and Human Hazard Identification. A method utilising both the Fault Tree (FT) and Event Tree (ET) techniques was selected to be utilised in the project [5]. The main incident categories used, aligned with the objectives of the POP&C, include collision, contact, grounding, non-accidental structural failure, fire, and explosion, contributing to the development of the POP&C risk model.

The FTs (one Fault Tree for each accident category) developed were partly populated based on the historical accident/incident information available from the analysis of POP&C database. Historical data were not sufficient to fully quantify the risk model due to incompleteness of the information on individual incidences, thus a brainstorming approach was considered based on expert judgement involving experts from the maritime industry. The objectives of the brainstorming exercise were

- to estimate the likelihood of occurrence of the accident scenarios.
- to estimate the consequences of each scenario for the ship, human life and the environment.
- to identify risk control measures able to prevent or to mitigate the effect of these incidents.

The brainstorming exercise yielded very tangible outcomes in the sense that it enabled Fault Trees to be populated quantitatively and Event Trees to be populated based on qualitative judgement. Based on the discussion with the experts a list of risk control options was also identified to be further elaborated in determining Risk Control Options (RCOs) for prevention and/or for mitigation and control (active measures). Based on the populated FTs and ETs, the accident scenarios were ranked according to their risk index, which is the combination of the frequency of their occurrence and the severity of their consequence, and thus critical scenarios were identified based on risk indexes calculated considering the three separate consequences indicated above [6].

The identification of the most critical scenarios is a two steps process, which considers the results of the event tree analysis and the results of the fault tree analysis. The reason for the identification of the most critical scenarios is that although total risk is made up of summation of a very large number of scenarios, a small number of critical scenarios may contribute significantly (say 90% or above) to the total risk level. This allows scenarios judged of minor importance to be ignored for the analysis, thus reducing the effort significantly. Actually, a scenario of an accident is a sequence of events starting from one or several basic events of a given fault tree to the final event of the related event tree. A minimal cut sets analysis was performed for the fault trees in order to identify the most critical basic events for each type of incident. For the event trees, as mentioned previously, consequences due to loss of life, loss of property and oil pollution were used in the ranking process.

2.2. Loss of Damage Stability

Three situations will arise following an accident leading to breach of watertight integrity; the ship will capsize as a result of loss of stability, the ship will break up and sink as a result of loss of structural integrity or the ship will remain afloat having suffered some sinkage/trim (see Figure 1). The immediate concern would be on the loss of stability since this would result in rapid capsize, whereas loss of structural integrity may be a more gradual event. Thus, the survivability performance of a tanker will need to be assessed next.

The survivability of a ship needs to be investigated probabilistically considering all possible damage sizes. This requires the probability of the damage extent for all pertinent incident categories (grounding, collision, contact, structural failure, fire and explosions) to be determined.

The statistics of damage extent for collision and grounding were extensively collated and consolidated in the HARDER project [7] for all ship types, making it the most comprehensive data available for collision damage. POP&C project partners have investigated whether the HARDER database can be utilized for tankers only and for both collisions and groundings. The key findings of this investigation [8] are as follows.

For AFRAMAX tankers the collision and grounding damage extent distributions developed by MARPOL, modified to limit extent for collision damage length and collision penetration for large tankers, should be used. The proposed SOLAS Harmonized distributions [9], derived from HARDER statistics for all types of ships, are not as good a match for the tanker only data. For smaller tankers these distributions will underestimate collision damage penetration and length and alternative distributions would be more appropriate. It is noted that the HARDER data utilized were supplemented by the IMO MARPOL distributions currently used for evaluation of alternative tanker designs.

Although significantly less data is available in HARDER database for contact-ensuing damagethe analysis of the data indicates that amage extent is reasonably approximated by that corresponding to collision damage. Therefore, it has been suggested that the MARPOL statistics for collisions be used for the AFRAMAX tanker investigation when a contact takes place. Of course, the probability of having a contact will be treated separately from collisions, and it is expected that the consequences of the damage may be quite different depending upon sea conditions and environmental constraints.

Unlike collision, contact and grounding, a literature search has revealed that no comprehensive data exist for fire, explosion and structural failure damage extents. Moreover, the POP&C accident database has proved insufficient to develop probability distributions for damage extents in the same way as collision and grounding damage extents. Therefore, a different approach had to be adopted in identification of damage extent from fire, explosion and structural failure. Efforts concentrated on determining the probability of loss of watertight integrity and damage leading to pollution, loss of lives / injuries due to fire and explosions, and structural failure. It is assumed that depending on the amount of oil spillage, a damage size could be identified as one compartment or multi-compartment damage.

For fire and explosions, the location of the damage was identified by considering areas/ compartments with specific functions such as engine room, pump room, boiler room, accommodation area, ballast tanks, cargo and slop tanks, etc. where the likelihood of such hazards realizing is high. For structural failures, the location of the damage was identified as in "cargo area" and "non-cargo area".

From the statistical analysis of AFRAMAX tankers and also from an analysis of ALL TANKERS greater than 10,000DWT, it was found that 83% of the fire incidents started in the aft area and 12 % were in the cargo/slop tanks. Although 11% of the total fire incidents resulted in total loss of the vessel, it is noted that this percentage does not directly relate to capsize (as a result of loss of stability) and breaking up (as a result of loss of structural integrity) cases, since in most cases the ship was scrapped for financial reasons (i.e. the ship being beyond economic repair).

Explosions can lead to loss of watertight integrity and oil pollution, either directly through hull breaching or loss of the ship. Twenty-two percent (22%) of explosions for AFRAMAX tankers and 25% of explosions for ALL TANKERS greater than 10,000DWT led to total loss of the vessel (economic or physical loss). In the case of the AFRAMAX tankers the analysis established that a third of these losses were physical losses. It is interesting to note that for loss of watertight integrity, existing regulations provide for survival of most outcomes of fires and explosions.

Oil pollution arising from explosions that do not lead to total loss can be approximated to the spillage from at most two tanks in nearly all cases: 42% of events occur in the Cargo and Slop tanks or Ballast and Void space areas, and in all these damage can be limited to breaching of one transverse bulkhead; 50% of the damage is assigned to occur in the engine and pump rooms with damage limited to those spaces; while the remaining 8% is assigned to take place in other places.

For structural failure incidents, 30% of the incidents occurred in "non-cargo area" whilst the remaining 70% of the incidents occurred in "cargo area". Heavy weather was a significant contributing factor in structural failures with 46% of the incidents directly influenced by heavy weather conditions. Also, 3% of the structural failure incidents led to oil pollution greater than 7 tonnes.

Numerical prediction models of single hull and double hull tankers have been developed to carry out the theoretical estimates of capsize. The product of the probability of an individual damage case occurring, and the probability of loss due to that damage in a seaway is summed over all damage cases with appropriate weights pertaining loading conditions to develop an overall probability of loss. A similar approach has been developed to estimate the overall expected mean oil outflow. This is similar to existing IMO methodologies. In this way, a survivability index A is determined for a large number of cases and its complement used for estimating loss probabilities [10]. Since the historical data contains mostly single hull tankers, comparison and calibration between the theoretical estimates and the historical data needs to be restricted to single hull tankers only. From this, index A will be calibrated against the historical risk first and subsequently it will be used to find the risk associated with the loss of damage stability for any vessel construction.

The approach agreed upon to calibrate the results is the one presented above. In taking this approach it was recognized that various configurations and sizes of Aframax tankers would need to be considered to establish the validity of results for all Aframax tankers. Thus a description of the fleet at risk with the proportion of the fleet at risk for the various sizes and configurations would be needed. A possible calculation methodology is shown in Figure 2. This would require more than 10,000 calculations to be performed to determine the survivability index.

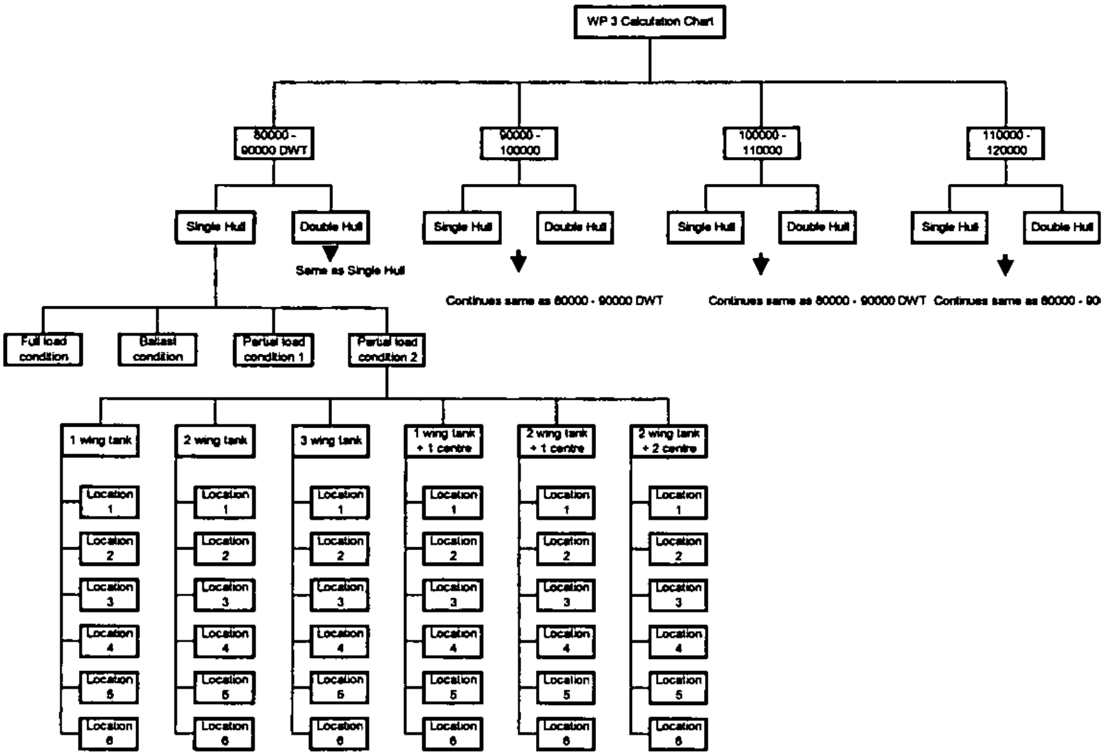

Figure 2 - Survivability index calculation matrix.

2.3. Loss of Structural Integrity

For Aframax tanker accidents, the probability of loosing the hull structural integrity in the event of loosing the watertight integrity of the hull was investigated next. The structural reliability of a damaged tanker was assessed considering global and local loads acting on the hull structure considering all relevant limit states. To achieve this, the following steps were considered.

Identification of the damage scenarios for the detailed structural analysis

This requires, the description of the damages sustained by the ship but also the definition of the loads acting on the ship pertinent to the sea state at the time of the incident. These two types of information are required to perform modelling and structural assessment. However an accident scenario is a complex set of events which is not limited to the size of the damage and to the loading condition. Actually a damage scenario is characterised by a number of factors such as duration of the scenario, location of the ship at the time of the incident, weather conditions encountered by the ship, actions taken by the crew, external assistance, etc.

Hence a general methodology was developed in order to describe in a structured manner a scenario of an accident [11]. This led to the definition of an exhaustive list of damage scenarios. A scenario was described as a sequence of events starting from the initiating event to the end event of interest that can be divided into 5 main blocks.

Block1 - *The initial situation*
The first block gives an overview of the situation prior to the occurrence of the incident, i.e. the ship, her loading conditions, her location and the environmental conditions.

Block2 – *The incident*
This block describes the incident sustained by the ship. In POP&C project, the following six incident categories were considered: Collision, Contact, Grounding, Non-accidental structural failure, Fire, and Explosion. Each of these incidents may potentially lead to the vessel's loss of watertight integrity and consequently cause pollution and environmental damages.

Block 3 - *The immediate structural damage description*
Block 3 presents the damage from its general state to a detailed description; in particular the following information is given: damage area, damage type and extent.

Block 4 - *A sequence of events immediately after the occurrence of the incident*
The sequence of events right after the occurrence of the incident is described in this block. It includes both the progression of the damage that was described in block 3 and the events such as "Temporary repairs", "Pumping", "Beaching", "Ship floats free or Hard aground", "Progressive Flooding", "Ship starts listing – loss of stability", etc. that can describe the situation or actions taken by the crew. In general, the damage progression results from events subsequent to structural failure appearing on board, i.e. a succession of torsion, buckling, tearing movement causing the rupture of the ship.

Block 5 - *A sequence of events occurring during a longer period of time*
This block has the same aim as the block 4, but in a longer-term situation which means approximately 10 hours after the incident. Discharge of cargo, Beaching, Re-floating, Towing, Sailed by her means and Damage Progression could be the events described in this block diagram. The environmental conditions are in this case of primary importance for the ship survival.

Non-linear dynamic collision analysis for both single and double hull tanker

Existing collision and grounding damage statistics are based on historical accident data mainly for single hull tankers and do not realistically represent double hull designs. It is expected that collision and grounding damage statistics for double hull tankers will be different and the use of existing damage statistics may lead to unrealistic conservatism.

Therefore, rational damage extent statistics for double hull vessels from the existing data on single hull vessels have currently been developed by carrying out dynamic collision analysis. The approach adopted is as follows:

A number of collision scenarios are applied to single hull tanker. For each of the scenario the selected collision speed, angle and orientation, and the collision energy and damage extent are recorded. The same collision scenario (i.e. same contact speed, angle and orientation) is then applied to double hull tanker resulting in different collision energy and damage extent. Using the exiting relationship between the damage probabilities and damage extents for single hull tankers, one can generate damage extent probabilities for double hull tankers. The non-linear Finite Element dynamic analysis code LS-DYNA is utilised for this study.

Non-linear residual strength analysis on both single hull and double hull tanker for the selected limited number of scenarios

Probabilistic residual strength assessment for damage ships requires a simplified, fast and accurate method of analysis so that a large number of scenarios can be evaluated within a reasonable time. Such a simplified method is under development within the POP&C project. It is necessary that such a simplified method will have to be validated and verified for complicated scenarios against detailed numerical calculations using non-linear finite element modelling and analysis.

For this reason, seven damage scenarios per ship type (i.e. single and double hull tanker) have been considered: 3 collision cases, 3 grounding cases and 1 explosion. Detailed numerical calculations are currently being carried out by considering 3 hold models using ABACUS non-linear finite element software.

Development, Validation/Calibration of a simplified residual strength assessment numerical method to be able to handle large number of damage scenarios

A simplified residual strength assessment numerical method is to be developed to be able to handle a large number (thousands) of damage scenarios. This simplified method will be validated and calibrated using the results of non-linear finite element analysis.

Once the simplified model is validated satisfactorily, the simplified model will be used to determine the probabilities of failure that the tanker is lost/seriously damaged due to loss of structural integrity after damage.

2.4. Consequence Analysis

In general, consequences of tanker accidents are grouped into three: oil pollution, loss of lives/serious injuries, and loss of property.

As expected, the emphasis in POP&C project is on the probabilistic oil outflow performance and the associated oil pollution risk to the environment. A probabilistic oil outflow method [12] (adopted by IMO) will be employed to determine the amount of oil outflow for each of the accident scenarios. This is relatively straightforward prediction methodology. The difficulty arises when the effect of the amount of oil spilt to the environment is considered. Factors such as type of oil, amount and rate of spillage, physical, biological and economic characteristics of the spill location, weather conditions, proximity to shore, and time of year need to be considered. Such an assessment will vary significantly from one location to another and it is very difficult to make generalization applicable to all oil spill accidents. There is also debate on whether this assessment should be based on monetary value rather than physical measures such as amount of oil spill, area or length of shoreline polluted, etc. as discussed above. A study was carried out by the Marine Board, USA [13] which concluded that it was very difficult to put a realistic cost value to a pollution accident and therefore used pollution quantity as a measure.

It was therefore decided that physical measures are to be considered to determine the consequences of oil pollution to the environment. For the environmental impact analysis, selected specific locations around Europe namely Baltic Sea, Bosphorus Strait (Mediterranean sea), Bay of Biscay, English / French Channel where significant tanker traffic is present will be considered. The environmental impact analysis for these locations will be determined considering the above-mentioned factors specific to these areas.

Although, consequences of environmental impact are the focus of POP&C, consequences to lives and property are also to be considered in the project.

2.5. Determination of Risk

In general, the risk is defined as the frequency (probability) of occurrence times the consequence. Probabilities of oil outflow, loss of lives/serious injuries and loss of property for the main hazards identified as collision, contact, grounding, fire, explosions and structural failure will be determined, where possible, from the first principles approaches discussed in earlier sections of this paper. For instance, probabilistic damage stability calculations and damage ship structural reliability calculations will provide frequencies of tanker vessel capsizing or breaking into pieces (resulting in total loss) enabling the probabilities of oil outflow and loss of property to be determined. There is no direct relationship between the loss of lives and the ship being damaged or lost. In this case, the analysis of historical data will be used to determine the frequency of occurrence.

In this way, the risk due to individual hazards can be calculated as

$$\begin{Bmatrix} R_{collision} \\ R_{contact} \\ R_{grounding} \\ R_{fire} \\ R_{\exp losion} \\ R_{structural\ failure} \end{Bmatrix} = \begin{Bmatrix} P_{collision} \\ P_{contact} \\ P_{grounding} \\ P_{fire} \\ P_{\exp losion} \\ P_{structural\ failure} \end{Bmatrix} x \left\{ P_{capsize}, P_{strength}, P_{\sin kage} \right\} x \left\{ \begin{Bmatrix} C_{pollution} \\ C_{property} \\ C_{lives} \end{Bmatrix} x \left\{ W_{pollution}, W_{property}, W_{lives} \right\} \right\}$$

where, **P** represents the probability of occurrence vector, **C** denotes the consequences vector and **W** is the weighting function vector.

Total risk, R_{total} is then determined by summing up the risks for individual hazards;

$R_{total} = \sum_{i=1}^{6} R_i$ where, *i=collision, contact, ...,structural failure.*

In the above equation, a weighting function is introduced in an attempt to combine the consequences due to oil pollution, loss of lives and property. It is still under discussion whether such an approach is rational. This approach will resort to the requirement of acceptability criteria for the combined risk, which has to be developed. The calculated risk is then compared and checked against the acceptability criteria.

An alternative approach is to calculate risk to oil pollution, risk to lives and risk to property separately without resorting to any weighting functions. In this way, the calculated risk is checked against three separate acceptability criteria (these acceptability criteria are already established) for three categories of risks (oil pollution, loss of lives and loss of property).

2.6. Risk Reduction through Active Prevention

For each tanker design the risk will be calculated inherent to the features of design, condition of the ship, area of operation, etc. This calculated risk can be reduced by considering active preventative measures (mainly aimed at reducing the frequency of accidents) and active mitigation and control measures (mainly aimed at reducing the consequences of the accidents). In this part of the study, risk reduction through active preventative measures is addressed.

The study will incorporate:

- Identification of measures to reduce pollution risk by prevention in ship operation, and the development of an adequate number of counter-measure scenarios.
- Examination and evaluation of scenarios which include the use of integrated on-board data (navigation- and weather data, tank gauging and flooding sensors).
- Scenarios which contain counter measures appropriate for high seas and for coastal waters; scenarios will include risk control by manoeuvring and tug escort options.
- Identification of generalised scenarios and counter measures; operability diagrams for pollution prevention will be developed and their effectives will be assessed.
- Development of an active risk-reduction index.

2.7. Risk Reduction through Active Mitigation and Control

Risk reduction through active mitigation and control is aimed at reducing the consequences of the oil pollution. A pollution mitigating and control framework capable adequately covering oil spill incidents/accidents will be developed. This will be achieved by identifying, ranking and assessing a critical mass of risk reduction proposals and measures (Risk Control Options (RCOs) and Pollution Control Options (PCOs)). Onboard procedures, policies, guidelines, technologies and practices, along with human factor aspects and characteristics will be examined to produce a reliable operational synthesis for adequate oil pollution mitigation and control.

The study will focus on onboard procedures and activities and onboard salvage activities to mitigate pollution, although it is worth noting that a direct investigation into the recovery of oil by dealing with oil confronting technologies, such as skimmers and other external devices, is outside the scope of this study. It is expected that the effectiveness of onshore pollution containment activities and issues such as close proximity containment measures (deployment of onboard booms) will be incorporated.

Operational issues of pollution mitigation and control based on the selected pollution control options will be integrated in order to formulate the operational matrix. The operational and environmental conditions of the identified PCOs (hardware, software or "liveware") will be determined and their efficiency in terms of pollution mitigation capability will be assessed.

Human factors in terms of pollution mitigation efficiency and capability will be dealt with by addressing a comprehensive functional analysis and the consequent incorporation of procedural guidelines and training issues.

Although it is not in the scope of the project to develop an onboard decision support tool for pollution mitigation and control, the usefulness of a potential decision support tool will be assessed.

A risk reduction index through mitigation and control will be developed and will be incorporated into the total risk discussed in the previous section.

3. Conclusions

As a result of recent tanker catastrophes within EU waters, the prevention of future oil spills receives the highest importance from the European Commission (EC). The financial support provided to POP&C project is one testimony to the commitment of the EC.

The aim of the POP&C project is to improve the overall safety in transportation of hazardous goods through the development of a risk-based methodology that encompasses ship design and operation (passive and active safety). For existing tankers, the focus is to control risk through identifying and evaluating cost-effective pollution preventative and mitigative measures by active means. For new designs, the focus is to approach the design of tankers rationally by integrating risk analysis into the design process, assessing risk systematically using first-principles and addressing prevention/reduction of pollution risk by passive (design) and active (operation) means as one of the design objectives alongside more traditional objectives relating to performance and functionality.

Achieving all of the above will introduce a sea change on tanker safety.

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CORROSION CONTROL METHOD BY USING CLEAN INERT GAS TO BALLAST TANKS AND PERMANENT VOID SPACES IN MARINE AND OFFSHORE STRUCTURES

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This paper presents the economical solution to control corrosion of cargo oil tanks, ballast tanks and other marine / offshore structures by using clean inert gas system such as inert gas generator or N_2 *generator. The investigation shows that inert gas generator can be installed onboard with relatively small amount of initial cost and operating cost for most of crude oil tankers. The optimised design is proposed in this research and cost evaluation between conventional boiler flue gas uptake inert gas plant and inert gas generator system are investigated. In addition, time-variant hull section modulus degradation is estimated based on using the clean inert gas for double tanker.*

1. Introduction

Sea water is an aggressive corrosive environment because it is a good electrolyte and contains corrosive salts. The marine environment is a sea water environment and this means that corrosion in marine structures which are generally fabricated from various grades of mild steel and low alloy steel, is often very severe, not only under immersed condition in ballast tanks but also under general exposure to atmospheric conditions.

Corrosion eventually reduces the thickness of a ship's structure and corresponding reduction in both local and overall strength of the structure. Improperly maintained ageing ship structure could finally lead to disastrous casualties in rough seas and heavy weather. There are many methods that can be employed in order to protect marine structures from corrosion, such as paints and other forms of coatings and cathodic protection, etc. However there are no perfect long lived corrosion protection systems or methods which are used in a marine environment and it is inevitable for vessels to experience some corrosion to some greater or lesser extent.

In the mid of 1970's there were series of explosions in crude oil tankers, especially during the tank cleaning work on-board and where an inert gas system was not installed. As a consequence an inert gas system is now required on new tankers as described by Regulation 60 and Regulation 62 of Chapter II-2 of the SOLAS Protocol [1]. With such a gas system protection against a tank explosion is achieved by the introduction of inert gas into a cargo tank in order to keep the oxygen content low and to reduce the hydrocarbon gas concentration in the tank atmosphere. Recently Matsuda et al.[2] and Tamburri et al. [3] have introduced a new concept to prevent aquatic introductions and to reduce corrosion by using clean inert gas in ballast tanks. However the initial cost for installation and operating cost are still too high to adopt these kinds of new system to many ship's owners.

This paper presents an economical solution to control corrosion in marine/offshore structures by using inert gas. As an economical solution, an inert gas generator or a N2 generator can be used to control corrosion of both cargo tanks and ballast tanks. Especially an inert gas generator can be installed onboard with a small amount of initial cost and moderate operating cost for most of crude oil tankers. Whereas a N_2 generator can also be economical solution for the ballast tanks and permanent void spaces in container vessels and bulk carriers and in offshore structures where the inert gas system is not compulsory by the rule requirement.

An optimised design is proposed in this paper with approximate cost evaluation. In addition, the time-variant hull section modulus degradation is estimated based on using clean inert gas in the ballast tanks and void spaces in order to verify the effectiveness of new corrosion control method.

2. Types of Inert Gas Systems

The main purpose of inert gas systems in crude oil tankers is the protection against a tank explosion by the introduction inert gas into a tank in order to both keep the oxygen content low and reduce the hydrocarbon gas concentration in the tank atmosphere.

Generally an inert gas system is used during the following operations of crude oil tankers:

- Cargo oil discharging,
- Hydrocarbon gas purging after tank cleaning for gas freeing,
- Tank cleaning,
- Topping-up at sea,
- Gas freeing of ballast tank in cargo area.

For a gas carrier, the inert gas system is used for following operations:

- To supply inert gas into the cargo tanks during gas purging,
- To supply inert gas into the cargo tanks during air purging,
- To supply dry air into the cargo tanks during aeration,
- To supply dry air for drying the cargo tanks and cofferdam spaces,
- To supply inert gas for inerting cargo piping, cargo machinery and cargo machinery room via spool piece,
- To supply dry air for drying the duct keel via spool piece etc..

There are three types of inert gas plants, namely conventional boiler flue gas uptake inert gas plant, inert gas generator by fuel oil or diesel oil burning and pure N_2 generator, each of type described as follows:

2.1. Conventional boiler flue gas uptake inert gas plant

A conventional boiler flue gas uptake inert gas plant uses the flue gas taken from the exhaust gas duct of the auxiliary boilers. This plant typically consists of a scrubber & demister, two(2) inert gas blowers, a deck water seal unit, a pressure vacuum breaker, and associated ducting and necessary fittings. A typical arrangement of this type of inert gas system for tankers is shown in **Figure 1**.

Basic boiler flue gas and inert gas compositions are typically as in following **Table 1** [4].

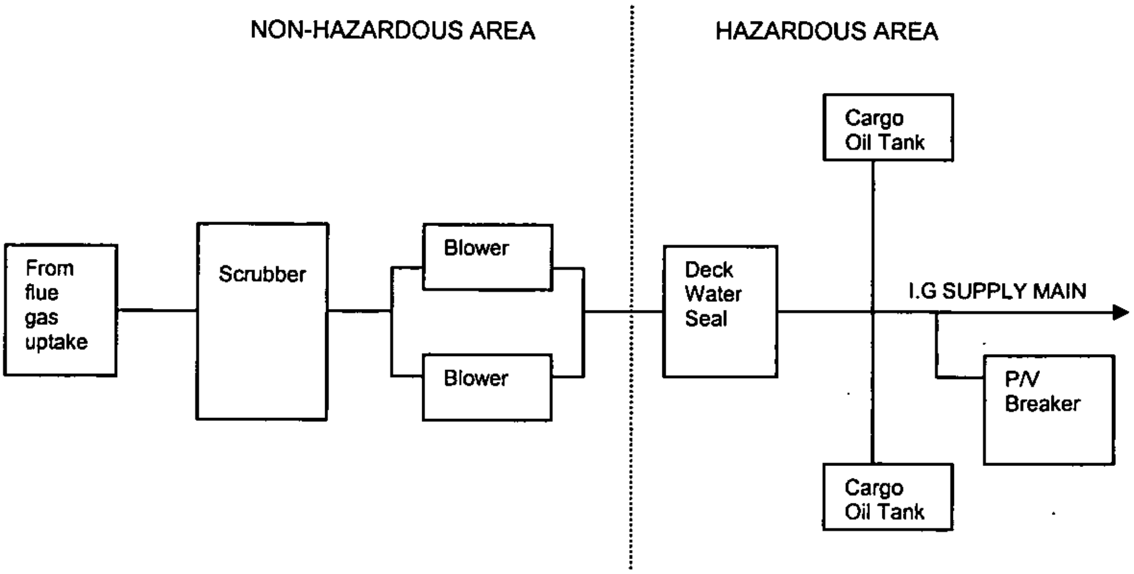

Figure 1 - Typical schematic of a boiler flue gas uptake inert gas system.

Table 1 – Typical Boiler flue gas and corresponding inert gas composition [4].

Item	Flue gas composition	Inert gas composition
CO_2	13.5 %	13.5 %
SO_2	0.3 %	less than 0.03 %
O_2	4.2 %	4.3 %
N_2	77.0 %	79.6 %
H_2O	5.0 %	2.0 %

However, actually each manufacturer has slightly different standard in inert gas composition. Generally the SO_2 content is not more than 100 ppm in inert gas composition and O_2 is less than 5.0 % by volume. Inert gas has to have an oxygen content of less than 8% by the rule and this will result in a reduced corrosion rate compared with normal atmosphere conditions. The rate of corrosion of steel structure is significantly reduced when the oxygen content is below 1 %. This low oxygen level can be achieved by other types of inert gas plants such as the inert gas generator and N_2 generator systems.

The corrosion rate tends to increase with increasing O_2 and SO_2 levels in inert gas. Sulphur dioxide is of major importance for atmospheric corrosion. Absorption of SO_2 into the surface of a metal depends on the relative humidity and the presence of corrosion products. SO_2 oxidizes to SO_3 in the atmosphere or in the moisture film on the metal surface and this subsequently reacts with the H_2O to form H_2SO_4 and which leads to an acid reaction against metal surfaces. The SO_2 content in a tank is more directly related to the type of crude oil cargoes carried rather than to its presence in inert gas. Sometimes, for example, the hydrogen sulphide content is more than 600 *ppm* depending on the type of crude oil [5].

2.2. Inert gas generator by F.O and D.O burning

This type of inert gas system uses a separate discrete inert gas generator being provided with two or more fuel oil or diesel oil pumps. This type of inert gas generator is normally used where high quality inert gas is required, typically such as chemical tankers and gas carriers where it is necessary to protect the quality of cargoes and spaces. However the price and operating costs of such systems are somewhat more expensive than conventional boiler flue gas uptake inert gas systems.

Table 2 shows a general design specification from one existing manufacturer and **Figure 2** shows a typical arrangement of inert gas generator system.

Table 2 - The composition of gas contents [6].

Item	Inert gas generator
CO_2	Approx. 14%
CO	Max 100 ppm
SO_2	Max 1 ppm
NO_x	Max 150 ppm
O_2	Approx. 1% ~ 3%
N_2	Balance

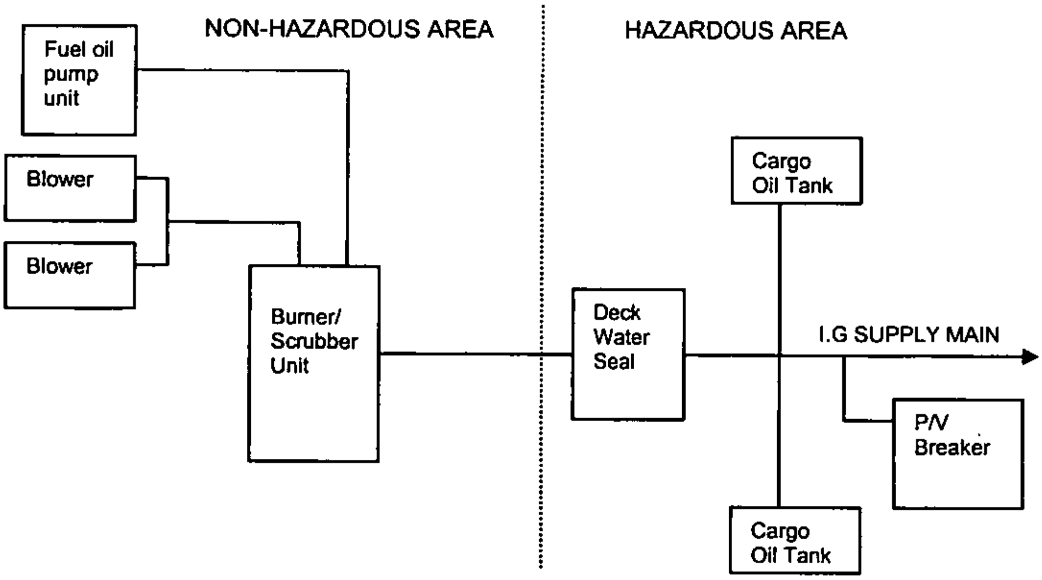

Figure 2 - Typical schematic of an inert gas generator based system for a tanker.

As shown in **Table 2,** the quality of the inert gas from an inert gas generator is much better than that from a conventional boiler flue gas uptake system. The SO_2 content is less than 1 ppm and the oxygen content can be controlled to approximately 1 % by volume. This means that an inert gas generator can control and reduce the corrosion degradation rate significantly compared with both conventional boiler uptake flue gas inert gas systems and the normal ambient air condition.

2.3. N_2 generator systems

Direct nitrogen gas generator is an expensive solution for an inert gas system and there are some restrictions in production capacity and in installation for a large capacity equipment. However there is no sulphur or oxygen in their products and this means that such system can reduce corrosion rate significantly for enclosed steel structure in marine and offshore environments.

Typically a N_2 generator is used in gas carriers for the following operations:

- To supply the inter-barrier spaces and insulation spaces,
- To purge boil-off gas line in the engine room,
- To purge cargo liquid line, vapour lines and vent masts,
- To seal high duty and low duty compressors.

A N_2 generator consists of air compressor, separators, filters, heaters and membrane modules as shown on **Figure 3**.

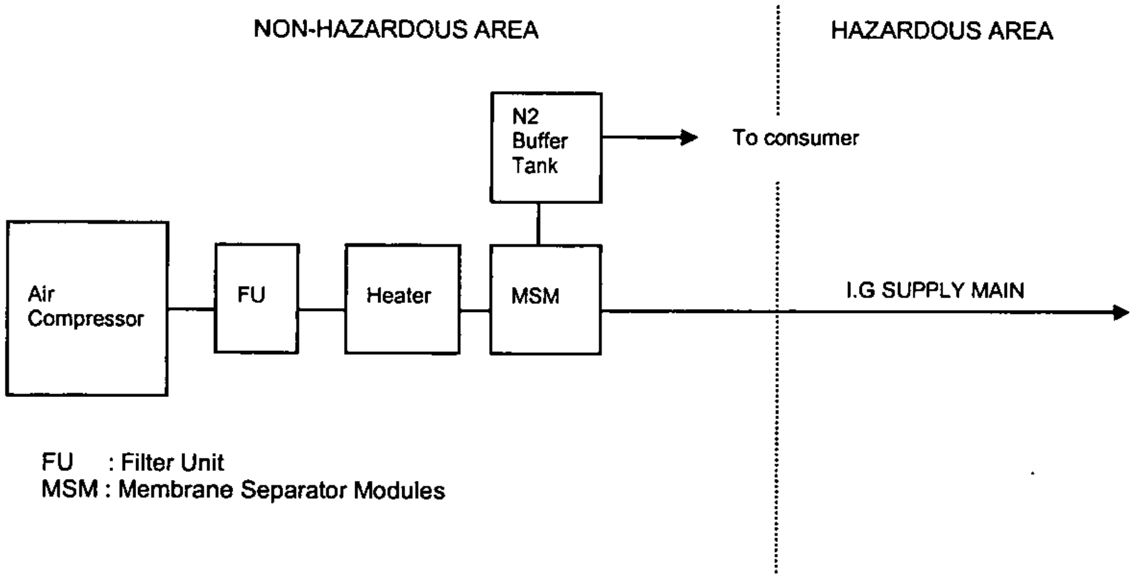

Figure 3 – Typical schematic of a N_2 *generator.*

The gas composition from the N_2 generator depends on the design of the system, normally between 95% and 99.9% N_2 with 5% to 0.01% of inert gases which can be adjustable by changing the operating conditions.

3. Inert gas system for ballast tank and ship structure

Ship structures are continuously suffering from corrosion related fatigue and other problems under the sea water environment. There have been only a few investigations undertaken regarding the effects of inert gas on the corrosion of ship structures. Johansson et al. [7] studied the atmospheric corrosion of a commercial steel by laboratory tests under relative humidity of 90% at 22 °C and with the following conditions:

- Type A : Polished steel samples were exposed to an inert gas consisting of 3.0 % O_2, 12.0 % CO_2 and 10 ppm (by volume) SO_2
- Type B : Polished steel samples were exposed to a mixture of humid air and 10 ppm (by volume) SO_2
- Type C : Polished steel samples were exposed to an inert gas consisting of 3.0 % O_2, 12.0 % CO_2 and 100 ppm (by volume) SO_2

- Type D : Polished steel samples were exposed to an inert gas consisting of 3.0 % O_2, 0 % CO_2 and 100 ppm (by volume) SO_2
- Type E : Pre-corroded samples were exposed to the same atmosphere as in experiment C
- Type F : Pre-corroded samples were exposed to an atmosphere consisting of 3.0 % O_2, 12.0 % CO_2 and 300 ppm (by volume) SO_2

However, on the contrary to common expectations and other recent researches, the study revealed that high concentrations of SO_2 in an inert gas may, under certain circumstances, be corrosion-inhibitive by creating the formation of a protective coating consisting of iron sulphide and iron sulphite hydrate on the surface of the steel. This result demonstrates that it is difficult to simulate in a laboratory corrosion test method. The actual environment of a cargo oil tank with inert gas and thus a full actual onboard test is considered to be necessary in order to evaluate the effects of inert gas on marine structures.

Miyuki et al. [8] have carried out laboratory simulations of corrosion in a wet inert gas environment (13% CO_2, 5% O_2 and a small amount of SO_2) and they found that corrosion rates increased with increasing levels of O_2 and SO_2 contents in inert gas [5]. Matsuda et al. [2] have introduced a new anticorrosion method that purges oxygen from ballast tanks by providing a continuous supply of nitrogen. The design concept is that liquid nitrogen, that is stored in tanks, supplies nitrogen gas passing through an evaporator and a reduction valve into the ballast water. The pressure within the ballast tank is controlled by a pressure release device and the ballast tank is monitored by pressure, temperature and oxygen sensors. In order to verify the system's efficiency in the control of corrosion, an experimental test was carried out in a 150,000 tons coal/ore carrier over a period of 18 months (583 days). Steel test plates were used, one with nitrogen gas control and the other untreated in a standard ballast tank condition. Subsequently they found that the rate of rusting on the shot blasted steel test plates placed at the bottom of the nitrogen treated ballast tank was 0.06 mm/year, compared with 0.47 mm/year for the same type of plates at the bottom of a standard ballast tank with a normal operating tank atmosphere condition, as shown in **Figure 4**.

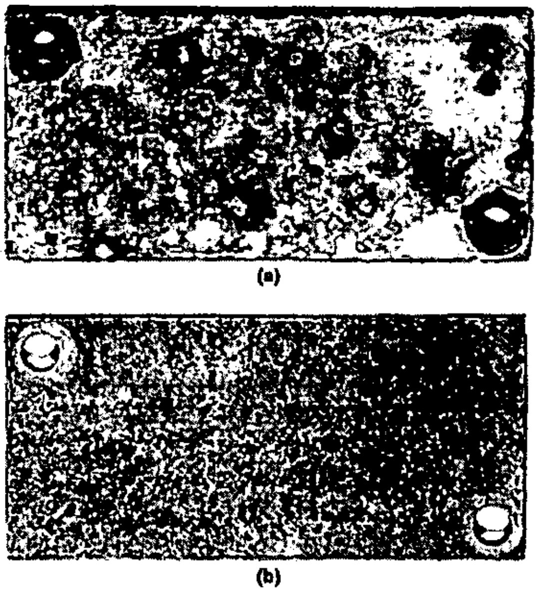

Figure 4 - Corrosion levels on steel plates placed in ballast tanks during the 18 months shipboard study: (a) plate from controlled tank under constant air saturation levels with a corrosion rate of

0.382 mm/year, (b) plate from the nitrogen treated ballast tanks under periodic hypoxia with a corrosion rate of 0.039 mm/year [2], [9]

It was also found that for painted steel plate with the nitrogen atmosphere treatment the corrosion rate was reduced to 0.001 mm/year.

Another new solution was introduced by Tamburri [3]. This is called the *Ventury Oxygen Stripping™* system. The system produces inert gas by combusting low-sulphur marine diesel in a special device and then mixing the output gases with the ballast water using a ventury injector that is installed in-line, just down stream of the ballast pump. Both the continuous nitrogen supply system and the *Ventury Oxygen Stripping™* system are used for ballast water treatment in order to reduce both aquatic organism introduction and corrosion control in ballast tanks. But the initial cost of installation and operating costs are still too high to adopt these types of system to many ship's owners.

However the company Hellespont has adopted full inert gas coverage of its ballast tanks during laden voyages, in both old and new ships. The inert gas is double scrubbed to produce a sulphur dioxide content of less than 2 ppm. There is separate inert gas injection pipe with holes at each stringer level installed at the aft end of each ballast tank in order to ensure good purging flow and adequate distribution of inert gas pressure. This innovative design apparently cuts corrosion of the steelwork and piping considerably in the ballast tanks where coating has begun to break down [10], [11].

Cox [12] briefly introduced and reviewed the advantages and disadvantages of the various inert gas systems to ballast tanks

4. Optimized anti-corrosion design by inert gas provision

It is apparent that an oxygen content of below 1% will reduce the rate of corrosion significantly. An inert gas generator or a N_2 generator can thus be used to control corrosion within cargo tanks and ballast tanks. An inert gas generator especially can be installed onboard with small amount of initial cost and subsequent operating costs and this system would reduce the corrosion rate of ship structure. A N_2 generator could be an economic solution for container vessels and bulk carriers where an inert gas system is not compulsory by the rule requirements. This means there is no restriction in capacity and the capacity of the N_2 generator could be designed in accordance with the design operation concept of the ballast tanks and their tank capacity.

An optimised design approach is proposed in this research and a cost based evaluation between a conventional boiler flue gas uptake inert gas plant and an inert gas generator system is investigated.

4.1. Proposed design

SOLAS Regulation II-2/59.4 [1] requires oil tankers constructed on or after 1 October 1994, to be provided with suitable arrangements for gas freeing and for ventilation of double hull spaces. In addition, oil tankers fitted with inert gas systems are required to have suitable arrangements for inerting double hull spaces, when necessary. The arrangements for the inerting of double hull spaces may be through portable connections to the inert gas system for cargo tanks or by fixed piping connections. Practically, a cross connection with portable spool piece, non-return valve and manual isolation valves are to be provided between the inert gas main line and the water ballast main line in the cargo oil pump room so as to supply either inert gas or fresh air into the ballast tanks.

Figure 5 shows a typical schematic of the inert gas supply from an inert gas generator to a double hull ballast tank through an existing inert gas supply main and ballast piping line. There is no additional piping, except for the cross over, necessary for a crude oil tanker and this design allows the system to put the inert gas into the ballast tank during a laden voyage when the ballast tanks are emptied.

However there is no onboard corrosion test data available which compare the difference in corrosion rates between a conventional boiler flue gas uptake system and an inert gas generator system. However from the test data obtained by Matsuda et al. [2] we can assume that an adequately inerted environment will result in significantly reduced corrosion degradation rates than the normal sea water environment in ballast tanks.

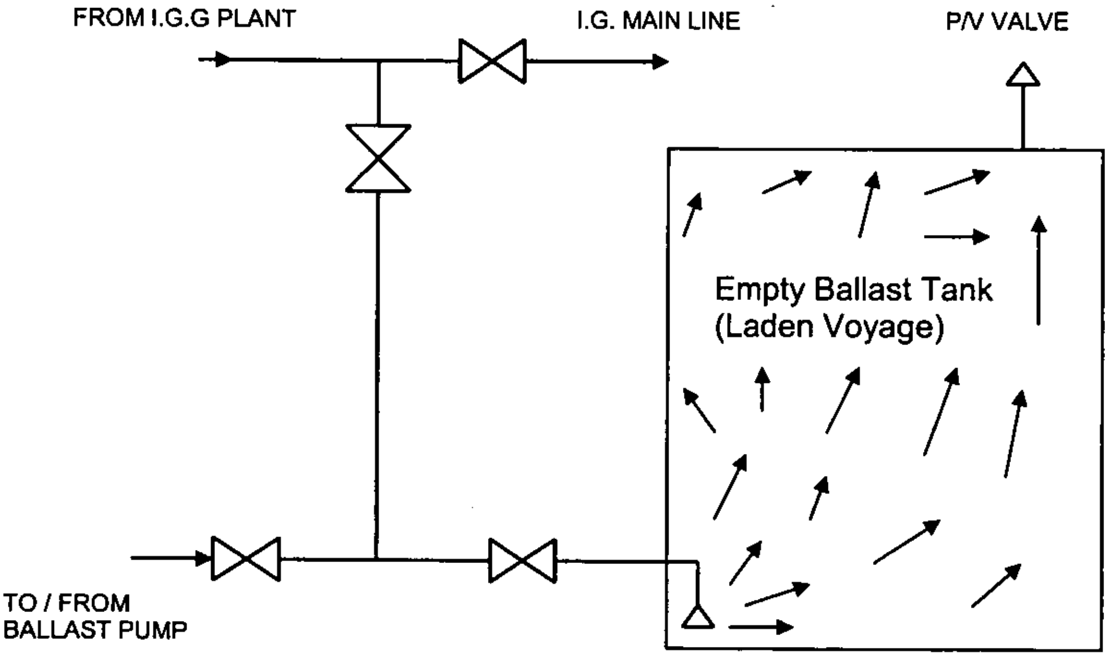

Figure 5 - Inert gas supply to double hull space during laden voyage.

4.2. Design considerations for double hull tanker inert gas supply

The above design approach outlines the most economic solution to supply inert gas to double hull spaces. There are many alternative and improved designs that are available, however this research is to focus on introducing the most economic solution that will be specifically required in order to appreciably reduce the corrosion rates in ballast tanks and cargo tanks.

The provision of inert gas supply to the double hull spaces through existing ballast piping is carried out after completion of de-ballasting in the tanks. There are no specific rule requirements to supply inert gas to ballast tanks and some classification societies may be more conservative in the application and interpretation of this system. However considering the potential reduction of corrosion rate and the resultant increasing reliability of ship's structure, a more optimistic interpretation is justified in order to apply this system.

Generally the following should be considered during stage the initial design of an inert gas system for double hull spaces.

- Air vent heads for ballast tanks should be blinded during laden voyages and permanent high velocity pressure vacuum valves are to be provided for each ballast tank.
- The size of high velocity pressure/vacuum valves should allow for the design concept of inert gas supply rate to each double hull tank. However during the operation it is advisable that the ballast tank access hatch should always be opened during inert gas supply to ballast tanks.
- If high velocity pressure/vacuum valves are not of a water-tight design, then they should be located such as to avoid any accidental flooding during heavy seas, such as near the ship's centre. Alternatively the possibility of accidental flooding rate through pressure/vacuum valve into water ballast tank should be calculated and considered during the design stage.
- Interpretation of classification society rules and requirements should be checked in order to ensure compliance.

4.3. The potential effect of clean inert gas on hull girder section modulus degradation

It is apparent that low oxygen and low SO_2 levels as can be provided by an inert gas system can control corrosion and potentially reduce the corrosion rate to one-tenth of the normal environment rate [2]. This means that a properly designed clean inert gas system to ballast tanks and void spaces can improve the ship's longitudinal strength of ageing ships due to less corrosion related scantling degradation during ship's life. In this paper, the effect of high quality inert gas on the longitudinal strength is estimated by assuming that the corrosion rate of under inert gas condition is respectively 10%, 30%, 50% and 70% of the average corrosion degradation based on Paik et al. [13] and Wang et al. [14] data (PW model) with the assumption that the effective coating life is 5 year.

The section modulus represents a direct measure of a ship's longitudinal vertical bending strength and the section modulus should be always greater, during the life of the ship, than the rule minimum requirement. The location of neutral axis, H_{NA}, of the hull cross section above the base line can be calculated as follows:

$$H_{NA} = \frac{\sum a_i h_i}{\sum a_i} \tag{1}$$

where a_i is the cross sectional area of the ith structural member and h_i is the distance of ith structural member from the base line. From the parallel axis theorem, the moment of inertia of the hull cross section is given by:

$$I_y = \sum a_i (h_i - H_{NA})^2 + \sum k_i \tag{2}$$

where k_i is the local moment of inertia for each member.

Finally the section modulus at deck(Z_D) and keel(Z_K) are given respectively by:

$$Z_D = \frac{I_y}{D - H_{NA}} \qquad (3)$$

$$Z_K = \frac{I_y}{H_{NA}} \qquad (4)$$

where D is Depth of ship (m).

The potential progressive changing with time of the section modulus at deck and the section modulus at keel were investigated for an existing AFRAMAX Double Hull Tanker (L=219.08m, B=42.0m, D=21.3m). **Figures 6** and **7** illustrate the time variant section modulus degradation at deck and keel.

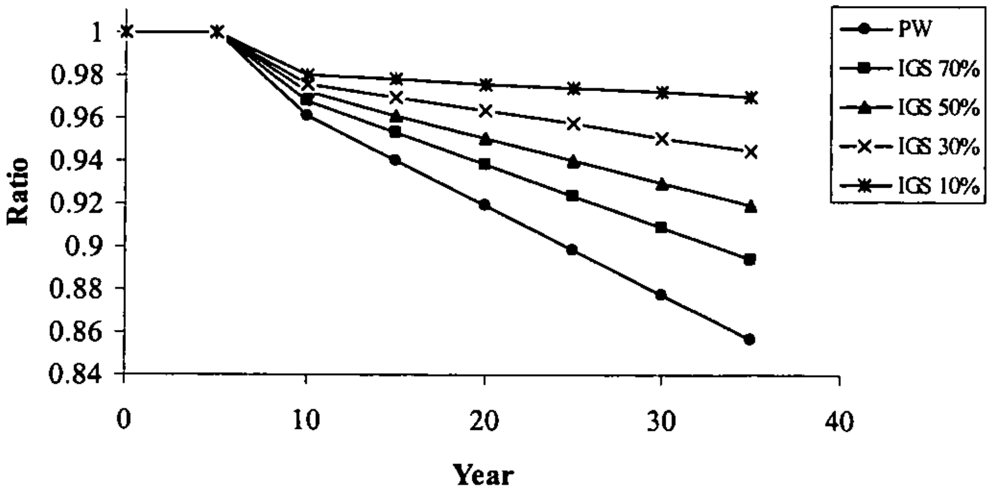

Figure 6 - Time variant section modulus changes at deck.

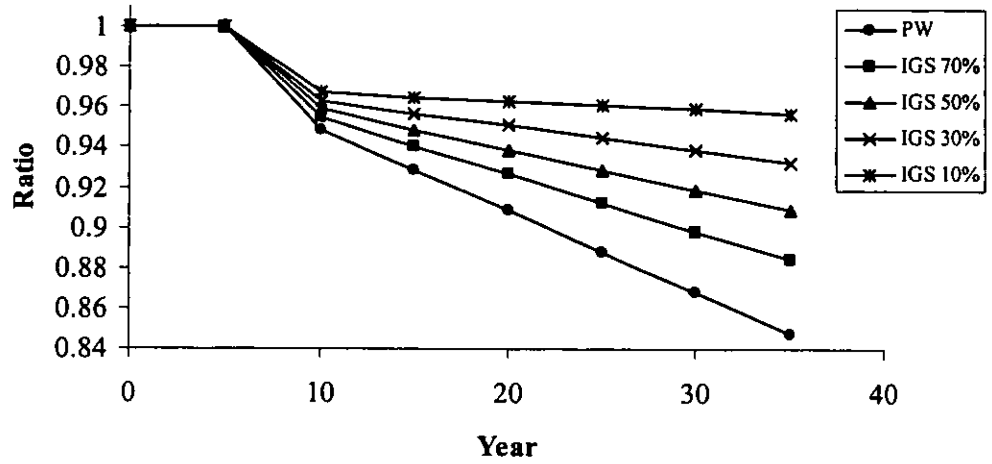

Figure 7 - Time variant section modulus changes at keel.

4.4. Cost evaluation

Table 3 provides an approximate cost evaluation between a conventional boiler flue gas uptake inert gas system without inert gas supply to the double hull space and an inert gas generator with inert gas supply to the double hull space and which was investigated based on an AFRAMAX tanker. The cost figures are based on one of Far East shipyard and the estimated cost could be different in different shipyards.

Table 3 - Cost comparison between a flue gas uptake inert gas system and an inert gas generator system.

ITEM	**Flue Gas System without Inert Gas Supply to Ballast Tanks**	**Inert Gas Generator System with Inert Gas Supply to Ballast Tanks**
I.G.S. Equipment (9,375 m3/h) - Scrubber - I.G blowers - Deck water seal - P/V breaker - Control valves and fittings - Control panel	USD 200,600 - Scrubber - I.G blowers - Deck water seal - P/V breaker - Control valves and fittings - Control panel	USD 257,000 - Burner / Scrubber unit - Fuel oil pump unit - I.G blowers - Deck water seal - P/V breaker - Control valves and fittings - Control panel
Piping from boiler uptake to Scrubber	USD 2,000	-
Additional piping for high velocity P/V valve to prevent flooding (150A x 180m) - include installation cost	-	USD 7,000
High velocity P/V valve for ballast tanks (150A=6 inches) - include installation cost	-	USD 2,500 x 12 sets = USD 30,000
Fuel oil consumption	-	0.075 kg x 9,375 capacity x 2 air changes x 26 times / year = 36.56 tons x USD 320 = USD 11,700 / year USD 117,000 (10 years) USD 234,000 (20 years) USD 351,000 (30 years)
Total Cost	USD 202,600	USD 411,000 / 10 years USD 528,000 / 20 years USD 645,000 / 30 years
Difference	USD 208,400 / 10 years USD 325,400 / 20 years USD 442,400 / 30 years	

The fuel oil consumption is assumed to be that required to fill inert gas into No.1 ~ No.6 water ballast tanks (34,340 m^3) at a rate of two air changes in each voyage(7 days interval). However any additional fuel oil consumption of a boiler flue gas system when inert gas topping up is required during a voyage, and unexpected inert gas operation of a conventional system, is not considered in the cost comparison.

The cost comparison in **Table 3** is just illustrative and for approximate guidance. The actual operating cost should be evaluated by each operator because operation conditions and concepts would be different for each operator, route and period of voyage.

Generally, it is recommended to install clean inert gas system in crude oil tankers, if the total cost of the boiler flue uptake inert gas system is expected more than the total cost of clean inert gas system as follows:

$$\sum(C_{F-M} + C_{F-I} + C_{F-O} + C_{F-MT}) > \sum(C_{G-M} + C_{G-I} + C_{G-O} + C_{G-MT}) \quad (5)$$

Where C_{F-M}, C_{F-I}, C_{F-O}, C_{F-MT} are the cost of material/equipment, cost of installation, cost of operation and cost of maintenance (hull structure and equipment) during designed ship's life, respectively for boiler flue gas uptake inert gas system. C_{G-M}, C_{G-I}, C_{G-O}, C_{G-MT} are cost of material/equipment, cost of installation, cost of operation and expected cost of maintenance (hull structure and equipment) during designed ship's life, respectively for clean inert gas system such as inert gas generator or N2 generator.

If ship's and offshore structures are not required to have an inert gas system by rule, it is recommended to install an clean inert gas system when the total cost of maintenance of hull structure is expected being more than the total cost of clean inert gas system given by:

$$\sum(C_{MT}) > \sum(C_{G-M} + C_{G-I} + C_{G-O} + C_{G-MT}) \quad (6)$$

Where C_{MT} is total maintenance cost for whole design life.

5. Conclusion

Either a high quality inert gas generator system or a N2 generator system can be used to reduce corrosion degradation in marine structures in the areas such as ballast tanks and permanent void spaces. This system can be adopted to not only crude oil tankers but also bulk carriers and container vessels. The application on bulk carriers, container vessels and other types of vessels has the advantage that there is no capacity restriction to apply inert gas system and the operator can adopt smaller capacity considering operation concept and can reduce equipment cost.

High quality inert gas can be an effective economic solution considering appreciably reduced corrosion, maintenance, time out of service/trade, repair/steel replacement costs and improved re-sale value for the vessel, etc. However the application of this system solely depends on ship's owner during design stage by comparing total cost of material/equipment, installation, operation and hull renew or repair cost in the future.

It is recommended that further research activities with actual tests onboard in order to evaluate the effects of clean inert gas system on marine/offshore structures in order to verify economical solution for certain type and size of vessels.

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SURVIVAL OF BACTERIA AND PHYTOPLANKTON IN SHIP'S BALLASTS

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Billions of tons of ballast water are released world-wide every year. Living marine, brackish or freshwater organisms, including those noxious or unwanted, can travel by that way from a part of the world to another. A successful introduction needs: 1) survival during the pumping process. 2) survival in the ship's ballasts. 3) survival and reproduction in the new environment. To assess the survival conditions in ship's ballasts, a small scale pilot system has been built (MARTOB project), more realistic than laboratory vials and easier to handle than a real ballast. Bacteria and phytoflagellates coming from ship's sampling or from cultures were introduced in the system; their survival in several waters or sediments are studied, a useful method to assess the efficiency of further treatment processes at small scale and thus low cost.

1. Introduction

The most significant economic activities in coastal areas are the coastal fishing and aquaculture. Unwanted, noxious or pathogenic species introduced in these areas by ship's ballast waters and sediments release is a major threat for these activities: human or animal diseases, livestock and financial losses can affect entire regions.

A successful introduction of alien species supposes:
1) survival during pumping processes: this is the case for most of the small species, particularly phytoplankton and bacteria.
2) Survival in ship's ballast during travel or long storage of the ballast water (in the forepeak particularly): phytoplankton and bacteria producing cysts, are among the most fitted for survival in these apparently harsh conditions.
3) Successful setting in the new environment: again, phytoplankton and bacteria, due to mutation ability are generally the best fitted;

This is why it must be interesting to study their survival in the ballast environment. Working on this matter aboard a ship is difficult:

- Microbiologic experiments need a laboratory, hardly installed aboard a bulk or container or car carrier, as the samples taken regularly need to be cultivated at short notice.
- Phytoplankton introduced in ballast, generally tumble down unless some agitation by air lifting is organised.
- In real ballast, the huge size compels to put large volume of cultivated phytoplankton or bacteria to expect significant or at least usable samples.

This is why the work on medium or small scale pilot systems appears to be more convenient for the first trials.

2. Material and methods

2.1. The pilot scale system

Designed to carry studies on ballast environment conditions, the two tanks system has been built with naval grade steel, epoxy tar coated like a real ballast, and pivot mounted to simulate lurch if necessary. Internal framing provide areas for sedimentation (fig. 1).

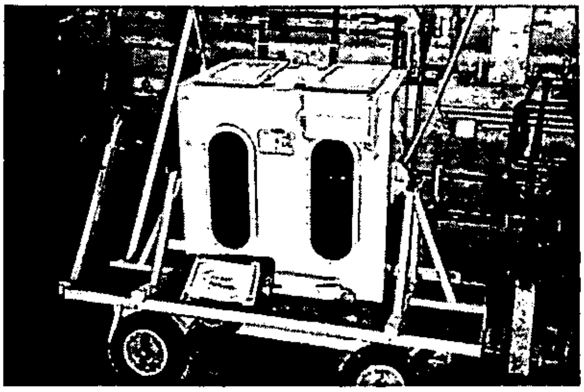

Fig. 1- Ballast scale pilot system.

2.2. Bacteria strain

To assess bacteria survival, a convenient cultivated strain is needed. Better than common E. coli, bacteria found in ship's ballasts seems more convenient. In this case, we used *Vibrio parahaemoliticus* discovered in water filling the hold (used as ballast tank) of a huge bulk carrier coming from South East Asia to La Rochelle (France).

The 1 litre (sterile bottle) sample was sent back to the lab at ambient temperature in thermal box (when looking for Vibrios, the cold storage must be avoided).

The typing has been done with selective medium (EPSA: Peptone Alkaline salted water), isolation on TCBS medium, subculturing on GNA and confirmation with Oxydase, salted Kigler media and API 20 E gallery.

Even the pathogenic characteristics (none here) have been checked by PCR. The isolated strain is since preserved in the lab on storage medium, sub cultured every 6 months. The culture for experiment is done on EPSA medium at 37 °c. The pilot scale tanks were filled with estuarine turbid water for the first experiment, then with bulk carrier ballast water for the second. The tanks were maintained in the dark. The water was previously analysed and if the ballast water contained some ubiquitous germs (as Pseudomonas), no *Vibrio parahaemoliticus* was found.

2.3. Phytoplankton

Waiting for a convenient natural phytoplankton bloom seeming quite difficult, we used a monospecific culture of Tetraselmis suecica (flagellate, Prasinophyceae).

This particularly resistant species was available in our research oyster hatchery, cultivated in 300 l Fiberglas culture vessels (fig. 2).

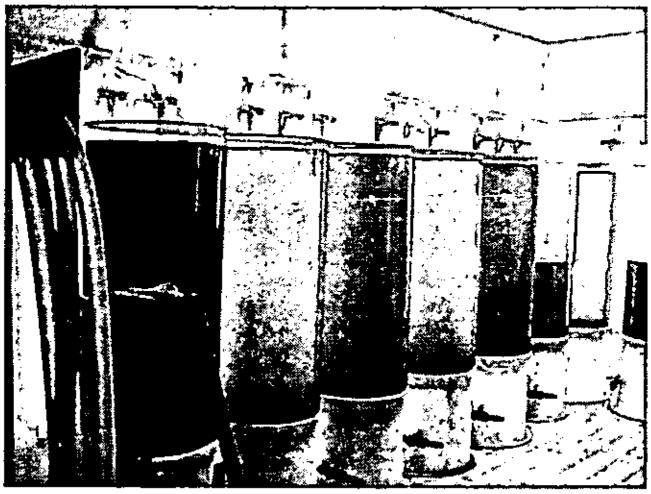

Fig. 2 - Phytoplankton culture vessels.

Ten litres were poured in each tank (already filled with 40µ filtered seawater) of the pilot scale system, and to avoid the sedimentation of the cells, stirring by air diffusion was maintained all the time.

One of the tanks was maintained in the dark, like a ship's ballast tank, the other one, acting as a control was well lit by neon light during the experiment, just like the culture vessels.

The first cell count was done in the bucket before pouring it in the tanks, using an image processing system (Samba technologies, France).

Every day, a one litre sample was taken in each tank, filled at different depth from bottom to top for a good mixing.

Probably due to water stirring, a lot of suspended matters and particles was soon observed, rending the processing system useless (unable to separate cells and particles).

So, a sub sampling was done, then: two 10 ml microscope observation chambers were filled from each sample and the counting was done manually (and painfully) on microscope (x100) after three hours for sedimentation (Fig. 3).

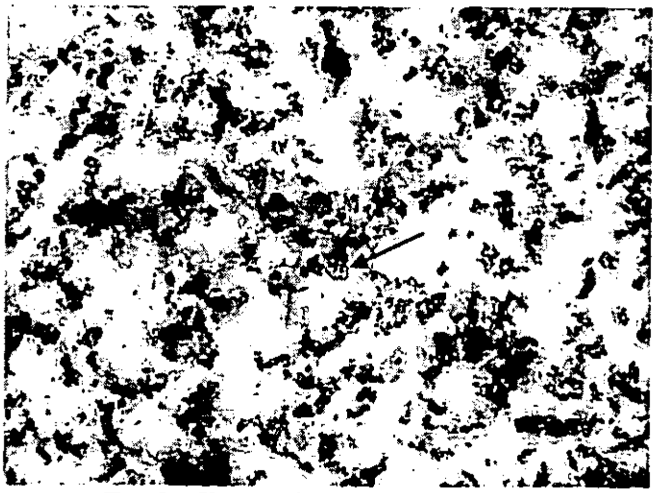

Fig 3 - Tetraselmis cell in sediment

The number of cells counted in the chambers was recalculated to a litre. This is the standard procedure used for the REPHY (french toxic phytoplankton watching network).

3. Results

3.1. Bacteria survival

The first experiment was done with water directly pumped from the Seudre estuary (25 km long) in close proximity of the station and used in the hatchery system (Fig. 3).

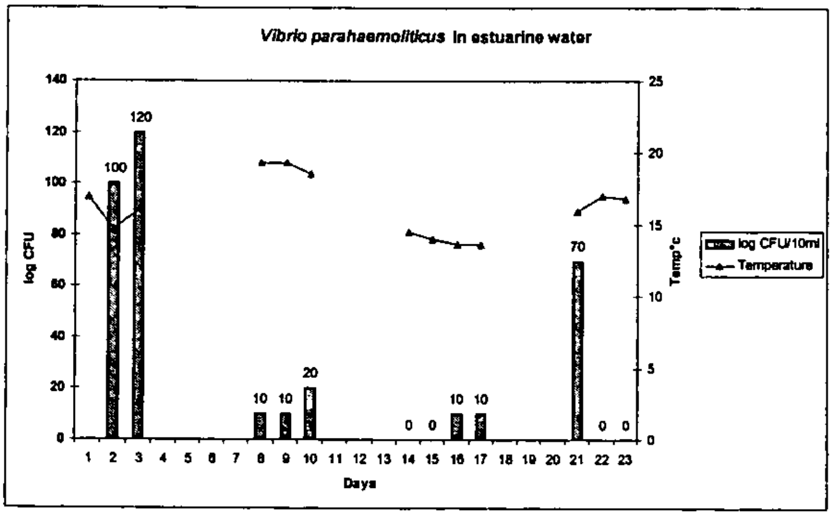

Fig. 4 - Survival of vibrio parahaemoliticus in estuarine water

After 24 days, V. parahaemoliticus has disappeared from the water. A month after, sampling in the sediment in the tank bottom let appear 1.3 CFU (colony forming unit)/ 100 ml: the germ is still present in the sediment.

For the second experiment, the pilot system was filled with real ballast water. This was done by taking double bottom ballast water aboard a bulk carrier coming from Pasajes (Spain), and containing a mixing of port and Gulf of Biscay water (Fig. 4).

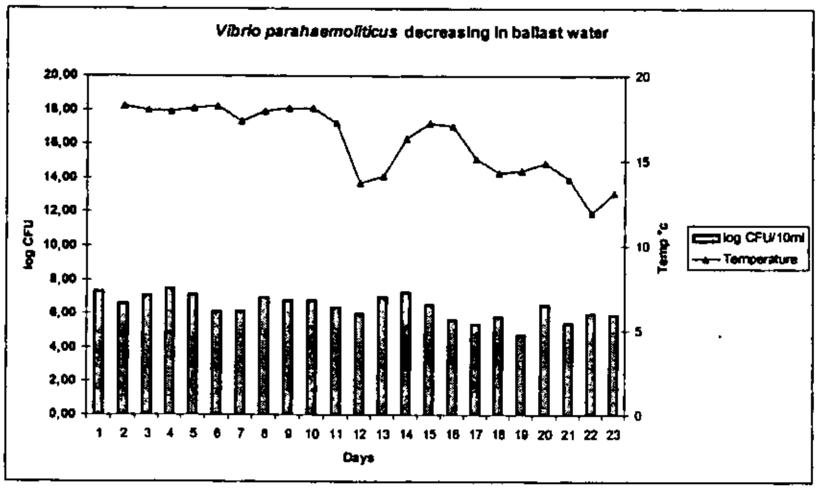

Fig.5 - Survival of Vibrio parahaemoliticus in ballast water

The decreasing is slow. After 45 days, the decreasing observed is only one log: 7.34 to 5.97 log CFU/100ml.

More important, the sediment is contaminated at the same rate than previous experiment on estuarine water (1.4* 10^7 CFU/ 100ml).

3.2. Phytoplankton

From a 2 ml sample taken in the 10 l bucket, 0.1 ml was set on a haemocytometer slide and counted with the image processing. We had 174 million cells/l, giving 6.69 million/l in the 250 litre tanks (just like a real bloom at sea). The cell number decreasing was observed daily during 6 days (Fig.6).

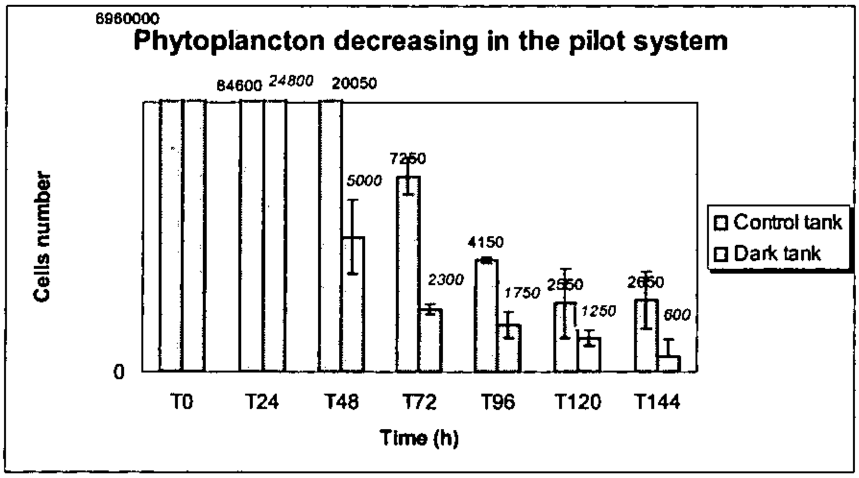

Fig. 6 - Tetraselmis suecica survival in pilot scale water

Even with air agitation, the number of cells decreases rapidly after 48 hours: 20 500 cell/l in control, 5000 cells/l in the dark. After 6 days, 2650cells/l remain in the control, versus 600 in the dark.

4. Discussion

4.1. Pilot scale

The use of this system as an alternate way for working aboard a ship presents some advantages:
- Manage the whole environmental conditions: temperature, salinity, dissolved oxygen, turbidity, light...,
- Start, stop and change the experiment conditions at any time,
- Handle reasonable volumes of water: from 250 l to several cubic metres (mesocosmic size), far from the thousand cubic metres of a real ballast;
- Spare money and time in prototype design and trials.

The main drawback is obviously the artificial situation, and especially for treatment assessment, further experiments must be carried aboard a ship.

4.2. Bacteria

The Vibrio parahaemoliticus survival has already been presented (see MARTOB subtask 4 report), but the comparison with phytoplankton is interesting: both species used are widely present in the coastal waters, and although non pathogenic, can be very similar in behaviour with pathogenic species or strains; The experiment with real pathogens (V. cholerae for example), far more complicated considering the danger, must be preceded by a work on non pathogenic similar species or strains.

4.3. Phytoplankton

The same remark applies to phytoplankton: we intend to carry a further work on some well known toxic dinoflagellates, as Alexandrium tamarense (this species being cultivated in some laboratories), including the cysts research in the sediments.

The Tetraselmis species used here is well known for its survival ability, even on the tiles of the culture room floor...The only difference between the pilot scale and the culture vessel was the lack of carbon dioxide bubbling, leading perhaps the cells to adhere on the walls of the pilot system. The experiment didn't last long due to technical considerations, but finding still 600 cells/l after six days in the dark suggest that the environmental conditions in the ballasts are not so harsh, after all...

5. Conclusion

The use of pilot scale system simulating ship's ballast conditions is a sort of technical challenge to work as close as possible to the real ballast environment. The size effect must be considered but other characteristics are very similar: dark, rusted (even muddy) environment, with steel walls and frames providing sediments traps.

It seems difficult to put contaminated water in the pilot system straight from the ship's ballasts, not knowing the nature of the contamination before; this is why the use of a cultivated bacteria strain is highly preferable. Its survival even after two months in the sediment is a technical challenge for treatment methods.

The same remark applies to phytoplankton flagellates, with their ability to make cysts, and a further work will study this possibility, with existing techniques.

6. Acknowledgements

The authors wish to thank MM Ledu, Billy, Phelipot, Bodin, Mrs Pommepuy and Ms Cornette for their help.

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TREBAWA SYSTEM OPTIMISATION AND TESTS

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The harmful environmental effects on the ocean environment as a result of translocation of foreign or unwanted aquatic bodies via ballast water has been well documented. The TREBAWA group is a European consortium that addresses this issue by focusing on the development of a new technically and economically competitive ballast water treatment system to be employed onboard ship. The proposed system consists of a primary (hydrocyclone) pre-treatment phase together with a secondary integrated UV system to prevent micro-organisms transport by disinfection of the ballast water.

The paper will present research methodology applied in the project, detailed results of system design optimisation with CFD simulation, prototype assembly, system set up and operation, results of field tests and sea trials and an outline of conclusions and recommendation to further work.

1. Introduction

Ballast water is essential on ships in order to maintain a high degree of stability and propulsion efficiency. During loading of ballast water, large volume of sediment and microscopic marine species from the water columns and harbour floor are sucked into the ballast tanks.

With an estimated 10 billion tons of ballast water moved by commercial vessels per annum, 100 million tons of sediment and microscopic marine species are relocated to environments to which they are alien and in many cases destructive and harmful. As shipping trade continues to grow and vessels become faster, the possibilities for organisms to survive the journey and maintain an invasive threat to new locations is increased.

Minimising transport in turn puts limitations on commercial prosperity and open-ocean exchange of ballast water is practiced with much difficulty.

Current methods of ballast sludge removal induce large costs and do not remove sediment which reduces the capacity of the cargo hold and causes problems with stability.

The objective of the TREBAWA project is the development of a two-phase ballast water treatment system consisting of a primary hydrocyclonic particle separation unit, which will remove solid particles and the larger marine micro-organisms present in the seawater, and a secondary Ultra Violet (UV) system which will disinfect the remaining micro-organisms too small or light to be removed by the separation unit. Such a system would not only provide an environmentally sound method of ballast water handling but could prove commercially successful in an increasingly demanding market.

2. Design Objectives

The design and implementation of the system involved both computational and practical elements of optimisation and testing. Computational Fluid Dynamics (CFD) was employed in the design optimisation of the primary hydrocyclonic separator and the UV chamber. Further to the CFD computations a prototype of the system was field tested to validate the calculation.

Design criterion for the system stipulated:

- A flow rate for the system of 125m^3/hr was required
- A maximum inflow velocity of 3m/s at the inlet of the pipe systems was set
- The primary separator would produce a high percentage of "clean water " from the given inflow
- A high percentage of particles of the scale 20µm – 150µm with specific gravity 1.1-2.5 introduced at the separator inlet would be sent to the underflow drain of the primary unit.
- "Short-circuiting" and secondary flow effects in both the separator and UV chamber were to be avoided
- Pressure drop was to be minimised across the UV chamber while an appropriate pressure drop was to be maintained across the hydrocyclone separator to maximise separation efficiency

2.1. Hydrocyclone separator unit

The hydrocyclonic separator, figure 1, works by imparting centrifugal force on the fluid forcing the heavier particles to the outside of the cyclone. The drop in pressure resultant of the air vacuum created in the centre of the cyclone causes a secondary counter-rotating cyclone to be formed in the centre of the unit moving upward toward the overflow outlet. The heavy particles forced to the outside of the unit via the primary cyclone are drained through the underflow outlet while the water drawn into the secondary cyclone is guided toward the overflow outlet by the vortex finder.

The "clean" water, or that leaving the hydro-cyclone separator through the overflow outlet, is passed directly into the ultra violet chamber which treats the existing bacterial element. The benefit of the hydrocyclone separator is that it contains no moving parts and therefore is relatively easy to construct. As there are no mechanisms to the cyclonic separator, the retention time of heavy particles in the primary cyclone and the position and strength of the secondary cyclone depends on the geometry of the unit.

2.2. Ultra Violet chamber

The ultra violet chamber emits radiation to the sea-water passing through via high intensity lamps. The "kill-rate" of the chamber depends upon the residence time of the particle in the chamber, the distance of the particle from the lamp and the intensity of the lamp itself. The efficiency of the chamber is measured as a ratio of the minimum time of any particle in the chamber to the average time of any particle in the chamber. This ratio is referred to as the "time to first trace".

3. Optimisation using CFD

3.1. Separation theory and scale up considerations

A vast amount of work has previously been carried out regarding the modelling of flow regimes in hydrocyclones. Numerous approaches from simple empirical methods such as the equilibrium orbit theory and the residence time theory to more sophisticated analytical techniques which model boundary layer development and the formation of internal eddies have been employed. Svarovsky[3] provides further reading on theoretical separation approach.

Experimental optimisation of many commercial hydrocyclones has been carried out by Rietema[7] and the work of Ortega-Rivas[9] gives light to the use of dimensional analysis in the design of hydrocyclones. Both these approaches are out-with the remit of the present work.

3.2. Optimisation of primary separator

3.2.1 Geometrical considerations

Formation of the primary and secondary cyclones depends on the unit's principle dimensions shown in figure 1. Each dimension is considered as a ratio of the main cylinder diameter.

Inlet

Cylindrical or rectangular shaped inlets have been used in the past. Rectangular inlets have been thought to bring particles closer to the wall on entry to the main cylinder however, as most ships will have cylindrical pipe fittings, a cylindrical inlet was used in the current study to minimise complications with system integration at a later stage. Spiral inlets which are said to minimise the intersection angle between fluid rotating in the cyclone and the fluid entering through the inlet can dramatically increase the cost of manufacture of the unit and so are not used in the present study.

Main cylinder

The main cylinder, often referred to as the feed chamber, is cylindrical and effectively sets the diameter of the cyclone. For this reason the main cylinder diameter, D_C, is used to non-dimensionalise the other geometrical elements of the unit. Flow Reynolds number in the separator is defined using D_C as the critical dimension. In general the height of the main cylinder is at least 100% of the diameter. An increase in length generally will increase the retention time of the fluid in the separator.

Vortex Finder

The vortex finder leading to the overflow outlet is used as a control mechanism for the flow leaving the separator. Generally cylindrical in shape, the vortex finder extends downwards into the cyclonic region beyond the inlet. This ensures that short-circuiting does not occur where the flow entering the separator leaves directly from the overflow without forming the critical cyclone. The key features of the vortex finder are its length and diameter which have a large influence on the volume of flow leaving the separator through the overflow.

Conical Section

The conical section is vital in controlling the formation of the secondary vortex. The restriction of the apex to the downwardly spiralling primary vortex determines the location of the secondary vortex formation. Length and angle of the conical section influences the retention time of the fluid in the separator. In many commercial hydrocyclonic separators additional features within the main cylinder and conical sections are used to further control elements of the flow. For example a solid core within the separator is thought to minimise clogging and abrasion within a narrow apex. This approach is not considered in the present work as it generally applies to applications involving heavier slurry type flows where larger, denser particles are expected in the feed fluid.

Underflow Outlet

The diameter of the underflow outlet, or apex, determines the behaviour of the particles exiting from the separator. Sizing of the apex nozzle depends largely on the application at hand. Ideally flow exiting the apex nozzle should form a conical flow with a hollow centre. Should the apex be too large in size a spray effect in the outflow can be expected which generally indicates maximised particle output is not being achieved. Similarly if the outflow is devoid of a hollow centre and is more spiral in form the apex is too small and particles which should be removed from the underflow may instead be reporting to the overflow.

3.2.2 Efficiency measurement of the hydrocyclonic separator

In the present work separators are gauged on the static pressure drop across the unit (due to entrance, frictional and rotational kinetic energy losses between fluid inlet to the separator and exit via the overflow outlet), the percentage of particles removed by the hydrocyclone for any given input and the percentage of "clean water" reporting to the overflow outlet for UV treatment for a given inlet flow rate.

With space limitation a key factor, a four separator system was employed each separator having an inlet flow rate of $31.25m^3hr^{-1}$ to accumulate the $125m^3hr^{-1}$ required. The inlet diameter was held constant as was the diameter of the main cylinder. The main cylinder diameter was maintained at 254mm. All other geometrical features were altered.

3.2.3 Results

Test cases

Over 30 hydrocyclone separator configurations were considered in the optimisation study. Grid density, turbulence model, number of injected particles and fluid properties were kept standard for all configurations in order to maintain a comparable result for each case calculated. Two of the hydrocyclone separators used in the study are shown in figures 2(a) and 2(b). Separators in the study are considered in both full-scale and half-scale sizes as restrictions onboard the ship will determine the size of the required system.

Particle tracking and clean water production

The particle tracks in Cases A and B can be seen in figure 3. It was found that in Case A 48% of the original inflow reported to the overflow outlet while a minimum particle removal of 70% was shown for all size particles of all density, figure 4. In Case B, a minimum particle removal of 35% for the smaller particles (20µm-50 µm, S.G. = 1.1-2.5). However at 80µm the removal efficiency increases dramatically with density, figure 5. The Case B separator showed the percentage of the inflow water reporting to the overflow outlet to be 70%. This was considered to be a more realistic clean water output when considering running cost of a separation system onboard a ship.

Pressure drop calculations

The pressure drop across the separator, (i.e. the ratio of pressure at the inlet and overflow outlet), is shown in figure Table 1. Lower pressure drops are observed in the long narrow cone designs. This will reduce operation costs but may also have an effect on the strength of the secondary vortex within the separator.

The second stage separators, (Cases A and B), showed favourable pressure drops in comparison to other designs and in particular the commercial designs studied.

Multiple inlet separator

A separator model identical to Case B but having four inlets positioned at equal height each at 90°

from one another was calculated under identical conditions to the previous cases. Each inlet had a velocity inflow of 2.74ms^{-1} thereby encompassing the 125m^{3}hr^{-1} flow rate required (Figure 6).

It was predicted that the particle separation of the unit was not compromised by the presence of several inlets, neither was the percentage of total inflow reporting to the overflow outlet altered.

The main drawback of the multi-inlet separator was the increase in pressure drop across the unit. A 226% increase was observed in comparison to the standard Case B unit.

While a multi-inlet separator would help to reduce required space onboard the ship, failure or maintenance of the unit would require the entire system to be stopped.

General observations from the optimisation study

The CFD study generally found that:

- Unfavourable flow conditions can be observed when a narrow cone angle and small underflow diameter is combined with a short cone length
- Using a vortex finder which extends too far into the main cylinder causes flow instability within the cyclone
- Using a vortex which is too wide can cause a large percentage of untreated water to emerge from the overflow outlet and can disrupt the formation of the circular flow in the main cylinder formed after fluid entry from the inlet
- Using a vortex finder which is too small results in secondary flow recirculation at the top of the separator as the secondary vortex pushes upward causing high velocity regions at the entrance to the vortex finder
- Stability and symmetry in the flow is achieved best when the retention time of the fluid in the cyclone is greatest
- Employing too large an underflow diameter reduces the volume of flow reporting to the overflow and hence there is not sufficient water being sent for ultra violet treatment.
- Employing too small an underflow diameter can disrupt the flow near the cone apex and cause a large volume of un-separated flow to emerge from the overflow outlet
- Using a vortex finder which is too large in either diameter or length can disrupt the formation of both the primary and secondary cyclones and hence produce poor flow distribution and separation results
- If the cone angle is too small the flow can become blocked and cause the stability of the cyclone system to be jeopardised
- Conversely if the cone angle is too wide only the very largest particles can be removed
- Long cone lengths and extended main cylinder lengths increase retention time of the separator but must be used in conjunction with the correct size of vortex finder in order to ensure the required percentage of clean water emerging from the overflow outlet.

These findings as expected agree with the findings of numerous experimental optimisation programmes [3]-[5].

3.2.4 Conclusions

In conclusion the optimisation study showed that in any practical case a compromise must be reached where outflow of clean water is traded for a reduction in particle separation and vice versa.

Case B, where the required clean water percentage is achieved at the expense of separation efficiency for some of the smaller, lighter particles was chosen as the unit to be used in the prototype TREBAWA system. The decision was based on the following considerations:

- A system which does not produce a high enough clean water ratio will be economically punishing to operate and is unlikely to prove a commercial viability. Therefore Case B provides the most economically sound design
- Smaller particles, particularly those low in density are likely to be marine organisms which can be killed off during the ultra violet treatment
- Using four Case B separators in parallel means that should any one separator need replaced the system can continue to run on the remaining three units without a complete shut down being required
- The pressure drop across the Case B unit compares favourably with other designs and hence will minimise operational costs
- Using a multi-inlet model leaves the system venerable in times of repair

3.3. Optimisation of UV chamber

Previously ,several authors have used CFD techniques to evaluate UV treatment system performance[15]-[16]. Wright et al. [15] and Baas[17] have highlighted the usefulness of CFD in such applications. Both these works developed algorithms to simulate UV dosage and hence were able to compare design efficiency of various system configurations. Wright et al. [15] found that making relatively minor changes in the location of the inlet and outlet branches improved the uniformity of the flow within the chamber and increased the approximation of UV dosage. Bass[17] concluded that the chamber design could be improved by placing several lamps across the chamber as opposed to one running the length of the camber parallel to the flow.

The present CFD study was aimed at determining areas of unwanted secondary and re-circulating flow within the chamber, areas of flow stagnation and lamp by-pass (short-circuiting) through particle tracking. UV dosage was compared here also using "time to first trace" which is the ratio of the shortest time spent by a particle in the chamber to the average time spent by any particle in the chamber. Pressure drop was compared for each design to evaluate potential running costs of each system

3.3.1 Test Cases

Over 75 chamber configurations were used in the optimisation study. Configurations were taken from commercially available systems as well as proposed design recommendations from Willand UV Systems Ltd who specialise in UV chamber design.

Chambers were varied in terms of:

- UV lamp configuration
- Flow rate into the chamber
- Chamber orientations
- Position of the inlet and outlet branches

Under the recommendation of Willand UV systems Ltd, the diameter of the UV lamps was kept at a constant 36mm. Two families of configuration were used in the study, firstly where the inlet and outlet form branches off the main chamber and secondly where the inlet and outlet were positioned "in-line" with the chamber.

3.3.2 Results

Particle tracking

Figure 7 shows an example of particle tracking through various chamber configurations. It is seen that for branched designs flow rotationality within the main chamber is increased. Also secondary flow effects and recirculation can be observed near the flow inlet branch. In contrast the in-line design produces a more stable flow regime where re-circulation and stagnation are minimised considerably. Lamps which were placed perpendicular to the flow were found to be more effective than a single lamp being placed parallel to the flow along the length of the chamber.

The parallel lamp was found to increase flow rotation within the chamber. An added advantage of having multiple lamps is that failure of one lamp does not necessarily mean the system can not operate effectively. Having multiple lamps ensured that the exposure time to radiation of any particle was not compromised as the particle moved downstream. Intensity was maintained by the accumulative radiation of each lamp in turn thereby excluding the creation of low treatment zones.

Having all the lamps at equal height within the chamber was found to cause less retention time than with a staggering given to the lamp location. This improved the time to first trace efficiency of the chamber.

Pressure Drop

In terms of static pressure drop across the chamber, in-line designs were shown to provide a 30% reduction as compared to the branched configuration, table 2.

Flow Orientation

Further to the in-line design and out-with the direct remit of the current work an additional section of study looked at producing a flow control element within the UV chamber which would effectively move the outer flow near the chamber wall to the centre of the chamber and the inner flow near the row of UV lamps to the outer wall. This was in an effort to give all particles passing through the chamber, be them at the outer wall or in the centre of the chamber, an equal dosage of radiation. The limitations on the design of the flow control element were that:

- The flow would have to be "flipped" over a relatively short distance in order to ensure an even dosage for all particles
- There could be no induction of unwanted secondary flow effects or rotation downstream of the element
- The pressure drop would not be dramatically increased
- The time to first trace ratio of the system would not be compromised dramatically
- There would be no additional stagnation of the flow within the element

These factors had to be ensured in order to make the gain of an equal dosage distribution valuable against the other primary design criterion of pressure drop, stable flow and time to first trace efficiency.

3.3.3 Conclusion

In conclusion, the CFD optimisation showed that:

- Branched inlet and outlet created secondary flow effects and circulation within the main chamber
- In-line designs showed a decrease in static pressure drop

- Using several lamps perpendicular to the flow may produce a higher cumulative dosage than a single lamp placed parallel to the flow along the chamber
- Staggered lamp positions in the inline design resulted in a reduction of the time to first trace efficiency
- Further work is needed on the flow control device before it can be implemented

From these conclusions the inline UV chamber shown in figure 8 was manufactured at Willand UV Systems Ltd.

4. CFD simulation of parallel separators

4.1. Model and domain discretisation

The configuration shown in figure 9 was used in the initial calculation of the flow within the TREBAWA parallel separators. The flow conditions are $125m^3hr^{-1}$ at the inlet pipe.

4.2. Initial results

Initial results highlight some potential problems with the separator configuration. Firstly particle tracking shows that particles which are suspended in the fast moving flow within the manifold feed pipe to the separator inlets are likely to travel in the centre of the pipe. This results in the particles by-passing the inlets of separators 1 and 2, (i.e. the two upstream separators), and making their way to the inlets of the second two downstream separators. Therefore separators 3 and 4 are forced to deal with the majority of particles suspended in the inflow. A central feed chamber with the separators arranged radially along the circumference may prevent this occurrence and ensure an equal feed to each individual separator. Also this arrangement may help to reduce space onboard.

Secondly, the position of the underflow outlet on the drain at the bottom of the system may be positioned too close to the underflow outlet of separator 1, (the furthest separator upstream on the inflow). The sudden exit to ambient pressure shows a suction created at the base of separator 1 and to some extent separator 2 causing a breakdown of the cyclone formation within each separator. It is recommended this is looked at during modification.

5. Experimental Field tests of the TREBAWA system

Following the optimisation of the system components a full scale prototype of the TREBAWA unit was constructed. The separator installation (figure 11) was set up on the pier at Millport, the Marine Biology Research Station of the Universities of London and Glasgow, Isle of Cumbrae.

5.1. Experimental equipment

5.1.1 <u>Pump and drain off</u>

Inflow to the system was performed via a Godwin series ET1507/TS3 pump which delivered a flow rate of $200m^3hr^{-1}$. Before entering the 6" inlet pipe the seawater was passed through a T-section junction which had a 3" drain-off for controlling the inlet flow rate.

5.1.2 TREBAWA Parallel Separators

In addition to the drain-off T-section a flow control valve was fitted at the inlet. Each separator in the group also had a shut-off valve at the inlet and overflow outlet. Each separator could then be individually shut off and hence removed from the parallel system. To control back flow at the underflow drain a control valve was placed at the end of the underflow pipe.

5.1.3 Measurement equipment

Pressure was measured via pressure gauges located at the inlet manifold pipe nearest the far separator. Flow rate in the inlet and overflow pipe sections was read externally using a Micronics Ltd Portflo SE clamp-on, ultrasonic, transit time flowmeter.

5.1.4 Sampling points

There were samples taken from the inflow at the T-section bypass and at the overflow outlet. These were used to compare particle content of the inlet and "clean water" flow and hence demonstrate the separation efficiency of the separators.

5.2. Test programme

The system is run at 100% (i.e. the flow rate at the inlet is $167m^3hr^{-1}$). Here all separators are operational. Maintaining this flow rate the separator nearest the inlet is shut off completely using the valve at the feed pipe. Further the second separator is then closed. The convention for the test case is "A" for all separators operating, "B" for three separators operating and "C" for two separators operating.

The flow rate is then reduced to 75% of the initial inflow at the inlet ($125m^3hr^{-1}$) and the process repeated. The final flow rate of 50% ($83.3\ m^3hr^{-1}$) follows in turn. The case naming convention where all separators are operational for reduced flow rates are "A1" for 100% flow rate, "A2" for 75% flow rate, "A3" for 50% flow rate and so on for idle separator tests "B" and "C". Three samples were taken during each case and the inlet pressure is read from the inlet pressure gauge.

5.3. Results

5.3.1 Particle separation

The flow rate for the separators were controlled so that 70% of the inlet flow emerged from the overflow therefore an accurate estimation of the separation efficiency could be gained.

Samples A.2.2 inlet and A.2.2 outlet were analysed under the microscope. 25ml of each sample after mixing were placed in settling chambers with Lugol's iodine as a fixative. The samples were left for over 12 hours whereby the fixed cells had sunk to the bottom of the chamber.

Sand grains (>50μm)

In the 25ml inlet sample showed 148 particles. The outlet sample for the same case showed 16 particles in this category giving a particle removal efficiency of 89%. This is in agreement with the CFD prediction which puts the larger particles ≈100μm with large specific gravity such as sand in this region.

Planktonic organisms

The inlet sample showed:	The outlet sample showed:
96 Skeletonema costatum cells	93 Skeletonema costatum cells
5 Pseudo-nitzschia seriata	12 Thalassissira spp
1 Nitzschia closterium	8 Chaetoceros spp
	2 Coscinosira polychlorda
	2 Nitzschia closterium
	1 Ditylum brightwellii

The present separator seems unable to remove these type of planktonic microorginisms which are low density and in some cases far from spherical in shape. It is understood that for particles less dense than water separation is not possible and the system will rely on the UV unit to kill the remaining organisms. An example of the input and output samples is shown in figure 17.

5.3.2 Pressure measurement

At 75% flow rate with all separators operating a pressure of 0.2 bar. This was in agreement with the CFD calculation which showed a 0.18 bar operating pressure across the separator inlet manifold.

6. Conclusions

In conclusion, the present study has shown:

- CFD has proved a useful tool in the design optimisation of the main components of the TREBAWA system;
- The geometrical relationship between the main components of the hydrocyclone separator must be chosen carefully and to suit the required separation and clean water production criteria;
- A high rate of clean water production must be traded off with a reduced level of particle separation for a single separator;
- Separators working in parallel provide an alternative to a single unit where height or space in general is a restriction;
- Using a multi-inlet separator does not reduce the separation efficiency or the clean water production but wear and pressure drop will be increased and the system may have to be shut down completely for maintenance;
- An inline UV chamber reduces flow re-circulation, swirl and other secondary flow effects in comparison to branch inlet/outlet designs and can reduce the pressure drop across the chamber by up to 30%;
- Using several UV lamps perpendicular to the flow may give a higher average dosage than using a single lamp running parallel to the flow along the length of the chamber
- Staggering the height of the UV perpendicular UV lamps reduces the time to first trace efficiency of the chamber;
- The current arrangement of the hydrocyclone separators in the TREBAWA system may result in suspended particles moving in the centre of the manifold inlet pipe by-passing the first two separators in favour of the two downstream separators;
- A radial arrangement around a central feed chamber may be needed to ensure an equal inlet to all separators thus increasing the efficiency of the system and decreasing the wear to any one particular separator;
- The position of the underflow drain outlet may have to be altered in order to avoid a suction effect and the breakdown of the cyclone development in separators nearest the underflow exit;

- A tier system of separators may be needed to separate the finer, lighter particles currently passing through the separators. Smaller separators will intake the clean water from the overflow outlet of the current separators and the separation process will re-commence on a finer scale.

7. Future work

The ongoing experimental and computational programme hopes to produce further comparable data for presentation. At the present time the experimental results are still in analysis and the computational model at an early stage. Initial experimental feedback suggests a reasonably high degree of success with the initial separator prototype. The computational results to date suggest that a re-arrangement of the system to ensure all separators are given an even feed and this will have to be looked at in further development initiatives. A separator tier system may also be looked at in order to account for particles and organisms not separated from the clean water by the original separator design. A system of sequentially reducing separators should be considered for further development of the system.

Table 1 - Comparison of static pressure drop across separator designs.

Design	Inlet Diam (mm)	Dc	Underflow/ Dc ratio	Overflow /Dc ratio	Overflow Length (mm)	Pa	mbar	bar	Cyclone Height (mm)
1D5D	127	254	0.5 Dc	0.5 Dc	750	4500	45	0.045	1270
1D5D	127	254	0.5 Dc	0.5 Dc	325	3750	37.5	0.0375	1270
1D5D	127	254	0.5 Dc	0.5 Dc	180	4000	40	0.04	1270
1D5D	127	254	0.15 Dc	0.5 Dc	180	8800	88	0.088	1270
1D5D (50%)	63.5	127	0.5 Dc	0.5 Dc	375	4500	45	0.045	760
1D5D (50%)	63.5	127	0.5 Dc	0.7 Dc	180	5000	50	0.05	760
1D5D (50%)	63.5	127	0.5 Dc	0.5 Dc	180	3750	37.5	0.0375	760
1D5D (50%)	63.5	127	0.5 Dc	0.35 Dc	180	5200	52.0	0.052	760
1D3D	127	254	0.25 Dc	0.5 Dc	180	9500	95	0.095	1016
1D1D	127	254	0.25 Dc	0.5 Dc	180	14000	140	0.14	508
1D2D	127	254	0.5 Dc	0.5 Dc	180	11000	110	0.11	762
1D2D	127	254	0.1 Dc	0.5 Dc	180	14500	145	0.145	762
1D2D	127	254	1.0 Dc	0.5 Dc	180	5000	50	0.05	762
2D2D	127	254	0.25 Dc	0.5 Dc	180	8600	86	0.086	1016
2D2D	127	254	0.5 Dc	0.5 Dc	750	16000	160	0.16	1016
2D2D	127	254	0.5 Dc	0.5 Dc	325	9000	90	0.09	1016
2D2D	127	254	0.5 Dc	0.5 Dc	180	4000	40	0.04	1016
3D1D	127	254	0.25 Dc	0.5 Dc	180	8200	82	0.082	1016
Rietemar (100%)	127	455	0.2 Dc	0.34 Dc	181	4000	40	0.04	2300
Rietemar (50%)	63.5	227	0.2 Dc	0.34 Dc	90.5	3750	37.5	0.0375	1150
MKS200 (50%)	127	-	-	-	-	23500	235	0.235	1200
MKS200 (50%)	127	-	-	-	200	27500	275	0.275	1200
MKS300 (50%)	127	-	-	-	-	27500	275	0.275	1200
AKW (100 %)	56	120	0.4 Dc	0.75 Dc	-	3750	275	0.0375	770
Krebs	127	503	0.35 Dc	0.35 Dc	200	3800	380	0.038	1430

(100%)									
Krebs (100%)	127	503	0.35 Dc	0.35 Dc	400	4000	400	0.040	1430
Krebs (50%)	63.5	252	0.35 Dc	0.35 Dc	100	3500	350	0.035	720
Krebs (50%)	63.5	252	0.35 Dc	0.7 Dc	100	3250	325	0.0325	720
CASE A	63.5	254	0.35 Dc	0.5Dc	150	2634	263	0.0263	1220
CASEB	63.5	254	0.35Dc	0.7Dc	150	2860	286	0.0286	1251

Table 2 - Comparison of static pressure drop across UV chamber designs.

Case	Flow Rate (m^3/hr)	Chamber Length (mm)	Number of UV Lamps	Pressure Drop (mbar)
uv1	120	1025	1	13.7
uv2	120	1025	1	16.1
uv3	120	1025	1	11.1
uv4	120	500	4	9.8
uv5	120	1025	1	14.1
uv6	120	2 x 1025	2	31.2
uv7	120	1025	1	15.4
uv8	120	1025	6	22.5
uv9	120	1025	4	18
uv10	120	500	4	12.1
uv11	120	1025	4	7.25
uv12	120	1025	4	8.3

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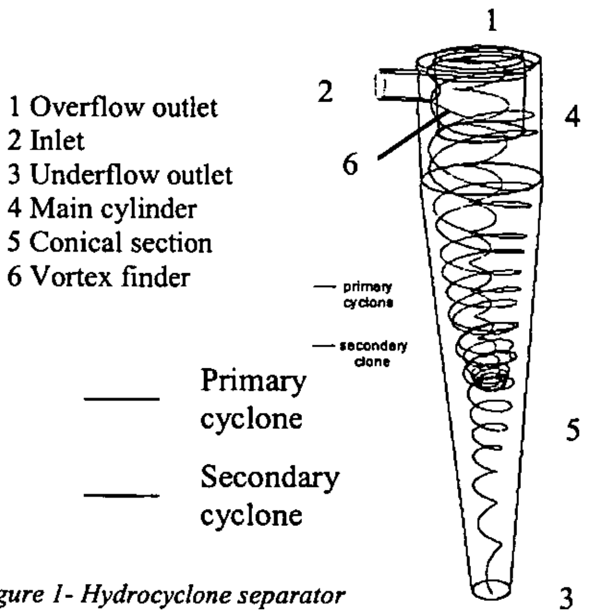


Figure 1- Hydrocyclone separator

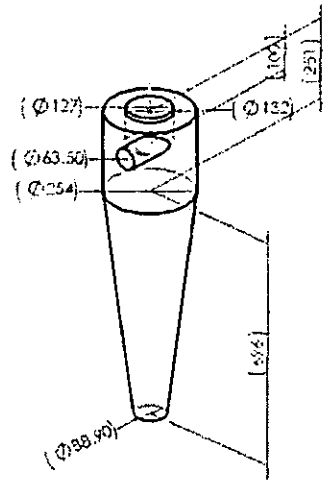


Figure 2(a) - Case A Separator, dimensions in mm

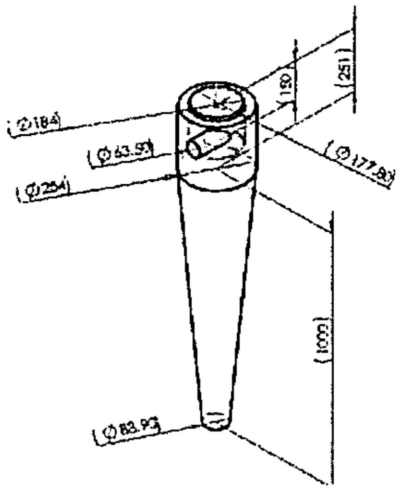
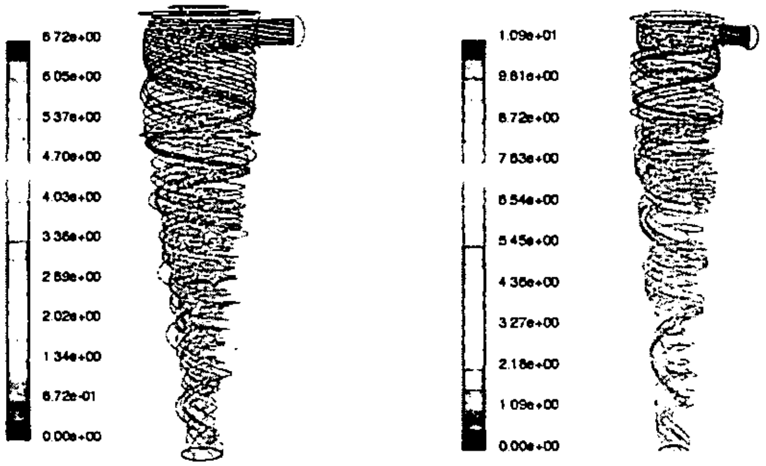


Figure 2(b) - Case B Separator, dimensions in mm



(a) Case A *(b) Case B*

Figure 3 - Particle traces for separators A and B

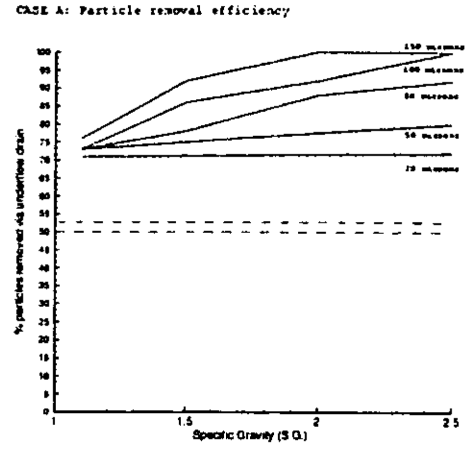


Figure 4 - Particle removal efficiency plot Case A

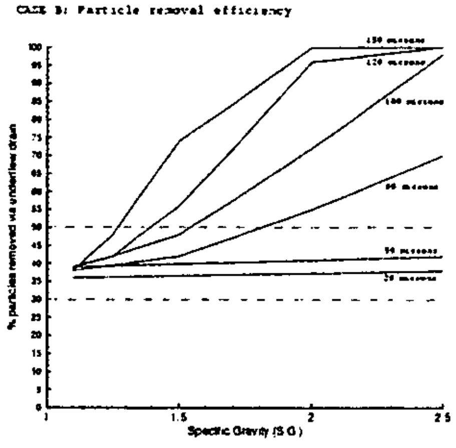


Figure 5 - Particle removal efficiency plot Case B

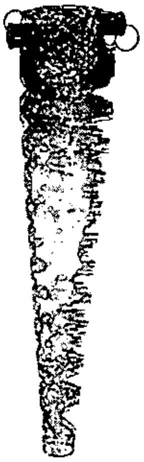


Figure 6 - Particle trace for Case B 4 inlets

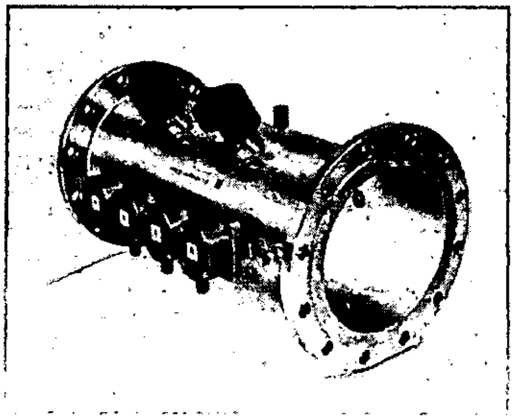
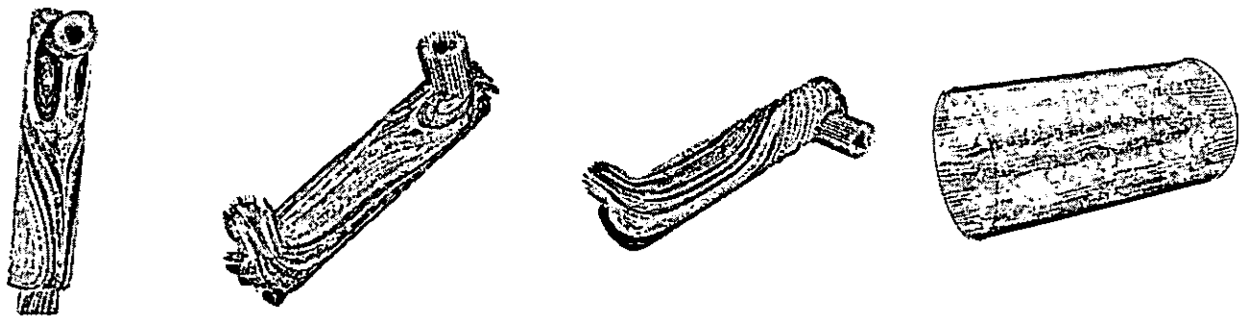


Figure 8 - TREBAWA inline UV Chamber



(a) normal/inline branch (b) normal/normal branch (c) normal/normal branch (d) inline design

Figure 7 - Particle tracks in branched and inline UV configurations

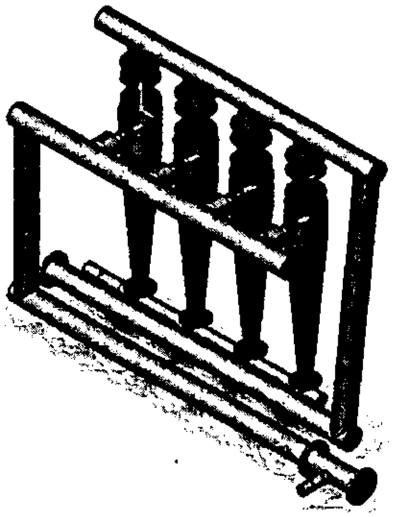


Figure 9 - TREBAWA parallel separator geometry used in initial CFD calculations

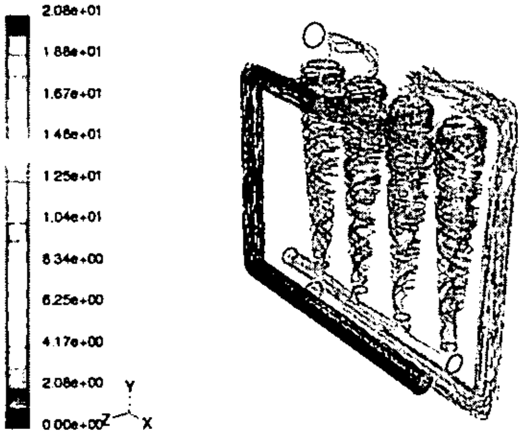


Figure 10 - Particle tracks in TREBAWA parallel separators

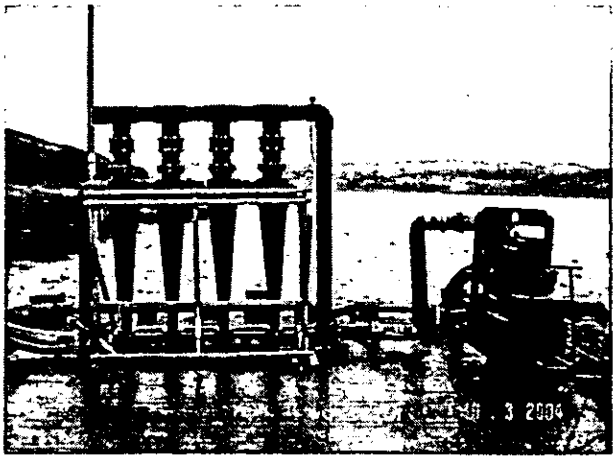


Figure 11: TREBAWA parallel separators in position on pier

Figure 12(a): Inlet sample A.2.2, sand particle = 130μm x 100μm

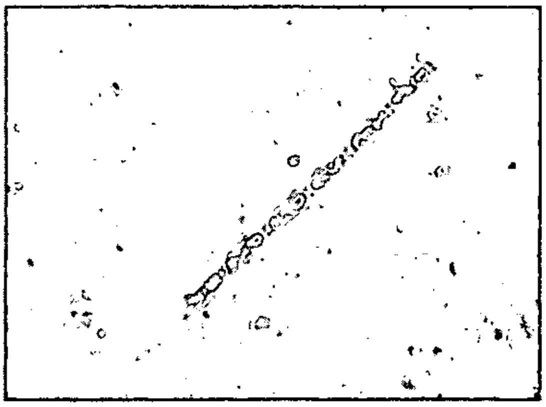


Figure 12(b): Outlet sample A.2.2, organism = 160μm x 7μm

A CRITICAL REVIEW OF BALLAST WATER TREATMENT TECHNIQUES CURRENTLY IN DEVELOPMENT

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Marine vessel ballast water has been identified as a key factor responsible for the transfer and introduction of harmful organisms into non-indigenous environments. This has been identified as one of the four greatest threats to the world's oceans. The significance of ballast water transferral of species has led to diverse research and development into ballast water treatment methods. Despite the number of ballast water management techniques in development, at present ballast water exchange is the only technique widely used. This literature review summarises the Ballast Water Treatment techniques currently at a research or development stage. An assessment of the potential effectiveness of each method, its corrosion implications and economic cost are all presented together with preliminary recommendations.

1. Introduction

Approximately 80% of world trade is transported by shipping. Currently there is a world shipping fleet of approximately 85,000 vessels and many of these ships use sea water as ballast. The use of water as ballast is currently essential to ensure the safe operation of vessels, and equates to approximately 3 to 5 billion tonnes of water transported by marine vessels annually. This transfer of water around the world has an enormous biological effect on coastal and freshwater ecosystems, due in part, to the significant quantity of organisms and organic matter suspended in ballast water. These organisms are deposited freely in coastal waters upon deballasting. The ready transport of debris and micro-organisms, coupled with the complex design of ballast tanks can also result in large quantities of sediment being deposited within ballast tanks (Figure 1). This can create a breeding ground in which certain organisms may flourish. These healthy organisms can then be deposited at ports around the world and, providing the environment is suitable, take hold.

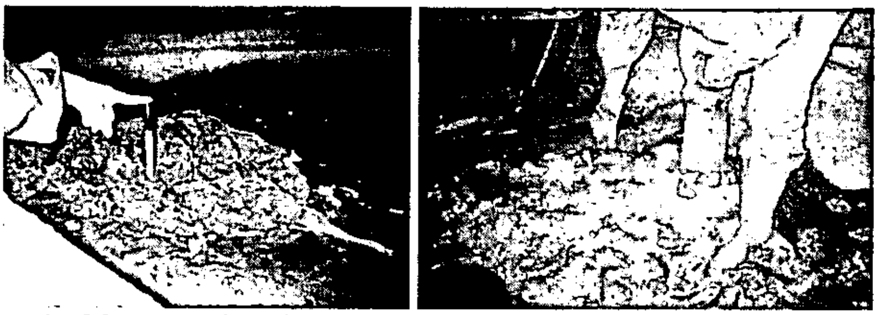

Figure 1 - Photographs' showing accumulated sediment within ballast tanks.

Many organisations are conducting research into potential treatment techniques for ballast water; however design of ballast tanks, complex operational characteristic, and huge costs involved currently limit the advance of the technology. The intention of this paper is to highlight the current situation with respect to ballast water treatment techniques in development. It aims to draw attention to significant issues surround many of the treatments, with respect to the criteria laid down by the International Maritime Organisation (IMO).

The IMO has recognised the significance of Ballast Water Treatment (BWT) and consequently set-up GloBallast. Criteria laid down by the GloBallast 1st International Ballast Water Treatment Standards Workshop [1] for new ballast water treatment technologies are as follows:

1. The technique must be safe (in terms of the ship and its crew).
2. It must be environmentally acceptable (not causing more or greater environmental impacts than it solves).
3. It must be practicable (compatible with ship design and operations).
4. It must be cost effective (economical).
5. It must be biologically effective (in terms of removing, killing or otherwise rendering inactive aquatic organisms and pathogens found in ballast water).

From the criteria listed biological effectiveness was deemed to be the most significant and hence the focus of most BWT mechanisms. The standard states that organism mortality/deactivation should be at least 95%. An additional category for organisms >100 microns specifies 100% mortality/deactivation.

2. BWT: Achieving Biological Effectiveness

There are three categories of BWT, mechanical, physical and chemical treatment methods. Within each category there are a number of treatment techniques, many of which are still in early development or prototype stages (Table 1). The systems are often modular and designed retro fit older ships as well as new build vessels.

Table 1 - Current BWT techniques in use or development.

1	Ballast Water Exchange
2	Sonic methods
3	UV Radiation
4	Heat Treatment
5	Screens/Filters
6	Hydro-cyclone
7	Chemical Biocides
8	Ozone
9	De-oxygenation
10	Gas Super-saturation

The key points each of the ballast water treatment methods have been outlined (Table 2). Many of the negative issues surrounding the various treatment techniques are currently being evaluated by research teams around the world. As such information was correct at time of print.

Table 2 - Summary of Advantages and Disadvantages of each BWT mechanism [2].

Treatment Method	Advantages	Disadvantages
Ballast Water Exchange	• There are a number of variations on the BWE method including re-ballasting, continuous flushing and dilution. • Can require little or no modification to the vessel and therefore has no initial cost.	• BWE is not a treatment. • Weather conditions may threaten the stability and/or the structural integrity of the ship. • Some ships do not have the correct facilities to enable ballast water exchange. • Many voyages are too short to allow complete ballast exchange.

Ballast Water Exchange cont.		• 99% volumetric exchange of ballast water does not ensure biological effectiveness. • Some oceanic species may be transferred from open waters to coastal waters and vice versa.
Sonic methods	• Minimal crew interaction required. • Targets micro-organisms. • Could destroy sedimentary particles	• Poor laboratory results. • Increase in ocean noise. • Potential increase in tank corrosion. • Susceptibility depends on organism type • Biological decay can increase tank sediment
UV Radiation	• Minimal impact on ballast flow • Targets macro and micro-organisms effectively • Can be used on deballasting as well as ballasting • Long history of effective water treatment • Ease of maintenance • Computer control can be implemented to regulate UV dose	• Many factors influence effectiveness, including temperature, water clarity and flow rate. • Organisms may be UV resistant • Biological decay can increase tank sediment
Heat Treatment	• Available heat source • Effective on all organisms, including sediment based	• Thermal stressing of vessel • High energy requirement depending on heat source • Biological decay can increase tank sediment
Screens/Filters	• Organisms return to source waters	• Can require "back-flushing" to clean filters • High cost for replacement screens
Hydro-cyclone	• Organisms return to source waters • No moving parts • Does not require "back-flushing" or similar cleaning	• Difficulty removing organisms with a similar density to ballast water, predominantly micro-organisms
Chemical Biocides	• Can be tailored to targeted specific organisms • Relatively low cost	• Unknown long term effects • Potential hazard to crew • Potential tank corrosion increase depending on chemical used • Biological decay can increase tank sediment
Ozone	• Long history of Marine use • Relatively low cost	• Highly toxic • Not suitable for waters with a high turbidity • Increased tank corrosion • Biological decay can increase tank sediment

De-oxygenation	• Up to 10% reduction in tank corrosion. • Biological or vacuum induced de-oxygenation is possible	• Some organisms phases (cysts, spores etc.) do not require oxygen • Unknown effects of vacuum generated within ballast tanks. • Biological decay can increase tank sediment
Gas Super-saturation	• Minimal crew interaction required.	• Has little effect on micro-organisms. • Organism type dependent • Potential increase in tank corrosion • Biological decay can increase tank sediment

2.1. Ballast Water Exchange

Existing IMO guidelines recommend Ballast Water Exchange (BWE) at sea as the current method used to minimise the transfer of invasive species. However BWE is not a treatment. The technique involves changing the ballast in deep water locations where there is no harmful sediment or potentially invasive organisms. This is based on an assumption that coastal organisms do not survive in deep water locations and vice versa. There are a number of variations on the BWE method including re-ballasting, continuous flushing and dilution [3].

A large proportion of the ballast water carried by ships (2.7 billion tonnes per year, [4]) will require a treatment other than ballast water exchange, this is confirmed by the fact that BWE has not led to eradication of organism transferral via ballast water, with an estimated 100 million tonnes of untreated ballast water in the North Atlantic alone.

An important consideration in the use of Ballast water exchange is the level of potential exposure of crew members to harmful contaminants. Continuous flushing or Brazilian dilution methods offer a possible solution. A significant advantage of Brazilian dilution is that crew interaction is no longer an issue. This method requires at least three complete cycles of exchange to be completed to ensure <95% effectiveness.

Case Study taking the *Iron Whyalla* Bulk Carrier as an example:

With a ballast capacity of 57,000 tonnes and capable of pumping up to 2000 tonnes/hour per tank, a total ballast/deballast rate of 10,000-20,000 tonnes/hour can be achieved [5]. With an average pump rate of 15,000 tonnes/hour, ballast exchange would complete in 3 $^{3}/_{4}$ hrs. Therefore 11 $^{1}/_{4}$ hrs would be required to achieve 3 complete ballast cycles, within this time (average cruise speed of 16 Knots) the vessel would have travelled 180 Nautical Miles (333 Km).

Hence organisms may be transported beyond any natural boundaries in their current environments into neighbouring waters. This "local" invasion could be particularly prominent around the Caribbean and other tourist routes due to a high number of cruise ship operations within coastal waters. In this instance ballast water may only be transported within a relatively small geographical area but could still result in the introduction of organisms which would otherwise not be seen in such waters.

Current ballast tank design can also give rise to areas of stagnant ballast within the tanks, resulting in reduced biological exchange despite high volumetric exchange. This scenario is highly dependent on the exact design of specific ballast tanks and may not be applicable to all vessels, regardless it could be seen as a significant downside to any method of ballast water exchange.

2.2. Sonic methods

Sonic BWT methods predominantly utilise ultrasound (20 kHz – 10 MHz). The technique relies on a transducer to generate sound energy within the ballast tank. As the sound energy passes through the ballast water it energises local particles resulting in the formation of cavities (bubbles). As these cavities collapse there is an intense energy output which causes both physical and chemical effects within the ballast water. If the effects are powerful enough the cells of the organisms local to the collapse will rupture [6]. The temperature surrounding the collapsed bubble can reach in excess of 2000° C and attain pressures of up to 1800 atmospheres; these factors ensure that organism mortality is achieved. The system can be controlled by altering the frequency and power density of the ultrasound to generate cavitation in varying densities of ballast water.

Despite the possibility of ultrasound as a feasible ballast water treatment technique, current laboratory tests have been unable to achieve organism mortality greater than 40% (University of Newcastle, UK). This may, in part, be due to the inability to induce cavitation accurately. In tests carried out the water used was flowing under laminar conditions into a static tank, however turbulent flow has been seen to increase the efficiency of ultrasound treatment. Due to the flow rates of water entering ballast tanks it is highly likely that turbulent conditions will arise.

One of the negative effects of any sound or cavitation induced BWT is an increase in ocean noise. Many organisations are looking to minimise the amount of sound generated by marine applications. This has come about due to evidence that high use of sonar and other general marine noise can disturb and potentially harm many marine species, particularly mammals. It has been suggested that marine mammals such as whales or dolphins communicate using sound in the frequency range of 1000 to 100,000 HZ. While the specific sonic frequencies used in BWT research are out of the immediately harmful range, the significant increase in sonar as a result of mandating BWT could prove hazardous to marine mammals.

Treatment of Ballast Water by sonic methods on the world fleet of 85,000 vessels each year would increase ocean noise tenfold. With the prospect of legislation being introduced to minimise ocean noise, and in particular the use of sonar, it would appear prudent to avoid the implementation of sonic methods as a standard BWT on ocean going vessels. To use sonar with the aim of conserving ocean biodiversity in light of current backlash from conservation organisations could potentially be costly.

2.3. Gas Super-saturation

Gas supersaturation is a mechanism which induces gas bubble trauma (GBT) within organisms. GBT is known to affect a number of the organisms present in ballast water; however the vulnerability to gas supersaturation varies between organism types. GBT affects multi-cellular marine organisms resulting in embolism and haemorrhages [7]. The process works best when hydrostatic pressures are lowered. The procedure involves over saturation of the ballast water with a gas, usually air or nitrogen. The equipment required consists of a gas generator connected to the existing ballast plumbing. This technique does not require the storing or use of harmful chemicals ensuring no detrimental effect to the crew or the outgoing ballast water and no handling of chemicals [8]. The main disadvantage of the technique lies in its inability to destroy micro organisms requiring a treatment targeted specifically at micro organisms, such as UV radiation.

Cavitation based techniques such as Ultra-sound or Gas Super-saturation can lead to significant erosion problems on the walls within a ballast tank. The problems arising from cavitation around a ships propeller are well documented and have been seen to cause rapid damage sometimes requiring replacement of a ships propeller after a single voyage [9]. While Propellers are not manufactured from the same material as tank walls the corrosion effects could significantly reduce the life of the vessel.

2.4. UV radiation

Ultra Violet (UV) radiation is absorbed by micro organisms and effect of rendering the organism inactive, preventing reproduction, or killing the organism. UV systems are relatively compact and as such are ideal for use on marine vessels. UV induced mortality can be influenced by a number of variables including water clarity, temperature, flow rate and organism type.

UV radiation is particularly useful as a secondary stage in a BWT setup, targeting micro-organisms specifically. Water clarity problems are resolved through the use of a primary system. Significantly UV can be used for both incoming and outgoing ballast water, reducing the effects of bacteria growth within ballast tanks [10]. This can all be controlled electronically ensuring the correct dose of UV radiation to deactivate organisms [11].

Case Study: a typical UV Reactor:

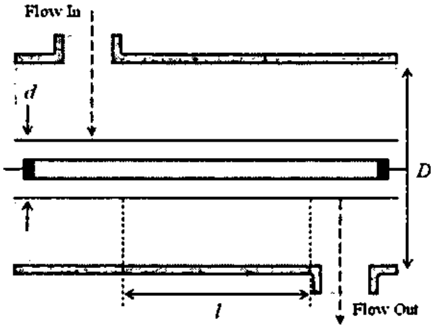

Figure 2 - Cross Section of a typical UV Reaction Chamber.

From the Beer-Lambert law we can determine the maximum UV dose a typical UV Reactor (Figure 2) will provide. The parameter I_x (Radiation energy), ψ (UV output), A (Absorbance per cm) and X (Distance to point of lowest intensity) are all used.

Beer-Lambert Law:

$$I_x = \left(\frac{\psi \times 1000}{2\pi r l}\right) \times 10^{-AX} \qquad (1)$$

Therefore $I_x \approx 2100$ mW/cm^2

Assuming a maximum loss of 40% due to debris etc $I_x \approx 1260$ mW/cm^2

The Dose received will therefore be the UV intensity multiplied by the length of time that the organisms are within the UV Reactor.

$$\text{Dose} = I_x \,.\, t(s) \qquad (2)$$

Therefore Dose ≈ 3500 µWs/cm^2

The capacity of the typical UV chamber analysed is thus,

$$Q = \frac{\left(\left(\pi D^2\right)-\left(\pi d^2\right)\right)\times l}{t} \qquad (3)$$

Therefore $Q \approx 94.5\ \mathrm{m^3/h}$

Thus UV can achieve IMO standards when used in conjunction with a first stage system to induce desirable conditions for UV dosing.

2.5. Heat Treatment

Heat treatment relies on the break down of organisms by increasing the temperature of the water. This heating of ballast water has the effect of either destroying or deactivating unwanted organisms. Current heat treatment systems in development employ the use of a heat exchanger, linked to the vessels exhaust system. This arrangement system would ideally be suited to voyages in the region of 10 days or more as the time taken to increase the temperature within the ballast tanks is significant. Other systems heat small quantities of water either on entering or leaving a vessel, achieved using heat circulation methods, ideally be suited to passenger or container ships which tend to have frequent stops with only minor changes in ballast volume made. Two key temperature ranges tend to be targeted, low temperature systems (< 40°C) and high temperature systems (40 – 80 °C). Low temperature trials onboard *Iron Whyalla* have shown that most phytoplankton are killed at temperatures as low as 35°C with treatment times ranging between 30 minutes and several hours.

Generally a minimum of 4,000 tonnes (general cargo vessel [12]) of ballast needs to be treated and can increase up to 80,000 tonnes, the heat energy required to achieve this can be immense, additionally while some trials have shown total mortality of specific species at temperatures as low as 35°C this may be too low to destroy all hazardous organisms including dormant cysts.

Many high temperature systems are being developed to achieve temperatures in excess of 70°C [13]. This would require a vast energy reserve with the majority of ships engines generating no more than 20 MW of excess energy. The actual requirement could be as high as 90 MW (Australian Quarantine and Inspection Service, 1993) [14]. As such initial cost effectiveness of heat based treatments may not be applicable to high temperature techniques and sustained heating may be unachievable on shorter journeys. Heat treatment trials onboard *MV Iron Whyalla* [15] suggest that short term local heating would be insufficient to ensure mortality and may not be practical for many commercial ventures.

Ship design and layout may prevent appropriate piping or heating capabilities. Heat treatment trials so far have relied heavily on the initial temperature of the water taken onboard operationally it seems highly likely that heat treatment will not be able to guarantee the 95% mortality rate required by the IMO.

The energy and time required to achieve ideal mortality temperatures of 70°C for three typical vessels of varying ballast tank size are shown.

Case study: Heat treatment for different initial temperatures and quantities

For a large bulk carrier assuming 20MW of excess power and intake water temperature range of 0°C - 30°C the time taken to achieve the desired temperature rise can be shown, the mass of the water (m), c is the specific heat capacity and t_1 and t_2 are the initial and final (assuming no heat losses);

$$Q = mc\,(t_2 - t_1) \tag{4}$$

$$Time = \frac{Energy}{Power} \tag{5}$$

$$Power = \frac{Energy}{Time} \tag{6}$$

Tables 3 and 4 show the heat energy (Q) required to raise temperature of two quantities of ballast, Assuming 20MW initial excess power, The time to achieve a temperature of 70°C for 80,000 tonnes Ballast is also;

Table 3 - Heat energy requirements and time taken to achieve 70°C for 80,000 tonnes Ballast.

80,000 tonnes Ballast Capacity	Required Heat Energy	Time to 70°C	Power required to reach 70°C in 5hrs
t_1= 0°C	$Q \approx 2.3\ x10^{10}$ kJ	≈ 13 Days	≈ 126 MW
t_1= 30°C	$Q \approx 1.3\ x10^{10}$ kJ	≈ 7.5 Days	-

Table 4 - Heat energy requirements and time taken to achieve 70°C for 4,000 tonnes Ballast.

4,000 tonnes Ballast Capacity	Required Heat Energy	Time to 70°C
t_1= 0°C	$Q \approx 1.1\ x10^{9}$ kJ	≈ 16 Hours
t_1= 30°C	$Q \approx 6.5x10^{8}$ kJ	≈ 9 Hours

These figures indicate that the power required to heat the water the ballast water, even for smaller vessels, is greater than the excess currently available from engines. On a commercial vessel the time to temperature would need to be in the region of five hours. Power required to achieve this rapid heating for a large scale bulk carrier is also given and equates to 106 MW more than currently available engine excess. Cost implications of this power requirement renders heat treatment unviable as a ballast water treatment mechanism.

2.6. Screen filtration

Screen filtration has been in use for many years in a large variety of applications. The technology has been developed continually over the years to a point where screens are capable of filtration down to 10μm. Large scale tests have seen screens shown to be 74-94% effective at removing debris (Using 25μm filters) [16] however tests have shown that 50μm is the practical limit for ship board use [17]. Screen filtration in its current form has been around for many years. This has led to significant research and development conducted into filtration systems [18]. The major advantages of mechanical filtration include the lack of harmful by-products, and the return of debris to the initial ballasting site. Filtration units could easily be incorporated into existing plumbing and pump systems. Filtration in its current form could provide adequate primary particle removal, however bacteria and virus removal would be far too costly when compared to other systems such as UV radiation [17].

Clogging with waste is a common drawback of traditional screen filters during heavy use. In order to overcome this, a differential pressure sensor allows for a brief "backwash" cycle in order to clean the screens. This backwashing can delay the ballast water intake and output rates, and although the exact water loss achieved can be as low as 1%.

2.7. Hydro-cyclonic filtration

By design Hydrocyclones have no moving parts and do not require back flushing. The fluid enters tangentially and a conical section induces spiral flow. This rotational flow causes dense solid particles to be forced towards the walls of the separator where they are discharged, this discharge makes up for less than 5% of the total ballast water intake [19]. However some organisms have a similar density to water and as such are not are not affected by the centripetal force acting within the cyclone, as a result they always discharged.

Presently dual stage hydrocyclone/UV systems are the only BWT systems fitted to commercial vessels [7]. Currently commercial use will increase the rate of development of BWT hydrocyclones as current BWT hydrocyclones do not resemble separators from other engineering fields. Further development of separators using research conducted in other sectors may achieve the efficiency required for BWT. A typical commercial BWT Hydrocyclone (Figure 3) is shown:

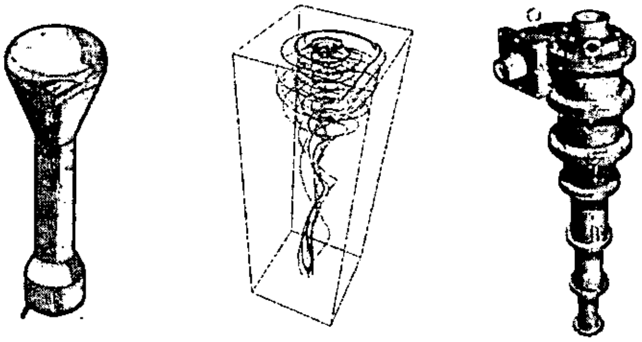

Figure 3 - a) Commercial BWT Hydrocyclone. b) Velocity Streamlines within a hydrocyclone c) Reverse flow hydrocyclone.

Due to the design of current BWT separators it is difficult to apply the geometry and scaling rules of other separators. One of the most widely used hydrocyclone designs follow the parameters set by *Rietema*. The *Rietema* empirical data relating to geometry ratios etc. can potentially be applied to redesign BWT hydrocyclones therefore allowing verification of multiple hydrocyclone designs and their corresponding efficiencies through the use of Computational Fluid Dynamics (CFD).

Hydrocyclones designs are evaluated based on their dimensionless cut size (D_c), Recovery of water to underflow (Rf) and the Volumetric recovery of debris to underflow (Rv), these ratios are given (Table 5) additionally the product between Stokes number and Euler number (*7*) is constant for geometrically similar hydrocyclones [20].

Table 5 - Reitema hydrocyclone design ratios.

Ratio	D_i/D_c	D_o/D_c	L_l/D_c	l/D_c	θ
Reitema Hydrocyclone	0.28	0.34	5.0	0.4	20°

The following parameters have been given by M.A.Z. Coelho and R.A. Medronhob [21]. Experimental work completed by the pair has shown that the product $Stk_{50}Eu$ is a function of water flow ratio R_w and volumetric feed concentration C_v.

$$Stk_{50}Eu = k_1\left[\ln\left(\frac{1}{R_w}\right)\right]^{n_1}\exp(n_2C_v) \qquad (7)$$

$$Eu=k_2\, Re^{n}{}_3\, \exp(n_4C_v) \qquad (8)$$

$$R_w = k_3 \left(\frac{D_u}{D_c} \right)^{n_5} Eu^{n_6} \tag{9}$$

The parameter *k* and *n* are given (Table 6), additionally the remaining parameters, $Stk_{50}Eu$, *Eu (Euler number)*, *Re (Reynolds number)*, and R_w (Flow ratio) are given (10 – 13).

Table 6 - Rietema Hydrocyclone design parameters.

Constant	Rietema Hydrocyclone
k_1	0.0474
k_2	371.5
k_3	1218
n_1	0.74
n_2	9.0
n_3	0.12
n_4	-2.12
n_5	4.75
n_6	-0.30

$$Stk_{50}Eu = \frac{\pi(\rho_s - \rho)\Delta P D_c (d'_{50})^2}{36\mu\rho Q} \tag{10}$$

$$Eu = \frac{\pi^2 \Delta P D_c^{\,4}}{8\rho Q^2} \tag{11}$$

$$\mathrm{Re} = \frac{4\rho Q}{\pi\mu D_c} \tag{12}$$

$$R_w = \frac{Q_u(1 - C_{vu})}{Q(1 - C_v)} \tag{13}$$

Experimental work in conjunction with numerical calculation will provide the support required to verify future BWT hydrocyclones using CFD.

2.8. Chemical Biocides

There is a limit to the types of chemical treatment available for BWT. This is due to the diverse nature of the organism targeted. Despite the availability of many commercial chemicals capable of rendering inactive all ballast water transported species, the chemicals used would have to have a short lifespan in order to prevent damage to indigenous coastal species on ballast deployment. As a result of the marine cross section encapsulated in ballast water most current chemical biocides are organic based, resulting in complete degradation during the course of the voyage [22]. The use of chemicals as BWT will require regular handling by crew and as such treatments will need to be safe for repeated handling. Advantages of chemical treatments include low purchase cost and no requirement to modify existing vessels. Many existing chemicals are being tested for ballast water use. As a result chemical treatments should be ready for ship deployment much sooner that mechanical or physical treatments. Due to the nature of ballast water requirements it may be that chemical treatments are used as an interim BWT while other methods continue being developed [23].

However as with all chemical agents the long term implications are unknown and the potential environmental impacts could be severe. Additionally large quantities of decaying organic matter would be pumped into coastal waters; this could become a significant food source to indigenous species eventually causing an imbalance in current species biodiversity.

2.9. Ozone introduction

The use of ozone as a disinfectant for water has occurred since the late 1800's, since when it has been implemented in many marine applications. Ozone is an oxidising agent which destroys hazardous organism within minutes. The short half life of ozone (5.3 seconds) makes it an environmentally safe chemical treatment [24}. This short half life requires the ozone to be generated on site, thus necessitating an ozone generator. This works by passing a high frequency electrical discharge through air. Despite the safe environmental impact of ozone the gas itself is highly toxic and is difficult to detect. This would require a high number of safety measures to be adopted by the crew. In addition to these factors ozone treatment is not suitable for water with a high turbidity, thus requiring a primary BWT method to remove larger organisms and debris [5].

Ozone introduction is a chemical process and as such it suffers from similar issues to chemical biocides. The potential long term environmental impact of chemical use is unknown hence Chemicals and biocides should be avoided.

2.10. De-oxygenation

By removing saturated oxygen from the ballast water effectively the micro-organisms in existence are oxygen starved. De-oxygenation can be achieved by a number of different methods including nitrogen introduction, vacuum generation and biological introduction. This system works on any oxygen dependent organism, however it does not affect certain organisms adapted to low oxygen environments such as bacteria, fungi and viruses. A number of hazardous organisms also have an oxygen resistant phase of development such as a cyst or pore. However in conjunction with a secondary mechanism such as UV or ozone treatment de-oxygenation can ensure almost total fatality of organisms. The benefits of each method include at least a 10% reduction in corrosive effects of ballast water on tank walls [25]. Nitrogen introduction purges the oxygen from the ballast water creating hypoxic ballast water. An alternative system works by creating a vacuum within the ballast tanks and maintaining a low oxygen level for up to 10 days. The de-oxygenation of the water also reduces the corrosive effects of both sea water and organism pollutants on the vessels structure. As a mechanical system crew would have full control over the system if required, however the device used could be automated. The benefits of such a system include long service life and the ability to "plug and play" with relative ease of introduction to current systems. Biological de-oxygenation requires the addition of nutrients to encourage growth of oxygen dependent organisms. These organisms rapidly use up the oxygen during growth which results in anoxic ballast water within 3 days, if this state is maintained for up to six days complete mortality of oxygen dependent organism can be achieved [26]. De-oxygenation like numerous other methods could easily be incorporated into a multi stage BWT system. Oxygen depleted water would mix readily with coastal waters ensuring re-oxygenation on ballast water emptying [27]. Despite the relatively safe methods used to achieve de-oxygenation it appears that vacuum induced de-oxygenation would be favourable as there is no addition to the ballast water. The increase in nitrogen generated from nitrogen purging and the potential for high levels of H_2S generated by biological methods could be deemed undesirable.

Structurally the vessel may not be suitable for de-oxygenation. The generation of a vacuum within a ballast tank is likely to be outside the original design parameters of the tank. As such the unknown stresses may put vessel owners off the idea of vacuum induced deoxygenation.

3. Summary

There are a number of BWT in development which could potentially solve the ballast water problem. Significant biological tests have been carried out to determine the exact nature of successful invasive species. For a successful invasion of a particular species an adequate density and quality of specimen is required. It can be assumed that where species suffer a high mortality during transit, the remaining specimens are likely to have suffered and thus be in poor condition. These poor condition organisms significantly reduce the chances of a successful invasion [28]. Therefore any BWT technique, or combinations of techniques, which eradicate upwards of 95% of species (GloBallast criteria) will have a significant effect on the species ability to invade successfully. Trials indicate that no single treatment method will remove 100% of the organisms contained in ballast water. Many BWT methods rely on the natural mortality of organisms due to the trauma incurred during the ballasting process, and the subsequent lack of food (Food Limitation Hypothesis [28]).However if organisms are killed within the ballast tanks this could increase the quantity of food available to bacterial grazers and scavengers. Onboard tests of species diversity have identified as many as 50 live coastal species present in ballast tanks (onboard *Leon*). In some cases additional species where collected during open ocean BWE. This broad spectrum of species capable of surviving transfer via ballast water requires multiple treatment techniques to ensure 100% unsuccessful invasion. The effectiveness and operating costs of the key BWT systems are shown (Table 7).

Table 7 - BWT technique operating cost and effectiveness (Various Sources).

Treatment	**Time/flow rate required for effective kill**	**Effectiveness (%)**	**Operating Cost (US cents per m^3 water, unless specified)**
Ballast Water Exchange	N/A	85% -99%	~2.85
Heat treatment	>80 Hrs @ 45° C	99% @ 70° C	~3.55
Screening/Filtration	50tonnes/hr (test)	82-95%	~0.61
Hydrocyclones	3000m^3/h	>90%	~0.38
UV Irradiation	350m^3/h	85% minimum	~0.05
Sonic methods	Unknown	~40% at present	Unknown
De-oxygenation	72Hrs @ 5° C	~86%	Unknown
Chemical Biocides	up to 48 Hrs	100%	<0.20
Electro-ionisation	<10mis	~95% in Lab	Unknown
Ozone	5-10mins	88.89% max in	Unknown
Gas Super-saturation	>30 Days	80% @ 30 days	0.02-0.05

Not all treatments satisfy the all five GloBallast criteria. BWT utilising chemical/biological additives could be potentially hazardous to the environment, and further testing would need to be completed to ensure this was not the case. Other methods appear effective but are let down by practicality issues such as energy requirements or the operational conditions. Many of the most effective environmentally sound and practical BWT methods are also the most costly. The approximate cost of 200,000 – 310,000 US$ for BWT system integration per vessel is sizeable [6]. However this cost compares favourably to the estimated cost of the damage already caused by untreated ballast water, thought to be in the region of Tens of billions of US$ [29].

4. Conclusions

BWT techniques are still at an early design/prototype stage and existing measures to prevent non-indigenous species invading other waters will continue for the foreseeable future. The introduction of IMO legislation should increase BWT development.

The potential rate of growth of resident organisms due to an increased food source in the form of nutrients from dead matter deposited in coastal waters, as a result of chemical/ physical treatments, could cause a bottom-up effect. Increased micro-organisms, such as dinoflagellates, may result in increased predators higher up the food web. If this is unsustainable it may have a detrimental impact on species towards the top of the food chain.

Treatment Systems which remove organisms and biological matter at the sources are likely to have the least affect on coastal waters. Environmentally the best suited methods appear to be mechanical and physical BWT. Observation and maintenance of BWT would be easiest on mechanical/physical BWT systems.

Most viable BWT will consist of two stages; include a large matter removal system, such as screen or hydrocyclonic separation, in conjunction with a secondary system targeting micro-organism mortality, such as UV radiation.

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MODELING OF BALLAST WATER MIXING AND FLOW DYNAMICS TO UNDERSTAND BALLAST WATER EXCHANGE

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A Computational Fluid Dynamics (CFD) Ballast Tank Modeling Program was initiated to develop an experimentally-validated high-resolution model to study mixing and flow in ballast tanks during ballast water exchange (BWE). Development and validation of a flow and mixing model will provide a tool to better understand the fluid dynamics occurring in ballast tanks, to identify deadspots, and to predict the efficacy of ballast water exchange for different ballast tank architectures. A CFD model was developed for a bulk cargo vessel ballast tank typical of the North American Great Lakes trade. A 1/3-scale model of tank structural features was constructed and used to experimentally validate the model's full-scale buoyant flow at the bell mouth, over a stringer; over a lightening hole, and at the discharge point. Experimental and computational results were encouraging, but also identified data gaps that must be addressed to improve the overall confidence and minimize uncertainty in the computational simulations. The experimentally validated model will be used to simulate a three-tank-volume exchange in the full size ballast tank with freshwater as the starting condition.

1. Introduction

Ballast water exchange (BWE) has been and remains the primary management practice with widespread application for reducing the spread of nonindigenous aquatic species via ballast water [1-5]. BWE was intended as an interim measure while more acceptable and possibly more effective or reliable methods are developed. While BWE by itself may not be a viable long-term solution, its use will likely continue for the foreseeable future. The recent IMO Convention on Ballast Water Management [6] sets a very aggressive agenda in order to eliminate all BWE by 2016, but this schedule may be difficult to achieve. Thus it would be useful to fully understand the ballast water exchange process, the flow dynamics inside a ballast tank during exchange, and how tank architectures affect the outcome.

Summaries [4, 7] of experimental shipboard attempts to quantify the effectiveness of BWE based on a variety of experimental approaches found that BWE appeared to achieve water replacement as high as 88-99% of the original water carried in the ballast tank. However, guidelines and regulations require consistent achievement of 95% or better. On-board studies have often involved different ships, different experimental conditions, and different sampling and analytical approaches. Experiments have also been conducted on cargo holds designed for alternate use as ballast tanks, or in forepeak tanks. There are many factors that can contribute to variances in experimental results such as sampling techniques, tank geometries, exchange approaches (reballasting vs. flow-through), flow rate during flow-through exchange, and starting salinity of the original ballast water compared to the salinity of mid-ocean water, to name a few. Obtaining samples from a ballast tank during exchange is not a trivial procedure. In addition, such on-board experiments generally rely on measurements taken at the overflow outlet of the tank, and do not necessarily represent the volume mixture that remains in the ballast tank. Limitations on tank access and sampling equipment generally prevent collection of more than a few spatially and temporally distributed samples, and better sample/data resolution is needed to assure the results are representative of conditions throughout the tank.

There are many different types of ballast tanks (Fig. 1) and most are structurally complex, composed of interconnected bays separated by girders, floors, frames and plating, with associated lightening holes, limber holes and slots for drainage, and longitudinal frames or stiffeners (Fig. 2).

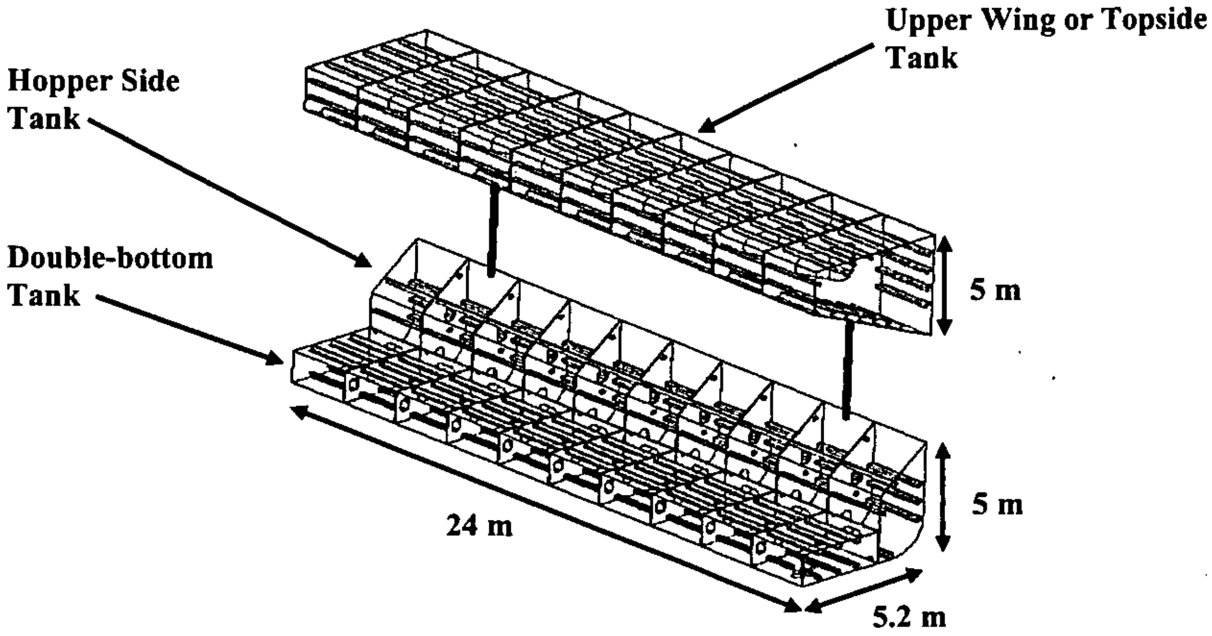

Fig. 1 – Computer-generated representation of the ballast tank used for this project. The composite tank consists of a double-bottom tank contiguous with a hopper-side tank, and a separate but connected topside tank.

Such structural features serve to both deflect and restrict flow during both the ballasting and deballasting operation. The fluid dynamics in large open-structure or structure-free ballast tanks, and particularly holds used as ballast tanks, will not be representative of those in double-bottom, hopper side and to a certain extent topside (wing) tanks which form the majority of ballast spaces on vessels entering U.S. coastal waters. The internal configuration of the more typical and common ballast tanks may create low fluid velocities (commonly referred to as deadspots) and stagnant zones that restrict and impede complete mixing. If there are deadspots in the ballast tank it may be possible that some original ballast water, especially if it is low salinity, can become trapped in small lenses and not exchanged.

The complex structural nature of ballast tanks and the difficulty of obtaining direct experimental verification from inside ballast tanks suggest that development of a computer-based model of the flow and mixing dynamics in ballast tanks could provide several advantages over on-board experimental approaches, and could also help interpret on-board experimental results. A Computational Fluid Dynamics (CFD) Ballast Tank Modeling Program was initiated as a joint project between the NOAA Great Lakes Environmental Research Laboratory (GLERL) and the Naval Sea System Command, Warfare Centers, Carderock Division. The goal is to develop and

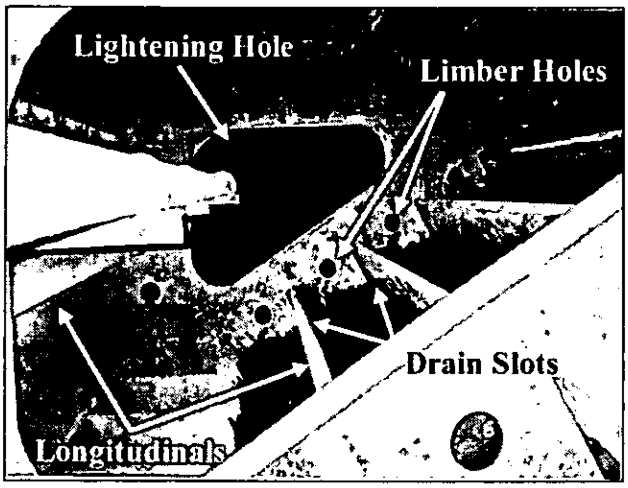

Fig. 2 – Example of the structural complexity of a typical ballast tank (upper wing tank in this example).

experimentally validate a CFD model of ballast tank flow and apply it to different scenarios of ballast water exchange. Particular emphasis is on exchange dynamics when the original coastal ballast water is fresh or low salinity and the replacement water is at mid-ocean salinity. The latter scenario is of considerable interest and poses the greatest threat to the North American Great Lakes, as well as the upper estuarine areas of other coastal ecosystems, such as Chesapeake Bay. The model will be portable to other ballast tank configurations and architectures, different ballasting and deballasting flow rates, and different starting conditions.

A successful model will predict ballast water exchange "effectiveness," that is, the percent of original water removed from (or remaining in) the ballast tank during (or after) the exchange process. A validated model will provide insight into the flow and mixing dynamics in the inaccessible recesses of a ballast tank. It will identify hidden areas of the tank that may contain deadspots), or the occurrence of "channeling," where a stream of water moves from inlet to outlet by the most direct route, never mixing throughout the tank. Identifying and understanding phenomena such as deadspots and channeling will provide the basis for developing approaches and improvements to the overall effectiveness and consistency of the exchange process. A validated model can also be used to test the effects of modifications to internal tank structures and cutouts. There is no need to wait for another transoceanic voyage to retest or run a test on the same tank under different conditions. A fluid flow model can be expanded to incorporate modules to examine the behavior of passive "particles", such as phytoplankton or sediment. Areas of sediment deposition may also be identified and proposed modifications to tank structures can be tested using computer modeling prior to making any actual modifications to operational tank design, to determine if there are ways to decrease sediment deposition and compaction.

2. Model Development

Model development includes measurements made in a 1/3-scale experimental model of a portion of a double bottom and side tank found in a typical handy size bulk carrier (Fig. 3), and construction of a CFD flow and mixing model to simulate BWE on both the 1/3-scale model and the full-scale (see Fig.1) tank. Ship tank drawings of a recent bulk carrier design were obtained from a corporate collaborator (Fednav International Ltd., Montreal, Canada) and were the basis of the experimental model design.

2.1. 1/3-scale Experimental Model Facility

Small-scale physical model experiments are an integral part of the study. These experiments provide a crucial means of validating the computational model, and also provide new understandings of the flow phenomena that exist in ballast tanks. A 1/3-scale experimental model of four contiguous bays of the ballast tank was constructed of 1-inch-thick acrylic plate except for the top, which was made of 1/8 inch steel plate (Fig. 3). An extensive effort was dedicated to ensuring that the appropriate non-dimensional parameters were scaled correctly throughout the experimental model's design. A combination of Richardson and Reynolds numbers were calculated at various points in the experimental model and were found to scale satisfactorily. *Note that the term "1/3-scale" refers to true geometrical scaling in that the height of the tank is 1/3 of a full-scale tank and the horizontal dimensions correspond to four bays of a full-scale tank with 1/3-scale dimensions.*

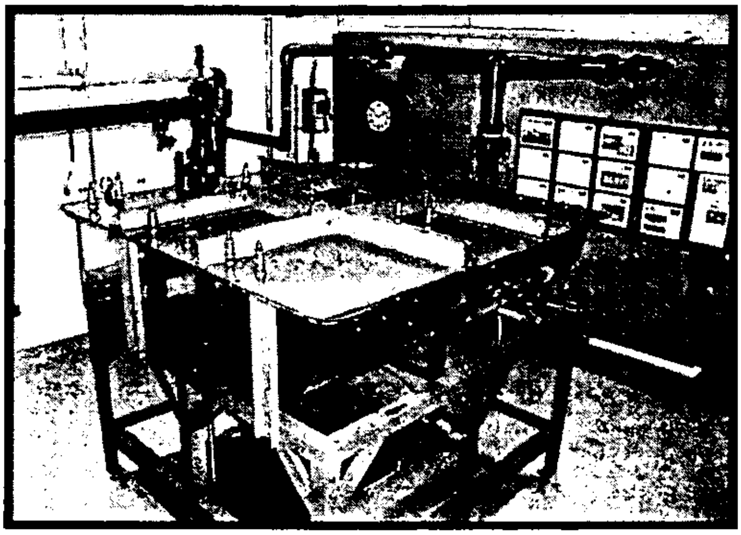

Fig. 3 – 1/3-scale experimental model (1.75 m x 1.8 m x 0.5 m).

The model facility was designed to support varying flow rates and consists of one 500-gal (1,893 l) premix tank, two 500-gal supply tanks, one 200 gpm (757 lpm) centrifugal pump, one vortex shedding flowmeter, two class 4 lasers, one class 3B laser and the 1/3 scale acrylic model of a bulk carrier ballast tank and hopper tank. The facility is located in an environmentally conditioned space equipped with approved class 4 laser safety devices. Sizing of the waste and supply tanks was based on the model capacity of approximately 460 gal (1,741 l) and a single flow-through exchange.

2.2. Experimental Approach

Laser Induced Fluorescence (LIF) was used to obtain two-dimensional temporal experimental data on the concentration of the fluid fraction of the two fluids at three planes (strategically chosen in areas where significant mixing occurs) within the experimental tank as well as in the exit pipe, during exchange. The experimental model tests were conducted to model full-scale buoyant flow phenomena (this effect leads to most salt/freshwater mixing) using Richardson number similarity. With this scaling, the ratio of gravitational to inertial forces, which are thought to be the most important forces for buoyancy-driven two-fluid mixing, are the same at model- and full-scale. Tests were performed at 65 gpm (246 lpm) which corresponds to a 1000 gpm (3,785 lpm) full scale flow rate. The experiments were run for only one model-scale tank-volume exchange due to cost and reservoir capacity factors.

During the physical model experiments, the original fluid in the experimental 1/3-scale tank (in this case, fresh water) is "tagged" with rhodamine-6G dye. The incoming (exchanging) fluid, representing mid-ocean saline water, is clear. Selected two-dimensional planes inside the tank are illuminated by a laser light sheet from a pulsed Nd:YAG laser with an output of 200 mJ/pulse at 532 nm and recorded using Hitachi KP-F120CL digital cameras with an image resolution of 1392 x 1040 pixels. The rhodamine dye molecules, when excited with the laser sheet, fluoresce with an intensity corresponding to the concentration (volume fraction) of the tagged fluid. By careful calibration using normalization by a "reference" image, this technique not only yields useful visualization of the mixing phenomena within the tank, but will yield an accurate quantitative measurement of the fluid fraction of the tagged fluid, and by difference, also of the untagged fluid. For a detailed description of the technique, see [8]

A typical experiment was performed as follows: each supply tank was filled with 500 gal (1,893 l) of freshwater from the building potable water system and approximately 225 lbs (102 kg) of magnesium sulfate was added to achieve an approximate specific gravity of 1.250 and an index of refraction of .833. The solution was then mixed by a combination of in-tank mixers and recirculation through the supply pump to assure uniform final salinity and density. The premix tank was then filled with 479 gal (1,780 l) of building freshwater and .035 g of rhodamine-6G was added and mixed into solution. The refractive index of the tagged freshwater was then matched to the saltwater by adding approximately 18 gal (68 l) of ethyl alcohol. The saltwater supply tanks and the premix tank were allowed to sit overnight for temperature stabilization. Once the temperatures stabilized the index of refraction and fluid densities for all tank solutions were measured and adjusted accordingly. Approximately a 2% density difference between the freshwater solution and the simulated seawater solution was maintained. The alcohol and rhodamine-6G freshwater solution was then slowly pumped to the acrylic model minimizing trapped air. Once the model was full and all air vented the lasers and high-speed digital cameras were configured and aligned to support LIF flow visualization. Four areas were selected for visualization, data recording and comparison to the CFD model they included; flow at the inlet bellmouth; flow over a stringer; flow through a lightening hole, and at the discharge outlet of the model. The experiments commenced by setting the supply flow rate while recirculating the saltwater back to the supply tanks rather then into the experimental model ballast tank. When the rates were steady and trapped air eliminated, the lasers and cameras were energized. The saltwater flow was then shifted through the model. Experiments were performed at a flow rate of 65 gpm (246 lpm; scale equiv of 3,830 lpm or ~230 m^3/hr). Trends in the mixing and dilution of the original fluid during exchange are obtained from the experimental data. This information is used to guide the CFD model development. Eventually, this set of data will be used for the evaluation of the overall accuracy of the CFD predictions.

Fig. 4 shows sample LIF results from the experimental portion of the project. Figures 4a and 4b show flow of saltwater through a lightening hole at 10 s and 60 s respectively. Figures 4c and 4d show flow of saltwater over a longitudinal at 10 s and 60 s respectively. The experimental design is such that these images are captured at a rate of 30 frames per second by three CCD cameras focused on three critical locations in the tank, for a total of 90 images per second. One tank-volume exchange takes 350 s in the 1/3 scale model, and the capacity of the experimental facility allowed the exchange to run for ~ 412 s, or ~1.2 tank-volumes. Each image is approximately 1000 pixels across the top and 1300 pixels across the side. Each pixel actually contains data in the form of an intensity of gray ranging between 0 and 10000. Through careful calibration procedures the returned intensity in each pixel was converted into the fluid volume fractions of freshwater and saltwater as a function of time contained in that specific pixel.

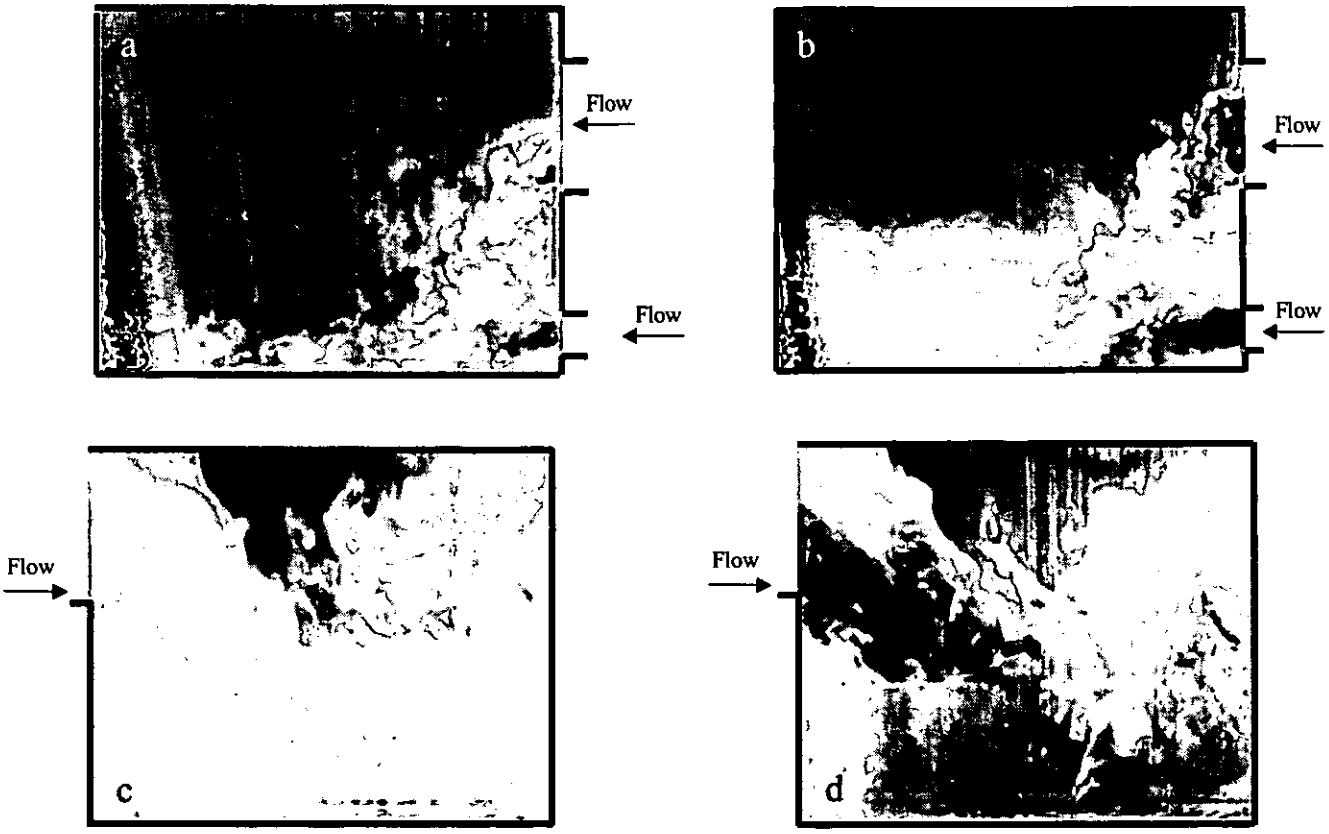

Fig. 4 – LIF images. (a) Flow through lightening hole at 10 s. (b) Flow through lightening hole at 60 s. (c) Flow over a longitudinal at 10 s. (d) Flow over a longitudinal at 60 s.

2.3. The CFD Simulation Model

The software used for the ballast water exchange simulations, Fluent™, solves the equations of fluid motion, i.e., conservation of total mass and momentum and the volume fraction of one of the fluids, including a turbulence closure which models the energy dissipation due to turbulent fluid motions. The equations are solved over the fluid domain that has been discretized into millions of cells, as shown in Fig. 5, and as such, the equations are expressed in approximate, discrete forms. Approximately 1.3 million cells are used for the 1/3-scale model simulations. Approximately 7-10 million cells will make up the grid of the final full-scale ballast tank model simulations. Since the efficiency of BWE is measured by the fraction of the original ballast water (in this case fresh) replaced by the incoming saltwater, its prediction depends upon correctly calculating the relative amounts of original water and replacement saltwater (the volume fraction) throughout the tank at the end of the exchange, not just at the outflow or discharge point. To get to this endpoint, however, the entire transient exchange process must be simulated, starting with the tank completely filled with the original ballast water. The ensuing simulation includes the in-rush of saltwater down the inlet pipe into the tank, and the flow of saltwater over the longitudinals and through limber- and lightening-holes, as well as quiescent flows far from the inlet, and mixing between the two fluids.

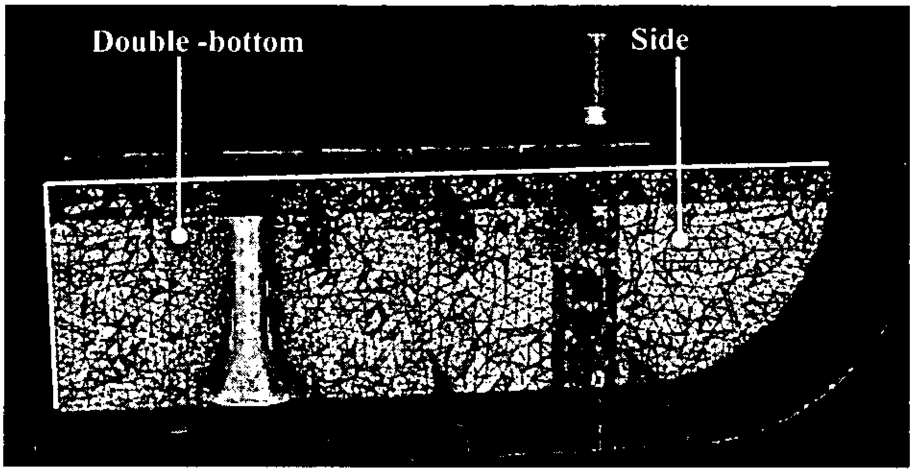

Fig. 5 – Slice (partially outlined with white border) through 1/3-scale experimental tank showing typical computational grid.

Advection and mixing both affect the BWE efficiency because significant amounts of the incoming saltwater will mix with the original ballast water, and mixed fluid advecting to regions of lower mixing may help to exchange fluid in such regions, where otherwise the two fluids might remain stratified and un-mixed. Thus, in order to predict the BWE efficiency at the end of three-tank-volume exchanges, it is equally important to be able to predict both mixing and fluid stratification. None of these details can be readily obtained via shipboard experiments.

Multiple simulations of BWE in the 1/3-scale model were performed. Several grids of the 1/3-scale model were generated, each refining various geometric aspects, particularly in the vicinity of the inlet pipe and bellmouth where a majority of the two-fluid mixing is shown to take place. CFD

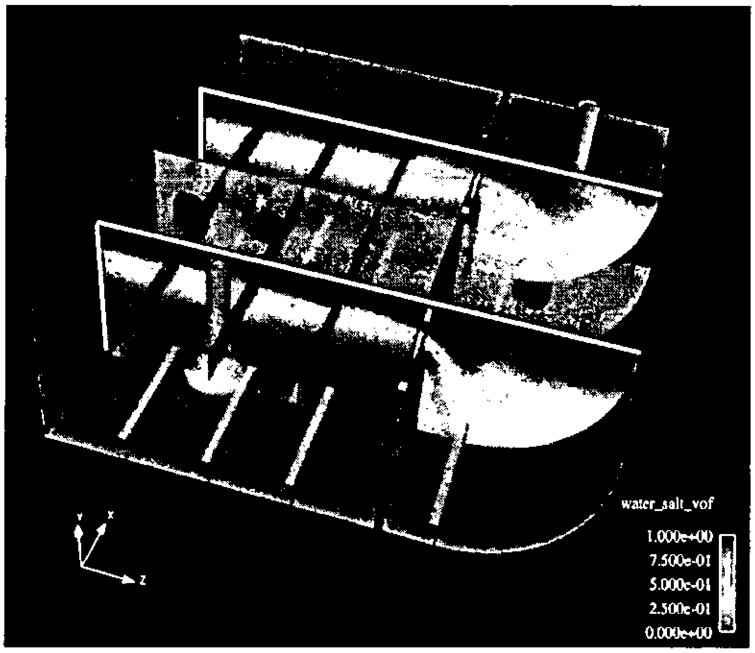

Fig. 6 –CFD Simulation of 1/3-scale experimental model ballast water exchange at 172 s (~0.5 tank-volumes). White lines identify two slices showing animation results in the vertical plane of the tank model.

simulations matched the conditions of the 1/3-scale experiments, with the tank initially full of freshwater and saltwater entering at 65 gpm (equivalent to a full-scale flow rate of 1,100 gpm or 230 m^3/hr). The saltwater is assumed to be North Atlantic seawater with a 35 ppt concentration of salt. The computer simulations were run for full three-tank-volume exchanges. The fluid volume fraction data are saved at each computational time step for each of the three experimental camera views and for the effluent discharge for comparisons with the experimental data. Complete three-dimensional data fields are saved every 5 seconds, generating over 60 gigabytes of data per simulation. These data are used to generate two- and three-dimensional animations, which are very useful for elucidating the flow phenomena during BWE. Fig. 6 is an example of the simulation output. It shows two vertical slices through the experimental tank at 172 s (0.5 tank-volumes) into the exchange. The dark area above the light gray layer is freshwater, while the dark area below the light gray layer is incoming saltwater. The gray layer is the zone of mixing between the fresh and salt-water end members (in the actual animation the end members are red and blue). At this instant in time, the salt water entering the double bottom tank has reached the level of the lightening holes between the double bottom and side tanks and the saltwater is pouring into the side tank in a series of waterfalls. The waterfall flows are particularly important because they generate a large amount of mixing which leads to significant amounts of saltwater exiting the tank. Another feature revealed (but not shown here) by the simulation is flow from the bellmouth. Saltwater exits the bellmouth at high velocity and flows along the bottom of the tank, trapped between the two longitudinals that flank the bellmouth, until reaching the bounding floors. At the floors, the force of the flow produces vertical jets that overturn, much like breaking waves, causing significant salt-freshwater mixing. A complete time-stepped animation of the exchange event through three tank-volumes will be presented during the ENSUS 2005 Conference.

3. Comparison of Experimental and CFD Simulation Results

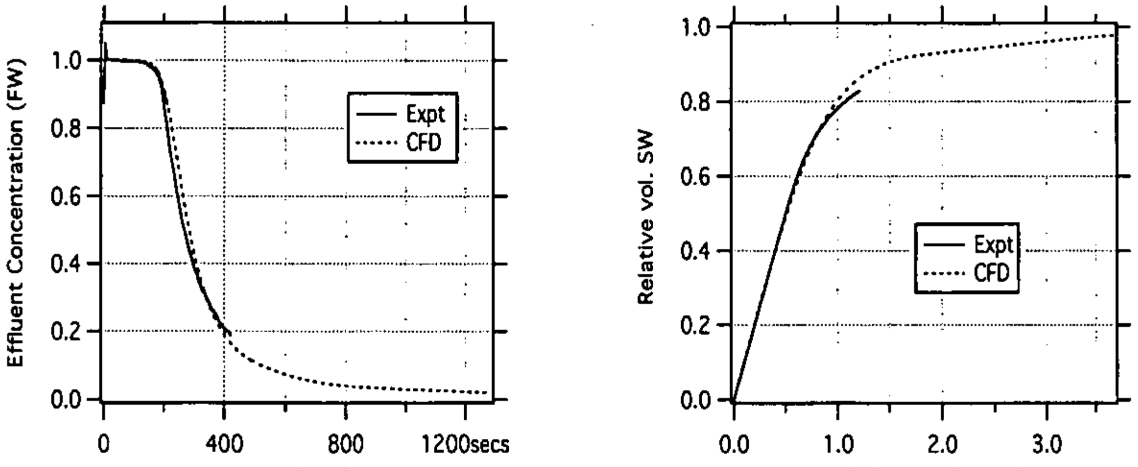

Fig. 7 – Effluent freshwater concentration (left) and exchange efficiency (right) for the 1/3-scale experimental tank model, from the CFD simulation and from direct experimental measurements.

3.1. Freshwater Effluent Concentration

Fig. 7 (left) gives the time history of the freshwater effluent concentration at the outlet port. It shows close agreement between the experimental data and CFD calculations. Until approximately 35 seconds, purely freshwater is exiting the tank. After that a decreasing concentration of freshwater exits the tank, with the concentration decreasing in an approximate linear fashion until about 350 seconds (one-tank-volume exchange). Around this time the slope begins to decrease, with the CFD-calculated concentration asymptotically approaching a value of 0 with increasing time. There are small discrepancies between the experiment and CFD predictions. Between 200 and 300 seconds the CFD values are greater than the experiment and after 350 seconds and until the end of the experiment at 412 s, the CFD values are less than the experimental values. The greater CFD values signify less saltwater in the effluent, indicating that the CFD is predicting less mixing within the tank. Later, when the CFD values are less than the experimental values, it can be inferred that the CFD is predicting more mixing within the tank. Stated more succinctly, the CFD model is under-predicting the mixing during the early stages (the first tank-volume) of exchange and may be over-predicting the mixing during the later stages (the second and third tank-volumes) of exchange. However, the experimental data does not extend out far enough in time to confirm and correct the latter. An uncertainty analysis would show if the discrepancies between the experiment and CFD predictions are within uncertainty bounds.

3.2. Exchange Efficiency

Fig. 7 (right) shows the calculated exchange efficiency as a function of time. Exchange efficiency is the relative volume of saltwater in the tank (not just at the outflow), with a value of zero being all freshwater and a value of 1 being all saltwater. At one tank-volume exchange, the experimental results show 78% efficiency, whereas the CFD predicts 80%. At two and three tank-volumes the CFD predicts 93% and 96%, respectively. At 1.2 tank-volume exchanges, where the experimental data end, the CFD over-prediction indicates that at that time the CFD predicts slightly more freshwater has exited the tank, which could translate into an overprediction of BWE efficacy.

The results indicate that the amount of two-fluid mixing predicted by the CFD model during the first tank-volume exchange is slightly low compared to the experiments, and after the first tank-volume exchange, it appears that the two-fluid mixing predicted by the CFD model may be slightly high. These discrepancies may reflect a deficiency in the mixing mechanism used in the model, which is only numerical diffusion in the volume fraction conservation equation. This may not be accurately modeling the energetic mixing that takes place during BWE. A mixing model may be needed. In such a model the rate of mixing would be proportional to the shear stress at the interface between the two-fluids. However, the development of a mixing model would depend on the degree of accuracy required in the CFD model. The required accuracy can be determined from uncertainty analyses of full-scale and 1/3-scale BWE, as well as the CFD model.

4. Full-Scale BWE Simulations

The geometry and grid for a full-scale handy-size bulk carrier ballast tank has been developed as shown in Fig. 1, with detailed structural elements included for the double-bottom, side, and upper wing tank areas (Fig. 8). The flow enters the double bottom tank at the inlet, eventually filling the double bottom and side tanks. The fluid is pushed up through twin risers into the upper wing tank. The total tank-volume is 185,740 gallons (703 m^3) including double-bottom, hopper side tank, and topside tanks, but not including volume in connection pipes and interbay connections (e.g., lightening holes, limber holes, etc.). A CFD simulation of BWE in this tank will be completed in 2005.

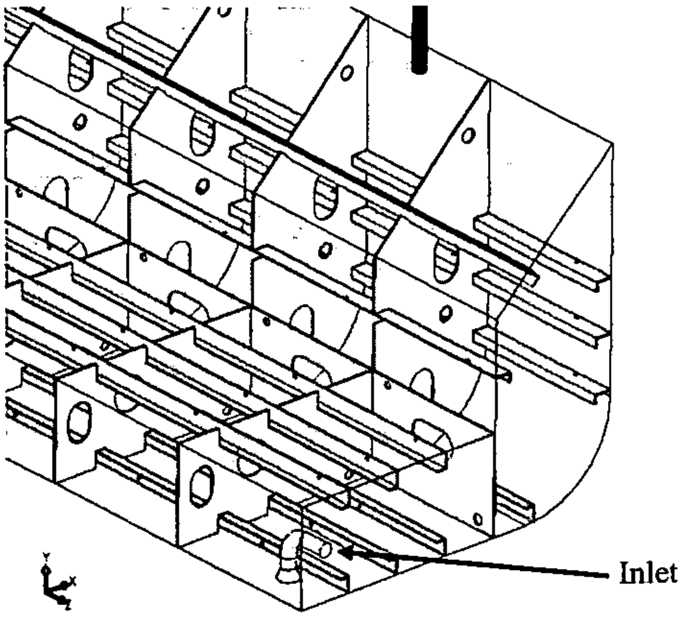

Fig. 8 – Detail from computer representation of the full-scale ballast tank shown in Fig. 1.

5. Conclusions

The application of CFD modeling to ballast tank fluid dynamics shows promise. Presently, the CFD model slightly under-predicts mixing during the first tank-volume exchange and appears to overpredict mixing during later stages (second and third tank-volumes) of exchange flow. However, data from a full three tank-volume 1/3-scale experimental model are needed to verify the latter. It is likely that a mixing model may be needed to account for the transition from buoyancy-driven mixing to dominance of stratified shear flow.

Use of this CFD model, when fully developed and validated, should be a useful tool for understanding ballast tank flow, mixing during ballast water exchange, and evaluating effects of different ballast tank architectures.

6. Acknowledgements

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AN ALTERNATIVE METHOD TO MEASURE RELEASE RATES OF COPPER AND ORGANIC BIOCIDES FROM ANTIFOULING PAINTS

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Abstract

Most antifouling paints of ship hulls currently in use release biocides to prevent biofouling. Quantification of the release rate is of importance for environmental impact assessments and also for the performance of the paints. Existing standard methods for the determination of biocide release rates (ASTM and ISO) were developed for the quantification of TBT leaching from the paints, but showed high variability for copper leach rates. Therefore, the existing standard methods have been modified in order to get more reliable results. This paper describes the changes and their advantages compared to the existing ASTM and ISO methods.

Modifications were made regarding construction, materials, simulated speed and sampling. The major change is regarded to be the permanent rotation of the test object in seawater instead of one hour daily and storage of the coated cylinder in a holding tank. With the permanent rotation the paint has the chance to build up a constant leach layer. All released biocides are collected on different adsorbers. This allows quantification of all released antifouling biocides - copper and organic biocides - by extraction of adsorbed compounds.

Other important changes are the use of steel instead of polycarbonate and the application of a complete coating scheme by airless spray technique. The results for copper and organic biocide release rates showed different patterns. The obtained data were modelled and transferred model to different speeds tested. Increasing speed resulted in increased release rates, but the release rate pattern was identical.

Keywords: *antifouling, release rates, organic biocides, copper*

1 Introduction

Almost every surface immersed in seawater is subject to growth of fouling organisms. The variety of organisms spans the trophic levels from bacteria and macroalgae to higher organisms like barnacles. On ships the growth of these organisms reduces the speed of the ship and increases fuel consumption, harmful atmospheric emissions and decreases manoeuvrability. To prevent the ship hulls from fouling, they are protected by antifouling coatings [1, 2, 3].

Since the first phase of the IMO ban of organotin containing antifoulings, a number of alternative antifoulings have been released into the market. Some new products are biocide free, but the majority are based on the use of copper compounds and other heavy metals. In addition, in some formulations a variety of different organic booster biocides are used to compliment the heavy metals.

The release of these biocides into the marine environment is important to determine. These rates would enable risk assessments to be made. Current ASTM [4], [5] and ISO [6], [7] test methods to measure release rates of copper and organotin from antifouling (AF) paints have a number of shortcomings:

1. The results of a round-robin test for the determination of copper release rates show high inter-laboratory variability [8], [9].
2. Results have been shown to be inaccurate by using short test intervals (1 hr). Extrapolation of the results to 24 hours might amplify a possible error.
3. The ASTM leach rate method is not predictive of real life coating behaviour because biocide diffusion is not linear with time.

4. Substrates, paint system, and paint application are not representative for practice in shipyards.
5. Speed of rotating cylinders does not represent the real life of ships.
6. Tests in artificial seawater are not transferable to natural seawater with e.g. biofilms.
7. The impact of different environmental conditions (pH, T, S) is of interest, because of the locations of shipyards and harbours.
8. Additional information about adsorption behaviour of the biocides and degradation rates under standard conditions are essential for thé interpretation of the results.

Further, attempts to predict environmental loading through mathematical modelling have proven to be inadequate and do not show good correlation with experimental results.

2 Methods and Materials

Each of the following methods is based on the existing ASTM methods D5108-90 (organotin) and D6442-99 (for copper). Therefore, only the experimental changes compared to the existing methods are described in this chapter. Standard methods for the different booster biocides are in preparation by ASTM and ISO. The coating tested is a commercially available SPC antifouling with copper and additional organic (booster) biocide as antifouling substances.

2.1 Analytical methods

Organic biocides were determined with HPLC and GC-MS methods, depending on their chemical properties. For confidentiality reasons, the single organic biocides are not named. For the same reason the analytical methods are not described. All copper determinations were carried out with copper ICP-OES (SPECTRO Analytical Instruments GmbH, Kleve, Germany).

2.2 Technical set-up of the experiments

Based on the assumption that the rotation time has an impact on leach rates, a permanently rotating cylinder was used in an experimental set-up similar to ASTM.

The following changes were made compared to ASTM:

The coated area of the test cylinder was changed for improved recovery. All other measures of the equipment were calculated relative to the ASTM method.

The container was made out of Pyrex® with a cooling mantle to keep the temperature in the desired range. The coated area of the test-cylinder was increased from 201 cm² to 700 cm². Further, the cylinder was made out of steel instead of poly-carbonate to mimic a ship hull. A complete coating scheme was applied with airless spray technique including primer, anti-corrosion and 3 layers of approximately 150 μm antifouling coating. The experimental set-up is shown in Fig. 1 and dimensions are shown in Tab1.

Tab. 1:Dimensions of the modified release rate tests methods compared to ASTM.

		ASTM	modified method
Coated cylinder or disc			
Outer diameter (da)	mm	64	115
Height (H)	mm	120	200
Distance from bottom	mm	n.d.	80
Coated area			
Distance from bottom (x)	mm	10	10
Height (L)	mm	100	200
Total surface	cm²	201	723
Container			
Inner diameter (di)	mm	130	235
Outer diameter	mm	n.d.	250
Height (h)	mm	190	350
Volume (water)	L	2	10
Wave breaker			
Depth	mm	3 rods	30
Width	mm		6
Height	mm		350
Speed			
	kn	0.4	0, 1, 4 1)

1) The speed can be adjusted by variance of rotor speed.

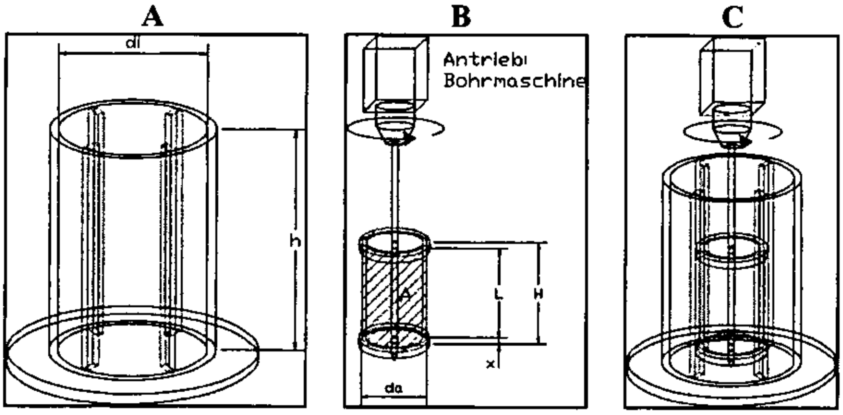

Fig. 1: Sketch of the release rate test container with rods (Fig. 1A), the coated cylinder with electrically driven machine (Fig. 1B) and the assembly (Fig. 1C).

The key problem with the permanent rotation of the coating is the over-saturation of the water with the leached biocides over 24 hours. High concentrations of biocides in the seawater might reduce the leach rate because of over-saturation and affect the accuracy of the results.

For that reason, the leached biocides were removed continuously using two different adsorbers. The first adsorber is an ion-exchange material to bind the Cu^{2+}-ions. The second adsorber consists of a solid phase extraction material (SPE), which retains the unpolar (largely insoluble) organic biocides. The adsorber materials are kept in cartridges, which are connected to the test container via a pump and hoses. An additional glass fibre filter (GFC, Whatman) was installed to remove possible particles. The pump rate was adjusted to guarantee a full water exchange per hour. Fig. 2 shows the whole experimental set-up.

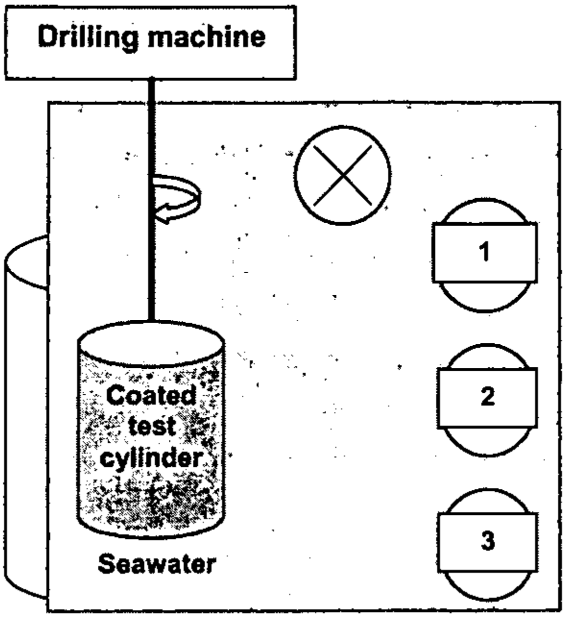

Fig. 2: Experimental set-up of the modified release rate method. 1 = glass fibre filter, 2 = organic AF biocide adsorber and 3 = ion exchange material for copper adsorption.

2.3 Sampling Method

For the first two weeks sampling was carried out daily by replacing the ion exchange and solid phase extraction cartridges (SPE) clean adsorbers. Subsequently sampling was done every second day. One additional sampling took place after 5 hours runtime of the experiment to capture early peaks in release rates. The capacity of the adsorber materials was tested to ensure that it was sufficient to adsorb the amount of biocides released over a 3-4 day period. A glass fibre filter was used to remove any solid particles from the system.

For the analysis of the copper and the organic biocide the adsorbers were extracted in the lab. The total amount of the adsorbed compounds was used to calculate the daily leach rates. Additionally, temperature and pH of the seawater in the containers were monitored.

2.4 Impact of speed

To analyse the impact of speed on the leach rate, the electrical current of the rotation device was converted to result in 1.07 and 4.17 knots, later referred to as 0, 1, and 4 knots. The test at 0 knots velocity was carried out without adsorbers. Instead the samples were taken directly. Speeds above 4 knots would require a different design of the test, because hydrodynamic turbulences were pronounced at higher speed.

2.5 Statistics

Statistical models were developed from the experimental results to enable the calculation of the release rates of organic biocides and copper. The software used was SYSTAT (Table Curve 2D). In addition the following statistical values were also determined:

- Confidence interval with 95 % probability
- Asymptotic standard errors
- Correlation with observed values

3 Results and Discussion

3.1 Release rate of copper

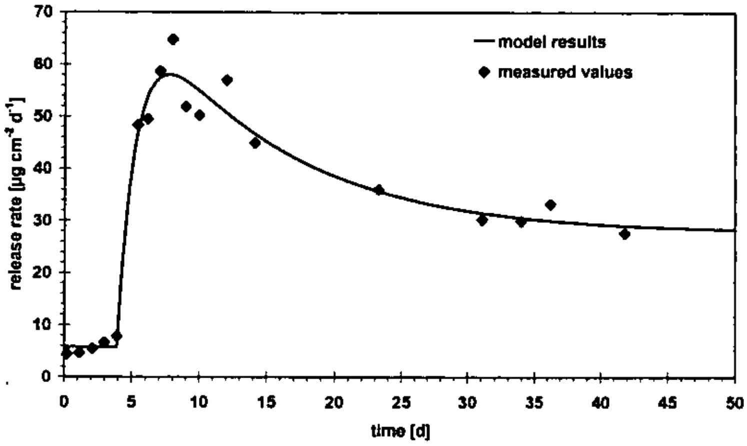

Fig. 3: Copper release rate of coating A, speed 1knot.

Fig. 3 shows the copper release rates of coating 4. Within the first four days the release rate increased only slightly from 4.38 to 7.77 µg cm^{-2} d^{-1}. The measure maximum was reached after 7 days with 65 µg cm^{-2} d^{-1}. After 42 days the paint seemed to reach a "steady state" release rate. The model calculates 27.7 µg cm^{-2} d^{-1} for the long-term release rate. The calculated parameters for the release rate model, as well as the 95 % confidence intervals are presented in Tab. 2.

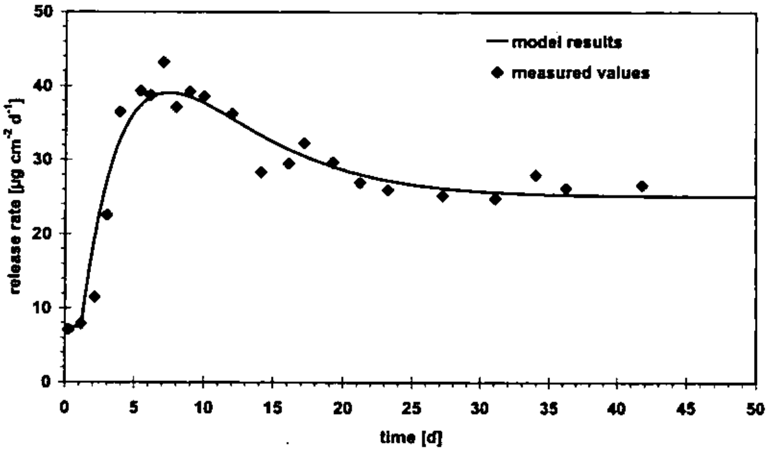

Fig. 4: Copper release rate of coating B 1st test, speed 1knot.

Coating B (Fig. 4) also had very low copper release rates at the beginning (7 - 8 µg cm^{-2} d^{-1}, 5 and 27 h). Other than coating A the release rate increased already at the 2nd day, increasing steadily to 43 µg cm^{-2} d^{-1} on the 7th day, like coating A. After 20 days the release rate varied only slightly around 27 µg cm^{-2} d^{-1}. The test was stopped after 42 days, because the coating was regarded to be in balance with the surrounding seawater. The long- term release rate calculated by the model is 25.1 µg cm^{-2} d^{-1}.

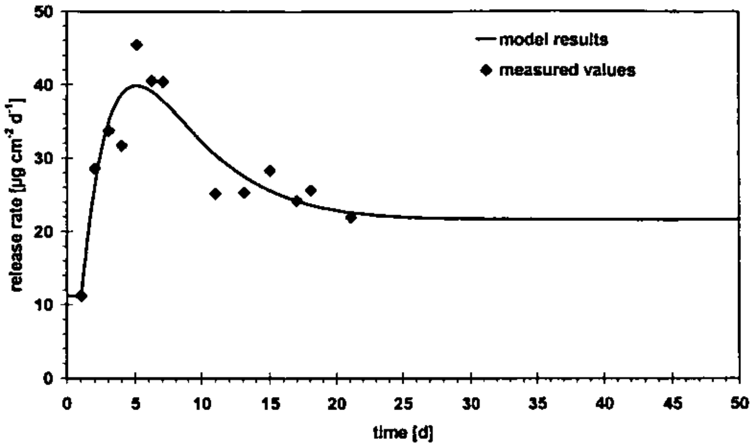

Fig. 5: Copper release rate coating B, 2nd test, speed 1knot.

To establish the repeatability of the method, the copper release rate determination was repeated (Fig. 5). Compared to the first test, the maximum copper release rate was reached after 5 days compared to 7 days, but the maximum release rate value was almost the same with 45.4 compared to 43 µg cm^{-2} d^{-1}. The modelled long-term release rate was a bit lower than in the first test (21.6 µg cm^{-2} d^{-1} compared to 25.1 µg cm^{-2} d^{-1}). The reason for this might be caused by experimental conditions such as the duration of the test.

On the other hand, the shape of the curves is almost identical with low release rate at the beginning of the experiment, a maximum after 5-7 days and a flattening of the curve after ca. 20 days.

All measurements were carried under continuos adsorption of the copper ions on the ionic adsorber, and therefore average the daily release rate. Although the long-term copper release rates differ, the method is regarded to give more reliable results than existing standard methods.

The application of the model resulted in good correlation coefficients R² expressed as predicted versus observed values with 0.943, 0.857 and 0.901 for tests A, B1, and B2, respectively.

Tab. 2:Parameters and confidence intervals for the model (equation 2) for the calculation of copper release rates from coating A (

Fig. 3, Fig. 4 and Fig. 5).

	Parameter	*A*	*A*	*b*	*c*	*d*	*e*
A	parameter value	5,755	65,400	0,725	0,063	0,032	3,920
	95 % confidence min.	-	46,911	0,281	0,001	-0,006	-
	95 % confidence max.	-	83,888	1,169	0,126	0,070	-
B1	parameter value	7.481	70.579	0.212	0.159	0.053	1.142
	95 % confidence min.	-	58.017	0.139	0.121	0.031	-
	95 % confidence max.	-	83.139	0.284	0.197	0.075	-
B2	parameter value	11.196	69.547	0.291	0.258	0.044	1.031
	95 % confidence min.	-	44.620	0.099	0.114	-0.006	-
	95 % confidence max.	-	94.474	0.483	0.402	0.093	-

3.2 Impact of speed on copper release rates

To analyse the impact of ship speed on the biocide release rate, the coating B (second test) was also tested under stagnant conditions and at a speed of 4 knots. Fig. 6 shows the results of the applied model (equation 2). The results show a clear increase of the release rates with increasing speed. The initial release rates of 1 to 4 knots are significantly different with maximums at 39.7 and 75.3 µg cm^{-2} d$^{\cdot}$1, although the "steady state" release were comparable with 21.6 and 25.4 µg cm^{-2} d^{-1} for 1 and 4 knots, respectively. The "steady state" release rate of 4 knots equals that of the first test with the same coating at a speed of 1 knot. Therefore, the release rate is not significantly different. Under stagnant conditions a maximum release rate of 34.7 µg cm^{-2} d^{-1} was reached after 3 days already, with a decline to 6.5 µg cm^{-2} d^{-1}, which is much less than at both other speeds.

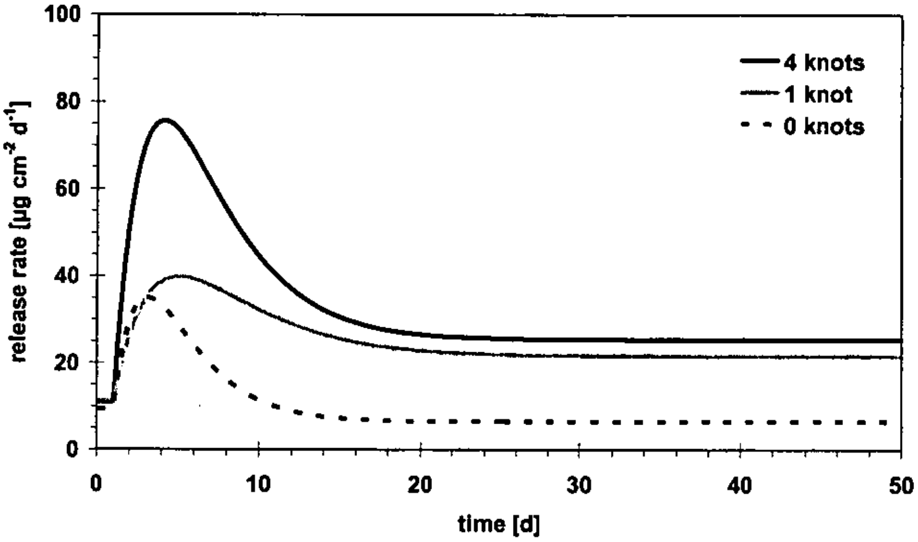

Fig. 6: Release rate of copper at 0, 1 and 4 knots.

3.3 Impact of speed on organic biocide release rates

Next to copper, the method allows the determination of the organic biocides, which are adsorbed on a SPE cartridge in the recirculation system. Fig. 7 A-D shows the results of the organic biocide release rates of coating B. The parameters for the model (equation 1) are presented in Tab. 3.

The shape of the three curves for all speeds is comparable, with very high initial release rates, and a rapid decline within the first 5 days. The quantity of the released biocides on the other hand varies significantly.

Taking the average release rate of the final 5 days for the static conditions (Fig. 7A), 2.23 µg cm^{-2} d^{-1} organic biocide were released. The model calculated a long-term release rate of 0.9 µg cm^{2} d^{-1} for the steady state. The 95 % confidence interval covers the range from 0.7 – 1.3 µg cm^{2} d^{-1}.

The release rate for 1 knot was significantly higher than under static conditions (Fig. 7B). In balance with the seawater, the average of the last 5 days was 3.12 µg cm^{-2} d^{-1}. The model result for the long-term release rate is 2.0 µg cm^{2} d^{-1} (1.8 - 2.3 µg cm^{-2} d^{-1}).

The release rate for 4 knots was only slightly higher than for 1 knot (Fig. 7C). At the end of the test on average 3.31 µg cm^{-2} d^{-1} leached out of the paint and the model calculated 2.4 µg cm^{-2} d^{-1} and a 95 % confidence interval of 2.0 - 2.7 µg cm^{-2} d^{-1}. It seems that the results for 0 knots account for the diffusion process only, whereas the release rates of the two other speeds also include the polishing rate.

The summarised models curves (Fig. 7 D) show the significant differences of the totally released biocide over time. As the static experiment (0 knots) was carried out without the use of adsorber, and the release rate remained constant after 4-5 days, an over-saturation effect can be excluded.

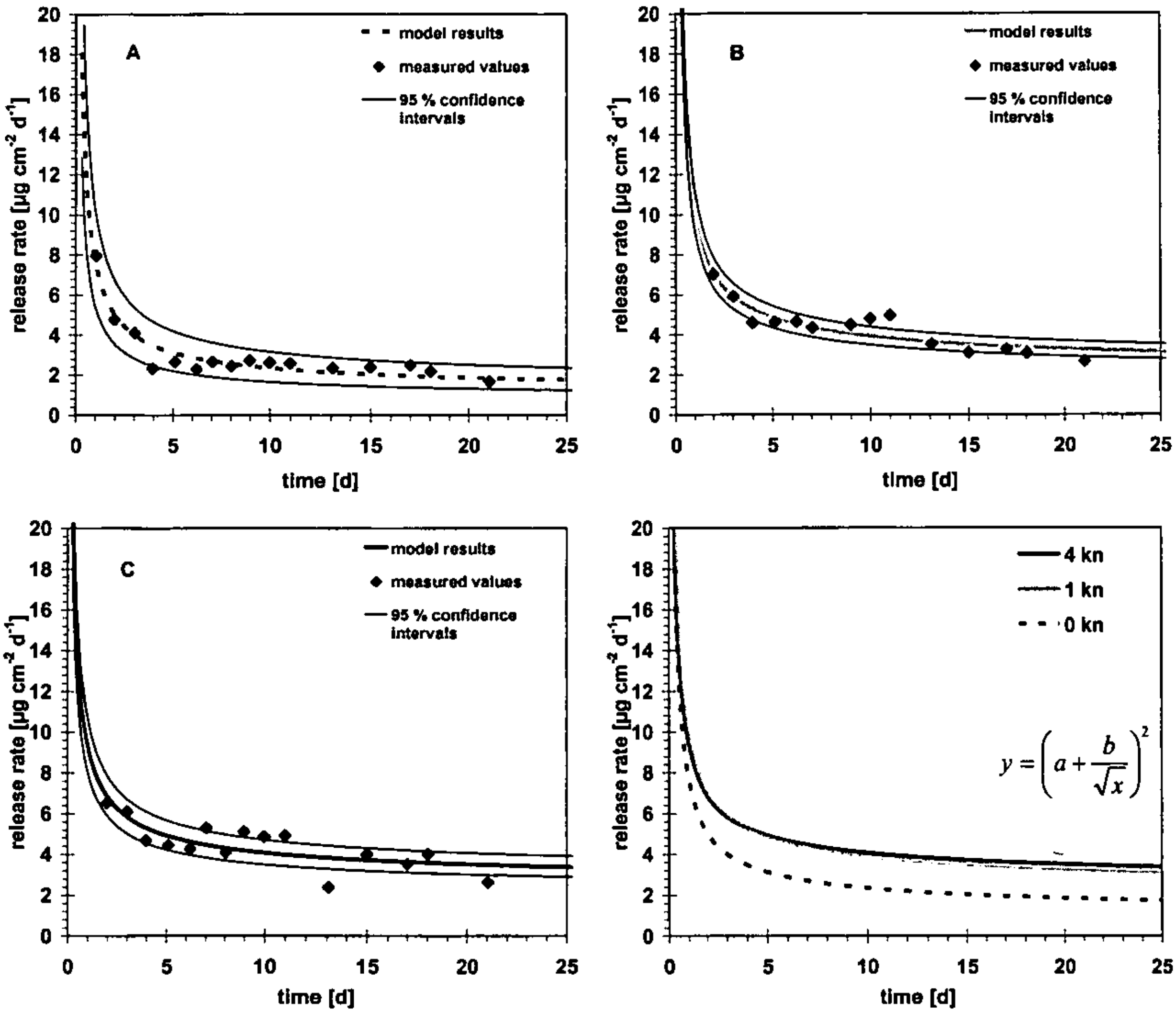

Fig. 7: Organic biocide release rates with the speed of A) 0, B) 1 and C) 4 knots and method 1. The black circles indicate the measured data, the red line is the curve of the model and the black lines indicate the 95 % confidence interval. Fig. D shows the model results for speeds. Values for the parameters are listed in Tab. 3.

Tab. 3: Parameters for the models (equation 1) for the calculation of organic biocide release rates (Fig. 7) and correlation coefficients for predicted versus observed values.

Parameter	*a*	*B*	*R^2 of the model*
0 kn	0.963	1.802	0.916
1 kn	1.424	1.749	0.993
4 kn	1.535	1.530	0.981

3.4 Comparison of copper and organic biocide release rates

In comparison with the copper release rates, the shape of the curves is completely different and the model seems much simpler. The copper release was low at the beginning, reaching the maximum after 5-7 days, at a time where the release rate of the organic biocides was low already. Further, the release rates for copper stayed on a relatively high level, compared to the initial release rates.

One reason for the high initial release rates of organic biocides at all tested speeds must be a high concentration of the organic biocides at the surface of the cured paint. One hypothesis could be that this effect is caused by evaporation of the solvent of the paint during the curing process, which also serves as carrier for the organic biocide. After immersion in seawater a high amount of organic biocide is released into the water. Once a constant the leach-layer thickness has built up, the release rate follows the regular processes of diffusion plus polishing rate of the binder.

In contrast to this, copper is dispersed in the paint. It occurs as copper oxide particles of different sizes embedded in the paint matrix. It obviously takes a few days until the water penetrates the paint matrix to reach the dispersed copper oxide particles covered by the binder. Once the seawater penetrates to the CuO particles, we observed high release rates. The hypothesis is that the CuO particles at the surface are covered with some polymer, stick out of the coating causing the surface roughness. After a constant leach layer thickness has built up, probably the release rate stays on an almost constant level.

The ratio of copper to organic biocide 4 release rates at 1 knot remained on a relatively constant level (16:1) after ca. 5 days (Fig. 8). This also indicates that the paint was in balance with the seawater within in a relatively short period of time.

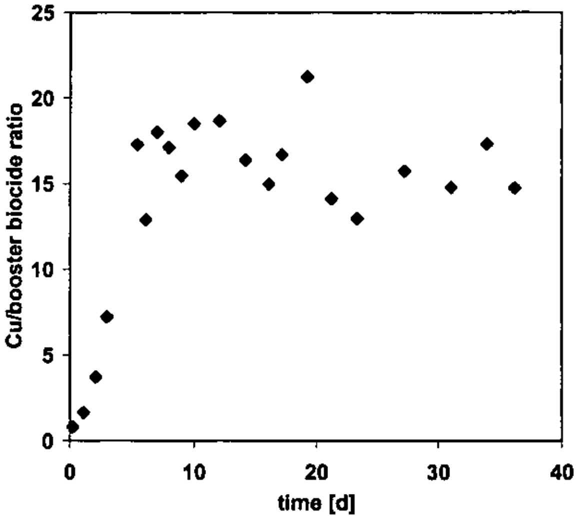

Fig. 8: Ratios of copper and organic biocide 4 release rates at a speed of 1 knot.

3.5 Release rate models for organic biocides and copper

Statistical models were developed from the experimental results (see below) to enable the calculation of long-term release rates of organic biocides and copper (see chapters 3.1 and 3.2). Using the SYSTAT software (Table Curve 2D) the following relationship was established for organic biocides:

$$y = \left(a + \frac{b}{\sqrt{x}} \right)^2 \qquad \text{(Equation 1)}$$

y = release rate [$\mu g\ cm^{-2}\ d^{-1}$]
x = time [d]
a and b = parameters provided by the software (values for these are shown together with the modelled results of method 2B).

As the value of b tends to zero, then y tends to a^2. The parameter a^2 also describes the limit of the release rate (y_{lim}), at which point the system becomes stable and the paint is in a steady state.

For the copper release rates the function is much more complicated:

$$y = A + a \cdot \left(1 - e^{-b \cdot (x-e)} - \frac{c}{c+d} \cdot \left(1 + \frac{b \cdot e^{-(c+d)(x-e)} - (c+d) \cdot e^{-b \cdot (x-e)}}{(c+d-b)}\right)\right) \qquad \text{(Equation 2)}$$

A, c, d and e are additional parameters describing the curve as provided by the software.

The limit of this function (y_{lim}) is:

$$y_{lim} = A + a \cdot \left(1 - \frac{c}{c+d}\right) \qquad \text{(Equation 3)}$$

4 Conclusions

Apparently, the rotation time of the coated cylinder in seawater has an impact on the leach rate, given as $\mu g\ cm^{-2}\ d^{-1}$. Longer test periods cause lower biocide release rates. Therefore, the best solution would be the permanent rotation of the coated cylinder under constant speed in the container, without any interruption.

The results of method 2A show an exponential decreasing release rate of the organic co-biocide during the first 3 months for an AF paint on a stainless steel disc (with anticorrosive, exposed in seawater at 60 rpm, resulting in speeds varying form 0.4-1.2 knots). A steady state develops after that 3-month period. An additional period of 3 months of dynamic ageing at 5-17 knots did not increase the release rates under more static conditions (0.4-1.2 knots) measured after ageing of the paint.

Organic biocides were successfully adsorbed on a solid phase material and copper on an ion exchange material. Eluates of these allowed determining the absolute amount of biocides released from the antifouling paints under permanent rotation. Short-term changes in release rates are averaged by this method.
The results of method 2B also showed that the release rate patterns for organic biocides and copper differ significantly. Within the first days these two biocides classes behave contrary.
A model resulting from the obtained data was transferable to different speeds (0, 1 and 4 knots).
The release rates of organic biocides increased with increasing speed, whereas the major difference was between 0 and 1 knot.

The alternative methods clearly demonstrate to have some practical advantages and/or are closer to real life situations than the present ASTM methodology. The release rate is not constant during the actual determination of 1 hour and it would probably be much better to extend that period to 3 hours or more.

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AN OPTICAL, NON-INTRUSIVE METHOD FOR MEASURING SURFACE ROUGHNESS OF ANTIFOULING COATINGS.

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Two of the critical parameters in evaluating the efficacy of novel antifouling coatings are surface roughness and dry film thickness. This paper reviews the methodology published in the literature for measuring these two parameters, and evaluates a new, non-intrusive optical method that can measure surface roughness at a nano-scale (>0.001 µm). It is shown that, after a 40-day rotary immersion test, micro–roughness (>1 µm) decreases, but nano–roughness increases due to a change in the pore structure that is a function of antifouling paints. It is concluded that this method is useful for measuring micro–roughness, which has been found to be more important than macro-roughness (>10 µm), nano–roughness, and for characterising the surface porosity and topography of a coating at the micro-scale.

1 Introduction

Biofouling of marine structures has been a significant global problem throughout the ages and is of particular relevance in today's world of trans-continental shipping. It can increase costs significantly, both in economic terms (fuel efficiency and in-service periods), and in environmental terms (emissions and the spread of non-indigenous species). A 1 mm thick layer of algal slime will increase hull friction by 80 %, fuel consumption by 17 % and cause a 15 % loss in ship speed [1]. In a presentation given at the 12th International Congress on Marine Corrosion and Biofouling, Touzot [2] estimated that the percentage fuel increases for commercial vessels due to different types of antifouling were: slime 3 %, weed 10 % and hard fouling 40 %, and that given a market value of $539 to $649 million, a 5 % saving in fuel efficiency could increase profit by 90 % in a bad fiscal year. It was estimated in 1996 that the introduction of TBT based antifouling coatings saved the US Navy alone US$150 million annually [3], and in the 1990's was worth US$5.7 billion per annum [4].

Since the early 1970s the most successful antifouling (AF) coatings have been those that had a matrix based upon a self-polishing copolymer (SPC) with a tributyltin biocidal pendant group, and Cu_2O as an additional pigment. These coatings not only had very effective biocidal properties, but also were self–polishing, meaning that as the polymer is hydrolysed by seawater, it not only releases biocides but also erodes, making it smoother and more hydrodynamically efficient. Due to the introduction of the ban on TBT in 2003, coatings manufacturers have had to devise new SPC coatings using Cu_2O as the main biocide, with additional booster biocides.

1.1 Surface roughness

In order to assess the efficiency of novel SPC AF coatings several parameters have to be taken into consideration. These include biocide leach rate, AF efficiency, self-polishing capacity, dry film thickness and surface roughness. The surface roughness of a ship's hull affects its hydrodynamics, important in terms of fuel efficiency and emissions, but also potentially in terms of the hydrolysis of the copolymer. Surface roughness also promotes organism settlement in microanfractuosities [5]. The adhesive secreted by marine organisms is a low viscosity compound that can flow into surface cavities. This then cures to a higher-modulus material, creating a secure mechanical lock at every surface imperfection [6]. Therefore, the rougher a coating surface, the more likely it is to be fouled and the worse the hydrodynamics of that surface will become.

Conversely, surface roughness has also been attributed to increased biocide release rates, which would inhibit biofouling, as a roughened surface increases porosity and the likelihood of Cu_2O dissolution [7]. Measuring dry film thickness and surface roughness before and after immersion studies give an indication of the polishing action of the coating, which in itself is an indication of the rate of polymer hydrolysis and therefore leaching rate. Roughness in SPC AF coatings is a result of both the components of the coating system, such as particle size distribution (PSD), and the application process.

1.2 Components of the coating system

1.2.1 Particle size distribution (PSD)

Cu_2O particles present in commercial SPC coatings are usually ground to a suitable PSD to avoid cracks in the coating upon drying. An example of a typical PSD is shown in Figure 1.

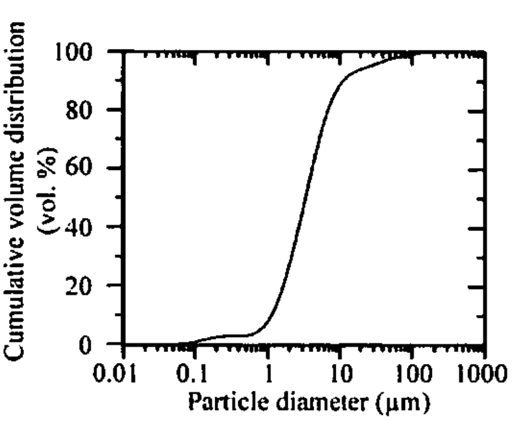

Figure 1 - PSD of Cu_2O in an antifouling coating after exposure to a mechanical shaker [8].

The rate of conversion of the active polymer binder in the leached layer is dependent upon the PSD. This is because the active surface area per unit volume of the leached layer is a function of the PSD of Cu_2O in the unreacted coating film (i.e. the empty polymer matrix, comprising the leached layer, is a template of the pigment particles which have dissolved). Using a model simulation based on a monodisperse PSD, Kiil *et al.* [9, 10] showed that changing the particle size from 10 to 0.1 μm increases the rate of polishing from 6.9 to 22.1 μm/month. However, reducing the particle size from 20 to 10 μm only changes the polishing rate from 5.2 to 6.9 μm/month. Thus an increase in small scale particles increases the polishing rate significantly but an increase in large scale particles is not important [10]. The PSD could also control the initial surface nano–roughness (>0.001 µm) of the coating before it is immersed in seawater. As has been mentioned this, in turn could have effects both on settlement of marine biota and on release rates.

1.3 Application procedures

AF coatings are applied by spraymist, airless spray or roller. In a commercial environment, the most common method of application is airless spray. Application by roller tends to be used in the case of private vessels, or in boat yards tending to small vessels around 30 ft where there is no access to commercial spraying equipment [11]. Using spraymist or airless spray, large volumes of coating may be applied in a short period of time and a smoother finish is achieved. In commercial applications stringent work protocols are used, where dew point, humidity, temperature and airflow are all strictly monitored

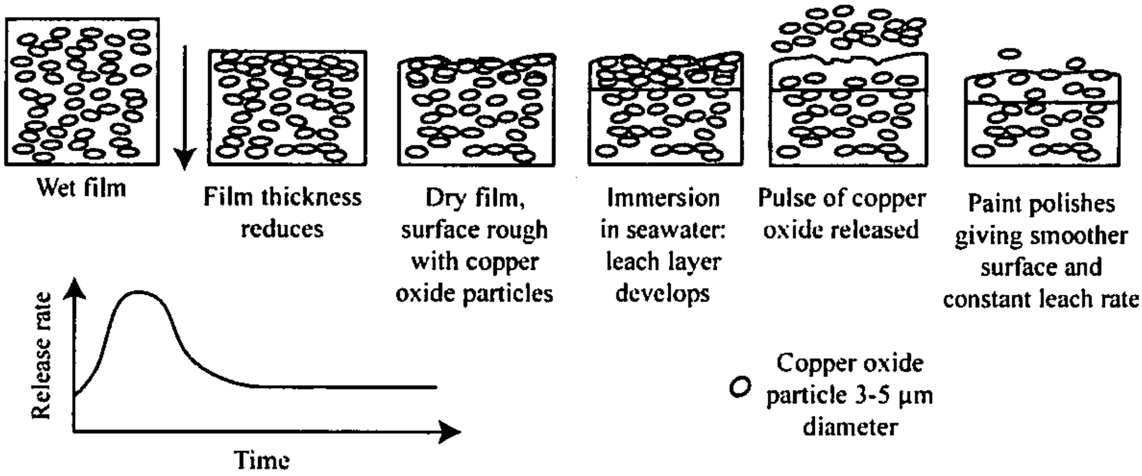

Figure 2 - Surface roughness caused by Cu_2O particles in SPC coatings

As the freshly applied SPC coating cures, it constricts (Figure 2, Table 1). Cu_2O particles that are near the surface of the film are concentrated there, leading to increased roughness. As both PSD and surface roughness have been shown to increase the rate of polishing and biocide release rate, this constriction process accounts for the initial pulse of Cu_2O seen early after immersion once the leach layer has built up enough to dissolve the Cu_2O [12]. After this pulse of biocide has been released, the coating polishes to a smoother surface, and a steady release rate is achieved.

2 Methods for testing the performance of SPC coatings

Several methods have been developed to test the performance of SPC AF coatings based on parameters such as biocide leach rate, AF efficiency, self-polishing capacity, dry film thickness and surface roughness. Those reported in the literature are almost exclusively variations on the premise that a solid material (steel, polycarbonate) is coated with the AF coating under investigation and immersed in seawater under various conditions. Test designs range from flat panels [13-18], through in-situ systems [13, 19, 20], to discs [18, 21] and cylinders [7, 10, 12, 18, 22-26], all with the goal of simulating the physical, chemical and biological conditions experienced on a ship hull.

2.1 Methods of surface roughness and dry film thickness analysis

In the literature regarding surface roughness and dry film thickness measurement of SPC AF coatings, three main categories of method have been used: stylus, optical or capacitance based. For each category there have been both intrusive and non-intrusive methods. Typically, with all methods reviewed there is a difficulty in measuring low levels of surface roughness that has led many experimenters to concentrate on roughness values which are orders of magnitude too high [27].

2.1.1 Stylus methods

The most widely used standard method to measure surface roughness is the BMT Hull Roughness Analyser (BMT HRA) [22, 24, 28-30]. The ball stylus of this hand-held equipment measures the highest peak to lowest valley perpendicular to the mean line, over a 50 mm interval (Rt_{50}). When the head has traversed the surface over about 0.5 m, fifteen readings of Rt_{50} and an average - the Mean Hull Roughness (MHR), are calculated [30]. It has been suggested that this needs to be modified so that it can record digital roughness profiles, and that the single amplitude parameter is insufficient to characterise the roughness of coating surfaces [24].

There are other stylus-based pieces of equipment used to measure roughness, all of which will undoubtedly suffer from the same lack of resolution as the BMT HRA. Weinell *et al.* [22] used the BMT HRA to measure macro-roughness and the Handysurf E-35A, a more sensitive stylus-based device, to measure micro–roughness. Thouvenin *et al.* [5] used a Mahr Perthometer M2 hand-held roughness analyser that works on the same principles as the BMT HRA with a vertical resolution of 0.012 μm.

2.1.2 Optical methods

Optical methods can be either intrusive or non-intrusive [10, 24, 31]. The intrusive method generally involves taking slices of the coating that are examined with either an optical measurement system, using the focus detection principle, or a scanning electron microscope (SEM) to determine both roughness and dry film thickness. Candries *et al.* [24] used a UBM Microfocus Measurement System that had a linear spot diameter of 1 μm, a measurement range of ±500 μm, and a vertical resolution of 0.01 μm. Optical systems have a much higher resolution than stylus systems and can measure three-dimensional (3–D) rather than two–dimensional (2–D) profiles. Even though optical methods have greater resolution than stylus-based methods, in many cases they are insufficient for measuring nano-scale roughness. Kiil *et al.* [10] report an absolute error margin of 5-10 μm or more when measuring dry film thickness.

The main problem with the majority of optical methods described in the literature is that they are intrusive. As each of the cylinders used in this study was manufactured to study biocide leach rates, it was imperative that a non-intrusive method was used to measure surface roughness both before and after immersion.

2.1.3 Capacitance method

The capacitance method [21] is based upon the premise that the capacitance of a film of non-conducting material sandwiched between two electrodes is given by:

$$C = \frac{(EE_0A)}{d} \tag{1}$$

where C is the capacitance; E is the relative permittivity (a measure of the ability of a material to resist the formation of an electric field within it, measured in farads per metre (F/m)) of the film material; E_0 is the permittivity of free space; A is the surface area of each electrode, and d is the thickness of the film. If everything else is constant, it follows that the thickness of the film is inversely proportional to the measured capacitance. It has been suggested that a capacitance change of 1 pF (easily detectable) will be produced by a thickness change of 0.2 µm [21].

This method has been shown to be effective in measuring coating dry film thickness, but the apparatus is very specialised and uses a coated disk rather than a coated cylinder. As the velocity of any point on the disk is proportional to the radius length, polishing theoretically increases with distance from the centre, as shear stress increases with velocity. The hydrodynamics of a disc, however, are such that it is difficult to verify the exact shear stress at any point on that disc. This makes the relationship between disc radius, velocity, shear stress, biocide release rate and polishing very hard to quantify.

2.2 Reported values of dry film thickness

Table 1 Film thickness specifications for major tin-free SPC antifouling coatings

Manufacturer	Product	Wet film thickness (µm)	Dry film thickness (µm)
Ameron	ABC3	N/a	100-150
Ameron	ABC4	N/a	100
Sigma Coatings	Ecofleet 530	N/a	75-150
Sigma Coatings	Alphagen 50 Series	N/a	75-150
International Marine Coatings	Interswift 650	216	125
International Marine Coatings	Intersmooth 465	313	125
International Marine Coatings	Intersmooth 360	313	125
Jotun	Seaqueen	150-300	75-150
Jotun	Seaquantum	160-320	75-150
Jotun	Seaprince	150-300	75-150
Jotun	Seaguardian	100-240	50-120
Jotun	Seaforce	130-260	75-150
Hempel	Globic 81900	175	80-150

Typically, a 3-year product specification for a TBT SPC AF product requires two coats, giving a total dry film thickness of up to 300 µm. For a 5-year specification, three or four coats are needed, resulting in a dry film thickness of up to 600 µm. Non-TBT SPC AF technologies are highly product specific and it has not been generally possible to give 'typical' product specifications [32].

Table 1 shows information given on product datasheets for the major tin-free SPC AF coatings. It must be noted that the figures given in Table 1 are for one coat only and actual thicknesses will vary on the product specification and resultant number of coats applied. Reported dry film thicknesses from sources other than commercial data sheets vary between 350 and 600 µm [10, 24]. The reason for the high values reported could be that during experimental work the coating is not applied using the same stringent work protocols found within a shipyard, where dew-point, humidity, temperature and air-flow are all strictly monitored.

2.3 Reported roughness values

Roughness is usually reported using three parameters: (1) the root mean square (RMS) roughness height - Rq (µm), a measure of the average displacement from the mean surface level [27], (2) the highest peak to lowest valley height Rt (µm), and (3) the average roughness height Ra (µm).

Table 2 Reported experimental roughness values

Author	**Coating type**	**Application**	**Method**	**Rq (µm)**	**Rt (µm)**	**Ra (µm)**
Candries *et al.* [14]	Tin-free SPC	Roller	BMT HRA	n/a	n/a	39-75
Candries *et al.* [14]	Foul-release	Roller	BMT HRA	n/a	n/a	44-64
Atlar *et al.* [16]	Tin-free SPC	Roller	n/a	4.04	19.98	n/a
Atlar *et al.* [16]	Foul-release	Roller	n/a	1.21	4.5	n/a
Candries *et al.* [24]	Tin-free SPC	Sprayed	BMT HRA	3.38-4.04	14.86-19.61	n/a
Weinell *et al.* [22]	Foul-release	n/a	BMT HRA / Handysurf	n/a	n/a	58-53 / 5-6
Weinell *et al.* [22]	Tin-free SPC	n/a	BMT HRA / Handysurf	n/a	n/a	53-86 / 15-20
Thouvenin *et al.* [33]	Tin-free SPC	n/a	Perthometer M2	n/a	6.37-13.83	0.49-1.65

Candries *et al.* [14] reported Rt values of an SPC coating as 39-75 µm using a BMT hull roughness analyser. Atlar *et al.* [16] reported Rq and Rt measurements of an SPC coating as 4.04 µm and 19.98 µm, respectively, and of a foul-release coating as 1.21 µm and 4.50 µm, respectively. Candries *et al.* [24] reported Rq and Rt measurements of an SPC coating as 3.38–4.04 µm and 19.61–14.86 µm, respectively. Thouvenin *et al.* [33] reported Ra and Rt values of SPC coatings from 0.49–1.65 µm and 6.37–13.83 µm respectively. Weinell *et al.* [22] reported macro-roughness measurements of three SPC coatings from 53–86 µm and micro–roughness from 13–20 µm. Measurements of silicone based foul-release coatings for macro and micro–roughness were 58-53 µm and 5-6 µm, respectively.

As can be seen from Table 2, in the majority of reported studies roughness has been measured using a stylus method such as the BMT HRA. This is useful for measuring macro scale roughness (>10 μm), which is sufficient for the large-scale undulations on the coating surface, but does not have the sensitivity to measure nano–roughness (>0.001 μm). To get sufficient vertical resolution to measure nano-roughness, one must use an optical method, which previously has only been used to measure dry film thickness, not surface roughness. Reported optical methods [10, 24, 31] have often necessitated the destruction of the coating under analysis, thus eliminating the possibility of measuring change after immersion.

3 Method

3.1 Apparatus

This work uses a rotary set-up involving the immersion of a coated steel cylinder (178 mm long and 64 mm in diameter according to ASTM method D 6442-03 [25]) into a cylindrical container (350 mm deep and 235 mm in diameter) filled with artificial seawater at pH 8.4 and salinity 34 PSU. The seawater was constantly re-circulated through solid phase extraction (SPE) and ion exchange columns to extract any biocides that leached out of the coating. This ensured that leaching was not impeded by elevated concentrations of biocides in the water creating a high diffusion gradient. These columns were replaced and analysed daily. The ion-exchange material used was Lewatit TP-207 conditioned to the calcium form to extract the Cu^{2+}. The SPE column contained a C-18 material to extract any organic biocides. pH and temperature were monitored throughout the experiment. Three cylinders were used, two were rotated at one knot (a, c) under the same conditions and one was kept under static conditions (b) to operate as a control. The immersion experiment lasted for 40 days.

Both, the construction of the cylinders and the application of the coating were done in the Meyer shipyard, Papenburg, Germany. The cylinders received a complete coating scheme: primer, anti-corrosive layer and the AF layer (cf. Figure 3) applied by airless spray. As there were three defined layers, the thickness of all parts of the coating scheme was possible. All cylinders were marked with indelible marker at the rim on the top end (primer) of the cylinder, and approximately 5 cm down the primer coating. This was to ensure that for repeat measurements the cylinder was upright and straight on the measuring plate.

The instrument used to measure surface roughness and coating thickness was a Zygo New View 5020 3-D surface profiler. This is an instrument based on scanning white-light interferometry, a traditional technique in which a pattern of bright and dark lines (fringes) result from an optical path difference between a reference and a sample beam. Incoming light is split inside an interferometer, one beam going to an internal reference surface and the other to the sample. After reflection, the beams recombine inside the interferometer, undergoing constructive and destructive interference and producing the light and dark fringe pattern. A precision vertical scanning transducer and camera together generate a 3–D interferogram of the surface, which is processed by the computer and transformed by frequency domain analysis resulting in a quantitative 3-D image.

The instrument has a vertical scan range of 150 μm, vertical resolution of 0.0001 μm and a lateral resolution of 0.45 to 11.8 μm. The measurements were taken using a 400x objective and the field of view was 350 by 265 μm (92,750 μm^2). This was reduced to 20 by 20 μm (400 μm^2) when measuring nano–roughness.

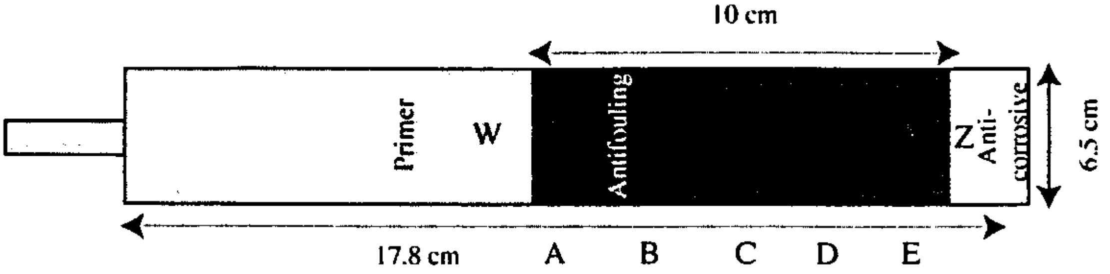

Figure 3 - Diagram of test cylinder

3.2 Analysis

3.2.1 Coating dry film thickness

Coating dry film thickness was measured before and after the leach rate testing. The measurements taken were based on a focus detection principle using the Zygo 3-D surface profiler. To measure coating layer thickness, four measurements were needed (c.f. Figure 3): (1) The focal distance on the primer layer (W), (2) the focal distance on the AF layer at the primer end (X), (3) the focal distance on the AF layer at the anti-corrosive end (Y), and (4) the focal distance on the anti-corrosive layer (Z). The layer thicknesses could then be calculated using the following equations:

$$W - X = \text{Anticorrosive} + \text{AF layer} \tag{2}$$

$$Y - Z = \text{AF layer} \tag{3}$$

$$(W - X) - (Y - Z) = \text{Corrosive layer} \tag{4}$$

To calculate the accuracy of this method, five measurements were taken at points Y and Z on cylinder b and the standard deviation and the standard error were calculated.

3.2.2 Surface roughness

It was noticeable from visual inspection of the cylinders that a certain amount of macro roughness was present in the form of undulations in the coating surface resulting from the application procedure. Using the Zygo 3-D surface profiler, micro- and nano–roughness can be measured as well as surface topography on a micro-scale. It has been reported that micro–roughness is more important than macro-roughness in terms of predicting drag resistance [22]. Micro–roughness was measured using Rq_L and Rt and nano–roughness was measured using Rq_S.

3.2.2.1 Micro–roughness

Five positions were marked out on a separate, linear scale (c.f. Figure 3, positions A-E). At each position, micro–roughness was measured by analysing the total field of view (92,750 μm^2), and studying two parameters: (1) the RMS roughness height (Rq_L) and (2) the highest peak to lowest valley height (Rt). Any inter- or intra-cylinder variation in these parameters was investigated.

3.2.2.2 Nano–roughness

To measure nano-roughness five random 20 by 20 µm (400 µm^2) sub-samples were taken within the total field of view at each sample position (A-E). For each sub-sample, the RMS roughness height was measured (Rq_S). This was then averaged to calculate the nano–roughness and error amount for that position.

4 Results

Unfortunately the coating on cylinder c (1 knot) was damaged during the experiment, so there was no replicate for the rotating condition.

4.1 Coating dry film thickness

The AF dry film thickness decreased more for the rotating condition than for the static condition (Figure 4), as expected. AF dry film thickness for the rotating condition decreased 9 % (±1.48 %) from 509 µm to 464 µm over 40 days, whereas the static condition decreased by 7 % (±1.93 %) from 381 µm to 357 µm. The anticorrosive layer (Figure 5), which should not be hydrolysed by seawater, decreased by 3 % (± 2.31 %) on the rotating cylinder from 306 µm to 298µm and increased by 3 % (±1.80 %) from 372 µm to 382 µm. To test the error of the method, at the start of the study five readings were taken at positions Y and Z on cylinder c to measure the AF dry film thickness. It was found that the AF layer was 324 µm, the standard deviation was 16.87 µm and the standard error was 6.89 µm. This error margin was with in those reported by Kiil *et al.* [10].

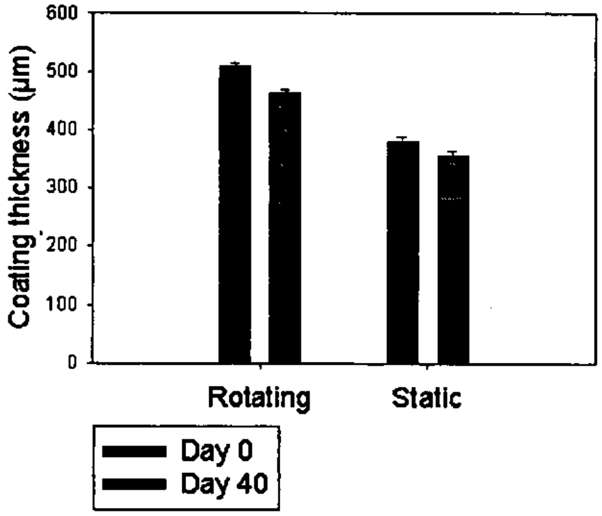

Figure 4 - Antifouling dry film thickness for rotating and static cylinders

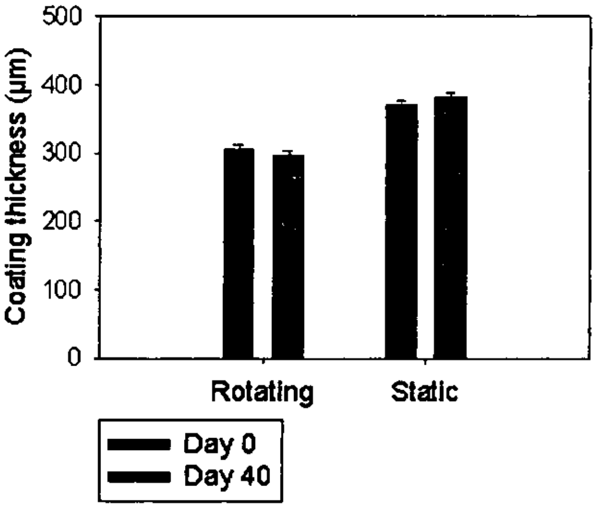

Figure 5 - Anticorrosion dry film thickness for rotating and static cylinder

4.2 Micro–roughness

As can be seen from Figure 5, taken from position E on the cylinder a at day 0, the coating surface is full of peaks and valleys under high magnification (400x). Usually this figure is in colour. Unfortunately the colour scale could not be converted to greyscale, which explains the contradictory legend in Figure 6. It is this overall geography of the coating surface that is referred to as micro–roughness and is defined in two ways, the maximum peak to valley height Rt and the root mean square roughness Rq_L. Figure 6 shows one of the main advantages of using this type of method, the fact that the surface topography of the paint can be observed. This is a very strong tool when working with foul-release coatings as being able to characterise the surface topography will give understanding to the attachment characteristics of micro-organisms, which can form stronger attachments in the microanfractuosities such as those shown in Figure 6 [5].

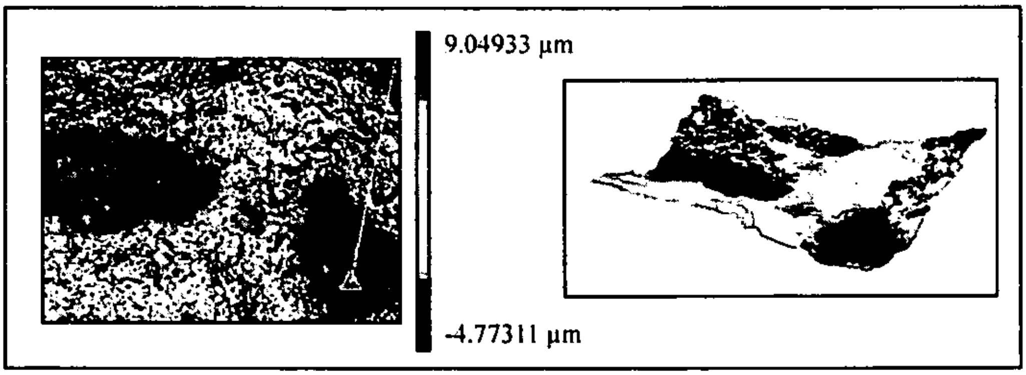

Figure 5 - Profile of micro–roughness on cylinder a, position E. The 2D plot has had any outlying spikes removed and the 3D plot has had points interpolated.

At day 0, before immersion, the average Rq_L range (Figure 6) was 0.91 μm (±0.1695) to 1.83 μm (±0.4094). The mean across all cylinders was 1.26 μm (±0.2602). These are significantly lower than those reported by Candries *et al.* [24] who measured Rq_L values of 4.04 μm to 3.38 μm from sprayed tin–free SPC coatings (Intersmooth 360 Ecoloflex). The values obtained in this work are much closer to those obtained by Candries *et al.* [24] from sprayed foul-release coatings (1.92 μm), which one would expect to be much lower than from conventional SPC coatings. Weinell *et al.* [22] reported Rt values that are similar to the Rq_L values reported here.

Average Rt range (Figure 7) was 6.02 μm (±0.68) to 10.42 μm (±2.36). The mean across all cylinders was 7.82 μm (±1.28) Again these measurements were significantly lower than those reported by Candries *et al.* [24] who measured Rt values of 14.86 μm to 19.61 μm for sprayed tin–free SPC coatings, but similar to those reported by Weinell *et al.* [22].

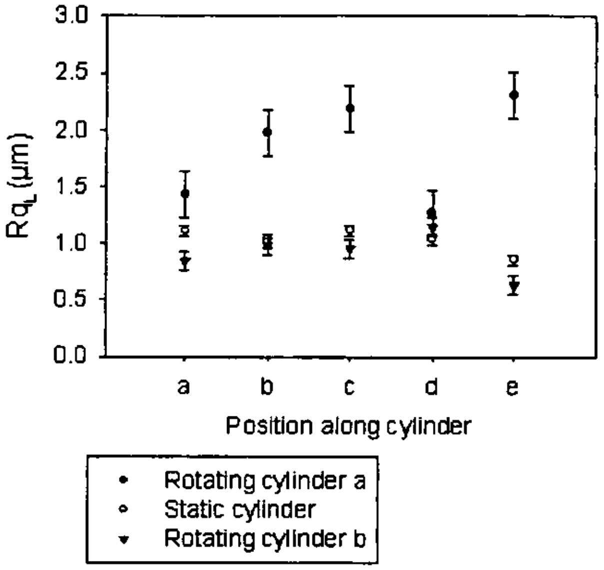

Figure 6 - Rq_L for all cylinders at day 0

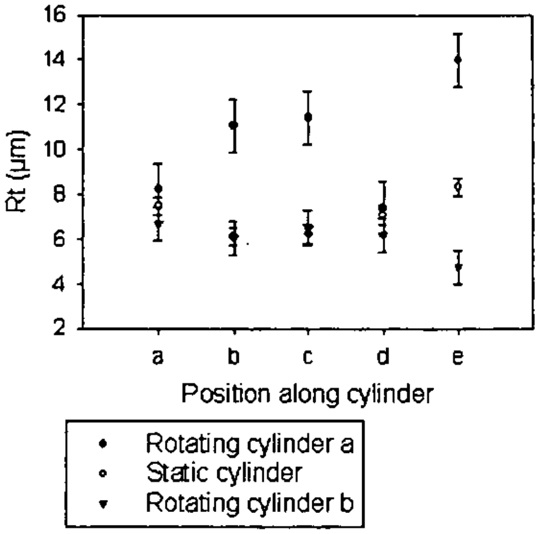

Figure 7 - Rt for all cylinders at day 0

Rq_L and Rt can be seen to follow the same pattern along the cylinder. A correlation exists ($R^2 = 0.867$) for all corresponding measurements of Rq_L and Rt. This agrees with work of Candries [29] who also found a correlation between the two parameters.

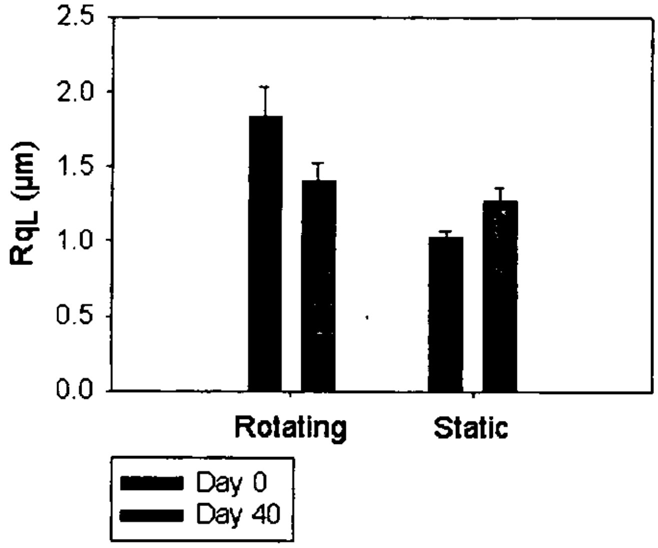

Figure 8 - Average Rq_L on day 0 and day 40 for rotating cylinder a and static cylinder

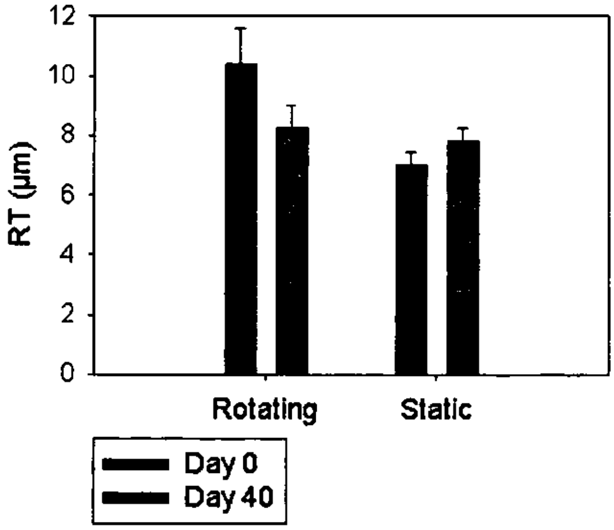

Figure 9 - Average Rt on day 0 and day 40 for rotating cylinder a and static cylinder

The average Rq_L (Figure 8) for the rotating cylinder decreased from 1.83 µm (±0.207) to 1.40 µm (±0.118) from day 0 to day 40, which was found to be significant using a paired t-test ($p=0.03$). Conversely, the average Rq_L for the static cylinder increased from 1.02 µm (±0.046) to 1.27 µm (±0.093) from day 0 to day 40, an increase that was not found to be significant using a paired t-test ($p = 0.06$). A similar trend was seen when observing Rt (Figure 9). The average Rt for the rotating cylinder decreased from 10.42 µm (±1.18) to 8.42 µm (±0.76) from day 0 to day 40. Again, this reduction was found to be significant ($p = 0.05$) using a paired t-test. The average Rt for the static cylinder increased from 7.04 µm (±0.41) to 7.85 µm (±0.39) from day 0 to day 40, and again was not found to be significant ($p = 0.1$) using a paired t-test.

The micro–roughness and dry film thickness results show that the effects of rotation (i.e. current speed) upon polishing results in a significant reduction in dry film thickness, Rq_L and Rt. This reduction would have been more pronounced if the study had been allowed to run for more than 40 days.

4.3 Nano–roughness

The average Rq_S range at day 0 (Figure 10) was between 0.1131 µm (±0.034) to 0.128 µm (±0.026). These figures all fell within 2SE of the overall mean, 0.120 µm (±8.48). An ANOVA was performed and there was found to be no significant difference between the Rq_S of the three cylinders ($p = 0.35$) unlike Ra and Rq_L.

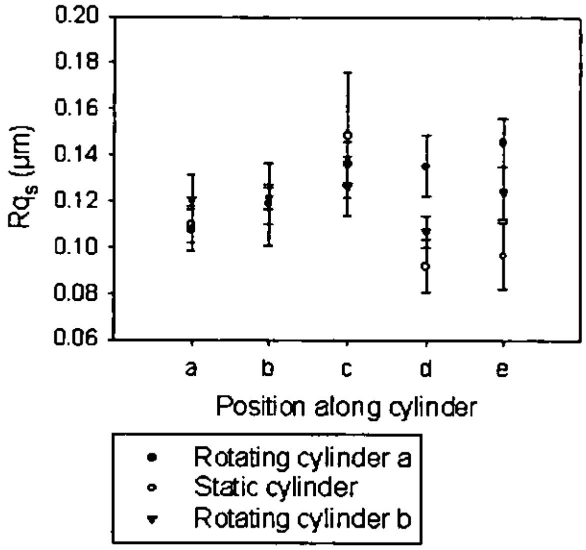

Figure 10 - Rq_S for all cylinders at day 0

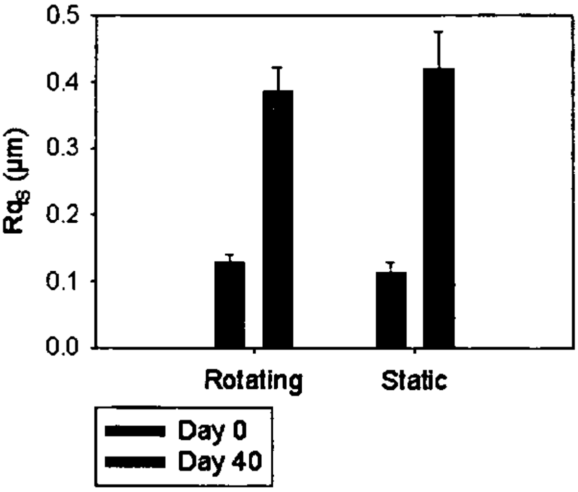

Figure 11 - Average Rq_S at day 0 and day 40

After 40 days the average Rq_S (Figure 11) for the rotating cylinder had increased by 301 % (±27) from 0.128 µm (±0.026) to 0.386 µm (±0.035) and for the static cylinder by 371 % (±13.68) from 0.113 µm (±0.016) to 0.419 µm (±57.41). In both the rotating and static conditions this increase was found to be significant using a paired t-test ($p=0.0009$ and $p=0.002$ respectively).

This increase in nano–roughness should not have any impact on drag resistance as the thickness of the sub-laminar layer is typically in the order of 10 to 30 µm. Roughness smaller than this value is expected to "hide" itself in the laminar layer and so is not expected to add to the frictional resistance. This increase in observed nano–roughness is likely to be related to the pore structure which is a built-in property of SPC AF coatings [34]. It can be concluded from these results that the pore structure of the coating has a greater effect on nano-roughness than the surficial copper particles drawn to the surface during the curing of the coating (Figure 2).

5 Conclusion

It has been shown that an optical, non-intrusive method using a Zygo New View 5020 3-D surface profiler is useful for measuring micro–roughness, nano–roughness, surface topography and dry film thickness of AF coatings. When testing the efficiency of AF coatings, this method can be very easily incorporated into a suite of tests for other efficacy parameters, such as biocide release rate or polishing rate, due to its non-intrusive nature. Not only does this method measure micro–roughness, which has been shown to be more important than macro-roughness when assessing drag resistance, but it also measures nano–roughness and surface topography at a micro-scale (Figure 6). This is a good tool for characterising the surface porosity and topography of a coating, factors that are important when assessing the surface structure and how this relates to the attachment mechanisms of biofouling. Due to the dual functionality of this method (roughness and surface topography) it would be useful in investigating both SPC and foul-release coatings.

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ENVIRONMENTALLY FRIENDLY COATINGS IN SHIPBUILDING AND SHIP REPAIR

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Changing requirements on the world market either caused by new ship designs or by international regulations placed additional challenges on marine coating activities. This presentation outlines the work to be performed within the project "Environmentally friendly coatings for ship building and ships in operation" (ECODOCK) which is funded by the European Community. The work includes the comparison of alternative surface preparation and application technologies, the development of test methods for the paint performance, the selection and further development of test methods to monitor the health and safety conditions as well as the environmental impact. It will show that with the selection of suitable surface preparation and application technologies together with the introduction of new paint systems the environmental impact of marine coating processes can be reduced.

Finally, it will introduce an internet portal for research and development activities for marine coating activities to be developed.

THE REGULATORY CHALLENGE FACING MARINE COATINGS

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Now that the TBT ban is in place, a number of other regulatory challenges that affect marine coatings and are getting more attention.

Whilst there are hopefully many environmental benefits of these changes in place, the statistics on the loss of life at sea imply that here has been no major change over the last 30 years. A problem with all this legislation is that it is focused on one individual item and the bigger picture of how it all impacts the whole of the shipbuilding, coating and ship operations is not taken into account. Some legislation has caused more problems in related areas than the benefit it was meant to give. If a more thorough understanding of the impact of the legislation on the whole of the shipping process was considered and the regulations harmonised, more productive, less repetitive solutions could have been identified by the industry. It would also probably take less policing and reduce the compliance checking for everyone. A major regulatory impact in the near future is in the area of ballast water treatment, which may also impact marine coatings.

1. Introduction

Over recent years many regulations that have come into force affecting marine coatings have often been as a result of regulatory bodies imposing rules to protect the environment and the health and safety of workers and passengers exposed to those products.

Within the last 15 years alone, over 11 separate regulations and standards have been introduced concerning just the coating aspects of ballast water tanks [1], in addition there have been numerous others relating to antifouling paints, solvent emissions etc.

This paper sets out to debate the methods by which regulations are developed based on a focus of the environmental impact of one part of the shipping/shipbuilding value chain, rather than a consideration of the effect of changes on the whole value chain.

The aim of any new legislation must be to provide a net gain to the environment when all factors are taken into account, rather than the improvement of one local process or activity.

Often the legislation that is introduced focuses on a micro scale environmental problem within one part of the value chain that doesn't necessarily bring any overall benefits on the macro scale, or even worse, can actually result in a negative impact over the whole value chain.

A number of different bodies with specific interests; e.g. International Maritime Organization (IMO), Port States, bring in legislation and various action groups such as the WWF and Friends of the Earth rightly influence these bodies. There is nothing wrong with that process in that it highlights the areas of concern that need improvement. It is the solutions reached that are at odds, in that they often assume that by optimizing a part of the value chain the net benefits are carried through to the rest of the chain, thus showing an overall net improvement to the environment. This is not always the case.

If a more holistic view of shipbuilding and shipping operations were taken by all these organizations, regulations that result in human and environmental improvements over the whole value chain would emerge. Such an approach may also reduce the amount of policing and paper work taken to implement and track the changes.

2. Micro changes – Macro effects

This paper focuses on the specific effect the following 'micro' changes have had on the overall 'macro' situation. The examples used in this paper to highlight this problem for marine coatings are as follows:

- The introduction of the double hull tanker
- The Tri Butyl Tin (TBT) ban in Antifoulings
- The control of Volatile Organic Compound (VOC) emissions

It is not intended to undermine these changes, but to open up the thinking on the overall impact of them so that any future debates concerning the introduction of new regulations consider the impact on the total value chain of the shipping industry.

2.1. The Introduction of the double hull tanker

The Exxon Valdez is often remembered as one of the greatest oil spills of all time (11 million gallons). It was not. It was however, one of the most devastating to wildlife and the environment because of its location in Prince William Sound, Alaska.

Land based operations are generally acknowledged as the largest source of marine oil pollution [1]. It is Offshore Platforms and Oil Rigs are sources of major greater levels of pollution in the event of a catastrophic incident. For example, the Ixtoc 1 in the Gulf of Mexico released 140 million gallons of oil in 1979, almost 13 times the amount of the Exxon Valdez.

Fig. 1 - The Exxon Valdez

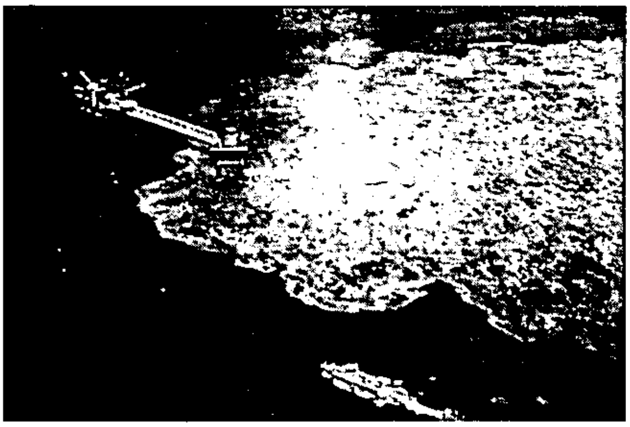

Fig 2. - Ixtoc 1

One of the responses to the Exxon Valdez incident was a desire to improve ship design to protect against grounding and impact damage. The ensuing debate gave rise to Oil Pollution Act 1990 in the USA (OPA 90) and the subsequent IMO/MARPOL convention (1992 amendments to MARPOL 73/78, Annex 1) that required all tankers > 5,000dwt to have double hulls (amongst other measures) to prevent such oil spills in the future. The phase out of single hull tankers has been accelerated following subsequent (single hull) disasters and should be complete by 2010 following the 2004 amendments. Even though, in many of these disasters age, corrosion, insufficient maintenance and inadequate surveys were all strong contributing factors to the structural failure of the ships.

Alternative design options were considered but it was the double hull (twin skin) approach that prevailed. The gap between the inner and outer hulls often being used as a ballast tank. So that if a ship is grounded or is involved in a collision, the double hull may provide the necessary additional protection to prevent the cargo tanks being damaged and therefore polluting the local environment.

However, using this space as the ballast tanks versus the previous practice of using a cargo tank or segregated ballast tank in single hull tankers, has resulted in some of the following negative effects and consequences for the whole value chain.

Table 1 – Effects and consequences of using double hull voids as ballast tanks.

EFFECT	CONSEQUENCES
NEGATIVE	
Ballast tank surface area has increased at least 3 times which results in additional surface preparation, coating and maintenance to prevent corrosion.	>3 times more coatings are required to prevent corrosion. More edges to corrode resulting in coating failure and increased repair effort. Greater surface areas to maintain. More energy consumed and more waste created at new build and maintenance & repair in the form of empty paint cans, liquid paint, solvent emissions, grit, dust, noise and other pollutants. Of course there are the associated coating manufacturing costs, transport and delivery as well as waste and the additional factory capacity required to meet this need.
Some parts of the ballast tanks have limited access in service and cannot be properly or economically maintained.	Corrosion protection must be in place at new build. Life time of the ship can be limited by ballast tank corrosion The concern is such that Classification Societies are increasingly vigilant about these areas and the quality of the coating.
As a result of the designs adopted a large area of the ballast tank surface is on the outer side of the cargo tanks and therefore subjected to cyclical temperature changes.	Causes stressing of the coatings resulting in failures. Hence additional resources needed to maintain the tanks to the required standards.
Steel weight of the ship increased by 25%. Crude oil tankers account for approximately 29% of the worlds' cargo carrying fleet by deadweight registered (2003). REF Lloyds World Fleet Statistics 2003	Requires bigger engine, which consumes more fuel, resulting in more emissions. More steel used and so more processing which creates waste.

Larger dry-docks	Larger repair facilities are required to handle the vessels as overall dimensions increased for the same cargo volume because of the double hull configuration.
Alien species migration	The increased ballast water requirements also aggravate the problem of invasive alien species migration, which will require additional equipment on board to manage it. [2]

In general the effect on the whole value chain tends to be negative with the adopted solution. It did solve the micro problem, but it does result in considerably more coatings being applied, which results in the associated increase of waste from coating activities, VOC emissions, cleaning materials etc. as well as increased energy and natural resource consumption. While at the same time increasing the burden of maintenance and the potential for corrosion.

As a specific example, BP Oil Shipping Co. have recently built an oil tanker for Alaskan waters in NASSCO which is described as the most environmentally friendly oil tanker ever built. It has built in a 100% redundancy for vital elements such as double rudders, double steering and double engines in segregated engine rooms, and of course a double hull.

The vessel uses seawater instead of oil to cool and lubricate propeller shafts so reducing the potential for oil leaks. But as always there are trade offs. The ship itself weighs around 5,000-6,000MT more than a similar ship without all the extras and so will burn more fuel and hence produces more emissions, require more ballast and more surface preparation work and of course coatings.

In the long run it may be worth it to prevent oil pollution, but only if the other penalties in the value chain are kept in check. It is the comparison of the preventative measures taken versus their intrinsic effects on health and the environment across the chain that needs to be considered, assessed and debated.
The point being that you cannot legislate for every unplanned disaster. Of course legislation and regulation are tools that can limit the loss of life and the impact on the micro - environmental effects, but it is much harder to balance the benefits across the whole value chain, because the totality of the value chain is often neither understood nor considered.

These unpredictable disasters teach us one lesson, it's often about being prepared to control and deal with the consequences of an incident to ensure their impact is limited rather than trying to legislate to prevent their recurrence that can give rise to real benefits. Whilst undoubtedly some legislation (such as SOLAS) can actually help save lives and prevent damage, others can have as many more detrimental effects than beneficial ones, and do not guarantee that the disaster will not happen again.

2.2. Ballast Tank Coatings

With the development of more extreme conditions, awkward shapes and greater surface area to corrode, new regulations on the protection and maintenance of ballast tanks have been brought in [3]. Corrosion control in segregated water ballast tank spaces is probably the single most important feature next to the integrity of the initial design in determining structural reliability. There are many systems being developed to remove organic species from ballast water and some are also trying to reduce the potential for corrosion at the same time e.g. using nitrogen to purge the oxygen out of the water and so kill any organisms and hopefully it will reduce corrosion by reducing oxidation of the steel [3]. This process would be carried out on board the ship. One question this is raising is "what is the effect of this process and the resulting water compositions on the ballast tank coatings?" Studies are currently being carried out to simulate and understand this [4]. This regulation will bring additional machinery onto vessels to effect the clean up their ballast water, alter the water composition and create additional waste products.

Ships used to carry bricks and rocks as ballast. Whilst this had its own negatives such as damage to the cargo tank and time to offload, at least it was recycled and had no ongoing environmental impact. The industry is caught up in the use of seawater and now the treatment of it to prevent transfer of invasive species. Perhaps a return to old fashioned reusable solid ballast should also be considered. Some companies have developed solid ballast material that can be pumped in and out of tanks e.g. as a slurry with water, the excess water removed once the ballast material settles. It is then reused after removal [5]. A mixture of solutions may be the answer. The point is rather than continue doggedly using sea water and introducing processes to manage its environmental impact, that in turn will inherently have n affect on the environment, we need to look at alternatives and look at how the world fleet can co-operate on the use of ballast.

2.3. Marine Antifoulings

And the worst offender is? Well that depends on where in time you stand.

Comments are often heard referring to how bad TBT (Tri Butyl Tin) antifouling was and even question how it was ever allowed for use on ships. But before tin there were lime, tar, arsenic, and mercurial compounds (a small selection of poisons and carcinogens which is why they acted as antifoulings).

Yet what is often forgotten is that the development of TBT antifoulings in the 1960s had numerous benefits such as:

Reduced deaths due to application
Longer life time on the ship, so less application of paint
Relatively low VOC content
Relatively low copper content

The TBT technology development also brought the ability to reduce fuel consumption and therefore emissions of "green house gases" into the environment by the self-polishing concept. If there is no antifouling effect on a ship and its left to foul up and then 'simply be cleaned by brushing', one huge consequence of this is the increased drag on the vessel caused by the fouling [6]. If there had been no antifouling then figures indicate a need to consume 40% more bunker fuel to compensate for the increased drag, and the fleet would then need to increase in size to cope with the reduced speed and availability of vessels. By 'self polishing' drag was significantly reduced and fuel efficiency increased, which is beneficial in the face of ever increasing fuel prices.

After some 10 years usage, data emerged indicating adverse affects of the leached tin on non-target marine life in areas of low water exchange. Hence the decisions to limit and ultimately ban the use of tributyl tin coatings.

At present we have replaced a system, which had a known and quantifiable effect on the environment with new and alternative technologies for which inadequate data currently exists on their performance across the whole value chain.

The concern with some of the work pinpointing one antifouling ingredient and generating data to show how bad it is, focuses on only one element of the value chain. Often the conditions of testing are not the same as in service and consideration is not given to the overall impact simply banning it will have. So before debating the merits or otherwise of any particular anti-fouling technology, an understanding of the world without any antifouling might be a better start point. Twice as many ships needed to ship the goods going at half the speed and using twice as much fossil fuel (There are currently some 98,000 vessels in the world fleet).

2.4. VOC Emissions

Legislating against materials in paint formulations while pushing the boundaries of research to find alternatives also leaves the industry to use what is available at the time of the ban, which in hindsight might be deemed equally poor.

The legislation to reduce emissions of volatile organic compounds (VOCs) e.g. solvents, is in place in Europe and USA [7,8] can have both environmental and health benefits. Paint formulations have in may cases had the level of such solvents reduced by increasing the volume of solids in the paint, which in practice has also brought additional complications in application and paint properties. A brief overview of some of these consequences is listed below.

Table 2 – Effect and consequences of low VOC paints.

EFFECT	SOME CONSEQUENCES
NEGATIVE	
High quality of surface preparation required – paint less tolerant of poor surface.	Preparation must be more exact and no contamination present. More time spent blasting with potential for more blasting waste materials to be handled, more energy consumed
Supplied as 2 component system as almost solid	Require specialist application equipment. Have to heat the lines to ensure the high solid material flows. Greater energy consumption
Pot life more critical	Potential for more paint to be wasted if pot life exceeded and required specialist disposal.
Low molecular weight materials used to obtain some flow	Can be more hazardous to health
More brittle as less pigment can be used	Less flexible coatings are resulting in different coating failures being seen.
Cleaning materials to clean application equipment more critical.	Greater use of cleaning solvents
POSITIVE	**SOME CONSEQUENCES**
Less VOC emissions from paint	Better for health and environment
Good edge retention	Less rework and less failures
Hard coating	More durable
Rapid curing possible	Reduce time of worker exposure

In the longer term coatings may have to move to water based technologies to overcome some of the bigger issues such as the low molecular weight polymers. While this will probably be a positive move, it will take time for the shipping industry to be reassured that the coatings can be routinely applied and perform. These products are available but the industry is reluctant to move to them at this time partly because of the control over the atmospheric conditions required for use.

3. Conclusion

All the maritime legislation and the national and local authority regulations are brought into force with good intent. What needs to be ensured is that the good intent to optimize some local activity is carried through by ensuring a net environmental gain across the whole value chain, rather than merely shifting the problem to other parts of the chain, often with adverse consequences. While this process is not so simple, it does require proper dialogue and engagement between industry and regulators to ensure that the desired benefits required are generated in a sustainable manner.

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ENVIRONMENTAL PROTECTION CLASS NOTATIONS FOR SHIPS AND THEIR APPLICATION TO RO-RO FERRIES AND PASSENGER SHIPS.

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This work is part of a research, currently in progress, which aim is to design RO-RO/Pax ferries and Passenger ships that minimize the impact on the environment during the normal operation and in case of accident.

Some critical environmental issues have been identified and counter measures proposed. The first issue takes into consideration the presence of the fuel tanks in the double bottom and in proximity of the sides. This conventional layout represents a danger in case of accident, because it would cause spill of fuel into the sea. The second consideration concerns the layout of the ballast system with the aim to minimize the transfer of seawater. The third aspect concerns the propulsion and the electric generation. In the latter case the design drives were: the reduction of energy required per unit cargo mass and the reduction of emissions per unit cargo mass.

Moreover the evaluation of the impact that the application of the environmental class notation can induce on the ship design has been assessed. To achieve this, three RO-RO/Pax and a Passenger ship have been analysed and the Rules for the GREEN STAR Class Notation have been applied to them.

1. Introduction

Short Sea Shipping is a competitive mean of transport that can greatly contribute to reduce traffic congestion on the road with major benefits for human safety and for environment. However, marine transport turns out to be not free of environmental impact, as well known disasters showed very clearly.

Over the last few decades the impact of shipping operations on the global environment has been a matter of increasing concern. Firstly, this concern concentrated on pollution caused by accidents to ships engaged in dangerous cargo transportation. More recently, this concern extended to operational pollution of the ship, i.e. emissions from engines, emissions during loading and unloading, discharge of garbage, antifouling paint and non-indigenous species from ballast water. The growth of pollution awareness parallels the growth of pollution legislation.

Marine and shore transport are subjected, in Italy and in most countries of the world, to an increasing number of environmental laws that cover a wide range of specific potential damages to the environment, i.e., gas emissions, noise, oil outflow.

The first part of the research concentrated on the evaluation of the global environmental impact of marine vehicles for comparison with shore vehicles in order to select the proper mean for the entire transport process (from the site of production to that of utilization for goods, or from origin to destination for human trips). To achieve this, a methodology based on the Environmental Impact Assessment (EIA) was proposed by one of the authors [1] and applied to evaluate the environmental impact of a new sea passenger line consisting of high-speed ferries and to compare the sea transports with other shore transport means (car and train).

The effectiveness of an environment protection strategy depends on the level of integration of environmental considerations in the decision-making process.

The application of this concept to maritime transport leads to, at minimum, the introduction of the environmental issues into the design process (design spiral) at the same level of importance of the other 'traditional' issues like stability, propulsion, strength, and so on.

The goal becomes to minimize ships' global environmental impact and not merely to comply with regulations. The effectiveness of the proactive approach is well recognized in the maritime community. In particular the Safety Management System (SMS) and the Formal Safety Assessment (FSA) should have an indirect but positive impact on the environment because they should reduce casualties and their consequences.

This part of the research is focussed on the design criteria for RO-RO/Pax ferries and Passenger ships that allow to minimize the impact on the environment during the normal operation and also in case of accident. The application of the rules for the Environmental Class Notations has been assessed and the impact on the ship design has been discussed for four different ships.

2. Identification of Environmental Hazards associated with short sea shipping

In the decision-making process, the identification of the most relevant environmental issues has the purpose to check the compatibility between every choice and the 'whole' system, with the objective of preservation and protection of natural resources.

The general procedure of every strategic method can be briefly summarized as follows:

- identification of the main environmental impacts;
- analysis and evaluation of impacts;
- adoption of a feasible system of estimation (i.e. monetary), target oriented to the comparison of different options;
- evaluation of the different alternatives;
- selection of the most favourable option.

The first step of the process has the aim to identify and rank environmental hazards on the base of their consequences and probability of occurrence. This was already addressed as one of the most critical aspects in [1].

At the moment only the hazard identification has been assessed in a numerical way; the quantification of consequences has been performed on the base of subjective judgment. The information used for the present hazard identification comes from a statistical analysis of marine accidents, collected by different national coast guards and international Organization (IMO, Intertanko, ITOPF, etc...) in the period between 1995 and 2000. Some data are presented in the following figures.

Fig. 1 shows accidents occurred to ships engaged in international voyages, between 1995-2000 (source: Italian Coast Guard). The data show that the ship type more frequently involved in accidents is the Ro-Ro/Pax.

Fig. 2 shows the number of accidents by type. The more frequent accident results the collision, mainly into or in proximity of ports.

Fig. 3 shows types of accidents occurred to UK flagged ships during year 2002. The figure shows the accidents occurred to all ship types, depicted in black colour, while the accidents occurred to passenger ships are depicted in grey.

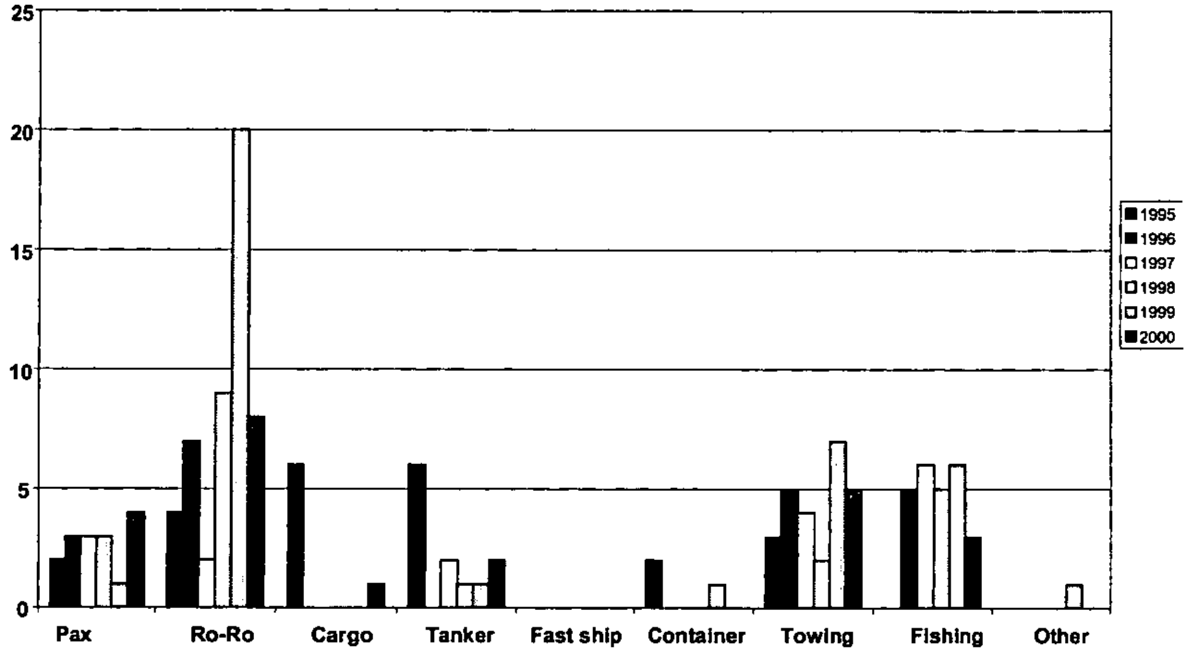


Fig. 1 - Accidents occurred to ships engaged in international voyages, between 1995-2000 (source: Italian Coast Guard).

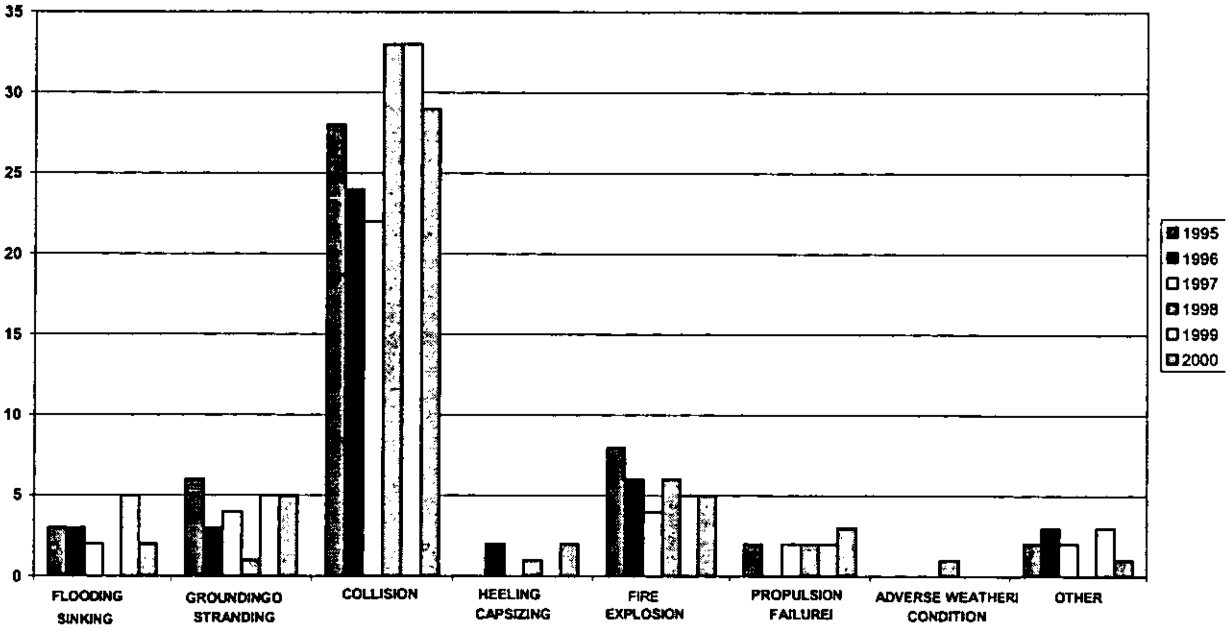


Fig. 2 - Number of accidents by type, between 1995-2000 (source: Italian coast guard).

Collision and groundings resulted very frequent accidents. Similar conclusions can be drawn from the analysis of data coming from the other analysed sources.

Analysing Ro-Ro/Pax ferries and passenger ships, during normal operation activities and also in case of accidents, three main causes of environmental impact have been identified:

- minor collisions and groundings ⇒ oil spill;
- ballasting ⇒ transfer of non-indigenous aquatic species;
- exhaust emissions ⇒ air pollution.

For each of them reasonable design approaches have been proposed to reduce their environmental effects.

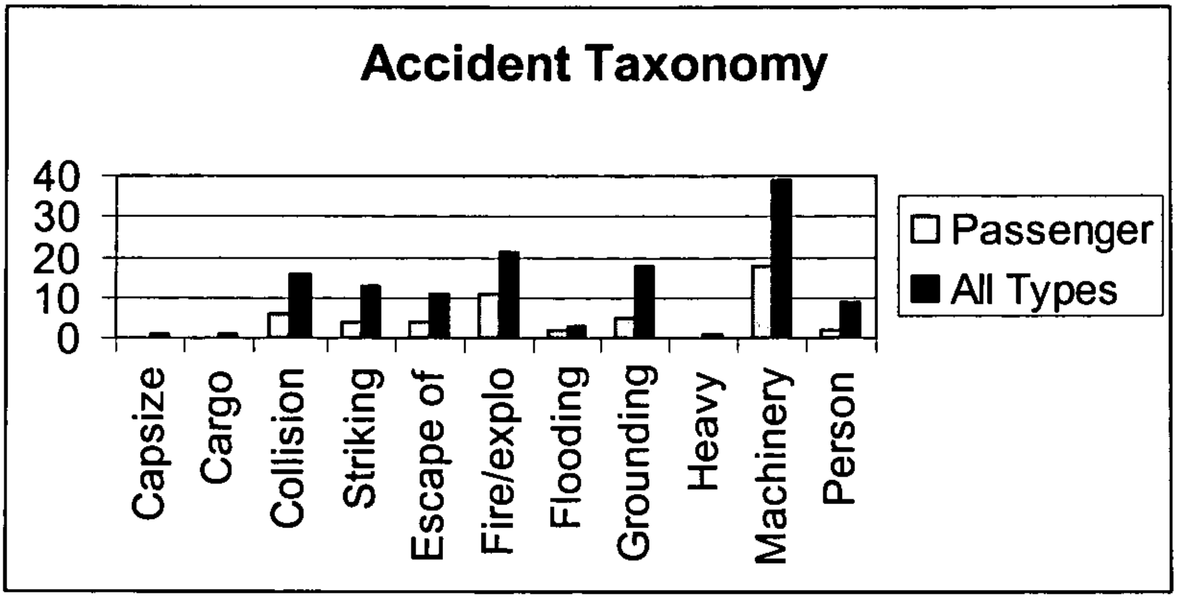


Fig. 3 - Accidents UK fleet 2002 (source MAIB).

The adopted methodology is clearly illustrated by the risk matrix, in which rows represent the frequency of impacts and columns their consequences.

For what concerns the effects due to collision and groundings the idea is to operate at ship design level, to lower the consequences; being the frequency not directly related to ship design factors.

For what concerns the effects of ballast water transfer, the idea is to design a ship that requires minor sea water ballast, in order to reduce the frequency of the ballasting operations.

For what concerns the air pollution, the idea is to reduce the consequences, reducing the amount of exhaust emissions. This objective may be achieved, at design stage, by using less polluting engines or by using new and more efficient energy converters like fuel cells, and by reducing the entire amount of energy required to drive the ship.

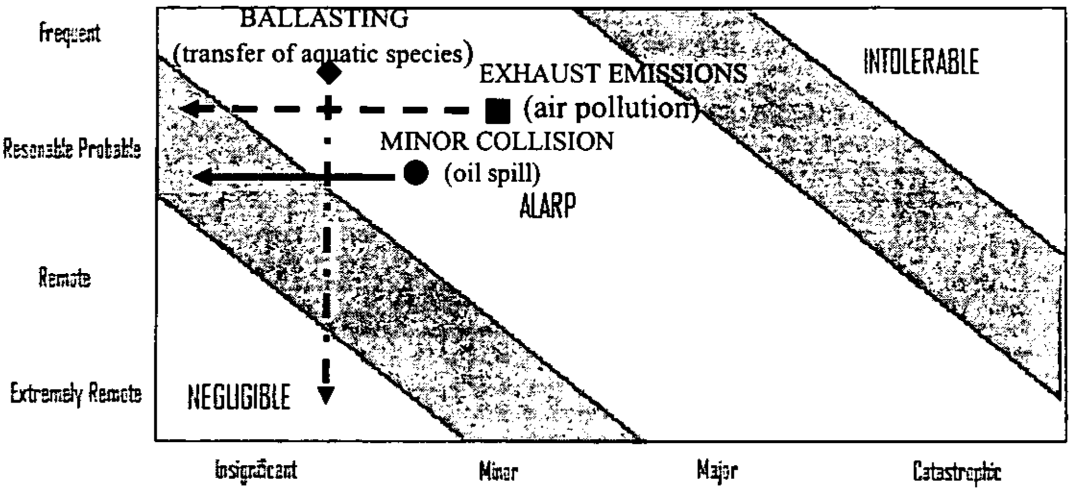


Fig. 4 - Risk reduction strategies.

The issues identified and the design response proposed have been compared with the design aspects included into the environmental class notations proposed by Ship Classification Societies.

3. Environmental class notations

Many Classification Societies, i.e. R.I.NA, ABS, DNV, LR, GL, BV and probably others, have developed the Environmental Class Notation for the prevention of pollution from ships.

The Environmental Class Notation is assigned to ships that are designed, built and operated in such a way to ensure maximum respect for the environment. The Environmental Class Notations can be applied to all ship types, but they seem more appropriated for ferries and passenger ships that operate near the land and in environmentally sensitive areas of the world.

These regulations are based on the MARPOL that is the International Convention for the Prevention of Pollution from the Ships. The Convention includes six technical Annexes. Annex I applies to all ships and concerns oil pollution, Annex II applies to ships that carried noxious substances in bulk, Annex III concerns prevention of pollution by harmful substances in packaged form, Annex IV regards prevention of pollution by sewage, Annex V regards prevention of pollution by garbage and Annex VI concerns air pollution. Annexes I, II, III, IV, V have been ratified, Annex VI will entry into force in May 2005.

The Rules of the Environmental Class Notation, based primarily on MARPOL 73/78, Annexes IV, V, VI, state requirements for ship design and operation, for equipment and systems with the aim to reduce the environmental impact from emissions to air and discharge to the sea.

The Classification Societies and their Environmental Class Notation considered in this work are:

- RINA: CLEAN SEA, CLEAN AIR, GREEN STAR DESIGN,
- BV: CLEAN SEA, CLEAN AIR, CLEAN AIR/TRANSIENT,
- DNV: CLEAN, CLEAN DESIGN,
- Lloyd's Register: Environmental Protection (EP),
- Germanischer Lloyd: Environmental Passport (GL-EP),
- ABS: Environmental Safety (ES).

RINA, BV and DNV propose two environmental class notations. The RINA and BV environmental class notations are CLEAN SEA and CLEAN AIR. The CLEAN SEA provides rules to prevent the emission of polluting substances in the sea and the CLEAN AIR provides rules to prevent the emission of polluting substances in the air. The RINA GREEN STAR Notation is awarded to ships, which meet the requirements of both additional class notations CLEAN SEA and CLEAN AIR. The additional class notation CLEAN AIR/TRANSIENT, proposed by BV, is assigned to ships which are in compliance whit the additional provisions related to smoke emissions from diesel engines under transient conditions. The class notation CLEAN SEA of BV highlight the number of consecutive days the ship is able to operate in no discharge conditions.

The DNV environmental class notations are CLEAN and CLEAN DESIGN. The CLEAN class notation identifies the basic requirements for controlling and limiting operational emissions and discharges. The CLEAN DESIGN identifies additional requirements for controlling and limiting operational emissions and discharges. In addition, this notation specifies design requirements for protection against accidents and for limiting their consequences.

Lloyd's Register EP class notation is assigned in two different ways: there are minimum requirements for assignment of the EP class notation and additional requirements. Ships complying with additional requirements will be eligible for one or more of the associated supplementary characters.

Certificates, documentation, operational procedures and drawings are required in order to receive the environmental class notation.

Table 1 reports the main issues covered by the environmental protection class notations of the considered Classification Societies.

Table 1 – Required documentations for environmental class notation

	RINA	**LR**	**DNV (CLEAN)**	**DNV (CLEAN DESIGN)**	**ABS**	**BV**
Safety Management Certificate in accordance with ISM code		x	x	x	x	
MARPOL Certicates, mandatory			x	x		
MARPOL Certicates, not mandatory		x				
Oil pollution prevention procedures	x	x	x	x	x	x
Ballast water management plan	x	x	x	x	x	x
Sewage treatment plan	x	x	x	x	x	x
Garbage management plan	x	x	x	x	x	x
NO_X emission control	x	x	x	x	x	x
Procedure for defining, ordering and checking fuel oils so as to fulfil the required content of sulphur						x
Oil fuel management for the control of SO_X emission	x	x	x	x	x	
Refrigerant management	x	x	x	x	x	
Engine room operation control procedures				x		
Bridge operation control procedures				x		

3.1. Main Environmental issues covered by the Additional Class Notations

3.1.1 Tank arrangement

Usually, fuel oil tanks are located in the double bottom and in proximity of the sides (in RO-RO Ferries and in Passenger Ships). This conventional layout represents a danger in case of accident, because it would cause spill of fuel oil into the sea. Many Environmental Class Notations give requirements to locate the fuel oil tanks in a protected location away from the ship side or bottom shell plating. Fuel oil tanks including, in some cases, overflow tanks, sludge tanks, waste oil tanks of capacity greater than 20 m^3, have to be considered for a proper layout. The distance "w" of the fuel oil tanks from the side shell plating as required by the environmental class notations is listed in *Table 2* and it is drawn in *Fig. 5*.

Table 2 – Distance of the fuel oil tanks from the side

CLASSIFICATION SOCIETY	DISTANCE FROM SIDE (m)	APPLICATION
RINA e BV	w=0.01*(68.69+0.0657*v)	20<v<2000 m^3
	w =2	v>2000 m^3
Lloyd's Register	w>0.76	v<1000 m^3
	w>1.5	v>1000 m^3
DNV	w>0.76	Gross Tonnage<20000 tons
	w>2	Gross Tonnage>20000 tons

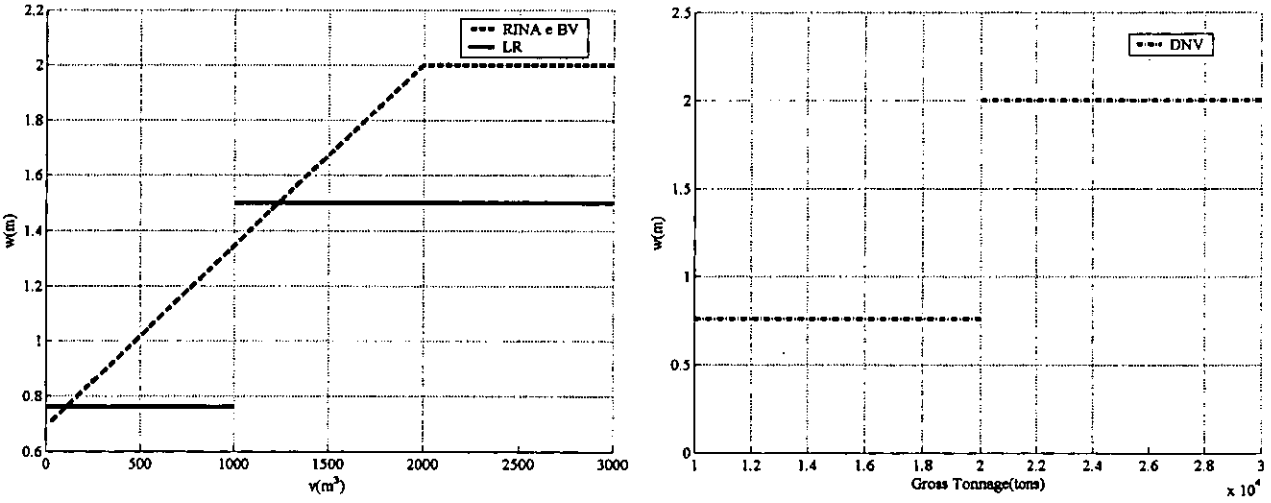


Fig. 5 – Distance "w".

The distance "h" between the fuel oil tank and the bottom shell plating is listed in *Table 3* and plotted in *Fig.6*.

Table 3 – Distance of the fuel oil tanks form the bottom

CLASSIFICATION SOCIETY	DISTANCE FROM THE BOTTOM (m)	APPLICATION
RINA e BV	h>= min(B/15; 2T/11; 2) with un minimum of 0.7 meters	v>20 m^3
Lloyd's Register	h>0.76	v<1000 m^3
	h>1.5	v>1000 m^3
DNV	h>= min(B/25; 1,5) with un minimum of 0.76 meters	v>20 m^3

3.1.2 Ballast water management

Ballast water has been recognized as a significant means of transfer harmful and pathogens species into new environments. The subsequent establishment of a reproductive population can upset the ecosystems of ports, lakes, estuaries and coastal waters.

In response to the threats posed by invasive marine species, IMO has promoted in year 2004 the International Convention for the Control and Management of Ships Ballast Water.

The environmental class notations identify the ballast water management as an issue and the related requirements are based on the content of the annex to IMO Resolution A.868 (20).

For ABS, ballast water management is a prerequisite for the environmental notation.

3.1.3 Antifouling systems

All environmental class notations take into consideration the hazard represented by antifouling systems. In general all have prohibited the use of hull anti-fouling systems containing Tributyltin (TBT).

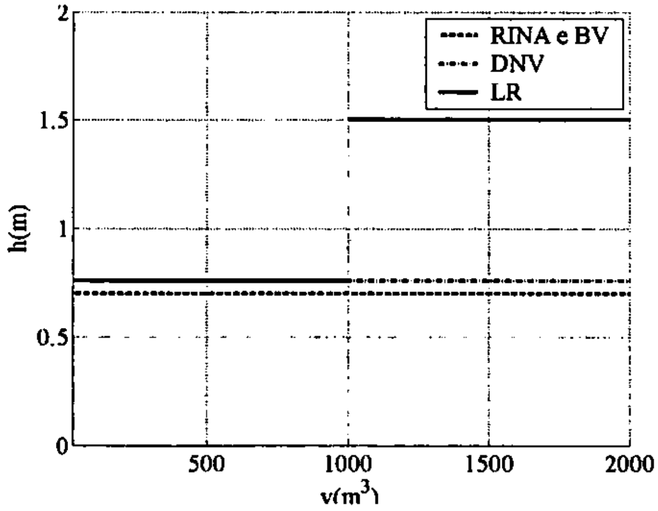


Fig. 6 - Distance 'h'.

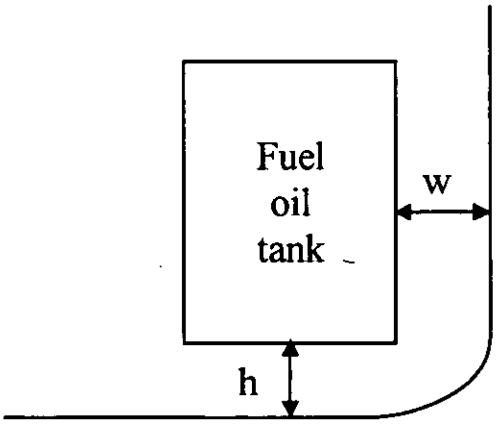


Fig. 7 – Definition of 'w' and 'h'.

3.1.4 Air pollution

Environmental class notations provide Rules to reduce air pollution. The rules, mainly based on the standards in Annex VI of MARPOL 73/78, are related to refrigerants, nitrogen oxides (NO_X), sulphur oxides (SO_X), shipboard incineration and fuel oil quality.

All environmental notations, except CLEAN DESIGN of DNV, prohibited the use of refrigerants which have a Global Warming Potential (GWP) greater than 2000, as defined by the "1987 Montreal Protocol on Substances that Deplete the Ozone layer". However, the use of HCFC can be accepted until 1 January 2020. CLEAN DESIGN notation accepted the use of natural refrigerants which have a GWP less than 1650 or Ozone Depleting Potential (ODP) = 0.

CLEAN AIR, CLEAN, ES and EP state requirements to limit emission of nitrogen oxide from engines. These requirements apply to all diesel engines whit power output of more than 130 kW. NO_X emissions shall comply with the level defined by the MARPOL NO_X-curve: maximum limits for NO_X per kWh depending on engine type.

CLEAN DESIGN class notation state more restricted limits for NO_X. NO_X emissions shall comply with 60% of the level defined by the MARPOL NO_X-curve. These limits are represented in Fig. 8.

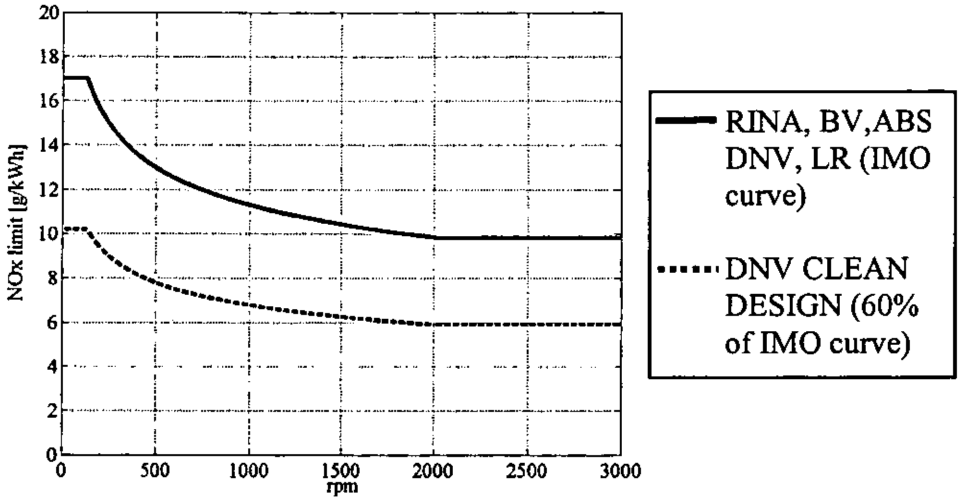


Fig. 8 – Limits for NO_X emissions for marine diesel engines.

For CLEAN AIR, CLEAN and ES the sulphur content of any fuel used on board ships should not exceed 3% by mass or the SO_X content in the exhaust gas do not exceed 12 g SO_X/kWh. For EP the maximum content of SO_X in fuel oil used on board is 3,5%. CLEAN AIR of BV accepted a maximum sulphur content fuel oil of 4,5%.

When the ship is in port or in SO_X- controlled areas, R.I.NA., BV, DNV (CLEAN) and ABS, accepted a maximum sulphur content in fuel oil of 1,5% or a maximum SO_X content in the exhaust gas of a 6 SO_X g /kWh.

CLEAN DESIGN accepted a maximum sulphur content fuel oil of 0,5% or a maximum SO_X content in the exhaust gas of a 2 g SOx/kWh, when the ship is in port or in SO_X- controlled areas.

4. Application of the Environmental Class Notation to four passenger ships

The purpose of this work is to identify feasible design solution for the RO-RO/Pax ferries and the Passenger ships that minimize the impact on the environmental during the normal operation and also in case of the accident. As a part of this job, the evaluation of the impact that the application of the rules of the environmental class notation can induce on the ship design has been assessed.

To achieve this, three existing RO-RO/Pax and a cruise ship, have been analysed and the Rules for the RINA GREEN STAR Class Notation have been applied to them. New preliminary ship designs have been produced and results compared with the existing solutions.

4.2. Ship number 1

Ship number 1 is a luxury ro-ro/passenger ferry for short sea shipping in Mediterranean waters. It is characterised by the high standard of passenger accommodation, similar to cruise ships. The following *Table 4* contains the main characteristics of the ship and *Fig. 9* represents the capacity plan of the original ship configuration. The existing ship design has been reviewed in order to obtain a more environmentally friendly ship, maintaining the original carrying capacity.

Two of the many factors that can cause environmental impact have been taken particularly into account. The first issue takes into consideration the layout of the fuel oil tanks, mainly in the double bottom and in proximity of the side. As previously identified, this conventional layout represents a danger in case of damage of the hull, because it would cause spill fuel into the sea.

The considered solution was a new fuel tanks arrangement, consistent with the requirements of the Rules of the GREEN STAR class notation. All fuel oil tanks have been arranged far away from sides and bottom, in a vertical zone, just aft the main engines compartment. The new arrangement of the tanks is shown in *Fig. 10*.

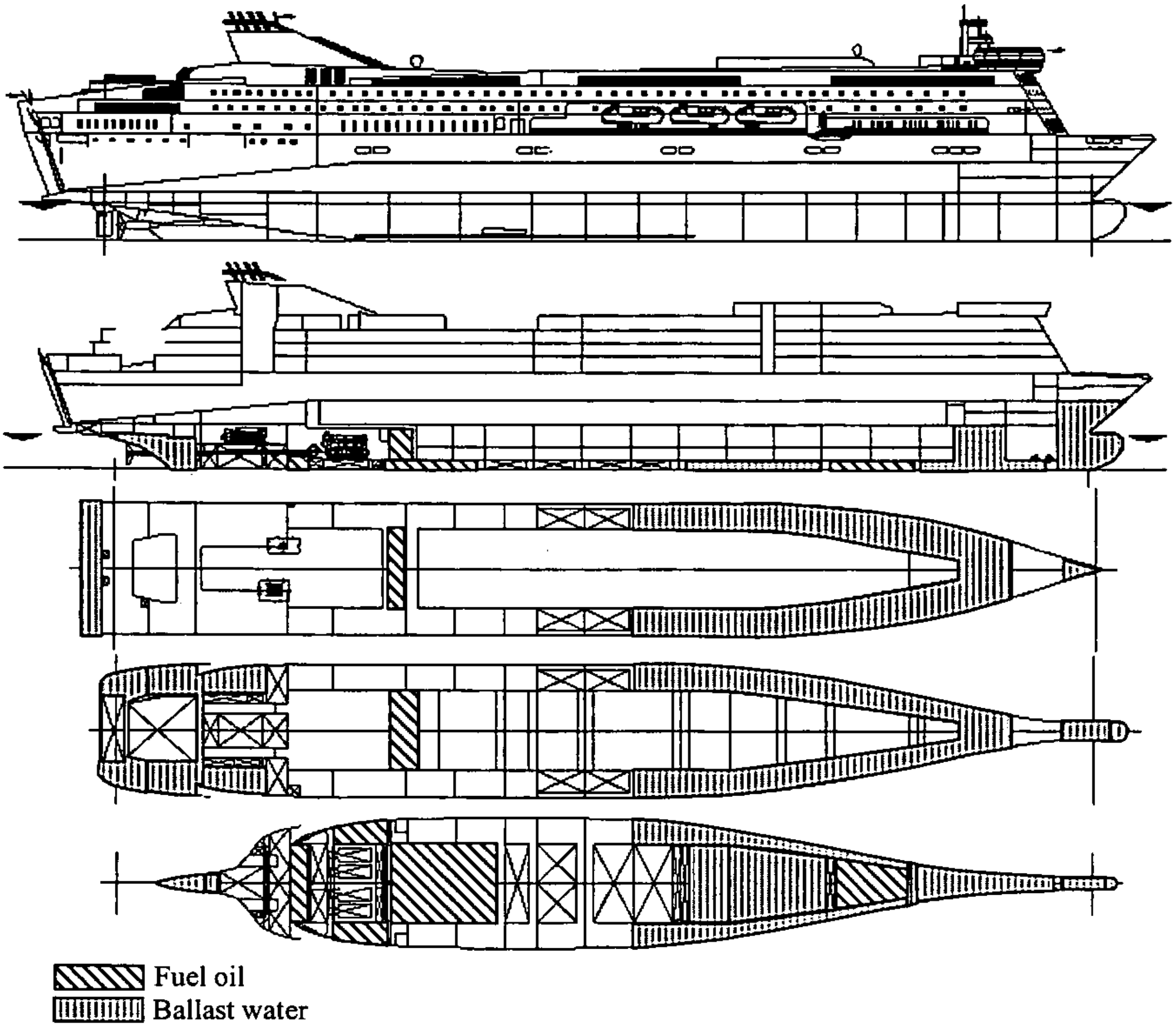


Fig. 9 – Original capacity plan layout.

Table 4 – Comparison between existing ship Excelsior and new design ship dimensions

Ship dimensions before the application of the RINA Environmental Class Notation	
L_{OA}	202.83 m
L_{BP}	176.01 m
B_{MAX}	28 m
B_{WL}	26.8 m
Draft at full load	6.65 m
Displacement at full load	21827 t
Maximum Speed	24 knots
Total Engine Power	28960 kW
Electric Power	8100 kW
Passengers	2323
Total lane metres	2700

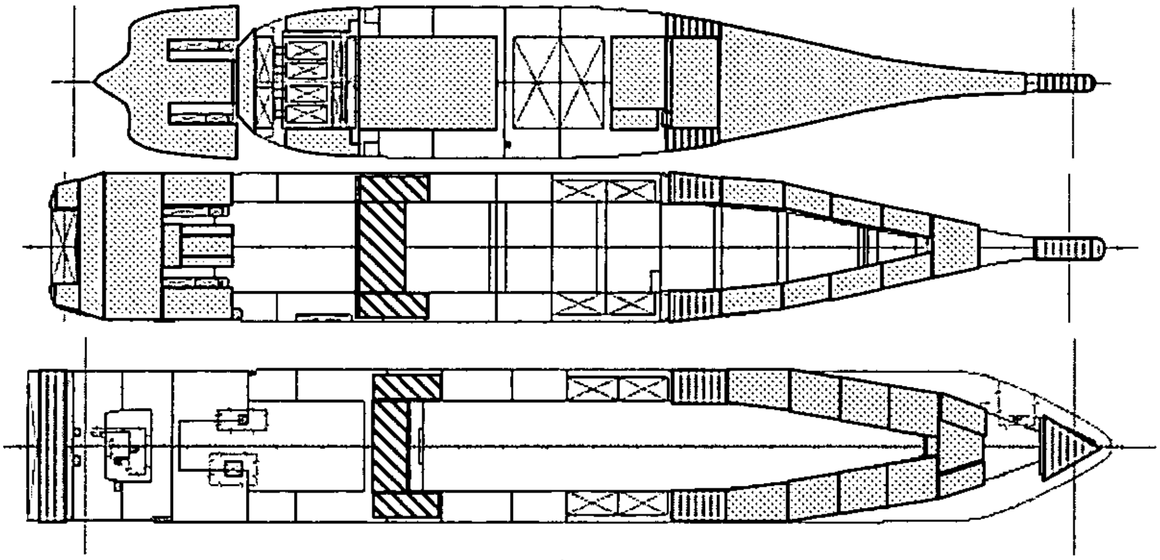
Ship dimensions after the application of the RINA Environmental Class Notation	
L_{OA}	205.36 m
L_{BP}	179.25 m
B_{MAX}	29 m
B_{WL}	27.8 m
Draft at full load	6.65 m
Displacement at full load	23296 t
Maximum Speed	23 knots
Total Engine Power	31200 kW
Electric Power	9100 kW
Passengers	2455
Total lane metres	2774 m

The second consideration concerns the layout of the ballast system with the aim to minimise the transfer of sea water.

All of the ships engaged in national and international voyages, to assure ship safety in term of stability, trim and strength, are forced to embark and disembark ballast, usually sea water. Ferries use ballast mainly to compensate for consumables and for cargo variations. In most Mediterranean routes the great amount of ballast has a seasonal variation, due to the two main cargo types shipped: trailers during winter and cars and passengers in summer. In this case becomes feasible and convenient a main seasonal fresh water ballast system supported by fore and aft peak tanks of sea water ballast, just to allow minor modifications of the trim of the ship.

This solution gives the possibility to reduce the daily ballast flow rate in order to easily comply with the new incoming rules about the management of ballast water, reducing also the dimension of the treatment plant. The arrangement of the ballast system is shown in *Fig. 10.*

Adopting these design solutions with the constraint to maintain the original cargo capacity, a small increment of the ship dimensions has become necessary, as shown in *Table 4.*



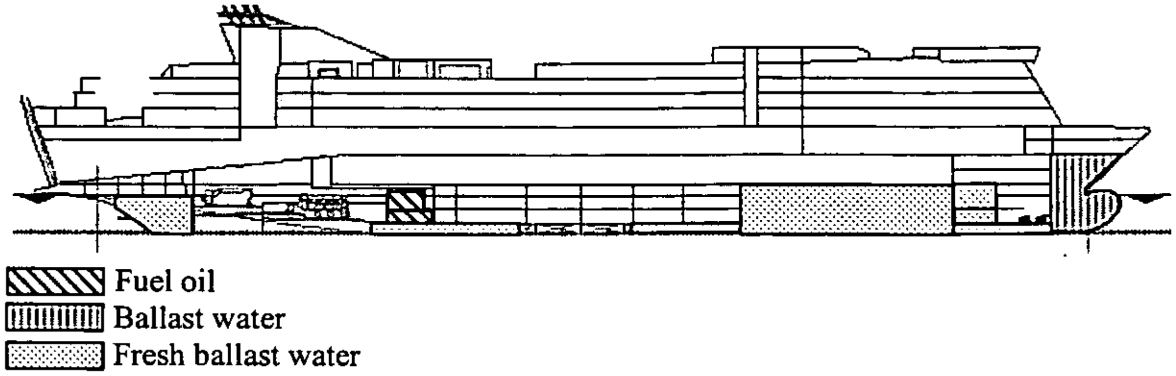


Fig. 10 – New layout of capacity plan.

4.3. Ship number 2

Ship number 2 is a ro-ro/pax ferry mainly designed to carry trailers. The main characteristics of the original ship are reported in *Table 5.* Applying the same considerations previously described, a new, more environmentally friendly, design has been produced. The main characteristics are reported in the second part of *Table 5* for comparison.

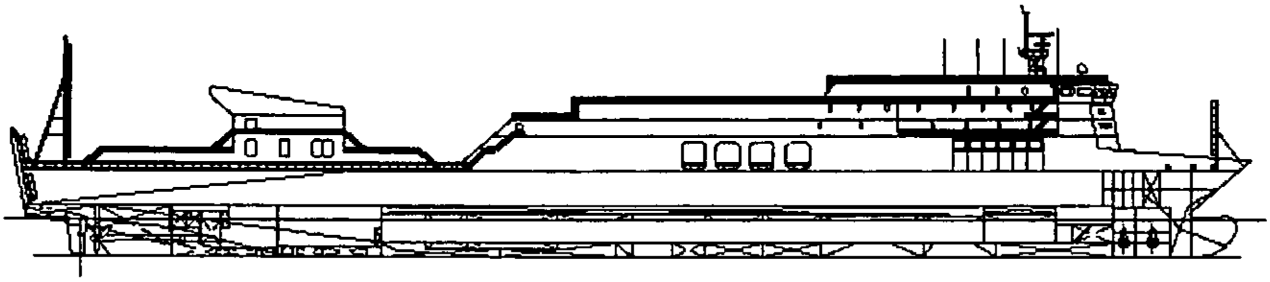


Fig. 11 - External view of ship number 2

Table 5-Ship characteristics of ship number 2

Ship dimensions before the application of the RINA Environmental Class Notation	
L_{OA}	197 m
L_{BP}	176.8 m
B_{MAX}	25 m
B_{WL}	23.6 m
Draft at full load	6.13 m
Displacement at full load	16400 t
Maximum Speed	22 knots
Total Engine Power	18900 kW
Electric Power	4548 kW
Passengers	308
Total lane metres	2266 m

Ship dimensions after the application of the RINA Environmental Class Notation	
L_{OA}	202 m
L_{BP}	181.8 m
B_{MAX}	25 m
B_{WL}	23.6 m
Draft at full load	6.13 m
Displacement at full load	15998.8 t
Maximum Speed	22 knots
Total Engine Power	18900 kW
Electric Power	4548 kW
Passengers	308
Total lane metres	2504 m

4.4. Ship number 3

Ship number 3 is a traditional Mediterranean ro-ro/pax ferry designed to assure a regular link between land and islands. Main characteristics are reported in *Table 6.* The application of the RINA

GREEN STAR, with the cargo capacity constraint, resulted in a new ship design whose final dimensions are reported in the second part of *Table 6*.

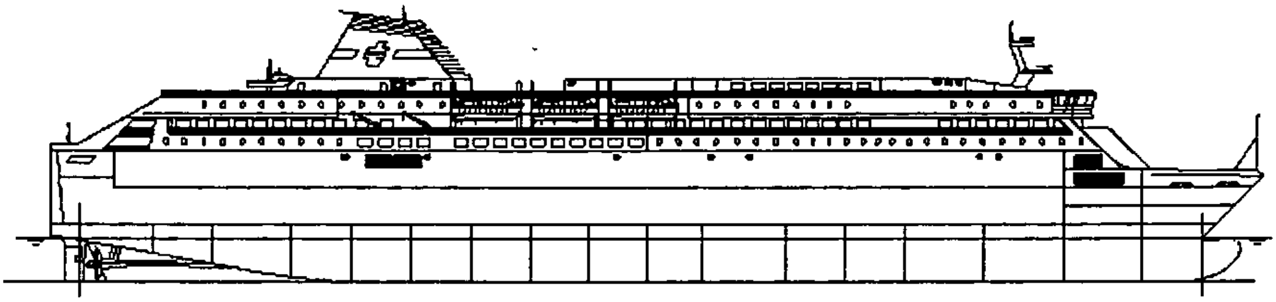


Fig. 12 - External view of ship number 3.

Table 6 - Ship number 3 characteristics.

Ship dimensions before the application of the RINA Environmental Class Notation	
L_{OA}	181.68 m
L_{BP}	166.5 m
B_{MAX}	26.8 m
Draft at full load	6.8 m
Displacement at full load	19858 t
Maximum Speed	23 knots
Total Engine Power	25200 kW
Electric Power	8310 kW
Passengers	1280
Total lane metres	2000

Ship dimensions after the application of the RINA Environmental Class Notation	
L_{OA}	186.18 m
L_{BP}	171 m
B_{MAX}	26.8m
Draft at full load	6.58 m
Displacement at full load	19707 t
Maximum Speed	23 knots
Total Engine Power	25200 kW
Electric Power	8310 kW
Passengers	2100
Total lane metres	2082 m

4.5. Ship number 4

Ship number 4 is a luxury cruise ship, the main characteristics are reported in *Table 7*. Also in this case, the application of the RINA GREEN STAR, with the cargo capacity constraint, resulted in a new ship design whose final dimensions are reported in the second part of *Table 7*.

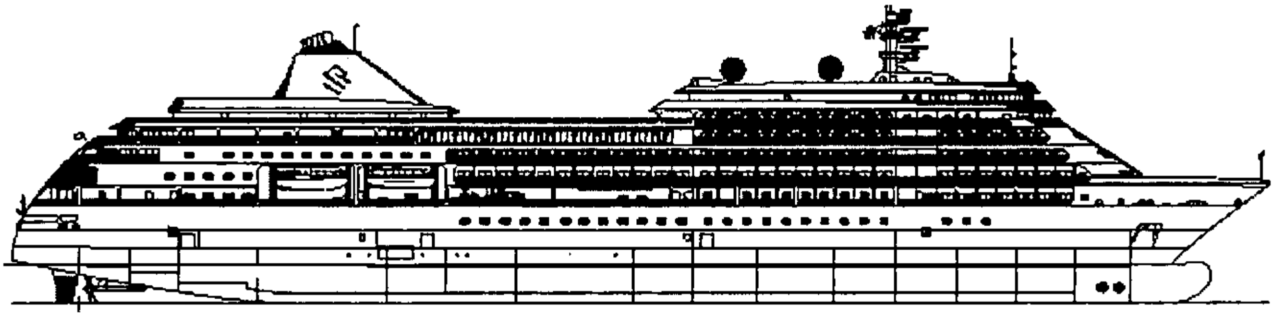


Fig. 13 – External view of Ship number 4.

Table 7 – Ship number 4 characteristics.

Ship dimensions before the application of the RINA Environmental Class Notation	
L_{OA}	186 m
L_{BP}	161.8 m
B_{MAX}	24.8 m

Ship dimensions after the application of the RINA Environmental Class Notation	
L_{OA}	192 m
L_{BP}	167.8 m
B_{MAX}	25.7 m

Draft at full load	6 m
Displacement at full load	15728 t
Maximum Speed	21 knots
Total Engine Power	15700 kW
Electric Power	7020 kW
Passengers	435
Crew	305

Draft at full load	6 m
Displacement at full load	16760 t
Maximum Speed	19 knots
Total Engine Power	14480 kW
Electric Power	8700 kW
Passengers	465
Crew	327

4.6. Results

In *Table 8* all the considered design solutions are summarised and main impacts on ship design are highlighted.

Table 8 - Design solutions and results

SHIP	SOLUTIONS TO MINIMISE THE ENVIRONMENTAL IMPACT	IMPACT ON SHIP DESIGN
RO-RO/Pax number 1 (solution 1)	1- Arrangement of the fuel oil tanks in a protected space. 2- Seasonal ballast water system 3- Diesel-electric propulsion	1- Ship lengthening of 6.48 meters 2- Increasing of the unused volume inside the double bottom.
RO-RO/Pax number 1 (solution 2)	1- Arrangement of the fuel oil tanks in a protected space. 2- Seasonal ballast water system 3- Diesel engines and generators and two Fuel Cell of 500 kW each one to provide the electric power during the stop in port.	1- Ship lengthening of 3.24 meters 2- Ship widening of 1 meter. 3- Increasing of the unused volume inside the double bottom.
RO-RO/Pax number 2	1- Arrangement of the fuel oil tanks in a protected space.	1- Ship lengthening of 5 meters 2- Increasing of the unused volume inside the double bottom. 3-Decreasing of the fuel oil tanks capacity
RO-RO/Pax number 3	1- Arrangement of the fuel oil tanks in a protected space. 2- Seasonal ballast water system 3- Diesel engines and generators that comply whit IMO NO_X and SO_X requirements.	1- Ship lengthening of 4.5 meters 2- Increasing of the unused volume inside the double bottom.
Cruise Ship	1- Arrangement of the fuel oil tanks in a protected space. 2- Ballast water treatment plant 3- Sewage treatment plant 4- Diesel engines and generators that comply whit IMO NO_X and SO_X requirements.	1- Ship lengthening of 6 meters 2- Ship widening of 0.9 meters. 3- Increasing of the unused volume inside the double bottom. 4-Increasing of the fuel oil tanks capacity.

5. Conclusions

Same design solutions to minimise the environmental impact of RO-RO/pax and cruise ships have been studied.

Also the application of the Rules of the GREEN STAR class notation to RO-RO/pax and cruise ships has been assessed for four ships.

Results of these preliminary designs show that, for a certain cargo capacity, it is feasible to obtain a more environmentally friendly ro-ro/pax with minor increments of ship size and consequently costs. Furthermore this minor increments can probably be reduced or vanish during a more detailed design phase, for example by reducing the double bottom volume.

Environmental Class Notations address the main environmental issues of shipping, contributing to a more safe and clean ship design and operation. Nevertheless the requirements contain, in author's opinion, two important margins of improvement: the consideration of the 'energetic' issue, presently not addressed, and the requirement of an improving strategy that thrust not only operators but also ship designer and shipbuilder to a continue environmental improvements during the years.

The application of these concepts could allow a step foreword in a more competitive and cleaner short sea shipping.

6. Acknowledgments

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SUSTAINABLE DESIGN METHOD FOR MARINE SYSTEMS BY ADDRESSING EXTERNAL AND INTERNAL COSTS IN THE EVALUATION OF CONCEPTUAL DESIGNS

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The growing attention towards sustainability opens the question how to design a sustainable marine system. This paper presents an attempt to do so.

The idea is to include the internal and external costs in the evaluation of conceptual designs by means of an integrated design evaluation tool.

Maritime operations do have an impact on the environment and the well being of people. By means of Life Cycle Analysis and impact pathway methodology the effects determining the degree of sustainability associated with an operational marine system are quantified. A distinction is made between effects on public health, ecosystems and economy.

These effects are valued as internal and external damage costs. External costs are costs imposed to a party, as a result of an activity performed by other parties. In contradiction to internal costs, external costs are usually not addressed to the originator of the activity. With the current knowledge only a part of the effects can be quantified.

After assessing damage costs, improvements can be suggested. An improvement can result in a win-win situation, wherein benefits are both external and internal. In a situation where benefits are primarily external the improvement will probably not be realised without the presence of relevant legislation or economical incentives, such as the green award system.

As an example, the design evaluation tool is applied on a Floating Production Storage and Offloading unit (FPSO) and shuttle tanker. Damage costs equal 4 – 12 % of total project costs (NPV lifetime calculation). Fifty % is associated with heavy fuel oil combustion and 24 % with VOC emission.

For example the reduction of VOC emission and improvement of energy efficiency decrease external costs with 10 % in a win-win situation. In most cases a decrease of external costs does not outweigh the costs of abatement.

SUSTAINABILITY, SHIPPING AND LEGISLATION, SEVERAL SUGGESTIONS IN INTEGRATING THESE ASPECTS BY MEANS OF AN ECONOMICAL APPROACH

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By **Ir. H. van Schuppen,** Delft University of Technology, The Netherlands

Sustainability is not always addressed properly in the maritime business world, a world mainly driven by cash flow and as such a notorious short term thinking environment. Instead, sustainability requires a particularly long term thinking attitude.

As known, sustainability is often described by the three P's, Planet, People and Profit. A balanced approach of the three P's without jeopardizing the future of the coming generations requires action in the maritime world.

Environment, safety and profit are often 3 different worlds each with its own language. This paper tries to introduce one language, the language of money, in order to integrate these worlds and to fit them in society. The social costs of shipping, environmental aspects and safety, are estimated. This approach is chosen to get sustainability on the agenda of ship owners, designers and society.

Current legislative measures are not encouraging enough to create real sustainable improvements. So, additional legislative measures will be necessary in the end.

International shore based developments are talking about emission rights besides process requirements like maximum sulphur contents of fuel. Marine shipping is not a part of the Kyoto agreement, but an exercise in applying the planned emission right system on the maritime world is interesting in order to get an idea about the possible and may be likely future developments.

All together, in contradiction to internal costs, external costs are usually not addressed to the originator of the activity. This paper gives an idea about the consequences if they are addressed properly.

For illustration purposes, a case study of a Floating Production Storage and Offloading unit (FPSO) has been performed. External costs are estimated as 4 – 12 % of total project costs. (NPV lifetime calculation)

DESIGN AND CONSTRUCTION OF MARINE VEHICLES FOR ENVIRONMENTAL SUSTAINABILITY: ADOPTION AND APPLICATION OF PRINCIPALS AND TECHNIQUES BY THE INDUSTRY

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The work of designing and constructing marine and offshore vehicles is becoming more onerous and complex year on year. Rules and regulations governing such vehicles are being amended and enhanced with growing frequency. Certain areas have particularly been targeted, and hence the corresponding regulations tightened, for example: emissions, anti-fouling hull coatings and the carriage/treatment of ballast water etc.

This paper looks at the way a variety marine vehicle builders address both environmental and sustainability issues. A cross section of the industry has been consulted, ranging from builders of pleasure craft to those of large merchant and complex naval ships and offshore structures. To contrast the approach of the marine and offshore industry their views are compared with those of a company in the nuclear energy industry. The results of the survey are presented and discussed. These results are compared with the focus of current marine and offshore vehicle industry research.

With regards to research, over recent years a number of techniques and methodologies have been developed to help ensure that when a marine or offshore vehicle is designed it meets environmental and sustainability needs. A number of techniques have been previously presented and discussed at this forum by the authors. Such techniques are often lauded as been the panacea to help ensure that the sea survives and remains a flourishing eco environment. This paper attempts to suggest why many marine and offshore vehicle builders do not see such techniques and tools in the same light as those responsible for there development and promotion.

1. Introduction

A previous paper by two of the authors [1] presented to this forum when it last met highlighted and discussed various design drivers and evaluation methodologies relating to the design of environmentally sustainable marine vehicles. These were proposed as the potential foundation of a designer's "applications toolbox" in support of the formulation of environmentally sustainable designs. An approach was also described as to how these often conflicting design drivers, and hence the diverse and complex but robust analysis techniques, could be brought together as a coherent whole for practical application by industry – initially at the concept design stage.

When this work was published, over two years ago, it was felt that there was rarely a coherent strategy to the assessment of environmental drivers during concept design. Therefore further research has been undertaken in an attempt to quantify what, if any, work is undertaken into whole life costs and environmental impact assessment during the design process. This paper presents some of the findings from this research into the current state of activity regarding these within industry.

2. Legalisation and Standards

One of the major problems with legal regulations applicable to industry is that they are continually changing due to external pressures, such as public interest and developing research. An Environmental Scientist from Company A, contacted as part of this research exercise, explains "A lot of environmental legislation is new, and many of the 'old school' developers and engineers still try and do things the old way - this is changing, even in the few years [I have] been in the game." Hence, this means that project managers etc. must continually update their working practices to stay ahead of the regulations in order to maintain the competitiveness of their business units and the projects on which they are engaged.

Standards such as ISO 14000 and ISO 9000 may be seen as an organisation's attempt to label itself for the benefit of publicity. But, the very incorporation of the methods involved in certification can prove to be a step in the right direction for many companies; raising employees awareness and creating a stable basis for continual improvement. More studies need to be made in to the effectiveness of these types of standards and companies' abilities to deal with the inherent increased requirement for information management and record keeping.

One large civil engineering company's environmental policy includes a promise to "Monitor its own environmental performance for compliance with regulations and strive to do better than they require, wherever possible and appropriate." [2]. Currently, this seems to be an increasingly popular approach from companies. This could be due to companies wanting to stay ahead of the ever-tightening legislation and so allowing them to get a head start on potential future regulations. However, perhaps for a large number of companies such an approach is due to the fact that legislation is merely used as guidelines, with each industry having the scope to put more stringent company policy in place within its own specialist area. There again such an environmental policy may just be a cynical marketing ploy, hoping to attract business and keep the 'greens' away.

It seems that when legislation is initially implemented it takes time for the education of the individuals to catch up. This often means that a great deal of time and energy are wasted 'passing the buck' or avoiding the issue. The increase in the amount of time required to resolve an issue could cause knock-on delays to a project, not to mention a great deal of frustration within the project team. It is this frustration which leads the human nature to look for short-cuts, or potentially 'turning a blind eye' to certain aspects of the project that may be considered an uneconomic use of time.

Companies, which operate under the approach discussed above, may find that they have to change. An Environmental Scientist working for a consultancy (Company A), which is often called in by companies to assess the environmental performance of various projects, stated "More legislation generally means more work for us. The environmental sector is expanding, and has been for the last decade. There isn't really any room for people to be devious, much of the legislation coming through comes from European Directives, so the penalties are pretty tight and the United Kingdom (UK) government is accountable".

Another company (Company B) involved in civil engineering projects stated "Engineers still feel that the environment is something that gets in the way of well poured concrete!" and went on to say that project managers "...have a constant struggle to maintain focus on environmental outcomes. Contract penalties or restrictions go a long way to focussing minds." The response to a similar question from a shipyard (Company C) was that "there is no corporate defence against breaches of environmental legislation [and] you can be held personally responsible for non-compliance".

As Stoyell et al. [3] discovered five years ago "...regulation is rated by the majority as the key driver which suggests that the command and control approach is still the more influential than proactive drivers, such as gaining accreditation to an Environmental Management Standard or pressure exerted from customers and competitors". Penalties, as a Quality / Environmental Manager from Company C described, are the harsh reality of project management today; they cannot be avoided, but with the team working together, they can be adapted to. All project specifications, including regulatory requirements and company policies, need to be communicated throughout the project team; from project managers to designers, stakeholders and external consultancies.

3. Communication

It is important to communicate with all the parties involved in and affected by a project. As Fraser and Zarkada-Fraser [4] noted "...sustainable success rests... with a systematic consideration of the needs and goals of all key stakeholders." A greater knowledge of the stakeholders produces better management of stakeholder concerns and the amount and quality of communication that is necessary. Akintoye [cited in 5] noted the importance of communication and stakeholder awareness from the initial quotation stage "Accurate estimations need accurate project information in terms of the quality of information and information flow, availability and supply of resources, and the expertise of the consultants involved".

BNFL's respect for its employees and other stakeholders is enunciated within its Environment and Safety policy [6]; "Achieving excellence in all aspects of environmental performance relies particularly on our people. Through open communications and training our workforce can become more environmentally conscious."

There are countless methods of communication, and it is important to use whatever methods are necessary to ensure incorporation of environmental measures, and of course, successful project completion. Company D explains "...communication is a lot more than formal written communications to successful communication. In addition to [written communication]... there are a range of project team meetings, work planning meetings, modification meetings, contractor Environmental, Health and Safety (EH&S) meetings etc. which aim to ensure relevant information (including environmental information) is communicated to project teams by functional specialists and is communicated within the team."

The remainder of this section aims to discover how environmental information is disseminated amongst the project team in real industry environments.

3.1. Feedback and information Sharing

It is imperative that communication works both ways; to get information to the project team and to receive feedback on project and organisational progress. At BNFL, feedback is encouraged from their workforce, and a system of 'Operational Experience Feedback (OEF)' exists. As BNFL [6] explains; "This is internationally acknowledged as an effective means of improving human and organisational performance. It works by learning from experiences and good ideas of other companies and organisations nationally and internationally."

Not only must project managers ensure a consistent dialogue between project team members and stakeholders but often communication is required externally to obtain necessary information. This can often be a controversial conflict between the need for environmental sustainability and the need to maintain company competitiveness.

3.2. Communication of Environmental Issues to the Design Team

Usually, the environmental issues of the project are included in the design specification, which the designers work from. As Company D explains, the formal method of communicating project requirements is through functional specifications. It is also notes that informal communication is equally important within the design team, along with cross-function communication "...between the design team and environmental specialists." This ensures that relevant environmental technicalities are dealt with. This need for competence may also "...necessitate specific training on the environmental issues for the project".

The research carried out by Stoyell et al. [3] identified that companies were using various communicational methods such as reports, meetings, memos, emails, informal verbal communication etc. It was noted that "The wide range of methods may lead to inefficient communication... [need to have] a more structured system using fewer methods so information exchange becomes more efficient and traceable".

Stoyell et al. [3] notes that "Design engineers are not environmental experts and therefore decisions involving environmental issues should involve a consensus of opinion, preferably from a multi-disciplined team". It was found that organisations preferred to use group discussion based decision-making rather than using software or paper based methods to make these decisions. For such a communications methodology to work demands that good communication within the design team and throughout the functional project team members. According to Stoyell et al. [3] this may be hard to achieve.

An EH&S Manager from Company D sums up the process by concluding that; "...in the end successful communications on any topic come down to personal relationships within project teams and between project teams and the relevant environmental managers/champions." This is closely related to the structure and culture of the company / project organisation.

3.3. Organisational Structure and Culture

All too often, organisations consider environmental sustainability to be the obligation of a specific department; as Stoyell et al. [3] found "...most respondents feel that environmental design should be the responsibility of the designers and that it should be integrated with the design process." This is all very well, if the department commands the respect that this responsibility requires, but all too often communication breakdowns occur between departments if the reasoning behind the decisions that have to be taken is not transparent.

It is essential that environmental concern is filtered throughout the organisation. Kjaerheim [7] noted that there can be complications if an organisation delegates environmental issues to only to certain individuals. These employees become educated and enthusiastic about environmental sustainability, but when they leave the company, for whatever reason, often the enthusiasm is not passed on throughout the company, and the enthusiasm and dedication to communicating environmental sustainability throughout the company can cease.

The key is to involve everyone. The main effort of Company D's behavioural observation programme is to encourage the necessary culture for good performance. This entails firstly "...a team training programme on the importance of people's behaviour in achieving safety and environmental protection," and secondly, a volunteer observer system, whereby volunteers "...carry out a number of observations on their colleagues work to identify areas for improvement and praise."

3.4. Project Team Education

Some companies turn to external instructors in order to raise environmental awareness and develop management techniques. Kjaerheim [7] describes the techniques he uses to educate companies, discussing with them "...how to define Environmental Performance Indicators (EPIs), which parameters to use, how to measure them, how to calculate them, how to present information, who needs the information and so on". This is a good option for companies who are taking the first steps towards ensuring that their company is operating in an environmentally sustainable way, and hence need to develop the tools, skills and methods to ensure that good performance is achieved and sustained. Kjaerheim [7] admits that his methods probably wouldn't create a sustainable society, but they do produce quantifiable results, raise awareness and change attitudes; which is 'a step in the right direction'.

At Company D, new recruits undertake general environmental training as part of the induction programme and "...those undertaking environmentally significant work on site..." go through more general environmental awareness courses. On top of this, Company D provides "...job specific environmental training for those undertaking specific roles." This stepped approach to environmental education ensures that project team members are trained to the level necessary to carry out their role, and ensures the company does not waste time and money on vague training for all, which can be too much for some members and not detailed enough for those in crucial roles. As an example, a typical project leader's training at Company D would cover within this system include:

- "Environmental leadership, standards and expectations
- Overview of key legislation, consents and authorisations
- Overview of environmental management systems
- Sustainability and significant environmental issues in project management
- Environmental risk assessment
- Individual environmental accountabilities

A project supervisor would probably cover a similar range of topics but focusing on environmental aspects in control and supervision and environmental risk assessment."

Kjaerheim [7] noted that with the right education employees develop and, more importantly, maintain an informed, responsible approach to environmental sustainability. He emphasizes that "Those that had 'seen the light' [through the education process described] would continue pollution prevention work." Equally important, however, is commitment from top-line management.

3.5. Customer Involvement

Along with the internal company project team, the customer must be involved in the environmental decision-making processes. As Stoyell et al. [3] point out such involvement should ensure project specifications are achievable and that environmental impact reduction is optimised in relation to the project investment. It has been found that within the shipbuilding industry that despite company policy and industry regulations, it is often the client who will hold the power regarding the environmental sustainability assessment procedures and actions; it is the client who ultimately controls the design budget.

A typical approach, especially within the consultancy area, is to leave it to the client to research the life cycle assessments. For example, at Company E, a construction engineering consultancy, most of their projects are owned by an external client and "...it is usually the client who will commission specific site surveys and who will define exact legal and other requirements." Not surprisingly, once legal responsibilities are incorporated into the design, the decision as to how far to take environmental incorporation comes down to a balance between environmental issues and finance "...ultimately it is the client's decision whether or not to spend their money on enhancements that are not requirements from a government or other outside body."

As mentioned previously, where the client holds significant purchasing power, Environmental Product Declarations (EPDs) "...can be a powerful tool for developing markets and companies to show a potential buyer the environmental benefits of their particular product" [7]. These are more beneficial for projects which end in the sale of a product such as a marine vehicle. ABB [8] explains that "These declarations describe the salient environmental aspects and impacts of a product line, viewed over its complete life cycle, including disposal and recyclability, and set relevant environmental goals and improvement programs. Declarations are based on Life Cycle Assessment (LCA) studies, created according to the international standard ISO 14025, using a new generation software tool developed by ABB. These declarations are being integrated into the strategic plans of ABB's business areas."

The LCA often assesses the "downstream" elements which are of customer concern, such as the through-life environmental issues, but it is also important to consider the "upstream" environmental sustainability, such as the products and services provided by the project suppliers.

3.6. Supplier Commitment

Committing suppliers to environmental sustainability ensures, as far as is possible for that project, upstream environmental sustainability. This is essential to the credit of the project; there is no point carrying out a project which claims to be environmentally sustainable if the supplied elements of it are not.

In this sense, the suppliers are a crucial element to be considered when carrying out an LCA on a project. Good communication between project management and the supplier is essential to ensure transparency and upstream environmental acceptability. One solution to the complications of environmental accountabilities is to involve a specialist consultancy.

Whether the environmental assessment is being carried out in-house or by a consultancy, there is a need for a structured decision-making process to ensure accountability for and communication of the decisions made.

3.7. Summary

The very concept of communication involves people, who are often complicated and chaotic to manage; nothing is purely 'black and white'. A good, solid corporate culture goes a long way to instilling the corporate values within the team, but ultimately it is up to the project manager to motivate individuals and make project communication work. Good communication with external stakeholders is also essential to overcome the eternal trade-off between environmental responsibility and customer finance.

4. Shipbuilding and Environmental Sustainability

4.1. Environmental Concerns

Rather than start at the beginning of a marine vehicle's life let us start at its end. The reason for doing so is that it appears that it is in disposal of marine vehicles that there is the most outspoken criticism, even if a lot of it is misguided.

Greenpeace, as would be excepted, is highly concerned about the end-of-life phase of marine vehicles [9]. Increasingly countries are taking action against subjecting their people to the toxic substances that it is claimed these ships contain. With reference to the recent "ghost-ship" events in the North East of England, an ex-Environment Agency employee, expressed to the authors the opinion that "...the case was blown out of all proportion by environmental groups... the PCBs they were ranting about were a minor contaminant in the rubber door seals and were completely safe to the best of my knowledge".

Greenpeace [9] tells of the international problems concerning the end-of-life phase of ships; the braking of 'toxic ships'. They also urge the International Maritime Organisation (IMO) to take action in preventing pollution and adverse health effects on workers during the process of shipbreaking. The IMO, on the other hand do take the subject seriously, but they feel that there is little they can do to improve the procedure, since, as the Secretary-General states in his opening speech [10] "Ship recycling is the most environmentally friendly way of disposing of ships."

To some extent, it can be seen that Greenpeace are blowing the situation out of proportion. But cost and regulations are forcing ship owners to dispose of ships in countries which do not have the necessary technology, equipment or finance to carry out the work in an environmentally sustainable way. This should be a concern for the IMO. Ship-breaking should be brought back to financially stable countries and dealt with in the correct manner.

As can be read in his speech the Secretary-General of the IMO [10] encourages governmental consideration of ship-breaking facilities, and invites ideas from the industry to help combat inefficient recycling, but fails to suggest any solutions. In all fairness, offering solutions to this area is merely treating the symptoms; the main problem lies in the original design of the ship and how it is used during its life-cycle.

However, it is clear from this year's press releases from the "CQD Journal for the Maritime Environment Industry" [11] that the main environmental focus within the industry this year has not been on the problems of ship-breaking but on ballast water and its ability to introduce unwanted 'nuisance species' to foreign waters, together with the concerns of fuel oil being leaked or spilled into the sea.

Oil spills are environmental disasters and attract worldwide media coverage, and as Leemans [12] notes "Improvements in the environmental performance of ships are usually triggered by major accidents and ecological disasters... Improvements are primarily focused on reducing the risk of maritime disasters and not on prevention of operational discharges." He goes on to explain that this usually either delays improvements to other, more relevant areas, or limits improvements to the particular issues identified in the disaster. As Secretary-General of the IMO [10] mentioned in his speech "...the shipping industry still has some way to go to reduce its contribution to air pollution.". This is a day-to-day issue, and causes much more environmental damage overall, which is why focus on making tankers 'leak-proof' and 'disaster-proof' delays the progress of making them more efficient during general operation.

4.2. Quality, Health & Safety and Environmental Policy

The authors research suggests that Quality, Health & Safety and Environmental (QHS&E) Departments of shipbuilding organisations tend to be more concerned with environmental sustainability within the workplace, rather than the environmental sustainability of the products. This approach is reflected in the quality, safety and environment statement of Cascade General, where the quality of the product, rather than any environmental concerns, prevails. The company states:

> "We believe in meeting or exceeding quality standards as required by project plans and specifications for the work we perform. We seek continuous improvement through systematically identifying and eliminating the cause of errors.
> Cascade General is committed to providing a safe and environmentally responsible workplace. It is the shared responsibility of each and every employee to make sure that job safety and environmental responsibility is a priority that is backed up with deeds, not just words." [13]

Bath Iron Works (BIW) in the USA are, according to them, "premier designers and builders of complex, technologically advanced naval ships." Their EH&S Policy [14] states that: "We are committed to:

- Recognize and prevent workplace hazards and pollution;
- Involve our employees and community to create a safe workplace and protect the environment;
- Comply with Environmental, Health & Safety laws, regulations and other commitments; and
- Periodically set and review objectives for continuously improving our processes to reduce illness, injuries, and prevent pollution."

The above BIW statement demonstrates the problem of grouping Quality, Health & Safety (QH&S) and the Environment under one policy; one or other tends to get overshadowed by the stronger elements. In most cases within the shipbuilding industry, the Health and Safety of the workers is paramount. Also, the responsibility of environmental issues in ship design is often passed directly to the design team, rather than including it in any company policy, other than committing to legislation.

Company G informed the authors that "we have an Environment policy within the company which we must adhere to and find it has now become part of our everyday pattern of work for our employees". This is a similar approach to the other industries in this study; the company policy is emanated throughout the organisation, through all activities. Company G also stated that many military and commercial "contracts have a very stringent environmental policy enclosed with their specifications... [organisations] have their own inspectors on site to implement their policy." This takes all onuses off the designers, leaving it to the client company to deal with their own environmental specifications.

It has been found that often organisational and vessel safety is filed under environmental issues. With respect to building ships to better withstand disasters such as sinking and holing, it could be argued that a ship spilling fuel is a safety issue; more to do with navigational, piloting or technical failure. In general, it appears that marine vehicles are designed in many respects to be environmentally safe, rather that environmentally friendly.

The environmental focus should be on the design of an operationally environmentally friendly ship, not on a ship that is environmentally safe if it should suffer damage. The safety integrity of a vessel should be something that is basic function of design. It should not be a function to broadcast as the environmental credentials of the vessel.

4.3. Legislation

Leemans [12] reports that "Current legislation, based primarily on the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), implemented with the backing of the IMO, have proven to be insufficient to stimulate a 'green revolution' in the shipping-sector." The MARPOL Convention focuses primarily on ship casualties and the risks of pollution through the damage of oil tankers [15], and came about due to the Torrey Canyon disaster in 1967, with Annexes added to incorporate other forms of pollution from ships. He also identifies that MARPOL is not the best way to improve environmental sustainability in shipbuilding because of difficulties attaining data, the delays caused in getting ratification and the resulting legislation being too vague to make an effective difference.

In the USA shipbuilders have to comply with at least three sets of environmental regulation:

- IMO regulations
- U.S. Environmental Protection Agency (EPA) regulations
- Specific port regulations which may be in excess of any other standard.[16]

The Maritime and Coastguard Agency (MCA) is the main governmental body in the UK marine industry. Their environmental quality statement is as follows:

> "The Maritime and Coastguard Agency is actively involved in the development, implementation and enforcement of maritime environmental policy. One of the major responsibilities of the agency's Environmental Quality Branch is the development of UK legislation, policy and guidance relating to the marine environment. Additionally the Branch is involved in the production of EU and international initiatives and their transposition into UK law. The overall aim of this work is to promote clean and safe seas through environmentally sustainable shipping." [17]

The concerns which the MCA are involved with at the moment include "ballast water, oil tagging, port waste reception facilities, sewage, prevention of oil pollution, marine litter, ship recycling, air pollution and anti-fouling/TBT" [17]. But the viewpoint of Company H is that the MCA regulations are mainly concerned with the health and safety of the crew, passengers and others working on the vessel. Covering such things as the use of material, for example, restricting the use of PVC as toxic fumes are produced when it burns and prohibiting the use of asbestos.

The MCA regulations have no requirement that the ship itself must undertake a full LCA during the design phase; the closest regulations to an LCA are regarding the design of passenger vessels, which, yet again, focuses mainly on human safety.

There is so much focus on the action of building the ship that the ship itself is often not considered from an environmental viewpoint. Current legislation on factory machinery, such as those regarding exhaust emissions, are adhered to at Company H, but with regard to building the marine vehicle they stated that "...they tend not to specify more stringent requirements where this would increase the cost significantly and hence harm our competitiveness".

When enquiring about the use ISO14001 and ISO9001 and their use within the ship building industry, a mixed response was received. Company C considers ISO environmental and quality standards to be a positive attribute at their shipyard operations, Company C being accredited to both ISO14001 and ISO9001. Their response stated "the idea of systems and procedures is to reduce human error, achieve consistency and eliminate quality [and/or] environmental failure. Any method that does that is worth considering". Company C were in stark contrast to Company I whose response was controversially contradictory "ISO 14001: that is no concern to us. If a rule or law is current and valid and required, we design to it. If it is not, then we don't. Regardless whether a customer quotes legislation from one industry at us or not. If it is not in current IMO maritime law, we don't include it into the design, unless the customer wants it, in which case he pays for it".

The response from Company G with regard to ISO14001 and ISO9001 was interesting. They stated "Initially we thought they were a hindrance but now we have had them in place for some time we find them to be to our advantage as more and more of our customers are asking our environment policy before placing orders." Despite this interest from their customers, there is no evidence to suggest EPDs are widely produced for ships. This is probably also due to the fact that ships are designed to order, so there is no open market for competition between companies; this largely means that they do no more than the client requests in terms of incorporating environmental issues. As Carraro and Leveque [cited in 18] pointed out in reference to the ISO 14000 standardisation series; "the costs of developing, documenting, and certifying Environmental Management systems (EMSs) may discourage many small and medium-sized companies from seeking certification." This is appears to be the case within the ship design industry.

Many builders use the excuse that designing for future regulation costs too much and is not required, but as Boylston [16] discovered; "While the economics of a ship can be impacted designing for future requirements that may be coming... the construction cost does not seem to have been adversely affected".

It seems that it takes legislation in the marine vehicle industry to convince ship design houses to produce environmentally friendly ships rather than mere advisory regulations. As Company I retorts; "Environmental sustainability. Not important what so ever... if the customer wants it, he pays for it. Unless it becomes IMO law to do so.".

4.4. Ship Designers

Kjaerheim [7] states that "Eco-design is about designing products that are easy to recycle... It is now widely accepted that consideration of waste management must be an integral part of the design process." But is it widely accepted within the shipbuilding industry?

Company J confessed; "We do not have any formal procedures for LCA or formally analyse the environmental sustainability of the design or processes involved." This is largely the case for small companies and designers of pleasure craft. In larger companies, as Company I informs; "[customers] rarely have their own in-house expertise; it is relied upon the designer to provide the solution". When this concerns environmental issues, the customer will generally not want to pay extra for any efforts over and above the legal requirement, so that is often how far the solutions go.

However, the larger and more important the client, the more seriously the process of environmental assessment is taken. For example, at Company H "Life cycle assessments are made at the early stage of a design, on naval vessels this is done in-house in co-operation with the [client] who have a significant experience and input into this aspect"

Stoyell et al [3] discovered that "...the design engineers would like to take responsibility for the reduction of environmental impact as opposed to taking advice from the environmental personnel in isolation of the design team." But, it seems that in the ship design sector, there are not the facilities to carry out the assessment tasks in a separate department, and the designers are often trapped behind the financial limits of the customer. This is why some companies often turn to consultancies.

Consultants, informs Company G, are used at our shipyard; "Any Life-Cycle Assessments are carried out externally by a consultancy." And also at Company I "If we do require something very special and is beyond our knowledge or facilities, we may then go to a specialist consultant."

Designers of, usually privately owned, pleasure craft still consider the main environmental impact of their products to be during the build stage, rather than in the use or disposal stages and that they have little responsibility for such things. Company J which is involved in very large pleasure craft design stated "yacht builders [as opposed to designers] are probably more likely to have to deal with environmental issues because of the direct nature of their use of different materials". Could it be that this lax approach of treating ships merely as sales items which is holding back the through-life assessment within parts of the marine industry?

4.5. Customers

When asked about customers, Company I responded "most customers only care about [two] things, the speed and the price. The main problem is that the buyer (owner) is generally not the operator. Therefore the buyer wants it as cheap as possible... the buyer will only get what is current IMO law in respect of environmental issues".

It depends on the experience and status of the customer as to how important environmental concerns are to the design. For example, the military vessels built at Company H have the benefits of the "experience gathered from [the clients] world-wide operations and general government requirements"; they even have their own research programme for anti-fouling paints, and prescribe the results for use on their vessels. At Company I however, a design and build company dealing with small marine vehicles, reported "...some customers require low wash vessels or low external noise. These are the exception rather than the rule". The problems of small vessel wash and its effect on the environment is discussed by Hotchkiss et al. [19]. There certainly appears to be a distinct need to educate certain ship design houses in ways of incorporating environmental sustainability issues in their work.

4.6. Financial Concerns

As has been shown, the main reason more environmental consideration is not taken during the design stage of ships is the cost of implementing the assessment procedure and the necessary training.

It is possible that when considering the through-life assessment of the vessel it should be investigated if the vessel can actually financially support the effort to exceed future legislation. For example, Boylston [16] points out that "...the decision process has to be tempered with the fact that

TOTE [Totem Ocean Trailer Express] will operate but two vessels... To take the ships out of service for modification, to comply with some future regulation, would certainly cost more than the modification itself." So "...while the natural reaction in design is to comply with current regulations, an objective analysis of future suspected regulation may bring operating advantages that would not have been considered.".

But since, as pointed out by Company I, the designer's customer is often not the operator, therefore these financial benefits would not be delivered early enough in the vessel's life cycle to benefit them. Hence they would prefer to pay out less initially and sell the vessel on at a competitive price; thus ensuring sales, and avoiding the responsibility thereafter. This is not the case with TOTE where they are both owner and operator.

4.7. Discussion

Having issued numerous requests for information from shipbuilding companies, and received little response (around 15%), it can be only assume that the situation is the same across the industry. There appears to be very few ship builders and designers who consider the through-life environmental impacts of the marine vehicles they design.

As mentioned previously, the authors strongly believe that safety and environmental issues are separate concerns and should be treated as such within the design phase. Environmental considerations within the design phase should also cover through-life concerns such as operational and end-of-life issues which can affect the macro environment, rather than, say, the consequence of damage (as required by current legislation) which only affects the micro environment.

5. Conclusion

One company's explanation for the lack of environmental sustainability assessments was "the relatively small number of yachts built per year at this level makes such a process somewhat trivial compared to say the automotive or house-building industries which are orders of magnitude greater in terms of output compared to our industry". Company J continued "There is no statutory requirement that we are aware of, either on the client or ourselves, with respect to conducting environmental impact assessments". Companies must realise the significance of their products in order to take environmental sustainability issues seriously.

Although communication is essential in the operation, development and maintenance of environmentally sustainable practice, the commitment of company management, full employee training and economic incentives for business are essential to drive the objectives and ensure devotion to environmental sustainability.

The challenge of changing a company from its normal practice to a one of being environmentally sustainable is often vast. Not only must companies show concern for the environment in their day-to-day activities but, there must be a move towards ensuring that the end-products are environmentally sustainable. This is particularly inadequate in the shipbuilding industry, where there are no set regulations to influence otherwise. Legislation such as ISO 14001 certification only advises on the day-to-day practice; the waste products and upstream materials used in products. There is a visible gap in legislation where through life impacts are concerned. Within reason, a company producing environmentally damaging products may be classed as being environmentally friendly if it uses environmentally friendly methods to produce them. These issues, especially within the shipbuilding industry, are clearly in need of consideration from organisations such as the IMO who have the power to develop regulations and drive research into solutions.

Legislation is clearly a powerful driver in the effort to produce in an environmentally sustainable manner. But unless companies have the financial incentive, they will crumble under unattainable regulation. It seems to be a constant battle between being environmentally friendly and being competitively priced; and this is why the customer is often given the responsibility to determine the balance.

Many of the tools available for life cycle analysis [1] seem to be competitive on paper, but it seems that companies, especially in the shipbuilding industry, are still in the same position they were in five years ago, when Stoyell et al. [3] carried out investigations into the subject. Since then, legislation has been produced, enforced, updated, and changed; leaving many companies confused and doing nothing at all to ensure their projects' environmental sustainability. They are forced to comply with legislation, but are left with little motivation to take designs any further.

The degree of environmental sustainability assessment process necessary, being different for various industries, companies and products or services, is often too complicated for smaller companies, and is not seen to be of any economic value. Large companies use conformation to legislation as a means of competition against competitors. It is the individuals within the companies, who grasp the concept, that will make the difference. This can be attained through the use of appropriate training and the dedication of management.

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7. Appendix 1

Below in table 1 is a brief description of the companies that took part in the research presented in this paper. To ensure the anonimity of the companies the descriptions are extremely brief.

Table 1 – Company descriptions.

Identity	Type	Size	Coverage
A	Civil	Large	UK
B	Civil	Medium	UK
C	Marine	Medium	UK
D	Nuclear	Large	Global

E	Multi-disipline	Large	Global
F	Multi-disipline	Large	Global
G	Marine	Small	UK
H	Marine	Large	UK
I	Marine	Medium	UK
J	Marine	Small	UK

8. Appendix 2

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THE APPLICATION OF "END OF PIPE" TECHNOLOGY TO REDUCE SULPHUR EMISSIONS FROM SHIPPING

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Sulphur emissions from ship operations in heavily trafficked coastal regions are becoming increasingly problematic, especially when viewed relative to the reductions achieved by land based industry and road transport. The obvious option and the one that regulators have focused upon, is switching fuel to low sulphur distillates. However this is not without significant challenges, including higher fuel costs, widespread availability, shipboard modifications, and a higher CO_2 emission per cargo mile.

BP Marine and P&O Ferries have supported an alternative end-of-pipe solution utilising sea water, a readily available consumable, to scrub clean the exhaust gases from marine diesel engines. As well as being extremely efficient, sea water scrubbing, (SWS), has side benefits, such as the removal of particulates and NOx.

The paper will present the details of IMO and EU legislation with a focus on the application of technology to reduce emissions. Although SWS has a significant application history dating at least back to the 1930's when scrubbing was installed in the newly built Battersea Power station in the river Thames, its application to marine diesel engines is relatively new with only a few previous examples. The paper will discuss just some of the many challenges of the installation and operation of SWS onboard a P&O Ferry operated between Dover and Calais and describe the key principles of SWS. Details of the work to provide necessary assurance that the technology is not harming the marine environment and continues to eliminate emissions of SOx to the atmosphere are also discussed.

ENVIRONMENTAL IMPACT OF SEAWATER SCRUBBING TO REDUCE ATMOSPHERIC SHIP EMISSIONS

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Marc Hufnagl, Forschungszentrum Terramare, Germany

A seawater scrubber has been installed on a P&O ferry to reduce atmospheric emissions. The majority of sulphur dioxide is captured in seawater. Additionally, some of the nitrous oxides and most of the combustion particles are removed from the exhaust gas. As a consequence of the adsorption of sulphur dioxide the water becomes acidic up to pH 3. The produced sulphuric acid is buffered by dilution with cooling water and then discharged to the sea with an average pH 6.5. The question arising is: do we cause any harm to the marine environment by discharging slightly acidic seawater into the sea? The study has been carried out in the harbours of Calais and Dover. Under the analysed circumstances and the seawater scrubber conditions, no significant pH change could be detected in the receiving waters.

1. Introduction

Burning of fossil fuels contributes significantly to atmospheric pollution. Major gaseous pollutants are carbon dioxide, sulphur dioxide and nitrous oxides. These cause problems for the environment and human health. For power stations a number of technologies have been developed to reduce these emissions, while the shipping industry has made less progress in limiting emissions. This will change in May 2005, when the IMO Air pollution rules (MARPOL Convention 1997, Annex VI) come into force. Annex VI sets limits on sulphur oxide and nitrogen oxide emissions from ship exhausts. In addition there is also a global cap of 4.5% m/m on the sulphur content of fuel oil, it further limits the sulphur content of fuel oil used on board ships to 1.5 % m/m in "SO_x Emission Control Areas". Alternatively ships must fit an exhaust gas cleaning system or use any other technological method to limit SO_x emissions.

The subject of this paper is the reduction of atmospheric emissions of ships with emphasis on seawater scrubber (SWS) technology (flue gas desulphurisation process). Seawater scrubbers transfer SO_x (95 %) and partly also NO_x (20 %) into aqueous solution, thereby producing acidic solutions, which are then buffered with seawater and finally discharged into the sea. The environmental impact of the effluent could be changes of pH and seawater composition. As nitrate from NO_x adsorption serves as a nutrient, eutrophication might also be a consequence of scrubber discharge. In addition organic pollutants like polycyclic aromatic hydrocarbons (PAH) could be present in the effluent. PAH are attached to the soot particles, although a cyclone removes most of the particles.

A seawater scrubber (SWS) was installed on the P&O ferry Pride of Kent, which travels between Calais and Dover. The exhaust gas of the ship is washed with seawater within the funnels, thereby adsorbing SO_2 and some of the NO_x. The gases convert into their acids H_2SO_4 and HNO_3. This acidic seawater is then partially neutralised by dilution with cooling water and discharged back into the sea. The ability of seawater to buffer the pH is well described in existing literature [1], [2], but the buffer capacity is limited, depending on the alkalinity of the water. Most aquatic organisms and some bacterial processes require that pH be in a specified range [3]. The aim of this study is to assess the impact of SWS effluents on the marine environment.

2. Method

2.1. Sampling locations on board of the ship

The "Pride of Kent" is equipped with four auxiliary engines (3 * 650-700 kW and 1 * 900 kW). The exhaust gas from these engines is cleaned (scrubbed) with a SWS (Eco-Silencer, DME, Canada). Usually only three generators are in service, the fourth being kept in reserve. The SWS and the receiving waters in the harbours were sampled four times during 2004.

Sampling dates and condition of the SWS:

- 24.03.2004: Three SWS and 3 generators in use, but not the corresponding ones. That means effectively only two SWS were active.
- 13.07.2004, 08.09.2004 and 16.11.2004: Three SWS in use.

The SWS was sampled at the inlet (1) and outlet (2), as well as directly after the SWS (3) while crossing the Channel (see Fig. 1). Sample names are presented in Tab. 1.

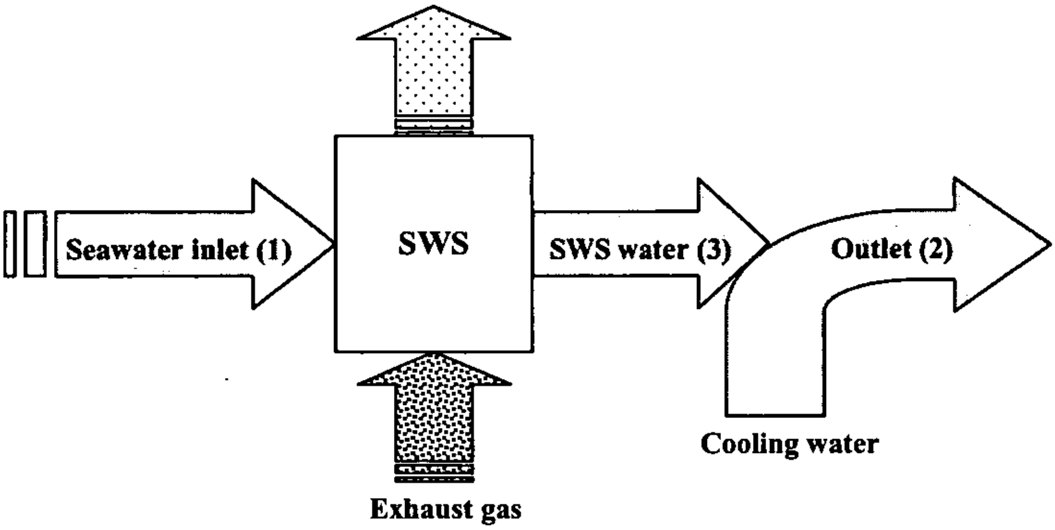

Fig. 1 - Sketch of the seawater scrubber system

Table 1 - Sampling stations on board. S = SWS samples, D, Ch, and C = samples taken in Dover, while crossing the Channel and Calais, respectively.

Name	Description
SD1	Dover inlet
SD2	Dover outlet
SCh1	Channel inlet
SCh2	Channel outlet
SCh3	Channel after the SWS
SC1	Calais inlet
SC2	Calais outlet

2.2. Sampling locations in Calais and Dover

The harbour of Calais is a semi-enclosed basin with jetty walls on both sides of the entrance (Fig. 2). At station Cal 3 (Quai de la Loire) freshwater enters the harbour via Bassin Carnot. The Bassin

Carnot is connected to the Canal de Saint Omer and a system of inland waterways. The harbours were sampled on the same dates as the SWS and also on 11.02.04, when the SWS was not in service. This additional sampling serves as a control. The names of the sampling stations in Calais and Dover are listed in Tab. 2. The harbour of Dover is also a semi-enclosed harbour, but with two entrances in the East and one to the West (Fig. 3). Water currents are very complicated and further disrupted by jetties at the Eastern entrance. Both harbours are tidally influenced with a tidal range of up to 2.6-4 m in Dover and 3-4.4 m in Calais.

Table 2 - Sampling stations in the harbours of Calais and Dover. See also Fig. 2 and Fig. 3.

Calais	**Description**	**Dover**	**Description**
Cal1	Quai en eau Profonde	Dov1	Eastern entrance 2
Cal2	Quai de Service	Dov2	Western entrance
Cal3	Quai de la Loire	Dov3	Middle port
Cal4	Jetée Ouest	Dov4	Western harbour
C0	Before arrival of ferry	D0	Before arrival of ferry
C5	5 m from SWS outlet	D10	10 m from SWS outlet
C50	50 m from SWS outlet	D50	50 m from SWS outlet
C350	350 m from SWS outlet	D350	350 m from SWS outlet
C700	700 m from SWS outlet	D600	600 m from SWS outlet

In both harbours the sampling stations were distributed taking into account the structure of the harbour. A second set of samples was taken during the stay of the ferry along a transect, which was sampled in July, September and November. Samples C0 and D0 are taken from the berth of the ferry directly before its arrival. C5 and D10 were taken as close as possible from the outlet of the SWS. The other transect samples were taken in increasing distances from the ferry towards the open sea.

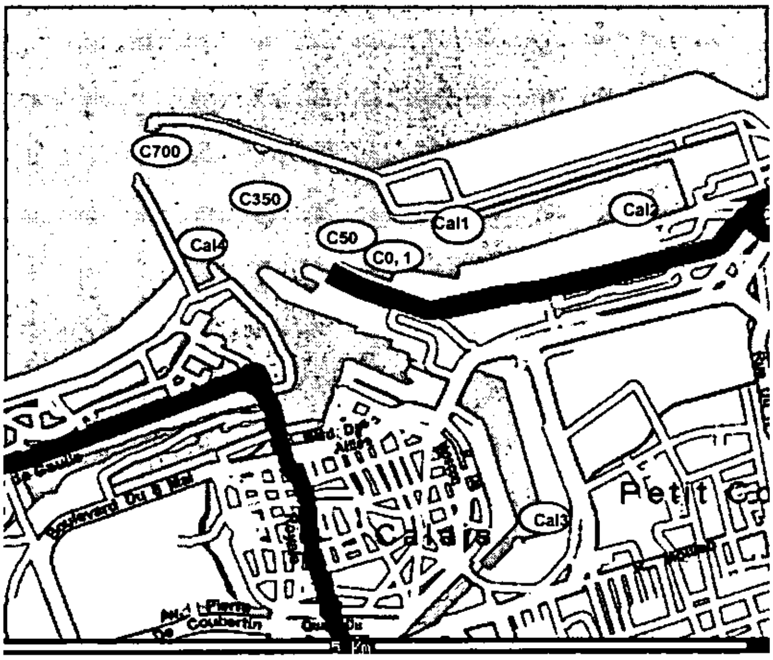

Fig. 2 - Sampling stations in the harbour of Calais.

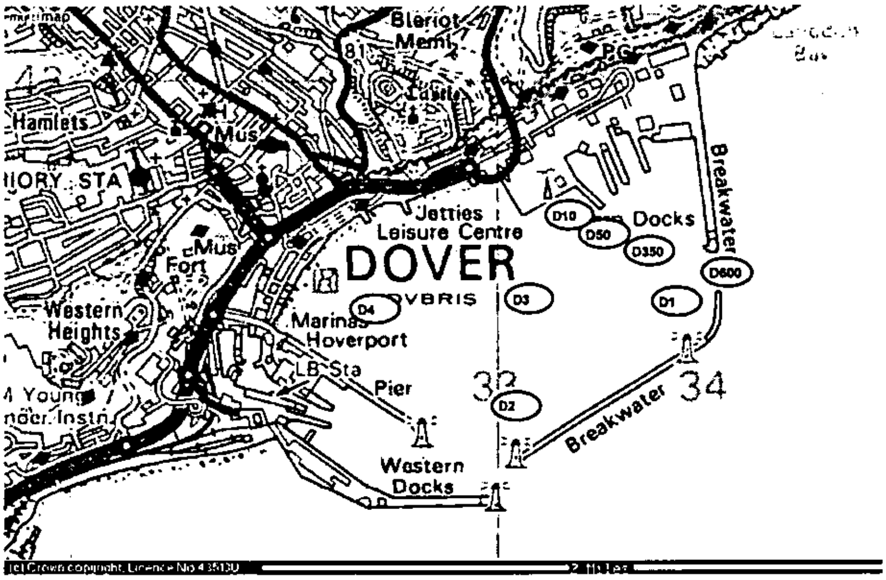

Fig. 3 - Sampling stations in the harbour of Dover.

In the harbours surface water samples were taken with a bucket. The on-board samples were taken from valves, which were installed specifically for the monitoring activity. The samples were collected directly into polyethylene bottles. The bottles were cleaned with diluted hydrochloric acid and distilled water before the sampling. During the sampling, the bottles were rinsed with the sample water before filling them completely. All pH-Values were measured immediately using a pH-Meter (WTW pH 320/WTW-SenTix 81 electrode) calibrated with two different buffer solutions (pH 7.00 and pH 4.02, Merck). Salinity, conductivity and temperature were determined electronically (WTW Cond 315i, Weilheim, Germany). The samples were then stored in cooling boxes for the transport to the lab for further analysis.

3. Results

3.1. Sampling in the harbours of Dover and Calais

The pH values and salinities of water samples taken in the harbours of Dover and Calais are illustrated in Fig. 5 and Fig. 4. The data show the natural variability of the two parameters in the harbours without the ferry (triangles) and the values of the transect samples (diamonds), while the ferry was berthing. All data over the course of 10 months (February – November 2004) are included. The error bars were applied to the harbour samples to indicate a pH-range of ±0.2. This is the maximum allowed pH change caused by effluents outside the initial mixing zone (US-EPA 1986).

In Dover the pH varied between 8.07 and 8.37 and salinity varied between 34 and 35.2 PSU. Both variables stayed in a very narrow range and are regarded as fully marine. The samples of the transect samples stayed well within this range.

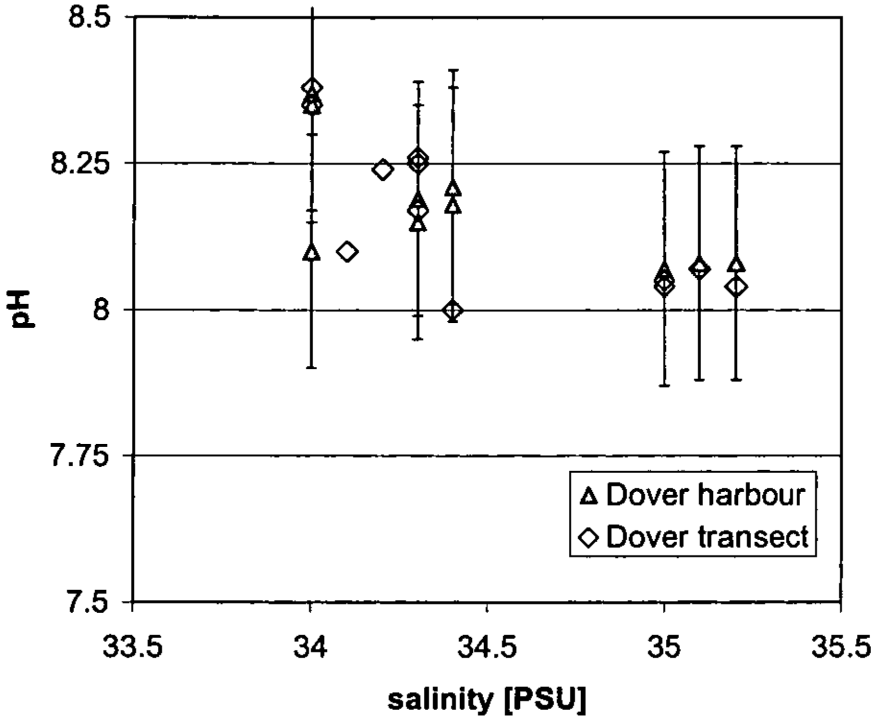

Fig. 4 - pH and salinity in the harbour of Dover. Triangles represent the natural variability during all samplings in 2004. Diamonds represent the values of the transect samples.

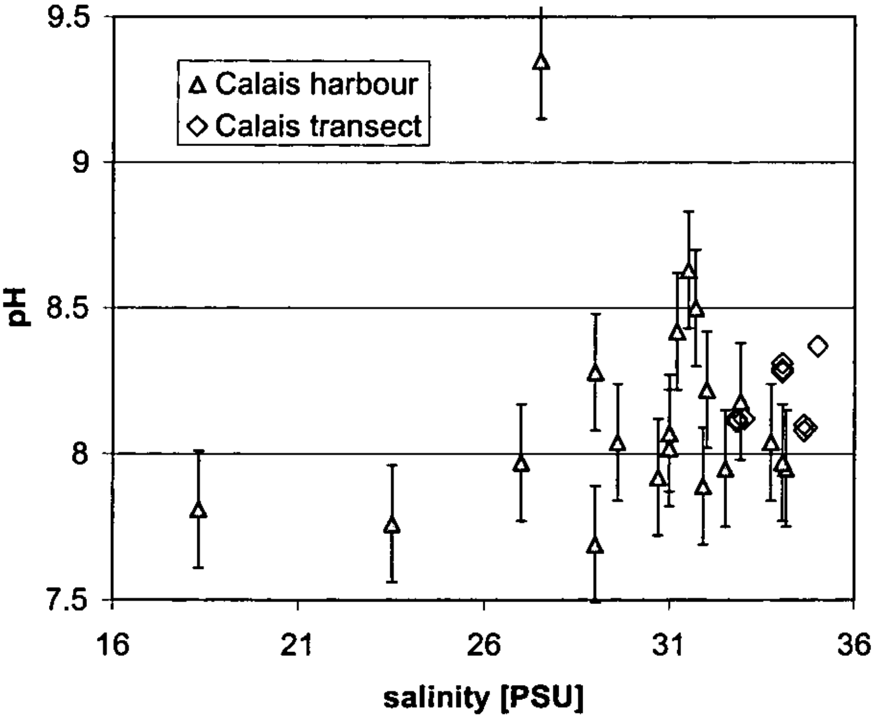

Fig. 5 - pH and salinity in the harbour of Calais. Triangles represent the natural variability during all samplings in 2004. Diamonds represent the values of the transect.

In Calais (Fig. 5) the variability of pH and salinity was much higher relative to Dover. The pH fluctuated from 7.69 – 9.35 and salinity varied between 18.3 and 34.1 PSU. The extreme pH of 9.35

was from station Cal3 in March. The salinity of this sample was 27.5 and an additional oxygen measurement showed an oxygen concentration of >20 mg L^{-1}. Two further samples with low salinities are noticeable. The lowest salinities were detected at station Cal2 with 18.3 and 23.5 PSU (pH 7.81 and 7.76, respectively). The values of the transect samples (diamonds) stayed within a narrow range of pH (8.08 – 8.37) and salinity (32.8 – 35).

3.2. Sampling of the seawater scrubber on board of the ship

Fig. 6 shows the pH values at the inlet of the SWS and of the effluent at the different locations Dover, Channel and Calais. The pH at the SWS inlet varied between 7.7 (Dover 24.03.04) and 8.4 (Channel, 17.07.04). The lowest pH values were observed in March, the highest in July. The effluent of the SWS had the lowest pH values in September. At this time the inlet also had relatively low pH values. The reduction of the pH was 1.78 on average.

In March the difference between inlet and outlet was not as pronounced as during the other samplings. The reason was clearly that only two SWS were running and the system was not stable at that time. The low pH of the effluent (SCh2) in March of 6.78 may be from the remaining acidic water in the system. In July and November the reduction of the pH was 1.4 and 1.65, respectively. Within the SWS system the pH dropped to 2.78, 3.09, 3.13 and 3.30 at each of the samplings (data not illustrated).

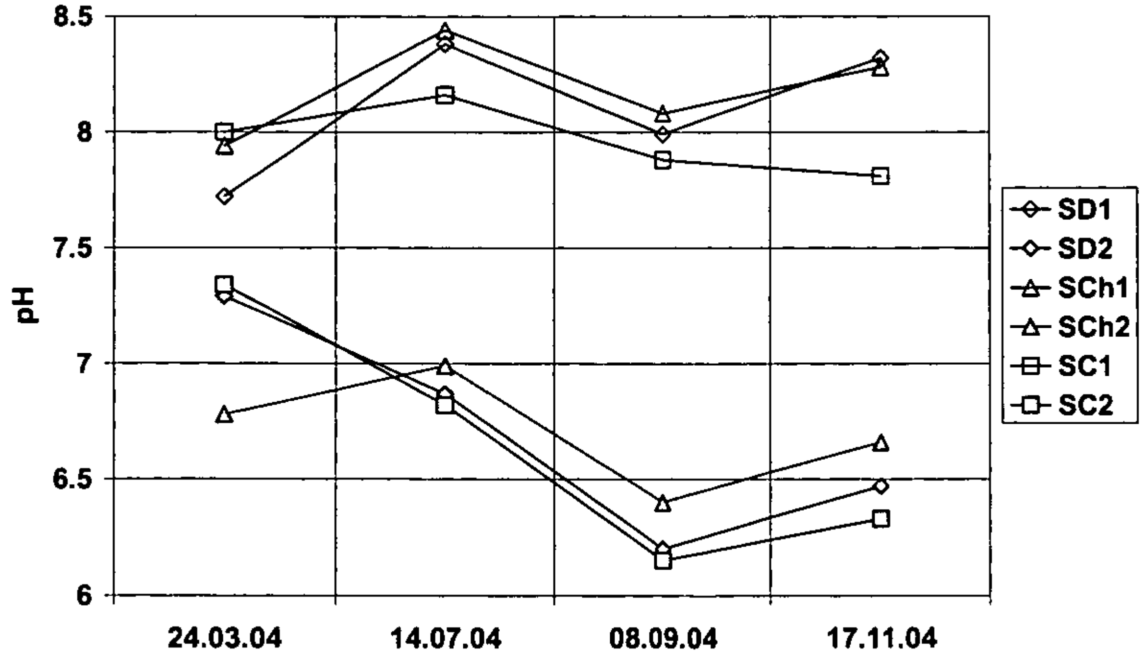

Fig. 6 - pH of the water samples taken from the SWS inlet (1) and outlet (2) in Dover (SD), Calais (SC) and while crossing the Channel (SCh).

3.3. The transect sampling in Calais and Dover

To analyse the direct impact of the SWS effluent on the harbour water, a transect was sampled with increasing linear distance from the ship (Fig. 7). It is important to indicate that the samples with 0 m were taken before the arrival of the ferry. The transect was sampled three times (July, September and November). In both harbours the highest overall pH values were observed in July, the lowest were found in September. There was only one exception from this general trend. The sample C0, taken before arrival of the ferry in November had the lowest pH of 7.86. When regarding this pH as an exception, only the sampling in September showed a slight increase of the pH (plus 0.09) with increasing distance from the ship. In November even a decrease of the pH along the transect was observed.

A slight reduction of the pH near the ship (<50 m) was found in Calais in July and September, and in Dover in November. The pH near the ship was between 0.01 and 0.02 lower, which is not significant. In three cases the arrival of the ferry elevated the pH, and in two cases no change has been observed (Calais 0 m for July is missing).

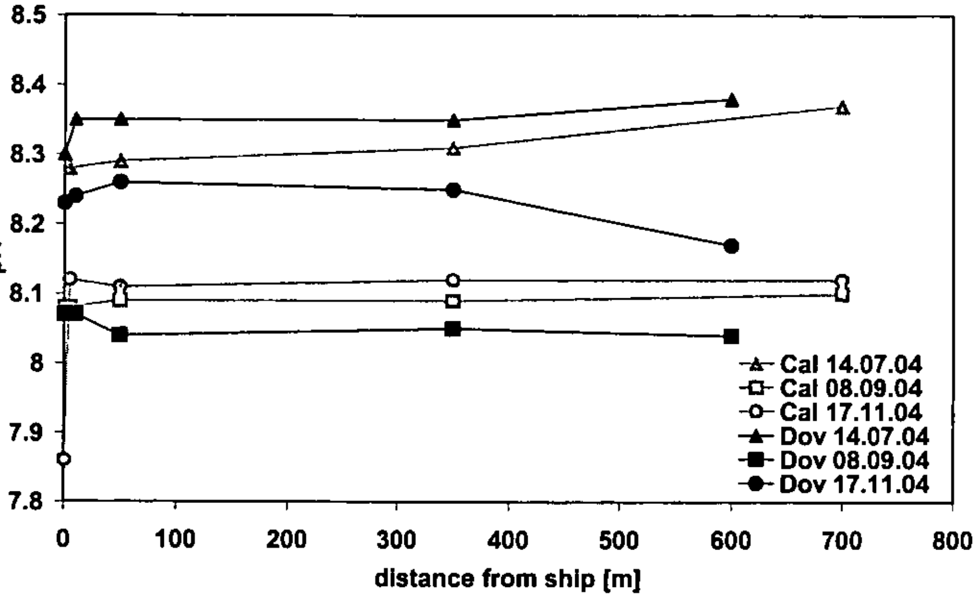

Fig. 7 - Impact of SWS effluents on the receiving harbour water in Dover and Calais at three sampling (July, Sept. and Nov.)

4. Discussion

Beginning with 19th May 2005 MARPOL Annex VI of the IMO MEPC (Marine Environment Protection Committee) comes into force. This will limit the sulphur content of marine diesel to 1.5 % sulphur. Alternatively, ships must fit an exhaust gas cleaning system or use any other technological method to limit SOx emissions to ≤ 6 g/kWh (as SO_2 mass) [4]. The Baltic Sea area was designated as a SOx Emission Control area in the 1997 Protocol. In March 2000, a proposed amendment to Annex VI was adopted to also include the North Sea as a SOx Emission Control area.

This paper describes the environmental impact of the alternative solution to reduce the SO_2 emissions using a gas cleaning system, in this case a seawater scrubber (SWS). The question arising from this is: do we shift an air pollution problem to a water pollution problem by allowing alternative technologies?

A passenger ferry "Pride of Kent" commuting between Calais and Dover has been fitted with an SWS. The exhaust gas is "washed" with seawater. SO_2 and other constituents of the gas are adsorbed or dissolved in the water. The SO_2 is rapidly converted to sulphuric acid via SO_3 causing a pH change in the seawater. After dilution with cooling water (also seawater) the pH is elevated to a certain degree, but is still lower than the pH of the receiving waters. To analyse the environmental impact of the SWS, water samples were taken from the SWS and the harbours. The samples were analysed regarding pH and salinity. The addition of sulphate ions to the sea is regarded to be harmless, because sulphate is one of the major constituents of seawater.

Although previous experiences with dumping of sulphuric acid from titanium dioxide production have shown that under open sea conditions the effects on seawater pH are negligible [5], no information exists on the situation in harbours. Between 1969 and 1989 12 % sulphuric acid was dumped into the sea about 12 sea miles north of Heligoland in the central German Bight. This sea-disposal was stopped in 1989, because the heavy metals caused dramatic changes in the ecosystem. At that time 750 000 t of sulphuric acid (12 %) were dumped into the sea per year. The pH of the water in the disposal area changed only slightly, due to the buffer capacity of the seawater. The dumping was stopped because of the high heavy metal concentrations in the wastewater.

Factors affecting the environmental impact of discharges in semi-enclosed basins are tidal range and freshwater impact. The water exchange rate per tide in the harbours is expected to be very good given the tidal range of 2.6 – 4.4 m and high current speeds in the harbour of Dover. This is supported by the salinities and pH-values of the harbour samples in Dover (Fig. 4), which stayed in a narrow range from February to November (pH 8.07 - 8.37, salinity 34 - 35.2 PSU).

In Calais (Fig. 5) the variability of pH and salinity was much higher (pH 7.69 – 9.35, salinity 18.3 - 34.1 PSU). Compared to Dover, more freshwater seems to enter the harbour via the canal (Cal3) and via surface water run-off from the harbour area. Probably surface water has a significant impact on the station Cal2, which is well within the harbour area. At this station the lowest salinities (18.3 and 23.5 PSU) and pH-values (7.81 and 7.76) have been detected.

The pH on board of the ship directly after the SWS dropped to 3 on average. After dilution of the SWS water with cooling water pH values have been raised 6.5 on average (Fig. 6). The pH of the effluent was strongly related to the pH of the inflow waters, which varied between 7.7 and 8.4. The mean reduction of the pH in the system was 1.78, with less variability than the inflowing water. In both harbours the highest overall pH values were observed in July, the lowest were found in September.

The factors affecting the natural variability of pH are numerous, but mostly related to the carbon dioxide cycle. High carbon dioxide levels produce low pH values, and conversely, low concentrations of carbon dioxide in the water result in higher pH values. The extent of the pH shift depends on the buffering capacity of the water which is referred to as alkalinity. Regarding alkalinity refer to e.g. [6].

The major ion responsible for the alkalinity is the bicarbonate ion. The amount of bicarbonate and other weak bases in seawater buffers the system, thus keeping the pH within a narrow range. Standard seawater has a bicarbonate concentration of 140 mg L^{-1}. Dissolved CO_2 and carbonates belong to the buffer system and are all related by the following four equations:

$$CO_2 + H_20 \longleftrightarrow (CO_2)_{aq} \qquad (1)$$

$$(CO_2)_{aq} + H_20 \longleftrightarrow H_2CO_3 \text{ (carbonic acid)} \qquad (2)$$

$$H_2CO_3 \longleftrightarrow H^+ + HCO_3^- \text{ (bicarbonate)} \qquad (3)$$

$$HCO_3^- \longleftrightarrow H^+ + CO_3^{2-} \text{ (carbonate)} \qquad (4)$$

Addition of sulphuric acid will shift the chemical equations 1-4 to the left and thereby increasing the partial pressure CO_2 in the water. The solubility of CO_2 is limited and depends on salinity and temperature. To keep the pH stable, CO_2 will be released to the atmosphere. Each molecule of sulphuric acid will be buffered by the release of two molecules of CO_2.

In July (Fig. 7) the increase of the pH was probably due to algal blooms in the harbours caused. Algal growth requires CO_2 to produce organic matter. Photosynthetic consumption of CO_2 causes an increase of pH because there is less carbonic acid formation and therefore less dissociation of carbonic acid into hydrogen ions. On the other hand decomposition of organic matter in the presence of dissolved oxygen increases the carbon dioxide content of water and the lowers the pH, which was most likely in September. In winter when processes that decompose organic matter (e.g. nitrate, manganese and sulphate reduction and denitrification) dominate, the pH to increases again. Unfortunately, there are more factors controlling the pH like the anthropogenic impact deriving from combustion of fossil fuels. Acidic nitric and sulphur oxides give rise to atmospherically derived acids and acid rain. All these acids reach the oceans via surface water run-off and rivers.

To analyse the direct impact of the SWS effluent on the receiving waters, a transect has been sampled form near the ship (5 and 10 m) to 600 m distance in Dover and 700 m in Calais. Also a blank sample was taken before arrival of the ship. The transect samples had the same salinities and a comparable pH like the harbour water samples and stayed well within the range of natural variability (Fig. 4 and Fig. 5). None of the samples had a pH below 8, except of the sample taken before the arrival of the ferry in Calais in November. This result is surprising with regard to the pH of the effluent itself. The seawater was able to buffer the pH of the effluent to normal values. Comparison of all transect samples showed no significant reduction of the pH near the ferry.

Legislation regarding acid disposals into the sea is very weak. The US-environmental protection agency (US-EPA) defined a so-called initial mixing zone (IMZ), which is the region immediately downstream of an outfall where initial effluent dilution processes occur. Because of the combined effects of the effluent buoyancy, ambient stratification and water currents, the prediction of initial dilution can be complex [7]. The IMZ is also defined as a limited area or volume of the receiving water where the initial dilution of a discharge is allowed to occur. The pH-change at the boundary of the IMZ should not exceed 0.2 pH-units [8].

The extent of the IMZ for a ferry in a harbour with tidal water currents and unknown velocity of the effluent remain unclear. An US-EPA approved mixing model called CORMIX [9] might help to get a better idea of the mixing processes in the harbours. However, the allowed range of pH 0.2 has not been exceeded by any of the transect samples and there was no significant trend with increasing distance form the ship.

5. Conclusions

The environmental impact of a seawater scrubber has been analysed in the harbours of Calais and Dover. There was no significant impact of the SWS effluents regarding pH of the receiving waters. The natural variability of the pH in the harbours was higher than the pH of the effluent.
Samples taken on a transect with increasing distance from the ferry showed no significant pH-change even close to the ferry.

At the boundary of the initial mixing zone the pH-change did not exceed 0.2 pH compared to the surrounding waters. The pH of the receiving waters was buffered by the release of CO_2.

After deposition the sulphuric acid deriving from the exhaust gas would reach the oceans anyway. At the coastline the acid rain could cause more harm to humans, soils, woodlands, etc. The SWS acts like a shortcut with excluding the atmospheric pathway.

As a very positive side-effect, other constituents of the exhaust gas such as particles are additionally removed from the gas. The particles contain the carcinogenic polycyclic aromatic hydrocarbons. These would reach the environment via the atmosphere and would be transported over long distances. These are collected on board of the ship with the help of cyclones and a settling tank. The resulting sludge can be deposited on the mainland.

Some open questions remain regarding the legislation, which is unclear. The US-EPA water quality criteria are also uncertain, because the extent of the IMZ is indistinguishable.

What will happen, if more thane one ferry uses SWS to clean its exhaust gas? It is desirable to carry out a complete mass-balance study, which includes engine loads, exhaust gas and effluent compositions.

6. Acknowledgements

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EMISSIONS TESTING FACILITY TO EVALUATE CLEANER ABRASIVES

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Dry abrasive blasting is an important surface preparation operation used by many industry sectors including the maritime industry. This process generates particulate matter (PM) emissions, which pose community nuisance and health risks. Health risks of PM depend on their sizes and chemical speciation. Optimization of abrasives and process used will result in waste minimization, regulatory compliance, and cost optimization. Feed rate, blast pressure, abrasive type, abrasive gradation, and number of reuses are key factors that influence abrasive consumption, solid waste generation, and atmospheric emissions. The factors thus have a bearing on shipyard costs, namely, labor, material, cleanup, disposal, environmental fees, and others.

In order to evaluate environmental-friendliness of abrasives, it is necessary to understand the relationships between environmental performance and process parameters. To accomplish this, an emissions testing facility was designed and constructed at UNO to carry out blasting operations within enclosed conditions. The primary objective of the study was ranking various abrasives based on their environmental cleanliness (lower emissions and consumption). The research identified best process conditions such as blast pressure and feed rate that result in lowest PM emissions and abrasive consumption. This paper presents the design of the emissions testing facility and research approach used in evaluating commonly used abrasives in the shipbuilding industry.

1. Introduction

Industrial unit operations and processes are major sources of multimedia wastes including atmospheric emissions and solid/hazardous wastes. In order to understand the environmental impact of different industrial processes, quantification and characterization of atmospheric emissions becomes critical. Quantities and characteristics of wastes generated are typical of the respective processes and can be understood by simulating these processes under controlled conditions. Emissions estimation and monitoring protocols can be standardized and applied to practically any process using fundamental principles of science and engineering. The central theme of this research was to construct a test facility that can accomplish both these tasks simultaneously. This research endeavor was aimed at streamlining the approach to:

(a) Simulate industrial unit operations and processes that release air pollutants (e.g.: blasting, welding, metal cutting, etc) under confined conditions and
(b) Quantify and characterize air emissions using established scientific and engineering methods for source sampling and emissions testing.

The first process that was studied in the emissions testing facility was dry abrasive blasting, one of the most widely used in maritime industry sector [1]. Dry abrasive blasting is the most common and popular surface preparation (surface cleaning and profiling) method in which abrasive materials are propelled on to the metal surface (less commonly used to clean concrete surfaces also) to be cleaned with the aid of compressed air [2]. This process involves removing surface contaminants such as rust, scale, paint, and others while leaving a profile for the new paints to adhere strongly thereby improving the paint life. Abrasive blasting is used by several industries such as shipbuilding and ship repair; boat building and repair facilities; air craft manufacturing; auto manufacturing; oil exploration, storage, and refining; municipal corporations (water treatment units, wastewater treatment units, and bridges); and a variety of chemical plants.

Major atmospheric emissions from the process include particulate matter (PM) in various size fractions, HAPs, and metals in particulate form. The United States Environment Protection Agency (USEPA) has documented raw materials, process conditions and emission factors from abrasive blasting carried out in the maritime industry. A detailed literature search indicates that, though there have been efforts to estimate emissions from the process, comprehensive data is not available for the whole range of abrasives at different process conditions.

This paper presents the research objectives, design and construction of the emissions testing facility at UNO, criteria governing the test facility design, experimentation, standardized monitoring methods based on published federal documents. UNO's research approach discussed in this paper helps comprehensively and simultaneously determine the performance of abrasives in terms of productivity (area cleaned per unit time), consumption (amount of abrasive used per area cleaned) as well as atmospheric emissions from the process.

2. Need for Research

Dry abrasive blasting process carried out with commonly used abrasives at shipyards poses potential health risk to workers and public owing to (a) quantity and toxicity of spent abrasives, and (b) atmospheric emissions in the form of particulates and metals [3]. Hence, one needs to understand the effect of raw material characteristics and process conditions on the quantity and characteristics of multimedia wastes generated (spent abrasives and atmospheric emissions). Metals cause both carcinogenic and noncarcinogenic health risks to workers at source and the public once dispersed in the ambient air. National Air Toxics Assessment (NATA) program analyzed national level ambient concentrations and toxicity levels of various pollutants using the industry reported values. Fine particulates released into the atmosphere cause human health problems affecting the cardiovascular, nervous, and respiratory systems. Currently, limited data is available on particulate matter (PM) and metal emissions from the commonly used abrasives. The emission factor data for abrasive blasting in shipbuilding and repair sector is not comprehensive enough to understand the process from an emissions reduction perspective. Consumption of the fresh abrasive, quantities and characteristics of the spent abrasive generated after the process, emissions of total PM, particulate size distribution, and metal content are expected to depend on important process parameters. Some variables have greater or lesser influence on waste generation and emission characteristics. These influences need to be studied in depth to understand which process parameters influence atmospheric emissions (PM and metals), abrasive consumption, and in what way. By understanding these relationships, process modifications can be implemented (appropriate pressure, feed rate combinations to minimize waste generation, emissions and worker exposure) and the best abrasive can be chosen based on environment friendliness. This study would have an international level applicability because abrasive blasting is used in all major process industries worldwide.

3. Theoretical Considerations

There has been various research efforts from industry, navy and independent research teams to study the abrasive blasting process exhaustively in terms of productivity (speed and efficiency of cleaning), consumption (raw material used per square foot area cleaned) and emission factors (mass of pollutant emitted per unit work done or raw material used). These research findings show that the important parameters influencing emissions from abrasive blasting process include: (a) Abrasive type (slag, metallic, synthetic), (b) Abrasive properties (hardness, size, shape), (c) Blast pressure (affects velocity of the particles impinging on the surface to be cleaned), (d) Abrasive feed rate, (e) Initial surface type (rusted/painted surfaces), (f) Initial surface characteristics (degree of rust, level of contaminants), (g) Number of re-uses of the abrasive, (h) Wind velocity for outdoor operations, (i) Exhaust fan capacity for enclosed operations (extent of negative pressure inside the chamber), (j) Blast nozzle size, (k) Standoff distance, (l) Angle of the nozzle to the surface being cleaned, and (m) Worker training. Since the influencing parameters are numerous, careful considerations were made while designing the research protocols.

4. Research Approach

This research was undertaken to evaluate the inter parameter relationships and their influences on atmospheric emissions and industrial performance (productivity, consumption) of the process. This section embodies different aspects of the research approach and respective criteria that dictated the project design.

4.1. Abrasives Tested

Abrasives can be broadly classified as: sand, slag, metallic shot or grit, synthetic, or other [2]. The costs, physical and chemical properties of abrasives dictate their application. In scenarios where reclaiming and reuse is impossible, silica sand has been used for blasting over the ages Owing to its high breakdown rate, sand blasting can result in high dust generation. Moreover, worker exposure to airborne crystalline silica has been demonstrated to have adverse health effects. Coal and smelter slags have been used extensively for blasting at shipyards. Coal slag (known as black beauty), is derived from coal-fired utility boilers in the form of crushed slag. The advantages of slags are their low silica content and higher cleaning rates. Their disadvantages include release of particulate matter and hazardous air pollutants (HAP). Some common metallic abrasives used in shipyard blasting are: specular hematite (bar shot), cast iron shot, cast iron grit, steel shot, and steel grit. The main advantage of metallic abrasives is their reusability. Synthetic and mineral abrasives have attracted attention because of their durability, reusability, and lesser emission potential compared to sand.

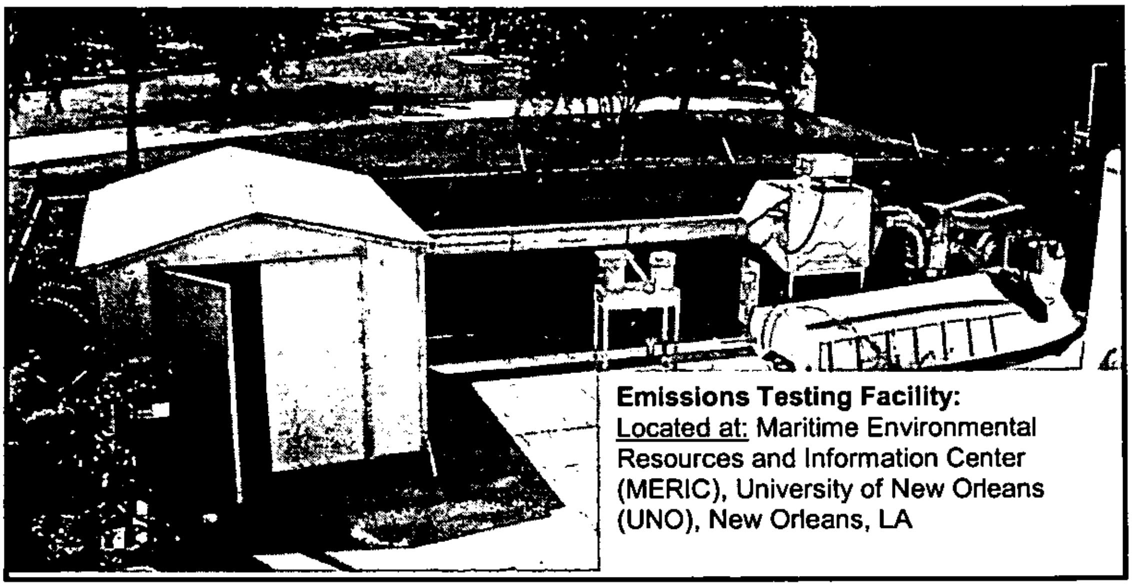
The following six abrasives were tested at the UNO emissions testing facility for consumption, productivity, and emission factors:

- Coal slag (mixture of metallic oxides)
- Garnet (ferrous, magnesium, aluminum silicate complex)
- Copper slag (metallic abrasive containing a mixture of copper and metallic oxides)
- Bar shot (metallic abrasive, also called hematite, primarily containing ferrous oxide)
- Steel grit (metallic abrasive with iron as the primary constituent and trace quantities of metallic and non-metallic oxides)
- Specialty sand (processed by Pontchartrain Materials Inc.)

Specialty sand was processed as follows: raw sand is hydraulically dredged, washed twice and passed through a rotary kiln. Most of the volatile impurities are removed by this process. This sand is then passed through a single-deck check screen filter system with a flat 0.25" screen. From there, it is carried by a bucket elevator to a three-deck speed shaker screen through which the sand falls by gravity. The sand used in this study was the medium fraction (1 to 2.5 anchor profile). Typical sand available for blasting costs about $14 per ton as compared to $40 per ton for the specialty sand used in this study.

4.2. Test Chamber Design

A test chamber of size 12'x 10'x 8' was designed and constructed to facilitate the experiments in "enclosed ventilation" setting. This chamber was constructed using PVC sheets and the floor was made of seasoned wood. Provisions were made to allow make up air to enter the test chamber as the airborne particles were exhausted through a fan. The fan installed has a maximum volumetric flow rating of 5500 cfm. To avoid atmospheric releases from the test facility, a two stage particulate collection system was designed and installed downstream of the exhaust fan. Figure 1 shows the test chamber, duct work, exhaust fan, and a 2-stage particle collection system.



Emissions Testing Facility:
Located at: Maritime Environmental Resources and Information Center (MERIC), University of New Orleans (UNO), New Orleans, LA

Figure 1 - Emissions Testing Facility.

4.3. Blast Pot and Test Plates

Sullair Model 375H and Ingersoll Rand compressors were used as compressed air sources. Schmidt feed valve was used to vary the abrasive feed rate. The test plates used for blasting operations were made of cast iron and had a size of 8'x 5'. A total of 4 plates were used and they were mounted on a mobile cart for the convenience of movement. Blasting was carried out with rusted panels (panels allowed to flash rust for about 24 hours) as well as panels painted with commercial marine paint (0.3 to 1.3 mils thickness).

4.4. Exhaust Duct

The exhaust duct was designed to comply with the EPA guidelines for source testing. The diameter of the exhaust duct is 12 inches. Sampling port was positioned at a distance of 8 diameters from the air intake (flow disturbance) and the variable speed fan was positioned at 2 diameters downstream from the sampling port. Velocity measurements were made with a standard S-type pitot tube at a number of positions on a cross-sectional plane perpendicular to the flow direction in the duct. According to EPA Method 1, a minimum number of locations needed to make measurements depend on the extent of disturbance or turbulence in the flow. A total of eight traverse points were chosen for the circular duct used in this project. The traverse points were measured and marked on the sampling probe to ensure accuracy and ease of traverse. For ensuring isokinetic flow conditions, a nozzle size of 0.18 inches was chosen for the runs [4,5]. Figure 2 shows the exhaust duct design from both inside and outside the test chamber.

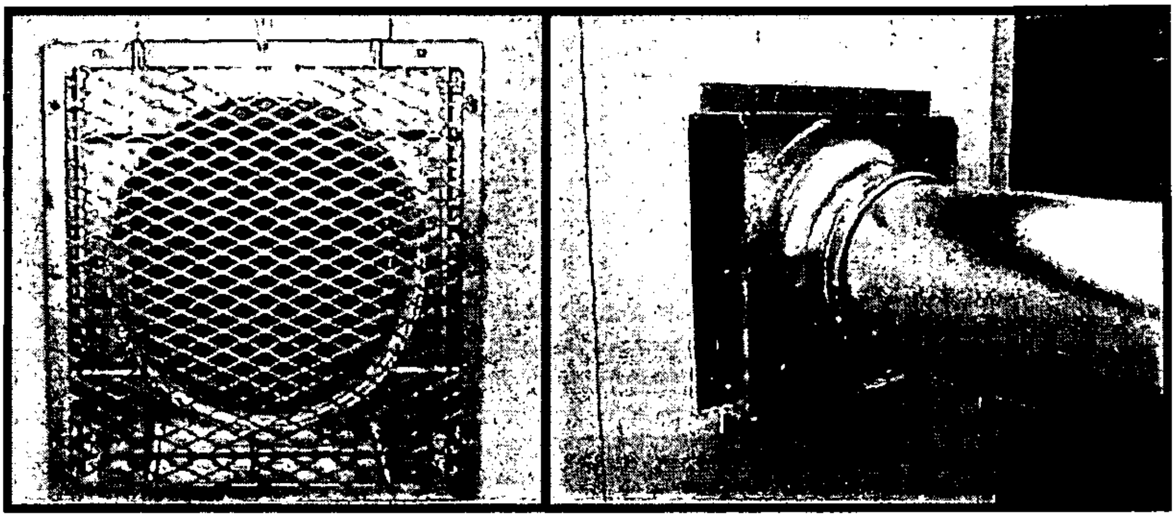


Figure 2 - Exhaust Duct to Capture Emissions from the Process.

4.5. Stack Sampling Equipment

A sampling train in accordance with EPA Method 4 was used for evaluating the volumetric gas flow rate.

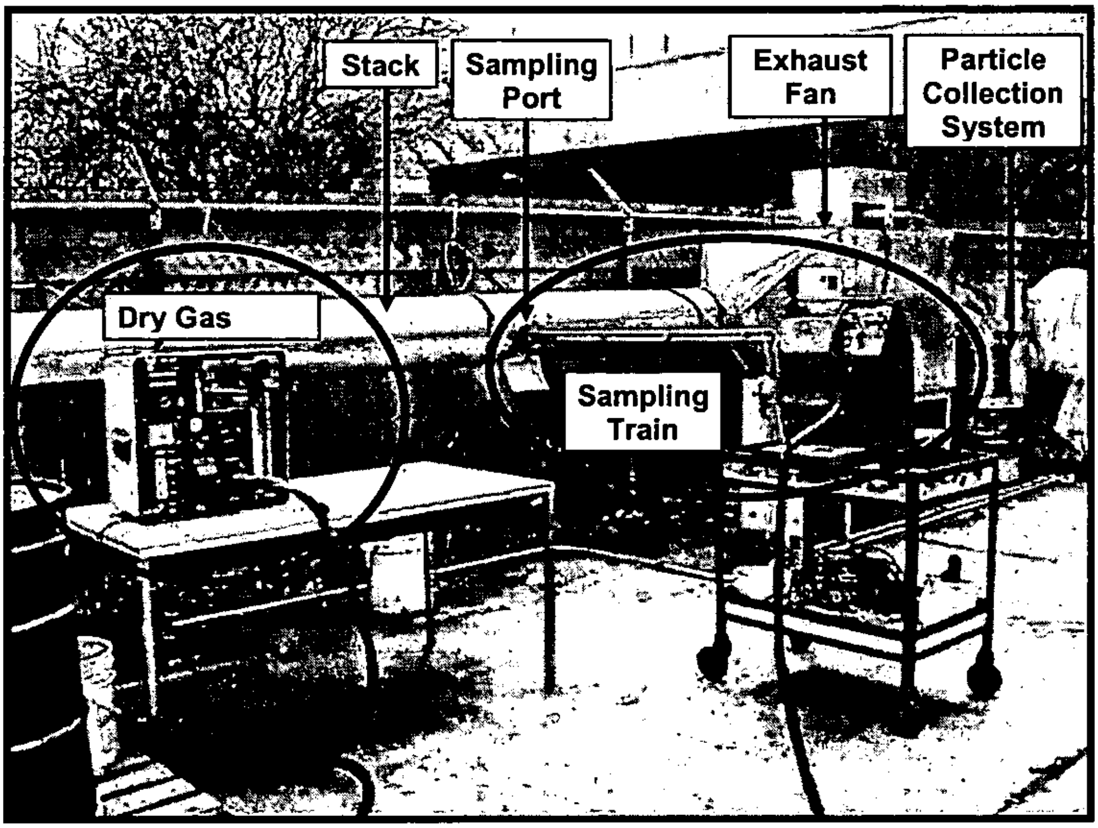


Figure 3 - Source Sampling and Emission Estimation Setup.

The apparatus consisted of four glass impingers connected in series and installed in an ice bath to achieve condensation of water vapor. The first two impingers were filled with an accurately measured quantity (100 ml) of water to allow the moisture to condense. The third impinger was left dry for further condensation. The fourth impinger contained known quantity of silica gel (adsorbent) that removed nearly all the remaining water vapor as the gas passed through it before entering the dry gas meter inlet [4,5]. Figure 3 shows the emission capture, EPA source sampling and particle collection systems.

4.6. Sampling and Analysis: EPA Method 5

Exhaust gas was sampled at various traverse points on a plane perpendicular to the gas flow. As mentioned earlier, the sampling port was located 8-diameters downstream of a flow-disturbance and 2-diameters upstream of a flow disturbance to minimize the impact of flow turbulence. Efforts were made to collect a representative sample. Particles collected on the inside tubing of the sampling probe were recovered by washing it thrice with laboratory grade acetone and the mass was added to that collected on the filter [4,5]. The filters were desiccated at humidity levels of less than 10% and were labeled and preserved.

4.7. Particle Collection System

A two stage filtration system was designed to collect the particles to prevent nuisance to the ambient environment. The first stage collected the coarse particles by changing the direction of the gas flow. The second stage collected fine particles by using a fabric filter. This two-stage particle collection system was placed at the end, downstream side of the exhaust fan. Sampling was carried out at the sampling port that was located at the upstream side of the exhaust fan. So, the measured emission factors represent "un-controlled emission factors" and the 2-stage particle collection system did not have any impact on the measured un-controlled emission factors.

4.8. Actual Experimental Conditions

The experiments were conducted according to the guidelines and considerations described above. Figure 4 shows a trained blaster getting ready to carry out blasting operation in the test chamber and sampling in progress.

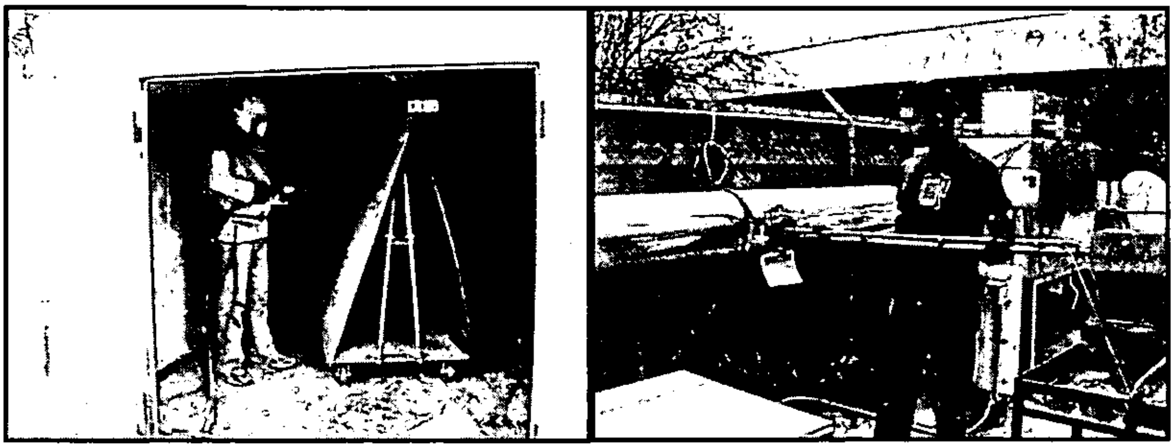


Figure 4 - Blasting inside Test Chamber (left), Sampling in Progress (right).

Independent test parameters studied in the field included the following:

- Abrasive: The abrasives tested were coal slag, garnet, copper slag, bar shot, steel grit and specialty sand (processed as described in section 4.1).

- Blast pressure: The tests were conducted at 3 blast pressures namely 80 PSI, 100 PSI, and 120 PSI.
- Feed rate: Feed rate of the abrasive was varied using Schmidt valve connected to the bottom of the blast pot, corresponding to 3, 4 and 5 turns open condition of the valve.
- Blast nozzle: Blast nozzle, BAZOOKA # 6, was employed in the experiment.
- Blasting time: The total blasting time was measured for each run using a stop watch.
- Sampling time was constant for all the runs: 2 minutes at each traverse point adding up to a total of 16 minutes for an entire run.

Dependent parameters measured in the field specific to each run are listed below:

- Area cleaned: The blasted area was measured using a measuring tape.
- Emission Factors: Emission factors can be defined as the amount pollutant emitted per unit output work done or amount of pollutant emitted per unit mass of raw material consumed. In this report, emissions factors are expressed as follows:
    - Mass of pollutant emitted (g) / Area Cleaned (sqft)
    - Mass of pollutant emitted (g) / Quantity of abrasive used (lb)
    - Mass of pollutant emitted (lb) / Quantity of abrasive used (lb)
    - Mass of pollutant emitted (lb) / Quantity of abrasive used (ton)
- Productivity: Productivity was calculated knowing the area cleaned and the time consumed for the cleaning.
  Productivity (sqft/hr) = Area Cleaned (sqft) / Total Blasting Time (hours)
- Consumption: It is defined as the mass of abrasive consumed per unit area cleaned
  Consumption = Quantity of Abrasive Used (lb) / Area Cleaned (sqft).

5. Current and Potential Benefits

Dry abrasive blasting project carried out using this research methodology will help in achieving the following specific goals:

- Understand consumption, waste generation potential and emissions of particulates, size specific PM (coarse, fine, and ultra-fine), and metal emissions
- Develop predictive (mathematical/computer) consumption and emission models that are useful in accurately determining waste quantities in multimedia streams for given raw material and process conditions
- Identify source/material/process changes including BMPs that will reduce solid wastes and air emissions thereby helping industries to make environmentally preferable purchases.

The research approach will greatly enhance the current knowledge on waste generation, abrasive consumption and emissions estimation from various industrial processes. This methodology will help estimate productivity, consumption and emissions from processes that can be simulated in controlled conditions. From the experimental results obtained, statistical and numerical models can be developed obtained for PM and metal emissions under varying source, material and process conditions. The models developed will help industries, scientists and regulatory agencies worldwide to identify changes in source design, process parameters and raw materials to reduce multimedia waste generated in terms of quantity and toxicity. The predictions obtained from these models can be used as thumb rules for minimizing consumption; emissions and optimizing raw material, operational and disposal costs. Industries use the existing emission factors in estimating their emissions while reporting to EPA and the state agencies. Using the consumption and emission models developed through this approach, industries as well as the regulatory agencies will be able to calculate waste generation and emissions more accurately. These models will serve as powerful tools in assisting industries to make environmentally preferable purchases in terms of raw materials, equipment, services, etc. The results of individual processes studied in this facility will aid human exposure and health risk assessment studies.

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DPM EMISSION CONTROL IN THE LARGE MOTOR YACHT INDUSTRY. THEORY, PRACTICE AND LEGISLATION

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The paper is a study of the current trends in emission control and in particular the generation of Diesel Particulate Matter, usually referred to as 'soot' or 'black smoke'. It provides information about the driving factors behind worldwide incentives to achieve an effective soot emission control, i.e. Owner requirements, operational requirements, acquisition and operational costs and legislation. Cruise ships and recently super yachts are the first in the marine sector to look at emerging technologies for soot emissions monitoring and control. However, the demanding nature of super-yachts with respect to the influence of operational profile on the load of propulsion engines and generators has created a unique impetus for engine manufacturers, systems suppliers and shipbuilders to develop more compact and cost-efficient soot reduction systems.

Efforts to regulate soot emissions from marine shipping have shown much progress in recent years, mainly inspired by the automotive industry, though hindered by the complexity of the problem. The paper outlines the existing regulatory framework, identifies opportunities for near-term cost-effective DPM emission reduction techniques and highlights the need for incentives to gain momentum in reducing marine shipping soot emissions through research and development programs.

The foremost intent is to promote substantial discussion between the different shipping industry parties over the future of DPM emission control technologies by drawing attention to the continuously expanding (in yacht numbers and physical size) mega-yacht industry.

1. Introduction

Marine diesel engines have become a growing concern with respect to air and water pollution from DPM mainly because of the following reasons:

- Worldwide research on emissions from diesel engines has revealed many of the unknown properties of DPM and the impact it has on total emissions.
- Pressure from health and environmental bodies; we still do not know exactly which of DPM's properties the most important ones to control so that health and environmental effects are reduced and study of this subject is still in progress.
- Regulations; steep pollution penalties emanate from air and water discharges, especially in sensitive areas that large yachts usually operate (Mediterranean ports, U.S. marinas and Californian waters, etc)
- Market pressures; engine manufacturers are under pressure from owners for "zero-emission" engines. Yacht owners do no longer tolerate visible emissions from their ships. No matter, though, how visible emissions might be, they still exist in a state of ultra-fine structure that can have a worse health impact. Some particles are large or dark enough to be seen as soot or heavy smoke either in ambient air or sea, but ultra-fine particulate matter (nanoparticles) is not visible to the naked eye; however, fine particles absorb and scatter light so that a cloud or plume of these particles may be visible. It is not uncommon for white painted yachts to look perfectly clean but a simple finger touch may reveal previously invisible soot accumulations.

This paper attempts to clarify the basic principles of "soot" generation with the help of experimental results from existing yachts and provide an insight into the effects of fuel and lube oil selection on final emission control strategy. Whereas the extent of this subject is vast and not yet fully comprehended there are, however, plenty of useful conclusions that can be drawn from the large motor yacht industry and the expanding international regulatory framework for ship emissions.
The following table presents a summary of the abbreviations used:

Table 1 – List of Abbreviations.

CDPF	Catalyzed Diesel Particulate Filters
DOC	Diesel Oxidation Catalysts
DPF	Diesel Particulate Filters
DPM/TPM	Diesel/Total Particulate Matter
EC	Elementary Carbon (C)
EPA	Environmental Protection Agency
FBC	Fuel Borne Catalysts
FSN - BSN	Filter Smoke Number – Bosch Smoke Number
HC - THC	Hydrocarbons – Total Hydrocarbon Content
MCR	Maximum Continuous Rating
MDF	Marine Distillate Fuels
MGO	Marine Gas Oil fuels
OC	Organic Carbon
PAH	Polycyclic Aromatic Hydrocarbons
SECA	Sulphur Emission Control Area
SOF	Soluble Organic Fractions
TC	Total Carbon content
VOC	Volatile Organic Compounds

2. Background: diesel particulate matter formation

Although it is not the major intent of this paper to explain all the complex mechanisms and parameters of DPM formation, a substantial understanding is essential of the fundamental principles of different types of particle generation and the factors affecting them.

The size distribution of DPM differs from engine to engine, among fuels and among different operating conditions in the same engine. Factors such as engine load and exhaust dilution (Fig. 1), incomplete combustion, fuel impurities, wear and tear of the mechanical parts, remnants of lubricating oil, unburned fuel oil and the use of fuel additives, are some of the major factors that influence the size and composition of combustion particles. Although the focus used to be the mass of particulates, the engine technology resulting in the emission of finer particles and their impact on health, have shifted the focus to their size characteristics. Diesel particles are relatively fine; the typical particle has a small diameter of less than 1 μm. Therefore, it seems very likely that future regulations will be based upon a size distribution of DPM [19].

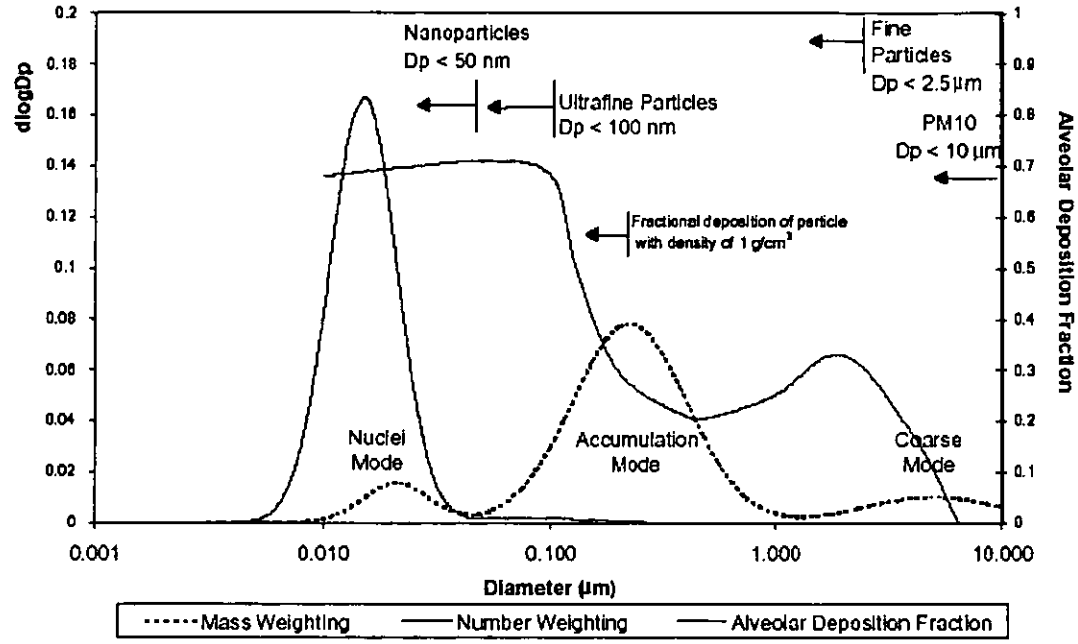

Fig. 1 - Typical engine exhaust size distribution where the number concentration of PM is dominated by nucleation mode particles; both mass and number weightings are shown [4].

Several approaches are been developed to determine the composition of Total Particulate Matter (TPM) and sorting into groups of substances with different properties. The simple standard method of analytical chemistry for the composition of DPM, breaks it down into soluble and insoluble - organic or non-organic - fractions, whilst another approach classifies solid and volatile or semi-volatile - organic or non-organic - compounds. The different categories are, therefore based upon the measurement technique used to determine the structure, composition and size of particles.

The soluble part of the TPM comprises fractions of unburned fuel and evaporated and atomised lube oil that escaped oxidation and appear as volatile or soluble organic compounds. These are most commonly known as Volatile Organic Compounds and Soluble Organic Fractions, respectively. VOC consist of Polycyclic Aromatic Hydrocarbons containing oxygen, nitrogen and sulphur and may remain gaseous or may undergo gas-to-particle conversion to form the SOF, the extractable fraction of DPM ([2], [4], [10]). The heaviest PAH therefore, make up the SOF fraction of DPM, while the lightest remain in the gaseous phase as hydrocarbon emissions. This explains why sometimes HC are considered separately from the particulate matter in regulatory standards (e.g. EPA standards), because of their gaseous state. In general, the SOF varies with engine design and operating conditions.

The insoluble fraction of the TPM consists of Elementary Carbon (also known as "soot"); that is solid carbonaceous particles formed during combustion in locally fuel rich regions where pyrolysis of the fuel constitutes the beginning of all forms of soot formation. It is common to use the word "soot" for the Total Carbon contained in the emissions, where

$$TC = EC + OC \qquad [OC : \text{Organic Carbon}],$$

due to OC's (SOF's) ability to absorb or adsorb onto the surface of the carbonaceous core of diesel particles, thus increasing their size and mass (Fig. 2).

The insoluble fraction also consists of sulphates. These can be formed as most of the sulphur content of the fuel oxidizes to SO_2, which under certain conditions (e.g. the use of diesel oxidation catalyst) is further oxidized to SO_3 leading to undesirable sulphuric acid and sulphates formation.

Recent research has shown that the sulphuric acid and metal contaminants originated from lube oil or fuel additives can act as nucleation sites for the SOF and that the particles are growing by adsorption onto the metal traces or absorption into the sulphuric acid.

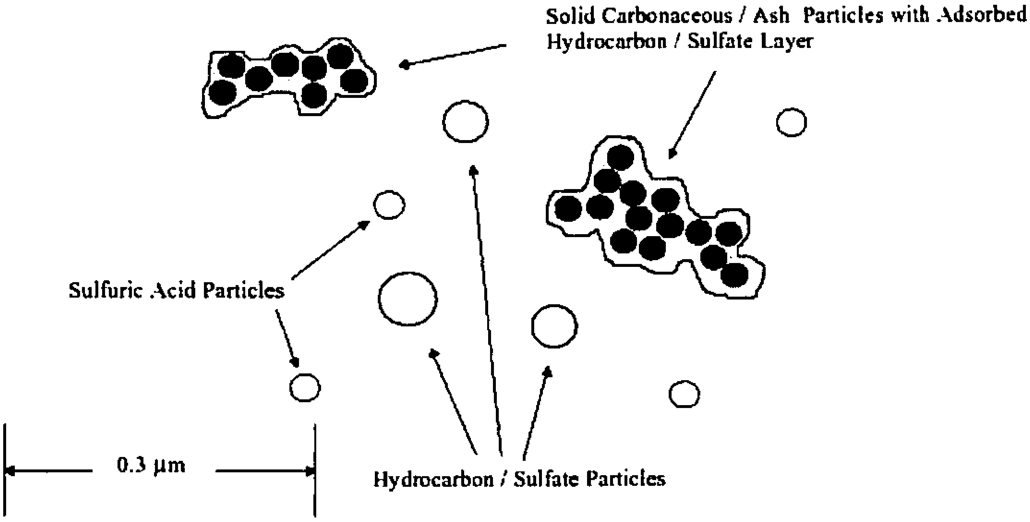

Fig. 2 - Typical structure of engine exhaust particles [4].

- In conclusion, an engine producing a large amount of volatile material but a low amount of carbonaceous soot is likely to have more particle nucleation and growth than an engine producing an equal amount of volatile material with more carbonaceous agglomerates [2]. Given that the SOF values are higher at light engine loads where low exhaust temperatures are present, it is therefore explained why higher levels and larger agglomerates of soot are formed during low engine load operation.
- Secondly, it is shown that the sulphur content of the fuel and the lube oil (in the case of low sulphur fuels) has an immediate effect on the entire TPM formation and not just in terms of the SO_x content in the exhaust emissions.
- Thirdly, fuel or lube oil additives may reduce the particle mass or reduce the regeneration temperature, however under certain conditions may act as precursors to the formation of high number of nanoparticles, thus reversing the soot reduction process. Consequently, lube oil may, under unfavourable combustion conditions, augment the rate of DPM coagulation, even when low sulphur fuels are used in super-yachts.
- Fourth, particle ageing is a major parameter that determines the entire process of DPM formation, growth and emission behaviour. Complex exhaust systems like those used on medium to large size yachts for ship side instead of funnel discharge, without any sort of exhaust after-treatment, easily promote soot agglomeration even on engines tuned for the finest combustion.

3. Global regulations as a driving force for engine emission technology

The key points of reference when designing a new ship, regardless of whether this is a merchant trading vessel, a navy combat ship, a large ferry or even a luxury mega yacht, are standards and regulations. There are indeed numerous and different sets of rules that determine structural and engineering detail onboard a ship to ensure a substantial level of reliability, redundancy, safety, cost efficiency and environmental friendliness. Exhaust emissions are a major factor concerning the environmental impact of a vessel and along with the type of fuel used and the pattern of operation and maintenance, have a key influence on the main and auxiliary engines selection process.

Current legislation on exhaust emissions from marine diesel engines is generally based upon the MARPOL Annex VI [1] that comes into effect on May 19, 2005 and contains requirements for ships over 400 gross tons to limit NO_x and SO_x emissions from ships, but sets no standards for CO or TPM. The Marine Environmental Protection Committee (MEPC) is currently focused on greenhouse gas emissions from ships but at the same time there is plenty of activity in the EU for tighter sulphur limits below the agreed 4.5% w/w and 1.5% w/w in SECA's down to 0.5%, possibly by 2010. In addition, where a post-combustion gas-cleaning mechanism is used to reduce exhaust emissions, the SO_x emitted are not to exceed 6 g/kWh [1] and there are tighter measures for 2 g SO_x/kWh under review by the EU.

While it has been established within the EU that shipping is a matter for IMO, the Commission has been very keen at present on taking active measures for regulating and cutting down emissions from ships [7]. There are proposals to amend Directive 1999/32/EC [8], while the recently adopted Directive 2004/26/EC (amending Directive 1997/68/EC) [24] follows the steps of EPA to set new standards for emissions of NO_x, PM and CO for new non-road engines marketed within the EU, including engines for use aboard vessels operating on inland waterways. These new limits are of similar format to the ones proposed by EPA and are gradually going to be strengthened over the time period 2006-2014.

Table 1 presents the Tier 2 emission limits for the different engine sizes including those on recreational vessels; Yachts not intended for charter fall into this category.

Table 2 – Tier 2 Standards for Marine Diesel Engines [21].

Category•	Displacement (liter/cylinder)	Power (kW)	Tier 2 Model Year	HC+NOx (g/kW-hr)	PM (g/kW-hr)	CO (g/kW-hr)
Small	-	<8 kW	2005	7.5	0.80	8.0
	-	8≤ kW <19	2005	7.5	0.80	6.6
	-	19≤ kW <37	2004	7.5	0.60	5.5
Commercial C1	disp. <0.9	≥37kW	2005	7.5	0.40	5.0
	0.9≤ disp. <1.2	-	2004	7.2	0.30	5.0
	1.2≤ disp. <2.5	-	2004	7.2	0.20	5.0
	2.5≤ disp. <5.0	-	2007	7.2	0.20	5.0
C2	5.0≤ disp. <15	-	2007	7.8	0.27	5.0
	15≤ disp. <20	<3300kW	2007	8.7	0.50	5.0
	15≤ disp. <20	≥3300kW	2007	9.8	0.50	5.0
	20≤ disp. <25	-	2007	9.8	0.50	5.0
	25≤ disp. <30	-	2007	11.0	0.50	5.0
Recreational C1	disp. <0.9	≥37kW	2007	7.5	0.40	5.0
	0.9≤ disp. <1.2	≥37kW	2006	7.2	0.30	5.0
	1.2≤ disp. <2.5	≥37kW	2006	7.2	0.20	5.0
	2.5≤ disp. <5.0	≥37kW	2009	7.2	0.20	5.0

The U.S. EPA on the other hand has set alternative standards to apply to engines on all U.S. flag vessels but is considering applying them to engines on foreign flag vessels too, that operate in waters under the U.S. jurisdiction [9]. The U.S. have not ratified Annex VI to date but under the Section 213 of the Clean Air Act which directs EPA to set standards for different categories of marine diesel engines, ship emissions are regulated depending on the engine size (for example for engines above 30 litres per cylinder) or on the operating pattern (e.g. recreational vessels). The first (Tier 1) emissions standards are separate from but are comparable to Annex VI, while the subsequent Tier 2 standards for new engines built after 2006 are expected to set even tighter emission limits. These standards have included NO_x, Total Hydrocarbons (THC), PM and CO limits as shown on table 1.

Although large yachts (i.e. those fully SOLAS compliant) are not actually affected by SECA restrictions and need only to fulfil the present 4.5% m/m maximum fuel sulphur content, efforts are continuously being made to get the lowest possible emissions. However, it is worth noting that while larger yachts burn the lighter MDF grades and there is a tendency for new builds to burn only MGO/DMA, the relatively low sulphur content of these fuels (max. 1.5% m/m for DMA but on average around 0.5% m/m) is not low enough to guarantee a complete 'zero-emission' emission strategy, as explained later.

4. Health and environmental considerations

Whereas the health and environmental effects have not been fully identified to date, there has been since the early nineties growing international activity in this area. The problem of fine particulate emissions is currently being discussed with regard to air quality. The World Health Organization, the EU Commission, the National Research Council and Environmental Agency in the United States, are highlighting fine particulate matter as one of the current priorities for environmental protection in Europe and the United States. There are also indications of health effects such as asthma, difficult or painful breathing, and chronic bronchitis, especially in children and the elderly. DPM is also thought to cause lung cancer and is therefore listed as a mobile source air toxic. Fine particulate matter can also travel long distances and thus is a major cause of haze, which reduces visibility, affecting cities and coastal and river areas. In order to protect public health, a technically feasible PM reduction of well over 90% has been suggested for diesel engines [20].

Ship emissions have been estimated to contribute between twenty to thirty per cent to the air concentrations of secondary inorganic particles in most coastal areas [8]. The vast majority (>90%) of direct DPM emissions from mobile sources in general are in the fine-PM size range. Fine particulate matter, that is liquid and solid particles with a diameter of 2.5 microns or less (known as $PM_{2.5}$) and ultra-fine particles (<100nm) are believed to have more effect on our health, as they are more likely to reach the deep lung tissue because of their greater surface area per unit mass. Moreover, such small particles make it easier to carry other toxic components to the human body. However, inhaled particulates behave in a different way depending on their solubility characteristics. Soluble PM, such as SOF can be easily dissolved and dispersed all over the human organism through entering our blood stream [23]. It can be assumed that their toxicity depends on the total mass dispersed or even the existence of carcinogenic PAH. On the other hand, insoluble particulates, depending on the location of deposition, may take years or even stay inside the lungs for life with diverse toxicity effects being affected by their size and composition.

Regarding sulphates there are many controversial studies about potential health risks, however most studies show that sulphates do have an effect on health [12]. From an environmental point of view, initial findings are favourable for water injected exhaust systems, that are used extensively on smaller to medium size yachts and for dry exhaust gas scrubbers, as sulphates are regarded natural elements of sea water with no harmful impact [18].

PM pollution is an environmental problem affecting urban and non-urban areas on a worldwide scale. Marine diesel engines contribute to ambient particulate matter levels in two ways:

- First they contribute through the direct emission of soot particles (EC).
- Second they contribute to indirect emission of PM through the emission of organic carbon

(OC), especially hydrocarbons (PAH). As already shown, organic emissions are transformed into particles in the atmosphere and other volatile or semi-volatile organic compounds (VOC / SVOC) can condense if emitted in cooler temperatures.

According to EPA findings, OC accounts for between 27 and 36 percent of ambient particle mass depending on the area [21]. The effect on visibility has been another clear measurement of the environmental effect of DPM, as visibility degradation is often directly proportional to decreases in light transmittal in the atmosphere and scattering by both gases and DPM reduce light transmittal. Fine particles with significant light-extinction efficiencies include VOC, sulphates, nitrates and elemental carbon EC (soot) [21].

5. Practical implementation of TPM abatement techniques

5.1. The influence of marine fuels on TPM emissions.

World ship fuel demand is essentially covered by several types of oil products, ranking from marine distillates to marine fuels. Heavy fuel oils or bunkers are mainly used in large ocean-going merchant vessels and are the least expensive mixtures of residual oil and distillates. These need to be treated i.e. centrifuged and filtered before using them and contain much higher organic nitrogen content, metals and sulphur content than the lighter distillate fuels. Consequently, they produce higher NOx, SOx and TPM emissions.

Contrary to the commercial vessels, large yachts nearly always use distillate fuels such as marine gas oil (MGO/DMA), less frequently distillate marine diesel oil (MDO/DMB) and very rarely blended marine diesels (MDO/DMC) for their main and auxiliary engines as owners are more concerned about 'smoke-less' operation of their yachts. The MDO/DMC grade may contain up to 10% IFO blended with either marine gas oil (MGO/DMA) or distillate marine diesel (MD/DMB) [5]. In general marine gas oils contain high amounts of aromatics which for DMA can be up to 60% m/m and is favourable to achieve "invisible" DPM emissions; that is the particle growth in the accumulation mode is restricted due to shortage of carbon and perhaps metal precursors. Therefore, PAH and SOF can remain either in the gas or droplet form or undergo the gas-to-particle transition to form a large number of nanoparticles.

In fact, in some areas marine gas oil (DMA) can be automotive diesel with maximum sulphur content according to current EU regulations of 0.035% m/m, due to be 0.005% m/m maximum in 2005 that is 350 ppm and 50 ppm, respectively [5]. In this case the type and sulphur content of lube oil required for adequate lubrication of the engine parts have to be considered very carefully in order to avoid adsorption of inherent SOF into lube oil originated precursors, thus getting large particulate compounds.

The rather low nitrogen content in these fuels does not promote high NO_x emissions and has an insignificant effect on total emissions. As the majority of NO_x originates from the reaction of nitrogen and air at high temperatures, decreasing DPM emission by high combustion temperatures and larger surplus of air in a direct-injected marine diesel engine favours the formation of NO_x [15]. Consequently, there needs to be a compromise between DPM and NO_x reduction. This is now dealt with by the engine manufacturers using NO_x favourable combustion conditions and by owners and shipyards by the addition of DOC and soot filters. DOC can be used to reduce DPM emissions to a certain extent, although their efficiency is restricted by the operating conditions and the sulphur content of the fuel used. They can have very good results in oxidizing SOF, the lighter hydrocarbons and even CO but they have no effect on EC (soot) which can be significant for older engines. The carbonaceous fraction of DPM cannot be oxidized and remains unaffected as it passes through the catalyst. A combination of a DOC and a DPF (soot trap) is considered a really promising option for large yachts with state-of-the-art engines. Using this method in such engines that produce relatively lower amounts of EC, we can significantly reduce DPM by oxidizing the largest SOF of the emissions. DOC, however, oxidize also the SO_2 to SO_3 which increases the formation of TPM emissions by the generation of H_2SO_4 and sulphates. In fact, the sulphates that can be generated in the catalyst at temperatures at or above 400 °C with fuel sulphur levels of just 500 ppm (DMA sulphur content ranges between 2000-5000 ppm) offset the effective removal of SOF and increase the total particulate emissions from the engine [16]. We very often come across exhaust temperatures in this range, on 1.5-3 MW medium speed main engines or generator sets of very large yachts; typically above 80 m in length.

Therefore, it is evident that the fuel oil selection is a vital element for an integrated emission control strategy. Switching to better distillate or ultra-low sulphur fuel oils, providing all other combustion and lubrication parameters are suitable, has been shown to have a positive effect on DPM and total emissions, in general. The problem, however, regarding TPM can be transformed, rather than eliminated, by emitting larger numbers of invisible, though more harmful nanoparticles ([10], [11], [12]). Current studies on the subject ([4], [10]) show that post-combustion after-treatment measures are hitherto deemed necessary to eliminate PAH and solid particles.

5.2. Experience from existing vessels

We have investigated the reduction of TPM levels in two separate but closely related areas:

- Existing yachts, where refit of existing engines and/or installation of post-combustion aftertreatment devices is needed and,
- New construction.

For the existing yachts with lengths between 45 and 80 meters the problem was mainly with diesel generators that employ water injected exhaust systems. In all cases, high amounts of soot were found in both the dry and wet discharge of the exhaust leading to black deposits on the hull and corrosion of the nearby area (Fig. 3). As it has not been feasible to take accurate DPM measurements onboard, a qualitative assessment of emission cleanliness was provided either as visibility level of the smoke emitted or by Bosch Smoke Number (BSN) measurements. However, BSN measurements may not be accurate for low engine loads and exhaust flows.

The duty cycle for generator engines depends on the yacht operating profile but usually varies between 50% and 90% of engine MCR. During the night with no guests onboard the engine output can be as low as 40% for up to 8-10 hours per day. The exhaust temperatures usually range between 300-450 °C.

- In general it was observed that the engines produced excessive 'smoky' emissions at low loads and high load extremes. Moreover, it was found that more EC i.e. soot was formed at these load extremes, as we anticipated. This is thought to be due to higher temperatures in the combustion zone fostering fuel pyrolysis making incomplete combustion more likely. Another major factor is the particular water injected exhaust systems used, the backpressure readings for which can reach manufacturer's limits at high loads thus impairing combustion dramatically.
- Transient conditions such as sudden engine load changes produced 'plumes' of smoke which is a typical characteristic for older engines with less optimised combustion

technology.

- On some occasions "oily" PM discharge has been observed at the exhaust water discharge of the generator which is a sign of high unburned fuel and PAH content.
- Several engine exhausts suffered chemical/electrolytic corrosion attack on various components accompanied by localized pitting corrosion spots (Fig. 4). Pitting corrosion is a typical result when corrosive agents like warm seawater and sulphuric acid are present.

Remedial actions to improve the situation included:

- Overhauling of air intake filters and engine room ventilation to ensure an adequate air supply, replacement of fuel injectors and fuel pumps, injection timing modifications by the engine manufacturer, etc.
- Use of light distillate, lower sulphur marine gas oil (DMA), instead of DMB/DMC.
- Overhauling the exhaust system components to reduce the effect of increased backpressure, such as the exhaust silencer, separator, piping, valves, etc and increasing their size or diameter accordingly.
- On one occasion a soot sinker was installed and tested. This was thought to increase the coagulation rate of PM on the wet side of the exhaust system. It was designed to produce larger globules of PM with consequently greater mass, allowing the PM to sink.

Apparently, the installation of a soot sinker is not considered an after-treatment system rather an attempt to quench the presence of PM and large sulphates-soot coagulates on the wet side of the exhaust.

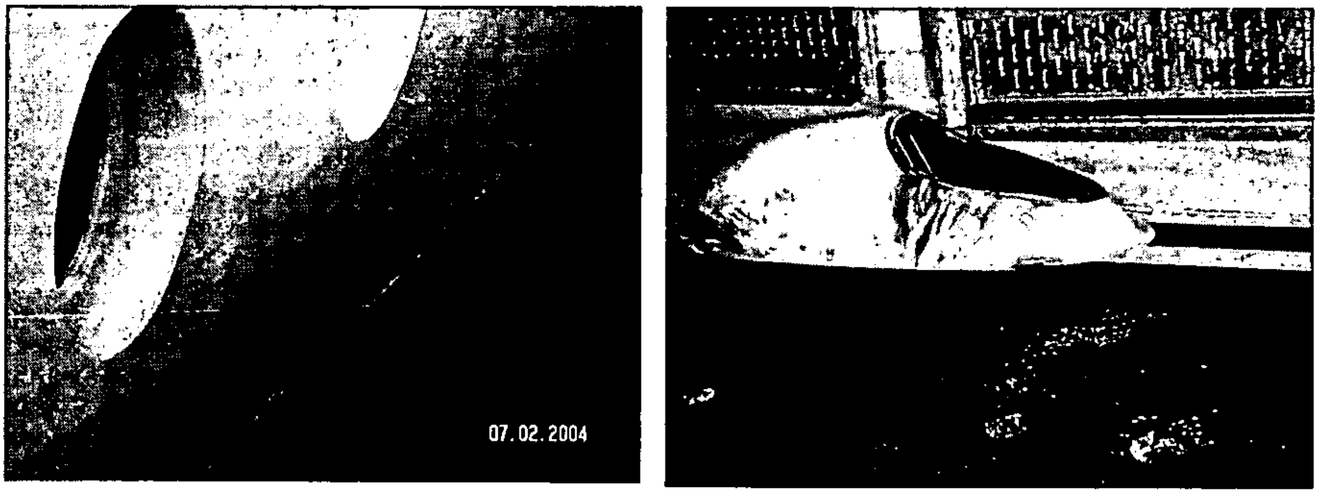

Fig. 3 – Typical examples of the condition of topsides of motor yachts with water injected exhaust systems and high DPM emissions.

After several months of operation under these conditions with careful maintenance and operation of the engines, the results were as diverse as the complexity of the DPM formation.

There was, no doubt, an advantage in replacing or upgrading parts of the engine and the exhaust so as to reduce backpressure, achieve better combustion and eliminate corrosion sites, especially on the wet stream. The soot sinker installation did not really have the expected results; there were some larger insoluble soot particulates, 3-4 mm in size, but in general not big enough to sink. The oily soot discharge has reduced since then, however this can also be attributed to better combustion at low loads and lower amounts of HC emitted. On average, there was a moderate improvement of the emissions on the dry stream of the exhaust, but generally DPM emissions remained visible, namely BSN levels above 1 minimum.

On one of the occasions where a catalytic converter was installed (CDPF) although emissions were still visible staining the topside of the vessel they were easier to clean than previously. To the surprise of the engineering crew when they overhauled the CDPF it was found perfectly clean, however the exhaust system after the water separator was choked full with solid carbonaceous compound that had to be dug out in order to clean (Fig. 5).

These results prove adequately what has been stated earlier i.e. the catalytic filter could have oxidized the relatively low amounts of SOF and HC while the major part of the emissions consisting of soot and heavier PAH, remained virtually unaffected. As a result, they passed through the catalyst-coated walls of the filter and formed huge compounds within the piping. Low exhaust emission temperatures (300-400 °C) proved inadequate for the filter to catalytically regenerate solid nucleated carbon particles and accumulation was prevented by a shortage of SOF. Moreover, for a continuous regenerating filter to work properly requires a virtually sulphur-free fuel (<10 ppm) otherwise unacceptably high emissions of sulphate are generated. At the same time the reaction $NO \rightarrow NO_2$ is reduced so that the reverse reaction ($NO_2 \rightarrow NO$) occurring at the filter which releases the required oxygen for oxidizing the soot (already at low temperatures), is dramatically reduced.

High sulphate formation and subsequent cooling of the exhaust emissions downstream of the water injection point and subsequent separation are also believed to have acted as local precursors of high carbonaceous-sulphate compound formation on the walls of the exhaust piping, a process usually referred to as ageing.

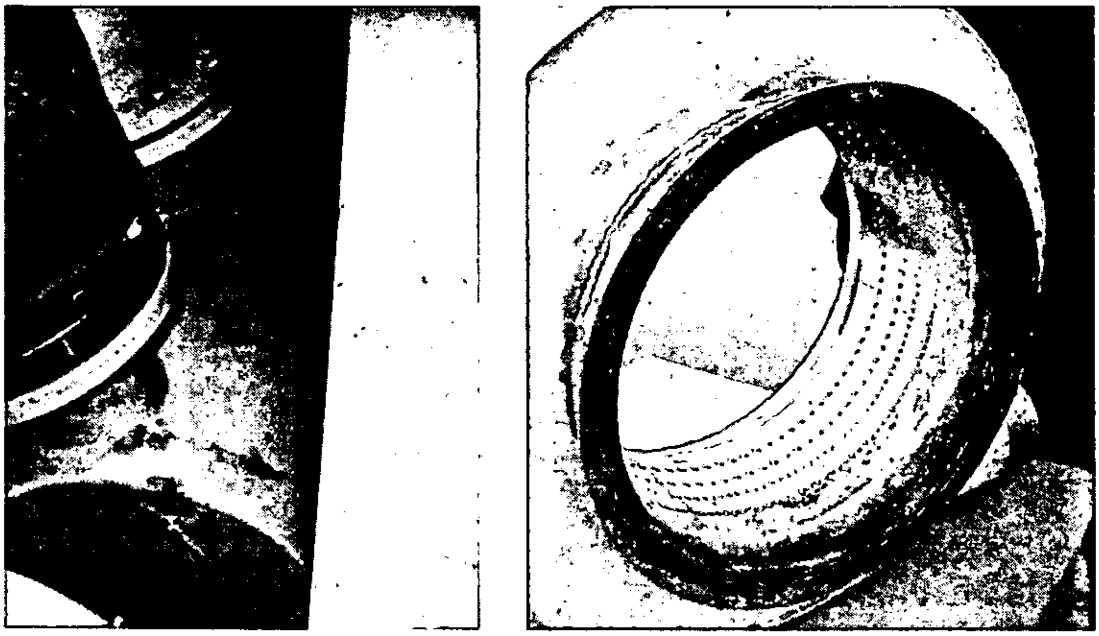

Fig. 4 – Signs of general corrosion for a water exhaust muffler (left) and a spray water injection ring (right) of a 150 kW generator engine, both made from st. steel 316L. Both of them were replaced by GRP and Inconel 625, respectively.

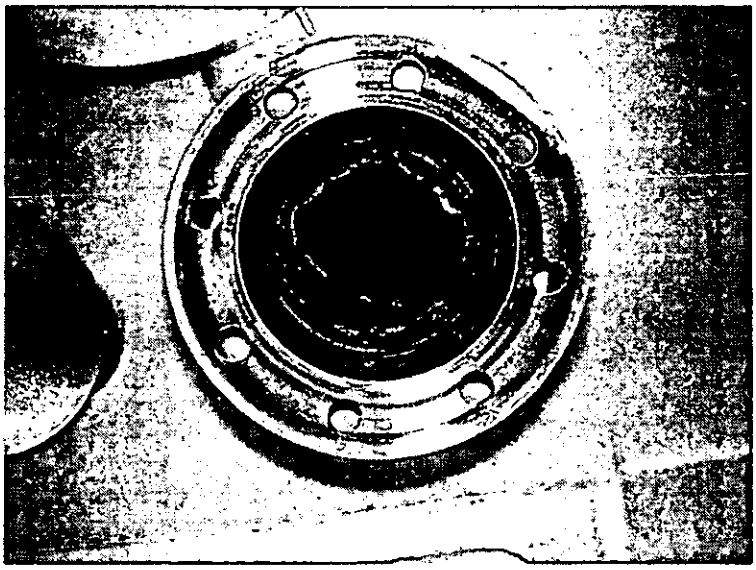

Fig. 5 – Dry exhaust outlet from the silencer clogged with solid carbonaceous particulate matter.

5.3. Present and future considerations for TPM abatement in new builds.

A common argument in the marine industry, in general, is that additional emission standards could cause engine manufacturers to compromise engine performance. Experience also has shown that trying to implement post-combustion DPM emission reduction technologies during the preliminary design of a new build, requires larger engine compartment and/or casings which results in reduced living spaces inside the Yacht. The problem may get even more complicated when combined with the non-conventional engine room arrangements for the latest generation of very large yachts that employ Diesel Electric propulsion options and azimuthing podded propulsors.

Another important aspect is the transfer of new technology to marine diesel engines. In particular, diesel engines used in large yachts either for propulsion or generator purposes can be land-based versions modified by the engine manufacturers ("marinised") to be used in marine applications. During the last few years however and with the demand for low sulphur marine distillate fuel, the aftertreatment technology has started to be considered a viable option and some manufacturers have started to look towards this direction.

The same "in-cylinder" emission control strategies that are used in commercial marine engines are now used on almost every new build super-yacht. These technologies include improved combustion control through electronic engine management of timing and duration of injection, improvements to fuel injectors and injection control (higher injection pressures), combustion chamber design modifications, advanced turbocharging and separate circuit aftercooling.
Selective shut-off of single injectors and optimised exhaust valve timing can have a remarkable effect on keeping the smoke emissions below the visible limit at very low speeds. The selective shut-off injectors can give more balanced engine operation than cutting out whole cylinders as required by systems with individual fuel injection pumps [22]. Additionally, dual stage or separate charge air coolers have been considered in various engine configurations to optimise the combustion air temperature when starting the engines to avoid smoke plumes, although there are many contradictory opinions among engine manufacturers and the efficiency of such a measure is yet to be established.

Regarding post-combustion aftertreatment measures, the major efficiency concern for larger engines i.e. above 500 kW brake power, seems to be regeneration. At present, the available DPF regeneration systems for the marine market are of 3 distinct types:

- Regeneration by means of diesel burners
- Periodic electric regeneration with the use of special ceramic or metal fibre heating filter elements.
- Low temperature regeneration with the addition of fuel additives (FBC). FBC lowers the soot ignition temperature from above 650 °C to 300-400 °C and consist of metals such as Fe, Mg, etc. that re-appear as ultra-fine particles in the exhaust gas and need to be filtered, accordingly.

The first two means of active regeneration mentioned are still under development and are currently being tested in several new-builds. Engine backpressure limitations have been the crucial operation parameters for every DPF installation, as in order for a DPF to operate effectively it needs under all load conditions to satisfy the following rule:
The soot burn rate has to be greater than the soot accumulation rate, otherwise the filter will "plug".

Consequently, the first option is at present seen as favourable for smaller generator engines (100-500 kW) that usually generate high carbonaceous particle emissions and primarily found in water injected exhaust installations where the available backpressure is limited. The filter and regeneration technology for these marine engine sizes is currently under development.

The heating elements operation clearly depends on the quantity (number and size) of DPM emitted. So far, the first results have shown that in order to follow the above rule and avoid filter plugging particularly for higher engine powers (>500 kW) the system gets very bulky and less cost efficient, i.e. consumes huge amounts of electric power. It was typical in the past to install twin DPF systems with heating elements and the time needed for regeneration of the first filter could be greater than the time it took for the second one to get clogged by soot. Thus the engine backpressure was increased, considerably. It can be concluded that for periodically regenerated systems with high DPM emissions, we either need high DPM burning rates or a very "bulky" arrangement which is not a practical option for yachts.

Several variations of CDPF also exist that similarly to DOC perform continuous regeneration at lower soot ignition temperatures. However like all catalytic converters they are sulphur sensitive (practically sulphur free fuel is required) and strictly dependent on operating conditions; peak temperatures from burning larger than normal soot flakes due to non-optimum operation of an engine can easily damage the catalyst. Hotspots have to be avoided in catalysed filter traps. CDPF seem a promising option for future vessels that will be required to use ultra-low sulphur fuels.

Due to diverse electrical load demands, the use of electrical load banks has been utilised to artificially increase engine output preventing low load running. For any yacht this is uneconomical but it becomes increasingly so for larger yachts where minimum and maximum output are widely separated.

6. Summary and conclusion

This paper has given an overview of the complex nature of DPM and the way it influences the total emissions from a marine diesel engine. The analysis is deepened by presenting experimental results from typical problems on modern large motor yachts and suggesting future prospects on aftertreatment technology. No doubt, research on this subject is still ongoing with manufacturers testing systems currently required for on-road engines facing tighter emission restrictions to larger, more demanding and complex marine diesel engines. Perhaps the lack of knowledge on the subject of emissions has resulted in little consideration until recently of using methods to achieve SO_x emissions reductions for shipping. There is historical evidence indicating that where there is a demand for a solution, that demand stimulates the creation of solutions. And there is no doubt that an industry impetus will result in the achievement of substantially lower emissions, at appreciably lower cost than a regulated option ([13], [14]). Experimental results and initiatives are necessary to produce realistic regulations that available technology and knowledge can follow in an efficient and reliable way. Efforts are presently being made to generate means of real-time measurement of emissions throughout the operational life of an engine and not just when it is initially tested. Onboard measurement of emissions is another huge and controversial issue under development at present, which will influence aftertreatment technology and regulations substantially in the near future. A universally common approach from regulatory bodies will certainly help to avoid system complexity and confusion. However, harmonization of marine emission standards is not guaranteed with unilateral actions taken from numerous marine nations.

It is evident that environmental regulations will drive engine technology forward while emission restrictions will continue to tighten especially in US and European waters mostly affecting unpolluted sea resorts that large luxury yachts usually visit. The continuously expanding motor yacht industry will continue to demand the highest standards for exhaust emission quality and urge engine manufacturers and shipbuilders to develop experimental and theoretical tools that can be used to assess particulate formation for existing and new marine engines and reduce them in an efficient way.

7. Acknowledgements

The content of the paper is the result of extended research to the elimination of DPM exhaust emissions in large luxury Yachts. The support from every one at Nigel Burgess is gratefully acknowledged. Special thanks are extended to Ray Steele and all Captains and Engineers consulted for the invaluable feedback and assistance.

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LATE QUATERNARY CLIMATE CHANGES IN CENTRAL AND NW-AFRICA AS RECORDED IN MARINE SEDIMENTS

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Although its well known that the geological era of the Quaternary is characterized by repeated changes in climatic conditions all over the globe, our understanding of the responsible driving forces for these variations is insufficient. For example, the specific importance of high and low latitudinal processes is still under debate, as well as the causes for the recognized temporal shifts between different regions. Research on natural rapid changes in the past is therefore one essential prerequisite for a reliable prediction of future environmental development, specifically against the background of the indisputable influence of human activity on the Earth's climate.

1. Introduction and Brief Summary of the Presentation

The most direct information on the long history of continental climate can be deduced from terrigenous and marine sediments. Although terrestrial records offer more direct, yet only temporally limited insights into regional climatic developments, continuously settled marine deposits permit reviews back to the Mesozoic (e.g. Wagner 2002). In this connection, the terrigenous input to the ocean is of great significance for our general understanding of the relevant processes. Its variability in quantity and composition is mainly controlled by factors like humidity and land-ocean temperature gradients (Fig. 1 and 2). Especially during the last three decades investigations on this topic were intensified in the equatorial Atlantic as representing a particularly suitable key position on Earth (e.g. Parkin and Shackleton 1973; Street and Grove 1976; Sarnthein 1978; Kolla et al 1979; Kutzbach 1981; Pokras and Mix 1985; Mix et al. 1986; McIntyre et al. 1989; deMenocal et al. 1993; Foley 1994; Hughen et al. 1996; Ganopolski et al. 1998; Zabel et al. 1999; Mulitza and Rühlemann 2000, Zabel et al. 2001). This region represents a corridor for the global water mass circulation, the dominant process of the inter-hemisphere and latitudinal heat transfer on Earth. On the other hand, the equatorial Atlantic is characterised by the contact of meteorological cycles between Northern and Southern Hemisphere at the Intertropical Convergence Zone (ITZC). In a very simplistic description, there are mainly the contrasting temperatures between land and ocean, or on global scale, between polar regions and low latitudes, combined with air pressure gradients which drive the atmospheric circulation, and therefore control climate conditions and marine sedimentation. As simple as this system may appear, its function is highly complex because interacting sub-processes strongly influence this system. One emphasis of research was placed on the investigation of variations in the African monsoon system which primarily controls the transport of water vapor onto the West African continent. Despite the large scientific progress in this field, there are still open and intensively discussed questions which concern, for example a) the link between fluctuations in the African climate and evaporation in the tropical Atlantic, b) the interplay between high and low latitude forcing of African climate variability, and c) the cause of rapid climate changes, especially during late Quaternary.

Like mentioned before, sediments from the equatorial Atlantic represent outstanding archive material. The region of the tropical Atlantic is one of the most important depot centers for the input of terrestrial source material. Particles are supplied to this area by eolian and fluvial transport from both adjacent continents (Fig. 3). Related to the affected sea-floor area, the eolian dust input from the African Sahara and Sahel regions may possess the greatest importance for the composition of the marine sediments. Estimates for the terrestrial dust deposition rate range between 100-400 Mt/yr

(Prospero 1981). The largest quantity is, however, supplied by the Amazon River. Its discharge of suspended particulate material is estimated to amount approximately to 1200 Mt/yr (Gaillardet et al. 1997). Depending on the ocean current pattern at present, the bulk of this material is carried parallel to the coast-line in northwestern direction to the Caribbean (Milliman et al. 1975). Nevertheless, there is evidence that Amazon suspensates may constitute the dominant portion of the terrigenous fraction as far as the Mid- Atlantic Ridge (Zabel et al. 1999). However, in contrast to this tremendous input, the wash- outs of the Niger River and the Zaire River are comparably small (each approx. 40 Mt/yr; Gaillardet et al. 1999). Apart from these four main sources, some smaller rivers of local importance additionally supply their load of suspended material.

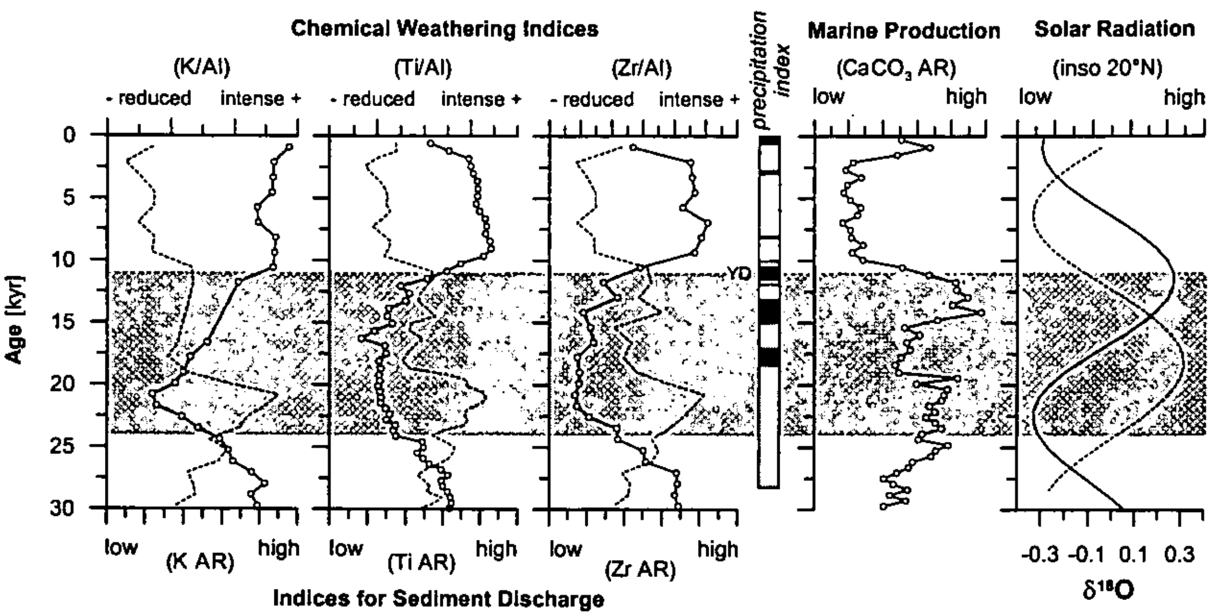

Fig. 1 - Comparison between indices of chemical weathering and sediment discharge (Niger River), marine productivity, solar radiation, $\delta^{18}O$ precessional signal, and precipitation index. Dotted lines belong to the lower axis. Precipitation intensity is based on pollen records from Lakes Bosumtwi and Barombi Mbo, and sea-level estimates. YR marks the Younger Dryas. (From Zabel et al. 2001)

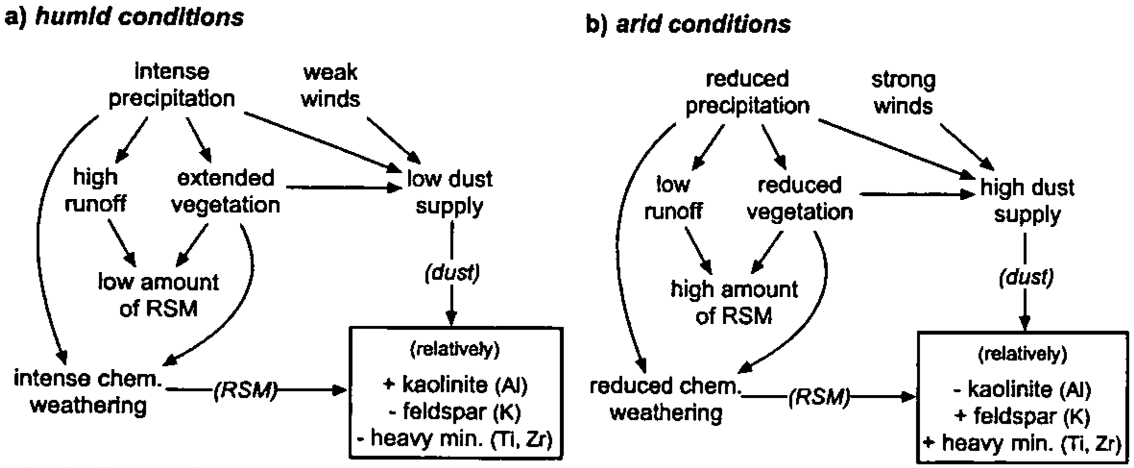

Fig. 2 - Relationships among factors controlling the composition of the terrigenous fraction in Niger Fan sediments during a) humid and b) arid conditions. In contrast to the eolian pathway, the composition of RSM depends more on the soil types than on the transport energy. (From Zabel et al. 2001)

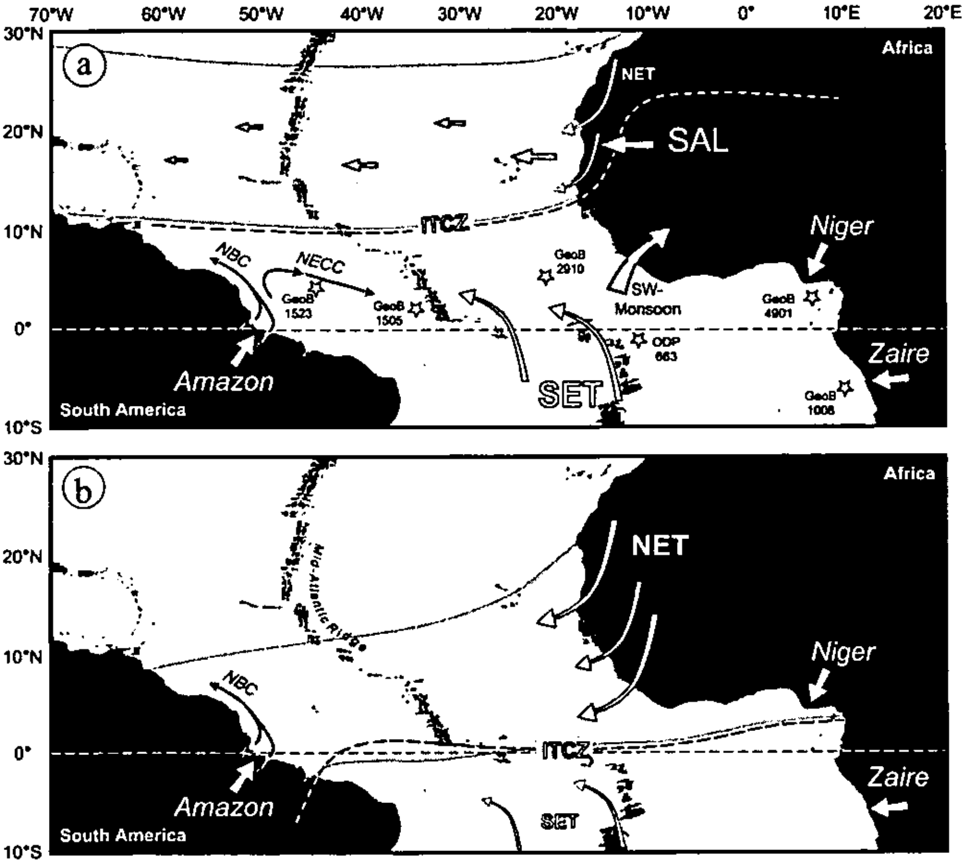

Fig. 3 - The equatorial Atlantic and source areas of terrigenous input. Current low, mid-tropospheric and underlying wind regimes and main river systems are additionally shown. Shaded areas indicate the seasonal positions of the dust plums (modified after Sarnthein et al. 1981). Stars mark locations for which records are presented. During the boreal summer season (a) strong SE trade winds (SET) move the Intertropical Convergence Zone (ITCZ) to about 10°N. African dust is mainly transported by the Saharan Air Layer (SAL). Because the enhanced retroflection of the North Brazil Current (NBC) which accelerates the North Equatorial Countercurrent (NECC), suspended matter supplied by the Amazon can drift eastwards (Zabel et al. 1999). During the boreal winter season (b) dust- loaded NE trade winds (NET) are dominant and the ITCZ is located close to the equator. River-suspended matter supplied by the Amazon is mainly transported in northwesterly direction. (from Zabel et al. 2004)

This presentation will synthesize some collaborative geoscientific studies on variations of the inorganic terrigenous fraction in marine sediments will be given which were conducted between 1997 and 2005 within the previous German Special Research Project 261 and the Research Center Ocean Margins. Beside examples from investigations of marine sediment cores, an additional focus will be set on the recent dust input to the ocean and its relation to climate conditions (e.g. Stuut et al. 2005).

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MID-CRETACEOUS EXTREME WARM CLIMATE AND THE MARINE CARBON CYCLE

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High-resolution, geochemical, isotopic, and molecular records from the Mid-Cretaceous tropical Atlantic are discussed in combination with climate simulations using GENESIS 2.0 to constrain the effects of orbital-driven fluctuations in African climate on ocean productivity, ocean chemistry, and black shale formation along the continental margin of the evolving Equatorial Atlantic Gateway. Marine records from ODP Site 959, recovered from the Deep Ivorian Basin off equatorial West-Africa, span a time interval of ~3 Myrs that covers one of the most important global climate transitions of the past 150 Ma, i.e. the transition from Mid-Cretaceous extreme warmth to Neogene cooling. The records presented improve our understanding of regional and global controls on tropical African climate, hydrological cycling and continental run-off, and the associated response in the tropical Atlantic. Coupling of geological records with global climate modelling provide a substantial progress in assessing and understanding controls of rapid change during past extreme warmth and its possible impact on coastal areas and continental margins.

Continental margins are sensitive to climate change, specifically to fluctuations in hydrological and nutrient cycling. As future global warming will affect human life and ecosystems specifically along coastal areas and continental margins with their associated sub-basins understanding the impact of climate change during greenhouse conditions is essential for all disciplines of the society. To improve our understanding it is indispensable to provide new cross-disciplinary, high-resolution geological climate records from past periods of extreme warmth. A surge of high-quality marine and continental paleoclimate records has become available in recent years that stimulated integrated research on climate and ocean dynamics during periods of extreme warmth, e.g. the mid-Cretaceous (e.g. Hesselbo et al., 2000; Jahren et al., 2001; Wilson and Norris, 2001; Norris et al., 2002; Voigt et al., 2004, Jenkyns et al., 2005). These new proxy records have provided a more precise picture how atmospheric and ocean properties have changed across latitudinal and bathymetric transects in response to climate fluctuations during periods of extreme warmth. The underlying causes and effects that operated during periods of extreme warmth however are still poorly constrained, especially for the impact of climate forcing and feedback mechanisms related to orbital forcing. This external control is known to essentially determine the temporal relationships of continental climate dynamics and the structure of ocean circulation.

Recent research on the dynamics of the Mid-Cretaceous climate-ocean system emphasize the importance of processes associated with the Land-Ocean interaction on the formation of organic carbon-rich sediments, i.e. marine black shale, and thus on the marine carbon cycle. Intervals of extreme warmth and enhanced sequestration of marine organic carbon, commonly termed Oceanic Anoxic Events OAE's (Jenkyns, 1980; Leckie et al., 2002 for review), are one prime focus of current paleoclimate research as they provide fundamental information on the functioning of biogeochemical cycles and their feedbacks during extreme conditions, especially when applied to areas expected to react sensitive to climate change, i.e. continental margins and their associated sub-basins. This study focusses on the final of the OAE's, the Coniacian-Santonian OAE 3. Black shales of that time interval have been reported from various basins surrounding the Atlantic and Tethyan Margin and the high latitude northern Ocean (Figure 1).

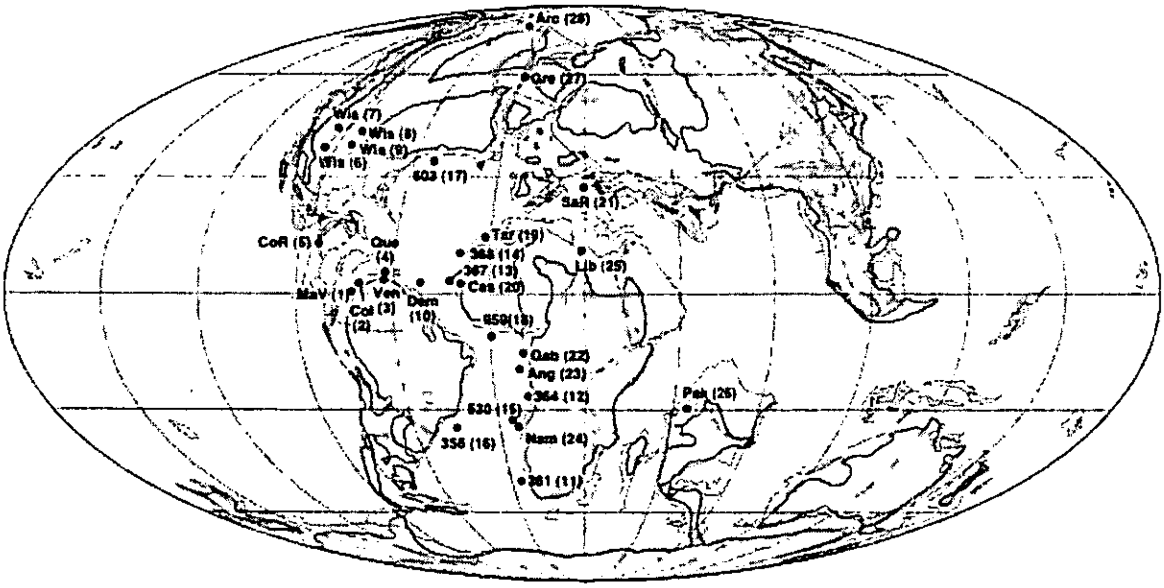

Figure 1 - Reported organic carbon-rich marine sites of Coniacian to early Campanian age superimposed on the paleogeographic map of the mid-Cretaceous at ~80 Ma (for locations and references see Wagner et al., 2004).

The recovery of a continuous, 1200 m long sequence at ODP Site 959 from the Deep Ivorian Basin off equatorial West-Africa covering sediments from Mid-Cretaceous (Albian) to the present day (Figure 2) and make this position a key location to study the long-term history of African climate and enhanced marine carbon burial (about 120 Ma) in a tropical near-continental setting along the evolving Equatorial Atlantic Gateway (Wagner, 2002). Of specific relevance for this study are expanded organic carbon-rich sections from the Mid-Cretaceous that cover one of the most important global climate transitions of the past 150 Ma, i.e. the transition from Mid-Cretaceous extreme warmth to Neogene cooling (Wagner and Pletsch, 1999). A unique record of Coniacian to Campanian organic carbon-rich sedimentation comprising the final of the OAE's (i.e. OAE 3) has been developed (Hofmann et al., 2003, Wagner et al., 2004; Beckmann et al., 2004, in-review) that provides new insights in the short term-climate variability and ist linkage to processes in the ocean.

The geological model for the Late Coniacian-Early Campanian OAE 3 interval is based on millennial-scale marine and continental proxy records from ODP Site 959. All records reveal a pronounced and persistent cyclicity that was attributed to orbital-forced (mainly precessional) fluctuations in continental supply from different African source areas and deep water redox conditions during the main period of the Oceanic Anoxic Event 3, the OAE-3 (Figure 3, Hofmann et al., 2003). The repetitive fluctuations in atmospheric and oceanic properties drove drastic changes in the rate of organic carbon burial (Beckmann et al., 2004) and were accompanied by extreme open ocean redox conditions, i.e. the temporal establishment of photic zone euxinia as indicated by molecular evidence (Wagner et al., 2004). The estimated average transient times from oxygenated to oxygen-depleted environmental conditions off Equatorial Africa were short, on the order of a thousand years or less, the duration of peak organic carbon supply and thus black shale formation was remarkably constant at about 5000 years followed by a gradual recovery period of about the same duration (Beckmann et al., 2004). The onset of maximum organic carbon burial rates however was delayed by about 1000 years relative to the runoff from tropical Africa (Beckmann et al., 2004) supporting the important conclusion that ocean properties in the tropical Late-Cretaceous Atlantic reacted to rather than triggered atmospheric circulation and hydrologic cycling. Simulation of total continental runoff from tropical Africa between 1-19°S and 15-45°W has shown that the 90°

precessional angle of the northern winter solstice (equivalent to modern spring configuration in an annual orbital cycle) caused the most extreme climatic contrasts on Africa that apparently promoted black shale deposition for the length of one-quarter of a precessional cycle, i.e. about 5000 years (Beckmann et al., in review).

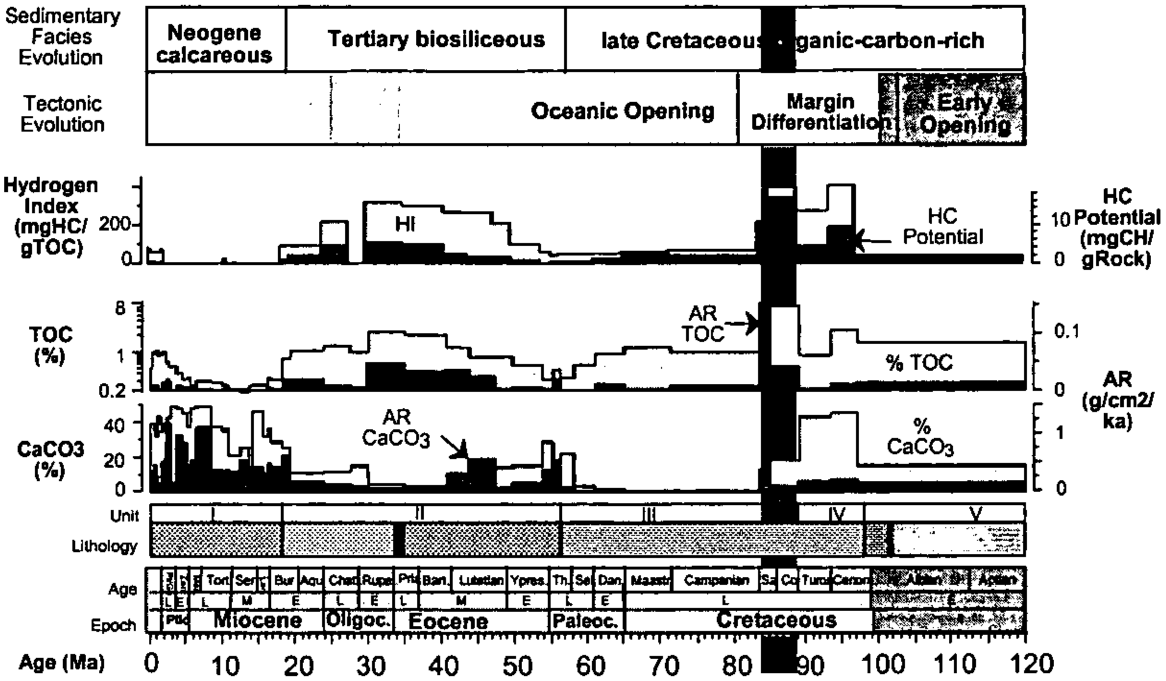

Figure 2: Cretaceous to modern trends in eastern Equatorial Atlantic carbonate and organic carbon deposition and development of associated petroleum geological measures at Equatorial Atlantic ODP Site 959. Red bar indicates research interval discussed in this study (modified from Wagner, 2002).

The climate record-based geological model implies some principle relationships between African climate and tropical Atlantic sedimentation that raise a number of fundamental questions. First of all it implies distinct fluctuations in African climate alternating between more arid and more humid conditions (aridity-humidity cycles). Results from global climate modelling support that conclusion showing pronounced precessional-driven chances in precipitation across tropical and mid-southern latitude Africa (Figure 4). These results question the location of the climate trigger (tropics or at higher latitudes?) and, if the trigger can be located at higher latitudes, what mechanisms connected the trigger source area to the response area? The nature of these questions is fundamental to verify the climate record-derived model and requests an approach that provides and links different critical climate parameters at local, regional, and global scale. Global climate modelling is capable to provide and integrate these data and thus has the capacity to improve models from geological records. Numerical simulations using the GENESIS (Global Environmental Ecological Simulation of Interactive Systems) General Circulation Model 2.0. are able to investigate the effect of precession of the equinoxes on key elements of the climate system. Different from previous modelling approaches, this study specifically examined the influence of precessional changes through intermediate setups allowing the analysis of one complete cycle as a continuum passing all of its four end member constellations (Flögel and Wagner, submitted), i.e. summer, spring, autumn, and winter. The transformation of orbital forcing down to marine carbon burial involves a succession of processes and feedback mechanisms that determine all elements of the hydrologic cycle. The process of signal formation at the ocean floor thus starts at the top of the atmosphere with solar insolation. Insolation is the key driver for evaporation, atmospheric transport of moisture, precipitation, surface and subsurface runoff, and ultimately total river discharge. As total river discharge is assumed to be the most important control mechanism for organic carbon accumulation on Site 959 all sub-compartments, from the top of the atmosphere to Earth's surface and further to the sea floor, are investigated (Flögel and Wagner, submitted). On short orbital timescales, the study provides new insights to the internal dynamics of climate, the different compartments of the hydrological cycle, and finally the sedimentary response within the oceanic realm during Cretaceous greenhouse conditions.

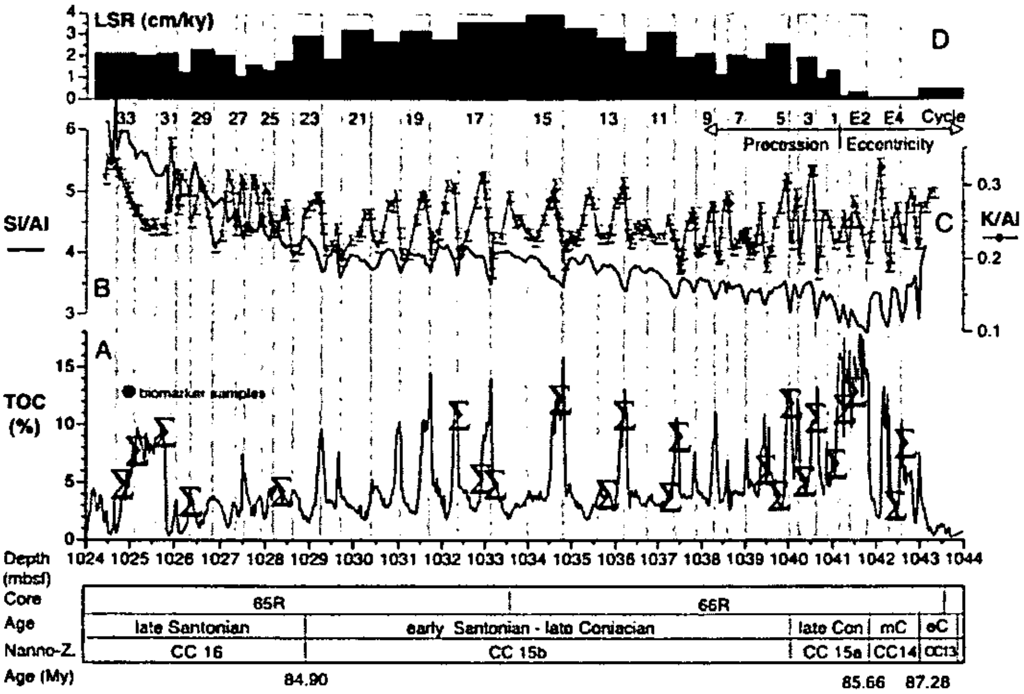

Figure 3: Cyclic fluctuations of (A) the total organic carbon (TOC) content, (B) the Si/Al and (C) the K/Al ratios with depth for middle Coniacian through late Santonian at ODP Site 959. Filled circles in (A) indicate position and TOC content of integrated samples selected for biomarker studies (modified from Wagner et al., 2004).

The modeling results show that the cross-latitudinal evolution of air pressure and wind fields likely linked tropical Africa to the mid-southern latitudes, at least during modern spring and summer orbital configurations. This previously unrecognized cross-latitudinal atmospheric teleconnection supports the conclusion that the tropics were less important as drivers of Cretaceous climate than previously proposed. Instead they suggest that tropical Atlantic black shale formation in the Late Cretaceous was ultimately triggered by climate change in mid-southern latitudes although indirectly transmitted through precipitation and runoff from tropical N-Africa. The mechanism connecting the trigger source area to the response area presumably was the temporal establishment of an atmospheric connection that imported humidity from the south to the response area in the north.

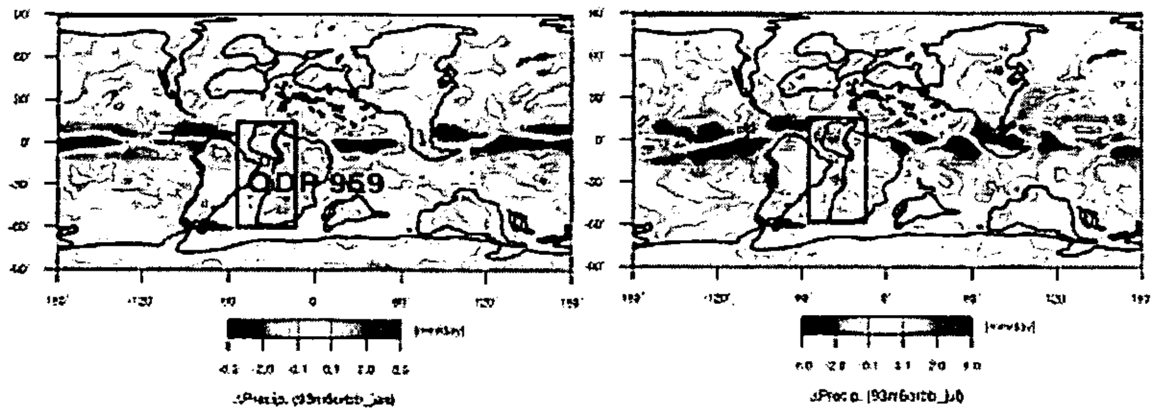

Figure 4: Annual variations in global precipitation as forced by precession at an angle of 90° (here shown as the difference to control run (<u>without</u> precessional forcing, 6xCO$_2$) based on global climate modeling (Flögel, 2002). Note pronounced changes between humid conditions during boreal winter situation (left image, ITCZ at southernmost position) and arid conditions during boreal summer situations (right image, ITCZ at northernmost position) for the tropical South-American-African sector (modified from Flögel and Wagner, submitted).

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A METHOD FOR PREDICTING BREAKING WAVE FORCES ON AN OFFSHORE WIND TURBINE SUPPORT STRUCTURE

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Abstract: As more and more offshore wind farms are being planned the effects of wave forces on the support structures is becoming an important issue. Unlike offshore platforms the wind turbine support structures, being mono-piles, are not as stiff and wave loading can become critical. The prediction of the wave loading on these structures, in particular for breaking waves, is not very well established. In this paper a prediction method developed for this purpose and the results obtained are presented.

1. Introduction

Due to the increasing difficulties of finding suitable onshore sites for wind farms, if the target of generating 10% of our energy requirements from renewable resources by 2010, then offshore wind farms have to be considered. In moving towards the offshore sites minimising transmission and maintenance costs would be the primary concern, limiting the feasible sites to within a few kilometres of the coast in relatively shallow waters where they are highly likely to be subject to forces from breaking waves. Unlike shallow water platforms for oil and gas production, the support structures for wind turbines are a lot more slender and thus, they are more susceptible to vibrations from impulsive and multiple-wave-frequency loading. As such, the design of these structures require careful analysis of the wave loads and design tools used for the land based wind turbines need major modifications before they can be used for designing offshore wind turbines. Therefore, prediction of wave loads on the offshore wind turbine support structures from steep and breaking waves in particular is an area receiving much attention.

The theories available for investigating nonlinear waves can be broadly divided into two groups based on breaking limit. The theories investigating near breaking waves are, to a large extent, analytical methods and have received extensive attention from the very early days while the breaking waves that cause the most severe forces to the marine structures are mainly numerical methods that have only come about in the last two decades. These methods have been investigated for their relative merits and the results have been reported before [1]. The wealth of different methods available for estimating the wave forces on marine structures in shallow water makes it a daunting task to establish a suitable strategy for selecting an appropriate method in design.

For near breaking waves any of the higher order methods will be suitable but only a breaking wave model can be suitable beyond the breaking limit. Even though the breaking wave model provides reliable estimates for the wave loading in all conditions, there are drawbacks associated with it. The method breaks down following the breaking of the wave making the calculation of the wave loading impossible after wave breaking. It is also a time consuming and complicated method to apply. A wind turbine designer while designing an offshore wind turbine has to determine the wave loading on the support structure and needs a simple semi-empirical method which reflects the physics with sufficient accuracy that can be applied universally. Such a method can be developed using the software in a systematic manner provided that the results are proven to be reliable. Although extensive numerical tests with the breaking wave method have been carried out showing the limitations of the linear theory in predicting the wave forces, there has been no comparison with experimental data to prove the validity of the results. The main objective of this paper is to validate the numerical technique developed by Okan et. al. [1] for predicting the wave forces on mono-pile in breaking waves.

In the next section the numerical method developed for predicting the breaking wave forces is presented briefly and validation of the wave kinematics against available experimental data is carried out in section 3. In section 4 the predicted results are compared with experimental data and good agreement is found. The final section is dedicated to the discussion of the results and some conclusions are drawn.

2. Breaking Wave Method

In an inviscid and incompressible domain irrotational flow can be described in terms of a velocity potential $\phi(x,y,t)$ where the velocity components are related to the potential as follows:

$$\frac{dx}{dt} = u(x,y,t) = \frac{\partial \phi}{\partial x} \tag{1}$$

$$\frac{dy}{dt} = v(x,y,t) = \frac{\partial \phi}{\partial y} \tag{2}$$

$$\frac{d\phi}{dt} = -\frac{1}{\rho}p_o - gy + \left[u(x,y,t)^2 + v(x,y,t)^2\right] = f(x,y,t) \tag{3}$$

It is clear from the above equations that if the velocity field is known, the integration in time of the equations above is relatively straightforward and can be performed with any one of the available numerical schemes. Therefore, prediction of the velocity field at each time step is the crucial aspect of this method and Cauchy's theory of analytical functions is used for this purpose. A complex potential is defined in terms of the potential and the stream function as follows:

$$\beta(z,t) = \phi(x,y,t) + i\psi(x,y,t) \qquad z = x + iy \qquad i = \sqrt{-1} \tag{4}$$

According to Cauchy's theory the complex potential defined on the closed contour C around the computational domain will satisfy the following equation:

$$\oint_C \frac{\beta(z,t)}{z - z_0} dz = 0 \tag{5}$$

As it stands, this equation will not be sufficient to determine the complex potential uniquely because in this form it will only yield a system of homogenous equations. On the other hand, if on parts of the contour C the potential $\phi(x,y,t)$ or the stream function $\psi(x,y,t)$ is known at a time t, then by using the known quantities the above equation can be reorganised to have a right hand side [2]. The new reorganised equation can then be used for determining the rest of the complex potential. Once the complex potential is determined around the contour the velocity and acceleration anywhere in the domain can be determined from the following relationships:

$$\frac{d\beta(z,t)}{dz} = u(x,y,t) - iv(x,y,t) = \frac{1}{2\pi i}\oint_C \frac{\beta(\zeta,t)}{(\zeta-z)^2}d\zeta \tag{6}$$

$$\frac{dw}{dt} = \frac{\partial w}{\partial t} + \frac{dw}{dz}\overline{w} = \frac{1}{2\pi i}\oint_c \frac{1}{(\zeta-z)^2}\frac{\partial\beta(z,t)}{\partial t}d\zeta + \frac{\overline{w}}{2\pi i}\oint_c \frac{\beta(z,t)}{(\zeta-z)^3}d\zeta \tag{7}$$

Here the bar on a variable refers to the conjugate of that complex variable. For the calculation of the complex potential a computational domain and the initial and boundary conditions in it have to be prescribed. Assuming that the wave is periodic in space, a computational domain can be constructed between the free surface, the seabed and two vertical lines joining them which are a wavelength apart. In the computational domain defined in this way the following boundary conditions will be valid,

- on the free surface the velocity potential will be prescribed,
- on the seabed, since it is always a streamline, the stream function will be constant, where its value can be assumed to vanish without loss of generality,
- on the vertical boundaries, due to spatial periodicity, the complex potential values are identical.

Introducing these boundary conditions into equation (5) a Fredholm integral equation of the second kind is obtained which can be solved numerically for the complex potential [2]. Unlike the first kind, the second causes no numerical instabilities and no coding difficulties are encountered.

3. Validation of Wave Kinematics

During the late eighties it became apparent that the breaking waves caused unduly large wave forces and a lot of work has been carried out in this area. However, due to the difficulties in measuring breaking waves, most of this work has been theoretical and very little data has been available in the public domain with which comparisons could be conducted. One of those is the data by Griffiths et. al. [3] where only the kinematics of the particles in the crest, in particular the horizontal velocity components are measured. The tests were conducted in the Edinburgh University Flume using an LDA device to perform the measurements. The flume was 9 m long and 0.32 m wide. An impervious bed with a slope of 1/30 was installed in the flume and regular waves with suitable periods and heights were tested so that the waves broke at a water depth of 0.185 m. Experiments were conducted with five different waves and the available information for the waves is presented in Table 1.

Table 1: Details of the Edinburgh University wave tests

Test	Initial	Wave	Final	Breaking	Wave
Case	Period (s)	Steepness	Crest H (m)	Total H (m)	Length (m)
Case 1	1.60	0.0225	0.101	0.128	2.16
Case 2	1.33	0.0411	0.106	0.139	1.80
Case 3	1.14	0.0575	0.099	0.133	1.54
Case 4	1.00	0.0760	0.087	0.127	1.31
Case 5	0.80	0.1095	0.076	0.108	0.97

For predicting the kinematics of a breaking wave the initial deep water wave height is estimated from the given wave steepness. The initial conditions for the velocity potential of the waves are derived from linear wave theory. In deriving them, to reflect the changing slope of the flume base, the depth of the flume is assumed to be the depth half a wave length ahead of the point of breaking.

The wave profiles for the experiments are not available and it is not possible to compare them with the predicted waves. However, principal characteristics such as wave height, crest height and wavelength are measured from the predicted profiles for all the methods and they are presented in Table 2 for comparison with the experimental data. The linear theory, and to a lesser extent the stream function theory, grossly underestimate these characteristics but a good agreement is obtained between the breaking wave theory and the experiments, in particular with the wave heights.

Table 2: Predictions of wave characteristic with different methods

Test Case	Methods								
	Linear Theory			Stream Function Theory			Breaking Wave Theory		
	Crest H.	Wave H.	Wave L.	Crest H	Wave H.	Wave L.	Crest H	Wave H.	Wave L.
Case 1	0.045	0.090	2.06	0.066	0.097	2.22	0.101	0.133	2.06
Case 2	0.057	0.114	1.67	0.092	0.118	1.86	0.097	0.140	1.71
Case 3	0.059	0.117	1.45	0.094	0.124	1.56	0.092	0.136	1.71
Case 4	0.059	0.118	1.24	0.093	0.123	1.33	0.085	0.126	1.23
Case 5	0.055	0.109	0.87	0.082	0.108	0.99	0.072	0.110	0.96

The wave lengths in all the cases are underestimated by the linear theory and the breaking wave theory, while stream function theory overestimates the wave lengths. Nevertheless, stream function theory predictions are much closer to the experimental results. The discrepancy is probably due to the fact that the tank bottom is assumed to have constant depth. It is probably not an entirely accurate way of modelling the sloped beaches as flat beaches when accurate predictions of the wave length are required.

The predicted wave profiles and the comparison of the horizontal velocity components with experimental data at the point of breaking are shown in Figure 1. The results for the test cases are given in ascending order from top to bottom with Case 1 results at the top and Case 5 results at the bottom of the figure. On the left hand side the wave profiles are displayed and the variation of the horizontal velocity components with the depth are displayed and on the right hand side. The undisturbed water level is taken as the reference level. In all the results linear theory is represented by dashed lines, dashed-dotted lines are used for Dalrymples streamline theory and the breaking wave theory results are shown with solid lines. The only available experimental data is the axial velocity components measured at discrete points at various depths at the point of breaking and they are indicated by circles. As the steepness increases through Case 1 to Case 5, the wave and crest heights predicted by stream function theory agree more closely with those of breaking wave theory and experimental results.

The results for the horizontal component of the velocity indicate that breaking wave theory is the only method which predicts them with reasonable accuracy. Both linear theory and the streamline theory fail to predict the experimental data in the crest. In the case of stream function theory the predictions are, in the worst cases, less than half the experimental values while the linear theory predictions are less than a third. As with the wave profile results, for steeper cases the results improve slightly but they are still not sufficiently accurate to be used to satisfactorily predict the wave kinematics. It should be noted that all these test cases are spilling breakers rather than plunging breakers for which the discrepancy is expected to be much bigger. Unfortunately measuring wave kinematics in plunging breakers is much more complicated and has not been attempted.

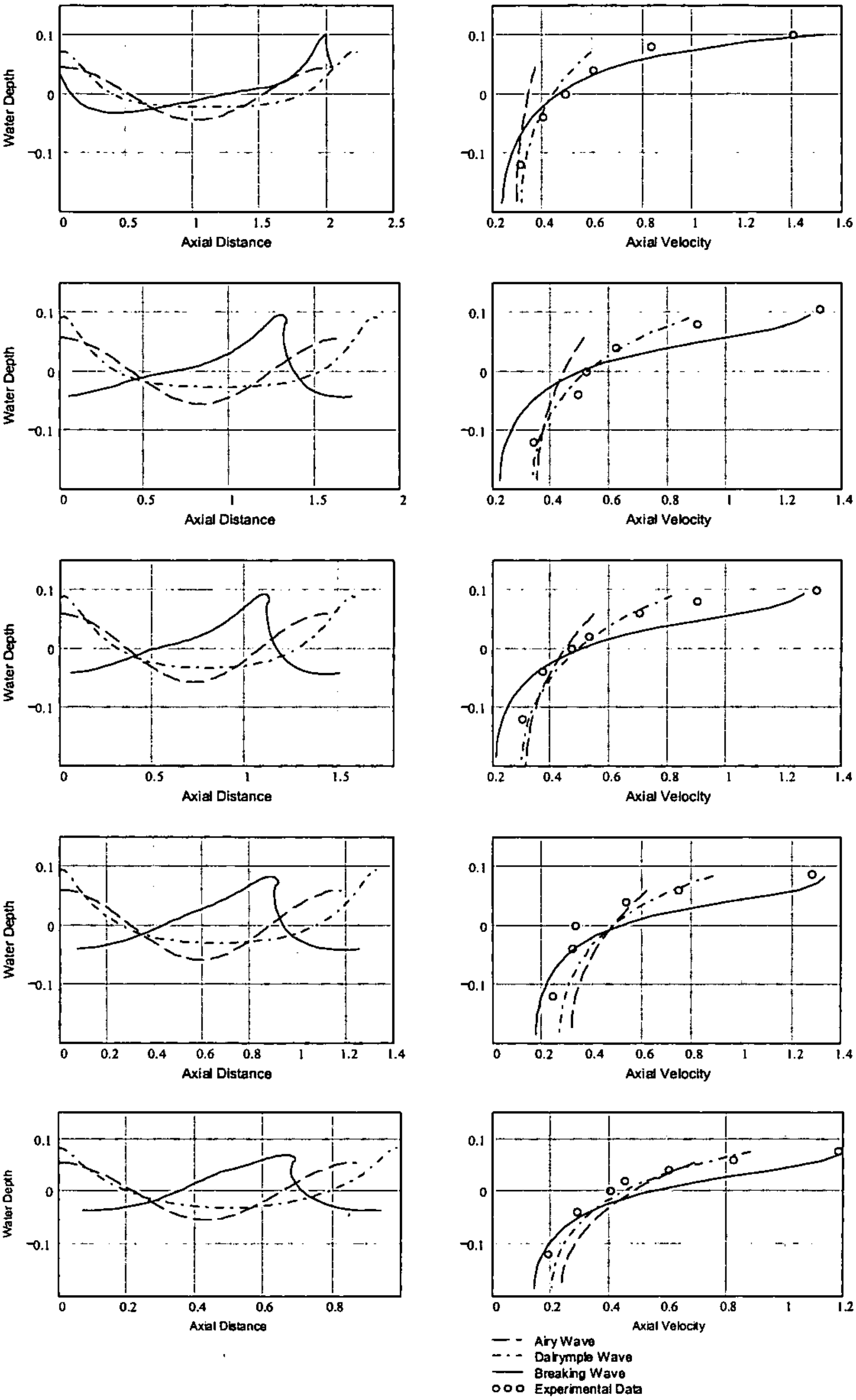

Figure 1: Wave profiles and the horizontal component of the velocity at the point of breaking

Overall the breaking wave theory predicts the wave kinematics with reasonable accuracy. It has to be noted that although the overall wave heights are very closely predicted the crest height are somewhat underestimated. Also the horizontal velocities near the crest are slightly over-predicted but away from the crest are under-predicted. Nevertheless the velocity values are considerably different to those predicted by linear theory. To investigate whether the flow kinematics computed by this technique could be used to calculate forces, they were incorporated into the Morison equation using standard force coefficients to predict the force on a vertical circular cylinder in breaking waves. The results were then compared with experiment.

4. Validation of Wave Force Predictions

Results from some experimental work on breaking wave loading recently undertaken in the Universities of Glasgow and Strathclyde were used for the comparison. The experiments were performed in the Acre Road wave tank which is 80.0 m long 4.6 m wide and 2.6 m depth. To create breaking waves during the experiments the tank bed was shoaled in two stages, the second stage varying from 1.0 m water depth to mean water level with a 1:20 slope. A segmented aluminium cylinder model with outer diameter of 0.204 m and a total height of 1.0 m was built and tested. Inside each 50 mm high segment there are strain gauged bars to measure the total force on each segment. Further details of the tests and instrumentation and the data is given by Xu and Barltrop [4,5].

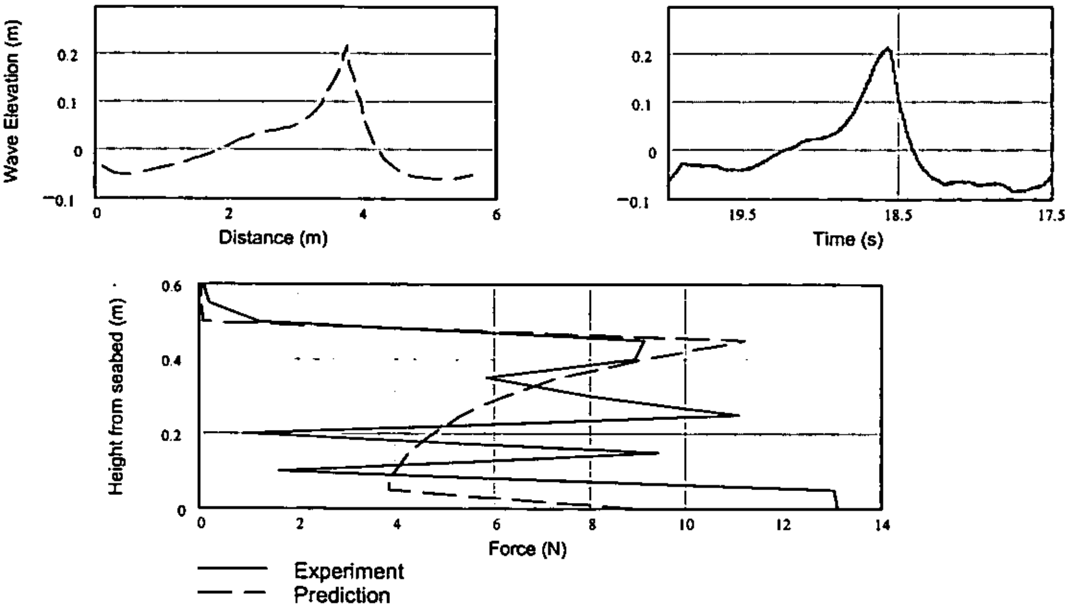

Figure2: Wave profiles and the horizontal component of the force for regular wave at the point of breaking (Deep water wave height = 0.2 m, wave period = 2.5 s)

Of the three different types of waves tested, comparisons were carried out only for the regular waves. Since the results are shown to be almost identical for all three types of tests [4] the comparison with regular wave results alone are sufficient for validation purposes. Regular wave tests were carried out for three periods, and in each case two wave heights were used. In Figure 2 the predictions are compared with the experimental data for a regular wave of 2.5 s period and 0.2 m height.

At the top of the figure, predicted wave elevations are presented in terms of the spatial profile on the left hand side, while the experimental data is presented as a time series on the right. It should be noted that for regular waves there is a one to one correspondence between the time series and the spatial profile and therefore the close resemblance between the predicted wave profile and the experimental time series can be taken as a measure of accuracy. The method, in this case, not only predicts the peak with remarkable accuracy but it also captures general features apart from very high frequency distortions.

The comparison of the predicted horizontal forces with the experimental data at the point of breaking is also presented in the lower part of Figure 2. It shows that the magnitude and the character of the force are captured in an averaged sense but the local oscillations of the experimental data is not evident in the predictions. The predicted forces are calculated by using Morison's formula. In applying Morison's formula only inertia and drag forces were considered and based on the finding that inertia and drag coefficients have very little influence on the outcome [6] they were taken as 2.0 and 0.8 respectively. For the initial conditions the results of the stream function theory have been used although initial conditions based on linear theory give similar results. At the present time there is no clear explanation for these unexpected oscillations in the forces along the height of the cylinder and investigations are still continuing. However, videos of the tests indicate relatively significant diffraction from the cylinder and the oscillations could be due to the interaction between the incident and diffraction forces.

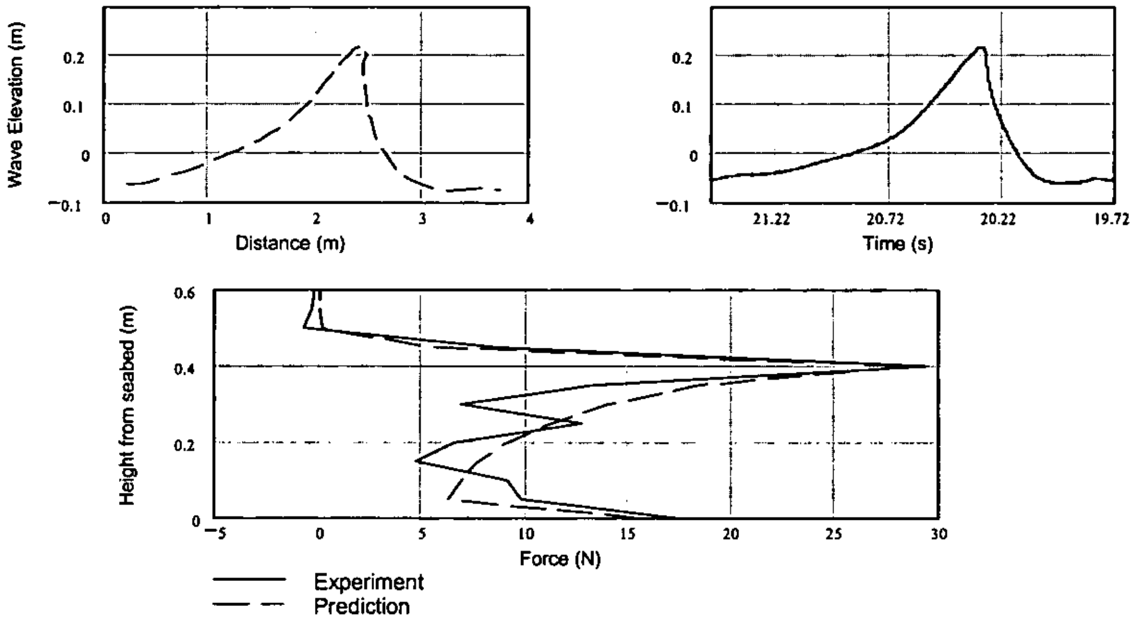

Figure 3: Wave profiles and the horizontal component of the force for regular wave at the point of breaking (Deep water wave height = 0.25 m, wave period = 1.67 s)

The results for regular waves of 1.67 s period and 0.25 m height are given in Figure 3. The predictions for this case are even closer to the experimental data but the oscillations along the cylinder height are of the same order of magnitude. It is important that the magnitude and the position of the peak loading are predicted with very high accuracy. Another important feature of the experimental data that has been captured in this method is the sudden increase in the level of force at the base of the cylinder. One normally expects the flow kinematics, and hence the inline forces, to decay with depth, but the variation is much smaller for shallow water. Since Morison's formula is used in the prediction of the forces and the magnitudes of the motions play an important part it is natural that this should be captured in the numerical method. The results for the other test cases are not shown here but they display the same level of accuracy.

5. Discussion and Concluding Remarks

A method for predicting the wave loading on wind turbine support structures in shallow water has been presented. Particular emphasis is placed on validating the code for breaking wave conditions and a good agreement between predictions and experiments has been obtained. The following conclusions can be drawn:

- Validation of the wave kinematics has shown that linear theory and even higher order theories are not likely to predict the wave forces using Morison's method unless an accurate way of including a slamming component is included in the predictions.
- Alternatively, with the proposed breaking wave method for predicting the wave loading, it is sufficient to use Morison's method with only inertia and drag components. The results are relatively insensitive to their variation within the practical range and they can be taken as 2.0 and 0.8 respectively.
- The choice of the initial conditions in the use of the present method raises some concerns with regards to the application of the method and special care has to be taken. Alternatively the present method can be used systematically to generate a simple semi-empirical procedure for predicting wave loading on wind turbine structures. Such a method is being developed at NaREC and Newcastle University and progress will be reported in due course.
- An enhancement to the present method to model the sloping sea-bed more accurately and to introduce irregular waves. This approach will overcome the difficulties associated with the initial conditions and will extend the capability of the method to any type of waves. Work in this area is in progress and the results will be reported in due course.

6. Acknowledgement

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ZERO-VISIBILITY RELATIVE SURVEY WITH AN AUTONOMOUS UNDERWATER VEHICLE

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Inspection of many marine structures is not a routine procedure because divers, ROV's, and autonomous vehicles operating in an acoustic navigation net are the main tools available today. Among these choices, autonomous vehicles are strongly preferred in terms of safety and human load, but autonomous survey is often made difficult by the poor acoustic environment, including very tight spaces and the potential for multipath in crowded harbour locations. We have developed a new capability and vehicle for relative inspection, wherein a Doppler velocimetry logger is used to navigate relative to the surface being inspected, and imaging is performed with a DIDSON imaging sonar. The system is capable of working with no compass or external navigation system, and in zero visibility waters. The ability to locate and lock onto a wall, and then perform survey "slices" is demonstrated by a new, hovering vehicle. Although developed initially for the detection of mines affixed to ship hulls, the technology has powerful application in ship husbandry and damage assessment, as well as environmental monitoring.

1. Introduction and Existing Capabilities

The majority of existing autonomous underwater vehicles (AUVs) are of a simple, torpedo-like design. The torpedo-shaped AUV has proven useful in many applications where a vehicle needs to efficiently and accurately survey a wide area at low cost. As the field of underwater robotics continues to grow, however, some new applications for AUVs are demanding higher performance in manoeuvring, precision, and sensor coverage. In particular, the ability to hover in place and execute precise manoeuvres in close quarters is now desirable for a variety of AUV missions. Military applications include hull inspection and mine countermeasures, while the scientific community might use a hovering platform for monitoring coral reefs, exploring the crevices under Antarctic ice sheets, or close-up inspection in deep-sea archaeology. The ability to inspect hulls, walls, jetties, and other harbour structures would be of interest in damage assessment, and a hovering vehicle could also be used for monitoring water composition in the outflow areas of industrial plants. An autonomous hovering platform has specific potential for industrial applications in some areas currently dominated by work-class remotely operated vehicles (i.e., tethered, ROVs): subsea rescue, intervention, and construction, including salvage and wellhead operations.

As one specific application, frequent hull inspection is a critical maintenance task that is becoming increasingly important in these security-conscious times. Most ships (whether civilian or military) are only inspected by hand, in dry-dock, and thus rarely - certainly not while they are in active service. Standards do exist for UWILD (Underwater Inspection in Lieu of Dry-dock), but divers have typically performed underwater inspections, a time-consuming, hazardous job. Additionally, there is a high probability of divers missing something important, because it is so difficult for a human being to navigate accurately over the hull of a ship, with their hands, and often in poor visibility. With a loaded draft on the order of 30m and a beam of 70m for a large vessel, debilitating mines can be as small as 20cm in size, and in this scale discrepancy lies the primary challenge of routine hull inspection. This same disparity can be found in many other inspection tasks.

The simplest inspection is a visual examination of the surface. Underwater however, (particularly for vessels in harbours and at anchor in coastal waters) a visual inspection must be performed very close to the hull or wall. Considering other modes of inspection, the health of a ship's skin may be judged by measuring plating thickness, or checking for chemical evidence of corrosion. For security purposes, a sonar image may be adequate because of larger target size. For instance, the US Customs Service currently uses a towfish sidescan sonar to check hulls [8].

Some military vessels are now using small, free-swimming ROVs for in-situ hull inspection [3]. This method eliminates the safety hazard of diver work, but retains the disadvantage of uncertain navigation and human load. The only commercial hull inspection robot, at the time of this writing, is the Imetrix *Lamp Ray. Lamp Ray* is a small ROV designed to crawl over the hull surface. The ROV is deployed from the vessel under inspection; the vehicle swims in and closes with the hull under human control, then holds itself in place using front-mounted thrusters for suction. The operator drives the ROV over the hull surface on wheels. This limits the survey to flat areas of the hull; more complex geometry around e.g. sonar domes, propeller shafts, etc. must still be visually inspected with a free-swimming ROV. The *Cetus II* AUV is an example of a free-swimming autonomous system that has also conducted ship hull surveys [7]. Using altimeters to maintain a constant relative distance from the hull, and the AquaMap long baseline navigation system (DesertStar, Inc.), *Cetus II* records globally-referenced position information, and this (with depth and bearing to the hull) is the primary navigation sensor used to ensure and assess full coverage. The AquaMap system uses a transponder net deployed in the vicinity of the ship being inspected (see URL in Reference 6.); clearly, a long baseline acoustic system could be used for any vehicle. In some applications, however, it should be noted that an LBL system is impractical – these are the environments of extreme multipath, e.g., many hard surfaces, as one would find in a congested harbour, or high ambient noise. Additionally, sometimes an LBL system deployment is simply impossible due to time, cost, expertise, person-power, and other constraints. Although today's LBL systems can provide high accuracy at distances of up to ten kilometres or so, they still require line of site communication, for which multiple deployments would be necessary to cover a given coastal area with significant structures.

Our vehicle program has several unique aspects to address the needs of ship hull and structure inspection: development of a *small* autonomous vehicle optimized for *hovering*, and of a *surface-relative navigation* procedure, wherein dependence on a deployed acoustic navigation system is avoided. The data product our vehicle will produce is a high-resolution sonar mosaic of a ship hull, using the DIDSON imaging sonar (University of Washington's Applied Physics Laboratory) as a nominal payload [1].

2. Physical Vehicle Overview

The hovering AUV (HAUV, Figure 1) has eight hubless, bi-directional DC brushless thrusters, one main electronics housing, and one payload module. The symmetrical placement of the large number of thrusters makes the vehicle agile in responding to wave disturbances, and capable of precise flight manoeuvres, such as orbiting targets for inspection or hovering steadily in place. The vehicle is intended to operate in water depths ranging from the Surf Zone (SZ) through Very Shallow Water (VSW) and beyond, up to depths of 100 meters; and to perform in waves up to Sea State Three. Onboard non-payload instruments include a Doppler velocity log (DVL), inertial measurement unit

(IMU), depth sensor, and acoustic modem for supervisory control. While we do carry a magnetic compass, this cannot be expected to work well in close proximity to a metal hull. As noted above, the nominal payload at this writing is the DIDSON imaging sonar. Both the DIDSON and the DVL are mounted on independent pitching servos at the front of the vehicle, because the DIDSON produces good imagery at an incidence angle greater than 45 degrees, while the DVL needs to maintain a normal orientation to the wall. The DVL can also be pointed down for a bottom-locked velocity measurement. The vehicle is strongly passively stable, with a gravity-buoyancy separation of about 3cm. We note that although the thruster arrangement does allow us to control pitch and roll to arbitrary angles, we have not used the thrusters for any purpose in roll and pitch other than to enhance damping. The vehicle has approximate dimensions of 95cm long, 65cm wide, and 35cm tall; it displaces about 100kg in prototype form.

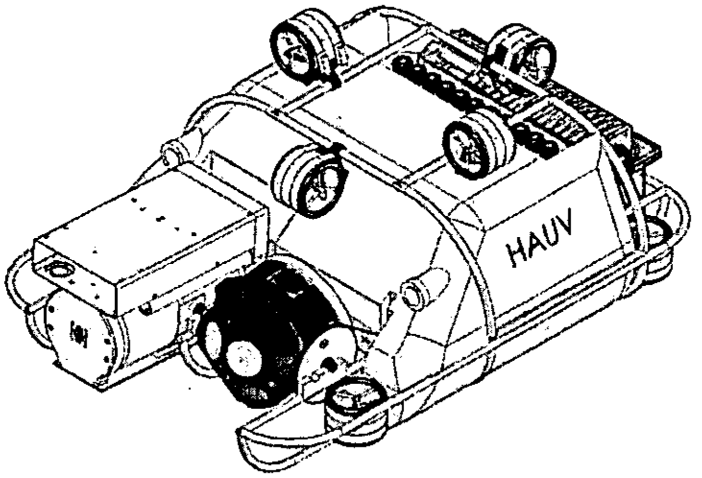

Figure 1 - The HAUV, showing DIDSON (light) and DVL (dark) on the front (left), light flotation in the mid-body, and a large battery at the stern. Thruster locations are reconfigurable; the main electronics housing is underneath the foam.

3. Approach to Wall Navigation

As noted above, we consider this problem from a feature-relative navigation standpoint, as this has some advantages compared to current approaches. Our basic strategy is to measure tangential velocity relative to the wall being inspected using a Doppler velocity log (DVL), and to servo a desired distance from the wall, and orientation, using the individual ranges from acoustic beams. The immediate impact of this functionality is the elimination of support gear for the robot itself; no localized network setup like LBL is needed. This reduces complexity and may provide a simple, quick deployment where the robot can operate unattended. The lack of a ship- or bottom-based navigation system also means the craft can be deployed quickly to respond to developing situations below the waterline. As a second benefit, the proposed feature-relative control schemes should work when a ship being inspected is fixed within a close berth (where LBL navigation could be poor), anchored and moving slowly about its mooring, or moving freely at very low speed, e.g., adrift.

The key technical point to note about navigating relative to a fixed hull surface is that the vehicle is constrained absolutely in the DOF normal to the hull, but not tangentially. A featureless hull is a poor candidate for visual or sonar image servoing, and the use of DVL velocity measurements for positioning invokes an obvious drift error over time.

3.1. Suitability of the DVL for this Task

The DVL (RD Instruments; see the URL given in Reference 5) comprises four narrow beam transducers, arranged uniformly at a spread angle of 30 degrees, and operating broadband in the frequency range of 1200kHz. The Doppler shift is measured for each beam, and an average sensor-relative tangential velocity vector can be computed. We also have available the four ranges from the individual transducers: the device provides range by using the return times from each sensor and the speed of sound in water. Complete (four-transducer) measurements are available at a bandwidth of 3-8Hz, depending on signal quality and range.

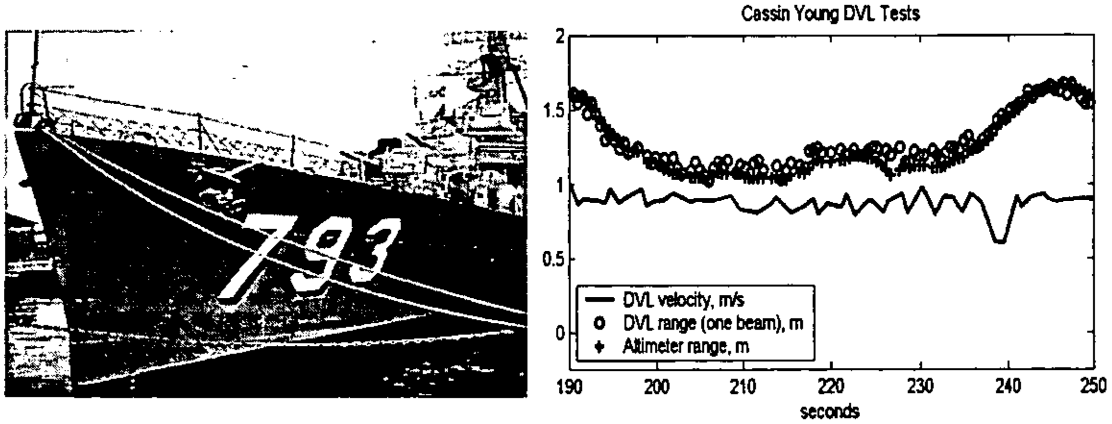

Figure 2 - DVL performance when towed along the hull of the USS Cassin Young.

We performed a series of tests with the DVL, with the specific goal of determining suitability for the wall-relative inspection task. Specifically, we ask: a) what is the drift rate of the integrated velocities? b) What is the noise characteristic of the independent range measurements? c) What is the effect of a metal hull, with biofouling? d) Does the DIDSON acoustic imaging system interfere with the DVL?

- On a cement and glass wall at the MIT Ocean Engineering Testing Tank, the position error in integrating velocity was confirmed to be about 0.5 percent of distance travelled. The error goes up substantially when the sensor is oriented more than 30 degrees from normal to the wall.
- We performed field tests along the hull of the *USS Cassin Young*, a WWII light cruiser berthed at the Navy Shipyard in Charlestown, Massachusetts. As shown in Figure 2, the range and velocity measurements are well behaved.
- We performed controlled tests at the Testing Tank, with simultaneous operation of the DIDSON and the DVL. DIDSON images (at 5fps) show the DVL pings as a faint flash, but the image is by no means unusable. Conversely, there is a slight degradation of the DVL's velocity performance. The drift rate approximately doubles, but remains below 1cm per meter of distance travelled, which is sufficiently low enough to satisfy our concept of operations.

3.2. Two Approaches Using "Slicing"

The DVL can be used to servo both orientation and distance to the wall (through the four independent range measurements) and to estimate the distance travelled, with reasonable accuracy. When coupled with an absolute depth measurement, two plausible inspection scenarios emerge for the majority of a large wall or ship's surface: vertical and horizontal "slicing." For the purposes of this paper, we confine our discussion to the large, relatively smooth surface of the hull sides, bottom, and bow of a vessel – complex structures are difficult for all modes of inspection.

In the case of horizontal slicing (Figure 3), paths in the horizontal plane are performed. The absolute depth provides bounded cross-track error measurement, while the integrated velocity provides the along-track estimate of position. This along-track position, with depth, is recorded for each image. Defining the end of a track at a given depth is a sensing challenge to which we see several possible approaches. First, there may be landmarks, such as weld lines, protuberances, or sharp edges as found near the bow or stern areas. These landmarks, especially if they occur at many depths, can be used to put limits on the search area, and to re-zero the integrated velocity error. Certainly prior knowledge of the ship's lines and these features can be incorporated into the mapping strategy at some level. On the other hand, the complete absence of features is workable also: operate at a given depth until the integrated velocity safely exceeds the circumference of the vessel, then move to another depth. When an object of interest is detected, immediate surfacing must occur in this scenario since location along the wall would be poorly known.

The horizontal slice method is very good for the sides and bow of a vessel. Many vessels, for example, large crude carriers (LCC's) have flat bottoms, which must also be inspected. Here, aside from the fact that the vehicle or the imaging sensor and DVL must be reoriented to look up, there is no cross-track error available, since the depth is roughly constant. Long tracks parallel to the hull centreline would be subject to accrued errors on the order of several meters. A *vertical slice* approach addresses this problem, by making paths down the sides of the hull and then underneath, in a plane normal to the hull centreline. Once at the centreline, options are to turn around and come back up on the same side, or to continue all the way under the hull to surface on the other side, after a 180-degree turn in place (which must be constructed based on rate gyro information only). In either case, the important property here is that the path length is limited, so that the cross-track errors are limited, and overlap can be applied as necessary. For instance, using a vertical path length of 130m implies a cross-track error on the order of 65cm, which is easily covered by overlapping images with field of view several meters, assuming no systematic bias.

Convex or concave, two-axis curvature of the hull also requires some overlap. For instance, in the extreme case of a spherical hull and the vertical survey, like ribbons around a ball, the imaged path lines converge at the bottom. These cases will require further study and mission design at a high level.

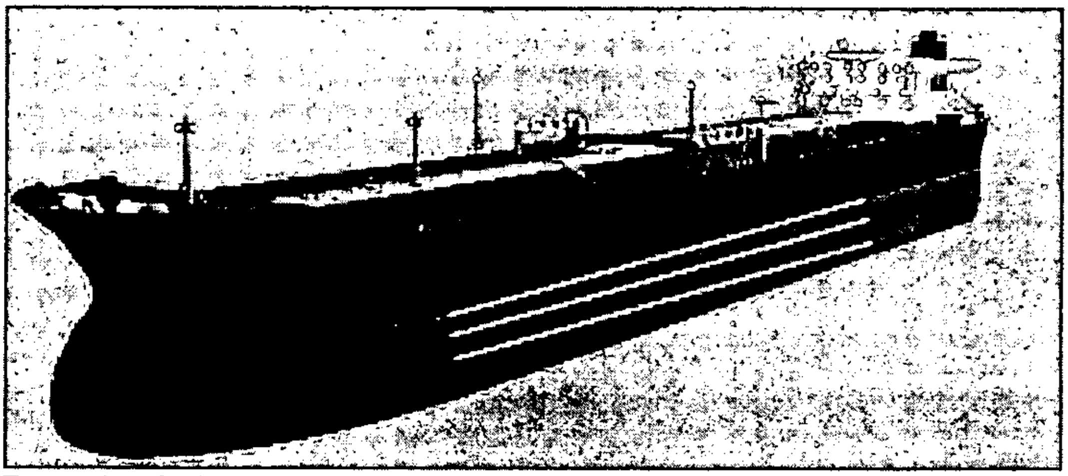

Figure 3 - The horizontal slice method; the vehicle makes passes at constant depth.

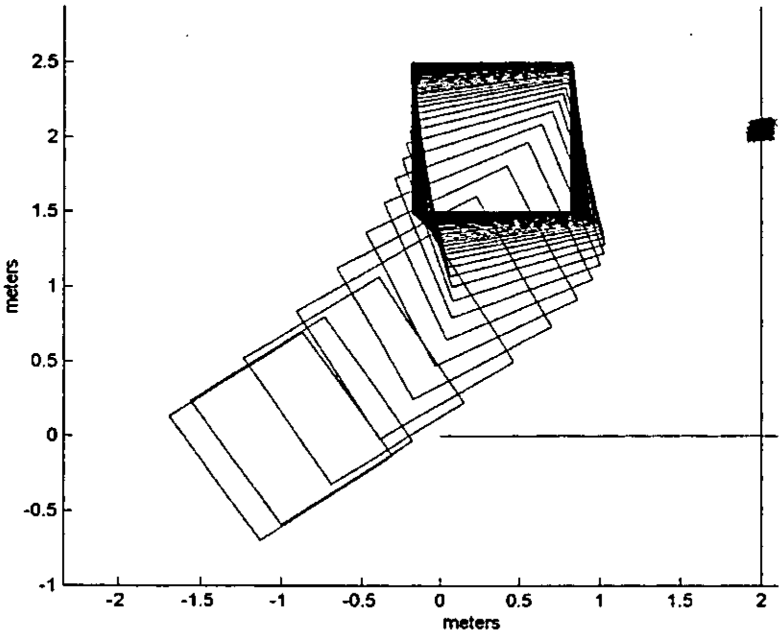

Figure 4 - Example of low- (PID) and mid-level (LQG) coupled control in the yaw-sway hull positioning problem. Vehicle initially is at a 42 degree bearing, 3m range; final position is zero degrees bearing, 1.7m range. The controller keeps the tangential velocity small while reorienting, so that the excursion of the DVL "pointer" on the wall (line on right hand side) is 12cm.

3.3. Role of Low- and Mid-Level Control

Dynamically, the vehicle is equipped with high-performance thrusters so as to operate in shallow waters, waves, and in proximity to walls. The primary sensor we have available, the DVL, however, is a comparatively low bandwidth device, which cannot provide robust measurements for direct control – the noise properties may be unpredictable, timing may vary, and missed data are not uncommon. Furthermore, loss of contact with the hull can occur in regular operation, and even be exploited as a landmark.

In waves, the depth sensor also fails as a high-bandwidth navigation sensor. As a consequence of these facts, the vehicle has to be capable of short-term autonomous navigation, through a high-end inertial measurement unit, and an integrated low-level control system. The division of control can be stated as follows: The low-level controller depends only on the core sensors of the IMU, while a mid-level layer incorporates the DVL and depth sensor, and a high-level controller manages the mission and desired pathlines. This multi-level control system is to be of the inner-outer loop type, with the DVL and depth sensor providing setpoints for higher-bandwidth inner loops. As in most cases of inner-outer design, the outer loop bandwidth should be at least 3-5 times slower than the inner loop.

Consider for example the case of yaw control relative to the wall. At the innermost level, a yaw rate servo runs at maximum update frequency and closed-loop bandwidth, employing a model-based estimator, i.e., a Kalman Filter for handling vehicle dynamics and sensor channels that are coupled due to gravity. The mid-level control has coupling, due to the fact that the DVL is like a velocity sensor on a moment arm, so that yaw and sway at the wall are kinematically coupled. This is one of many concepts from visual servoing that are appropriate here [4]. Figure 4 gives an illustration of hull servoing using nested low- and mid-level control, and DVL data.

4. Results

Figure 5 shows the essential low-level control capability of the vehicle, that is, its ability to maintain zero roll and pitch in the presence of disturbances, its ability to control and change depth, and to control heading. One interesting note is that we employed a negative proportional term in the roll control; this was needed because the natural roll period of about two seconds is too fast for the time scale on which the thrusters can create force at low levels. The use of negative gain effectively reduces the net righting moment, slowing down the response frequency and hence accommodating the thrusters' limitations.

We also note that the HAUV carries the full transit and waypoint capability of the Bluefin product line, which in the past has focused on survey vehicles. Although the vehicle has successfully completed these behaviours in open water, we will not discuss these tests here.

4.4. Acquiring and Approaching a Wall

The basic concept of operation puts the vehicle within DVL range of a trackable surface, such as a wall or hull, using transit behaviours and sensors, including compass, downward-looking DVL, and GPS. In the tests reported here, we deploy the vehicle within about five meters of the surface, and with arbitrary heading. After a short dive to operating depth, we first acquire the surface with the DVL, and then approach it so as to reach the specified range for the survey (see next sub-section). Both steps are made with the DVL rotated so that only two of the four beams are employed – i.e., two beams in a horizontal plane. This minimizes the possibility that beams will either reflect from the water surface, or be lost under the wall (e.g., hull curvature).

The acquire part of this procedure is strongly dependent on the fact that the DVL has null, sporadic, and then good behaviour as the angle to the wall becomes closer to perpendicular. In order to avoid excessive hunting that could be caused by missed hits, our algorithm first moves at a constant, slow yaw rate until two good hits are received. At this time, the vehicle stops yawing, and then waits for the next pair of good hits, after which an *incremental* yaw step is taken, that has constant magnitude, but carries the sign of the calculated relative angle error. This wait-step process continues until the vehicle is pointing directly at the wall. In a narrow tank (2.5m) we found that multipath can sometimes cause the final angle to be non-perpendicular, that is, that the behaviour settles on a non-zero bearing. In pools of width greater than 5m, however, no such difficulties were encountered, and this procedure was found to be quite robust. The acquire success at distances in the range 2-5m is better than 90% in these cases.

During the approach phase, the acquire behaviour's incremental yaw feedback is continued, and we also close a separate range loop. Here, the mean range error is used to drive the vehicle forward until the desired survey range is reached. It should be noted that this loop is fairly soft, because to overshoot the desired range significantly means that the range could go below that which the DVL can report (0.50m); in a more extreme case, the HAUV will hit the hull, possibly damaging the DVL or the DIDSON.

The acquire and approach behaviour ends when the angle and range errors are within specified tolerances for a specified amount of time.

4.5. Rectangular Survey

The imaging survey borrows from the above behaviours, but takes into account the transverse velocity reported by the DVL, leading to the multi-level control illustrated in Figure 4. In both cases of horizontal and vertical survey, on a vertical wall, a "lawn-mower" pattern is typical, with the geometry varying in accordance with the imaging payload, the resolution and overlap desired, and the wall geometry to some extent. These cases are illustrated in Figures 6-9 for three different deployments. The first is on a large steel barge at Quincy Harbour, Bluefin's local field operations centre. This barge has vertical walls, and the acoustic environment was quite benign, as evidenced by the relative clarity of the DVL data. The second deployment was off the *Cassin Young*, in Charlestown, Massachusetts. Like the barge, this is a steel hull, but in a somewhat poorer acoustic environment – it is moored next to other vessels and structures, and there was some ambient noise in the water due to traffic. We also note that the hull of the *Cassin Young* had more bio-fouling than did the barge's, when the tests were made, although it remains questionable whether biofouling alone can cause systematic degradation in the DVL performance – i.e., Figure 2. Finally, we performed tests at the Hanscom Air Force Base Pool (Bedford, MA), which has nearly vertical walls of fibreglass liner over concrete.

On the barge and the *Cassin Young*, we successfully performed acquire and approach behaviour, with long horizontal surveys. On the barge, we moved in one direction for more than two minutes. Not shown in any plot here, the maximum depth error during the slice was about five centimetres. On the *Cassin Young*, we moved in two directions – this can be seen clearly in the velocity data of Figure 8. More interestingly, the range data in this figure shows the variation of the lower beams' range along the length of the vessel. This is due to the sharp curvature of the hull below the waterline.

In the pool, we made horizontal and vertical (square, at least!) slices on the wall. The figures show the trajectory taken in the plane of the wall, as well as the depth and DVL data. Likely because of multipath in the closed pool, the velocity data are much more scattered than we saw in the open water tests above. The range data are cleaner, and show the coupling of vehicle lateral translation with yaw, through short variations in range which are being corrected by the control system.

In these tests so far, we control depth for the vertical DOF, and lateral velocity for the horizontal DOF. As with any velocity sensor, however, integrated errors do accrue and this applies to the DVL-based navigation. As mentioned previously, our future work will address the use of landmarks, so as to provide re-zeroing of path lengths whenever possible.

5. Summary

Doppler velocimetry with simultaneous ranging facilitates a new feature-relative approach for autonomous ship hull or marine structure inspection, one which allows several intuitive strategies that can account for the majority of the surface. The use of landmarks and ship's lines, as well as survey techniques for complex arrangements of equipment or structures are still open questions, however. The technology is broadly applicable to many subsea inspection and monitoring tasks, where a stable hovering platform is desired, but cabled control (ROV) and long-baseline acoustic navigation may not be feasible.

Support is acknowledged from the Office of Naval Research (Dr. T.F. Swean) under Grant N00014-02-1-0946, and from NOAA and the Sea Grant College Program, Grant NA 16RG2255.

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7. Appendix 1

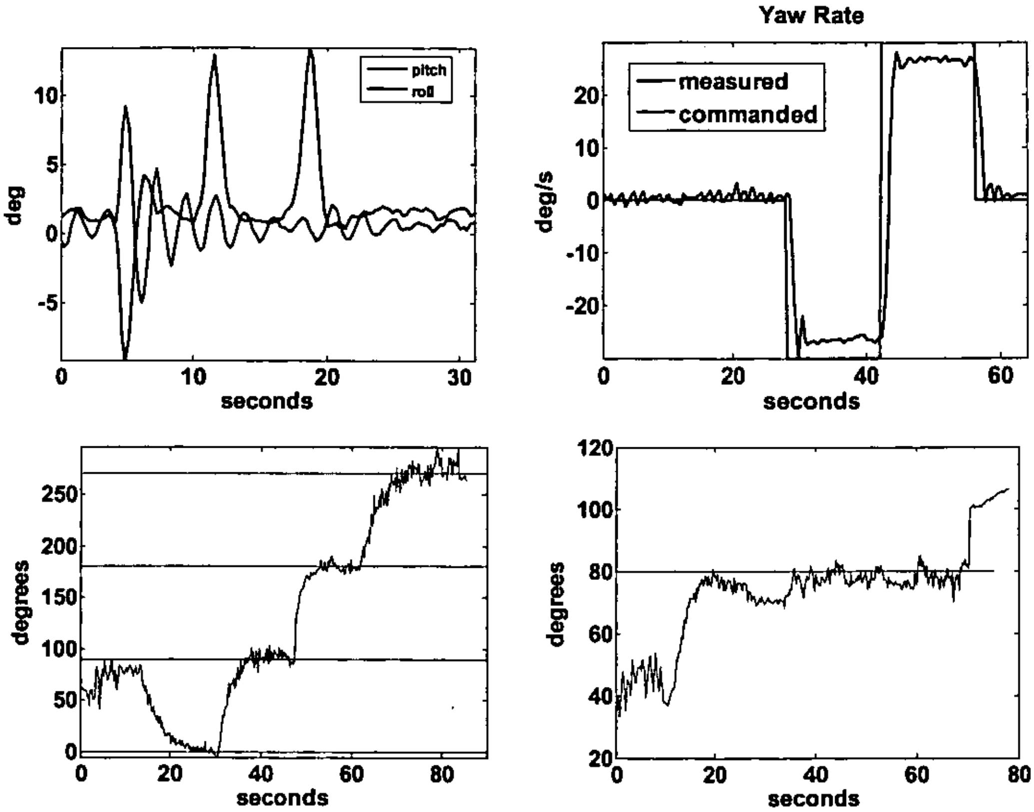

Figure 5 – Typical low-level control performance. Upper left: response to perturbations in hover with pitch control but no roll control. Upper right: vehicle response to commanded yaw rates (no integral action). Lower left: performance in following step changes in heading, in open water while hovering. Lower right: performance in keeping heading during transit at approximately 0.5m/s.

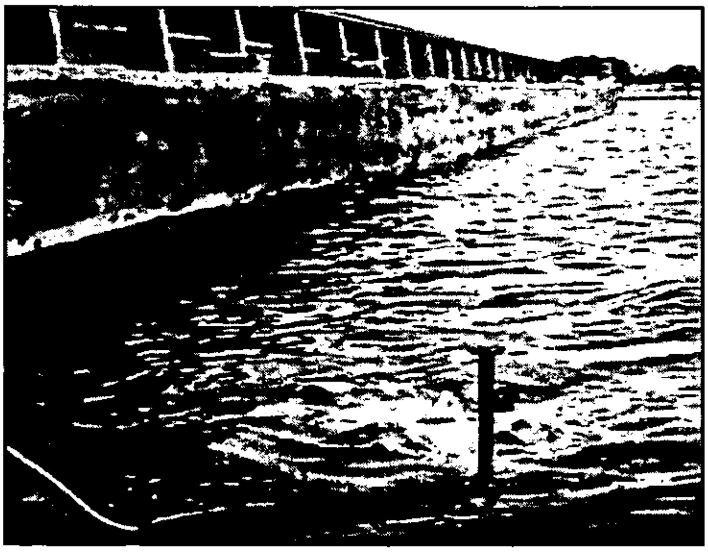

Figure 6 – The HAUV in action on a barge at Quincy Harbour (MA).

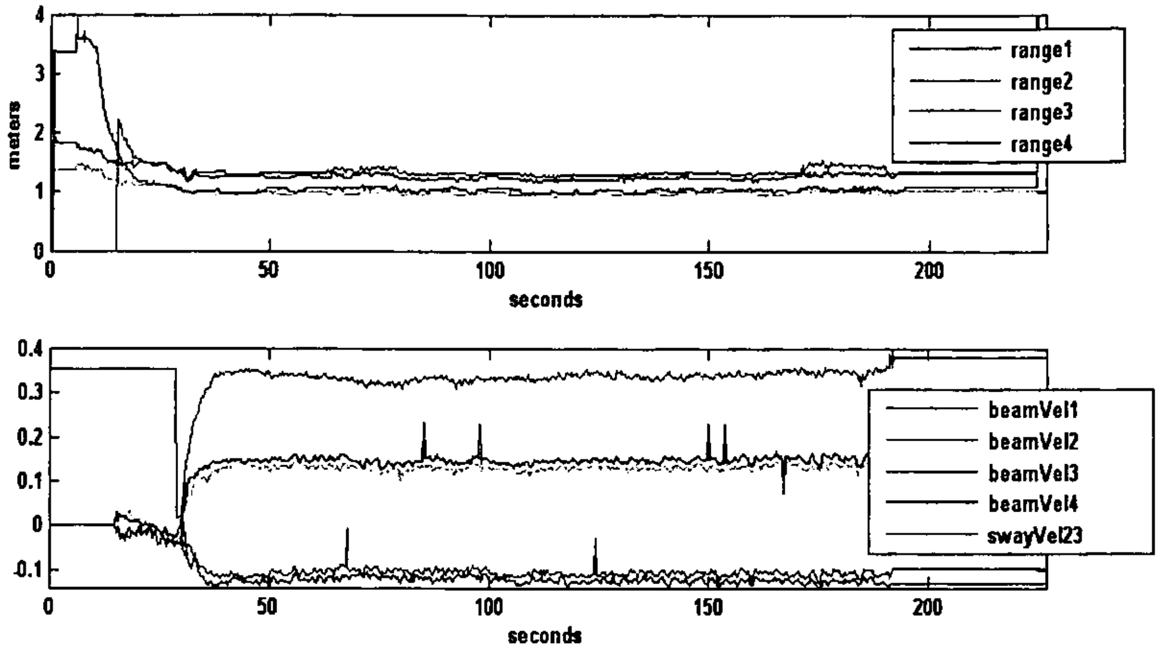

Figure 7 – DVL data during a long survey along a barge at Quincy Harbour (MA), demonstrating quality of the device when the orientation is successfully controlled to be near perpendicular. The magenta line in the lower plot shows the aggregate velocity – i.e., the one used for navigation.

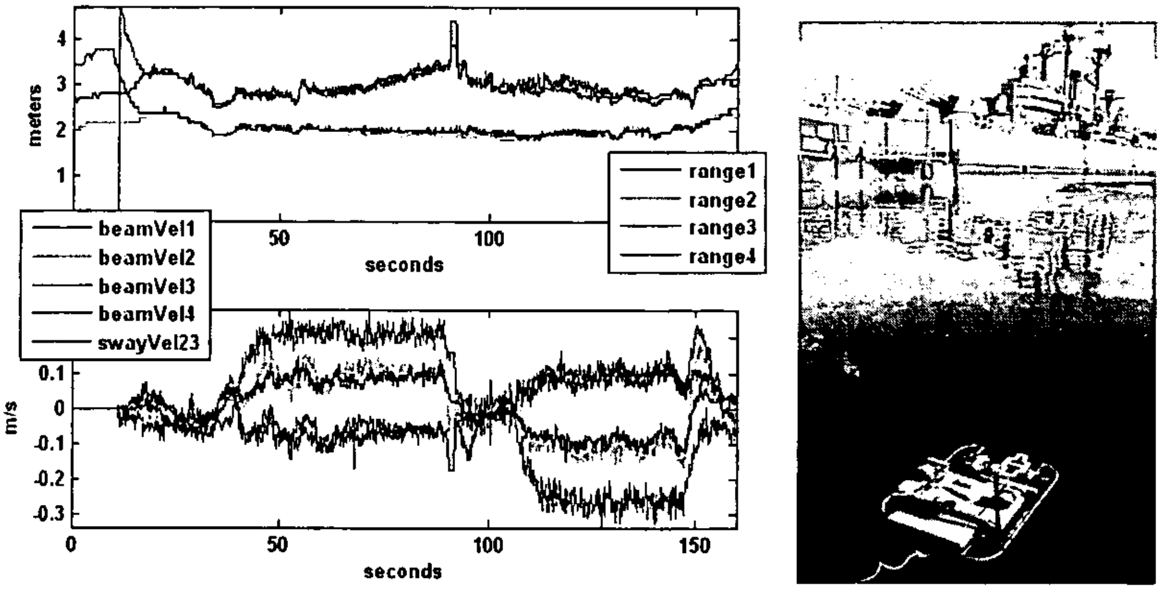

Figure 8 – DVL data from a survey on the Cassin Young (Charlestown, MA). In this case, the curvature of the overhanging hull is visible in the range data. The velocity data scatter is worse than for the barge because the vessel is in close proximity to other objects, but still admits reasonable position estimation.

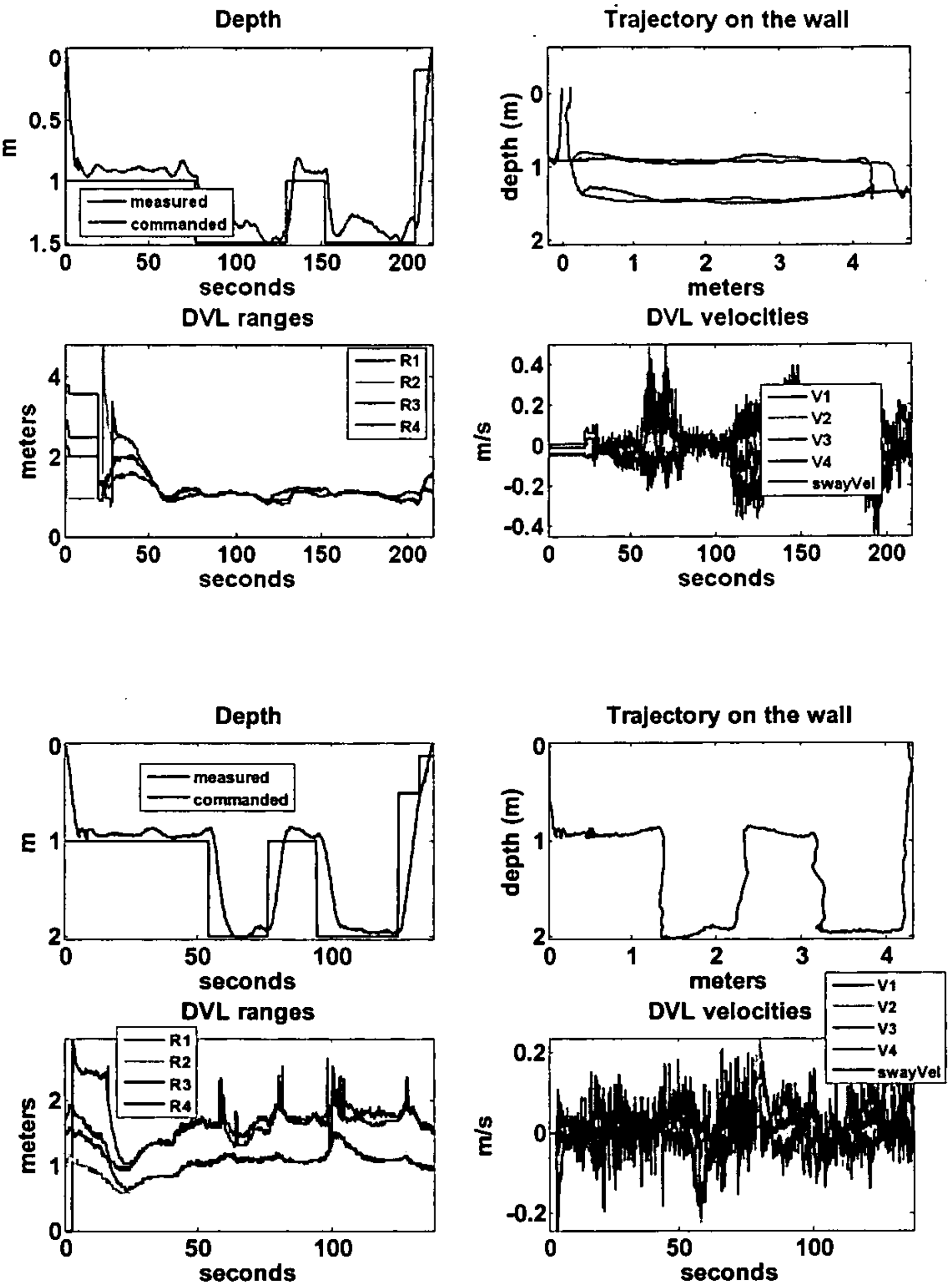

Figure 9 – Summary data of a horizontal survey (top) and a vertical survey (bottom), in the pool environment. The subplots show depth loop performance, estimated trajectory in wall coordinates, and range and velocity data.

PORT DEVELOPMENT AND ESTUARINE STEWARDSHIP

Matt Simpson, Royal Haskoning, UK
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Over recent years, a number of port developments and capital dredging projects have been either implemented or proposed in the Harwich Haven. Detailed hydraulic and environmental studies have been undertaken to assess the implications of such projects for the estuarine environment, in particular on sites designated under national and international legislation for their nature conservation importance, and have led to the development and implementation of a range of mitigation and monitoring initiatives. Through specific examples, this paper examines the approach taken to ensure the successful delivery of mitigation, monitoring and reporting. These projects are considered to represent examples of 'good practice' in the management of the estuarine environment where port development has occurred. The paper also discusses the need to accept a degree of 'risk' in implementing mitigation solutions, particularly in dynamic environments such as estuarine systems.

1. Background to major recent and proposed port development in the Harwich Haven

The Harwich Haven is formed by the confluence of the estuaries of the River Orwell (Suffolk) and River Stour (Essex) (see Figure 1). The area has a long maritime history, with the last century seeing significant development of port facilities, most notably at Felixstowe and Harwich. In terms of volume of container handling, the Port of Felixstowe is the largest container port in the UK and has a total berth length of over 4,100m. Harwich International Port currently has a total berth length of over 1,600m.

The scope of the discussion in this paper focuses on those major port expansion and capital dredging projects that have been undertaken in the Harwich Haven area since 1998, in particular the deepening of the dredged approach channel by the Harwich Haven Authority (HHA) in 1998-2000. This capital dredging project comprised dredging approximately 18Mm^3 of material and deepened the channel by 2m to -14.5m Chart Datum (CD).

In addition, in 2003 construction commenced on a 270m extension to the Trinity III Terminal at the northern end of the Port of Felixstowe to create additional deep-water berthing facilities. Capital dredging of approximately 900,000m^3 of material was associated with this extension. This construction work was completed in late 2004.

Furthermore, there are currently two proposed port developments in the Harwich Haven; the Bathside Bay Container Terminal and the Felixstowe South Reconfiguration. Both proposals involve reclamation of intertidal and subtidal areas and capital dredging of the approaches and berths. These proposals were both the subject of local Public Inquiries in 2004 and decisions on both projects are awaited.

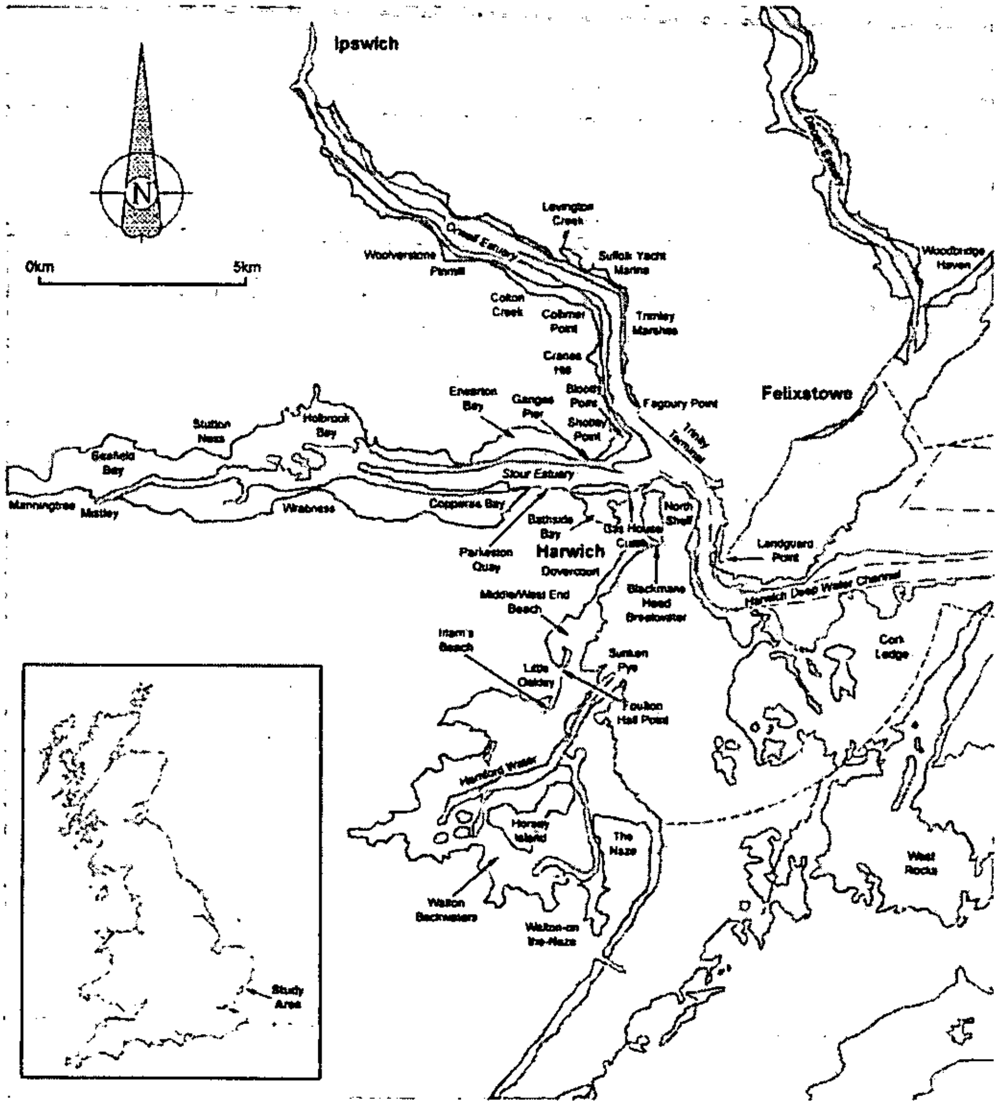


Figure 1 – The Stour and Orwell estuaries and the Walton Backwaters (source: HR Wallingford).

2. Designated sites within the Stour and Orwell estuary system

There are a number of sites designated for their nature conservation importance within the Stour and Orwell estuary system. Both estuaries are designated as separate Sites of Special Scientific Interest (SSSI) under the Wildlife and Countryside Act 1981 and these two SSSIs form the Stour and Orwell Estuaries Special Protection Area (SPA) (classified under the 'Wild Birds Directive') and Ramsar site.

3. Environmental studies in the Stour and Orwell estuary system

Partly as a consequence of the presence of major ports in the Stour and Orwell estuary system and the various proposals for development, the estuary is one of the most intensively studied systems in the UK and, arguably, in Europe. In particular, knowledge of the hydraulic processes and sediment budget of the estuary has been built up over a number of decades, resulting in well calibrated and validated numerical models of the system. Such knowledge is fundamental in that it provides the ability to predict the likely effects of development on the hydraulic and sediment regime of the estuary system with a high degree of confidence. These predictions are crucial in enabling detailed environmental assessment of the potential impacts of development on, for example, the morphology of intertidal areas to be undertaken and for informing the development of practicable mitigation measures to offset the predicted impacts of development, where required. Such environmental effects and mitigation measures have been reported through the Environmental Impact Assessment (EIA) process that has been undertaken for each of the proposed developments in Harwich Harbour.

In view of the designated status of the estuary system and the nature of the environmental impacts predicted to arise from each of the port developments and capital dredging projects described above, each project has, as part of EIA, also been subject to 'appropriate assessment' in accordance with Regulation 48 of the Conservation (Natural Habitats &c.) Regulations 1994. The purpose of appropriate assessment is to assess the implications of a proposed development for the designated status of any relevant 'European sites' (e.g. SPA), as defined through the sites' conservation objectives (which derive from the reasons, or qualifying features, for which the site was originally classified). In essence, it is the appropriate assessment process, which derives from the requirements of the Habitats Directive, which has driven the need to develop appropriate mitigation and compensatory measures in light of the various predicted effects of development on the habitats and species for which the Stour and Orwell estuary system is designated.

4. Overview of typical effects of port development and capital dredging projects

Although not the focus of this paper, it is necessary to provide a broad overview of the main typical effects of port developments and capital dredging projects on the estuarine environment to provide some context for the discussion of mitigation and compensation measures that have been implemented in the Stour and Orwell and how such measures are monitoring and reported. The effects described below are not exhaustive and represent the main potential effects of development on habitats that are important in the context of a site designated for its nature conservation interests.

4.1. Effect on tidal propagation

Port developments and capital dredging projects can result in a change to the cross sectional area of an estuary system which results in a change in the way that the tidal wave propagates within the estuary. Depending on the characteristics of the project (e.g. location in the estuary, depth of dredging, etc.) and the morphology of the estuary, this effect can manifest itself in either a decrease or an increase in tidal range. Such an effect is considered a one-off, permanent effect. The consequences of such changes can be either an increase or a decrease in the area of intertidal exposed at low water under certain tidal conditions and, therefore, there can be implications for the area of intertidal mudflat available to feeding waterbirds and hence total waterbird feeding time within the tidal cycle.

4.2. Effect on the rate of erosion or accretion of intertidal habitats

There are a number of possible mechanisms through which port developments and capital dredging projects can affect the rate of erosion or accretion of intertidal habitats (e.g. mudflats and saltmarsh). These effects are usually considered to be effects that are ongoing for the period of operation of a development and are normally expressed as magnitude of effect on an annual basis (i.e. an increase in the erosion of Xha of intertidal area per annum). In summary, some of the common mechanisms by which such an effect can arise are as follows:

- Wave reflection from new quay walls can increase wave energy over intertidal areas, resulting in erosion;

- Increasing the depth of dredged channels can, under certain wave conditions, allow greater wave energy into estuary systems from offshore, thus resuspending more sediment from intertidal areas and causing or enhancing erosion;
- The ebb dominant tendency of some systems can be enhanced by dredging, thus accelerating the net loss of sediment from the estuary system;
- Changes to current speeds and/or direction as a result of reclamation or dredging can affect sediment transport pathways and result in erosion or accretion of intertidal areas;
- Deepened channels can trap fine sediment which may previously have settled on intertidal areas. This material is then often removed from the estuary system by maintenance dredging and offshore disposal; and,
- New quay walls can 'streamline' flows and therefore reduce the tendency for suspended fine material to settle out from the water column.

The remainder of this paper uses specific examples to discuss the approach taken in the Harwich Haven to the mitigation of predicted environmental effects and to monitoring. It also describes the consultative forum that was established to disseminate the findings of the programme.

5. Harwich Haven Approach Channel Deepening

5.1. Introduction

In 1998, work commenced on a project to deepen the approach channel into the Harwich Haven from its' existing depth of -12.5m CD to -14.5m CD to improve navigation. The capital dredging would give rise to approximately 18Mm^3 of sediments, comprising a mixture of mud, sand and gravel and clay. Royal Haskoning (previously Posford Haskoning and Posford Duvivier), in association with HR Wallingford, undertook an EIA for the proposed channel deepening [1].

5.2. Overview of key predicted impacts

The environmental studies concluded that the channel deepening would give rise to a number of effects on the hydraulic and sedimentary regime of the Stour and Orwell estuary system. It was predicted that the effect of the channel deepening on tidal propagation would result in an increase in the level of the low water mark on spring tides (i.e. there would be a decrease in the tidal range) which, when the slope of the intertidal throughout the system was taken into account, notionally equated to the decreased exposure of approximately 4ha of intertidal area. In terms of the area of intertidal exposed for feeding waterbirds, this effect is viewed as a loss of intertidal area in the system; in reality, it is the conversion of intertidal habitat to shallow subtidal for a majority of tides. It is not possible to mitigate this effect.

In addition to the above, it was predicted that the rate of intertidal erosion within the estuary system would increase by approximately 2.5ha per annum. This effect was predicted to arise as a result of the trapping of muddy material in the deepened channel which would previously have been transported further into the estuary system and been deposited onto the intertidal areas. The trapped material would then be dredged during routine maintenance dredging campaigns (undertaken on an approximately 12 week basis by the HHA) and disposed offshore. The maintenance dredging would, therefore, represent a mechanism by which fine material is lost from the estuary system. It should be noted that the Stour and Orwell estuary system is currently an eroding system, with an estimated background rate of intertidal erosion in the order of approximately 10ha per annum overall.

5.3. Mitigation solutions

In order to mitigate the predicted increase in the rate of intertidal erosion of approximately 2.5ha per annum, a number of different approaches were explored, as summarised below (collectively termed 'sediment replacement'). Over time, and based on the results of trial placements of sediment and monitoring, the overall mitigation strategy has evolved into an approach that is considered to be the most effective (relying substantially on water column recharge; see below). The locations that are currently licensed for the placement of maintenance dredgings are shown in Figure 2.

- Subtidal placement of fine material

Fine sediments that are dredged during the maintenance dredging campaigns are placed on the seabed and act as a feed of material into the estuary system.

- Water column recharge

Maintenance dredgings are discharged from the dredger at certain defined placement locations within the estuary system adjacent to intertidal areas (see Photograph 1). Placements are made under specific tidal conditions that encourage material to disperse over intertidal areas.

- Increased overflow during maintenance dredging

During maintenance dredging, overflow is increased above the normal rate which acts as a further method of returning fine material within the estuary system.

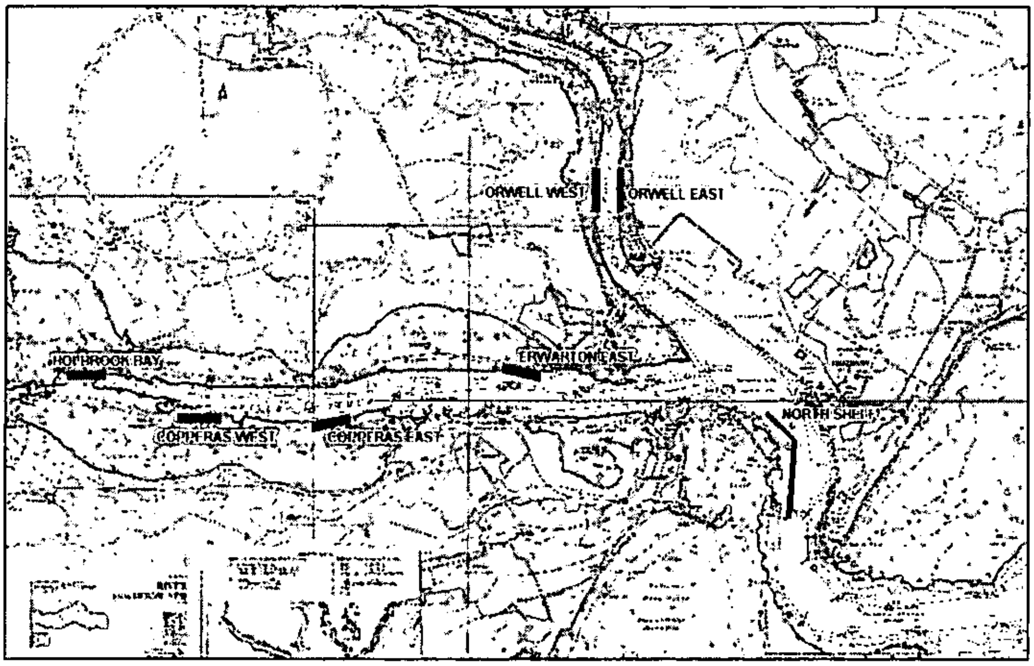
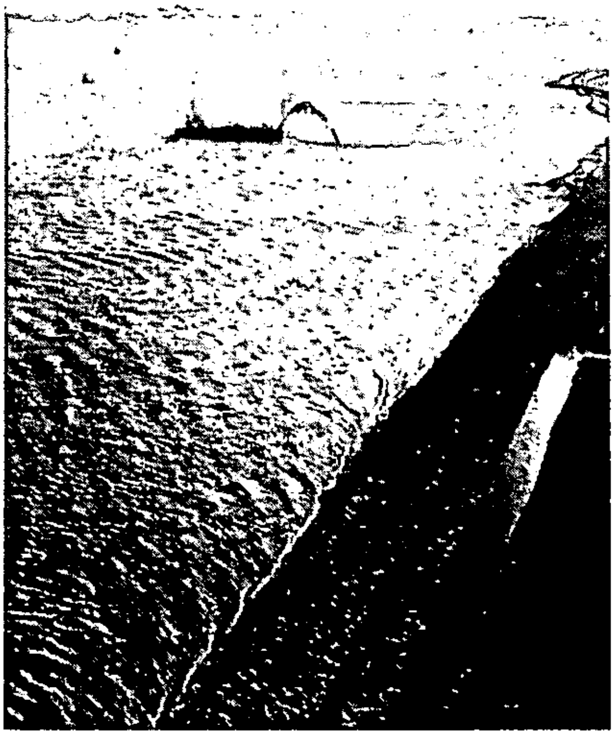


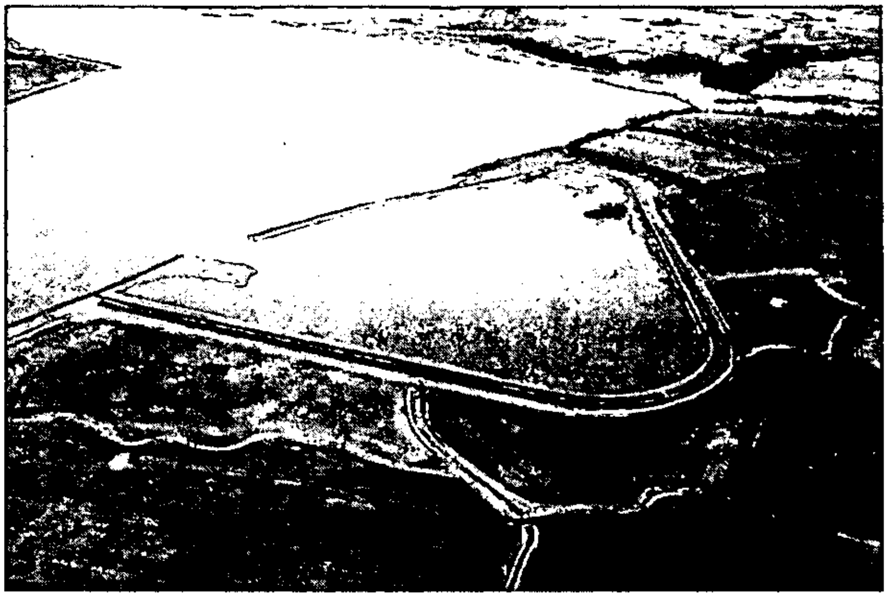
Figure 2 - Location of sites currently licensed for the placement of maintenance dredged material as part of the sediment replacement programme.



Photograph 1 – Water column recharge in the lower Orwell estuary (source: HHA).

5.4. Compensatory measures

In addition to the mitigation of the predicted increase in the rate of erosion of the intertidals in the estuary system described above, it was also necessary to take measures to address the effect of the proposed capital dredging on tidal propagation.



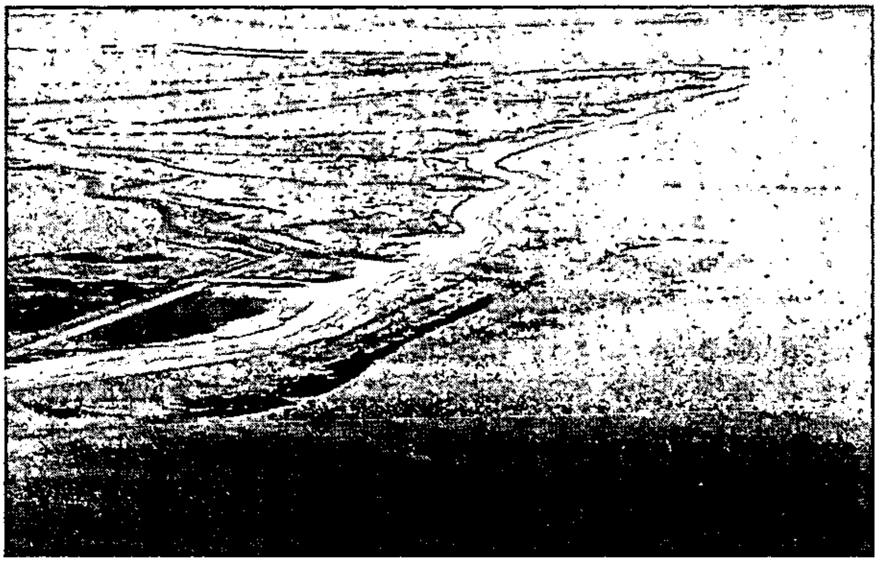
Photograph 2 – Aerial view of the 16.5ha Trimley managed realignment scheme on the eastern shore of the Orwell estuary, looking north-west (source: HHA).

The approach to compensating for the 4ha of unmitigable 'loss' of intertidal area due to the effect on tidal range was, therefore, to create additional intertidal area within the estuary system. This was achieved through the managed realignment of a seawall on the eastern shore of the Orwell estuary near Trimley (see Photograph 2). However, in addition to the 4ha of unmitigable loss, a precautionary approach was applied and it was necessary for the HHA to create an additional area of intertidal area that allowed for the possible failure of the mitigation measures described above for a period of 5 years (i.e. enhanced erosion of intertidal area at 2.5ha per annum, or a total area of 12.5ha). Therefore, the area of intertidal created at Trimley through managed realignment was 16.5ha (4ha plus 12.5ha).

5.5. Beneficial use of dredged material

A required part of the process for obtaining the necessary license for the disposal of dredged material is to seek options for the use of the dredged arisings in a beneficial manner. The aim of seeking the beneficial use of dredged material is to limit, as far as possible, the volume of dredged material to be disposed offshore (in essence, reducing the amount of waste that is generated).

A number of possible beneficial use schemes were identified within the Stour and Orwell estuarine system and within and adjacent to an estuary complex to the south (the Walton Backwaters) in association with the Channel Deepening. These various proposed schemes used clay, sand and gravel and included beach recharge between the Naze and Stone Point (see Photograph 3) and the creation of mudflat and saltmarsh habitat on the Shotley foreshore on the western shore of the Orwell estuary (see Photograph 4).



Photograph 3 – Beach recharge between the Naze and Stone Point (source: HHA).

Further discussion of the beneficial use of dredged material is provided in Section 6.

Photograph 4 – Creation of mudflat and saltmarsh at Shotley in the Orwell estuary (source: HHA).

5.6. Monitoring

A comprehensive estuary-wide monitoring programme was established which encompasses a wide range of parameters, with specific monitoring of the Trimley managed realignment scheme. Although a discussion of the details of the monitoring is outside the scope of this paper, it includes the following parameters:

- Bathymetry;
- Sediment transport pathways;
- Benthic invertebrate communities (biotope mapping);
- Saltmarsh vegetation;
- Waterbird counts (low water);
- Fish, shrimp and plankton; and,
- Suspended sediment concentrations and intertidal deposition.

The monitoring is undertaken based on a rolling programme with the frequency of monitoring varying between parameters (e.g. waterbird counts are undertaken annually whereas bathymetric surveys are undertaken once every 5 years rolling programme).

6. Other development in the Stour and Orwell estuary system

As mentioned in the introduction, there are a number of other consented and proposed developments within the Stour and Orwell estuary system (the Trinity III Terminal Extension (consented and recently completed) and the Bathside Bay Container Terminal and Felixstowe South Reconfiguration (proposed)). The environmental studies associated with these initiatives have predicted that they would give rise to effects of a similar nature to those described above for the Approach Channel Deepening, albeit the impacts are of a different magnitude. An important difference is that the port development schemes all comprise, to varying extents, the reclamation of both intertidal and subtidal areas and, therefore, give rise to direct losses of habitat. A summary of the key predicted effects of these developments on the habitats of the Stour and Orwell estuary system is provided in Table 1.

Table 1 – Summary of key predicted impacts of major consented and proposed port developments in the Stour and Orwell estuaries (without mitigation) [2, 3, 4].

Scheme name	**Intertidal reclamation (ha)**	**Tidal propagation effect on intertidal area (ha)**	**Effect on estuary-wide intertidal erosion rate (ha/annum)[c]**	**Localised erosion**
Trinity III Terminal Extension[a]	2.93	-0.4 to -0.6	-0.2	Lower Orwell estuary
Bathside Bay Container Terminal[b]	65	-2.7	-2.6 to -2.8	Lower Stour estuary
Felixstowe South Reconfiguration[b]	1.7	-0.7	+0.5	Lower Stour and Orwell estuaries

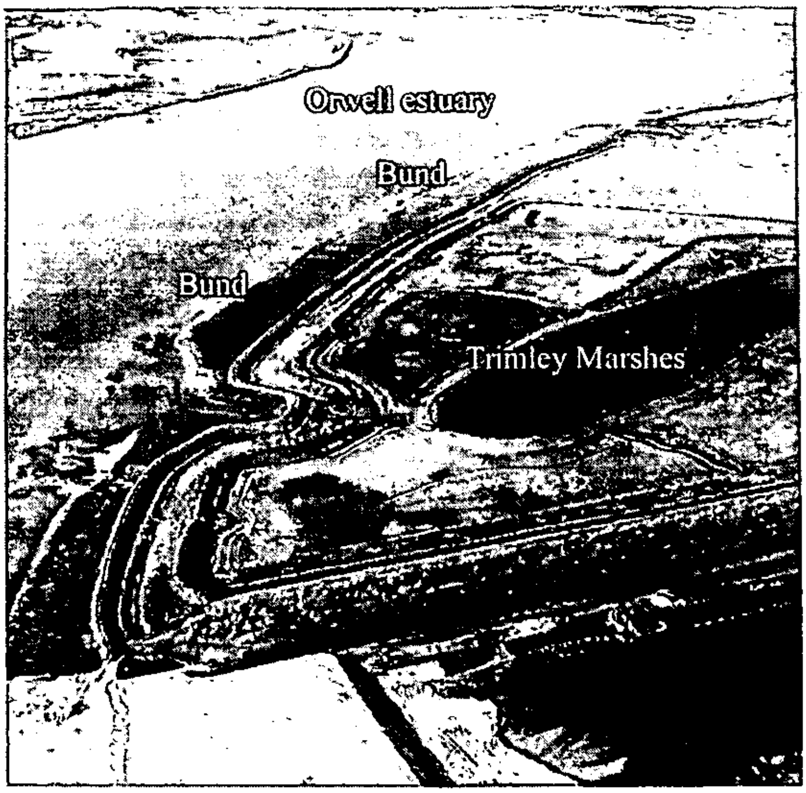
a Consented development

b Proposed development

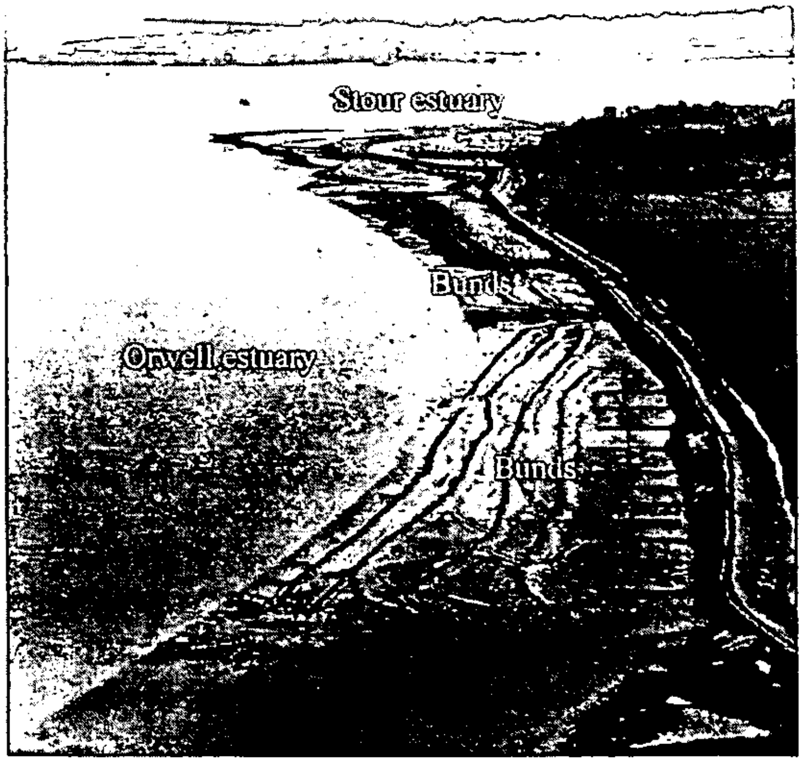
c A negative figure indicates an ongoing loss of intertidal and, hence, an increase in erosion rate.

The magnitudes of the effects quoted in Table 1 are those effects that are predicted to arise prior to the implementation of mitigation measures. Where possible, the various environmental studies undertaken for each of the proposed developments recommended compensation (where appropriate) and mitigation measures to offset any adverse impacts on the habitats of the Stour and Orwell estuary system. With respect to the implications of the various developments on the estuary-wide rate of intertidal erosion, it was agreed that the effects could be mitigated via the enhancement of the sediment replacement programme that was established following the Approach Channel Deepening in 2000.

In addition, specific measures were proposed to address the localised erosion of intertidal areas predicted to arise largely due to local changes in wave energy over certain intertidal areas. It is partly because of such predicted effects that 'habitat enhancement schemes' were proposed in the lower Orwell estuary on the Trimley foreshore (see Photograph 5) and the Shotley foreshore (see Photograph 6). These schemes comprised the placement of dredged clay and gravel at around the mean low water mark to form bunds (as shown on Photographs 5 and 6) which were backfilled within mud. These schemes served a number of functions; namely they provided intertidal habitat of higher ecological value (e.g. a mixture of mudflat and, over time, saltmarsh) than that which was formerly present and they increased the stability of existing flood defences in the lower Orwell estuary. In addition, they represent the beneficial use of dredged material. Crucially, the schemes were recognised by the regulators as not necessarily being permanent structures and they would erode and evolve over time. This was considered desirable as the habitat enhancement schemes would not constrain future options for the sustainable management of flood defences and habitats in the estuarine system.



Photograph 5 – The habitat enhancement scheme on the Trimley foreshore in the lower Orwell estuary, looking north (source: HHA).



Photograph 6 – The habitat enhancement scheme on the Shotley foreshore in the lower Orwell estuary, looking south (source: HHA).

7. Management of the mitigation and monitoring commitments

7.1. Establishment of a Regulators Group

The management of the mitigation and monitoring programme established as a consequence of the Approach Channel Deepening, and which has evolved and been refined in response to the findings of monitoring and the requirement to consider the implications of subsequent proposed schemes, has a number of key features. From the outset, a 'Regulators Group', with the authority to make decisions regarding the refinement of the mitigation and monitoring programme, was established. This Group represents the forum through which the programme is delivered. The Group comprises a number of bodies including English Nature, DEFRA, the Environment Agency, the Department of Transport (Ports Division) and non-statutory organisations including the Wildlife Trusts (Essex and Suffolk) and the RSPB.

A by-product of this collaborative approach that has partly arisen as a result of the HHA inviting other operators in the estuaries to also attend the meetings, has been an attempt to co-ordinate all mitigation and monitoring activities in the estuary system. This has derived from the open exchange of information and the establishment of a consultative forum. A culture of shared responsibility, between operators, regulators and NGOs, has consequently arisen.

7.2. Compliance monitoring and annual reporting

In order to assess the HHA's compliance with the large number of mitigation and monitoring commitments a process of 'compliance monitoring' was also established; overseen by an independent auditor (Royal Haskoning). This process involves documenting those actions and commitments that are to be undertaken during capital works and those to be undertaken following completion of the works. An annual compliance report is produced which describes work that has been undertaken with respect to each of the commitments and records when a commitment has been fulfilled. The process is overseen by the Regulators Group and the annual compliance reports are circulated to this Group.

In addition to compliance monitoring, an annual report is produced which details the findings of the research and monitoring that has been undertaken during the previous year and considers the ongoing consequences, if any, of development for the health, state and integrity of the estuarine system. This report is presented at an annual meeting that is attended by the Regulators Group to ensure that there is an open exchange of information between the HHA and the Regulators Group. This is an important process as the findings of the annual report and the discussions held at the annual meeting inform any changes to the programme of monitoring that may be required. Managing the process in this manner is the most effective approach to obtaining agreement from the various Regulators as to the way forward with respect to the mitigation and monitoring.

8. Dealing with uncertainty and consideration of 'risk'

The estuarine environment is inherently variable and in managing such a dynamic environment the requirement to accept of some degree of 'measured' risk is unavoidable. It is vital to recognise that there will be an element of uncertainty associated with predicting both the functioning of a natural system and the extent of any perturbations likely to arise as a result of development.

In the case of the Stour and Orwell estuaries this uncertainty (albeit limited) relates particularly to the ability of an artificial sediment bypassing system to efficiently replicate nature; the relevance of the placement locations; and the potential effect of sediment replacement on the benthic ecology and fish resources of the estuaries. These issues, however, can be informed through monitoring and an informed review of monitoring data. It is for this reason that the adoption of an iterative, flexible approach to mitigation, informed by good data, appropriate monitoring and an open exchange of information with stakeholders, is essential.

This is achieved in the Harwich Haven through a system of monitoring, reporting and response with a single point of responsibility. In addition, the mitigation is conditioned (and thereby any risk is reduced) through four steps, where a procedure is in place for each step to be taken sequentially should the previous step prove to be inadequate. That is:

1) A broad, estuary-wide sediment replacement programme, as described above;
2) Sediment replacement specifically targeted towards areas of 'need';
3) Direct placement onto the intertidals (with appropriate consent); and (if all else fails)
4) Compensation.

Overall, the flexibility and consultation built into this approach ensures that a well informed decision making process exists and enables successful mitigation to be delivered.

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LONG-TERM MARINE ENVIRONMENTAL SITE MONITORING -FOCUS ON DEFINING BACKGROUND SUSPENDED SOLIDS LEVELS

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Background suspended solid levels in the marine environment can be defined and predicted following long-term monitoring. Defining the existing levels poses a number of challenges including equipment, operational, data and reporting issues that require significant planning and well-structured management. A case study of a data collection and prediction programme, which was operational in the estuarine environment of Southampton Water (Hampshire, UK) from August 2001 to July 2004, forms the basis of this paper, but topics are discussed in a generic manner and are applicable to other marine environments.

The execution of this project was directed by a group of leading UK consultants to ensure that the resultant database provided an accurate record of existing levels. 'In-situ' monitoring was completed to enable the potential impact on suspended solids levels to be assessed during proposed future dredging activities and 'beneficial use' mudflat recharging in the estuary. Once the background levels had been defined a method of predicting future levels was also required.

Oceanographic parameters were recorded using an array of seven multi-parameter sondes equipped with sensors to measure turbidity, salinity, temperature, 3-Dimensional water flow and pressure. Meteorological data and local berthing activity data at the location were also recorded.

1. Introduction

Long-term monitoring in this paper refers to a time-scale of months and years where the unmanned collection of *in-situ* data for such extended periods of time requires significant effort and management. Most of the topics discussed could however be applied to shorter project periods.

Background levels are defined as the naturally occurring levels of a parameter, and for this project the suspended solid levels were of primary interest. To define background levels readings must be taken for a sufficient period of time prior to any anthropogenic activities, which could artificially affect natural levels. The definition of the monitoring period is dependant on the magnitude of the expected environmental impact of the activity (such as dredging), the complexity and existing understanding of the marine environmental processes that occur at the location, and the duration of the proposed activity [1]. This is a complicated decision to make which for the proposed dredging programme in Southampton Water required the formation of a group of leading experts to determine the duration. Due to the planned dredging being spread over a number of years it was apparent that annual variations were required to be examined and understood, especially in terms of meteorological impacts caused by dry summers and wet winters for example. An initial period of three years of background data was decided upon. As a continuous dataset was required, daily monitoring of the sensor performance was imperative to allow for rapid response to suspected failures or data quality issues. Any downtime had to be kept to a minimum and spare equipment available to swap if required. For the optical sensors this meant completing instrument calibrations in advance of the deployment so that they could be deployed swiftly. In the case of Southampton Water a 48-hour maximum downtime for any sensor was stipulated.

Such monitoring is completed for a number of reasons but in the case of Southampton Water the monitoring of dredging impacts on water quality was required to prevent adverse affects on the environment, such as smothering of benthos or the disruption of fisheries. This project also needed to ensure that sensitive industrial activities such as drawing cooling water were not subjected to increased suspended solid levels which could increase maintenance requirements on the plant. The resultant database also provides important scientific information on the complex nature of the flux of suspended sediment load which is of academic importance.

Once the dataset was complete, a method of interrogating the background dataset using a near real-time computer based system was to be established to enable trained operators to rapidly assess if observed levels were above the expected background levels. The dataset could therefore be used to make predictions of future levels.

2. Sensors and equipment

In the case of the installation in Southampton the sensors were deployed from a jetty terminal, which was used by vessels to berth alongside for unloading and loading petrochemical products (see Figure 1).

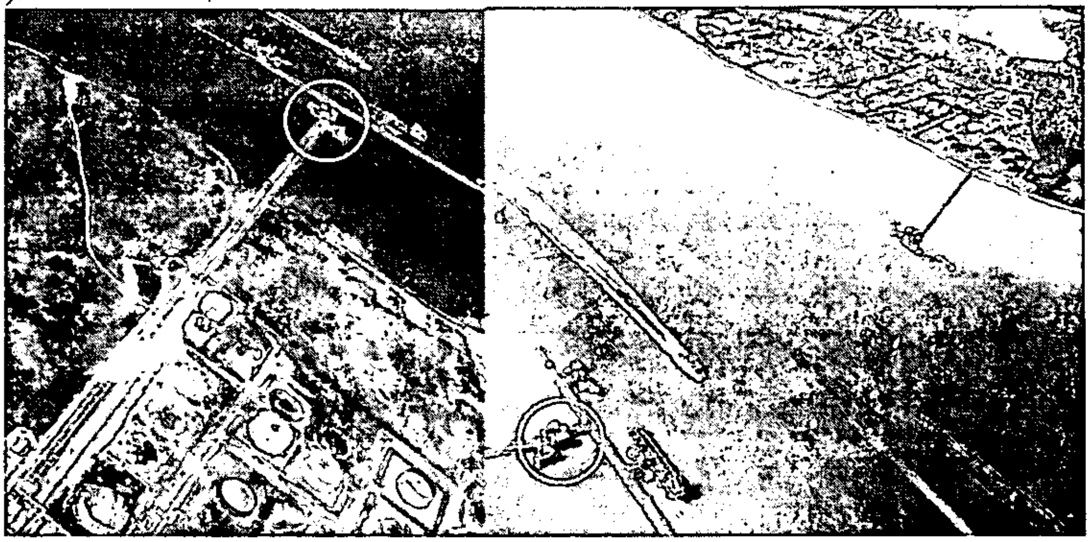

Figure 1 - Site location in Southampton Water at jetty terminal (circled). Photos by Neil Pittam.

Located within the terminal head were two cooling water intakes, which drew water from the estuary into the plant. Seven sondes were deployed in the vicinity of the intakes (see Figure 2) with five in the estuary consisting of one reference position (which was away from the influence of the intakes) and two each in front of the intakes at different depths. Sondes were also placed in each of the intake stilling pools (SWPH3 and 4), which were within the line that was then pumped ashore (see Figure 2). An acoustic doppler profiler (ADP) current meter was also mounted in front of the intakes to collect tide and three-dimensional water flow data (see Figure 3). All sensors were connected to a central logging unit which collected and transmitted the data to the data management office.

The outer sensors in the estuary were deployed to take readings from a position approximately 0.5 metres above the seabed, which at this particular location is around 'zero' chart datum (CD). All sensors were deployed on a weighted stainless steel wire so that they could be easily pulled up for inspection and cleaning.

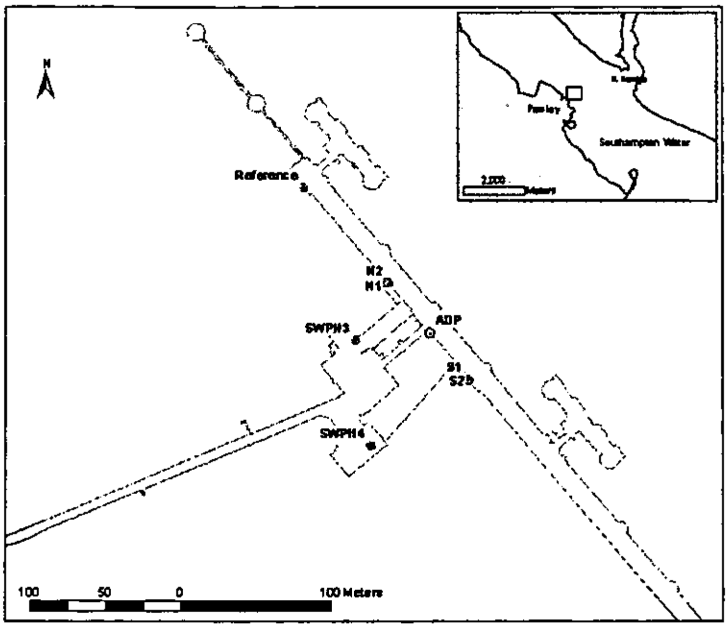

Figure 2 - Sensor locations around the jetty and jetty location in the estuary (insert).

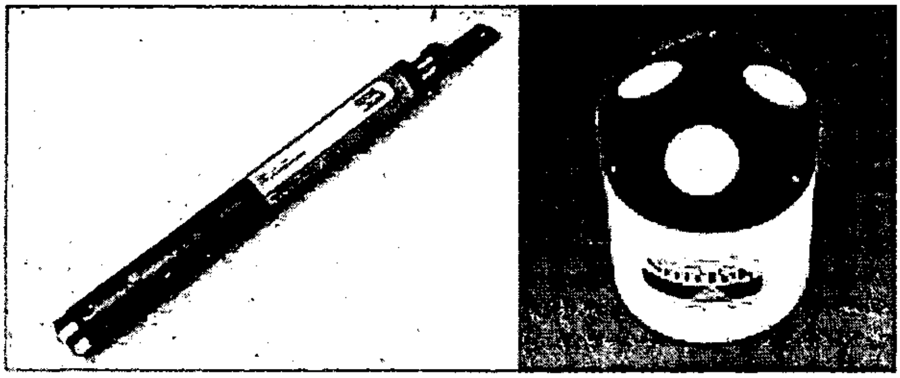

Figure 3 - Sonde (left) model YSI 600OMS, ADP model Argonaut XR (Courtesy of YSI and Sontek).

3. Operational Issues

The data was transmitted from the logger using a GSM data link which was selected after initially using a UHF radio link, which proved to be unstable and unreliable. Problems with the radio link included signal blocking by large car transporter vessels entering the estuary and the construction of a steel structured four-storey car park in line between the transmitter and the receiving antenna. By using GSM technology there were a number of added benefits which included improved data security and reliability of the data signal.

Problems relating to bio-fouling were minimised by the particular model of turbidity sensor used which was fitted with a wiper arm to clean the optical lens at user defined intervals, which was ten minutes in this case. The wiper itself does suffer from degradation over time as the foam wiper material wears and becomes contaminated with fine sediment, therefore ensuring that the wiper sponge is clean is paramount.

The remaining sensors on the sonde and the ADP current meter do not benefit from any wipers and therefore require routine inspection to ensure that there is no build-up of sediment or biological growth such as weed and barnacles. Routine maintenance is therefore carried out at monthly intervals in the winter and every two weeks in the summer. If this schedule is not strictly adhered to then degradation in the performance of the sensors and hence the quality of the data output will be observed [2].

4. Sensor Calibration

The requirement of the monitoring was to determine the background suspended solid levels in the water, therefore the relationship between the optically sensed nephelometric turbidity units (NTUs) and actual solid material content needs to be determined. A series of calibration exercise were regularly completed on the turbidity sensor to achieve this;

- Standard NTU solutions - for internal electronic stability checks
- In-situ water sampling with synchronised NTU readings – to relate actual suspended solid measurements with the sensor output
- Indigenous material testing in a laboratory environment – to replicate the in-situ water sampling but with greater control over the range of NTU readings.

The standard solution tests consist of known NTU concentrations being measured and the deviation of the sensor observed. Standard solutions are made from distilled de-ionised water mixed with latex microbeads [3]. A range of solutions were used from 0 to 800 NTU to check that electronic degradation did not produce significant electronic drift. If any drift is detected this is recorded so that at a later date a drift correction can be applied. The sensor is periodically re-calibrated (to the 0 and 800 NTU solutions only) to correct for any drift.

In-situ water sampling was completed 2 hours either side of the highest levels of turbidity which was typically one hour before low water (LW). This enables both lower and higher readings and samples to be collected, giving a good spread of readings for a calibration plot. One of the sensors was lifted and a double-ended water sampler (Niskin Bottle) was attached so that the sensor and the bottle chamber were as close together as possible. The sonde is disconnected from the main network and attached to a hand-held display unit which outputs turbidity readings at a rate of 1 H_z. The sensor and bottle were then lowered and when a suitable reading was observed the bottle was triggered and the NTU reading was recorded. This allows for sampling synchronisation to about three seconds, and it was established that the synchronisation must be of this order to generate an accurate relationship. Gravimetric analysis on the collected water samples determined the total suspended solids (TSS) and the volatile suspended solids (VSS). The difference between these is that the filter paper is dried at 105 and 500 degrees centigrade respectively. The first burns off any moisture and retains both mineral and biological content, and the second burns off the biological content leaving only a mineral content. This aspect is important when quantifying the variations in biological matter in the water column. Particle size analysis was also completed using a Malvern Instruments 'Matersizer' laser diffraction instrument to measure the size and distribution of the solid material.

Indigenous material tests involved removing all of the sensors from the array, cleaning them and placing them in a circulating chamber which allows for the water to remain in a constant flow. The use of a pump keeps any material added to the water in suspension (see Figure 4). The intention was to replicate the natural environment found on-site, therefore salt was added to the tap water in the chamber. Indigenous material, which had been collected from the top centimetre of the

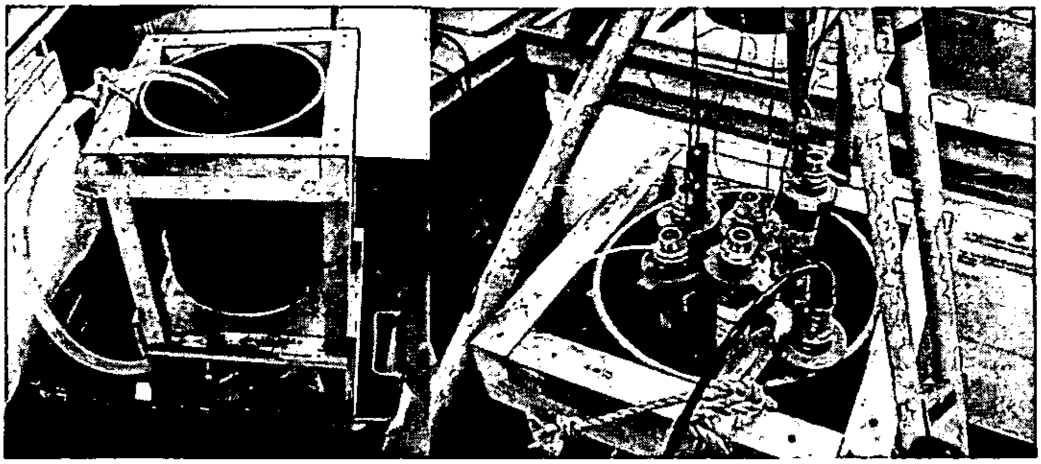

Figure 4 - Circulating chamber. Turbidity sondes inserted in right-hand photo.

seabed in the vicinity of the sensors, was mixed with estuarine water to produce a stock solution of very high concentration sediment loaded water. The stock was then gradually added to the mixing chamber and high frequency (2 H_z) readings were taken for 30 seconds with each sensor. Collecting this amount of data allows for statistical analysis on the stability of the mixture to be completed. A water sample was then taken and gravimetrically analysed for TSS and VSS content. This method was repeated for a range of NTU readings, allowing for the NTU to milligrams per litre to solid material relationship to be further defined.

A detailed log recording the serial numbers of sondes and sensors at a particular location must be kept to allow for calibration corrections to be applied and to relate the sensor specific in-situ and indigenous material test results. The implementation of QA procedures is essential to ensure that the quality of the final dataset is high. Record keeping of all activities must be very thorough for successful long-term data analysis.

5. Data Analysis

Once the data had been corrected following the calibrations and 'cleaned' of poor quality data, a method of comparing it to future observed levels needed to be derived. In the case of the Southampton Water dataset two options for completing analysis and hence future comparisons were considered by the group, these were tidal range and salinity based relationships. The basic reasoning behind the tidal range analysis was that larger ranges would produce greater current flows and hence there would be more disturbance and suspension of the bed sediments.

Due to the premature termination of this project, which resulted in the final analysis approach not being agreed or applied to new data, neither method was finally approved by the group. It was however thought that the tidal range analysis would provide a more directly comparable and analytical basis, which could be compared to newly observed tidal ranges and suspended solid levels in near real-time. This also allows for longer term predictions of levels based on tidal predictions. The focus of the analysis was based on this approach and extensive progress was made in deriving a thorough understanding of this relationship.

5.1. Tidal Range Analysis

The ten-minute data recordings were tagged with high and low water times so that each set of ebb and flood tide data could be isolated and analysed. Knowing the range for each tide it was then possible to generate an integrated value for suspended sediment for the period of the tide. This process was completed for the entire dataset which resulted in the generation of range versus 'total' suspended solid data (see Figure 5) for each part of the tidal cycle. Such plots show statistical trends, spread and the deviations of this relationship. Future NTU levels for a given tide range could therefore be anticipated. Analysis was primarily completed using Matlab software which used ASCII format (text) data files. Excel was also used for some tasks, with macros allowing for routine calculations to be run. As well as generating statistical outputs, Matlab produced graphical ouputs which were very useful for reporting requirements such as sensor performance.

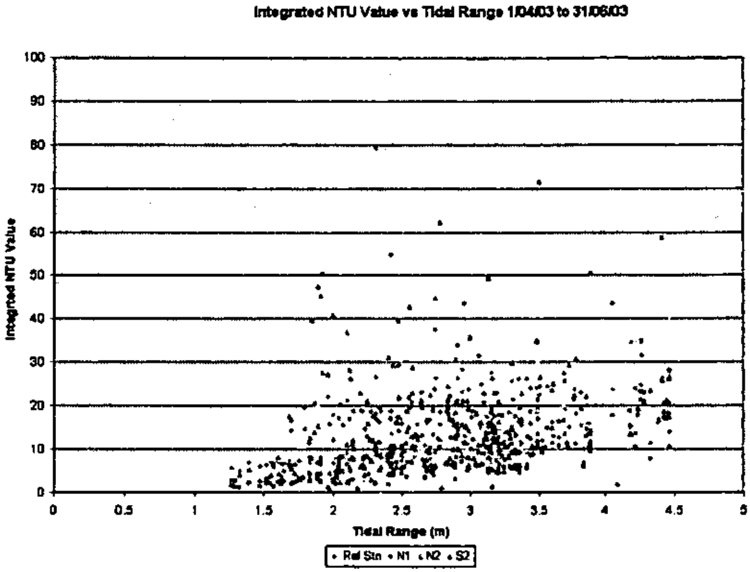

Figure 5 - Plot showing NTU vs tidal range analysis.

Once the tidal range analysis had been completed it was possible to complete seasonal and annual comparisons. This analysis also highlights when very low or very high turbidity levels are recorded. Such events can then be further investigated to find the reason for the unusual occurrence.

5.2. Anthropogenic influences

Due to the vessel movements in the vicinity of the intakes, it was important to understand the influence that berthing and sailing had on local turbidity levels. The tankers that operate at this particular location can also require the use of tugs for manoeuvring. Such activities in relatively shallow water can further agitate the bed sediments. Berthing and sailing events were logged in a spreadsheet and plotted onto time series data to manually observe if it was possible to correlate unexpected peaks in turbidity with ship movements. This process by nature of its execution tended to be slightly subjective as two different analysts could consider a peak in turbidity to either be relevant or not. It was however found that such events did not have a noticeable or long-lasting effect on local levels, instead short-lived events in the order of 15 minutes were observed. The percentage of peaks in turbidity that could be attributed to vessel movements was in the order of 5 to 10%.

5.3. Meteorological influences

A marine location is geographically likely to be subjected to more intense wave action and hence bed sediment disturbance when the wind blows from a particular direction with strong winds and for a sustained period of time. In the case of Southampton Water, which is orientated northwest to southeast, strong winds blowing up or down the estuary had a noticeable impact on turbidity levels. It is therefore very important to have a meteorological station in proximity to the monitoring location to be able to quantify these effects.

5.4. Near Real-Time analysis of data and prediction

Once analysis has been completed, and the anthropogenic and meteorological influences understood, it is then possible to use this information as the basis of a decision making tool that will enable near real-time analysis of new data, to assess whether conditions are at background levels or higher than background [4]. If new levels start to exceed this level then efforts can be taken to assess the cause of this increase and take the appropriate course of action such as suspending dredging activities. A software program needs to be written to complete this, as an evaluation based on the rapid interrogation of the dataset is required. This software needs to be easily understood and 'user friendly' so that staff with basic computing skills can operate it. It is likely that with a 24 hour dredging activity there will be a number of staff involved in the monitoring and this will be one task of many that the operator has to complete on any given shift.

Due to the termination of the project prior to realising this stage, this activity never became more than theoretical, yet the thoughts of the group regarding this matter are considered to be useful. The proposed way in which this was to be completed was to use predicted tides and the tidal range analysis data to estimate what the expected suspended sediment levels would be. This would then be displayed on a time series graph with two standard deviations also plotted above this level. This was the proposed deviation that was considered to be acceptable, which was observed as a naturally occurring deviation for short periods of time (days only). If the levels then exceeded this limit an audible alarm would be triggered, probably associated with a flashing red screen. The operator would then obtain recent weather records and assess whether it was the weather causing this increase by the use of simple 'look-up' tables based upon the analysis of the impact of meteorological events. If it was still thought that the present levels were high then the alarm could be raised with senior staff and the dredging operator. It must be remembered that the flood or ebb tide must be complete for it to be possible to analytically compare the tide to the database. A decision could then be made as to what further action should be taken. Such software needs to include a daily report on this comparison so that the data can be scrutinised and confirmation given that the operators judgement was in fact a valid one. Further sophistication could be added to this system if real-time tides were used, as this would result in a more accurate suspended solid load prediction.

6. Conclusion

The application of state-of-the-art technology to marine environmental monitoring can assist in ensuring that the environment is not being adversely effected by anthropogenic influences. This enables decisions to be made on whether or not the environmental is being managed in a sustainable manner. Long-term monitoring followed by data analysis can also facilitate the prediction of future levels.

Monitoring of this nature requires a considerable commitment of resources to generate an accurate database of the existing conditions. For an array of sensors, this is a costly exercise both in terms of initial capital investment, ongoing maintenance, data analysis and reporting. Relating the optical sensor readings to actual sediment loads carries a level of uncertainty, but this can be quantified and minimised by completing a rigorous series of calibrations. Once established, the resultant database is available for a range of statistical analysis for those looking to determine relationships that can be used to define complex physical processes existing at that location.

Future developments in remote sensing technologies such as satellite and airbourne could potentially reduce the cost of collecting background data and provide improved spatial coverage, to compliment existing *in-situ* measurements.

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ENERGY REQUIREMENTS FOR FUEL CELLS APPLICATION IN WATERBORNE TRANSPORT

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Fuel Cell systems, despite offering great advantages in terms of environmental impact, present some aspects that must be carefully analysed in order to make them usefully exploitable onboard ships. The paper provides a synthesis of some results achieved by an European research project concerning maritime applications of fuel cell systems (FCSHIP). In particular, it analyses the main energy requirements able to meet the load demand for the exploitation of fuel cell system in merchant vessels. The power profile of auxiliary services varies with both different environmental conditions (manoeuvre, sea going, and harbour) and the operating conditions (i.e. the start-up). The investigation of the energy demand in different operating conditions by using suitable simulation tools is able to point out the requirements related to ship load management system and fuel cell plus power conditioning sets. Furthermore, an onboard power plant has to provide a high level of availability able to guarantee the supplying to the essential services. The power plant usually consists of a number of Diesel Generating sets rated in such manner that the fault in one group does not influence the required load demand.

1. Introduction

Significant efforts have been spent over the last 10 years in order to strengthen the development of fuel cell technology, trying to address the basic technology for land and sea based transport applications.

So far, direct application of fuel cells in waterborne transport is not possible and so will be until the specific problems related to waterborne transport are properly dealt with.

However, some fuel cell applications have been exploited in navy projects as for example:

- the Royal Netherlands Navy developed studies and laboratory prototypes for submarines and for the so called All Electric Ship. Most tests have been performed with Polymer Electrolyte Fuel Cells (PEFC) of about 1 kW, by using hydrogen or synthetic reformer mixtures (premixed in steel pressure bottles);
- the Howaldtswerke-Deutsche Werft (HDW) has been involved in the development of fuel cell powered submarines for 20 years, and today delivers submarines equipped with fuel cell systems. The safety standards of submarines are significantly different from the commercial shipping ones and a system solution based on both pure hydrogen and oxygen, as in submarines, does not seem commercially viable.

Although hydrogen represents the best solution for fuel cell application, alternative and more conventional marine fuel types offer better guarantees from the safety point of view.

The European Project Fuel Cell Technology for Ships (FCSHIP), completed in December 2003 within the fifth Framework Programme, aimed at identifying those technical aspects of fuel cells which can already be applied to waterborne transport through the development of example designs and basic standards.

FCSHIP project mainly considered:

- the applications of fuel cells to supply the power demand of the auxiliary services of Ro-Ro and cargo vessels;
- the introduction of medium or high temperature fuel cells and reformers in the engine control room.

Main result of FCSHIP project is the definition of technological/functional requirements for the operation of fuel cells onboard ships in terms of system efficiency, power supply availability, electrical load demand and fuel storage.

The functional requirements related to the electrical load energy demand and to the power supply availability are described in the following paragraphs.

2. Description of a fuel cell system onboard ship

A fuel cell system able to supply the auxiliary services on a merchant vessel must comply at first with the general requirements provided by the Classification Societies. Specifically, it has:

- to provide the rated power to the load in case of total fault of one power generating set;
- to limit the alternating current (AC) voltage variation at the main bus bar according to Table 1;
- to guarantee a total harmonic distortion of the voltage at the main bus bar lower than 5 %.

Table 1 - Electrical requirements at the main bus bar.

Parameter	Variations	
	Continuous	Transient
Voltage	+ 6% -10%	± 20% (recovery time: 1,5 s)
Frequency	± 5%	± 10% (recovery time: 5 s)
Note: For alternating current components supplied by emergency generation sets, different variations may be considered.		

According to the aforementioned requirements and considering the load power, the fuel cell system must include at minimum two fuel cells modules each of them equipped with a power conditioning system.

The fuel cell power conditioning system can be designed in different way according to the voltage output of the fuel cell module and it must be able to provide the main switchboard with the AC voltage profile according to the requirements.

A simplified block diagram of the fuel cell based power plant is reported in Fig. 1.

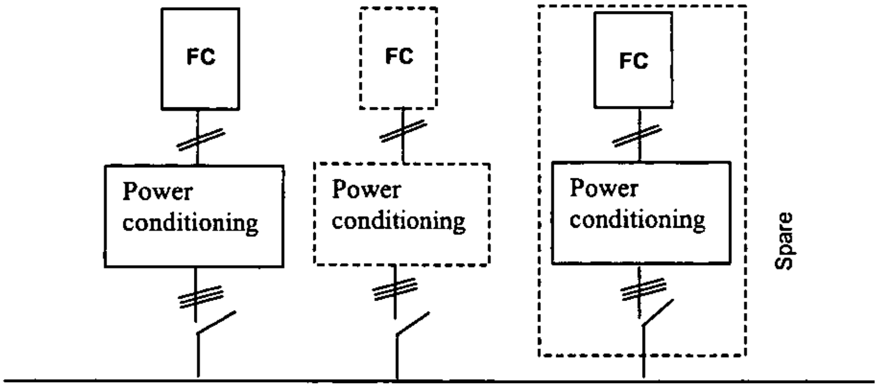

Fig. 1 - Simplified electrical scheme of a fuel cell based power plant.

The voltage value of the main bus bar is usually selected among the values 380 V, 440V, 690 V while the frequency can be either 50 or 60 Hz according to European or US standards.

3. Energy demand for fuel cell system onboard ship

A fuel cell system onboard ship able to supply the auxiliary services requires a detailed analysis of the energy demand in steady state and transient conditions.

Both these conditions cannot be simply derived from the electrical balance of a ship that is the typical information required to design and size the Diesel Generator power plant for the auxiliary services.

In fact, either a Molten Carbonate Fuel Cell (MCFC) or a Solid Oxide Fuel Cell (SOFC) is generally characterised by a I-V curve as reported in Fig. 2.

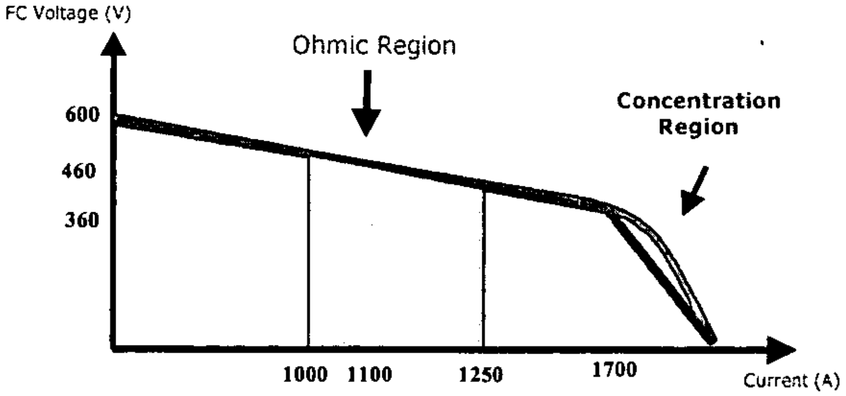

Fig. 2 - Static I-V of a 500 kW MCFC module.

The I-V curve represents the static behaviour of the electrical outputs where a high demand of current leads the fuel cell into the concentration region providing a sudden decrease of voltage corresponding to a dangerous condition for the main switchboard and a possible blackout for the ship.

In order to keep the fuel cell in the ohmic region and particularly in the safety area, it is necessary to know what the energy demand is during the insertion or the shut down of the electrical loads, or generally during the load variation, recording electrical variables with sample times of seconds and milliseconds.

In order to detail the energy requirements a measurement campaign must be performed on ships equipped with a conventional diesel generator power plant in order to replace it with an innovative fuel cell system.

Inside the FCSHIP project, a measurement campaign was performed on power plants for a Ro-Ro vessel and for refrigerated cargo vessel in order to define the main requirements in three different operating conditions:

- manoeuvre during inbound/outbound operations;
- sea going operations;
- in harbour operations.

The main results in terms of electrical power are reported in Fig. 3. The defined operating conditions are presented in three graphs, each of them showing the energy demand variation during a minimum time interval of 6000 seconds.

It has to be noted that the main variation around the mean value occurs during the manoeuvring operations and it is mainly related to a sudden introduction of the air conditioning system and the thrusters' motors.

The large variation is pointed out in Fig. 3a where the peak values have a duration in the range of 10- 30 seconds.

Furthermore, the sea going and harbour conditions show a variation around the mean value but the range does not overcome the 15 % of the mean value.

The duration of the energy demand is strictly related to the control and to the electrical systems connected to the large electrical motors as well as to the general energy management system.

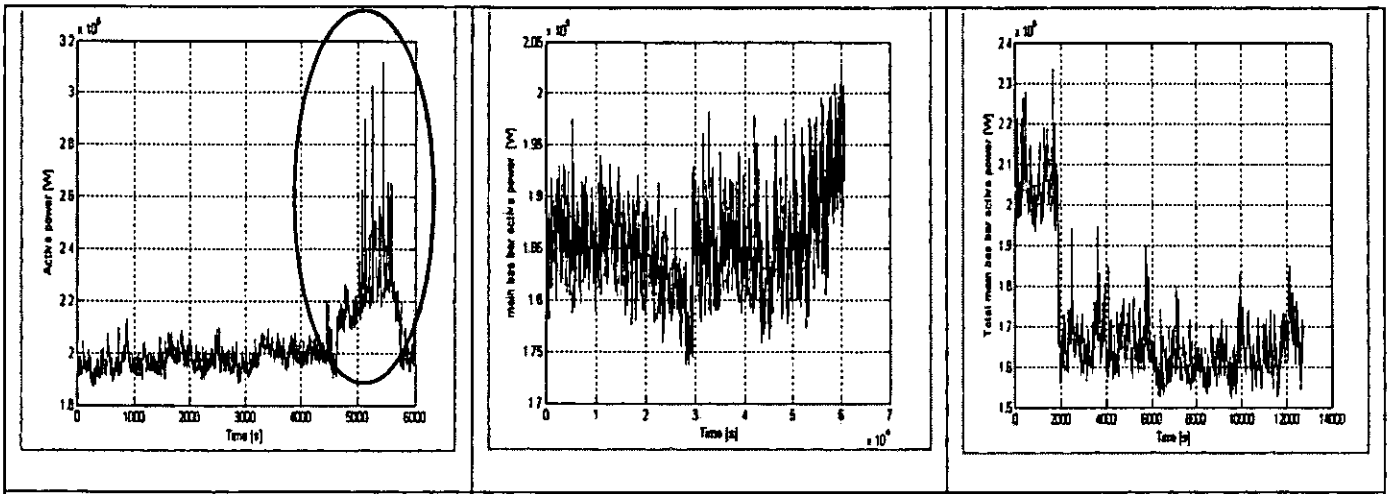

Fig. 3a - Manoeuvre power demand

Fig 3b - Sea going power demand

Fig. 3c - Harbour power demand

Fig. 3 - Energy demand of the auxiliary service power plant.

4. Energy demand for fuel cell operation

The energy demand for fuel cell units supplying the electric power onboard ship must be analysed with respect to two main conditions:

- steady state conditions at different level of power;
- transient conditions that are mainly related to the connection/disconnection of the electrical loads.

The activities described in this paragraph are described in [4]

4.1. Energy demand in steady state conditions

The energy demand of the auxiliary services is in the range of 1-3 MW for conventional Ro-Ro ferries and refrigerated cargo vessels. The loads can be supplied by a power plant including two or more fuel cell modules. The identified range of value leads to investigate on medium–high temperature fuel cell such as MCFC or SOFC.

The stationary conditions can occur either during sea going or harbour operations. Taking into account the electric balance of a ship and the previous defined conditions, it is easy to extract the mean values for power, voltage and current of each fuel cell module.

The electric balance is derived from the power demand of the main services for the ship a part from the main propulsion system that is supposed to be a conventional diesel engine system.

Each service, such as deck service, engine control room service and light service can include primary essentials services, secondary essential services and habitability services.

The total power demand of each service is derived from the rated power of the electrical loads of the service multiplied for the number of operating loads and the utilisation factor in each operating condition.

The final value of each operating condition leads to the preliminary sizing of the auxiliary service power plant. A general electric balance for a Ro-Ro vessel is reported in Table 2.

The required power derived from the electrical balance must be divided into the number of the fuel cell modules necessary for a continuous supply.

In this case, a sizing of a fuel cell power plant based on the values of the electrical balance requires five fuel cell modules and one spare unit if the fuel cell rated power is 500 kW.

It has to be noted that the thrusters' power covers a high part of the power demand and it usually influences the high power demand during the manoeuvring operations.

In case of 500 kW fuel cell modules, and for example considering the thrusters' motors supplied by a separate diesel generator unit, the number of fuel cell units in the power plant can be reduced to four operating and a spare one. In fact, as shown in Table 2, the power demand without the thrusters' motors load does not exceed 2000 KW.

Table 2 - Electrical balance for a Ro-Ro auxiliary service power plant.

			Electrical balance			
Item	Group	Group denomination	**Ship conditions**			
			Sea going	**Manoeuvring**	**Harbour**	**Emergency**
			kW	kW	kW	kW
1	A	Deck and hull service				
			78,67	52,59	185,65	8,37
2	B	Safety service				
			15,61	13,43	9,23	191,83
3	C	Cargo service				
			182,81	161,54	258,59	0
4	D	Engine room service				
			428,54	428,54	135,43	9,56
5	E	Air conditioning and ventilation service				
			646,60	662,60	622,60	
6	F	Galley service				
			83,67	73,40	73,40	0
7	G	Accomodation service				
			44,68	48,50	32,87	
8	H	Light service				
			104,00	104,40	130,00	55,00
9	I	Thruster service				
			0,00	850,00	0,00	0,00
A		Power required by the Plant				
			1584,59	**2395,00**	**1447,78**	**264,76**
B		Assumed Power factor	0,8	0,8	0,8	0,8
C		Apparent power	1980,73	2993,75	1809,73	330,95

4.2. Modelling and simulation of a fuel cell plant in steady state conditions

The modelling and simulation of a fuel cell based power plant in rated conditions can provide some interesting results related to the energy demand in steady state conditions.

A model of the fuel cell based power plant including five fuel cell modules and the related power conditioning systems has been implemented and the results of the simulation are reported in Fig. 4.

The output voltage of each fuel cell module has a mean value of 460 V and it is kept constant by means of the control system of the power conditioning unit connected between the cell and the main bus bar (Fig. 4a).

The ripple around the voltage mean value is due to the switching operation of the power conditioning system and is maintained inside the range of ± 5% by the control system.

The output current of the fuel cell module has a mean value of 1020 A and the ripple is kept inside the range of ± 8% by the control system.

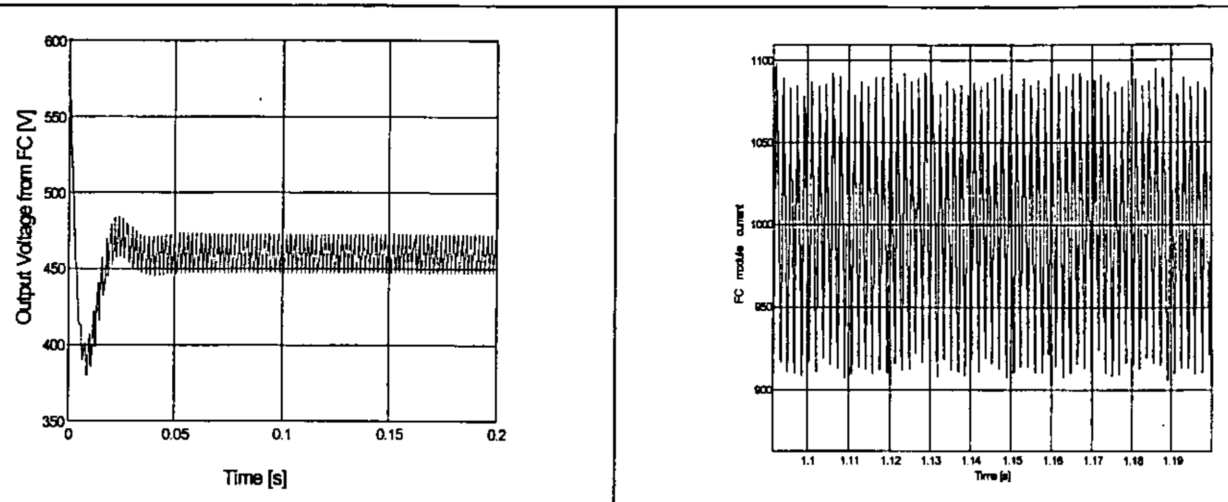

Fig. 4a - Fuel cell output voltage vs. time

Fig. 4b - Fuel cell output current vs. time

Fig. 4 - Fuel cell module output electric variables (voltage - current).

The ripple of the electrical variables is unavoidable due to the presence of a power conditioning system and it can be considered a short lasting transient condition. It involves only the electrical dynamic of the fuel cell and not the thermal/mechanical dynamic. Furthermore, the ripple must be taken into account especially during low power demand in stationary conditions, since a reverse current is not admitted to flow into the fuel cell unit.

4.3. Energy demand in transient conditions

The transient conditions can have peaks and duration according to the ship operating profile.
In general, the transient conditions occurring on a energy plant for auxiliary services can be identified as:

- long transient energy demand;
- short transient energy demand;
- fault conditions.

A long energy demand, which can include either the start up or the shut down of a fuel cell, is a frequent operation in a conventional power plant onboard ship, as well as a variation of the required power for more than one minute.

A short transient energy demand can include the power ripple related to the power conditioning system operation as well as the short transient power demand of the electrical loads such as the start up of motors, (the air conditioning system, thrusters, steering gears and compressors. The thrusters operation is the most critical one because it can be included in the short transient demand but the peak of power can lasts more than some seconds.

For medium or high temperature fuel cells the dynamic behaviour involves four main phenomena, each of them characterised by different time responses. They are:

- thermal;
- electro-chemical;
- electrical;

- mechanical.

Consequently, the models explaining the dynamic behaviour of a fuel cell system can be divided as follows:

- a model which explains the dynamic of the system up to the change of the set-point parameters of the plant (thermal/mechanical model);
- a model which explains the dynamic of the system after a load change even if with the set-point parameters are kept constant (electrical model).

The short transient energy demand involves mainly the electrical dynamic phenomenon, while the long transient energy demand involves the four phenomena. During the short transient energy demand, the thermal set point can be assumed as constant, while voltage and current profiles vary and can lead the fuel cell to the concentration region and to the short circuit.

During the long transient demand, also the thermal set point varies and the energy production of the fuel cell unit must comply with the load energy demand in the correct values and times in order to provide the required operating conditions of the ship.

4.4. Modelling and simulation of a fuel cell plant in transient conditions

The modelling and simulation of the fuel cell plant in transient conditions has been developed and deeply analysed only in the defined short transient operation. In this case, the set point parameters have been kept constant and only the electrical behaviour has been considered. The imposed power demand profile is derived from the measurement campaign where it came out that the largest variation occurs during the manoeuvre conditions and the switching of the thrusters' motors.

The highest transient demand is reported in Fig. 5 where the power demand at the power plant of a conventional Ro-Ro ferry during the manoeuvring operations has been measured and recorded with sampling time of one second (Fig. 5a), as well as the specific power absorbed by the thrusters motors (Fig. 5b).

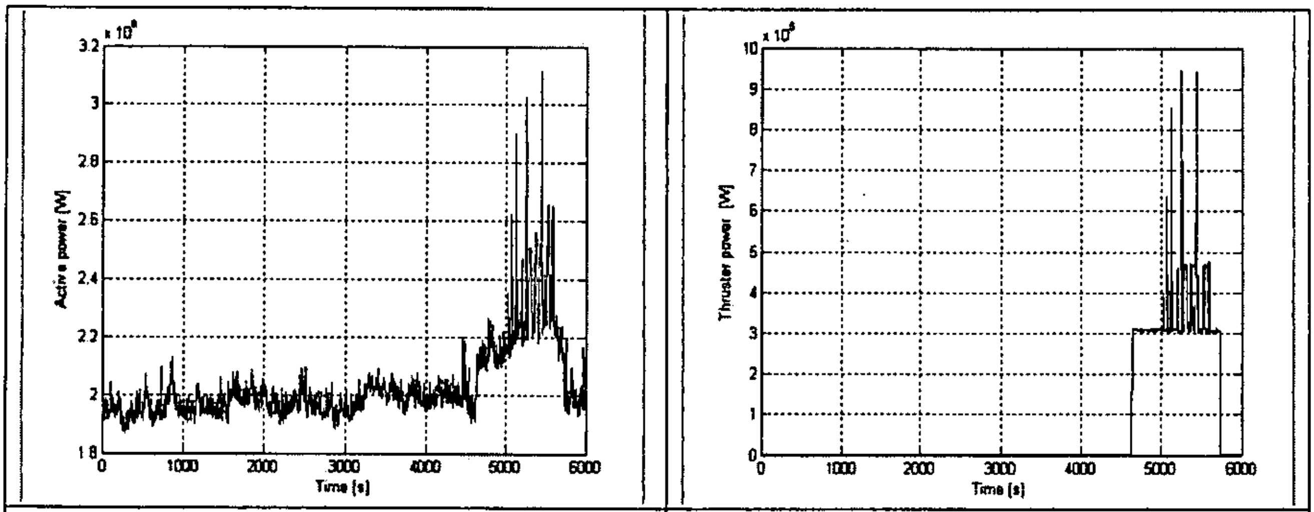

Fig. 5a - Active power profile during manoeuvring operations

Fig. 5b – Thrusters' motor power profile

Fig. 5 - Power demand related to thrusters motors.

The simulation of the fuel cell electrical behaviour during twenty seconds of high power variation due to the thrusters' motors operation has been performed and the results are reported in Fig. 6.

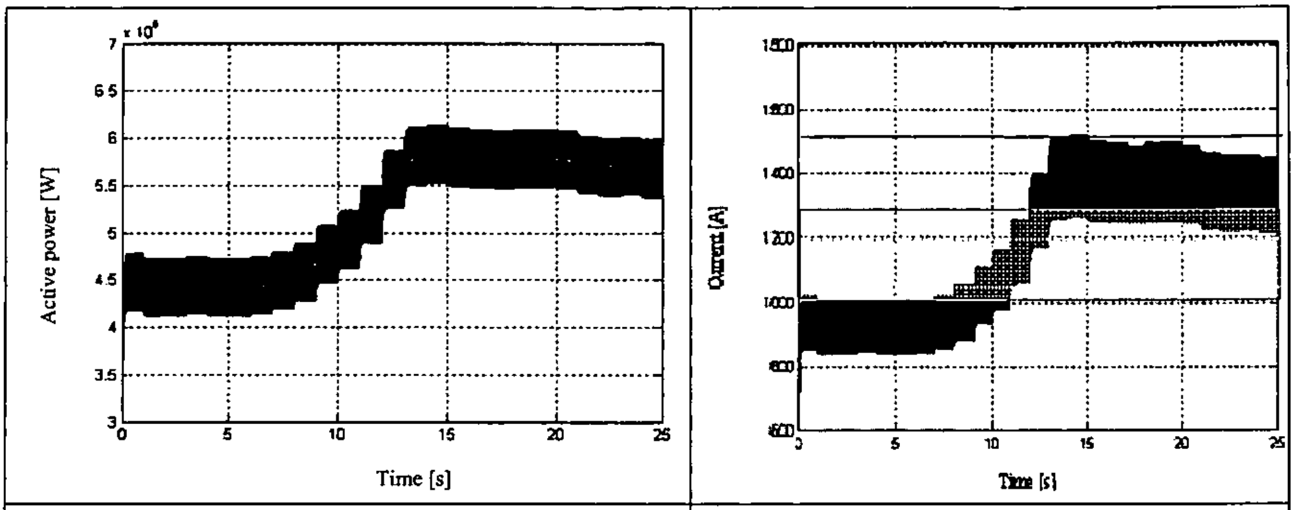

Fig. 6a - Fuel cell active power profile vs. time

Fig. 6b - Fuel cell current vs. time

Fig. 6 - Fuel cell power and current profile for thrusters motor loads.

The power of each fuel cell unit exceeds for more than twenty seconds the rated one and the dynamic response follows the demand providing a current value that overcomes the safety region and reaches a value close to the transition of the concentration region. The fuel cell unit usually is protected by this condition but the lack of power to the thrusters' motors could have a critical consequence on the correctness of the manoeuvring operations. The intervention of another fuel cell unit able to provide the power demand must be obtained in a short time.

To complete the short transient analysis, a detailed study of the fuel cell response at the start up of a large power electrical motor has been performed. An example is a fuel cell module of 500 kW that has to supply an AC induction motor whose rated power is 275 kW (about 50% of the fuel cell rated power). The motor start up in no mechanical load conditions has been modelled and the simulation results are reported in Fig. 7.

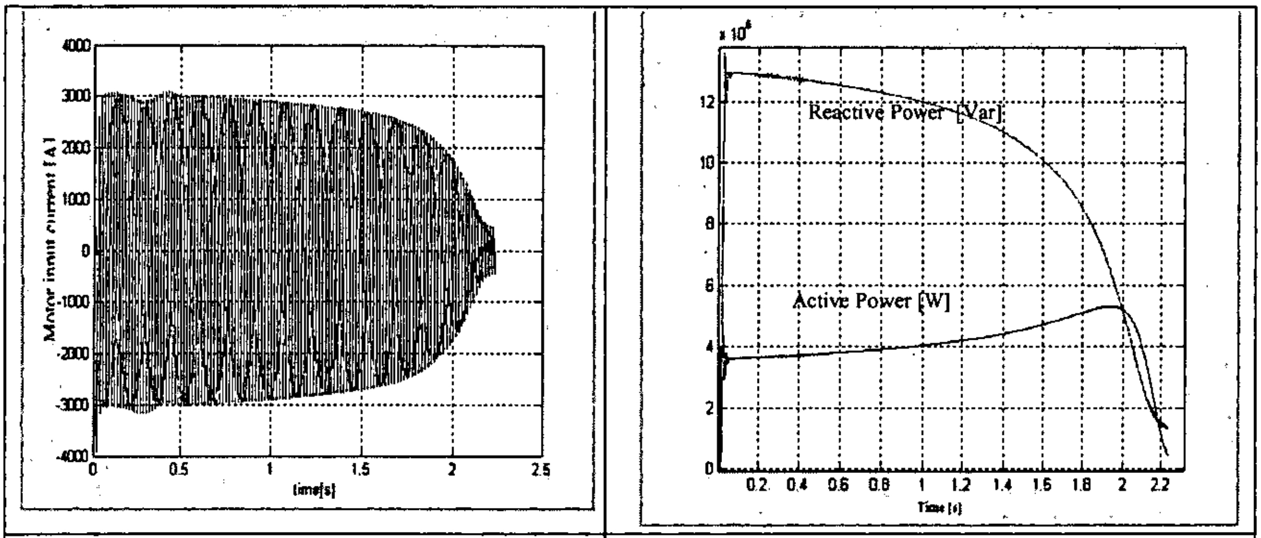

Fig. 7a - Motor current profile vs. time

Fig. 7b - Motor active & reactive power vs. time

Fig. 7 – Fuel cell current and power profile for the start up of a motor in no load conditions.

The transient condition takes about two seconds according to the inertial moment of the motor. The current value is 2200 Arms (Fig. 7a), about five times the rated current. In the first three periods of the motor connection, this value is more than 2670 Arms (6 times the rated current). This current demand can be a critical load for the fuel cell module. Fig. 7b shows the active power and the reactive power generated by the motor load during these transient conditions.

Consequently, the fuel cell provides the power demand as shown in Fig. 8.

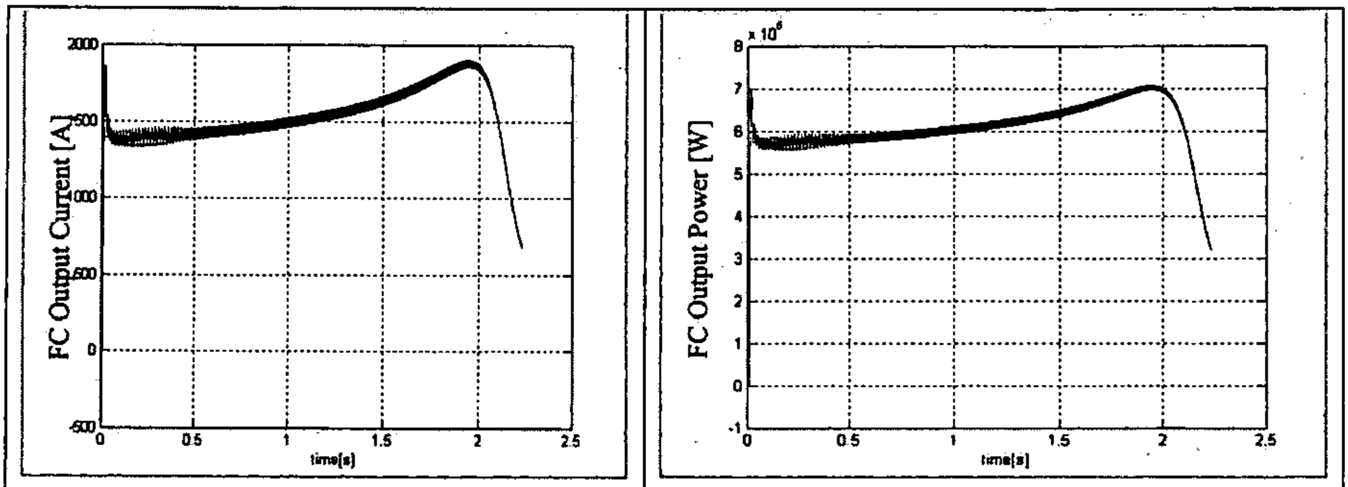

Fig. 8a - Fuel cell output current vs. time

Fig. 8b - Fuel cell output power vs. time

Fig. 8 - Fuel cell current and power profile for the start up of a motor load.

The fuel cell output current exceeds the value inside the ohmic region and a critical condition is reached despite the low rated power of the motor.

In this case the fuel cell can be protected by using a modern soft start system for large motor loads.

4.5. Modelling and simulation of a fuel cell plant in external fault conditions

The analysis of an external fault of a fuel cell, such as the short circuit of the motor load, must be considered in order to verify the fuel cell behaviour when a sudden short circuit occurs.

A model of a fuel cell unit feeding a motor load and the occurrence of the short circuit at the AC terminals of the motor has been developed and the results of the simulation are presented in Fig. 9 and in Fig. 10.

The sudden short circuit at the three phase AC terminals of the motor leads to a current increase of about eight times the rated current.

Consequently, the fuel cell output voltage drops to zero and the current raises suddenly (Fig. 10b). The current value in the present model is limited only by the internal resistance of the fuel cell unit but this value must be reviewed according to the dynamic behaviour of the fuel cell.

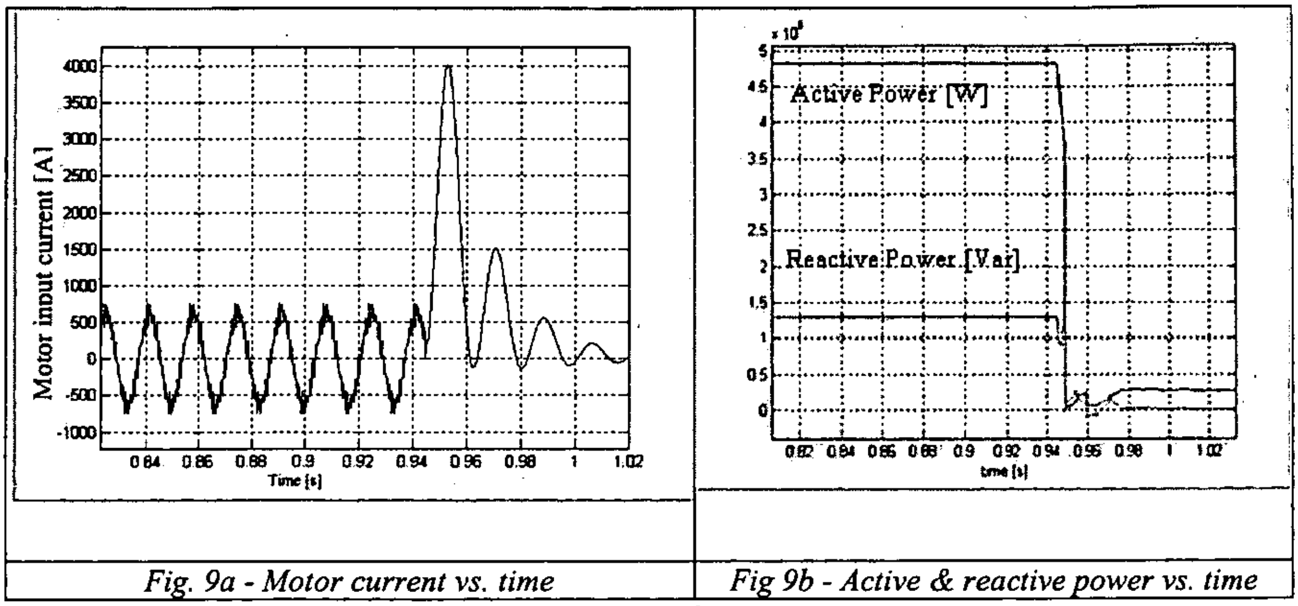

Fig. 9a - Motor current vs. time

Fig 9b - Active & reactive power vs. time

Fig. 9 - Motor short circuit.

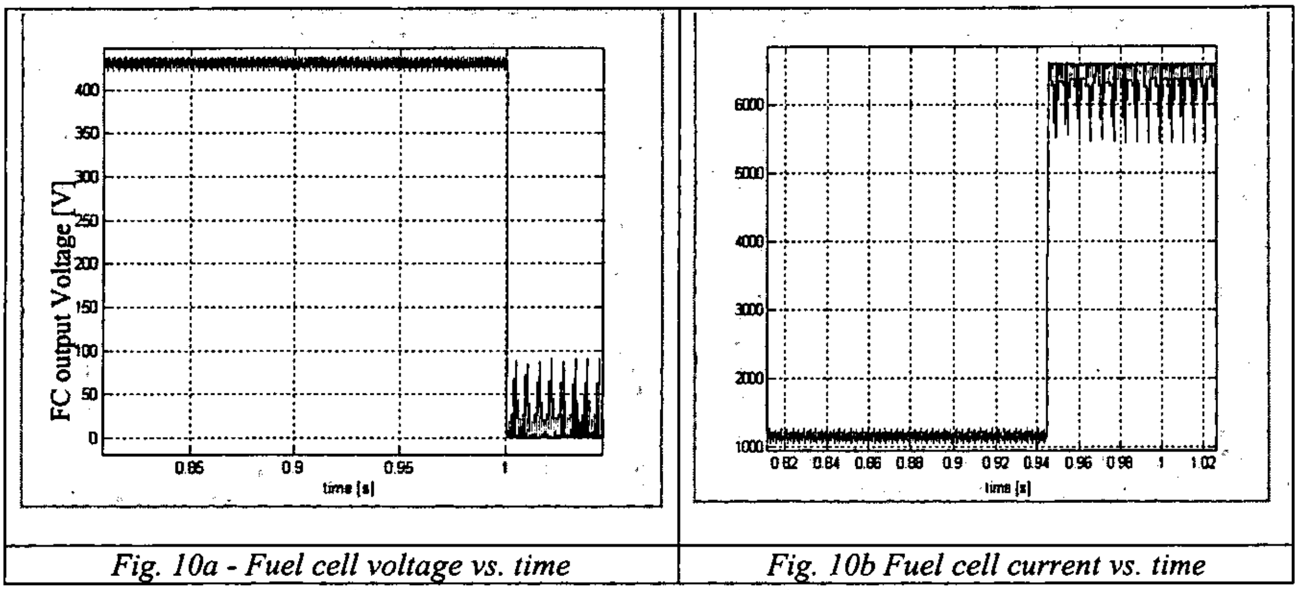

Fig. 10a - Fuel cell voltage vs. time

Fig. 10b Fuel cell current vs. time

Fig. 10 - Fuel cell voltage and current profile for the motor short circuit.

5. Energy requirements for fuel cell operation on shipboard

The energy requirements for the fuel cell operation in a power plant onboard ship can be partially derived by using the performed simulation. The support of models and simulations as well as the measurement campaign allows to identify the main requirements not only for the fuel cell unit but also for the whole power system.

5.1. Energy requirements for fuel cell operation in steady state condition

The energy requirements suggested in steady state conditions can be summarised as follows:

- fuel cell modules shall be able to operate in parallel connection equally sharing the power demand;

- each fuel cell module shall operate in the ohmic region and inside the safety area;
- reverse power cannot be admitted in the fuel cell module and the power conditioning system must ensure such operating condition.

5.2. Energy requirements for fuel cell operation in transient conditions

The energy requirements suggested in short transient conditions can be summarised as:

- fuel cell modules must be able to be connected or disconnected to the power plant in a short time (start up and shut down);
- fuel cell must be protected by the sudden requirements of current higher than the maximum value of the safety area. The protection must not disconnect the load supply;
- the general energy management system and the single load protection/start up device must be reconsidered and redesigned according to the fuel cell safety operation;
- the protection system at the main bus bar must be redesigned taking into account not only the current maximum values but also the voltage drop values.

6. Availability requirements for fuel cell based power plant

The power plant for auxiliary services requires a continuous operation especially for the essential primary services. In this case, the key role is played by the energy management system and by the performances of the generation units.

The fuel cell unit must provide a high value of availability that must be reached not only by the life time of the single unit, but also by considering the modularity of the power supply system and the different configurations (redundant/parallel). The fuel cell manufacturers must take into account the modularity requirement providing means for the use of the single stack of the fuel cell unit.

The fuel cell unit must also be connected to separate power conditioning systems by the main bus bar.

The fuel cell unit must be correctly protected but the black out shall be avoided in any condition.

The protection can consider not only conventional circuit breakers, but must be reached by means of static devices included in the power conditioning systems as well as measurement equipment of the voltage profile, of the peaks at the main bus bar and of the single fuel cell - power conditioning set.

7. Conclusions

The presented analysis aims at providing some specific requirements concerning the power supply realised by means of fuel cell units. These requirements are derived from a specific measurement campaign and a recording of data.

Thanks to the support of models and simulations, the main heavy operating conditions of high – medium temperature fuel cell units are identified and analysed.

Some assumptions concerning the dynamic behaviour of the electrical outputs of the fuel cell units have been stated according to the information provided by the fuel cell manufacturers.

8. Acknowledgments

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A LIFE-CYCLE ASSESSMENT OF MOLTEN CARBON FUEL CELLS FOR MARINE APPLICATIONS

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In the study, life cycle assessment (LCA) of a molten carbonate fuel cell (MCFC) plant for marine applications is performed and the results are compared to benchmark conventional diesel engine (DE) which operates as auxiliary power generating unit. The LCA includes manufacturing of MCFC and DE, fuel supply, operation and decommissioning stages of the system's life cycle. As still a new technology and very early stages of commercialisation, detailed and reliable data from the FC systems are not available. In order to overcome this problem, a series of scenario analysis has also been performed to evaluate the effect of various factors on the overall impact, such as change in power load factors and effect of recycling credit at the end of life cycle. Environmental benefits from fuel cell operation are maximised with the use of hydrogen as an input fuel. Among the challenges of fuel cell applications on commercial ships is the supply and storage of hydrogen on-board, and hydrocarbon based alternative fuels which requires on-board reforming process are investigated. For the manufacturing stage of the life cycle, input material and process energy requirements of the fuel cell stack assemblies and balance-of-plants (BOP) represents a bigger impact than conventional benchmark mainly due to special materials used in the stack and the weights of the BOP components. Additionally, recovering valuable materials through re-use or re-cycle will reduce the overall environmental burden of the system over its life cycle.

1. Introduction

In this paper, life cycle environmental impacts of high temperature Molten Carbonate Fuel Cell (MCFC) system to be used for a power supply on-board a ship, and its comparison with a conventional marine diesel engine (DE) as a benchmark is presented. Because of large power requirements for propulsion, potential on-board application of FCs are considered to be limited with lower power demanding areas such as auxiliary power generation.

Fuel cells have increasing popularity primarily due to their pollutant free operation when hydrogen is used as a fuel. The Fuel Cell (FC) technology demonstrates a certain level of acceptance and use in land- base applications with different research interest on both its construction technology and operating parameters [1]. However, because of the novelty of the product and its subsequent limitations such as commercialization, scale, fuel supply issues, its use in the commercial shipping industry is currently non-existent. Nevertheless, constant need for emission reduction in shipping operations provides a prospect for research efforts for addressing various maritime specific issues of the technology. In the meantime, potential benefits of the on-board FC technology should also be evaluated against its environmental impacts from manufacturing, fuel supply, and end-of-life characteristics throughout its operational life. As an integral part of new technology assessment, Life Cycle Assessment (LCA) plays an important role in evaluating the environmental performance.

Life cycle analysis of the system include the production of the fuel consumed by the MCFC and DE onboard, manufacturing of the main components of the DE, MCFC stack and BOP, onboard operation, and decommissioning aspect at end-of-life of the systems. The study analyzes the energy requirements, emissions of greenhouse gases (GHG) and air pollutants during various life stages of FC and conventional auxiliary power plants in a case ship. As a benchmark, the conventional fuels used in the case ship today are analyzed and compared to the selected alternative fuels for fuel cells: sulphur-free car diesel.

LCA is a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system through all stages of its life cycle [2]. The typical life cycle of a product is a series of stages originated from the extraction and of raw materials, manufacturing, transport, operation, maintenance, re-use, and decommissioning. Following the goal and scope definition of the system, a detailed Life Cycle Inventory (LCI) analysis of the energy and resource consumption and emissions of the systems have been performed. Assessment of the potential environmental impacts of the systems has been performed based on the methodological framework as outlined in the ISO14040 standard [3].

2. Fuel Cell Technology for Ships

Although fuel cell technology has been used successfully in both mobile and stationary applications such as aerospace engineering, automotives, power plants and navy ships, application of fuel cell and associated R&D activities for commercial ships have been very limited, technical feasibility of using fuel cells for ship propulsion and auxiliary power has been demonstrated by the successful application in navy vessels. Following the success of navy application, rational use of energy source and demand of environment protection system viability and performance of using a commercially acceptable fuel has been the recent research interest in fuel cell development.

For marine applications, Polymer Electrolyte Fuel Cell (PEMFC) is considered one of the most promising options. This is mainly due to PEMFCs high system efficiency, low operating temperature, rapid start-up, high power density and scalability. Another potential technology for marine applications is MCFC. MCFCs operate at a high operating temperature (650°C), which allows the use of non-noble catalysts. Thus, the catalysts are insensitive to certain degree of fuel contaminant which often damages other type of fuel cells, MCFCs in principle may use a range of gaseous fuels, such as natural gas, biogas or coal gas. A comparison of MCFC and PEMFC with conventional marine power systems is given in Table 1 [4].

Table 1 - Comparison of Marine Power Systems.

Criteria	**MCFC**	**PEMFC**	**Diesel**	**Gas Turbine**
NOx, CO, HC emissions, CO2	Very low, reduced CO2	Very low, reduced CO2	Medium, reduced NOx with emulsified fuel, no CO2 benefit	Medium, no CO2 benefit
Power Range	500-2500 kW, modular	20-2500 kW, modular	Up to 68 MW	Up to 50 MW
Start-up and warm-up characteristics	Hours	Less than MCFC	Minutes	Seconds
Noise, Vibration	Low	Low	High	Medium
Thermal Efficiency (%)	40-55	39-42	30-35	25-30

The main challenges of applying fuel cells in marine environment are requirement of quick dynamic response, high power density (weight and size), salt air, shock resistance, quick start and load responding characteristics. Other aspects such as fuel type, efficiency, reliability, maintainability, cell life, marine environment pollution, anti-shock, vibration and ship motions should also be considered. Apart from technical performance of fuel cells, capability of using commercially available fossil fuel, instead of pure hydrogen, is another challenge of fuel cells' application on commercial ships. It has been anticipated that, due to its low volumetric energy density, use of hydrogen in commercial shipping will be limited to inland waterways and coastal waters in the future [5]. Conventional liquid fuels, such as diesel oil or methanol, with higher a volumetric density compared to hydrogen will be the long-term solutions for commercial use.

In order to make fuel cells a viable option for commercial ships, traditional marine fuels have to be considered as the first choice of fuel. This requires a fuel reformer to extract hydrogen from marine fuels. Fuel reformation is a process by which hydrogen is extracted from hydrocarbon compounds by undergoing a set of chemical reactions. Fuel reforming can be performed at a centralised plant on-site at the fuelling port, or onboard ship or a combination of them.

3. LCA Modelling

To perform a comparative study between FC and conventional DE technologies, a MCFC system is selected for the study with a conceptual design of a FC electric generator of a power output of 500 kW for a RO-RO passenger ferry vessel. The existing auxiliary power system on the case ship consists of 3 units of diesel installation, each of 1000 kW at 900 rpm, with a specific weight range of 17.5 - 20.5 kg kW^{-1}. A model of generic MCFC system was developed. Fuel cell stacks and BOP components under the study are using the state-of-the-art materials and manufacturing process technology. An LCI of this conceptual design has been established. Verification of selected materials and processes as well as energy inputs by FC manufacturers has also been performed.

3.1. Scope of the study

Table 2 and Figure 1 outline the scope and boundary of the study, including the principle stages of the life-cycle of the systems to be investigated.

Table 2 - Summary of the study scope.

Life-cycle stage		**DE**	**MCFC**
Manufacturing		Engine Block manufacturing; • Material inputs • Production processes	FC Stack, casing, BOP manufacturing; • Material inputs • Production processes
Fuel Production and Supply	Fuel Production	• Fuel oil production • Lubrication oil production	• Diesel oil production
	Fuel Supply	• N/A	• N/A
Operation		• Load factor=1 (baseline scenario) • LF scenarios	• Load factor=1 (baseline scenario) • LF scenarios
Repair and Maintenance		• N/A	• N/A
Decommissioning		• Recycling credits for manufacturing material inputs	• Recycling credits for manufacturing material inputs

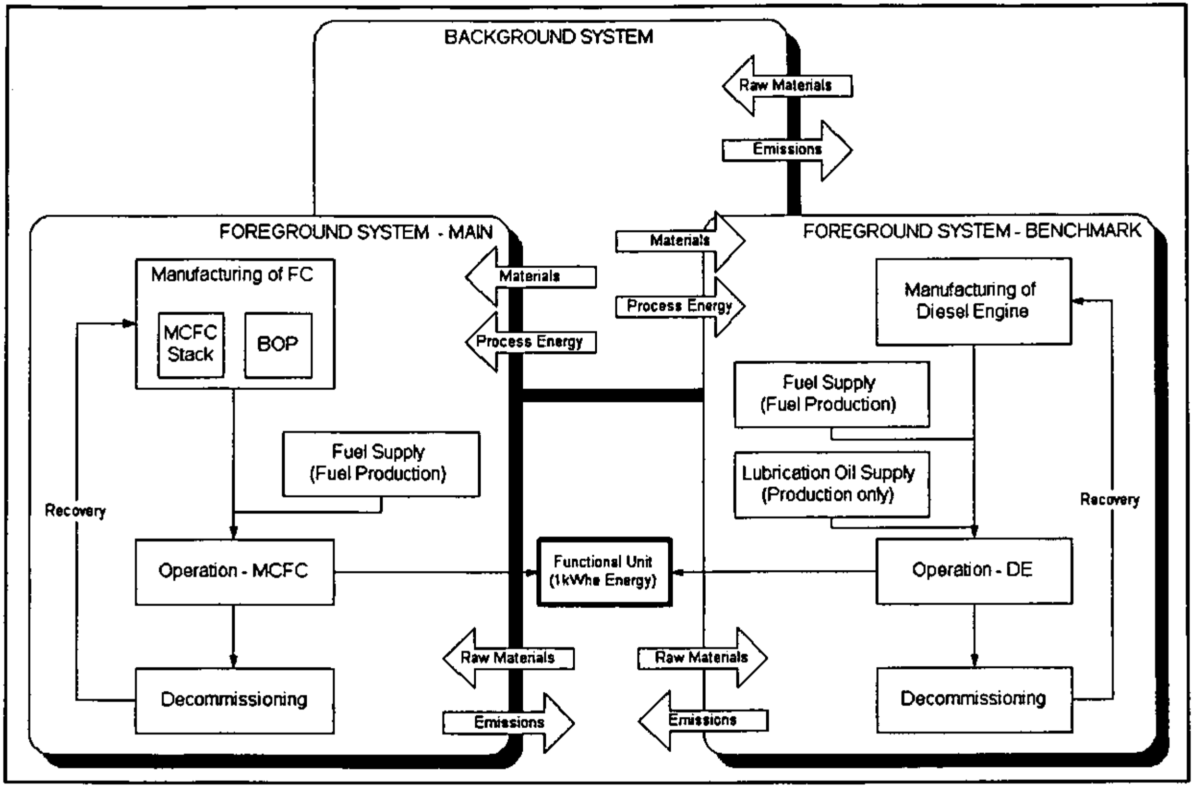

Figure 1 - System Boundaries of the LCA Study.

3.2. Assumptions

In addition to the scope of the study outlined above, the following assumptions are made in the LCA modelling:

- The energy and materials input required for manufacturing equipment, i.e. capital goods used in the production of the FC system, is not considered
- The environmental impacts associated with the transport of materials for FC manufacturing are not considered
- The planar design of MCFC is considered
- Annual operating duration of a single DE in the case ship is about 6000 hours, and that for the MCFC systems is also assumed to be 6000 hours
- Operating life span of the MCFC stack is assumed to be 30,000 hours, i.e. 5 years, and that for the DE is 20 years
- In order to compare the systems, lifetime of the MCFC system (casing and BOP) is also considered as 20 years with periodic replacement of FC stacks every 5 years, i.e. 4 stacks during the life time. Hence, total operating hours during the 20 years of life cycle is 120000 hours for both systems
- LCI of the fuel oil and lubrication oil supply paths are cradle-to-gate values and exclude fuel transport to ship
- FC Stack fuel utilization coefficient = 85%
- Diesel reformer efficiency = 85%
- Specific oil consumption for lubricating oil = 0.7 g kWh^{-1}
- Functional unit is 1 kWh of electricity generated by the system

4. LCA Study

4.1. Production of fuels

In the Case ship, as a conventional benchmark, low sulphur fuel oil (LSFO) with sulphur content 0.6% is being used in the internal combustion engine for auxiliary power purposes. The conventional fuel for ships is heavy fuel oil (HFO) (<1.0% S).

For the MCFC in case ship low sulphur car diesel has been chosen as an alternative fuel because the reforming systems require sulphur free fuels. Low sulphur car diesel (LSCD) is essentially sulphur free (< 10 ppm) making it directly suitable for reformers. Sulphur free ship fuels are not available on the market, while LSCD is already produced and will be introduced to the car market starting in 2005.

Lubrication oil consumption for the same operating conditions as in auxiliary diesel engine has also been modelled in the LCA. In the input materials stage of the LCA model, cradle-to-gate values for the production of HFO and diesel oil are used from the LCA software database [6].

4.2. Manufacturing

4.2.1 Diesel Engine

Weight of the auxiliary engine unit used in the study is estimated by averaging the data from set of DEs within the similar kW power range (900-1500 kW) and revolution-per-minute (RPM) range (900-1000 RPM) from various manufacturers. Weight of the installed unit including dry weight of the rigidly mounted engines and alternator is estimated as 15.2 kg kW^{-1}, and this excludes flywheel and pumps. Alternator weight assumed as 30% of the dry engine weight, and further 15% allowance (2 kg kW^{-1}) has been made for scrap and manufacturing losses. Cradle-to-gate alloyed steel cast part has been used for the engine material input in the LCA model.

Basic LCI for manufacturing of a generic DE is based on measurements data from the plant that is producing a wide range of DEs including the medium speed auxiliary engine used in the study.

During the testing stage of engine manufacturing, 0.350 kg kW^{-1} MDO and 1.886 kg kW^{-1} HFO is used. During the manufacturing of DE, the following energy sources are used: Electricity from national grid = 0.0072 MWh, Heating from city network (produced with coal only) = 0.0074 MWh. Energy inputs and emissions for electricity and heat are used from the LCA software database.

4.2.2 MCFC Stack and Components

In the study, analysis of the manufacturing of the MCFC system is divided into two sections:
1. Fuel cell stack manufacturing: This stage includes the manufacturing of electrodes, electrolyte and interconnect with the BOP. Only limited information is available on the production of MCFC stacks.
2. BOP manufacturing: This stage includes the manufacture of all other components in the MCFC system, including the casing.

For the LCA study it is not possible to select a commercially developed system, as presented in the potential manufacturer's data. A generic MCFC system that will accomplish the requirements of the Case ship auxiliary power needs is defined for the LCA study purposes, and LCI of this illustrative product using the state-of-the art materials and manufacturing process descriptions is performed. The main characteristics of the of the MCFC stack used in the model are:

- Power Density = 0.1 w cm^{-2}
- Electrode Area = 10000 cm2 (single cell)

Material weights calculated for either porous or non-porous components, as well as other parts are net values estimated from published literature and represents the best available and most likely values of ideal production. In order to introduce production losses, 15%wt has been assumed as a base figure.

In terms of MCFC manufacturing, a literature survey results in a range of various materials and processes developed since mid-1990s [7]. There is quite a few number of research papers outlining the development and commercialisation issues of alternative materials and manufacturing processes [7-17]. Although there is a number of research papers on manufacturing process of fuel cells, references are mainly focused on Solid Oxide Fuel Cells (SOFC) and data on MCFCs are limited [18, 19, 20]. In this study, inventory results for the MCFC stack manufacturing is used from [21, 22].

4.2.3 BOP and Components

Major BOP component weight groups are casing, reformer and power conditioning unit. Material breakdown of the BOP components and energy inputs for manufacturing process are obtained from a SOFC LCA data and presented in Table 3 [20]. Weight breakdowns for MCFC system components are summarised in Table 4 [23].

Table 3 - Energy inputs for the manufacturing of BOP components of FC

Component	**Material**	**Specific Weight ($kg\ kW^{-1}$)**	**Energy Inputs for Manufacturing ($MJ\ kW^{-1}$)**
Casing	Steel	30.6	11.2
Reformer	Steel, Catalyst	60	12.9
Power conditioning system	Aluminium, Purified silica, Plastics, Cu	5	4.3

Table 4 - MCFC System Weight Summary

	LCA model
System Components	**Weights ($kg\ kW^{-1}$)**
Stack	23.7
Casing	30.6
Reformer	16
Power conditioner	0.5
System weight	70.8

4.3. Operation

Operational profile of the Case ship represents the characteristics of typical short route shipping route. A "summer schedule" profile with 2 voyages per day has been selected for the fuel consumption calculations. Due to differences on the auxiliary power requirements during a voyage, operation modes are divided into three stages and fuel consumptions calculated accordingly.

During the operation, there is no sulphur oxides (SOx) emission from the MCFC system since the sulphur is removed before the reaction of the fuel in the stack. Emission characteristics used for the analysis of both power plants are also presented in Table 5 for functional unit [24]. During the conversion of g kg^{-1} fuel emission factors, fuel cell efficiency is assumed constant as 45%, and lower heating value (LHV) of the diesel oil is 40.2 MJ kg^{-1} fuel. Emission figures for the DE are also presented in Table 5 [25].

Table 5 - Emission characteristics of operation stage

Emission	**Emission Factor (g kWh_{el}^{-1})**		**Emission Factor (g kg^{-1} fuel)**	
	MCFC	DE	MCFC	DE
CO2	687	698	3120	3170
CO	0.030	1.68	0.16	7,4
NOx	0.015	13.43	0.08	57
SO2 (=20 x (0.61)%S content)	0	2.562	0	12.2
HC (Primarily CH4)	0.075	0.53	0.40	2,4
PM	0	0.55	0	2,5

4.4. MCFC End-of-Life Issues and LCA Scenarios

There are uncertainties and gaps in the research for end-of-life stage environmental impacts of MCFC. As a general rule, the hierarchy of approaches to dealing with waste that apply to the end-of-life stage follow this order of environmentally friendliness:

- Reuse
- Recycling
- Incineration with energy recovery
- Disposal

Due to lack of defined end-of-life strategies from manufacturers, detailed analysis of the above alternatives could not be performed for the MCFC. Similar to reusability and recycling options for materials, dismantling processes that may require additional material and energy resources at the end-of-life are also undefined. At the time of study, there is no information available about the end-of-life stage of the product and handling of materials afterwards for the MCFC technology, and on-site or off-site reuse and recycling of FC stack materials.

Principally, by recycling material as a secondary raw material, the need for primary raw materials and energy for primary production, hence emissions are reduced. On the other hand, material recovery and recycling also leads to environmental burdens because of the emissions related to disassembly, collection, sorting and re-processing activities. Therefore, the net effect should be considered.

The main materials used in the MCFC stack for the electrodes are Aluminium, Nickel, Chromium and Lithium, and due to economic and environmental reasons, recycling of those materials would be favoured., however, there is no detailed review of the environmental impact of the methods available. Bipolar plates are corrosion resistant metal alloys (stainless steel). Stainless steel production involves with the use of scarce resources (chromium, nickel and molybdenum). Components of the cell stack, such as casing, endplates or tension rods, and insulation materials can be re-cycled at the FC end-of-life. Stainless steel is mainly the preferred material because of its low cost characteristics. As stainless steel is a 100% recyclable material, recycling is the most likely option for bipolar plates. Insulation materials used to manage thermal profiles for stack and BOP units are silica based. It has been reported by manufacturers that recycling of insulation sheets and panels are not cost effective [26].

Significantly heavy parts of the MCFC system are casing and some BOP parts, which are made of steel and aluminium. Both materials are 100% recyclable and large energy savings can be made. Recycling steel requires 30-35% of the energy required to manufacture steel from the raw materials.

As a comparison, an energy value of 22.4 MJ kg^{-1} to produce steel from iron ore would be reduced to about 7.35 MJ kg^{-1} for recycling the steel parts from assembly. Along with energy saving, emissions resulted from material production will also be reduced by the reintroduction of the steel and aluminium parts into recycling stream [27]. In the study, some of the material outputs in certain stages are assumed re-usable, such as certain amount of stack and BOP, including casing.

In general, metal products such as steel and aluminium follow open-loop recycling scheme, which means product systems end-of-life products are recycled into raw material which maintains the same inherent properties as primary materials [28]. In the study, recycling system is assumed as closed-loop recycling system where materials are continually recycled into the same product. Recycling rate of the metal components of MCFC casing and BOP is assumed as 90%.

5. Results, Analysis and Discussions

5.1. Environmental Scores

Depending on interest of studies, LCA results analysis could consist of four steps, i.e. characterisation, normalisation, weighting and total effect, i.e. environmental scoring.

Characterisation is to group emission species into impact categories and multiplied by characterization factors that express their relative contribution (characterization values) of the substances. Normalisation is to compare the relative effects of different life cycle stages. With normalised values, it is possible to examine the relative contribution from each life cycle stage. Assignment of weighting factors is to analyse the normalised effects according to the relative importance of the effect. The total environmental effect can be represented by the environmental score defined as below, where, A represents characterised value, B is normalised factor and C is weighting factor:

Environmental Score = A x B x C

Table 6 presents a summary of main results from characterisation for the comparative study, with principal emission factors as well as main environmental quantities for each life cycle stage of the DE and MCFC systems. Due to different life-span characteristics of the system components, breakdown of the emission factors from manufacturing stage of MCFC are also presented for stack and BOP products separately. The stack manufacturing values in the table represents the values of 4 units to match the power output of the DE system and, each unit is assumed to have a 5 years life span, with a total life time of 20 years. The energy requirements for the materials production and manufacturing of various components of the MCFC module are also presented in Figure 2. Over the life time of the module in the base scenario, stacks with replacements represents the highest proportion of the material requirement, although single stack unit needs less energy input compared to insulation and casing components.

Table 6 - Total life-cycle emissions and environmental quantities for DE and MCFC for functional unit.

		DE					MCFC						
Substance	**Unit**	**Mnf**	**F.Supl**	**Oper.**	**Recycl.**	**TOTAL**	**Mnf-Stack**	**Mnf-BOP**	**Mnf-Total**	**F.Supl**	**Oper**	**Recycl**	**TOTAL**
Electric Energy	MJ	1.341E-03	2.083E-01	-	-8.425E-04	2.088E-01	2.280E-02	5.574E-03	2.837E-02	2.326E-01	-	-2.097E-02	2.684E-01
CO2	kg	4.453E-04	6.859E-02	6.150E-01	-2.955E-04	6.840E-01	5.790E-02	1.977E-03	5.988E-02	6.967E-02	6.302E-01	-4.231E-02	7.598E-01
CO	kg	2.356E-06	1.187E-04	1.436E-03	-1.792E-06	1.557E-03	4.083E-04	6.737E-06	4.150E-04	1.304E-04	3.178E-05	-2.919E-04	5.773E-04
NOx	kg	2.186E-06	3.527E-04	1.106E-02	-4.749E-07	1.141E-02	1.524E-05	6.324E-06	2.156E-05	3.880E-04	1.596E-05	-1.636E-05	4.255E-04
SO2	kg	1.082E-06	1.645E-04	2.367E-03	-6.288E-07	2.532E-03	1.291E-03	1.276E-05	1.303E-03	1.691E-04	0.000E+00	-9.148E-04	1.472E-03
NMVOC	kg	N/A	1.360E-03	4.462E-04	-1.021E-07	1.806E-03	N/A	N/A	N/A	1.518E-03	5.050E-07	#VALUE!	1.518E-03
CH4	kg	1.441E-06	5.453E-04	4.656E-04	-1.031E-06	1.012E-03	1.981E-05	3.394E-06	2.321E-05	6.089E-04	7.999E-05	-1.692E-05	7.121E-04
Acidification potential (AP)	kg SO2-Equiv.	2.628E-06	4.146E-04	1.011E-02	-9.752E-07	1.052E-02	1.307E-03	1.719E-05	1.324E-03	4.441E-04	1.117E-05	-9.304E-04	1.779E-03
Global warming potential (GWP 100 years)	kg CO2-Equiv.	4.761E-04	8.074E-02	6.248E-01	-3.175E-04	7.060E-01	5.873E-02	2.192E-03	6.092E-02	8.323E-02	6.319E-01	-4.308E-02	7.761E-01
Human toxicity potential (HTP)	kg DCB-Equiv.	5.195E-05	2.834E-03	3.254E-03	-5.339E-05	6.140E-03	2.107E-04	2.060E-06	2.128E-04	3.061E-03	4.149E-06	-1.493E-04	3.278E-03
Photochemical oxidant potential (POCP)	kg Ethene-Equiv.	2.022E-07	5.686E-04	2.406E-04	-1.139E-07	8.094E-04	1.530E-05	8.437E-07	1.615E-05	6.345E-04	1.914E-06	-1.147E-05	6.526E-04

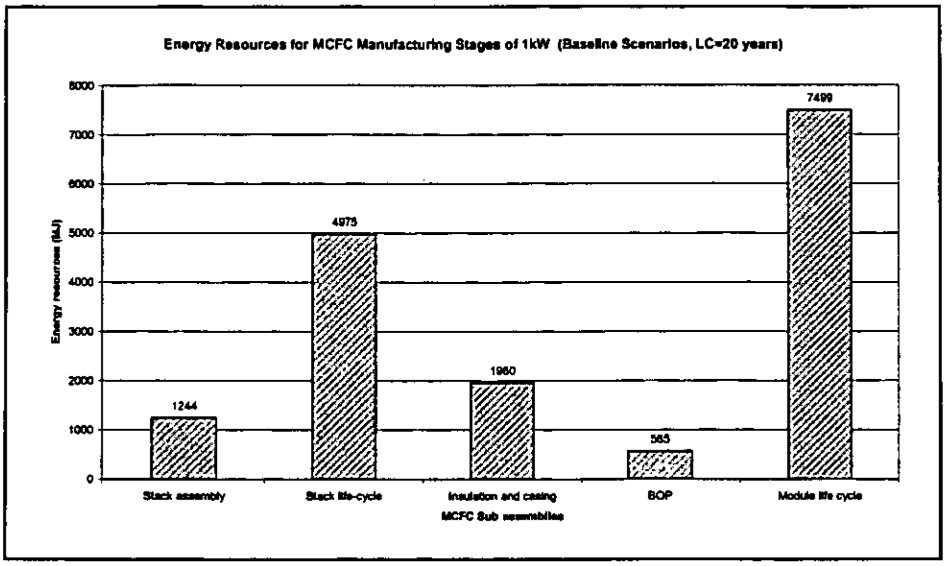

Fig 2 – Energy requirements for MCFC module manufacturing and materials production (Life cycle=20 years).

Comparisons of the contributions of each lifecycle stage to each impact category between DE and MCFC are presented in Figures 3 and Figure 4 respectively. It can be seen that the operation stage is the major contributor to global warming effect in both systems since hydrocarbon based fuels are used during operation of the both systems. Fuel supply stage has a great impact on photochemical oxidant potential (POCP). Compared with the manufacturing stage of DE, MCFC has a substantial contribution to acidification potential due to emissions, particularly, Nitrogen oxides (NOx) and SO_2 produced from cradle-to-gate production of the stainless steel casing. With the recycling of steel casing at the end-of-the life, the amount of impact will be reduced.

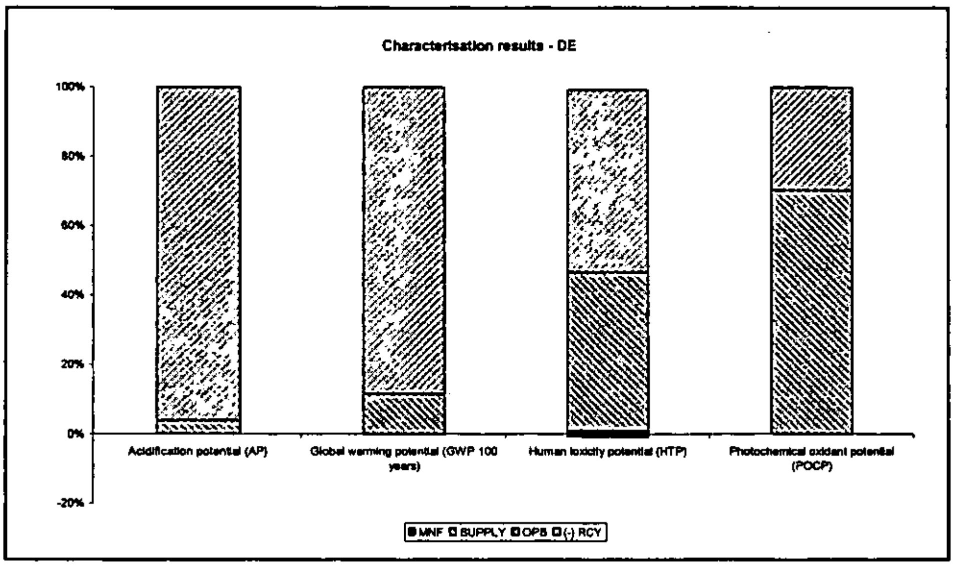

Figure 3 - Characterised results for DE.

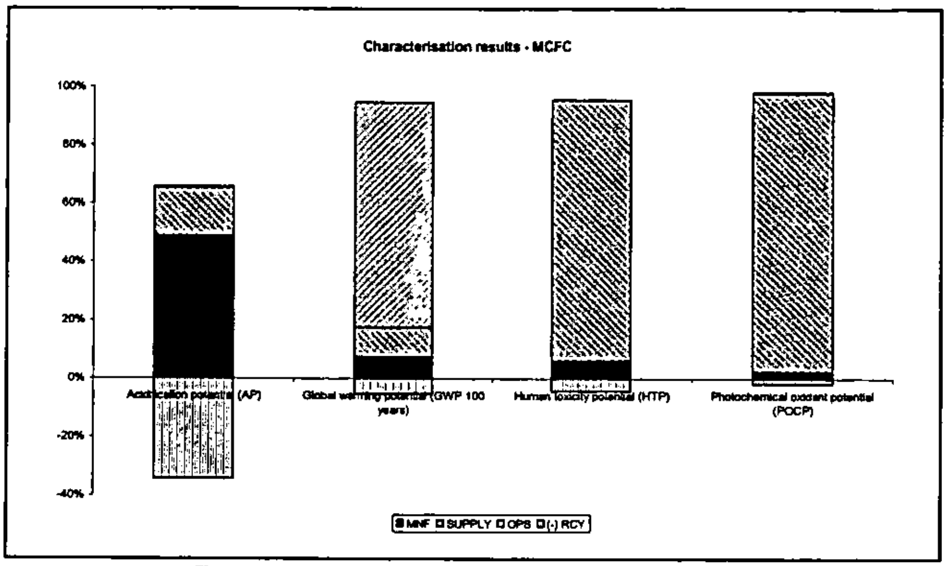

Figure 4 - Characterised results for MCFC.

The total environmental scores of per functional unit for each life cycle stage of DE and MCFC are shown in Figure 5. It's apparent that the emissions from the operation of DE make its operation stage of the biggest environmental score contributing to Global Warming Potential-100 years (GWP100) and acidification potential. For the fuel supply stage, MCFC has a slightly higher score than that of DE due to the high fuel consumption of MCFC.

Although MCFC has lower environmental scores in operation and fuel supply compared to DE, LCA results indicate that MCFC has significantly higher environmental impact during its manufacturing stage because of the emissions from the manufacturing of stack and casing, as well as manufacturing processes of cells. The higher environmental impact of MCFC due to the materials input can be reduced by recycling of materials at the end life of the system, hence reducing the overall environmental impact of the MCFC manufacturing.

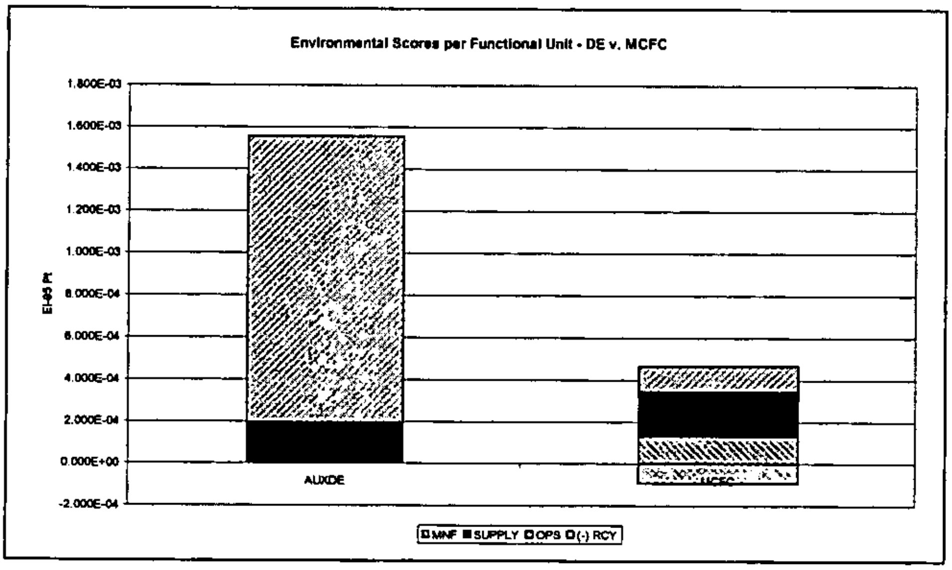

Figure 5 - Environmental scores (EI-95) per functional unit.

5.2. Scenario Analysis for Recycling Credits

Considering some uncertainties of the data from the system and sensitivity of change of system parameters on environmental effects, a series of parametric studies has been performed. The following presents the results of sensitivity studies with power load factor, MCFC efficiency and recycle credit. A comparison of environmental burdens over the life-cycle of MCFC materials for each scenario compared against the baseline values without any recycling or reuse rate. Values for each environmental burden, i.e. emission factor and quantities are then debited from the baseline values of the systems' life cycle. Baseline values initially include 20% scrap metal input for the material production.

The environmental effects of three scenarios with different values of recycle rate for stack and BOP at the decommissioning stage are studied. In the recycling scenarios part, manufacturing of the same materials is treated with 90% recycling rate and credits given to the system. Results in this part are recycling substitutions and to be credited to the system. Under this recycling scenario, net burden of the MCFC materials manufacturing is difference between the debits and credits.

The results show that CH4 has the highest sensitivity to the MCFC stack recycling rate, scoring at 80%, 62%, 45% respectively to the three scenarios over the total life cycle, and indicates improvement potential on overall emission compared to baseline scenario values. The magnitude of the amount is consider to be effected by the high CH4 emission rates during the production of aluminium, which is a power conditioning unit component for the BOP in the LCA model. Similar effects are also observed in the other emissions. The sensitivity of NOx over the three scenarios is of a similar magnitude to CH4, i.e. 65%, 51% and 30% respectively. In terms of environmental quantities, GWP100 is of the biggest change with the change of recycling rates (67%, 52% and 38% improvement potentials respectively).

6. Conclusions and Recommendations

In this paper, assessment of life cycle environmental performance of a MCFC as an onboard auxiliary power system in comparison with a DE power plant has been presented. Life cycle analysis of the systems include the production of the fuel consumed by the MCFC and DE onboard, manufacturing of the main components of the DE, MCFC stack and BOP, onboard operation, and decommissioning aspect at end-of-life of the systems.

The low environmental impact of hydrogen fuelled fuel cells as a means for reducing pollutant emissions such as SOx, NOx, and Particulate Matter (PM) compared to emissions from burning of hydrocarbon based fuels is evident and has been reported in various literatures. The study focused on LCA of fuel cells fuelled with diesel fuels. It has been predicted that conventional liquid fuels, such as diesel oil or methanol will be a long-term pure hydrogen substitute for marine fuel cell applications. This solution requires a fuel reformer to extract hydrogen from marine fuels. Contrary to zero emission from hydrogen fuelled fuel cells, a fuel cell with a reformer emits very small amount of pollutants to air.

Comprehensive Life Cycle Inventories including the weight breakdown of stack and BOP components of MCFC systems are required for further detailed studies. Due to early stage of system development and commercial confidentiality reasons, highly reliable data is currently not available. Materials used for MCFCs as well as other types of fuel cells are generally unconventional materials. Environmental impacts during raw-materials production, manufacturing, or operational stages have not been extensively studied. Fuel cell manufacturing processes involve consumption of a range of solvents and other chemicals which have potential impacts on the environment. Unfortunately, such data and the extent of their environmental impacts are not available. Alternative solvent materials with a low environmental impact need to be identified and used in the future studies.

Manufacture of MCFC including stack and BOP components, supply of materials and energy for the production contributes significantly to environmental impact compared to that of DE for the same functional unit. The use of uncommon materials and production process in MCFC manufacturing is the main reason for the higher environmental impact values. Although the impact of a single stack unit presents an insignificant environmental load, replacement of stack after its 5 years operational life, while retaining the BOP components, results in a higher impact of stack manufacturing over the MCFC system life cycle, i.e. 20 years. Technological developments should be forecasted and incorporated for better estimations of reducing the impacts during manufacture stage of the components. Any effort in the reduction of material weight through the introduction of alternative materials and manufacturing processes will directly improve the environmental performance of the manufacturing.

The reforming process combined with factors such as FC utilisation coefficient, electric converter and transform efficiencies that govern the overall efficiency of the MCFC system has a significant impact on the results and their variations, yet those are the factors liable to change with the development of FC technology. An exclusive analysis of the impact of the factors on the environmental performance should be performed. Environmental impact of onboard sulphur removal via a fuel reformer is also an area which needs further investigation.

Fuel cells are subject to major periodic maintenance operations in every five years, i.e. the stack assembly will be replaced with a new one. The removed stack assembly, including metals and electrolyte matrix, can be further disassembled for recovery of valuable components and materials. It is evident that valuable resources could be recovered and reused at the end-of-life, however, techniques to be used for material recovering would also require process energy, and may consume chemicals. Directly associated with material supply, recycling and re-use of components is an important factor in reducing environmental impact in the life cycle of the fuel cell.

7. Acknowledgments

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FUEL CELL TECHNOLOGY IN SHIPS: POTENTIAL APPLICATIONS IN DIFFERENT MARKET SEGMENTS AND A ROADMAP FOR FURTHER DEVELOPMENTS.

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During 2002 to 2004 an EU sponsored project on the application of fuel cells as a power generator on board of ships has been carried out by a consortium of 21 parners from 6 European countries. The overall objectives of the research as carried out in this project, known by the acronym 'FCSHIP' are, in the long term, a cost effective, substantial reduction of emissions from waterborne transport as well as improvement of the onboard working environment and comfort through reduction of noise and vibration.

The main objectives of FCSHIP (short and medium objectives) have been to:

- *Define the end users' demand for the application of Fuel Cells on board ships for both main propulsion and auxiliary applications;*
- *Evaluate safety and operational demands for ships equipped with Fuel Cells;*
- *Assess both economically and environmentally, the potentials of Fuel Cells application for waterborne transport.*

In short, the project objective has been to provide, a roadmap for further R&D on FC application on ships taking into account safety, operational, environmental, cost, infrastructure and market aspects.
The state of the art of fuel cell technology has been evaluated and applied for the development of design tools for marine fuel cell applications. Combined with the demands on advanced propulsion systems principle product visions of advanced fuel cell propulsion systems have been developed and discussed. The information gathered and reviewed has been the main knowledge source and therefore crucial for all the other work packages of the project.

Basic safety and operational requirements necessary to operate fuel cell systems of different types and sizes for different uses on board ships have been developed. This has been achieved by a systematic analysis of the different technical components and operational requirements, including land based industrial standards (it is noted that fuel cell technology is a completely new topic within SOLAS international regulations).

Based on a set of functional requirements and ship type selection, 3 conceptual ship designs with fuel cell system integration have been developed. In parallel with the development of the actual conceptual designs, design methods have been developed as well. Case ship analysis have been performed for benchmarking of FC technology application in ships, as well as providing input for the development of design tools and definition of functional requirements through long-term onboard measurements. A summary of consolidated ship design requirements for ship application of fuel cells and need for further R&D will be presented.

An assessment of the availability and requirement of infrastructure and supply chains, and an analysis on the energy efficiency, economical and environmental aspects of applying fuel cell technology on ships have been conducted. Cost effectiveness and environmental benefit have been analysed with respect to the application of FC technology on board ship, including fuel supply, operation and de-commissioning. The analysis has focussed on ship types, fuel cells and fuels

incorporated in the conceptual design analysis. Comparisons with conventionally powered ships have been undertaken.

The paper will highlight major achievements from the project including:

- *Several different market segments for application of fuel cells in ships; early niche markets will be different from long-term large market segments.*
- *Main reasons for the application of fuel cell technology in shipping are not only reduction of emissions but also sustainability, reduction of consumption of fossil fuels and moving towards a regenerative power supply.*
- *Various combinations of fuels and fuel cell types are relevant for application in ships. As fuel cell systems have a relatively high fuel flexibility, preferred fuels for fuel cells in ships depend on application, ship type and energy availability in the region of operation, and may change over time with the developing economic, technical, political, and environmental situation.*
- *Limitations related to performance and costs of state-of-the-art fuel cell technology compared to end users requirements have been identified. Manufacturers of fuel cells and fuel cell systems must take into account the specific needs and requirements for operation in the marine environment.*
- *No major obstacles have been identified for development of fuel cell systems that will fulfill basic requirements to safety and operation in ships. Introduction of new technology must be based on detailed design, verified and approved by an independent verification body. In an early phase this will require close interaction between all involved partners to develop safety requirements. Such requirements will be set by verification bodies as future standards, enabling both reliable and safe operation, and further development of new innovative designs. For fuel cell application in ships, no such commonly accepted basic requirements currently exist, but are vital for the future implementation of the new technology.*
- *There is a need for full-scale demonstration to validate and promote the potential of marine application of fuel cells.*
- *A number of areas where further RTD is required has been identified and structured, providing valuable guidance for future projects with the aim to realise application of fuel cells in ships*

ENVIRONMENTAL BENEFITS OF MARITIME FUEL CELLS IN A LIFE CYCLE PERSPECTIVE

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The use of Solid Oxide Fuel Cells with Gas Turbines with various fuel options was compared to conventional diesel engines to study the possible environmental benefits of using fuel cells for auxiliary power onboard a passenger ship. The principles of Life Cycle Assessment (LCA) were used.

Fuel cell technology offers 35-90% better environmental performance in the impact categories for global warming, photochemical oxidation and acidification compared to conventional auxiliary plants onboard passenger ships.

For a ship servicing the route Oslo – Kiel, the most environmentally advantageous scenario was found to be operating fuel cells using LNG produced in Norway. Fewer and shorter fuel transport links limited the impact from fuel production and transportation. Operation using LNG supplied from sources outside the EU was the least environmentally friendly fuel cell option. As operation of fuel cell systems emits very little NOx and SOx, the fuel supply chain carries the greater potential for photochemical oxidation and acidification. However, operation of the SOFC-GT still emits the larger amount of greenhouse gases compared to the other life cycle stages in this scenario.

1. Introduction

The shipping industry is facing tougher regulations on air emission related to greenhouse gases as well as oxides of nitrogen and sulphur. The Kyoto protocol, the Gothenburg agreement, and upcoming EU actions, in addition to the maritime MARPOL Annex VI, will all have an impact on the transport sector.

Conventional technology for propulsion and auxiliary power in ships has largely reached its environmental potential. Internal combustion engines cannot be optimised much further without compromising fuel efficiency. New and more energy efficient solutions must be found; fuel cell technology promises good potential to operating ships in a more environmentally efficient manner. In particular large reductions in the emission of NO_x are offered due to the omission of a combustion process, and SO_x due to their strict fuel quality requirements. The use of fuel such as LNG or methanol is found to reduce CO2 emissions with 50% due to improved efficiency compared to diesel engines, lower carbon content of fuels and higher energy content.

In this study, Life Cycle Assessment methodology was used to investigate the potential environmental benefits of using fuel cells for auxiliary power on a passenger ship servicing the Oslo-Kiel line. Fuel cells with attached gas turbines were compared with conventional diesel engines using future low sulphur fuel. Manufacture, operation with four fuel supply options and decommissioning (qualitatively) were explored.

The work has been undertaken partly as an input to the EU project "Fuel Cell Technology for ships" (FCShip), and partly as a Master thesis.

2. Goal, scope and system boundaries

A Life Cycle Assessment identifies areas where efforts should be concentrated in order to optimise the environmental performance of the system. It also shows how environmental burdens may be shifted between different life cycle stages as a result of new technology or isolated optimisation of one part of the system. Together with other decision making tools, LCA may provide input to the selection of one technology before another.

The Goal and Scope of this study is to explore and assess the environmental impact of use of Solid Oxide Fuel Cells with Gas Turbines (SOFC-GT) in maritime applications compared to conventional diesel engine technology, from manufacture, through the operational phase to the disposal of the units. A range of possible fuel options are explored. The end-of-life options are studied qualitatively as disposal and recycling mechanisms are still being explored for this emerging technology.

The functional unit of this study is 1 kWh power supplied by the SOFC system, and all data will be related this unit.

The system activities are divided into the foreground system, incorporating the activities which are central for the study, and the background system representing the other economic activities which interact with the foreground. The main foreground activities are:

- The manufacturing, operation and decommissioning of the SOFC-GT system and conventional diesel engine system
- The generation of electricity onboard the ship
- The different fuel supply scenarios for the ship

Raw materials in the background system are traced to the source. For the highly specialised materials for the fuel cell stacks the availability of data for mining, production and refining processes is variable. Further, as the SOFC manufacturing process is under development, efficiency of production processes in a mass production perspective is lacking. For the Balance of Plant, off-the-shelf units with conventional materials are assumed. Electricity inputs for manufacture are assumed to be a mix of UK national grid and Combined Cycle Co-Generation, thought to be a representative mix for future SOFC manufacture within Europe.

Within the system boundaries for the SOFC unit installed onboard is any special system required for the operation of the fuel cell, compared to a conventional system. This includes fuel reformers, fuel cell stacks, exhaust treatment or utilisation systems etc but excludes changes in tank configurations and structural modifications, due to lack of information on vessel layout options. This exclusion is deemed valid as the vessel must have some sort of fuel infrastructure in place, irrespective of the choice of auxiliary power technology.

Fuel supply scenarios (Well-to-tank) are included in the system as it is anticipated that the overall environmental performance of the system will be dependent on the type of fuel as well as the delivery options chosen.

The inventories are based upon other studies within the FCShip programme and data available in the public domain. The data is evaluated throughout the study using sensitivity analyses. These show that the results obtained are within a range which can help to determine which processes and parts of the system are of the greatest importance with regards to environmental impact.

The results are presented using the CML impact assessment method developed by Leiden University Institute of Environmental Sciences [18]. Due to the difficulties in collecting high quality data for fuel cell manufacture, a number of impact categories cannot be modelled accurately. For this study, only impact categories for global warming, photochemical oxidation and acidification are found to be supported by data in the inventory for the life-cycle stages. The other impact categories are therefore omitted.

A number of assumptions and limitations apply to this study, the most important are summarised below:

Inclusions and exclusions: The following are excluded from the inventory: Energy and materials required to produce capital equipment, impacts from land use for the manufacturing plant, the production of transport vehicles and transport of materials to the manufacturing plants. In some cases, however, aggregated data for the precursor materials include emissions related to transport. It has not been possible to separate out these data.

SOFC projections: The characteristics of the SOFC unit under scrutiny in this study are projected 5-10 years into the future, and are based upon the Manufacturers' claims and the views of the FC development community. It may be argued that some of the claims are too optimistic, especially with respect to system size and weight, as the current development for SOFC is focused upon cost reduction and lifetime enhancement. A limited sensitivity analysis is included. In addition some of the SOFC manufacturing data have been scaled up from smaller plants.

Fuel cell efficiency: The fuel cell is assumed to operate with a 47 % electric efficiency [24]. Waste heat recovery is assumed to increase the onboard system efficiency to 70 % by use of a gas turbine.

Fuel system configuration: The impact on fuel system configuration using different types of fuel is not considered, as this is outwit the scope of this study [5]. It should be noted, however, that the various options will demand varying amounts of materials, high grade steel for LNG tanks and insulation in particular.

Dependency on previous findings: As this study does not include data collected directly from manufacturers, it relies upon the findings of other studies. It is therefore limited by the scope, findings and quality of the other studies within the FCShip programme, and the other studies external to the programme, impacting on the system configuration and boundaries as well as the data quality.

3. Technical systems and inventories

3.1. SOFC-GT for Maritime Applications

Fuel Cells are electrochemical systems which convert chemical energy into electrical energy. Solid Oxide Fuel Cells (SOFC) operate at high temperatures of 600-1000°C, and they can therefore be combined with heat recovery systems such as gas turbines to increase the overall efficiency up to a theoretical 80% [13]. SOFCs can run on fossil fuels including Marine Diesel Oil with various requirements for fuel pre-treatment.

Fuel efficiency is the main advantage of fuel cells over conventional technology. A planar SOFC is supplemented with a gas burner and a gas turbine generator, to increase the overall efficiency of the system. This combination is termed a Solid Oxide Fuel Cell with Gas Turbine (SOFC-GT). The maritime application of the SOFC-GT in this study consists of 5 SOFC-GT units each of 500 kW, supplying a total of 2500 kW. The fuel cell will contribute 75% of the power, or 375 kW, whilst the gas turbine will supply 25% or 125 kW.

For this study "sulphur free" diesel and LNG are used [8]. The fuel auxiliary plant with supply systems and pre-treatment is assumed to be similar to that for conventional generator sets, at least in the case of sulphur free diesel fuelled SOFCs. For the LNG case this assumption may be somewhat questionable, but for all intents and purposes it is assumed that the impact on the vessel configuration is small.

Some special requirements regarding operation in marine conditions may apply, especially regarding the content of salt in the air supplied. This problem especially relates to the fuel cell catalyst. Further, the fuel cell systems must be able to operate in environments with vibration, movement and varying inclination as the vessel moves. Sealings, gaskets, fuel conditioning components etc. must be designed with this in mind. [13].

The electrolyte materials chosen for this study is $ZrO_2(Y_2O_3)$, an Yttrium stabilised Zirconium oxide [20]. The cathode is assumed to be made of doped $LaMnO_3$, Lanthanum Manganite with a certain amount of added Strontium [13], [20]. The anode consists of $NiO\text{-}ZrO_2(Y2O_3)$, a Nickel Oxide mixed with the electrolyte material Yttrium stabilised Zirconium [20].

Processes involved in the manufacture include ball and roll milling of materials, material printing, thermal drying of plates, and sintering at high temperatures, which is the process of burning off binder and plasticizer materials, and fixing the material to the substrate. Normal process materials used for binders, solvents and plasticizers can be polyvinyl butyral, ethanol, trichloroethylene, polyethylene glycol 200, dibutyl pthalate and fish oil [10].

The fuel cell components not directly related to the FC stack are collectively termed the Balance of Plant (BoP). BoP components are related to fuel and air delivery systems, exhaust gas and heat management system, and power management and control system. Depending on the type of fuel cell and fuel, the auxiliary components can consist of fuel pre-treatment units, gas burners, air supply system, assemblies, compressors, electricity conditioning equipment etc. These units consist to a great extent of steel or conventional alloys.

The gas turbine included in this study is a radial flow gas turbine with pre-combustion of the residual fuel in the exhaust gas from the fuel cell. The basic data are scaled up from a 250 kW stationary application gas turbine. Some of the components included in the gas turbine are subjected to high mechanical stresses and high temperatures, and must be made of high grade materials, manufactured to a high standard.

Energy and emissions from raw material extraction are included in the inventory.

3.2. Conventional Diesel Engines

The case ship has three engines for auxiliary power production, Wärtsilä 6L20, each with engine power of 1080kW, upgraded to Low NO_x edition. It is assumed that Wärtsilä will offer the Low NO_x option on this model in 5-10 years. The emission factors are therefore based on emission factors from Vasa32LN.

Table 3.1 – Characteristics for auxiliary engines onboard the ro-ro ferry [21].

Engine type	Speed	Engine effect	Gen'tor effect	Weight	Fuel consumption
6L20LN	1000rpm	1080kW	1025kW	16,8ton	185g/kWh (75%)

The ancillary system contains four main sub-systems: Fuel treatment, lubrication, cooling and exhaust systems. Specific data for materials and energy for manufacturing the engines and ancillary system could not be obtained, and the data are taken from SimaPro [18]. Mainly conventional steel of various grades and some alloys are relevant. Energy input for production of the engines is estimated based on data for the gas turbine in the SOFC-GT system. An assumption is made that the energy required for producing the machinery will be approximately the same per kW as for the gas turbine. Data for extraction and production of materials are world average data from the SimaPro database.

3.3. Fuel Supply options

The fuel alternatives selected for the application of SOFC onboard Case Ship 1 are [8]:

- Liquefied Natural Gas (LNG)
    - Imported from outside Europe
    - Transported by pipeline and liquefied onsite
    - Produced in Norway
- Sulphur free car diesel

The conventional diesel engines are assumed to use marine diesel with a maximum of 0.2% sulphur, in accordance with the proposed amendments to the EU Sulphur Directive [34].

For LNG fuel, each fuel supply scenario includes data for

- Natural gas extraction and processing
- Natural gas liquefaction
- Transport of LNG

Data is included for energy consumption and emissions to air.

LNG imported from outside Europe is extracted and processed on site, piped to a liquefaction plant nearby and transported as LNG by ship 5,000-6,000 nautical miles to Zeebrugge, Belgium; from there by truck 800 km to Kiel, where it is stored. The vessel is refuelled by truck from the quay.

LNG from onsite liquefaction is assumed to be liquefied at the ferry quay. It is assumed that natural gas is transported via pipelines to Kiel. For compensation of pressure drop every 150 to 250 km, compression is required. The compressors are powered by natural gas fuelled gas turbines. Materials and energy for the quayside liquefaction plant are omitted.

LNG from Norway is extracted offshore in the North Sea and piped to shore where it is liquefied and transported 300 km by truck to a depot in Oslo harbour. It is delivered to the vessel by truck, each truck carrying 19 t of LNG.

Crude oil is supplied from locations outside Europe, and is refined to higher value products at the Scanraff refinery on the Swedish west coast. Sulphur free fuel is required for the FC system to avoid sulphur poisoning of the pre-reformer, e.g. degradation of the nickel catalyst. It is expected that Sulphur-free diesel oil will be available for use in cars in the EU by 2005. This fuel has sulphur content of < 10 ppm [8], [19]. The sulphur-free diesel oil is transported by truck [19], and the vessel requires a total of 51 t of sulphur-free diesel at every three round-trips. As one truckload of fuel equals 26 t, 2 truckloads are needed at each refuelling.

The fuel used for the conventional diesel engines is transported from Scanraff 250 km to Oslo by a product tanker, where it is stored and delivered to the ship by a bunker barge once a week.

3.4. Operation and maintenance

3.4.1 SOFC-GT

Very little onboard maintenance of the fuel cell modules is assumed, as they are highly specialised pieces of equipment, and Manufacturers' representatives are likely to be involved when maintenance or repairs are needed. Skid mounted SOFC-GT units may be replaced easily for major repairs and maintenance. Maintenance of the BoP components is assumed carried out by the crew.

It is assumed that the Balance of plant (BoP) and Gas Turbine (GT) have a life time of 30 years, while the stack has a service life of 20,000 equivalent full load hours. For the BoP and the Gas turbine expendable parts are replaced during maintenance. It is assumed that 10% of the weight of the BoP is replaced every 10 years, which means that 20 % of the weight is replaced during the whole lifetime. For the GT it is assumed that the hot section components are exchanged, i.e. components of mainly nickel alloy, copper and steel. The nickel alloy is replaced every 8th year, while for copper and steel 10% is replaced during the 30 year lifetime. This constitutes the material and energy needs related to maintenance.

A SOFC-GT combined system will have higher NO_x-emission than a pure fuel cell module during operation due to higher pressure and temperature characteristics of the GT stage. Sulphur emissions are non-existent due to the use of sulphur free fuels. The levels of other pollutant emissions such as non-methane VOC, particulates etc. are lower than for conventional power systems.

3.4.2 Conventional diesel engines

Both the engines and the ancillary system are assumed to have a lifetime of 30 years., the same as the ship, and will not be replaced. Maintenance is taken into account and estimated as 1000 kg of components per engine, based on a maintenance plan for a ro-ro passenger ship [37]. Maintenance is assumed to be carried out by the crew onboard during operation, with support from shore side crew and manufacturer's representatives when required.

The electric efficiency of the auxiliary diesel engine is dependent on engine load, but is estimated to be about 42%,. Two engines run at 70% on average at all times, whilst the third acts as a stand by.

3.5. Decommissioning

As many of the materials in the fuel cells are of high value, it is expected that re-cycling and re-use schemes will be set up. Certain materials may also require special care due to their potential environmental impact.

Re-cycling: Some of the materials involved are scarce or precious metals and can be of high value. This is especially true of the anode, cathode and electrolyte materials, but also steel and metal alloys.

Re-use: Key components such as pumps, pipes and heat exchangers will have longer lifetimes than the FC stacks and may be re-used in new SOFC-GT systems. It is assumed that skid-mounted SOFC-GT modules are taken off the vessel for major repairs and maintenance, and are then re-used onboard other ships in their entirety. An arrangement with return and re-imbursement may be envisaged. The gas turbines in particular will probably be re-used in their entirety after each removal from the ship. Gas turbine lifetime expectancies are much higher than for the fuel cells, and the SOFC-GT unit may therefore be divided into usable components while the gas turbine is used again.

Landfill: Depending on the condition and the value of the units, some components and materials of the spent FC modules will have to be disposed of. As most of the material comprises metals and ceramics, incineration or volume reduction will not be an option, and deposition in landfills may be the best option for ultimate end-of-life handling. Depending on whether any hazardous substances are included, the materials may be used for fill material.

Diesel engines are today mostly recycled with the rest of the ship and are used as a resource of materials, and in some instances re-used partly or in full. Some studies indicate 95% recycling of the engine materials [40]. Recycling of materials may instill an energy demand, but will also save energy for production of virgin materials. The two effects may balance out, or the recycling option may carry a slightly lower total energy demand due the omission of some steps in breaking, transportation and smelting of iron ore.

4. Impact analysis and interpretation

4.1. Overall comparison of options

The SOFC-GT system has 35-93% lower contribution in all impact categories compared to conventional diesel engines. In the global warming category the diesel engine contributes with about 35% more emission than the sulphur free diesel SOFC-GT and nearly 45% more than the natural gas SOFC-GT alternatives, due to the higher electric efficiency of the SOFC-GT. For photochemical oxidation the contribution from the diesel engine is 50-86% higher than the fuel cell alternatives, due to NO_x-formation. For the acidification category the diesel engine has a 73–93% larger contribution than the other alternatives, as the fuel utilised contains sulphur.

Table 4.1 – Comparison of technology and fuel options.

Impact category	Unit (1/kWh)	Diesel engine	FC w/ Sulp free Diesel	FC w/ LNG via Kiel	FC w/ LNG via Norway	FC w/ LNG liquef onsite
global warming (GWP100)	kg CO2 eq.	0,725	0,466	0,415	0,394	0,411
Photochemical oxidation	kg C2H4	3,38E-05	1,20E-05	1,68E-05	4,68E-06	1,15E-05
Acidification	kg SO2 eq.	0,00124	0,000276	0,000333	8,15E-05	8,83E-05

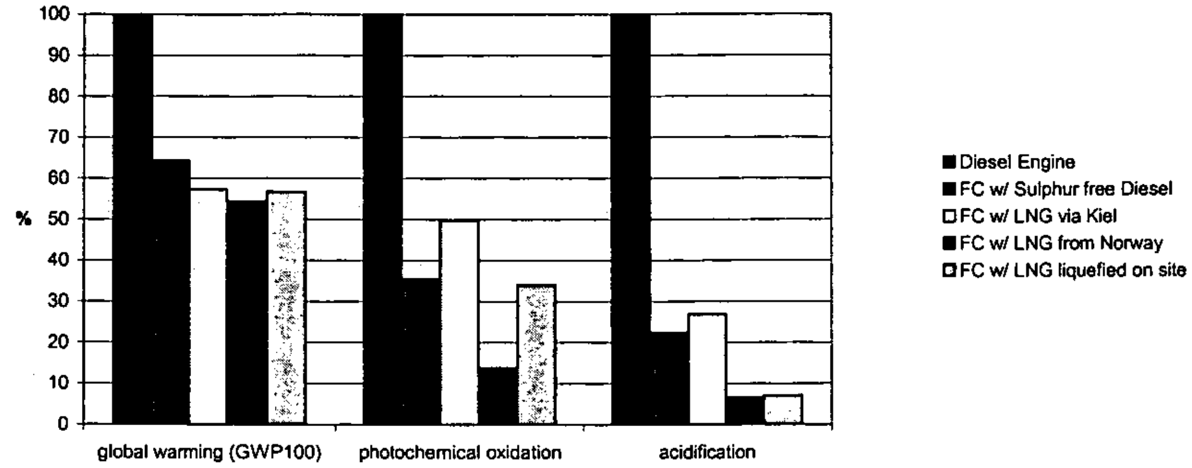

Figure 4.1 – Comparison of technology and fuel options.

4.2. Manufacture

Comparing the manufacture of SOFC-GT with diesel engines, the SOFC-GT system has a much higher contribution to global warming and acidification, whilst the diesel engine has the highest score in the photochemical oxidation. The manufacturing of the fuel cell stack carries the greatest impact for the SOFC-GT. The large amount of Chromium-Yttrium alloy with its energy-intensive production, is responsible for 80-90% of the contribution to all three categories. The main contribution from the manufacturing of the diesel engine system comes from material use and manufacturing of the engine, about 90-98% in all categories.

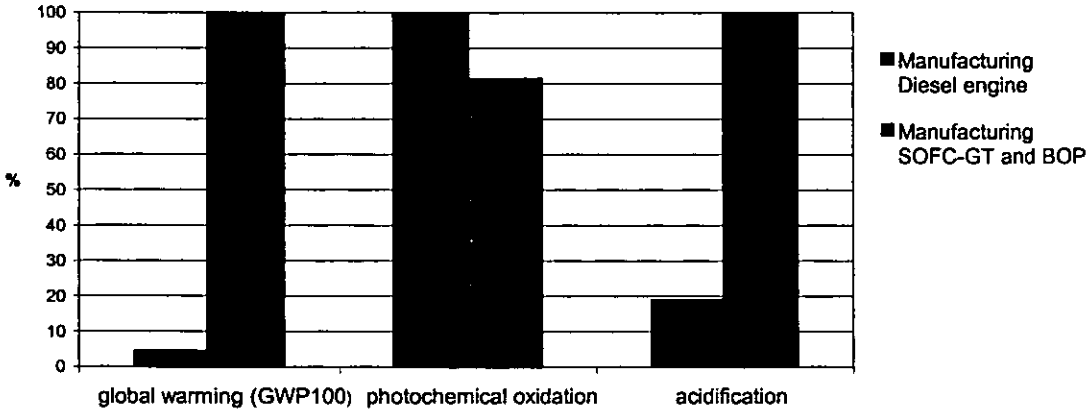

Figure and Table 4.2 – Comparison of manufacturing stage for technology options.

Impact category	Unit (1/kWh)	Manufacturing Diesel engine	Manufacturing SOFC-GT and BOP
global warming (GWP100)	kg CO_2 eq.	0.000489	0.0109
photochemical oxidation	kg C_2H_4	6.98E-07	5.68E-07
Acidification	kg SO_2 eq.	1.50E-05	7.89E-05

4.3. Breakdown of one option – SOFC-GT LNG via Kiel

When comparing all the phases in the life cycle, the operating phase and the fuel supply phase has the highest contribution in all categories. The operating phase has the highest contribution to the global warming category, 76 % of total contribution to this category, while the fuel supply phase has the highest contribution to the photochemical oxidation and acidification category, 93 % and 76

% respectively. A further breakdown reveals that the maritime transport of LNG to Europe carries the greater load, as the LNG vessel uses a mix of gas and heavy fuel oil for propulsion. The two phases represents 95-97 % of the contribution to both the global warming potential and photochemical oxidation. The manufacture of the planar SOFC has the second largest contribution to the acidification category and contributes with 20 % to the over all contribution to this category.

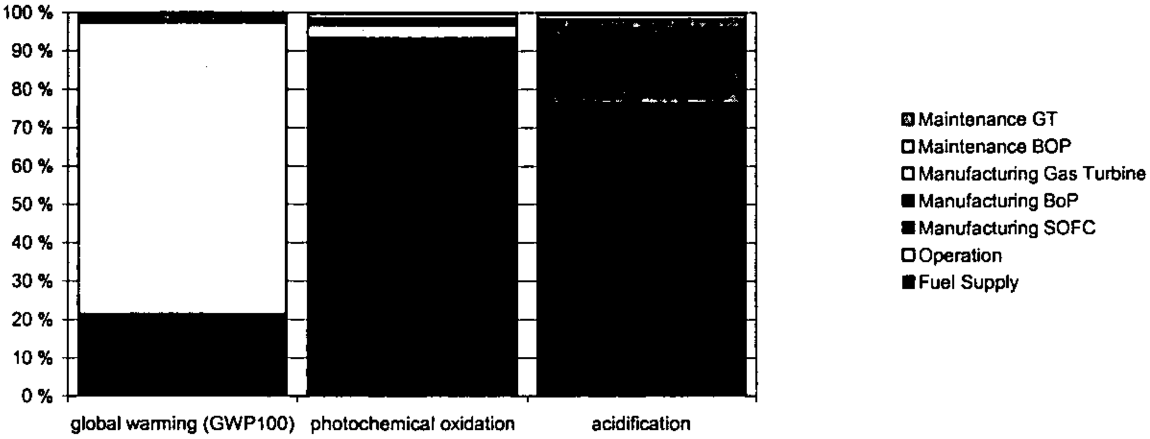

Figure and Table 4.3 – Breakdown of one option – SOFC-GT LNG via Kiel.

Impact category	Unit (1/kWh)	Total	Fuel supply	Operation	Manufact. SOFC	Manufact. BoP
global warming (GWP100)	kg CO2 eq.	0,415	0,089	0,315	0,00949	0,00073
photochemical oxidation	kg C2H4	1,68E-05	1,57E-05	5,34E-07	1,24E-07	2,06E-07
Acidification	kg SO2 eq.	0,000333	0,000254	0	6,53E-05	8,58E-06

Impact category	Unit (1/kWh)	Manufact. Gas Turbine	Maintenance BOP	Mainten. Gas Turbine
global warming (GWP100)	kg CO2 eq.	0,000505	0,000146	5,43E-05
photochemical oxidation	kg C2H4	1,78E-07	4,12E-08	1,91E-08
Acidification	kg SO2 eq.	2,91E-06	1,72E-06	4,14E-07

When looking at the manufacturing of the SOFC-GT system in isolation, the stack (here represented as Manufacture planar SOFC) has around 10 times higher contribution to the global warming and acidification categories than the manufacturing of the other components (BoP and GT). For photochemical oxidation the three components has almost the same contributions. The manufacturing of the maintenance material is about 10 times smaller than manufacturing of the BoP and gas turbine in all categories.

4.4. Operation

Comparing the operating phases of the three alternatives for auxiliary power production onboard the ro-ro ship, LNG fuelled SOFC-GT and sulphur free diesel fuelled SOFC-GT shows significant advantages. The conventional diesel engines contribute 37% more than the sulphur free diesel option and 53 % more than the natural gas option in the Global warming category. This is related to process efficiency. In the Photochemical oxidation category, the potential impact from the two SOFC-GT options is only 3-5% in comparison to the contribution from the diesel engines, as the NO_x-emissions are close to zero for SOFC-GT. The contribution to acidification is zero from SOFG-GT due to the use of sulphur free fuels.

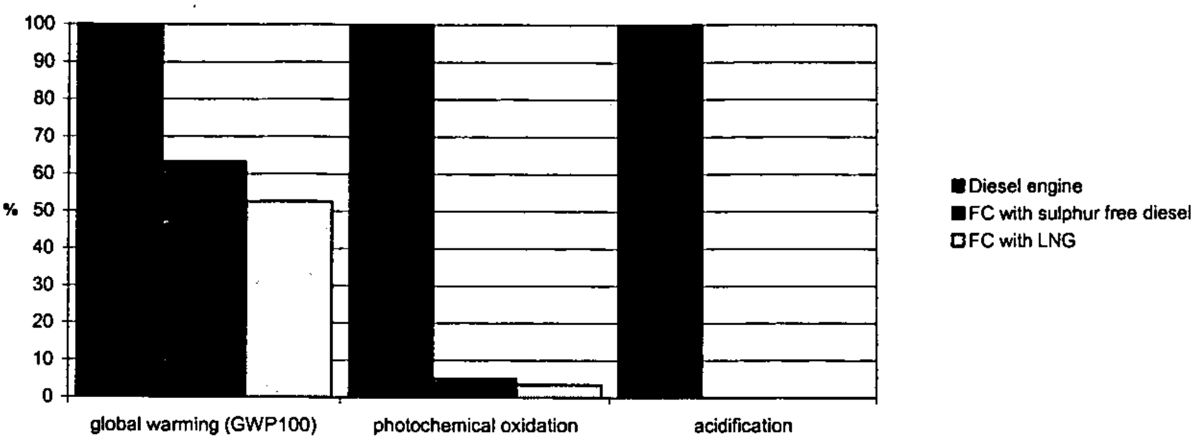

Figure and Table 4.4 – Comparison of operational stage for technology options.

Impact category	Unit (1/kWh)	Diesel engine	FC w/ sulphur free diesel	FC w/ LNG
global warming (GWP100)	kg CO_2 eq.	0,599	0,379	0,315
photochemical oxidation	kg C_2H_4	1,55E-05	8,11E-07	5,34E-07
Acidification	kg SO_2 eq.	0,0009	0	0

4.5. Fuel supply

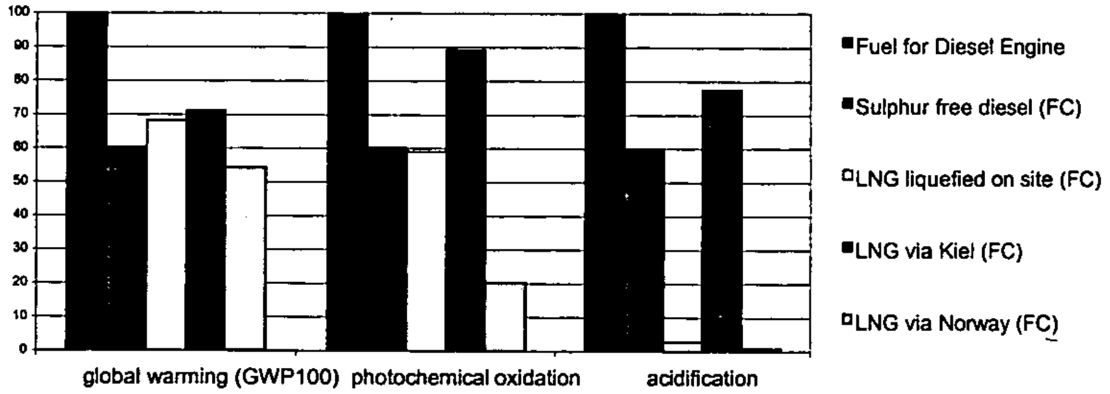

Figure and Table 4.5 – Comparison of fuel supply options.

Impact category	Unit (1/kWh)	LSHFO for Diesel Eng.	Sulphur free diesel (FC)	LNG liquefied on site (FC)	LNG via Kiel (FC)	LNG via Norway (FC)
global warming (GWP100)	kg CO_2 eq.	0.125	0.0754	0.0853	0.089	0.0679
Photochemical oxidation	kg C_2H_4	1.76E-05	1.06E-05	1.04E-05	1.57E-05	3.58E-06
Acidification	kg SO_2 eq.	0.000328	0.000197	9.35E-06	0.000254	2.61E-06

The SOFC-GT fuel options carry 30-90% lower contribution dependent on impact category. The overall efficiency is the major reason for the fate of the diesel engine option. Amongst the SOFC-GT options, the shorter supply chains with large scale operations score better in general. For global warming, the low sulphur heavy fuel oil (LSHFO) supply chain contributes with about 35% more emission than the sulphur free diesel supply chain, and nearly 55% more than the natural gas fuel supply chains. For photochemical oxidation the LSHFO figures are 50-75% higher than the fuel cell alternatives. For the acidification category the diesel engine has a 75–93% larger contribution than the other alternatives. Supply chains including maritime transportation with subsequent use of heavy fuel oils carry a higher impact.

5. Sensitivity Analysis

5.1. Stack Lifetime, SOFC-GT

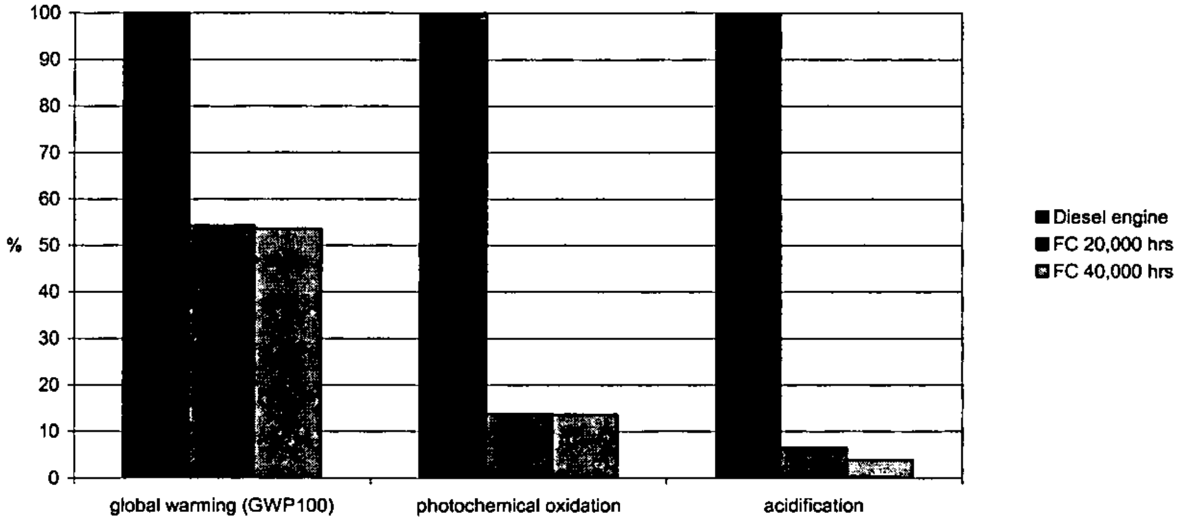

Figure and Table 5.1 – Sensitivity Stack lifetime, SOFC-GT.

Impact category	Unit (1/kWh)	Diesel Engine	FC lifetime 20,000 hrs	FC lifetime 40,000 hrs
global warming (GWP100)	kg CO_2 eq.	0,725	0,394	0,389
photochemical oxidation	kg C_2H_4	3,38E-05	4,68E-06	4,62E-06
Acidification	kg SO_2 eq.	0,00124	8,15E-05	4,89E-05

A comparison of the diesel engine and two SOFC stack lifetime scenarios, 20,000 and 40,000 equivalent full load hours, is conducted. The SOFC-GT fuel option chosen in this comparison is LNG via Norway. The different lifetimes has little influence on the total environmental performance compared to the conventional system. The decrease in the contribution to the different categories when doubling the lifetime of the stack, is between 1-3% in the three categories, most in the acidification where the manufacture of the stack has a large impact.

5.2. SOFC-GT efficiency

A reduction in SOFC-GT efficiency from 70% to 50% results in a 6% higher contribution to the global warming and acidification category, while 33% higher for photochemical oxidation category relative to the contribution from the diesel engine. Emissions in the operational phase increases with the lower efficiency, but the impact is modest.

Table 5.2 – SOFC-GT efficiency.

Impact category	Unit (1/kWh)	Diesel engine	SOFC-GT 70 % efficiency	SOFC-GT 50% efficiency
global warming (GWP100)	kg CO_2 eq.	0,725	0,394	0,42
photochemical oxidation	kg C_2H_4	3,38E-05	4,68E-06	7,06E-06
Acidification	kg SO_2 eq.	0,00124	8,15E-05	7,73E-05

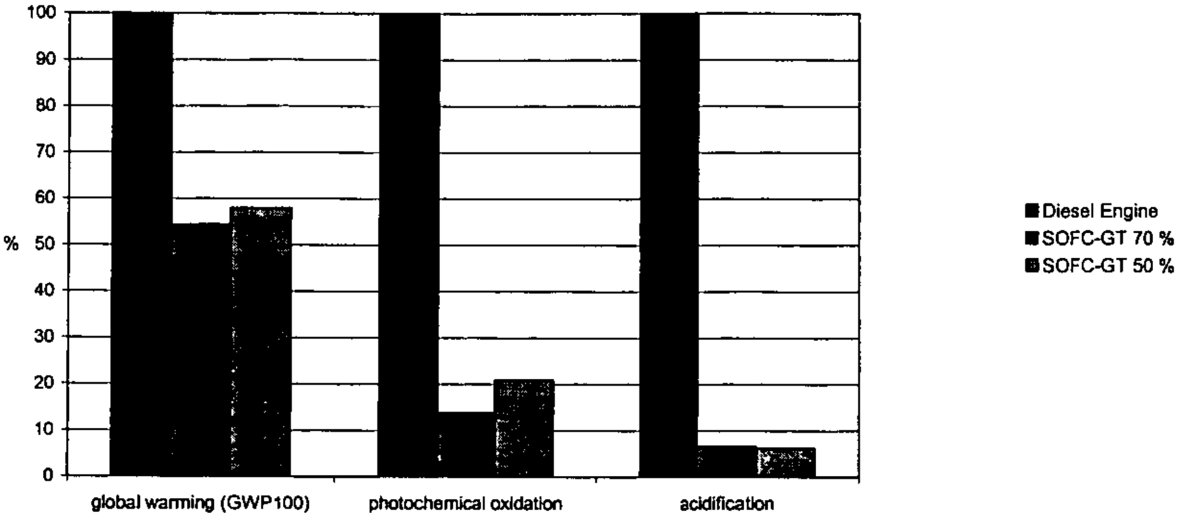

Figure 5.2 – SOFC-GT efficiency.

6. Conclusions

- All SOFC-GT scenarios have approximately 35-90% better environmental performance in the three selected impact categories. LNG supply via Norway has the lowest contribution in all impacts categories considered, approximately 60% lower global warming potential, 85% lower photochemical oxidation and 90% smaller contribution to acidification. This is mainly due to fewer and shorter transportation legs in this scenario.
- The SOFC-GT operation is most important for the global warming category, whilst fuel supply is most important in the photochemical oxidation and the acidification category. This means that if the environmental performance of the system is to be optimised on greenhouse gas emissions, efforts should concentrate on the operational stage; however if photochemical oxidation or acidification are in focus, the fuel supply stages are of importance.
- Sensitivity analyses show that neither increase in life-time of the SOFC nor the fuel efficiency have any significant influence on the results of the study.

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CFD MODELLING OF GAS FREEING OF VLCCS

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The present day process of gas-freeing crude oil tanks on Very Large Crude Carriers (VLCCs, vessels ranging from 160,000 to 320,000 dwt) is a slow and lengthy process. The existing legislation governing the procedures of de-gassing are based on empirical practises and as such the operation is possibly slower and less efficient since the internal flows of the gas and air inside the tank are largely unknown.

The widespread emergence of computational fluid dynamics (CFD) has allowed the analysis of very complex aerodynamic flows and has been widely accepted in other forms of engineering. The present work uses CFD to visualise the interactions between the injected air jet with the structural frames and the gas inside the tank. To this end, the long-standing problems with existing de-gassing methods can be analysed and highlighted.

This paper examines the fluid flow in a typical VLCC tank subject to a gas-freeing operation through the use of CFD tools. Various configurations are examined with respect to vents and fans. The results are presented with recommendations.

1. Introduction

During scheduled maintenance of the vessel, crude oil tanks are usually de-gassed; this is a process whereby a crude oil tank is purged of any inert, chemical or volatile organic compound (VOC) gas that has remained in the tank from previous operations. To purge the tank, fixed or portable fans are used to blow a jet of air through one of the many vents on the top deck. The addition of air mass at high velocities into the tank causes mixing between the newly-introduced air and the gaseous

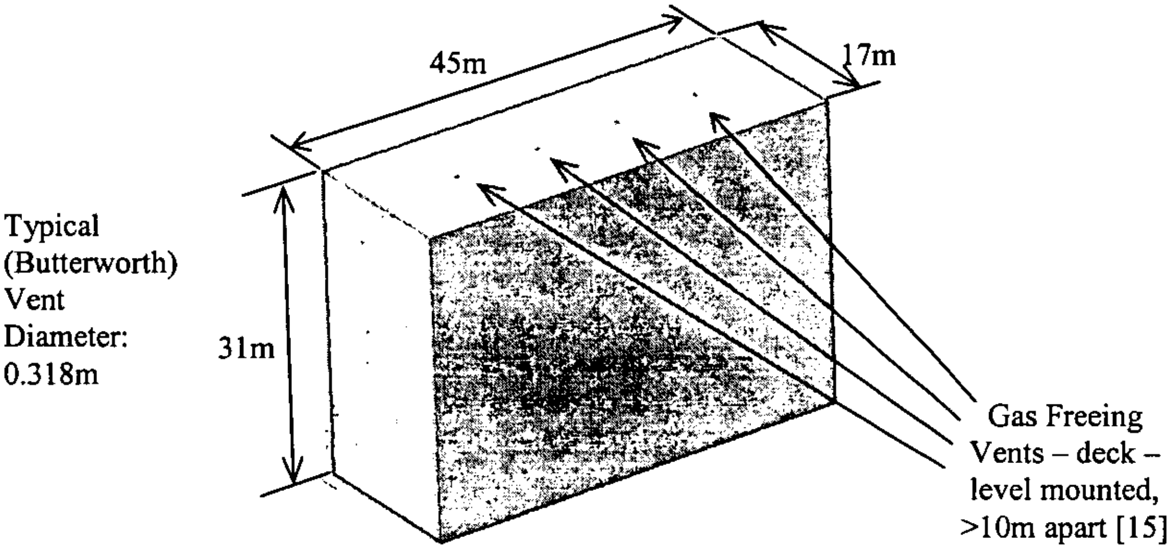

Figure 1 - A typical crude oil tank. Compare vent sizes to the overal dimensions of the tank.

vapours that reside in the tank; the opening of additional hatches allows the gas to escape through these vents to the open atmosphere, or to be collected and reconstituted elsewhere. This blowing of air is continued until the concentration of unwanted gases inside the cargo tank is reduced to a safe level, and the concentration of oxygen is such that unaided breathing inside the hold is possible.

1.1. Operation

Gas freeing can be an operation by itself or as part of an integrated tank cleaning and overhaul procedure. Depending on the application, gas freeing can be conducted either to remove VOC gases directly (for example to examine the tank prior to overhaul), or to re-introduce air following an inerting process during tank cleaning and maintenance.

Usual procedure involves the use of a fan blowing air into the tank whilst a number of other vents are used through which the inert gas or VOCs leave the tank. Depending on the situation, the location of the air fan can be moved mid-way during the gas-freeing process to enhance the gas-freeing operation, or on larger cargo tanks, an additional fan can be used, though it is usual to leave the fans in place throughout the duration of the operation. If the internal geometry is complex, as is the case on older tankers whose tanks are broken by many large baffling bulkheads, ducting can be attached to the fan outlet so that air can be fed directly to wherever it is needed in order to unsettle unwanted gas deposits. This method of ducting can be useful in order to penetrate stratified layers of VOC gas; however the pressure loss involved in ducting can greatly reduce the effective flow of air into the tank space. Sometimes, centrifugal fans are available, where the higher static pressure involved with these fans is much more useful for ducting operations.

1.2. Existing regulations

SOLAS (Safety Of Life At Sea)[15] chapter II-2 regulation 4.5.3.4 specifies that the minimum discharge velocity of the gas-freeing fan is maintained at 30m/s at all times. Because of this high air velocity, axial fans are predominantly used on VLCC tanks; whilst centrifugal fans can deliver a much higher static pressure, they cannot deliver a large enough mass flow rate needed for larger tanks; as such, axial flow fans are dominant so far. The effects of mixed flow fans, which are able to deliver high nozzle velocities as well as relatively high static pressures, remain to be seen.

During the gas freeing process, it is usual to let the tank undergo a number of air changes before checking with hand-instruments that the tank is gas free. Usually, given a relatively clear internal geometry, unobstructed inlet vent and a number of outlet vents (at least three), allowance is given for 5-6 air changes. For more complex situations, operators allow around 8 hours of gas-freeing, though this time is based on operator experience as a "rule of thumb" rather than any mathematical or researched rule. This relatively unregulated should be compared to other parts of the ship such as the pump room (20 air changes per hour [15]) and the ventilation of offshore modules which are subject to similar explosive gaseous vapour, requiring 6 to 12 air changes per hour depending on likelihood or severity [17].

The main regulations that deal with the classifications of a tank being gas free are described in ISGOTT [16], in which several different levels of "gas free" are defined. The most basic level is for the reception of cargo, in which the level of hydrocarbon gas must be reduced to 40% of the lower flammability limits (LFL). The next stage is for entry and cold work in the tank, where the tank must be below 1% of the LFL, as well as checks being performed for the levels of oxygen and other toxic gases (such as hydrogen sulphide, benzene and others) before being certified as gas free. Finally, the most stringent level is being cleared gas free for hot work inside the tank, where the vapour content must be less than 1% of the LFL and any standing sludge or liquid that can emit flammable vapours removed; the tank is also routinely monitored between shifts.

Whilst ISGOTT and SOLAS define some operational criteria and the definitions of gas free, it is interesting to note that neither specifies that a specific number of air-changes MUST be performed in order to assure that the tank is gas free. Whilst it is in the best interests of tank operators to ensure that tanks are gas free, safety may be put at risk for faster turn-around times.

1.3. Problems during Gas Freeing

The size and internal structure of particularly the older crude oil tankers make the internal flows inside the tank very complicated. Due to the interaction of high-velocity air with different, and potentially stratified stagnant gas species, as well as their combined interaction with the tank web frames, complex internal flows can arise – the size of the structure requires that a number of web frames are included in order to maintain structural rigidity; in effect these act like baffles to the flow. Due to the large size of the tank – some over 30 metres deep with typical volumes of over 25,000 m^3 – de-gassing times can be very long, taking many hours for a typical tank, and even then there may be regions where the flow of air is insufficient to remove the unwanted gas.

On newer double-hulled tankers, particularly the smaller chemical/crude-oil vessels up to around 100,000 dwt, designers are moving away from having large frames to reinforce the tank, instead introducing large "corrugations" into the tank walls to provide the necessary buckling strength and stiffness. The impinging air flow is allowed to spread along the surface of the tank floor much more freely rather than being restricted to a few intermediate between-frame compartments - the effect of corrugated walls on the flow and mixing efficiency is still unknown. On much larger vessels however, especially those on the higher end of the tonnage range, large reinforcing struts or frames are still likely to be predominant because of the structural loads involved.

2. Previous Work

There are few studies of jets in vessels of such large volumes. A number of papers are available that concern jet mixing in smaller scales, however there is also a fair amount of work on natural ventilation that, due to the combined effects involved, are relevant.

Fossett and Prosser [1][1] are widely acknowledged for their early experimental work which considered side-entry jets of liquids into large and small tanks with variable injection incidence. Of their larger experiments, the tank volume used was around 15200m^3, whose diameter was around 43.8m. Fossett noted that if pure rotational swirl was induced, it would lower the efficiency of the mixing process.

Fox & Gex [2], and Maruyama et al [3] performed much smaller scale experiments of jet side-entry mixing in cylindrical tanks. Fox & Gex noted that the location of the jet was not of prime important with respect to mixing time, as long as pure rotational swirl was not induced. Maruyama concluded that a mid-plane jet resulted in much better flow patterns, resulting in better mixing, as a high or low-mounted jet would encourage the jet to flow up the sides, acting as a wall jet. This would greatly increase the recirculation time of the whole fluid, resulting in poorer mixing, whereas a side-entry jet would have a range of high and low recirculation times.

More recent investigations include CFD studies of jet-mixed vessels. Jayanti [4] studied a cylindrical tank with a diameter of 0.643m through which two side-entry jets acted. As well as examining the mixing times of the vessel, the variation of mixing time to tank length, effect of base shape and injection period were investigated. In this study, Jayanti concluded that the mixing time is strongly influenced by the shape and thus the internal circulation patterns of the vessel; in extension to this, it was theorised that parts of the flow may be diffusion-dominated due to the regions of strong recirculation not encompassing the entire domain, and that increasing the strength of recirculation may not improve matters, as regions of dead air that are not subject to the influence of the major recirculation patterns will mix primarily by diffusion. Therefore, the optimisation of the internal flow is of prime importance. Work by Ranade [5] examined the flow field when subject to periodically varying flows; mixing was achieved by alternating jets, which would activate in a sequence, through which mixing occurred. In this way, regions which were subject to little circulation when under the influence of one jet would be excited when the active jet alternates. Ranade computationally studied different sequences of jet alternation with respect to mixing time with mixed results; he found that whilst two alternating jets that project mass in the same direction may not decrease mixing time, alternating jets that project in different directions is more efficient at mixing, and that improvement spatially periodic jets may not be applicable to all geometric situations.

Patwardhan [6] and Zughbi et al [7] examined mixing vessel with a nozzle at the base of the tank, adjustable from horizontal to vertical; like Jayanti, the vessel was internally unobstructed. Patwardhan examined the mixing time of the vessel with respect to the variation of the nozzle entry geometry, whereas Zughbi studied the mixing time with relation to the position and entrant angle of the jet. Zughbi reinforced the idea that the location and angle of the jet with respect to mixing times is totally dependant on the shape of the vessel. Experiments with two jets noted a large increase in blend times, though this was found to be dependant on Reynolds number. As Zughbi studied relatively low Reynolds number flows (3000-7000), the Reynolds dependency is likely to be quite high; it is widely accepted that as the Reynolds number increases, it becomes less and less of a factor in blending times and the performance of jet mixing. This relation is reinforced by experiments conducted by Perona et al, [8] in their work on mixing in long tanks, whereby a direct correlation with jet Reynolds number and mixing times was found up to 105,000. The experiments also confirmed a theoretical model by Lehrer [9] who proposed that mixing time was directly related to the entrainment ratio, which is a ratio of jet mass flow rate to that of the flow rate of the injected stream. This entrainment ratio depends on the effective jet distance.

Lee, et al [14] recently conducted research into building ventilation, examining the effects of internal partitioning with respect to indoor air quality, which is somewhat analogous to internal framing inside of a tank. His findings were that the partition had a profound effect on the airflow and thus the ventilative characteristics of the room, creating a complex flow field directly behind the partition, hindering the removal of unwanted vapours.

3. Present Work

Previous simulations on jet mixing using CFD have usually been on small-scale models, whereas the current task involves looking at various crude oil tanks of volumes up to 23,000m^3. Clearly, this is not an easy task, yet a balance has to be drawn between visualisation accuracy and computational time. Because this work is in a very early stage, situations involving multi-phase flow and stratified layers will not be examined, and the scope limited to a qualitative examination of the flow patterns inside the tank with respect to mixing efficiency. A number of different tanks will be simulated coarsely, based on existing geometry. This includes older vessels whose tanks are constructed with a large number of internal baffles, and also newer designs which incorporate corrugated walls to retain stiffness.

3.1. Computational Methodology

The model is simulated on the commercial code PHOENICS as developed by CHAM Ltd. It is based on a finite-volume method of solving the discretised flow field. Whilst the equation model can take on several formulations, the elliptic staggered formulation is used in conjunction with an orthogonal Cartesian mesh. The solver uses a variant of the SIMPLE algorithm, called SIMPLEST (SIMPLEShorTened) which has a slightly different formulation of the finite volume equations; this has the benefit of having smoother convergence without the need for as much under-relaxation.

The issue of turbulence modelling in this initial study is critical due to the large scales involved and the limited computational power available. Many authors make use of 2-equation models, such as the well known K-ε model as developed by Launder and Spalding [10], and the RNG variant developed by Yakhot and Orszag[11]. In this application, due to the expected large eddy scales as well as the prevalence of turbulent structures inside the tank, usage of a lower-order model would not bring about accurate results, yet at the same time a higher order model such as the Reynolds Stress Model would be too computationally intensive, as involves no less than 7 partial differential equations in it's 3-dimensional form.

Despite the known deficiencies in the use of the K-ε model [10], it is used here as it delivers an adequate level of accuracy required without the computational effort involved becoming substantial. Although it performs less well in swirling or flows with axisymmetrical jets, the RNG model is known to exhibit a substantial deterioration in centreline jet decay in axisymmetric jets. Also, the solution of the RNG-based model is slightly less stable due to the reduction of calculated ε, and thus may result in convergence problems.

Concerning the constants in the K-ε model, there is much dispute over what represents the proper value. Patwardhan [6] performed a limited examination of which values gave more realistic solutions for his particular scenario; however a similar related study for this application is not possible at this early stage. As such, the default values of $C\mu=0.09$, $C_{1\varepsilon}=1.44$ and $C_{2\varepsilon}=1.92$ are used.

As this work is in its initial phase, a number of idealisations will be assumed in order to reduce the time taken to run the simulations, and also to prove some initial information before detailed examinations are performed. Constant density is assumed, so buoyant effects are neglected. Also, the study will be performed as a single phase fluid, so the stratified oil substrates are not present in this work. Temperature differences will also be neglected, so the remaining domain will be simulated as an incompressible, constant temperature single-phase simulation.

3.2. Model

The domain size is based on existing tank drawings, as is the internal structure where appropriate. Three different geometries were examined; one smaller tank (<10,000m^3) which incorporated corrugated walls for stiffness, and two increasingly larger (18,000 and 22,000m^3) tanks which used internal web frames for rigidity. Basic structures were modelled, for example the lower corner angles, the frames and the ceiling geometry were as fixed blockages. Other structures such as maintenance gangways and stairways inside the tank were not modelled in this stage. The 4 ceiling-mounted vents are based on the dimensions of the Butterworth hatches, with a diameter of 0.318m.

The location of vents is arbitrary; here, they are equally spaced for equal coverage. The inlet vents had fixed-velocity boundary conditions prescribed, and the outlet vents were defined as fixed-pressure outlets.

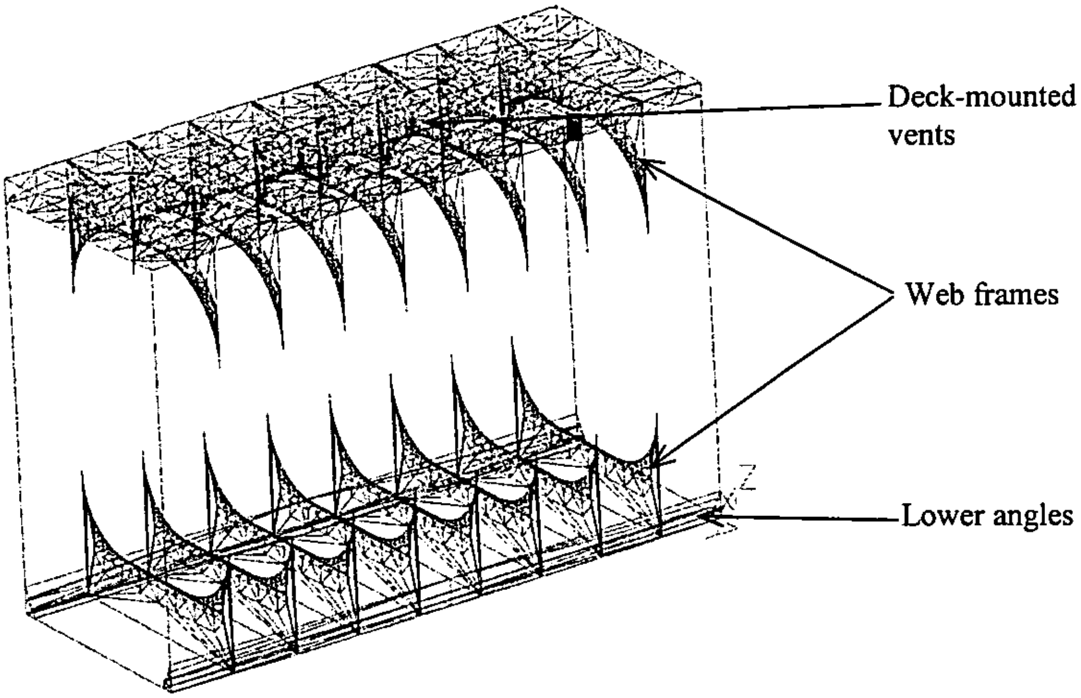

Figure 2 - Wireframe CAD diagram of geometry Case 1 - 22,500m3 Crude Oil Tank.

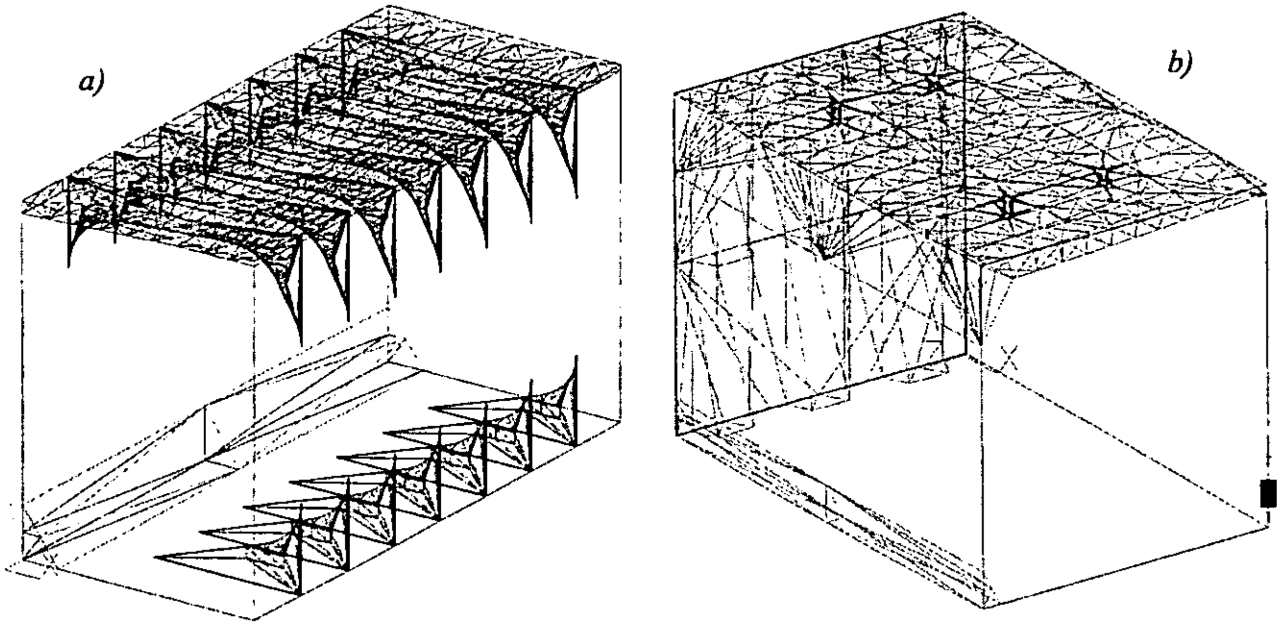

Figure 3 - a) Wireframe CAD diagram of Case 2, 8,512m^3 crude oil tank; b) Wireframe CAD diagram of geometry Case 3, 2,592m^3 Chemical/Oil tank.

3.3. Computational Mesh

Because of the large scale of the domain volume involved, a large number of grid cells will be required. Whereas Jayanti [4] conducted simulations in a 2 dimensional domain with around 5000 cells and Patwardhan [6] used 216,000 cells in a 3-dimensional domain, upwards of 1,000,000 cells are likely to be needed to capture the large scales of internal flows as well as the required definition of the jet, due to the large size of the tanks involved in this study. To find out how many cells would be required, a limited mesh sensitivity study was performed, as scaled experimental data is not available at the time.

To ensure that the mesh used was of sufficient fineness and that the results are independent of the mesh chosen, a series of simulations were performed with different mesh densities in order to ascertain the degree of mesh independence.

Two correlations were studied using Case 1 geometry. The jet centreline decay was compared to a mathematical formulation of an axisymmetric jet created by Abramovich [12], and also the jet velocity profiles of the various simulations were compared. 7 Meshes from 250,000 cells to 2,411,000 cells have been examined.

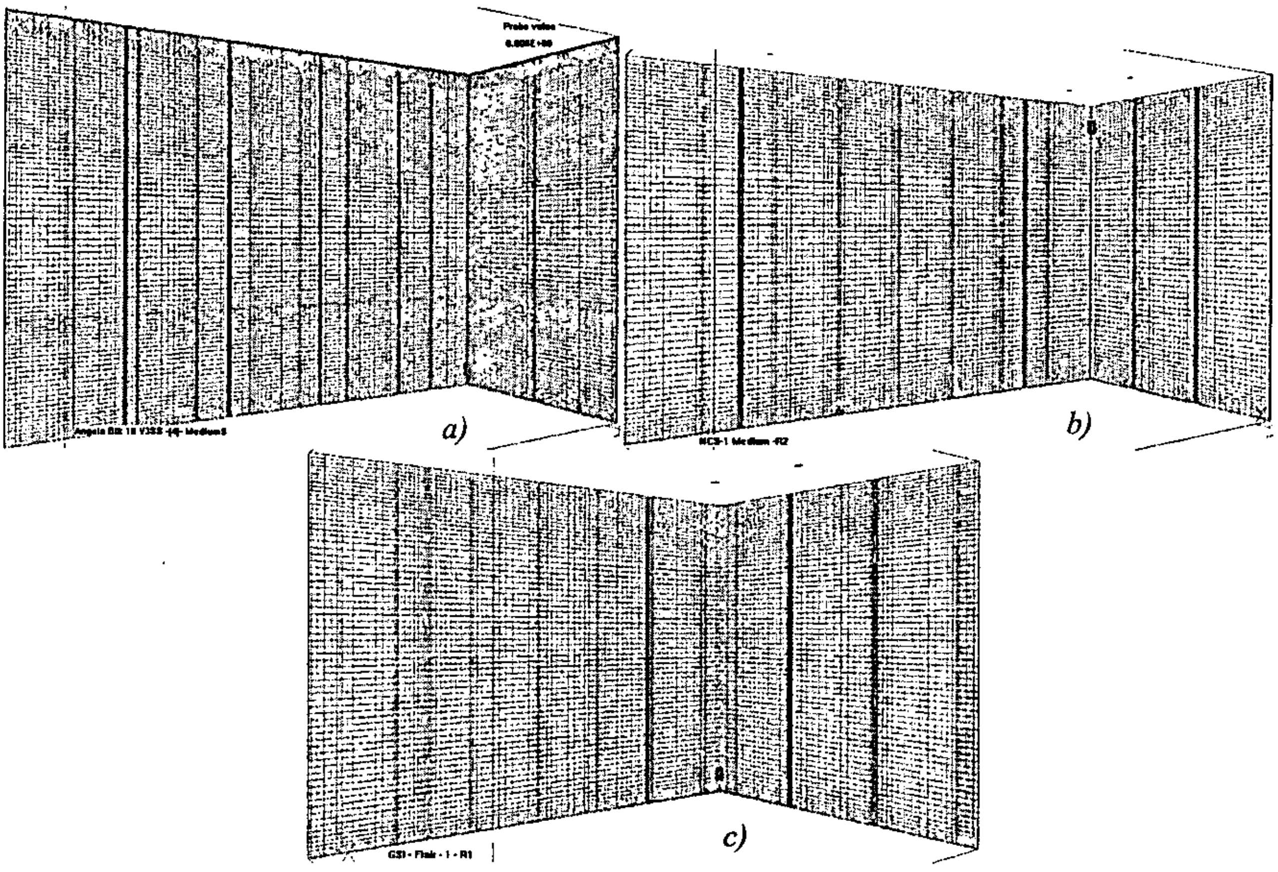

Figure 4 – Computational wall meshes – a) Case 1, 860,456 cells, 22,500m^3; b) Case 2, 840,956 Cells, 8,512m^3; c) Case 3, 652,190 cells, , 2,592m^3.

The centreline velocity (Figure 5) shows the close bunching of the analyses, with the exception of the 1,600,000 case; it is possible that the simulation at this grid density was computing flow features that were picked up by the more dense mesh but not properly resolved as the grid was not dense enough, whereas the 1,860,000 is dense enough to properly resolve the flow. In the terminal decay, or main region, the simulations conform well to the mathematical model already proven by Abramovich in his works. Closer to the jet nozzle in the initial potential core and transitional regions, the simulations are less accurate, the jet carrying more velocity than the expected. The lie of the results here suggests that this is due to the behaviour of the K-Epsilon turbulence model. Strangely, the 1,600,000 cell model is more accurate in this respect, but suffers as the jet develops.

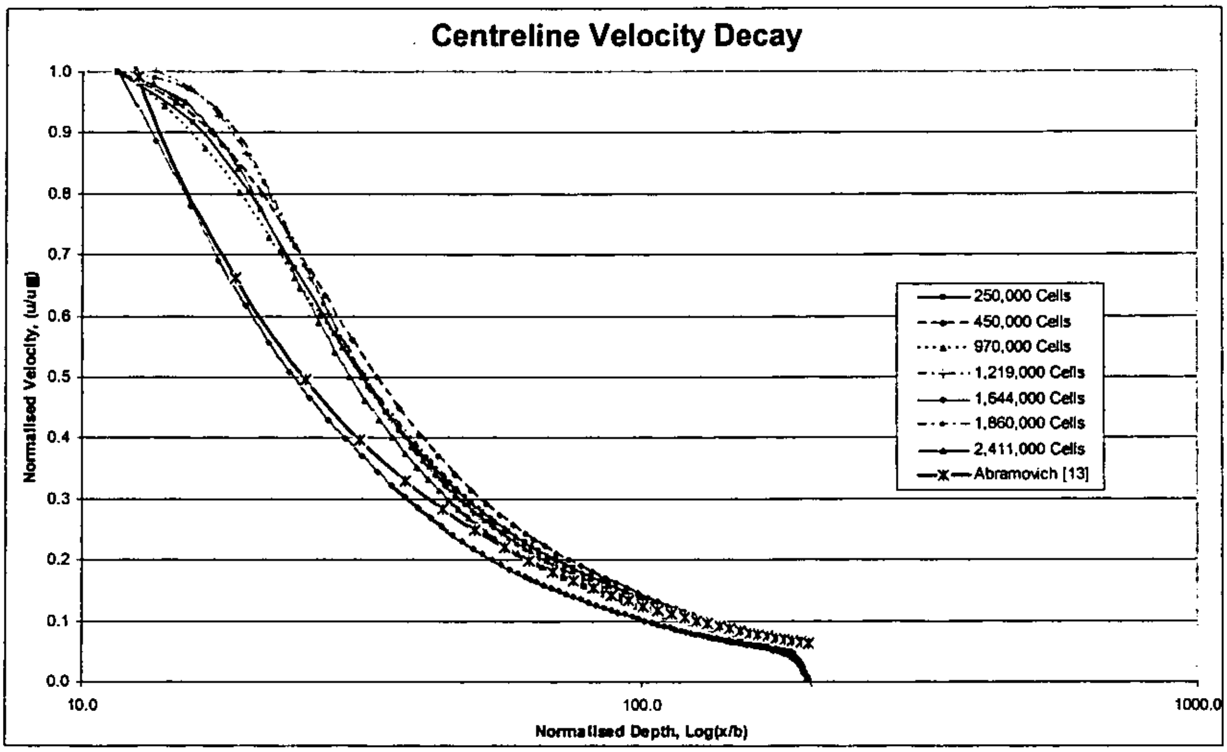

Figure 5 - Centreline Velocity Decay Comparison with Abramovich [13].

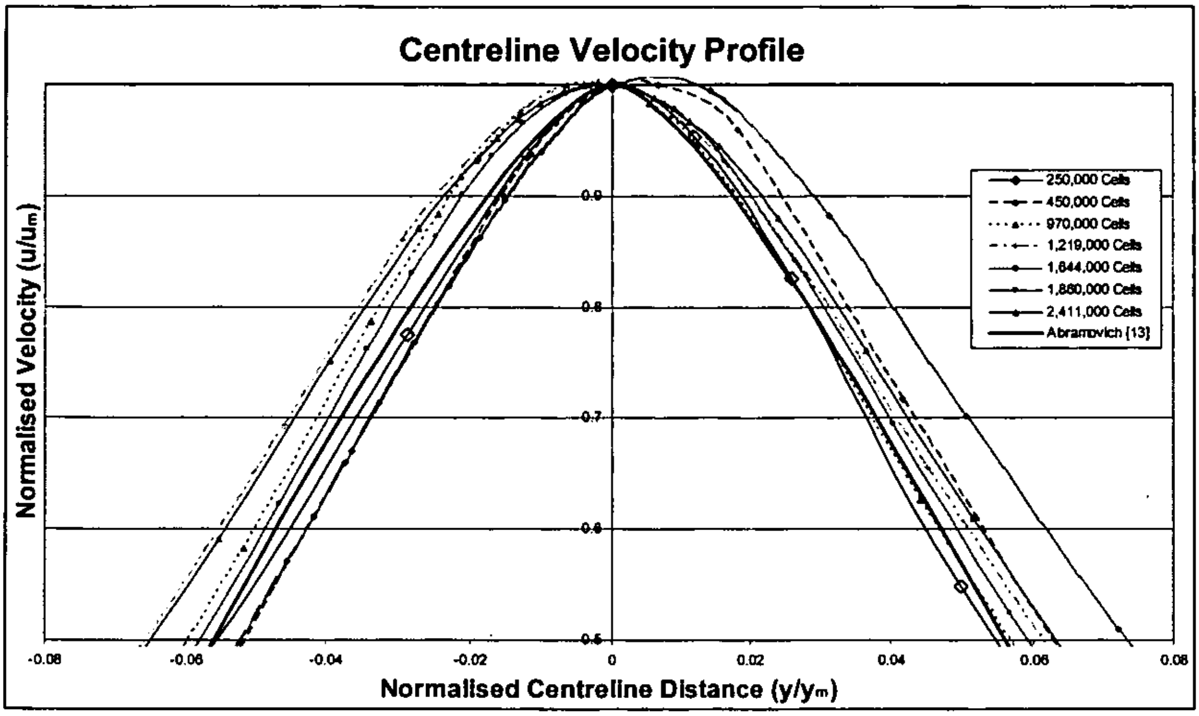

Figure 6 - Centreline velocity profile comparison with Abramovich [13].

The centreline velocity profile comparison shows that the K-Epsilon model over-estimates the centreline velocity; this is a well-known phenomenon [13] with this turbulence model in conjunction with round axisymmetric jets. Here, the 1,860,000 and 970,000 cell mesh are both comparatively near to the mathematical relationship formed by Abramovich. The shifted centre on the graphs, particularly the 450,000 and 1,644,000 cell plots is due to a lack of cell points at the centre of the jet, resulting in a skewed plot.

4. Results

In all, five results are presented here, involving three different internal geometries, as shown from the velocity plots in Figure 7 to Figure 11. The contour illustrations are calibrated for velocities of 0m/s (black) to 1m/s (white).

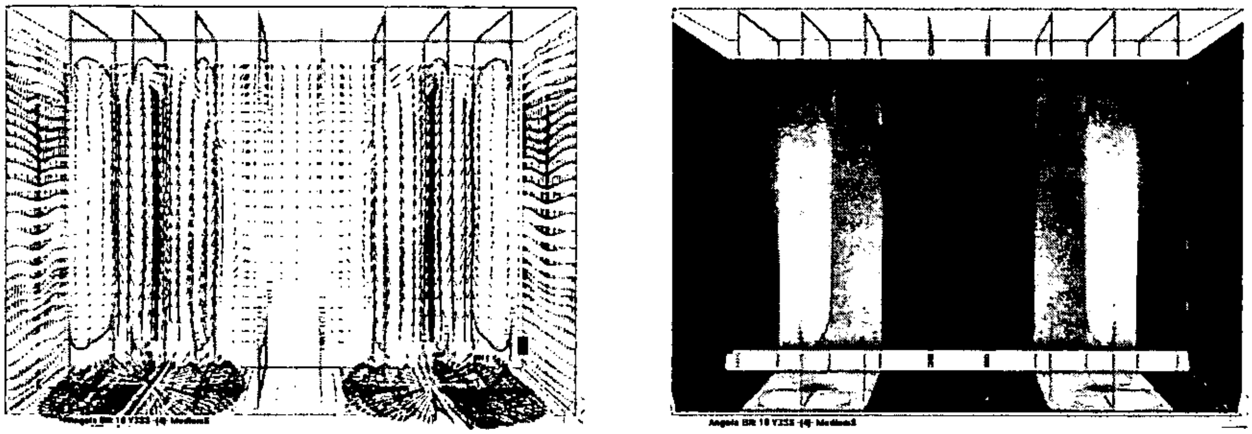

Figure 7 – Case 1 geometry with two air jets; Vector lengths show velocity; white tone on contour plot show regions of high velocity, black indicates stagnant air; High velocity jet is heavily confined by structural frames.

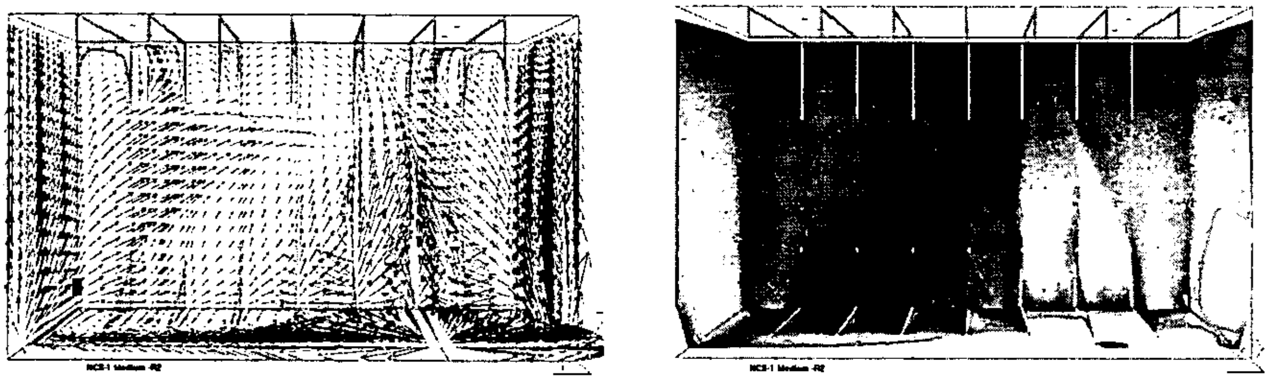

Figure 8 – Case 2 geometry; one air jet impinging on the open floor; Vector lengths show velocity; white tone on contour plot show regions of high velocity, black indicates stagnant air; High velocity air allowed to spread, but stagnant air resides in 'shadow' regions behind frames.

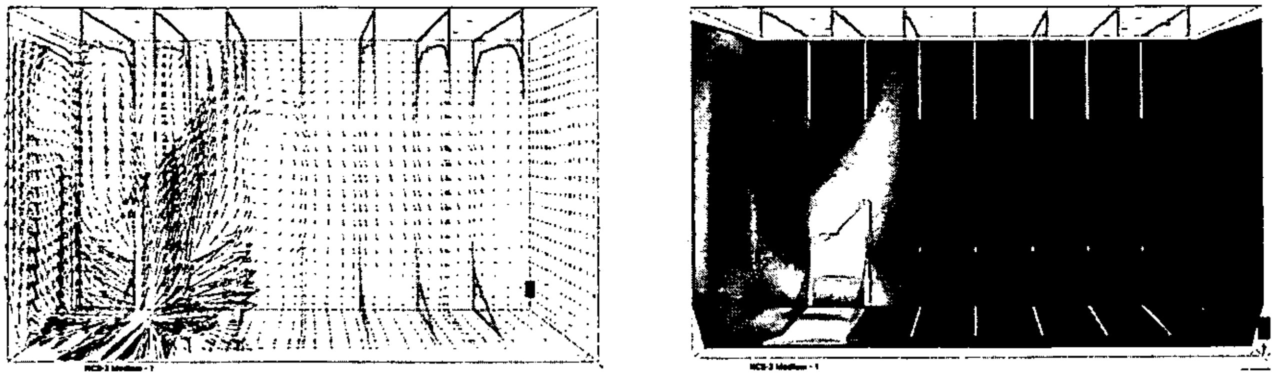

Figure 9 – Case 2 geometry – one air jet impinging into the framed region Vector lengths show velocity; white tone on contour plot show regions of high velocity, black indicates stagnant air; Here, air jet is heavily restricted to the left hand side of the tank.

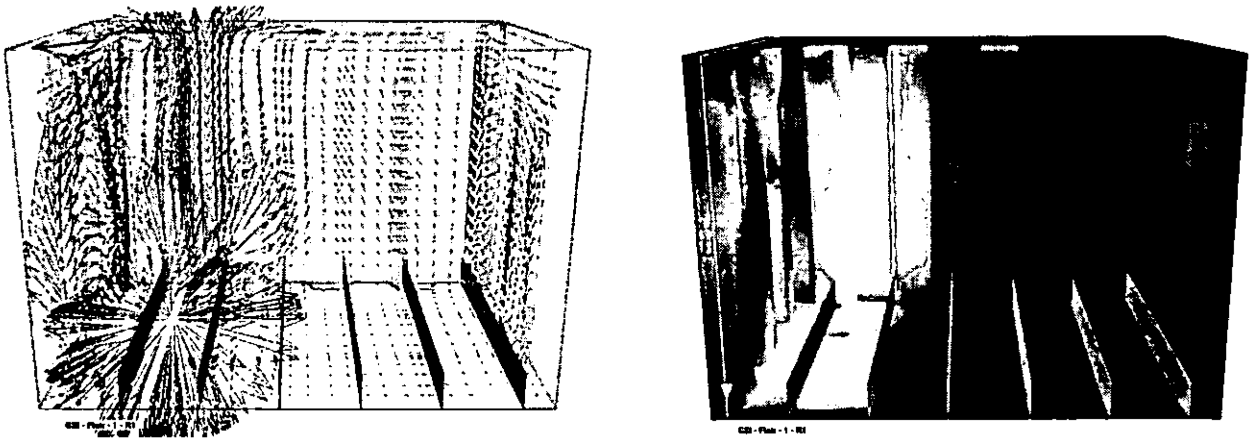

Figure 10 – Case 3 Geometry – Floor baffles added Vector lengths show velocity; white tone on contour plot show regions of high velocity, black indicates stagnant air; Addition of floor baffles restricts spreading of jet across the floor.

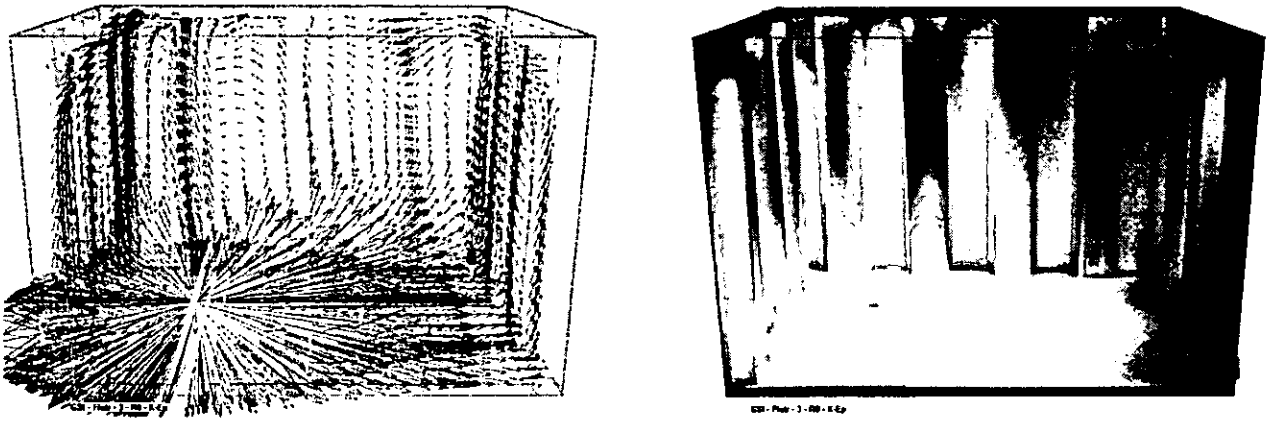

Figure 11 – Case 3 Geometry – Floor baffles removed Vector lengths show velocity; white tone on contour plot show regions of high velocity, black indicates stagnant air; With baffles removed, jet is allowed to spread much further around the tank.

Figure 7 depicts two air jets injected into a large, tank with highly intrusive brackets and transverses. As can be seen on the contour plot, the airflow is clearly restricted into the two bays directly in the path of the jet. Due to the presence of the frames along the floor, the impingement region of the jets are greatly restricted to just the divisions where the jet is located, and the majority of the air is forced up the wall, guided by the frames. The only air movement that affects the adjacent regions is caused by recirculation effects in the upper regions of the jet, driven by the large shear differential. There is also some spill-over recirculation in the bottom of the tank, but these flows do not carry over into the other inter-web spaces, and the magnitudes of these effects are very minor in comparison to the effects of the jet. Whilst the effect of the frames is detrimental to the mixing and subsequent ventilation of the tank as a whole, the constraining of the impingement region concentrates the dynamic energy into that region, resulting in vigorous mixing in the related spaces between the frames, but negligible mixing elsewhere.

Figure 8 and Figure 9 involve the same geometry, however the location of the jet has been moved to examine the effects of jet placement to frame location; Figure 9 is set up with the jet impinging directly into the floor half-frames, whereas Figure 8 impinges into the open area past where the frames have ended. Some comparison can be drawn between Figure 7 and Figure 9; the restraint by the frames restricts the air flow to the inter-web spaces, resulting in a large portion of the air climbing up the wall as a wall-jet. The air that spreads along the floor is channelled by the frames, only spreading out when it reaches the far wall. This can also be seen in Figure 10, where 1.4m high baffles were added to compare the effects. Again, it can be see with stark clarity that the baffles, if at floor level, seriously constrain the spreading of the jet, forcing most of it to the walls, creating wall jets. The tendency for flow to be channelled up the wall is more evident in the vertical corrugations on the smaller tank, leaving the raised part of the corrugation with a lower air velocity, especially at higher elevations in the tank.

A significant amount of spill-over air into the adjacent frame space is seen in Figure 9; as the frame is smaller than that of the Case 1 geometry, more of the air can circulate, resulting in a ring vortex which, although is not as strong as in the partner simulation, still has some strength. However, the successive frames severely retard the flow, relying on shear from the larger scales of motion in the higher-up clear region of the tank to churn up the lower layers amongst the frames.

The two figures below are mid-plane sections through the flow field. As can be seen, especially in Figure 12, the presence of flow-restricting geometry can have a large effect on the far-field velocity flow field. On the other hand, in Figure 13 it can be seen that without baffles, the flow spreads along the floor and up the wall, setting up large scale rotation. As mentioned previously by several authors, this type of mixing is not the most efficient way of encouraging the dispersal of unwanted gas; however it is better than no movement at all.

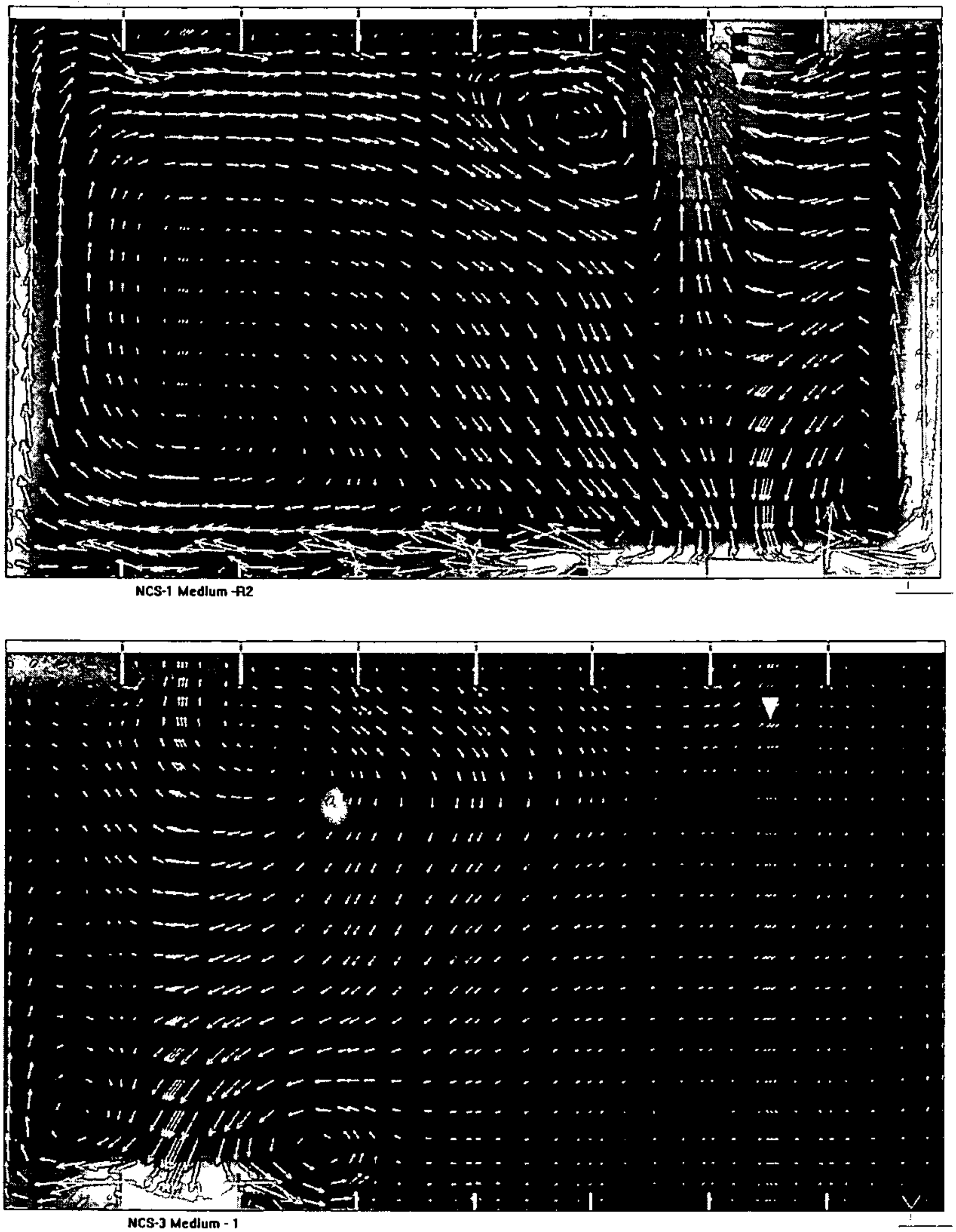

Figure 12 – Case 2 geometry, mid-plane section; a) one air jet impinging on the open floor; b) one air jet impinging into the framed region

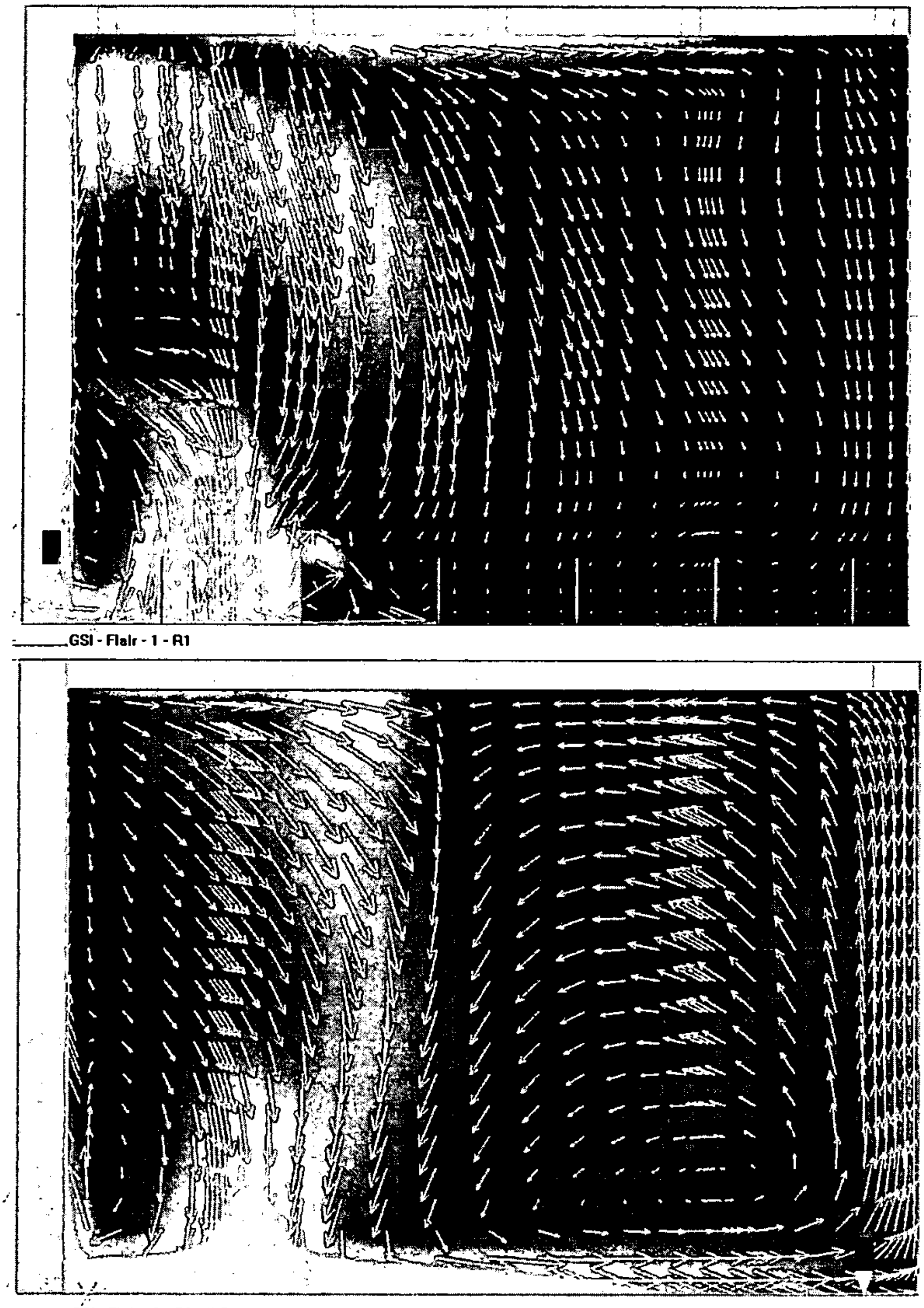

Figure 13 – Case 3 Geometry, mid-plane section; a) Floor baffles added, b) Floor baffles removed

5. Conclusions

The present work has qualitatively examined a simple model of gas freeing using computational fluid dynamics and highlighted a number of issues concerning the current operational procedure, as well as the aerodynamics involved. The main pertinent points from the study are:

- Internal frames that are floor mounted massively restrict the ability of the jet to spread, instead channelling the jet up the wall bound by the frame. Whilst this will lead to very good mixing in that area, the remainder of the tank will remain largely unaffected by the air jet;

- If jet air impinges on an open region on the floor of the tank that is some distance from a frame, the spread of the jet (even if only corner brackets are present) is still greatly improved than if it were blown straight into a channel between frames;

- Blowing jet air into almost totally open geometry leads to large-scale fluid rotation. Whilst this is good for mixing of shear layers on the periphery of the swirl, fluid towards the centre will simply rotate without much mixing. In large scales such as crude oil tanks, this behaviour is inefficient unless transient variation of the rotation can be induced, perhaps by vectoring the jet periodically, or simply by moving the fan to a different vent and resuming the procedure [5]. This way, more gas can be entrained by the jet without re-entrainment of already mixed fluid.

The work completed is only the start of a dedicated work effort into the examination of internal flows inside a crude oil tank of size typical on VLCC's. Future work will look into adding more detail into the simulations with a view to forming a quantitative relation that describes tank gas freeing. The next stages of work will involve examining transient characteristics, buoyancy due to density and temperature effects, and multi-phase issues. In addition, other variations of gas freeing will be examined with different nozzle configurations. Although the methods involved in gas freeing are based on the mixing ventilation methodology, there is potential that displacement ventilation (which involves injecting air at the bottom of the tank underneath the stratified layers) may prove useful, and may be investigated further.

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CO_2 EMISSIONS FROM CO_2 OCEAN STORAGE SYSTEM

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Ocean storage of anthropogenic carbon dioxide (CO_2) is a possible option for mitigating the increase of atmospheric CO_2 concentration. The technical concept of CO_2 dispersion in the deep ocean by ship is proposed to reduce the potential environmental impacts associated with high concentrations of CO_2 near the injection point. That is, captured CO_2 is liquefied and transported to the site to be injected into the ocean depths with a pipe suspended from a slowly moving ship. The higher speed and the greater depth of CO_2 releasing point are preferred from the viewpoint of dilution, and the longer transportation allows the flexible site selection. However, the trade-off relations should be considered with the higher energy consumptions accompanied by CO_2 emissions. In this paper, CO_2 emissions from the ocean storage system are assessed, based on transport of 20,000 ton/day of CO_2, which is equivalent to the output from 1,000 MW of coal-fired power plant. As the major CO_2 emissions, the boil-off from ships and shore-based storage tanks, the exhaust of ships' engines for navigation and pipe towing, and the exhaust of electric power generation for CO_2 injection into the ocean depths, are taken into account. As a result, the rate of CO_2 emissions to transported CO_2 is estimated 3 to 6 % in a realistic scale of transport distance, CO_2 injection depth, and ship speed for CO_2 release.

1. Introduction

1.1. Background

Global climate change due to the increasing concentrations of greenhouse gases in the atmosphere has become a great concern internationally, and the understanding of the necessity for taking measures against it is now held in common. CO_2 is the main greenhouse gas emitted by human activities. Since it is closely related with the thermal power generation, the supply of construction materials such as steel and cement, the fuel for transportation, *etc*., the immediate reduction of large amount of CO_2 emission is recognized very difficult.

CO_2 capture and storage [1]-[3] is expected to be so-called 'bridging technology' from the present society supported highly with the consumptions of fossil fuel, to the sustainable future society supported with carbon-free energy. That is, CO_2 would be separated from exhaust gas and collected at the large sources, and injected into the subterranean reservoirs or into the deep ocean to be isolated from the atmosphere for a sufficiently long time period.

The atmospheric concentration of CO_2 has increased from 280 ppm in the days before the Industrial Revolution to 370 ppm in 2000, and is still growing 1.5 ppm every year. The total amount of CO_2 emitted by human activities is evaluated almost twice as the increment in the atmosphere. The balance is presumed cancelled mostly with the absorption into the ocean in natural process. In other words, the increase of atmospheric CO_2 concentration has been mitigated owing to the ocean. The CO_2 ocean storage, CO_2 injection into the ocean depths by-passing the surface layer, might be explained as the artificial process driving CO_2 absorption into the ocean.

Needless to say, the careful considerations of the oceanic environmental impacts will be quite important. Ocean already holds vast quantity of CO_2, but additional dissolution of CO_2 in seawater will decrease pH of the water and affect on marine organisms corresponding to the pH changes. Research on assessment of CO_2 impact on marine environment is in progress [4]-[8]. Technologies to minimize the impact should be considered [9], [10].

1.2. CO_2 injection and dispersion by moving ship

As the measures to minimize the environmental impact of the CO_2 ocean storage, the technical concept of CO_2 injection and dispersion by moving ship was proposed [11], [12]. A schematic view of this concept is shown in Fig.1. The captured CO_2 at the plant on land is delivered by ship to the CO_2 storage site, and injected into the ocean depths with a pipe suspended from a slowly moving ship. Horizontal movement of CO_2 releasing point will be effective for distributing CO_2 in the site area without accumulation of dissolved CO_2 in seawater. And vertical journey of CO_2 drops with gradual dissolution will be put good use for the vertical dilution [13]. Simulation studies suggest that CO_2 drops will rise more than some hundreds meters, if their initial sizes are adjusted over 10 mm [14].

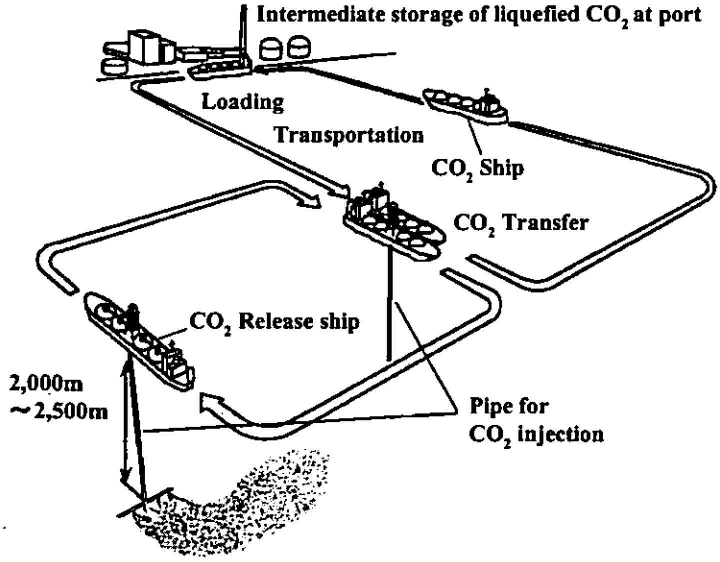


Fig.1 - Conceptual view of CO_2 dispersion in ocean depths by moving ship.

1.3. Objectives of this study

When CO_2 will be injected and dispersed by moving ship, as expected easily, the higher speed and the greater depth of CO_2 releasing point are preferred from the viewpoint of dilution, and the longer transportation allows the flexible site selection. But the trade-off relations should be considered with the higher energy consumptions accompanied by CO_2 emissions. If the CO_2 emissions are significantly large compared with the amount of transported CO_2, the concept has no sense.

In this paper, CO_2 emissions due to the marine transportation and the CO_2 release by moving ships are assessed. The amount of captured CO_2 from the operating plant is assumed to be 20,000 ton/day, and the parametric case studies are carried out in a realistic scale of transport distance, injection depth, and ship speed for CO_2 release.

2. System description and major CO_2 emissions

2.1. Diagram and scope of study

Fig.2 shows the diagram of the CO_2 capture and ocean storage. CO_2 would be captured at large concentrated sources such as thermal power plants, steel-manufacturing plants, some types of chemical plants, *etc.* Most CO_2 capture processes produce gaseous CO_2 at atmospheric or slightly elevated pressure. When the capture plant is remote from a port, the CO_2 would have to be compressed and transported by pipeline to the liquefaction plant near the port.

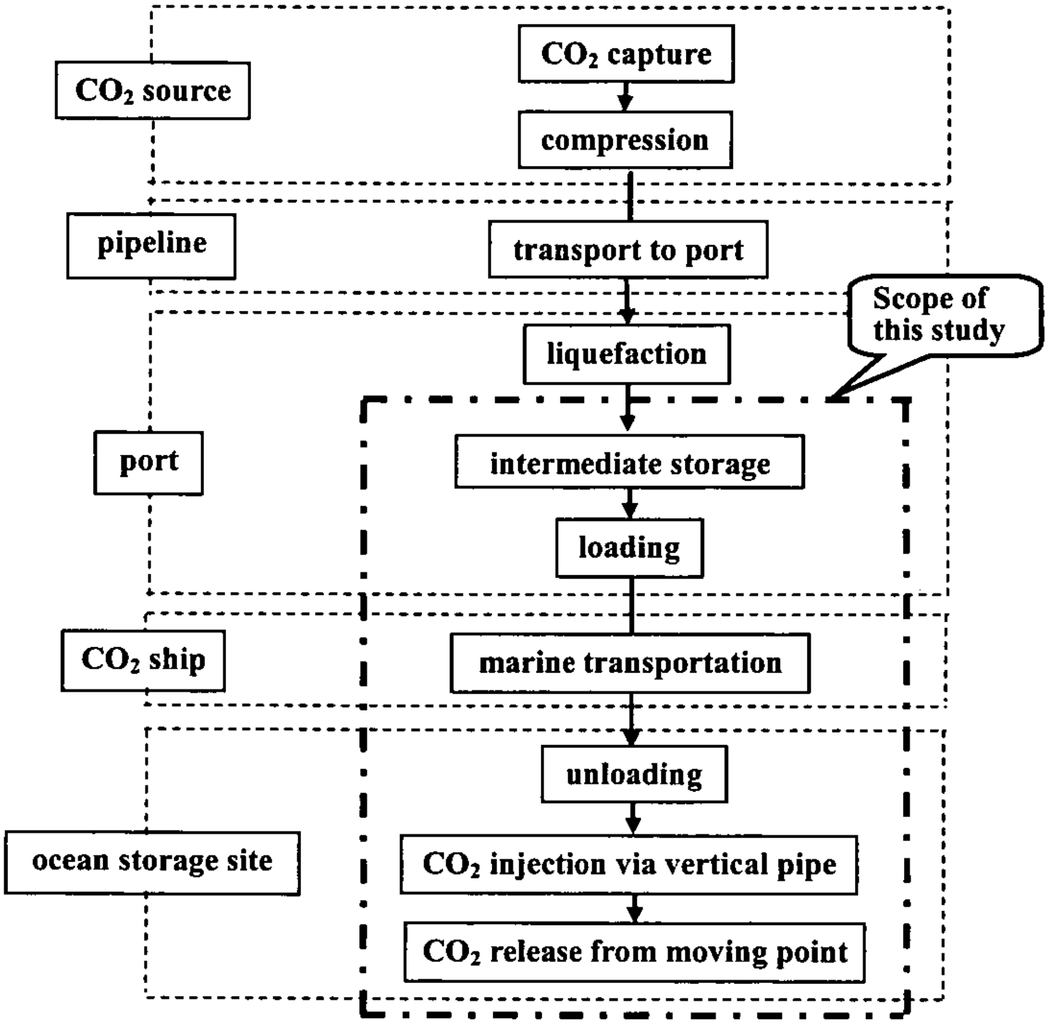


Fig.2 - Diagram of CO_2 capture and ocean storage.

It is common to liquefy the gas for ship transport to reduce the volume. The design point of cargo condition in temperature and pressure depends on the characteristics of the gas. For large-scale storage and transport of liquefied gas, the design point tends to be set as modest pressure as possible. If the design pressure is higher for a more modest temperature, the maximum tank size would become smaller and the number of necessary tanks and equipments would be more and they would have to be set over quite wide area. Referring the phase diagram of CO_2 as shown in Fig.3, the recommended design point is near the triple point, -50 degC and 0.7 MPa for example. Liquefaction of CO_2 is not a novel technology, and it was indicated that the power consumption for CO_2 liquefaction would be greatly reduced in the case the CO_2 is transported from the capture plant by high-pressure pipeline [15].

Before shipping, the temporary storage of the liquefied CO_2 is required, because CO_2 is continuously captured at the CO_2 source, but the cycle of ship transport is the discrete event and buffer storage at the port is needed. Then, the CO_2 is delivered by CO_2 ship to the site, transferred to the ship for releasing, and injected *via* pipe into the ocean depths.

Akai *et al.* [16] evaluated the energy penalties and costs for various combinations of fossil fuel system with CO_2 capture, transportation and storage, and resulted that the upstream process from capturing to liquefaction accounts for the great portion. From the point of CO_2 emissions, however, the additional CO_2 emissions due to electric power consumptions on land would be recovered with use of the common facilities at the capture plant. In this study, CO_2 emissions due to the marine transportation and the CO_2 release by moving ships are assessed.

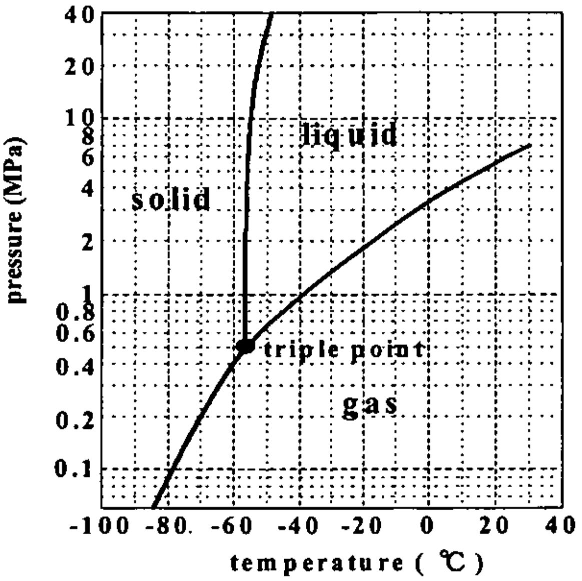


Fig.3 - Phase diagram of CO_2.

2.2. Intermediate storage at port

Since there was no need to store quite large amount of CO_2, we have had no experiences in the world to construct and operate CO_2 tanks whose individual capacity is greater than thousands ton. But on the analogy of large-scale storage of pressurized liquefied gas, horizontal cylindrical vessel or spherical one would be used. Under the current capabilities of manufacturers, the maximum capacity of spherical tank which withstands the inner pressure of 0.7 MPa may reach approximately 20,000 m^3: the inner diameter of the tank is about 34 m and the wall thickness is 50 to 60 mm. The structural material of the tank wall will be high tensile steel proofing against low temperature as used for LPG tanks. Heat absorption from outside is restrained with thermal insulating material on the wall.

The major CO_2 emission from the storage tanks will be caused as the boil-off. In this study, the daily boil-off rate is assumed 0.2 % of capacity. In order to reduce it substantially, re-liquefaction of the boil-off CO_2 might be possible technically, but it would be more realistic at first to pursue the higher performance of the heat insulation of the tanks.

2.3. Loading facilities

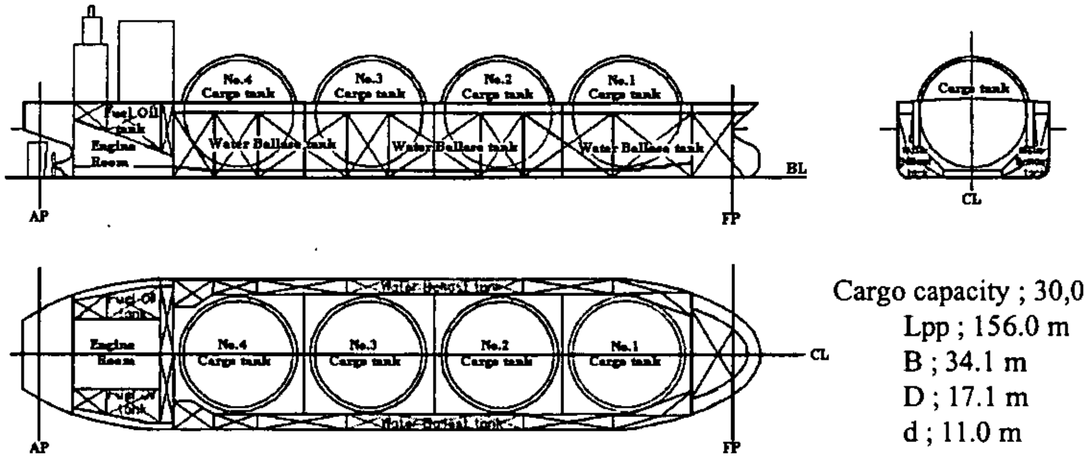
The submerged pumps in the intermediate storage tanks and the loading arms set at the quay would be used to transfer the liquid CO_2 from the tanks to the CO_2 ship. Electric power is required to operate the facilities, and strictly speaking, additional emission of CO_2 due to the electric power generation should be considered. In this study, however, it is assumed that such CO_2 emission is negligibly small on the whole.

2.4. CO_2 transport ship

CO_2 ships have already been constructed, though they are not large (1,265 m^3 for example). For much larger CO_2 ships, the construction technology and the operating experiences of LNG ships and LPG ships could be useful.

In order to estimate CO_2 emission due to the fuel consumption, CO_2 transport ships were preliminarily planned based on the practical designing scheme of existing liquefied gas ships [15]. For example, the outline of CO_2 ship of 30,000 ton capacity is shown in Fig.4. It is assumed that the ships are powered by diesel engines burning heavy fuel oil, and the CO_2 emissions are estimated as shown in Table 1.

Boil-off CO_2 from the cargo tanks would be another major emission. The boil-off rate is assumed here 0.2 % of capacity per day.



Cargo capacity ; 30,000 ton
Lpp ; 156.0 m
B ; 34.1 m
D ; 17.1 m
d ; 11.0 m

Fig.4 - Outline of CO_2 transport ship of 30,000 ton capacity.

Table 1 - CO_2 emissions due to fuel consumption for navigation of CO_2 transport ship.

Ship size (carrying capacity)	Service speed (full load/ballast)	CO_2 emissions during navigation
10,000 ton	15 knots / 16 knots	3.48 ton/hour
20,000 ton	15 knots / 16 knots	4.00 ton/hour
20,000 ton	18 knots / 19 knots	7.65 ton/hour
30,000 ton	15 knots / 16 knots	4.44 ton/hour

2.5. Unloading facilities

CO_2 is shifted from CO_2 transport ship to CO_2 release ship at site. In order to avoid the gasification of the CO_2 during transfer due to the temperature rising, it is preferred that the distance between cargo tanks of each other is as short as possible. Therefore, side-by-side mooring seems to be a possible option. Unloading from CO_2 transport ship will be carried out with use of the pumps in the cargo tanks of the ship.

Additional emissions of CO_2 due to the electric power generation on board will be needed for the operation of mooring, unloading, *etc.*, but it is assumed that they are negligibly small as a whole.

2.6. CO_2 release system

The ship for CO_2 release into ocean depths is fairly novel. The required functions are; 1) receipt and storage of liquid CO_2, 2)raising and lowering of pipe longer than 2,000 m, 3)CO_2 injection *via* hanging pipe and release with slowly moving through the water. Fig.5 is an impression of a moving ship releasing CO_2 on site.

Research and development studies on the engineering issues of CO_2 release system has been made (see ref.[17], for example). The principal achievements at present are as follows:

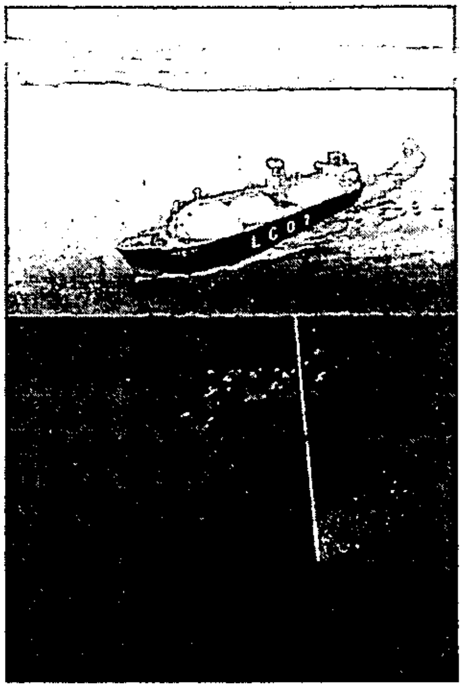


Fig.5 - Imaginary picture of moving ship releasing CO_2 on site.

1) the towing of a long pipe at speed of up to 3.0 m/sec was found to be feasible; the drag force coefficients and the influence of the vortex induced vibration for inclined pipe in the super-critical Reynolds number should be clarified to determine more accurately the limit of the towing speed;
2) technology for continuous release of CO_2 droplets controlled in their initial size was verified experimentally; use of streamlined nozzle aligned with the towing direction and control of the towing speed to be near the discharge velocity proved promising;
3) from the numerical study, it was found possible to dilute CO_2 into seawater at an initial ratio of less than one to hundred thousands in an engineering realistic scale.

As the major CO_2 emissions from the CO_2 release system, the boil-off, the exhaust of ships' engines and the exhaust of electric power generation for CO_2 injection into the ocean depths are to be considered. Regarding the boil-off CO_2, 0.20 % of capacity per day is assumed again. But CO_2 gas is usable during CO_2 release for the replace of cargo tank space instead of liquid CO_2, therefore the emitted CO_2 is to be counted in this study except the releasing time period.

In order to estimate CO_2 emission due to fuel consumption of ship engine, the fluid resistance to the towing pipe should be evaluated, as well as to the ship hull. The pipe becomes inclined in the towing condition as described in Fig.6, and the release depth of CO_2 should be ensured by use of a pipe long enough to counter the geometric ascent of the lower end of the pipe. It can be assumed that the characteristics values of the towed pipe in steady state are evaluated by simple modeling of an inclined straight pipe. The inclination of the towed pipe, θ, is derived from the equilibrium condition relating to weight and drag force, described as

$$[\rho_s g \frac{\pi}{4}\{D^2-(D-2t)^2\}+\rho_c g \frac{\pi}{4}(D-2t)^2-\rho_w g \frac{\pi}{4}D^2]\sin\theta=\frac{1}{2}\rho_w C_D D(V\cos\theta)^2 \qquad (1)$$

where ρ_s is the density of pipe material, ρ_c is the density of liquid CO_2 in pipe, ρ_w is the density of seawater, D is the outer diameter of the pipe, t is the thickness of the pipe wall, C_D is the drag force coefficient, V is the towing speed, and g is the gravitational constant. The required length of pipe, L, for a release depth, H, is evaluated by

$$L = H/\cos\theta \qquad (2)$$

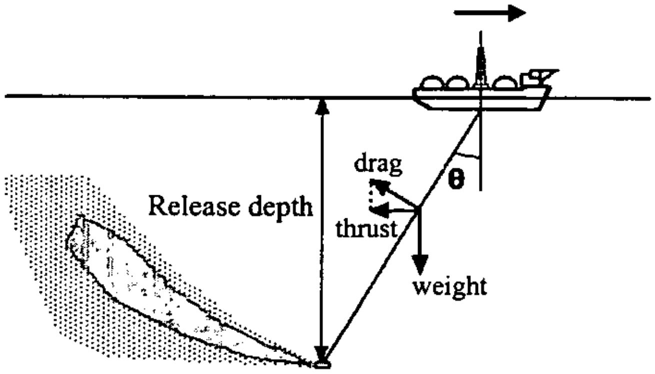


Fig.6 - Inclined pipe in the towing condition.

and the thrust force, P, needed to tow a pipe of the required length is evaluated by

$$P = \frac{1}{2}\rho_w C_D D (V\cos\theta)^2 L\cos\theta \tag{3}$$

When the outer diameter and wall thickness of pipe are assumed 0.20 m and 0.01 m, respectively, the inclination angle as a function of towing speed is shown in Fig.7, and the relation between towing speed and thrust force is shown in Fig.8. Finally, assuming that the ships are powered by diesel engines burning heavy fuel oil, the CO₂ emissions from ship engine during CO₂ injection are estimated as shown in Table 2.

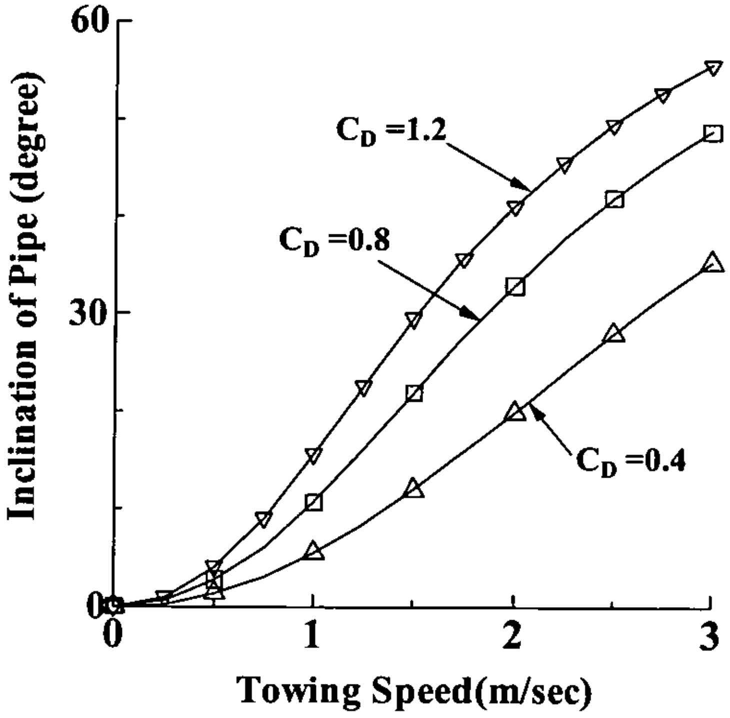


Fig.7 - Inclination angle of pipe as a function of towing speed.

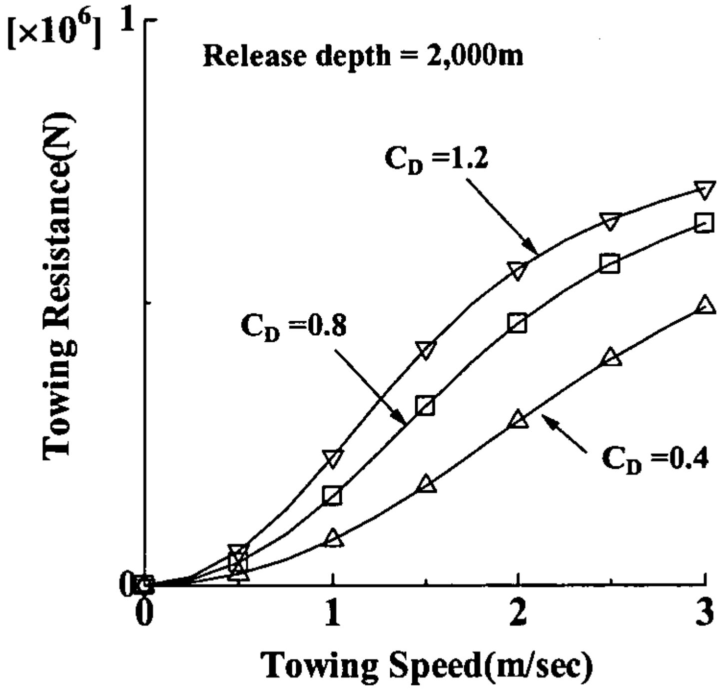


Fig.8 - Thrust force required to tow the pipe as a function of towing speed.

Table 2 - CO_2 emissions due to fuel consumption during CO_2 release.

Ship size [ton]	Release depth [m]	Drag coef.	Speed [m/sec]	Ship hull resistance [kN]	Towing pipe resistance [kN]	CO_2 emissions [ton/hour]
20,000	2,000	0.8	1.0	19	158	0.45
20,000	2,000	0.8	2.0	73	462	2.74
20,000	2,000	0.8	3.0	164	640	6.17

Regarding CO_2 injection, the detailed design has not yet been completed. It is assumed in this study that the pressure needed at the outlet of pump is 5 MPa, which is sufficient for keeping the CO_2 condition as a liquid phase when the temperature in pipe rises up to 15 to 20 degC due to the heat absorption from the surrounding water in the surface layer of the sea. Since the density of liquid CO_2 is nearly equal to that of seawater, the pressure of deep water such as 20 MPa is not necessary at the top of the pipe. Under the case study condition, 0.1 ton/sec in flow rate of liquid CO_2 (nearly equal to 0.1 m^3/sec), 70 % in total efficiency of pump, and 0.20 kg/kWh in fuel demand, then the CO_2 emission due to the electric power generation for CO_2 injection is estimated as 0.46 ton/hour.

3. Case study

3.1. Parameters

In order to assess the CO_2 emissions from the ocean storage system, case studies are carried out. The following parameters are fixed for convenience:

Amount of CO_2 to be transported; 20,000 ton/day
(equivalent to the output from 1,000 MW of coal-fired power plant)
Capacity of spare tanks for intermediate storage; 40,000 ton in total (2 days' amount)
Storage capacity of a CO_2 release ship; same with a CO_2 transport ship
Outer diameter and wall thickness of pipe; 0.2 m and 0.01m

The following parameters are considered, where the underlined values indicate the base case:

Transport distance (one way); 500 km, 1,000 km, 2,000 km
Carrying capacity of CO_2 transport ship; 10,000 ton, 20,000 ton, 30,000 ton
Service speed of CO_2 transport ship (full load-ballast); 15-16 knots, 18-19 knots
CO_2 release depth; 1,500 m, 2,000 m, 2,500 m
Ship speed during CO_2 release; 1.0 m/sec, 2.0 m/sec, 3.0 m/sec
Drag force coefficient of pipe; 0.4, 0.8, 1.2

To determine the number of ships and total capacity of intermediate storage tanks, the ship operating schedule should be planned considering the parameters. Fig.9 shows an example of the schedule plan for CO_2 transport ships in the case of 1,000 km transport by 20,000 ton ships of 15 knots in full load condition and 16 knots in ballast condition, and for the corresponding CO_2 release ships. Here, the loading and unloading time is assumed to be 12 hours in daytime, and the needed time period for CO_2 release is evaluated considering the CO_2 flow rate to be 0.1 ton/sec. It takes 4 days for one round trip of each CO_2 ship, and it takes 3 days for one cycle of operation of CO_2 release ship in this case.

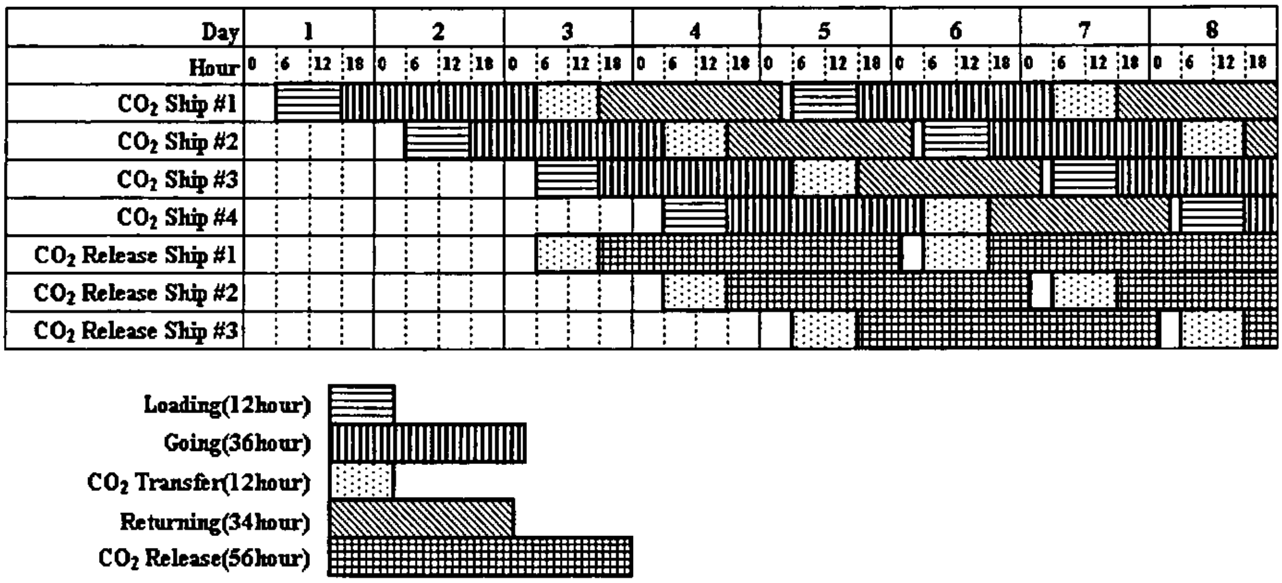


Fig.9 - Schedule plan for CO2 transport ships (1,000 km transport by 20,000 ton ship).

3.2. Results and discussions

Total CO_2 emission from the ocean storage system is estimated under the following assumptions:

1) Boil-off of the intermediate storage tanks occurs without ceasing from all tanks including the spare ones.
2) Boil-off of the transport ships occurs constantly excepting unloading time period.
3) Boil-off of the release ships occurs constantly excepting releasing time period.
4) CO_2 from transport ships' engines is exhausted during navigation.
5) CO_2 from release ships' engines is exhausted during CO_2 release with pipe towing.
6) CO_2 due to electric power generation for CO_2 injection is exhausted during CO_2 release.

The result for the base case study is shown in Table 3. The rate of total CO_2 emission to the transported CO_2 is 3.67 %. Roughly, a half emission is shared by ship transportation, and one third is shared by CO_2 release. Total amount of boil-off CO_2 from the system is 36 %, and CO_2 in exhaust of ships' engine is 60 %. CO_2 emission due to electric power generation for CO_2 injection is comparatively small.

Table 3 - CO_2 emissions from the ocean storage system in the base case study.

	Parameters		Consequences		CO_2 emission / transported CO_2	
Intermediate storage tank	-		Total capacity	60,000 ton	Boil-off	0.60 %
CO_2 transport ship	Distance	1,000 km	Number of ships	4	Boil-off	0.59%
	Ship size	20,000 ton	One round trip -loading/unloading -navigation -waiting	4 days -24 hrs -70 hrs - 2 hrs	Ship engine	1.47 %
	Speed	15-16 knots				
CO_2 release ship	Release depth	2,000 m	Ship size	20,000 ton	Boil-off	0.13%
			Number of ships	3	Ship engine	0.76 %
	Moving speed	2.0 m/sec	One cycle -receipt -CO_2 release -waiting	3 days -12 hrs -56 hrs - 4 hrs	Pump for CO_2 injection	0.12 %
	Drag coeff.	0.8				
					Total	3.67 %

Figs.10 to 15 show the results to investigate the influence of parameters. The horizontal axis is the rate of CO_2 emission from the system to the transported and injected CO_2, and the total emission is broken down to the components.

The influence of the transport distance is shown in Fig.10. The necessary number of transport ships depends strongly on the distance. Therefore, the difference appears in the component of boil-off and exhaust of engines of transport ships. Since the emission due to ship transportation shares a half in the base case, it can be said that the CO_2 emission from the system is sensitive to the transport distance. Quite long transportation, greater than ten thousands kilometers for example, seems to become insignificant from the point of 'CO_2 mitigation measures'.

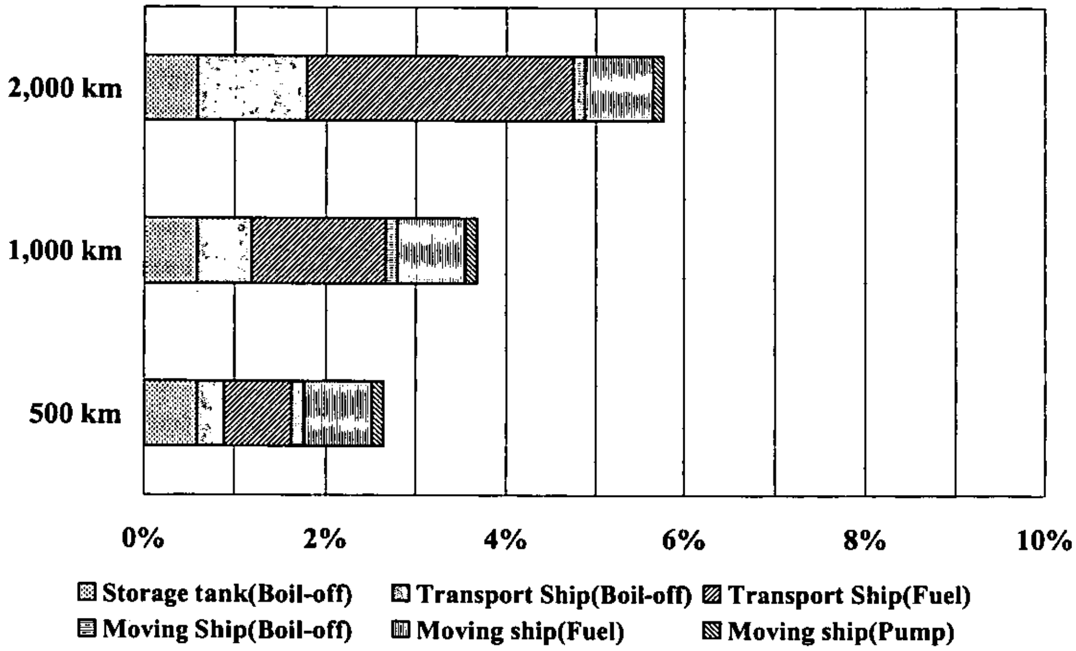


Fig.10 - Influence of transport distance on CO_2 emissions from ocean storage system.

Fig.11 shows the comparison of results in case the transport ship size is different. Using fewer ships of larger cargo capacity has an effect of scale merit on fuel consumption, but the interval of the loading of CO_2 at port becomes longer and the necessary capacity of the intermediate storage becomes larger, that raises the boil-off CO_2. In this study, the scale merit of CO_2 ship seems saturated between 20,000 ton and 30,000 ton.

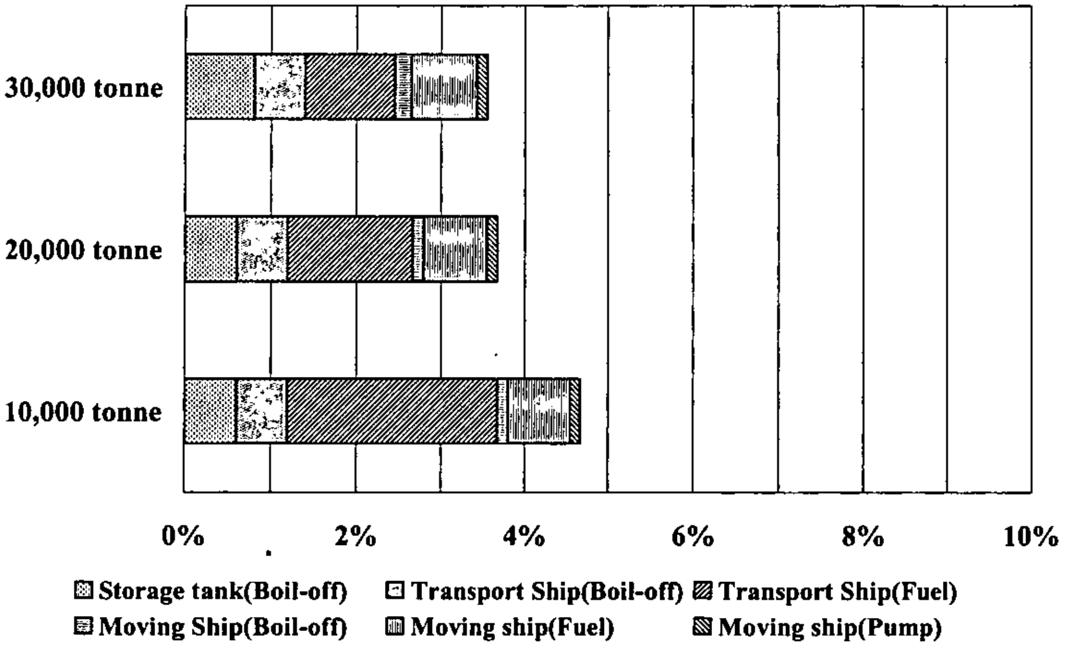


Fig.11 - Influence of transport ship size on CO_2 emissions from ocean storage system.

Fig.12 is the results in case the service speed of transport ship is different. Higher speed ships can offer lower capital costs because of a reduction of the necessary number of ships, and less boil-off CO_2. But it is a trade-off with higher running cost and more CO_2 exhaust due to the greater fuel consumptions. Regarding CO_2 emissions, it is resulted in this study that 15 knots is better than 18 knots.

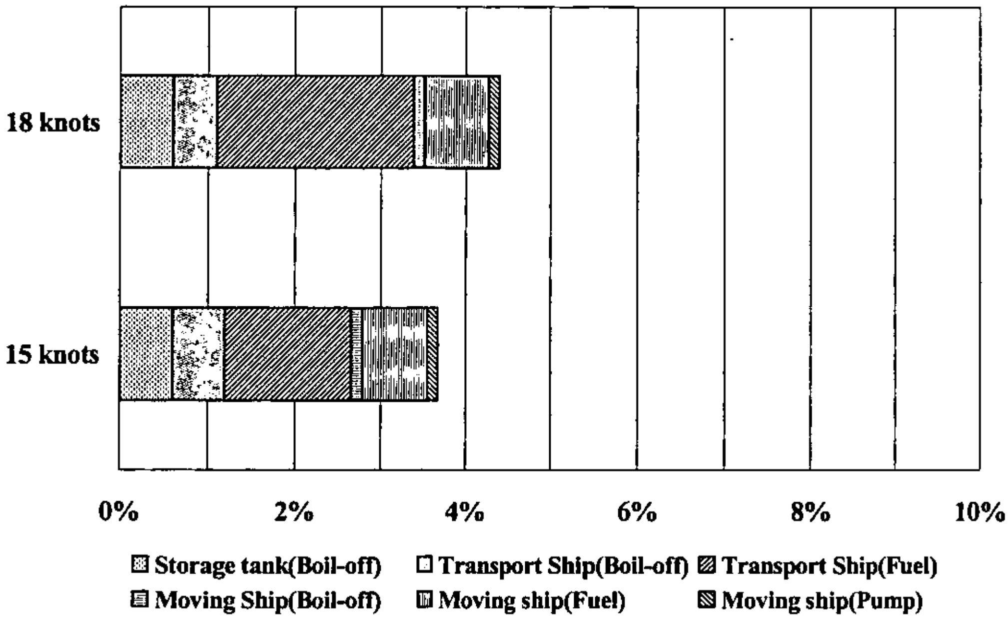


Fig.12 - Influence of service speed of transport ship on CO_2 emissions from ocean storage system.

Figs.13 and 14 show the comparison of results in case the CO_2 release depth and the drag force coefficient of pipe, C_D, are different, respectively. The difference is caused by exhaust of engine of release ships, because the necessary thrust becomes greater when the pipe is longer or C_D is greater. When the portion of the CO_2 exhaust from the release ships' engines is not so significant, the difference of total CO_2 emission is small anyway.

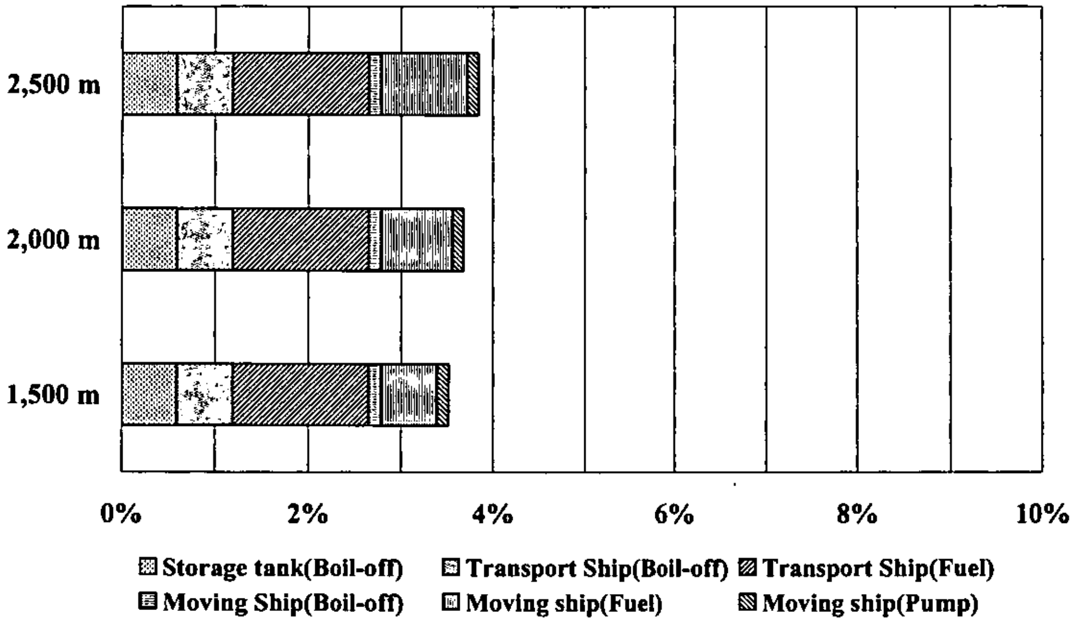


Fig.13 - Influence of CO_2 release depth on CO_2 emissions from ocean storage system.

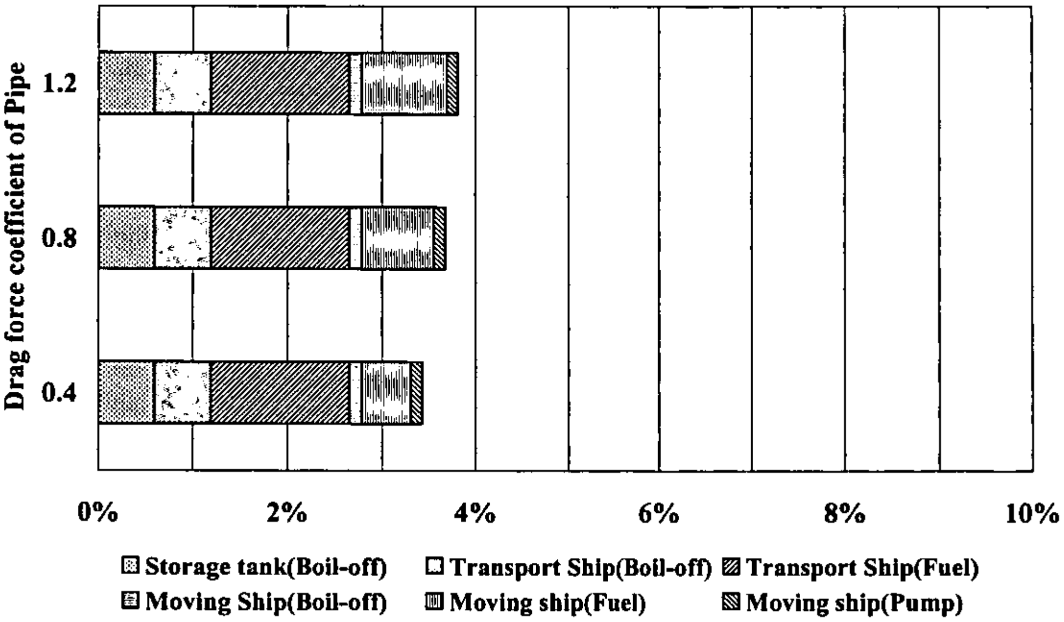


Fig.14 - Influence of drag force coefficient of pipe on CO_2 emissions from ocean storage system.

Finally, Fig.15 is the results in case that the moving ship speed during CO_2 release is different. This parameter also affects on the CO_2 exhaust from the release ships' engines due to the necessary thrust for pipe towing. The fluid resistance to the pipe is almost proportional to the square of towing speed and then the necessary horsepower of ship engine becomes proportional to the third power of the ship speed. When the moving ship speed is 3 m/sec, the portion of the CO_2 exhaust from the release ships' engines becomes significantly large. That is, it is found the required speed for CO_2 release is quite influential for the estimation of CO_2 emissions when it becomes high.

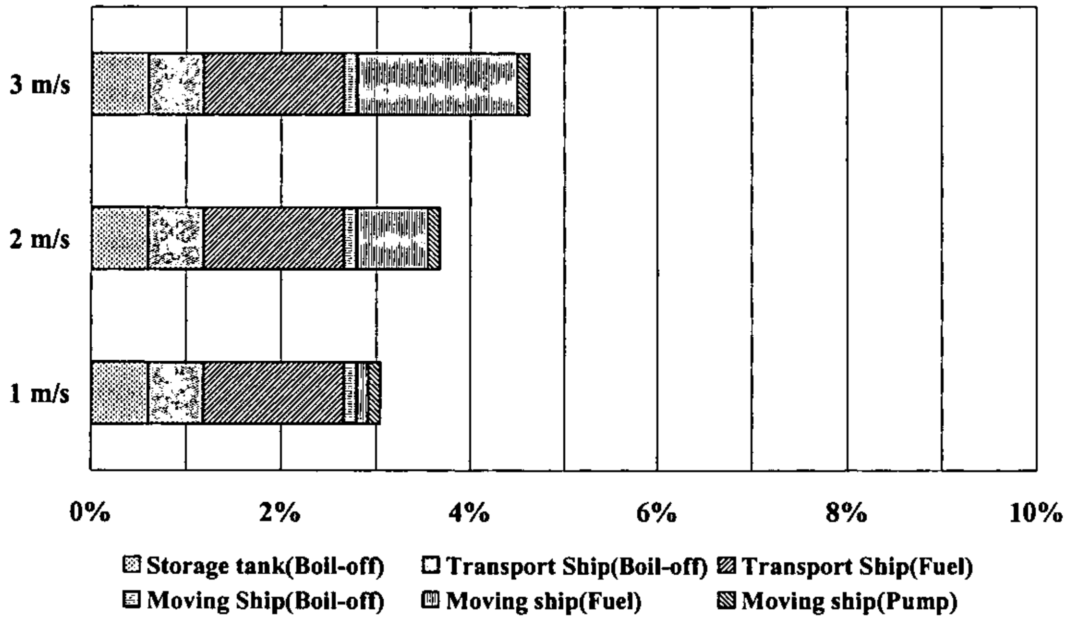


Fig.15 - Influence of moving ship speed on CO_2 emissions from ocean storage system.

4. Conclusions

CO_2 emissions from the ocean storage system are assessed, based on transport of 20,000 ton/day of CO_2. As the major CO_2 emissions, the boil-off from ships and shore-based storage tanks, the exhaust of ships' engines for navigation and pipe towing, and the exhaust of electric power generation for CO_2 injection into the ocean depths, are taken into account. The principal results of the parametric case studies are as follows:

1) The rate of CO_2 emissions from the system to the amount of transported CO_2 is estimated 3 to 6 % in a realistic scale.
2) In the base case, a half emission is shared by ship transportation and one third is shared by CO_2 release. Since the necessary number of CO_2 ships depends on the distance, the CO_2 emission from the system is sensitive to the transport distance.
3) In the base case, the boil-off CO_2 from the system accounts for 36 % of total emissions, and CO_2 in exhaust of ships' engines for navigation and pipe towing accounts for 60 %. CO_2 emission due to electric power generation for CO_2 injection is comparatively small.
4) CO_2 emission due to pipe towing is quite sensitive to the moving ship speed. The required speed for CO_2 release becomes an influential parameter for the estimation of CO_2 emissions when it is higher than 2 m/sec.

5. Acknowledgments

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REDUCING INHALATION INDUCED HEALTH RISKS

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Many industries including the maritime industry within the United States are now required to demonstrate that the residual risk from the industry's air pollutant emissions is insignificant. Residual risk is defined as the risk from the balance (left over) emissions after implementing the maximum achievable control technologies (MACT)) under Section 112(g), the air toxics program of the Clean Air Act.

Some industry sectors such as shipbuilding and ship repair yards have a large area over which process activities are distributed. Emissions take place from a combination of point, area, and volume sources distributed across the facility area. Air toxics emitted from these sources are of two categories, metals and organics. Carcinogenic and non-carcinogenic toxicity of these air toxics differ greatly from pollutant to pollutant. Some airborne pollutants, particularly metallic compounds such as manganese, cadmium, arsenic, nickel, and chromium have high inhalation induced toxicity. A small error in the analysis can have a big impact on the health effect and the control costs which demand rational scientific methods of health risk assessment.

Understanding the source, meteorological, and dispersion parameters will help evaluate and reduce the impact on the ambient air quality of the impacted region correctly. This will also help reduce the health risks to the community. This paper presents a discussion of specific parameters and their effects on the ambient air quality as well as the health risks.

1. Introduction

Environmental health risk is defined as the likelihood that an adverse effect will occur in a chemical exposure situation. Exposure to higher concentrations of harmful pollutants for longer durations causes more serious health effects and increased risk. Exposure pathways of pollutants to the human body are (a) inhalation (through air), (b) ingestion (consumption – water, land/soil, and food chain), and (c) dermal contact (air, water, swimming, etc). Of these routes of exposure, inhalation contributes to about 70% of the exposure [1].

The United States Environmental Protection Agency (USEPA) classifies health risks due to airborne pollutants as cancer and noncancer risks based on the type of toxicity and exposure levels. Residual risk is defined as the risk from the balance (left over) emissions after implementing the maximum achievable control technologies (MACT) under Section 112(g), the air toxics program of the Clean Air Act (CAA). As part of rising concern from federal and state regulatory agencies, industries including shipbuilding and ship repair sector within the United States are now required to demonstrate that the residual risk from the industry's air pollutant emissions is insignificant. Under the CAA, the Congress has listed 189 hazardous air pollutants (HAP). HAPs have different levels of toxicity (carcinogenic and noncarcinogenic), and their ambient concentrations vary spatially and temporally. The USEPA has identified urban areas (hot spots) with high ambient concentrations of HAPs that pose greater inhalation induced health risks.

Important sources of air pollution are industries, motor vehicles, smoking and a few natural sources. Airborne metals (Mn, Cd, As, Ni, and Cr) and metallic compounds have high inhalation induced toxicities as shown in Table 1 [2].

Table 1 - Cancer and Noncancer Inhalation Toxicity Ratings by USEPA.

Air pollutant	**Cancer Risk Factor, Unit Risk Estimate (URE: per $\mu g/m^3$)**	**Noncancer Risk Factor, Reference Concentration (RfC: mg/m^3)**	**Target Organ for Chronic Critical Effect (Non-Cancer)**
	Higher the URE, higher the pollutant carcinogenicity	**Lower the RfC, higher the pollutant noncarcinogenic risk**	
Chromium (Cr) compounds	1.2 E-02 (1000 times Pb URE)	1 E-04 (15 times Pb RfC)	Lung injury in rats
Nickel (Ni)	4.8 E-04 (40 times Pb URE)	2 E-04 (7.5 times Pb RfC)	Respiratory track inflammation in rats
Manganese compounds		5 E-05 (30 times Pb RfC)	Central nervous system (CNS)
Lead (Pb) compounds	1.2 E-05	1.5 E-03	Central nervous system (CNS)
Cadmium (Cd) compounds	1.8 E-03 (150 times Pb URE)	2 E-05 (0.075 times Pb RfC)	Kidney

Source: Health Effects Information Used in Cancer and Non-Cancer Risk Characterization for the National Air Toxics Assessment (NATA) 1996 National Scale Assessment (EPA).

Reduction in emissions from the above mentioned sources (overall quantities as well as specific compounds with high toxicity) will reduce their impact on human health. Health risks can be accurately estimated by effectively employing risk assessment methods which include: (a) emission quantification and characterization, (b) ambient concentration estimation (through direct measurement or dispersion modeling), (c) exposure assessment, and (d) integrating exposure data and toxicity data. Errors in health risk assessment can be minimized by reducing uncertainties in determining ambient concentrations and exposure levels. This paper focuses on reducing uncertainties in inhalation induced risk assessment methods through accurate emissions estimation and dispersion modeling.

2. Current Risk Assessment Methods

Risk due to chronic exposure is assessed by estimating carcinogenic and noncarcinogenic potential of a pollutant. Most of the currently available risk assessment methods use inhalation exposure levels to estimate the risk. These models assume that a person is breathing the ambient air and use ambient concentrations of pollutants to determine exposure levels. Thus, determining true pollutant concentrations in ambient air is significant in health risk assessment.

Cancer risk is defined as follows:

$$\begin{aligned} Cancer\ Risk &= CDI\ X\ SF && \rightarrow low\ risk\ (< 0.000001) \\ &= 1 - e^{-(CDI\ X\ SF)} && \rightarrow high\ risk\ (\geq 0.000001) \qquad (1) \end{aligned}$$

Where, Risk = probability of occurrence of cancer over a life time

CDI= chronic daily intake over a 70-year lifetime, (mg/kg.d)
SF = slope factor, $(mg/kg.d)^{-1}$

Inhalation induced cancer risk can therefore be calculated from the above formula using exposure concentrations ($\mu g/m^3$) as chronic daily intake and unit risk estimate, URE ($1/\mu g/m^3$) as slope factor.

Non-cancer risk indicated by hazard quotient or hazard index (HQ/HI) is the ratio of chronic daily intake to a reference dose level over an assumed average time period.

$$Non\text{-}cancer\ Risk\ (HQ/HI) = CDI / RfD \quad (2)$$

Where, CDI = chronic daily intake over a 70-year lifetime, (mg/kg.d)
RfD = reference dose, (mg/kg.d)

Inhalation induced noncancer risk can be calculated from the above formula using exposure concentrations (mg/m^3) as chronic daily intake and reference concentration, RfC (mg/m^3) as reference dose [1]. The various components in the risk assessment hierarchy are shown in Figure 1.

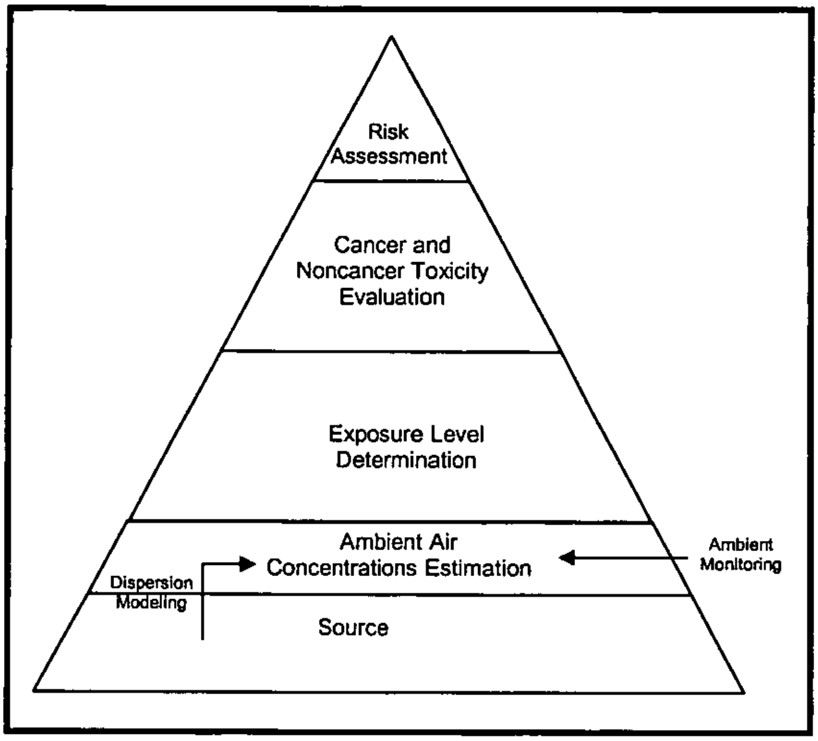

Figure 1 - Risk Assessment Hierarchy.

3. Determination of Ambient Concentration

The concentrations of pollutants released from sources at ambient locations can be determined using either direct monitoring or modeling. The first method involves establishing monitoring stations at various locations around a source and monitoring pollutant concentrations by sampling and analysis. The second approach involves atmospheric dispersion modeling using suitable dispersion models. Downstream concentrations can be calculated using these models from known source concentrations and meteorological conditions [3].

Gaussian equation for downstream concentration ($\mu g/m^3$) estimation at a location (x,y,z) is:

$$C_{(x,y,z)} = \frac{Q}{2\pi\sigma_y\sigma_z U}\exp\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-0.5\left(\frac{z-H}{\sigma_z}\right)^2\right]+\exp\left[-0.5\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\} \tag{3}$$

Where,
Q = emission rate (μg/sec)
$\sigma_y = ax^b$
$\sigma_z = cx^d + f$
a,b,c,d, and f are constants based on atmospheric stability conditions
U = wind velocity (m/sec)
H = effective stack height (m).

State agencies within the United States typically use Continuous Ambient Monitoring Systems (CAMS) to estimate particulates, metals, organics and other pollutant forms in ambient air. Establishing monitoring stations can be advantageous since they give long term ambient pollutant concentrations for corresponding regions. But establishing and operating numerous stations can be difficult, cumbersome and expensive. On the other hand, dispersion modeling can be a powerful tool for concentration prediction at much lesser costs compared to field measurements. However, the prediction accuracy of such models largely depends on selecting the appropriate model and precisely supplying input variables.

4. Critical Parameters Affecting Ambient Concentrations and Inhalation Induced Risk

Emissions, both quantities and characteristics, vary by process, process conditions, and raw material thus influencing the ambient concentrations. Emission sources can be classified broadly as: (a) point sources, (b) area sources, and (c) volume sources. Meteorological conditions determine the transport and dispersion of pollutants from source to ambient air. Ambient concentrations depend on the following parameters:

- Source characteristics
    - Source type (point, area, and volume)
    - Source location
    - Emission height
    - Stack diameter
    - Stack gas velocity
    - Exit gas temperature
    - Emission rate and characteristics
    - Building height and width

- Meteorological Conditions
    - Wind speed
    - Atmospheric stability
    - Wind direction
    - Ambient temperature
    - Cloud cover

- Others
    - Land use
    - Terrain effects.

Ambient concentrations decrease with increase in emission height, exit gas velocity, exit gas temperature, wind velocity, source separation. Whereas decrease in stack diameter for the same volumetric flow rate will result in increased gas velocity and plume rise thus reduced ambient concentrations. Considering the interrelationships among processes, emissions, exposures, dispersion, and inhalation risk, it is important to have comprehensive knowledge of the above aspects.

5. Methods to Reduce Ambient Concentrations / Inhalation Induced Risk

Inhalation induced health risk can be reduced by (a) reducing emissions and (b) identifying critical parameters that affect pollutant levels in ambient air. Also, it is important to assess health risks correctly by using rational methods from source estimation to risk calculation. Source emissions can be reduces by:

- Understanding consumption, waste generation, and emission potential
- Identifying source/material/process changes including BMPs that will reduce air emissions.

Estimating true ambient concentration using dispersion modeling is a two step process; (1) correctly estimating source strength either through source measurement or through emissions modeling, and (2) adopting suitable dispersion models to truly represent actual emission scenarios. Often, erroneous predictions of ambient concentrations cause confusion in health risk assessment and decision making. In order to prevent this road block in risk management, uncertainty involved should be eliminated which is the focus of the paper. The level of uncertainty is illustrated using a test case that involves both, emission estimation and dispersion calculations.

5.1. Test Study 1: Evaluation of Cr(VI) Exposure Levels in Maritime Industry

A study was conducted by the University of New Orleans (UNO) to evaluate worker exposure to hexavalent chromium (Cr(VI)) from various welding processes. The research suggests that Cr(VI) constitutes 1.8% of total chromium levels for flux-cored arc welding (FCAW) and 18.3% for shielded metal arc welding (SMAW) [4]. On an average, hexavalent chromium constituted approximately 2.5% of the total chromium considering several other welding processes. Though this "Cr(VI) to total chromium" ratio was obtained from worker exposure monitoring, the same ratio is assumed to be true for ambient conditions.

5.2. Test Study 2: Eliminating Uncertainties in Ambient Concentration Estimations through Dispersion Modeling

Type of emission source (stack, area, and volume) and source separation are important from a dispersion modeling point of view. In this example, a typical industry with ten emission sources was assumed with varying source separations. AUSPLUME, a dispersion model developed by Environmental Protection Authority, Victoria, Australia was used to analyze the impact of varying source types and separations. In one scenario, all emissions were assumed from a single stack or a volume source and in another scenario, source separations were considered. For example, in a shipyard setting, emission sources such as blast shop, paint shop, dry dock and others are distributed over a large area. In this study, emissions were modeled from assumed stack (20 ft high) and volume sources (50 m x 10 m source with zero height). An emission rate of 1 g/s was assumed for the entire industry. Thus, when multiple sources were modeled, emission rate for each source was 0.1 g/s (uniformly distributed among 10 sources.) Six modeling runs were performed to study the effect of single and multiple sources when sources were assumed to be 50 m apart and 100 m apart. Artificial meteorological data METSAMP (wind from West to East; hourly data for 11 days) was used for all the six runs. Thus, the modeling scenarios were:

Run 1: All emissions from a single stack
Run 2: All emissions from a single volume source
Run 3: Emissions from ten stacks, 50 m apart
Run 4: Emissions from ten volume sources, 50 m apart
Run 5: Emissions from ten stacks, 100 m apart
Run 6: Emissions from ten volume sources, 100 m apart

Table 2 shows the input matrix of the test runs. AUSPLUME was first run for these scenarios with an emission rate of 1 g/s for the industry. To study the effect of reduced Cr (VI) emissions on ambient concentrations, emissions from test study 1 were integrated with the model run results. Results of the test runs are summarized in Table 3.

Table 2 - Input Matrix for Dispersion Modelling.

Run No.	**Stack Dia.**	**Stack Temp.**	**Exit Gas**	**Emission Height**	**Emission Rate**	**No. of Sources**	**Source Type**	**Vertical Spread**	**Horizontal Spread**	**Distance**	**Wind Dir.**	**Receptor**
	(m)	**(Deg. K)**	**(m/s)**	**(m)**	**(g/s)**			**(m)**	**(m)**	**(m)**		**(m)**
1	1	298	0.1	6.1	1	1	Stack	NA	NA	0	West	x=0-500
2	1	298	0.1	0	1	1	Volume	10	50	0	West	x=0-500
3	1	298	0.1	6.1	0.1	10	Stack	NA	NA	50	West	x=0-500
4	1	298	0.1	0	0.1	10	Volume	10	50	50	West	x=0-500
5	1	298	0.1	6.1	0.1	10	Stack	NA	NA	100	West	x=0-500
6	1	298	0.1	0	0.1	10	Volume	10	50	100	West	x=0-500

Table 3 - Model Results Summary.

Run No	**Model Run Description**	**Ambient Concentration ($\mu g/m^3$)**				
		100m	**200m**	**300m**	**400m**	**500m**
1	Stack	372	123	63	39	27
2	Volume	87	47	30	22	17
3	10 Stacks – 50 m apart	179	74	46	32	24
4	10 Volume – 50 m apart	77	42	28	21	16
5	10 Stack – 100 m apart	42	61	31	22	17
6	10 Volume – 100 m apart	**19**	**31**	**22**	**17**	**13**
Reduction Factor at Various Receptors		**19.58**	**3.97**	**2.86**	**2.29**	**2.08**
Reduction Factor, if Cr(VI) = 0.025Cr		**40**	**40**	**40**	**40**	**40**
Combined Reduction Factor		**783**	**159**	**115**	**92**	**83**

It is clear from the above table that ambient concentrations are lower when emissions are distributed over multiple sources as compared to a single source. The above examples illustrate that by using an appropriate emission scenario and carefully furnishing exact model inputs, uncertainties in ambient concentrations can be minimized. This will facilitate precise quantification of inhalation induced health risk.

6. Conclusions

The test case presented in this paper shows that even small errors in emission rate and modeling scenarios can result in faulty health risk estimates. Example used for a shipyard setting indicated a 700 fold increase in health risk estimate from true value. With increasing pressure from regulatory agencies, industries are forced to invest on air pollution control devices to reduce residual risk. However, inappropriate health risk tools and procedures will lead to misappropriated funds that may defeat the purpose.

This paper emphasizes the need for reducing uncertainties from health risk assessment procedures. By fine tuning the input variables and assumptions from actual field conditions and past experience, the risk estimates will become more reliable. Hence an integrated approach of emission quantification, coupled with accurate atmospheric dispersion modeling, actual health risks can be better assessed. Detailed technical discussions among industry personnel, regulators, and modeling experts often eliminate misconceptions about processes and emission scenarios. This will aid industries as well as regulatory agencies in drawing common conclusions which will expedite health risk reduction initiatives.

7. References

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SELECTED TOPICS OF ENVIRONMENTAL IMPACTS OF FAST PODDED ROPAX VESSELS

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This paper, based on investigations done within the 5 FP project OPTIPOD, presents selected environmental impacts, exerted by a fast podded Ropax. These ship types, which meet strong requirements concerning passenger ships, distinguished also by very high installed powers and service speeds, are interesting subjects for different studies. That is why, CTO has studied, apart from standard hydrodynamic performances, such phenomena as wash waves and slipstream wash generated by fast Ropax, sailing in restricted waters up to critical speed levels. Moreover, vibration and noise risks were investigated analytically and by series of respective, comparative tests in a cavitation tunnel. Safety matters were analyzed throughout wide scope of maneuverability tests not only by use of free running Ropax models on a lake but respective, captive tests as well.

The pod propulsion, recently applied widely on variety of ship types, introduces a new quality in many aspects, being a step towards fully electric ship. Being distinguished by many natural features, its environmental impacts belong to the most important matters to be known.

In order to recognize deeper quantitative influences of pods, series of respective tests were carried out with use of adequate scale models of both classical and podded Ropaxes, designed within the project consortium, according to state of the art.

In the wash waves case, the received results were related to bare hull performances. Majority of tests, concerning environmental impacts, were done in model basins and cavitation tunnel of CTO but course keeping and steerability tests were carried out in its lake facilities.

1. Introduction

Pod propulsors have been successfully introduced in marine applications for recent 20 years. This tendency results from natural features of this propulsion, combining advantages of electric power plant, shaft lineless power transmission and vectoring thrust of pod units. Usually, there were individual approaches of owners and shipyards. The worldwide publicity and new stimulations were given by their applications on cruise vessels. The appearing versatile feedbacks, from first voyages, were the greatest motivations to organize a complex scientific approach to recognize, in the ordered way, all natural advantages and drawbacks of this kind of propulsion. It has been also possible under auspices of 5th Framework Program of the European Union. The resulting OPTIPOD project [1], grouping 15 European partners, was executed within years from 2000 through 2002. A project consortium, involving shipowners, shipyards and researchers from the whole Europe, had taken up to investigate and analyze the most important topics including hydro mechanical, operational, structural, safety, economic and environmental aspects of pod propulsors applications. It was done as case studies, of four representing state of the art ship types, in range from an auxiliary vessel throughout a typical cargo vessel and fast Ropax, up to a respective cruise vessel.

Majority of these ship types were propelled by twin pods but the cargo vessel which was using only one pod unit. Also the test programs were different, being suited to the complexity of a given ship.

That is why the Ropax vessel was a subject of the most pronounced test program due to highest service speeds, most powerful pod propulsors and great number of people on board.

The main expectations, connected with project completion, concerned respective guidelines, which could be used by shipowners, shipyards and research institutions.

Environmental matters belonged to the most important ones, accounting for a lot of novel solutions, accompanying this new kind of ship propulsion. They were investigated as environmental impacts towards:

- **Seaways and their surroundings**, aiming at hull generated wash waves and podded propeller generated slipstream wash,
- **People on board,** assessing the risk of vibrations and noise together with resulting accelerations in waves,
- **Ship safety,** embracing structural and hydrodynamic integrity aspects together with essential operational matters.

Having in mind the wide scope and depth of investigated subjects, related to limited frameworks of this paper, there will be presented subsequently the selected but most attractive results of hydrodynamic tests and analyses, directly touching environmental sustainability.

2. Subject of investigations

As it was mentioned above, the podded Ropax vessel was a subject of the most pronounced investigations. It was designed according to state of the art by a consortium member - Deltamarin, being accompanied by the nearly adequate classical alternative, propelled by fixed pitch screws on shaftlines [1].

Designs of pod units were delivered by Rolls-Royce Kamewa in two stages. The initial ones were of a solid state type, being supplemented by flapped pods during project execution [9].

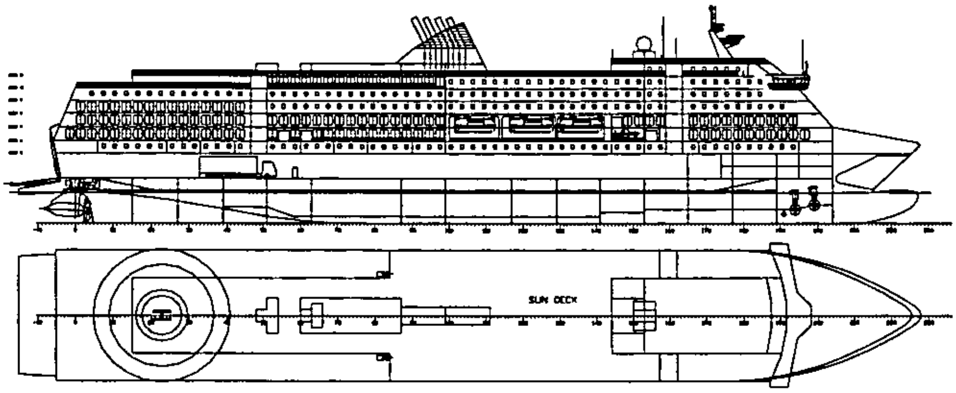


Fig. 1 - General plan of podded Ropax.

2.1. Main ship characteristics

- Hull dimensions and its shape:
  L_{OL} = 194.4.0 m L_{BP} = 172.2 m B = 28.40 m T_d = 6.60 m C_B = 0.58 LCB = -2.61 %
  Its geometry is presented in figure nr 2.

- Power plant data:
  The both Ropax vessels had as main power source four Wartsila 18V38 engines , each of them developing 13050 kW of MCR. Service speed 28 knots.
- Propulsors:
  Two propulsor system have been designed:
    - two standard, Mermaid type , pod propulsors [9],
    - two classical fixed pitch propellers with shaftlines, bosses and struts.

2.2. Visualization of hull shape and tested propulsor types

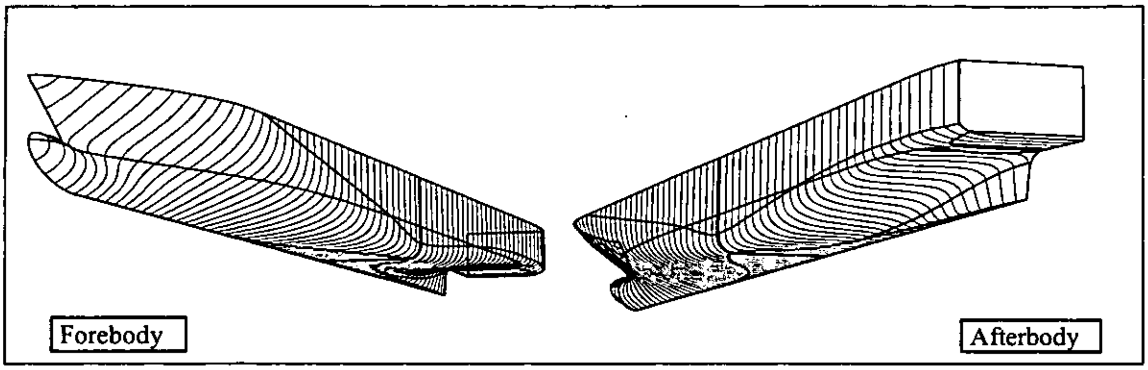


Fig. 2 – Izometric views of bare hull shape.

a) Standard, Mermaid type, pod unit *b) Appendages of classical Ropax*

Fig. 3 – Kinds of propulsors.

3. Environmental impacts towards seaways and their surroundings

3.1. Wash waves

Wash waves in the near field , are generally considered as derivatives of a hull shape, ship load state, water depth and ship speed. Presently, they can be easily depicted by means of typical CFD tools-see Fig.4 [8]. Being radiated into far fields, their structure is getting dependent on seaway bottom configurations. These waves can be classified by the depth related Froude number, which is the ratio of the ship speed to the maximum of a gravity wave can travel in a given water depth. At lower depth Froude numbers, corresponding with subcritical ship speeds, a typical wash pattern contains the both divergent and transverse waves. On critical speed levels, the influence of the limited water depth is getting more visible and the ship speed is equal to the speed of a depth limited wave. In such cases, transverse waves disappear because they can not so fast to keep up with the ship. As an effect, very long waves with small amplitudes carry big energy to littoral zones causing versatile, negative, effects: biological life is destroyed in shallow waters and their littoral vicinities, resulting in dead zones appearance.

- pleasure boats are in a permanent risk of capsizing or grounding on submerged banks in troughs of long period waves;
- overtaken and mooring ships are exposed to unexpected and heavy motions;
- people on beaches can be trapped against sea walls and knocked off their feet what diminishes coastal activities like fishing and walking;
- also docksides and other coastal constructions are put on risk of destruction.

That is why fast vessels, sailing frequently in restricted waters, are a subject of checking analyses from the point of view of potential risks connected with such zones. Since the podded vessels demand special afterbody configurations for optimum pod locations, podded Ropax vessels should be examined in scope of potential routes. Having in mind that there are no sufficient criteria for such verdicts, majority of novel vessels are assessed by means of comparative model tests with classical, adequate and commonly acceptable solutions.

The Ropax vessel within the OPTIPOD project was investigated in the same way. It means the similar runs were carried out with a bare hull and supplemented by similar measurements with a hull model, propelled by podded and classical screw propulsors. In order to have more data these parallel runs were performed at two water depths so as to get respective data results for one depth related Froude numbers and two these length related factors.

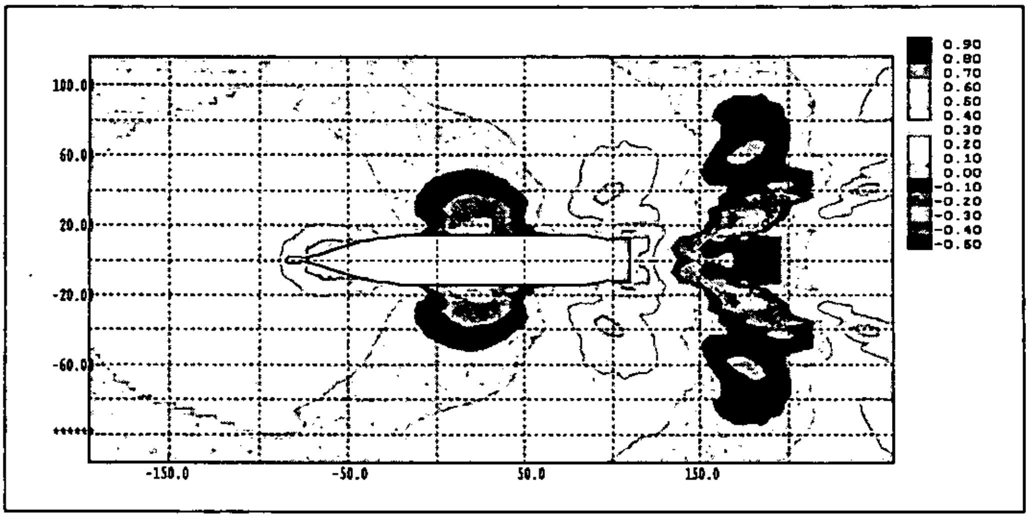


Fig. 4 – Wave pattern received by means of CFD tool.

Measurements of wash waves were carried out in the medium size model basin of CTO, in conditions of near field. A hull model was towed asymmetrically, in respect to basin CL, on two water levels 0.35m and 0.7 m. Five vertical wave probes, of inductive type, were installed at left side of the model, in equal spaces. Wave profiles were measured simultaneously and each time they were started 1.5 model length before probes transverse plane. Moreover each run was recorded on a video tape. All results have been presented in a graphical form as the so called wave cuts for each probe in time domain. They were divided in groups dependent on the water depth and depth related Froude numbers.

There were done due comparisons aiming to assess the influence of a propulsor type in respect to bare hull results. Moreover, both propulsors were compared between themselves in scope of generated wash waves [3]. Respective examples are given in figures nr 5, 6 and 7.

- Comparison of wave profiles received for bare hull and with pod propulsors at smaller water depth (0.35m) – corresponding ship speed $V_S = 24$ knots.

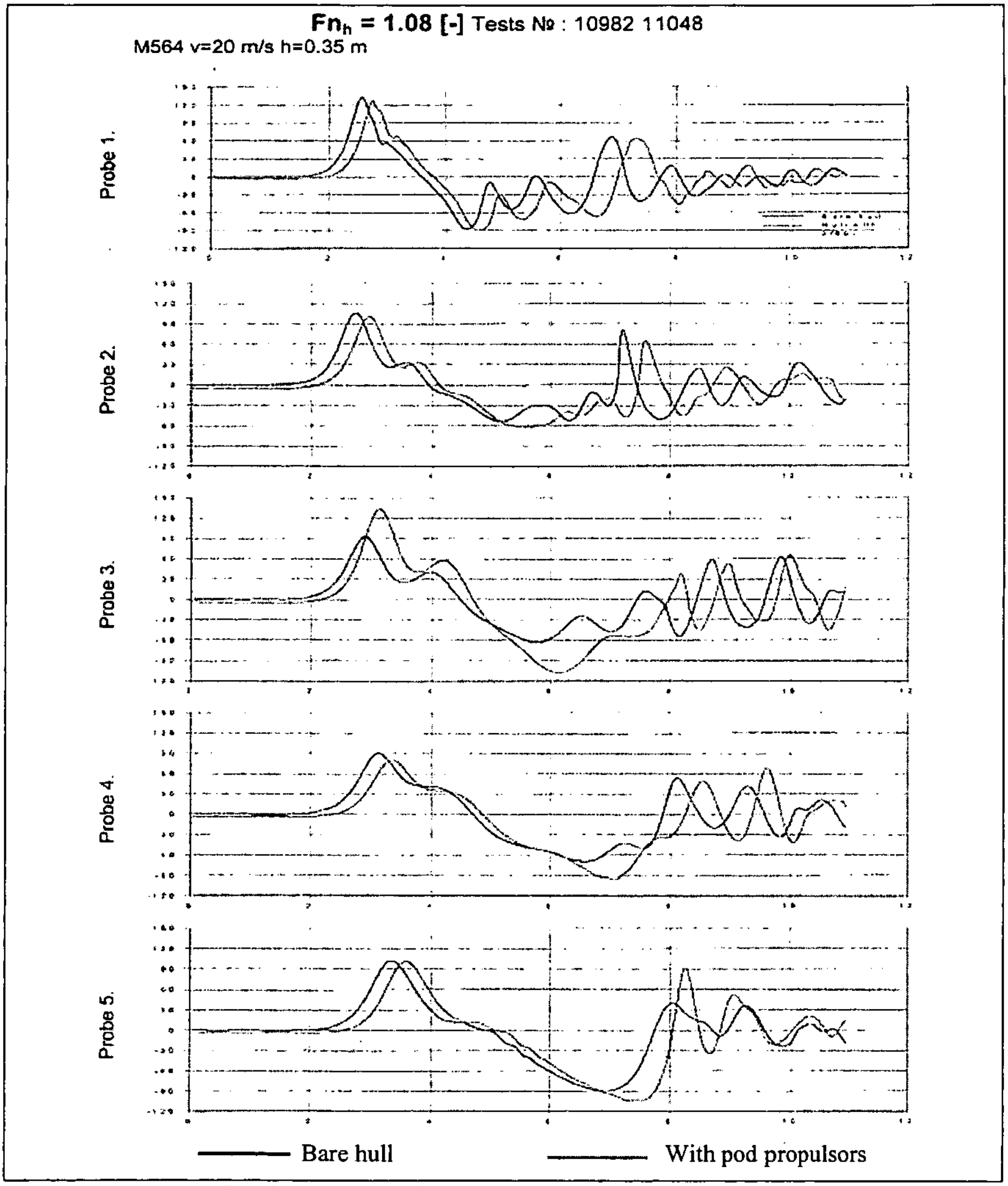


Fig. 5 – Wave cuts for bare hull and with pod propulsors.

- Comparison of wave profiles received for bare hull and with classical screw propulsors at smaller water depth (0.35m) – corresponding ship speed V_S = 24 knots.

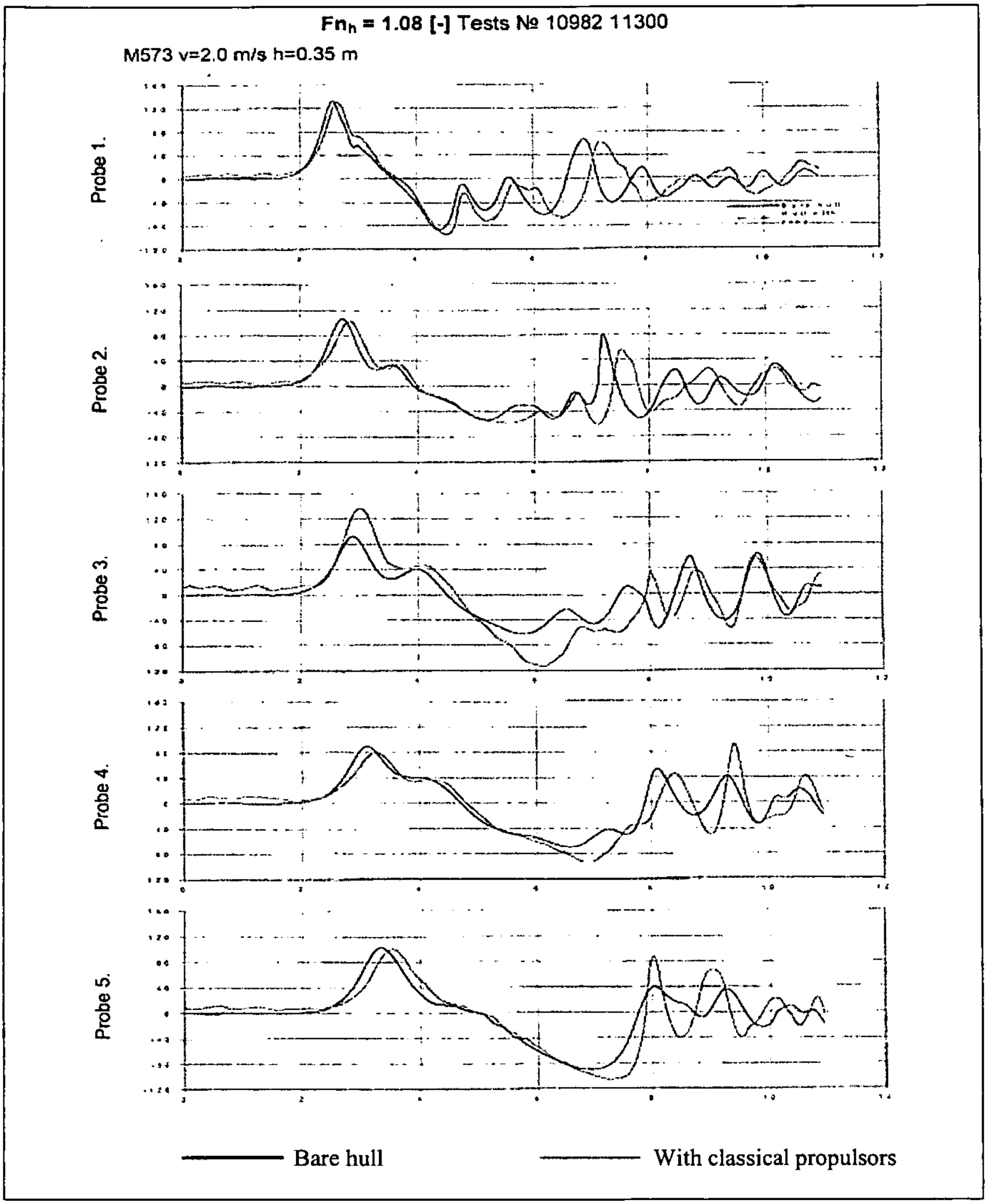


Fig. 6 – Wave cuts for bare hull and with classical screw propulsors.

- Comparison of wave profiles received for propelled both podded and classical Ropax vessels at smaller water depth (0.35m) – corresponding ship speed $V_S = 24$ knots.

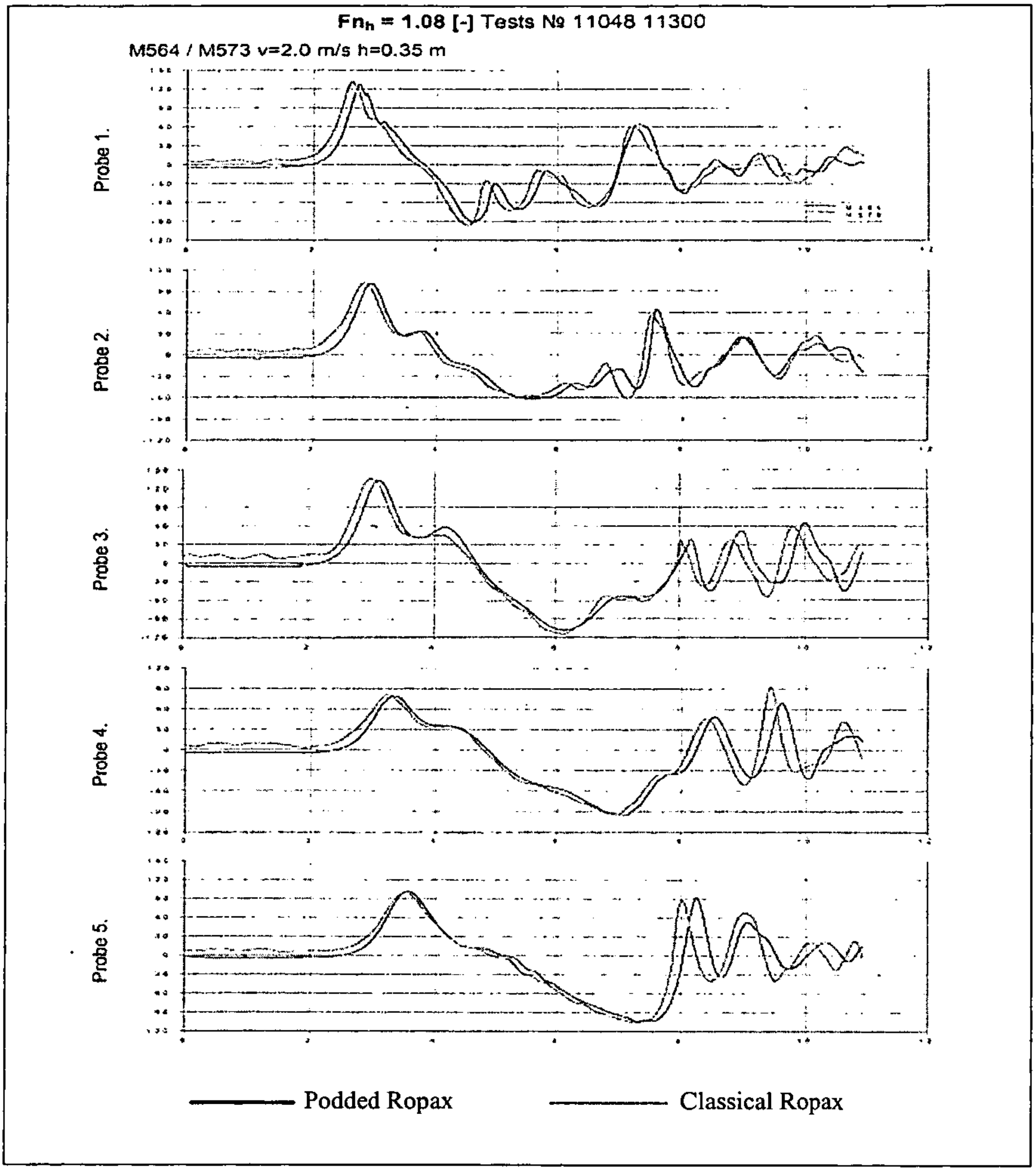


Fig. 7 – Wave cuts for podded and classical Ropax versions.

3.2. Slipstream wash

Slipstream wash, generated by pod propulsors, is especially important for analyses in case of pulling pods where it interacts with pod bodies. Such screw arrangements result in a very uniform water inflow to propellers in design conditions. However, the presence of nacelles and struts complicates widely the slipstream along these bodies. Since such displacement bodies can not have only negative effects, pushing more streamed waters to the seaway bottom but certain positive effects throughout improving the flow along ship afterbody as well. That is why it is necessary to recognize this phenomenon to get enough data for reliable assessments and possible modifications. Usually it is investigated, similarly to the wash waves, in the comparative way.

Respective measurements can be carried out: by means of Particle Image Velocimetry (PIV) technology around the pod body, by measurements of wake structures behind pod units and as measurements of pressures exerted to precisely modeled bottom below working podded propellers. The PIV technology was chosen by partners from Newcastle University and is presented in [6]. CTO has conducted measurements of effective wakes in two planes, located few diameters behind podded propellers and one diameter below the base plane, in modeled design conditions [4].

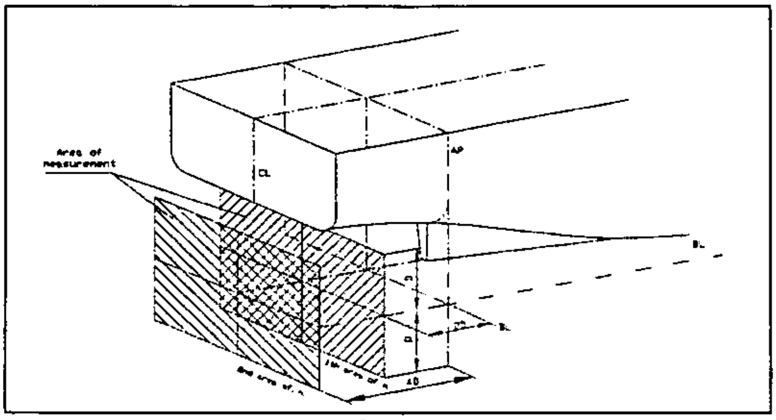


Fig. 8 – Location of measurement planes.

Exemplary results of such measurements, depicting axial and transverse slipstream wash components at one plane (x = - 0.56m), are presented in figures nr 9 and 10.

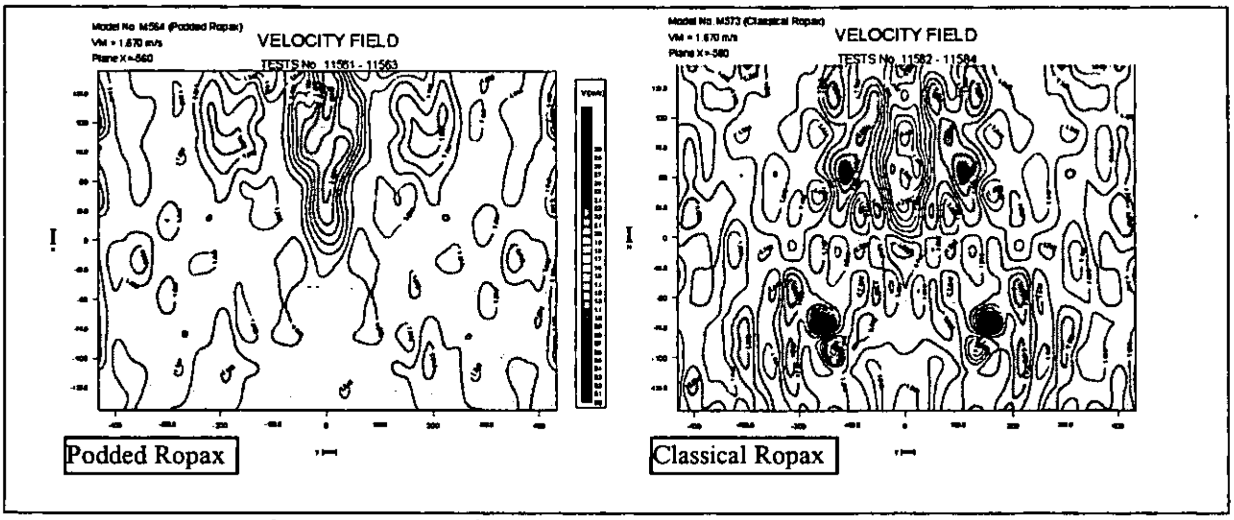
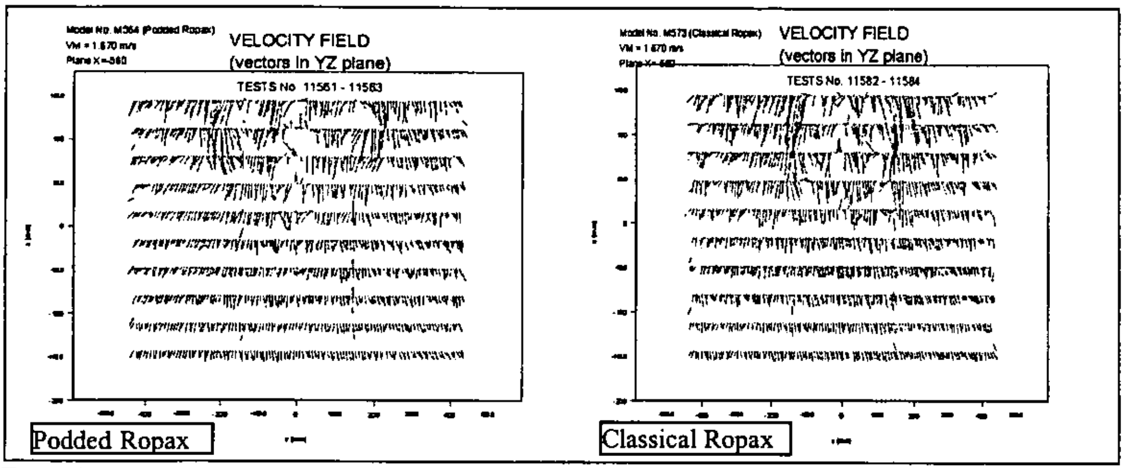


Fig. 9 – Axial components of slipstream for podded and classical Ropax vessels.



Podded Ropax Classical Ropax

Fig. 10 - Transverse components of slipstream for podded and classical Ropax versions.

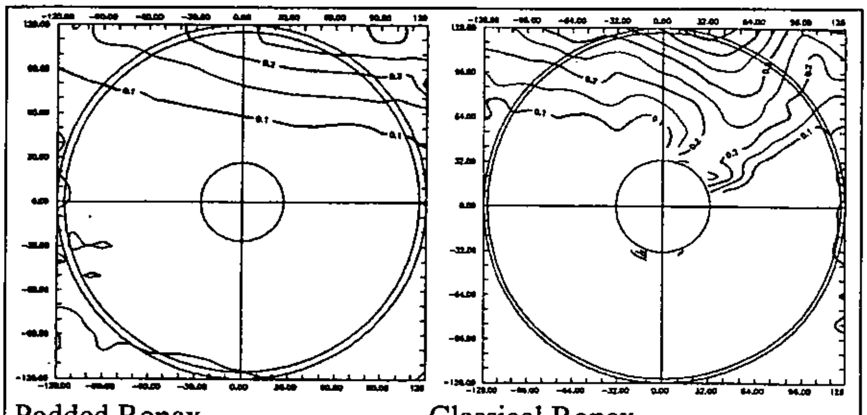
4. Impacts on people on board – risk of propulsor induced vibrations

Screw propulsors can be a source of excessive vibrations due to their work in non-uniform wake fields. There are not fixed quantitative limits for such phenomena, however each situation can be assessed by pressure pulses levels which are permissible levels for a given ship type. The most stringent requirements are for passenger vessels and their values on the level of 2 – 3 kPa is considered as acceptable. In case of pod propulsors, pulling twin pod solutions are privileged, having evidently more homogeneous water inflows to propeller disk planes. Situation is slightly worse when pods are forced for yaw motions due to poor course stability at high speeds.

The pod units, elaborated within the OPTIPOD project, were verified twofold: by means of due calculations of fluctuating pressure pulses and bearing forces and moments [7], being supplemented by observations of cavitation range and pressure pulses measurements in a cavitation tunnel. The received results were related to adequate performances of the classical Ropax.

The both groups of tests were carried out in the CTO cavitation tunnel. The propeller of the Ropax classical version was tested at its design point. The podded propeller was additionally tested for few slewing angles, in range from –6° up to +6°, in 3° steps.

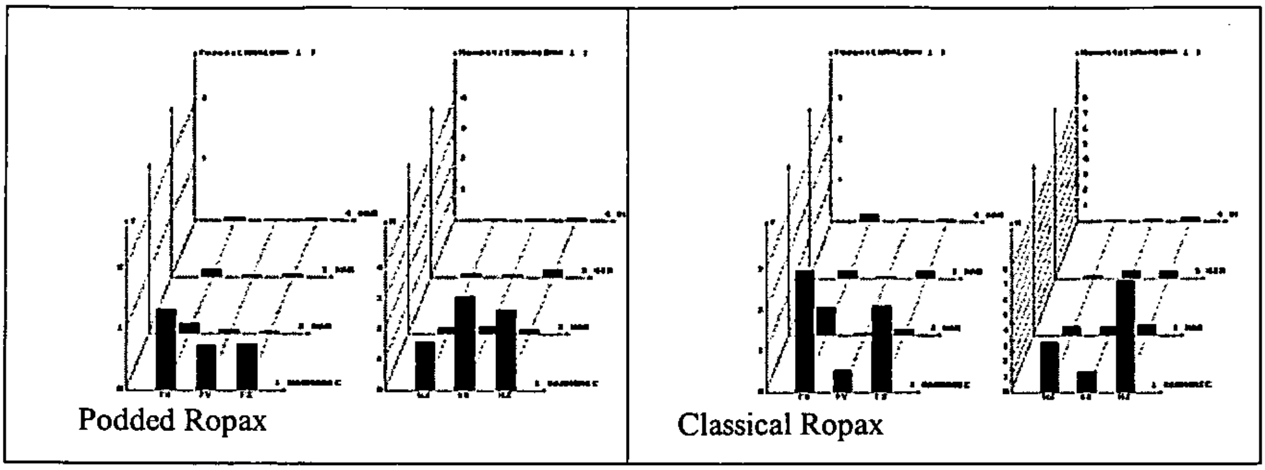
- Axial wake structures taken for investigations [2].



Podded Ropax Classical Ropax

Fig. 11 – Nominal wake structure at propellers disk planes.

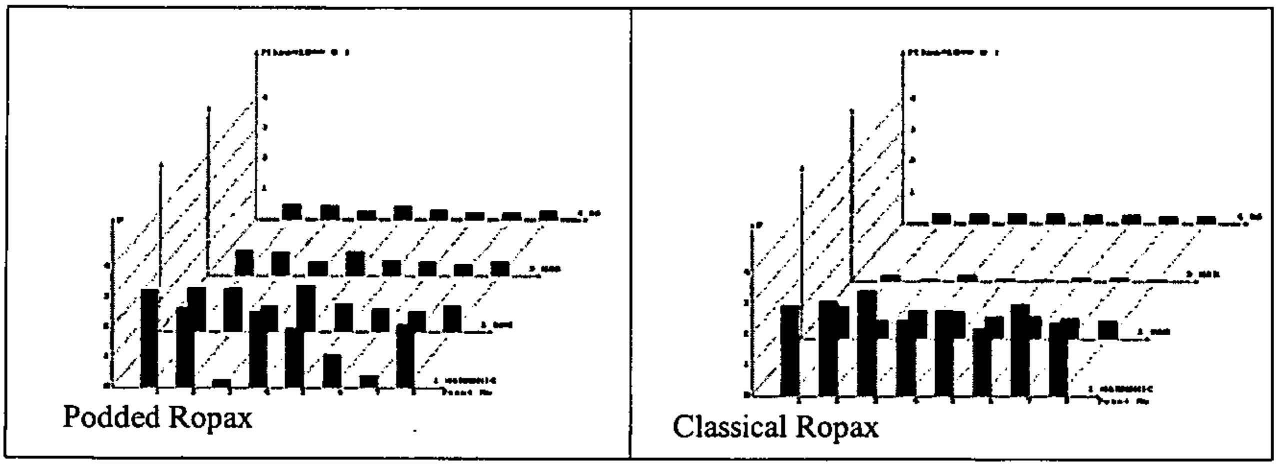
- Results of fluctuating bearing forces/moments and pressure pulses calculations [7].



Podded Ropax

Classical Ropax

Fig. 12 – Harmonics of bearing forces and moments.



Podded Ropax

Classical Ropax

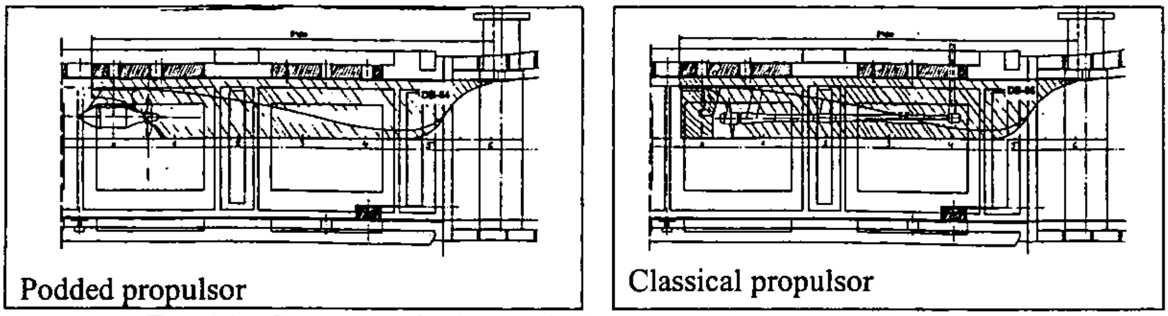
Fig. 13 – Harmonics of pressure pulses.

- Results of tests in cavitation tunnel [10].

Table 1 – Parameters set in cavitation tunnel.

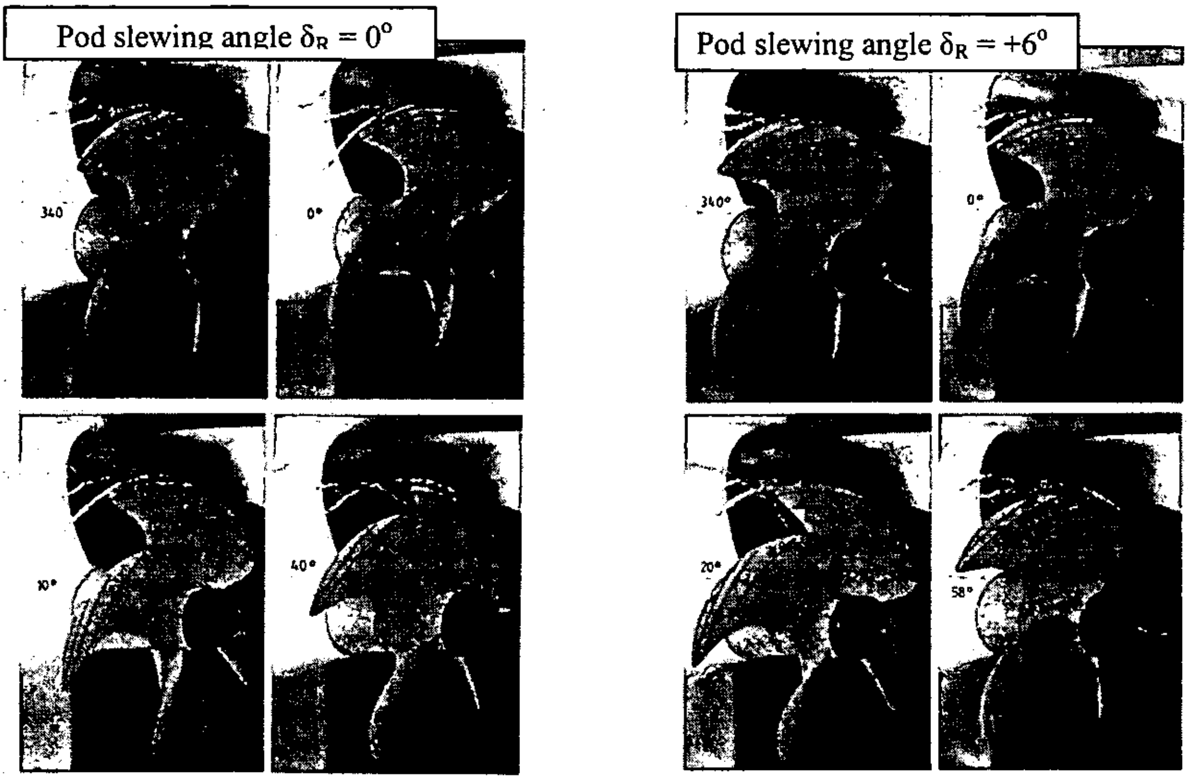
Object	Podded Ropax	Classical Ropax
Test No	11189	11210
Pitch ratio at 0.7 R [-]	1.389	1.2759
Aft draught [m]	6.60	6.60
Delivered power [kW]	20000	20000
Ship speed [knt]	28.19	27.91
Propeller rev. [rpm]	141.8	155.5
Torque coefficient [-]	0,0565	0,0425
Cavitation number [-]	1.422	1.185

Cavitation tests and measurements of pressure pulses on a hull above propellers were executed in the same conditions in CTO cavitation tunnel. Each kind of propulsors was tested with use of an individual "dummy body". Pressure pulses were measured in the same points on the hull as it was taken for calculations of propellers induced excitations.


Podded propulsor

Classical propulsor

Fig. 14 – Location of "dummy bodies" in cavitation tunnel chamber.


Pod slewing angle $\delta_R = 0^o$

Pod slewing angle $\delta_R = +6^o$

Fig. 15 – Cavitation phenomena on podded screw blades for selected positions.

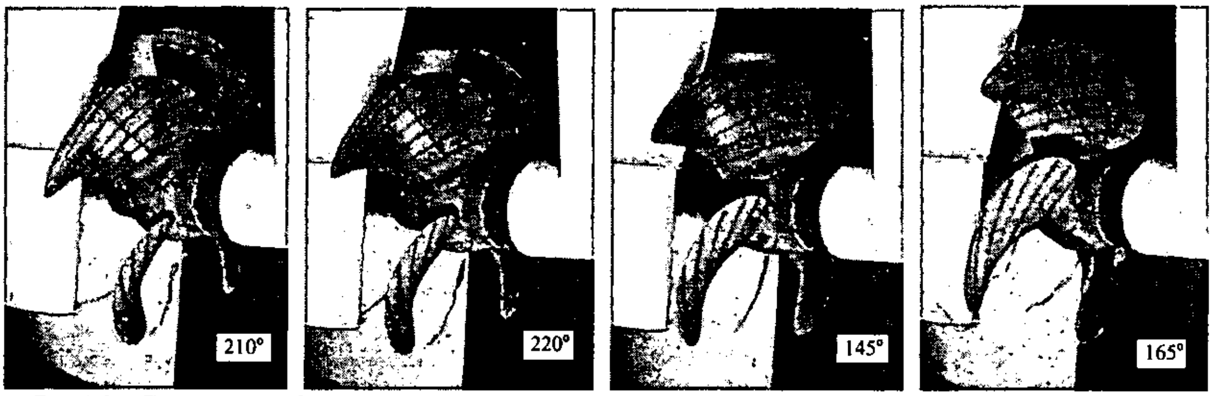


Fig.16 - Cavitation phenomena on classical screw propulsor blades at selected positions.

5. Impacts on safety aspects

Safety aspects were investigated within the project in variety of directions. The main ones included analyses of hydrodynamic and structural integrity for passengers carrying Ropax and Cruise vessels. Moreover, Ropax was a subject of pronounced manoeuvrability tests, aiming to recognize its course stability and steerability properties. It was done as respective tests according to IMO requirements [11], with use of a free running tests on the lake and also with use of the Planar Motion Mechanism in the model basin. Similarly to previous tests, majority of podded Ropax manoeuvres were related to due performances of the classical Ropax.

Additionally, a group of manouvrability tests [5] was done to recognize possibilities of steering at highest speeds only by means of flaps, proposed by RR-KAMEWA [9], installed on pod housing struts. The positive results could give chances to maintain a Ropax vessel at straight course without any movements of pod units, initiating podded propellers cavitation. Selected results of manoeuvrability tests are given in tables nr 2, 3 and 4. Due criteria are taken from [11].

Table 2 – Compared results of turning circles for podded and classical Ropax[5].

Test No.	**Approach speed V_0**		**Type of propulsion**	**Rudder/POD angle δ_R**	**Advance x_{090}/L_{PP}**		**Tactical diameter y_{180}/L_{PP}**	
	ship	model			true	crit.	true	crit.
	[knt]	[m/s]		[deg]	[-]	[-]	[-]	[-]
10718	28.0	3.01	classical	35° STBD	2.8	4.5	2.9	5.0
10842			pods	35° STBD	2.7	4.5	2.4	5.0
10718			classical	35° PORT	2.8	4.5	3.0	5.0
10842			pods	35° PORT	2.5	4.5	2.2	5.0

Table 3 – Compared results of Zig-zag tests for podded and classical Ropax [5].

Test No.	**Approach speed V_0**		**Type of propulsion Kind of test**	**Initial turning ability** t_a' <2.5	**1st overshoot angle ψ_{01}**		**2nd overshoot angle ψ_{02}**	
	ship scale	model scale			true	crit.	true	crit.
	[knt]	[m/s]		[-]	[deg]	[deg]	[deg]	[deg]
10715	28.0	3.01	Classical propulsion Zig-zag test 20°/20°	1.7	17.0	25.0	17.8	-
10833	28.0	3.01	Podded propulsion Zig-zag test 20°/20°	1.6	8.0	25.0	8.0	-
10714	28.0	3.01	Classical propulsion Zig-zag test 10°/10° S	1.4	6.2	11.0	8.2	26.0
10827	28.0	3.01	Podded propulsion Zig-zag test 10°/10°	1.4	3.8	11.0	6.3	26.0

Table 4 – Compared results of stopping manoeuvres for podded and classical Ropax[5].

Test No.	Approach speed V_0	Track reach s_F/L_{PP}		Head reach x_{0F}/L_{PP}	Lateral deviation y_{0F}/L_{PP}
		True	Crit.		
	[knt]	[-]	[-]	[-]	[-]
	Classical Ropax				
10720	28.0	6.1	15.0	6.1	0.3
	28.0	5.8	15.0	5.8	0.1
	Podded Ropax				
10859	28.0	10.8	-	10.4	0.7
	28.0	11.1	-	10.9	1.8
	28.0	11.3	-	10.1	3.3

6. Summary

The whole scope of investigations, carried out for both the Ropax versions, have resulted in widespread knowledge in all major aspects connecting versatile environmental impacts. In majority of subjects, the standard experiments were executed. Where it was not fully feasible, they were supplemented by respective numerical analyses. In some cases non-standard experiments were added to the tests program. Generally, all types of environmental impacts were modeled and due comparisons were made on the same assumptions. Some initial optimizations were reduced there, where concrete results were known from the professional literature.

Summarizing, the scope of performed investigations has made possible to answer nearly all questions, put at the project beginning. All investigations, carried out not only in the work package devoted to environmental matters but within the whole project as well, have given versatile conclusions in environmentally analyzed aspects, confirming also majority of existing and positive opinions. Thus the podded Ropax has following advantages in respect to the classical solution. Firstly, its direct environmental friendliness has been confirmed by a higher hydrodynamic efficiency, connected mainly with the lack of appendages. Also electric power plant gives benefits connected with use of low sulphur fuelled generators and their quantity more suited to propulsive power needs. As effects, less fossil combustibles are used and resulting emissions are reduced in mass and contributions of harmful compounds diminish.

It can be also stated that application of pods as external propulsors, composed of nacelles, struts and screws does not exert any negative impacts like increased wash waves or intensified slipstream wash. Oppositely, such structure of these novel propulsors gives chances to model and control afterbody local flows. Due to a uniform inflow to propellers of pulled pods, it is possible to reduce respective risks and noise as results of their work in heavy conditions. Applications of steering devices in form of additional flaps, reduces pod yaw motions at highest speeds, minimizing transitory situations. Manoeuvring properties of the podded Ropax themselves should be underlined as belonging to best ones, ensuring great safety of exploitation on congested routes. Also changes in mass distribution do not increase accelerations in vital ship compartments. On the contrary, there is a freedom of a longitudinal power plant locations and internal space subdivision.

The only noticed drawbacks of pod propulsion, are connected with applications of single propulsors located in CL in a slow wake. It happens because main advantage of pods, like uniform water inflow, is seriously reduced in such locations. Moreover, the course stability is worsened, because a pod unit works in hull wake what creates zones of reduced sensibility while steering at small pod slewing angles. Only a central skeg and symmetrically located couples of pods can be a solution.

7. Acknowledgment

The author would like to express his special thanks to European Commission for funding OPTIPOD project and to project coordinators and participants for having created atmosphere of efficient work for Polish debutants.

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FAST LOW WASH MARITIME TRANSPORTATION: A REVIEW OF FLOWMART PROJECT RESULTS

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The project FLOWMART which stands for ***Fast Low Wash Maritime Transportation*** *have been funded under fifth frame work programme of European Community for Research, technological Development-Key Action for Land Transport and Marine Technologies, Critical Marine Technologies, Efficient, safe and environmentally friendly ships and vessels. The 36-month project started 1 February 2000 and finished 31 January 2003. The Consortium consists of 11 partners from 5 different European countries. Amongst the eleven partners involved, there are two ship yards (specialised on High Speed Craft), 4 universities, 1 research centre consultant, two ship design consultants and two model basins.*

FLOWMART project is set up to achieve several primary objectives that are recognised as being fundamental to the future success of the high-speed marine transport sector.

- *The first is to develop knowledge and tools that can be used to quantify the wash making characteristics of a particular vessel, based upon its hull form and propulsor. These tools will be extended to enable the optimisation of the hull forms in question, for minimising the wash making, and hence, improving their efficiency.*
- *The second problem to be investigated is that of how the wash from such vessels impacts on surrounding environment in terms of erosion of the bed and banks and harbours and narrow channels, and in turn, how this erosion can affect marine life.*
- *The final objective will be to draw up guidelines that will enable the close control and monitoring of the rapidly growing number of vessels operating in this sector.*

The paper presents the overview of the project results, which can be outlined as follows:

- *Development and use of various numerical techniques to predict the wash and perform the optimisation of low wash hull*
- *Full scale trials with different types of hull forms including the guidelines to carry out full scale trial wash measurements*
- *Model tests to measure wash prediction of the hulls used in full scale trials as well as the developed low wash hull demonstrators*
- *Low Wash Design Methodology to minimise the wash effect from HSMV.*
- *A Wash Impact Assessment Procedure to reduce the environmental impact, particularly on marine life and erosion*

FLEET STATISTICS - HOW " STATS" DON'T ALWAYS GIVE YOU WHAT YOU WANT!

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We're all guilty, media, politicians ship-owners and classification societies. Guilty of wanting black and white statistics that tell us exactly what we want to know and, more importantly, what we want to hear to back up our opinions, ideologies or prejudices. Never mind if the data is limited, incomplete or gives only a partial view of reality.

This paper aims to outline the areas where commercially available data is deficient in giving a consistent image of fleet sizes, in specific tonnage categories, and how these lacunae could give a false impression to legislators when deciding the course that future legislation should set.

ENVIRONMENTAL KNOWLEDGE: HOW GOOD IS IT AND WHERE DOES IT COME FROM?

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There are calls for increased public involvement in environmental management processes. This will require a public that is both motivated to care about the environment and one that is environmentally literate. We used people's ability to name common organisms from colour illustrations of them as a measure of environmental knowledge, albeit a limited one. There were considerable differences in the performance of different social groups in these tests. Most schoolchildren and students, who have enrolled on university courses in the biological sciences, had poor abilities to name organisms and, with the exception of undergraduate biologists, there was little evidence of improvement in ability with age. We believe that there is a real danger of producing a generation of 'armchair biologists' who can write scholarly essays about species that they would be unable to recognise if the encountered them in the wild. There is therefore a strong case for reversing the decline in fieldwork teaching in schools and universities. Nevertheless, some adult groups, especially those whose professions or hobbies bring them into close contact with the environment, such as fishers, nature wardens, wildlife enthusiasts and sea-anglers, have good environmental knowledge. We believe that their knowledge is an under-valued resource and should be used more widely in environmental decision-making and planning processes.

1. Introduction

There are increasing calls from scientists[1] and official government bodies[2] for greater involvement of the lay public in science policy related debate and environmental planning and management processes. Benefits are likely to be of at least three kinds. First, public involvement in science will improve their trust of the scientific process[3]. Second, involvement will help in the implementation of policies. This is because policies that recognise, respect and weigh the public's attitudes and values, along with other factors, are likely to win public support[4]. Third, incorporation of the public viewpoint can improve the quality of the decision-making process. This is because society possesses a wealth of non-scientific knowledge, wisdom, skills and perceptions, including cultural and social ones, and these may be highly beneficial in determining wise policy on environmental issues.

However, the public must be well-informed about the environment before it can make meaningful contributions to planning and decision-making processes affecting it[5]. It is paradoxical therefore that the explosion of knowledge that is currently occurring in the environmental sciences[6] is at a time at which the public seems to have lost its affinity with the environment[7] and public knowledge and understanding of environmental issues is said to be low[8,9]. Gigliotti (in Gambro and Switzy[10]) commented that 'we seem to have produced a citizenry that is emotionally charged but woefully lacking in basic ecological knowledge'. Nevertheless, the generalisation that environmental knowledge is universally poor may be an over-simplification. Society consists of a range of people with different educational backgrounds, skills and interests, as well as experiences of wildlife in their normal lives. It would be extraordinary if there were not equally diverse in environmental knowledge.

Authors' Biographies
Emeritus Professor **Stewart Evans** holds a personal chair in 'Research and outreach in Biology' at Newcastle University. **Sarah Dixon** and **Justina Heslop** are graduates of the University.

The overall purpose of this study was to measure one aspect of environmental knowledge (i.e. the ability to name common animals and plants from colour illustrations of them) in a range of different groups in society, and to consider ways in which it can be improved. It is divided into four parts:

1. Assessments of knowledge of common birds in schoolchildren.
2. Assessments of environmental knowledge in university undergraduates.
3. Assessments of environmental knowledge in adults.
4. Improving environmental knowledge.

2. Methods

These studies were carried out between October 2000 and September 2001[11].

Study 1: Children's knowledge of birds.
Assessments were based on schoolchildren from schools in Cullercoats, Marden and Whitley Bay in the catchment area of the borough of North Tyneside. Their ages ranged from 7 to 16 years old.

Knowledge of birds was tested by asking children to write down the names of 18 bird species which were shown to them as colour illustrations (Table 1). The chosen birds included common garden, lowland farmland and shore birds. The tests of knowledge were carried out in class during school time, under the supervision of class teachers. Participants recorded birds' names on the answer sheets. A mark was given for each correct answer and half mark for an incomplete answer, such as 'gull' instead of 'herring gull' or 'woodpecker' for 'green woodpecker'. Allowance was made for alternative correct answers, such as hedge sparrow or dunnock, both of which were considered correct. Misspelling was not penalized and an answer was considered to be correct as long as it was recognisable phonetically. Results were analysed on the basis of yearly age groups, rather than school classes. The numbers of boys and girls in groups were approximately equal (not significantly different from chance; P>0.05 for each age group; Chi-square Test).

Table 1 - The species shown were used in tests of knowledge of schoolchildren.

Tests of knowledge in schoolchildren of different ages		
Garden birds:	Shore birds:	Lowland birds:
Blackbird	Golden plover	Curlew
Blue tit	Herring gull	Goldfinch
Dunnock	Oystercatcher	Green Woodpecker
House sparrow	Puffin	Jay
Robin	Redshank	Kestrel
Starling	Sanderling	Long-tailed tit
Tests given to schoolchildren before and after taking part in garden bird surveys		
Blackbird	Greenfinch	Robin
Blue tit	House sparrow	Starling
Chaffinch	Jackdaw	Song thrush
Collared dove	Magpie	Wren
Great tit		

Studies 2 and 3: Environmental knowledge in undergraduate students and adults.
Assesments of knowledge in undergraduate students and adults were carried out as 1:1 interviews. Participants were shown illustrations of 10 land birds, 10 shore birds, 10 marine fish, 5 mammals and 5 trees (Table 2).

Tests were given to members of four groups of undergraduates, all of whom were under 21. Abbreviations used for each of the groups are shown in brackets.

First Year Undergraduate Students Reading Biological Sciences. This group (SB1) consisted of 26) students.

Final Year Undergraduate Students Reading Biological Sciences. This group (SB3) consisted of 26 students.

First Year Undergraduate Students Reading English. This group (SE1) consisted of 25 students.

Final Year Undergraduate Students Reading English. This group (SE3) consisted of 25 students.

Table 2 - The species shown were used in tests of knowledge of undergraduate students and adults.

Land birds:
1. Blackbird *Turdus merula*
2. Blue tit *Parus caeruleus*
3. Bullfinch *Pyrrhula pyrrhula*
4. Chaffinch *Fringilla coelebs*
5. Dunnock *Prunella modularis*
6. Great tit *Parus major*
7. Greenfinch *Carduelis chloris*
8. House sparrow *Passer domesticus*
9. Robin *Erithacus rubecula*
10. Wren *Troglodytes troglodytes*

Shore birds:
11. Black-headed gull *Larus ridibundus*
12. Cormorant *Phalacrocorax carbo*
13. Fulmar *Fulmarus glacialis*
14. Gannet *Morus bassanus*
15. Great black-backed gull *Larus marinus*
16. Herring gull *Larus argentatus*
17. Oystercatcher *Haematopus ostralegus*
18. Puffin *Fratercula arctica*
19. Razorbill *Alca torda*
20. Ringed plover *Charadrius hiaticula*

Marine fish
21. Bass *Dicnetrarchus labrax*
22. Cod *Gadus morhua*
23. Haddock *Melanogrammus aeglefinus*
24. Hake *Merluccius merluccius*
25. Herring *Clupea harengus*
26. Lemon sole *Microstomus kitt*
27. Mackerel *Scomber scombrus*
28. Plaice *Pleuronectes* platessa
29. Turbot *Scophthalmus maximus*
30. Whiting *Merlangus merlangus*

Mammals:
31. Badger *Meles meles*
32. Hedgehog *Ericaneus europaeus*
33. Mole *Talpa europaca*
34. Common shrew *Sorex araneus*
35. Grey squirrel *Sciurus carolinensis*

Trees:
36. Ash *Fraxinus vetulina*
37. Beech *Fagus silvatica*
38. Elm *Ulmus campestris*
39. Oak *Quercus pendunculata*
40. Sycamore *Acer pseudoplatanus*

The same tests were also given to adult (over 21 years old) members of 7 social groups. Each person tested was asked to give personal information about age (there were three age categories: under 21; 21-45 years old; and over 46) and educational qualifications (either no formal educational qualifications at GCSE level or equivalent or qualifications at GCSE level or above). Subsequently, participants were sub-divided into sub-groups on the basis of age and educational qualifications. However, some sub-groups were poorly represented due to biases in the age distributions or educational backgrounds of members of different groups. Data were therefore analysed only for those sub-groups for which there was a minimum of 10 people.

The social groups, and sub-groups, are shown below.

Athletes. They were members of local athletics' clubs. There were three sub-groups: (i) Under 21 with formal educational qualifications (A1; N = 16)); (ii) 21-45 with formal qualifications (A2; N = 15); and (iii) 21-45 with no formal qualifications (A3; N = 11)).

Women's Institute. Participants were all over 45 years old. There were two sub-groups: members of one had formal educational qualifications (W1; N = 17)); and those of the other had no formal qualifications (W2; N = 19).

Fishers. All participants were in the age range 21-45. There were two sub-groups: those in one had formal educational qualifications (F1; N = 16); and those in the second sub-group had no formal qualifications (F2; N = 10).

Nature wardens. There was a single group of wardens, all of whom were 21-45 and had formal educational qualifications (NW: N = 17).

Lecturers. They were university staff, whose research interests were in ecology. There was a single group, all of whom were over 45 with formal qualifications (L; N = 16).

Sea-anglers. There were three sub-groups: (i) 21-45 with formal educational qualifications (SA1; N = 14); (ii) 21-45 with no formal qualifications (SA2; N = 18); and (iii) >46 with no formal qualifications (SA3; N = 20).

Bird-watchers. There were two sub-groups: (i) 21-45 with formal educational qualifications (BW1; N = 13); and (ii) >46 with formal qualifications (BW2; N = 10).

3. Improving environmental knowledge

Bird surveys involving schoolchildren. Surveys of garden birds were carried out by children who were either 12 (n = 58) or 13 years old (n = 160). They were carried out during the period from January to March, 2000. Each class was given a one-hour illustrated talk on identifying garden birds, and each pupil was provided with a copy of Brooks' basic guide as an identification aid[12]. Children were then asked to record the numbers of each species of bird seen either in their garden or nearby parkland in four separate 15-minute recording sessions during the forthcoming weekend. These were entered on recording sheets which were returned to school after the weekend.

Knowledge of garden birds was tested in each of the participating children before and after the surveys, using the protocol described above but, in this case, restricting it to garden birds that they were likely to encounter during the surveys. The same birds were included in both tests, which were carried out in class under the supervision of the class teachers. None of the children was aware that they would be tested on the second occasion. Some of the parents (n = 125) were also asked to perform the same tests as the children before and after the surveys, since it was suspected that some of them would assist their children in the surveys. These tests were carried out as individual interviews.

Residential field course for undergraduates. Abilities to name common birds and littoral organisms were tested in 28 students in the second year of the honours degree course in Zoology before and after attending an 8-day residential field course on the Isle of Cumbrae, west Scotland. The species chosen were ones that occur on Cumbrae. The course itself was project based, with students working on both littoral organisms and terrestrial ones. Students were encouraged to observe local wildlife and identification guides were made available to them. A class bird list was kept during the week. Students were also expected to visit the Aquarium of the University Marine Biological Station, Millport. The tests were carried out in the classroom. Students were not aware that they would be given the identical test twice.

4. Results

Study 1: Children's knowledge of birds.

Knowledge of birds, as indicated by their abilities to name species, in Tyneside children was poor. Many children could name four common land birds, the blackbird, blue tit, robin and green woodpecker, and two shore birds, the herring gull and puffin (Table 3).

Table 3 - Percent correct responses to colour illustrations of birds in schoolchildren between ages 7 and 16.

	Age group (years old)										
	7	8	9	10	11	12	13	14	15	16	
Numbers tested	17	14	25	14	18	23	24	22	21	11	Overall mean
Species:											
Robin	100	100	96	90	83	91	100	77	95	91	92.3
Blackbird	56	93	56	75	70	77	90	64	80	91	75.2
Blue tit	91	71	52	70	76	73	100	50	80	82	74.5
Puffin	31	50	52	70	65	77	100	68	85	82	68.0
Herring gull	38	43	28	40	37	43	45	36	43	50	40.3
G. w'dpecker	19	14	17	20	17	23	40	14	25	36	22.5
Kestrel	0	0	0	0	9	18	10	14	20	55	12.6
Starling	0	7	22	5	0	9	20	5	10	27	10.5
Jay	13	0	0	18	4	5	20	9	10	9	8.8
Longtailed tit	13	0	4	10	7	7	25	5	8	5	8.4
Dunnock	9	0	4	5	2	5	15	2	5	18	6.5
H'se sparrow	6	0	2	5	7	5	20	2	8	9	6.4
Curlew	0	0	4	5	0	9	10	9	10	0	4.7
Goldfinch	0	0	6	5	2	5	15	5	5	0	4.3
Oystercatcher	0	0	0	5	0	5	0	5	0	0	1.5
G'den plover	0	0	0	3	0	0	0	5	0	0	0.8
Redshank	0	0	0	0	0	0	0	0	0	0	0
Sanderling	0	0	0	0	0	0	0	0	0	0	0

Scores for two of these species, the herring gull and green woodpecker, were relatively low because many of those tested named them as 'gull' or 'woodpecker' respectively, attracting half marks only. Most other test species, including common garden birds, such as the house sparrow and starling, were poorly known. Two shore bird species, redshank and sanderling, were not known at all and three, curlew, golden plover and oystercatcher, were named correctly by a small minority of children.

There was relatively little, if any, improvement with school age (Fig. 1). The Spearman Rank Coefficient of Correlation (r_s) between mean score and age was 0.6121 ($P<0.05$). The slight improvement appears to be attributable largely to two species. The kestrel was evidently unknown to children of <10 years old but increasing numbers of older children (and more than half of the16 year olds) were familiar with it (Table 2); in this case, $r_s = 0.93$ ($P<0.001$). Similarly, the puffin was correctly named by only 31% of 7 year olds but it was better known to older children ($r_s = 0.83$; $P<0.01$).

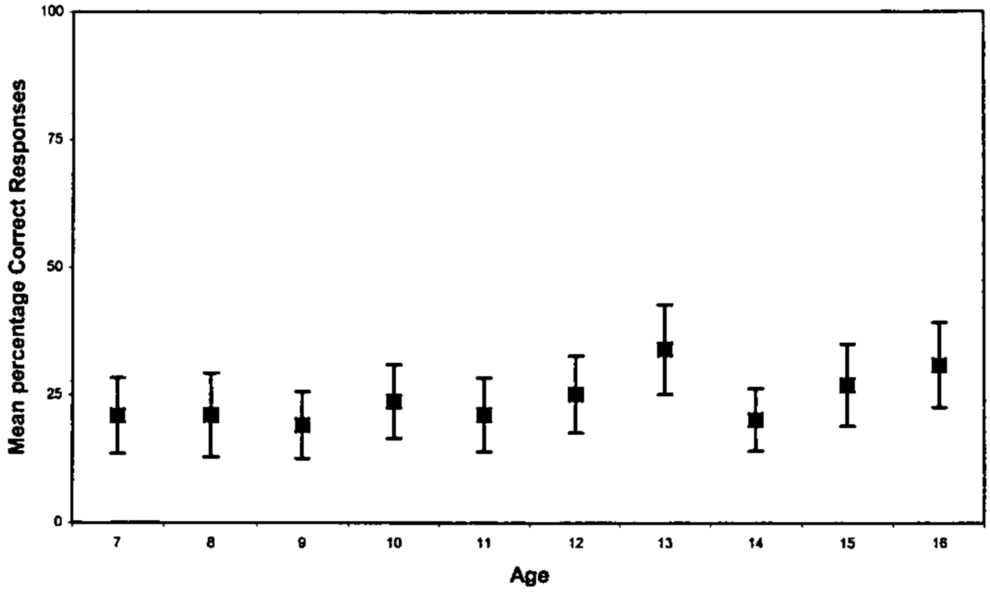

Figure1 - Mean percent correct responses to colour illustrations of birds in schoolchildren aged 7 – 16.

Study 2: Knowledge of undergraduate students.

The overall knowledge of three sub-groups of university students' (SE1, SE2 and SB1) was poor. Their abilities to name common birds were similar to those of schoolchildren, although the range of species to which they were tested was not the same. Nevertheless, like schoolchildren, almost all university students were able to name some common species but few of them could name others. Thus, three land-birds (Blackbird, Blue tit and Robin) and one shore-bird (Puffin) were correctly names by most undergraduates in these sub-groups. However, the Bullfinch, Chaffinch, Dunnock, Great Tit, Greenfinch and House Sparrow and were correctly named by relatively few of them (Table 4).

Students' knowledge of other groups of organisms was equally patchy (Table 5). Four mammals (Badger, Hedgehog, Mole and Grey Squirrel) and one tree (Oak) were given their correct names by most members of sub-groups SE1, SE2 and SB1. However, most other organisms were correctly named by less than 50% of participants. Marine fish, with the possible exceptions of Cod and Plaice, were scarcely known at all.

The performance of one sub-group of students SB3 was superior to that of the other groups of undergraduates (SE1, SE2 and SB1), especially in the ability to name birds (P< 0.001 in each of the three comparisons; Wilcoxon Matched-Pairs Signed-Ranks Test).

Table 4 - Mean correct responses to each group of organisms in each sub-group of students. N = number of people tested.

Sub-group	N	Land-birds	Shore-birds	Marine fish	Mammals	Trees
Students SE1	25	35	18	6	85	31
Students SE3	25	32	16	7	90	38
Students SB1	26	33	23	9	83	34
Students SB2	26	65	55	10	87	46

Table 5 - Percent correct responses to each species in student groups.

	Student group					Student group			
Species	SE1	SE2	SB1	SB2	Species	SE1	SE2	SB1	SB2
Blackbird	88	72	69	92	Bass	0	0	8	0
Blue tit	80	64	62	88	Cod	24	16	23	31
Bullfinch	16	8	12	46	Haddock	0	0	0	0
Chaffinch	16	16	4	58	Hake	0	0	0	0
Dunnock	4	12	19	42	Herring	0	8	0	4
Great tit	20	12	19	58	Lemon sole	0	0	0	0
Greenfinch	8	8	4	62	Mackerel	8	20	19	19
H'se sparrow	12	12	15	62	Plaice	24	28	35	46
Robin	88	96	100	100	Turbot	0	0	0	0
Wren	16	24	27	42	Whiting	0	0	0	0
Bl-h'ded gull	24	12	23	62	Badger	96	100	100	100
Cormorant	20	8	19	69	Hedgehog	100	100	96	100
Fulmar	0	0	0	46	Mole	92	100	92	92
Gannet	16	16	12	69	Cm'n shrew	36	52	27	42
G.Bl-b'k gull	8	16	19	42	Grey squirrel	100	100	100	100
Herring gull	20	24	54	73					
Oystercatcher	12	0	12	62	Ash	12	24	8	19
Puffin	84	80	88	100	Beech	8	12	19	35
Razobill	0	0	0	12	Elm	16	12	19	15
R'ged plover	0	0	0	19	Oak	68	72	69	77
					Sycamore	52	68	54	65

Study 3: Knowledge in adults.

Most of the adult groups performed better than undergraduates in these tests (Table 6), and some of them, notably fishers, lecturers, nature wardens and bird watchers were far superior to them.

Table 6 - Mean correct responses to each group of organisms in each social sub-group. N = number of people tested.

Sub-group	N	Land-birds	Shore-birds	Marine fish	Mammals	Trees
Athletes 1	15	46	26	13	88	35
Athletes 2	11	56	30	17	89	44
Women's Inst. 1	17	68	35	23	93	70
Women's Inst. 2	19	64	30	19	87	68
Sea-anglers 1	14	55	58	64	90	43
Sea-anglers 2	18	57	66	63	93	37
Sea-anglers 3	20	59	68	64	86	46
Fishermen 1	16	45	73	95	81	49
Fishermen 2	10	52	75	95	78	52
Lecturers	20	92	74	25	90	85
Nature wardens	17	96	85	18	88	92
Bird-watchers 1	13	97	90	32	89	83
Bird-watchers 2	10	95	86	24	90	80

Age itself may not did not appear to be an important factor in determining differences in performance between sub-groups of adults. There were two cases in which there were sub-groups within the same group which had the same educational background but were of different ages: sea-anglers (SA2 v. SA3) and bird watchers (B1 v. B2) (Table 7). The older sub-group of sea-anglers (SA3) obtained a slightly higher overall score than the younger group (SA2). However, the reverse was true in the case of ornithologists; the younger group (B1) performed better than the older one (B2). Differences were not significant in either comparison (P>0.05 in both cases; Wilcoxon Matched-Pairs Signed-Ranks Test).

There was no evidence that educational background affected performance in these tests. There were four cases in which sub-groups in the same groups had different educational backgrounds but were of the same age categories: athletes (A2 v. A3) sea-anglers (SA1 v. SA2), fishermen (F1 v. F2) and Women's Institute (W1 v. W2). The slight differences in the scores obtained between matched pairs were not significant (P>0.05 in each case; Wilcoxon Matched-Pairs Signed-Ranks Test) (Table 7).

Table 7 - Mean overall scores for each of the sub-groups, which were based on age and educational background (see Methods).

Under 21	21-45		46-65	
Formal	Formal	No formal	Formal	No formal
Stud. Eng. I (SE1): 29.4				
Stud. Eng. III (SE2): 29.8				
Stud. Biol. I (SB1): 30.4				
	Athletes (A1): 36.6			
		Athletes (A2): 42.3		
				Women's Inst. (W2): 47.6
Stud. Biol. III (SB2): 48.7				
			Women's Inst. (W1): 51.9	
	Sea anglers (SA1): 60.9			
		Sea anglers (SA2): 63.0		
				Sea anglers (SA3): 64.3
		Fishermen (F2): 69.5		
			Lecturers (L): 69.9	
	Fishermen (F1): 71.8			
	Nat. wardens (NW): 72.3			
			Bird-watchers (O2): 72.5	
	Bird-watchers (O1): 76.3			

The best overall performances in these assessments were from the adult sub-groups/groups, whose professions or hobbies bring them into close contact with wildlife. Thus, bird watchers (B1 and B2) performed particularly well, followed by nature wardens (NW), fishers (F1 and F2), lecturers (L) and sea-anglers (SA1, SA2 and SA3) (Tables 3 and 4). These abilities were specifically related to the nature of the environmental experience. For example, sea-anglers (SA1, SA2 and SA3) and fishers (F1 and F2) were the only groups that could name most of the marine fish and they also had relatively good knowledge of shore birds.

Study 4: Improving environmental knowledge.

Birds surveys involving schoolchildren. There were records of 27 species in the survey of garden birds. Involvement in it resulted in significant improvements in their abilities to name birds

(P<0.001; Mann Whitney U Test) (Table 8). The knowledge of parents was initially higher than that of their children but, nevertheless, it too improved significantly following the surveys (P<0.001 in both cases). The probable explanation is that some parents had assisted in the surveys. Parents were invited to a meeting at which the results were presented. About 20 of them attended and there was general consensus that this had happened.

Table 8 - The scores of children and parents in tests of knowledge of birds before and after the survey of garden birds.

Number tested	Mean score (percent)	
	Before	After
	Children	
217	31.1±0.2	48.0±0.2
	Parents	
125	59.6±0.3	67.0±0.3

Residential field course for undergraduates. Students ability to name both bird and littoral species increased significantly after attending the field course (P<0.001 in both comparisons; Mann-Whitney U Test) (Table 9).

Table 9 - The mean percent scores of 28 students to birds and littoral organisms before and after attending a residential field course.

	Mean percent scores (± standard errors)	
	Birds	Littoral
Before	42.4 ± 4.8	32.0 ± 1.0
After	56.9 ± 3.5	39.9 ± 2.5

5. Discussion

The results of this study suggest that there are considerable differences in environmental knowledge in different social groups in society. Young people, in this case schoolchildren and university undergraduates, had poor abilities to name common organisms. This was true even of those recent school-leavers who had entered university to read degrees in biological sciences and who might have been expected to show close affinities with the environment.

Lock[13] attributes poor environmental knowledge in schoolchildren to deficiencies in the education system, and this view tends to be borne out by the data presented here. School education appears to be having little impact on at least knowledge of birds because schoolchildren between the ages of 7 and 16 showed little evidence of improved abilities to name bird species. Formal education can certainly be effective if it is designed appropriately and it is noteworthy that students in the final year of their degree programmes in biological sciences performed significantly better in the tests than those in the first year of the same degree programmes. Nevertheless, they were no better able to name common organisms than members of groups, such as the Women's Institute, and were inferior to groups such as fishers and sea-anglers. It is alarming that our education system appears to be in danger of producing a generation of armchair graduate biologists, who may be able to write scholarly essays about species of wildlife, but would be unable to recognise the same organisms in the field.

The limited knowledge of species that young people do have does not appear to have come from actually seeing them in the wild. This is because common species which are likely to be seen daily, such as the house sparrow and starling, were not known by most children. However, they did know charismatic species, such as the robin, blackbird, blue tit, puffin and woodpecker. These latter species are subjects of cartoons or nursery rhymes, often occur as motifs on Christmas cards, or are manufactured as animated toys, and knowledge of them presumably comes from other sources. They probably include general reading, watching nature programmes on television or reading magazines and newspapers.[14, 15, 16]

There is no doubt that bringing people into close affinity with the environment improves their knowledge of common species. It was shown here that schoolchildren (and their parents) learned to recognise bird species as a result of undertaking surveys of them, and undergraduate biologists became familiar with birds and littoral organisms while attending a residential field course. There appears to be a clear case for increasing the time spent on practical ecological studies in schools. It is depressing, therefore, that the reverse trend is apparent in both school and university teaching.[17, 18, 19, 20] While constraints of modern curricula, financial and health issues make the organization of fieldwork difficult, there is an obvious need for initiatives that permit students to spend more time in the field, especially those that enable them to 'use' their knowledge in, for example, contributing to national surveys[21], making management recommendations for areas of conservation importance[22] or communicating science to a wider audience.[23]

Despite the deficiencies in the education system, some people in society do acquire excellent environmental knowledge. 'Amateurs' with little or no formal training have been able to use their expert knowledge of species to make major contributions to national or international surveys.[24, 25, 26] In this case, knowledge does appear to emanate from close contact with the environment. It was shown here that it is well-developed in fishers, nature wardens and ecologists, as well as sea-anglers and bird-watchers, whose livelihoods or hobbies give them broad experience of wildlife. Their knowledge almost certainly goes well beyond the ability to recognise common species.[27,28] We believe that such knowledge should be recognised as an important resource, and used in environmental planning and decision-making processes. As Christie & White[29] have argued, local knowledge, coupled with specialist knowledge of the scientist, is more potent than either kind of knowledge on its own. In fact, there are increasing numbers of examples, including fisheries cooperatives in Japan,[30] fisheries management in Denmark[31] and stock assessment in Canada,[32] where such knowledge is being incorporated into the planning process. Examples are not restricted to fisheries science. Opinions of volunteer ornithologists has been used to influence the UK Government's Arable Options of the Countryside Stewardship Scheme through recommendations made in the British Trust for Ornithology's Crops for Wintering Birds project.[33] Similarly, Wilson[34] has suggested that the specialist knowledge of farmers can benefit assessments of the environmental impact of the Environmentally Sensitive Areas Scheme, and Harrison *et al.*[35] believe that it is valuable in the development of Local Biodiversity Action Plans.

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THE DECLINE IN BIOLOGY FIELDWORK: FACT OR FICTION?

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There is strong evidence that science fieldwork is declining in schools and colleges across the UK. Although no central or co-ordinated database of outdoor activity exists, the available data indicate a long-term trend which appears to have accelerated in recent years and could now be affecting the numbers and quality of candidates available for recruitment to the environment sector. Similar trends could threaten many environmental monitoring programmes the majority of which have a high dependency on volunteers. Underlying causes are complex and multiple solutions at a variety of levels are needed to remedy and reverse these trends. Scientists and educators will need to work together more closely to deliver a coherent approach to 'lifelong learning' in the environment sector.

1. Evidence

In addition to the evidence indicating *historical trends* in numbers of groups carrying out biology fieldwork in schools and colleges in the UK, there is also evidence that the *length of course*, *location*, *timing* and *content* have changed, for upper secondary groups at least.

1.1. Historical trends

There is no single source of data for levels or trends in biology fieldwork in the UK, even within government education departments and their advisory bodies. However, although the available data are fragmented and cannot be amalgamated, they do point to a consistent and long term decline in science/biology fieldwork at secondary and university level. Several recent papers and reports confirm this for secondary schools[1,2,3,4] and universities[5,6]. The evidence at primary level is inconclusive.

Between 1970 and 2003, biologists as a proportion of groups visiting Field Studies Council (FSC) centres in the UK fell by one third (from 54% to 36% of all visiting groups). The FSC is the largest independent provider of such courses and these data which represent over 1,000 different groups from schools and universities each year represent the largest body of evidence available to date. During this period the overall number of groups visiting FSC centres increased with the biology groups mainly being replaced by geography groups. Smaller, or more local, surveys amongst teachers outside FSC centres have all shown that biology teachers and university lecturers perceive a recent (less than 5 years) and longer term (up to years) decline in fieldwork[3] and that this may have been more marked in state compared to private schools[4,7].

1.2. Length of course

Over the 20 years to 2003, the average course length at an FSC centre has halved from the 'traditional' 7 days to 3.9 days[8]. Similar trends have been commented on at University level[5,6].

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1.3. Location

There is a close and significant relationship between travelling time and course length in FSC centres and there is anecdotal but consistent evidence that the contraction in course length has been associated with the fieldwork experience becoming more local[2,3,6] .

1.4. Timing

The increasing modularisation of courses at upper secondary level, combined with tightly defined subject criteria published by the government's curriculum advisers and examination specifications set by Awarding Bodies, has reduced the flexibility in timing for carrying out fieldwork. This has resulted in a marked peakiness in the timing of fieldwork, with most A level biology fieldwork being carried out in eight weeks of the year (mid-June to Mid-July, and mid-September to mid-October)(see[3]). The influence of the curriculum is demonstrated by a comparison of geography and biology A level fieldwork in FSC centres; in the former, most (82%) of residential fieldwork is carried out in the first (AS) year with 18% in the second (A2) year, whereas there is an almost exact reversal in biology. This is entirely due to curriculum design. Recent advice from AQA, one of the largest A level Awarding Bodies, to postpone fieldwork until the late-autumn of the second (A2) year may squeeze fieldwork into a even narrower, and probably inclement, period later in October.

1.5. Content

Biology fieldwork at upper secondary level is very strongly associated with coursework, a piece of assessed practical project which contributes towards the final A level award. Therefore, the fieldwork content is dictated strongly by coursework criteria and assessment protocols laid down by A level Awarding Bodies. In practice, this means that most fieldwork is intended to cover the teaching of the techniques and skills – including data gathering - needed to complete coursework and its assessment for examinations, rather than a wider understanding of ecology and its applications[3]. This narrow focus may unbalance the role of fieldwork, and contribute to the low interest, relative to other bioscience topics, shown towards whole-organism and environmental biology amongst A level and undergraduate biologists [4,9].

2. Influences

Most published accounts referring to influences on fieldwork provision[1,2,3,4,6,8] highlight five major contributory factors: curriculum; administration and management; teachers' confidence and competence; cost; and health and safety.

2.1. Curriculum

For upper secondary biology teachers the curriculum is often identified as the biggest influence[1]. Although ecology probably occupies as much space in the GCSE and A level curriculum as it ever has, fieldwork remains optional. This contrasts with the geography curriculum which has a statutory requirement for fieldwork. As a result, geography teachers receive more initial and continuing professional training to support fieldwork activities and their students are up to ten times more likely to experience fieldwork[3].

2.2. Administration and Management

Even within science departments there may be little enthusiasm for fieldwork and this hinders the ability of fieldwork advocates to organise out-of-classroom activity. The lack of a statutory requirement for science/biology fieldwork influences the perception of its importance and status in schools, particularly when the schools' effectiveness in delivering statutory curriculum content is subjected to external scrutiny and reported on to parents and the wider public; the maxim 'if it isn't inspected, it isn't important' applies in many schools. In a recent survey of Office for Standards in Education (Ofsted) subject reports, the inspectors commented on the extent and quality of fieldwork provision in a large majority (81%) of geography subject inspections (as described above, secondary school geography fieldwork is compulsory), but this was rarely the case in the science reports where fieldwork received comment on only 18% of occasions[10]. This provides a very weak base from which fieldwork enthusiasts can apply pressure on teaching colleagues and senior managers in their schools.

2.3. Teachers' confidence and competence

The absence of statutory requirements are not wholly responsible for the apparent dearth in science fieldwork; recent surveys of residential fieldwork provision in 134 London secondary schools shows that the level of science fieldwork for Key Stage 3 (11-14 year olds) lags well behind other subjects which also lack statutory support for fieldwork within their curricula, including history, modern languages, drama and music[8]. There is some evidence that outdoor experience is not as highly regarded by science teachers compared to geography colleagues, and that the teachers of these subjects have quite different reasons for doing fieldwork; geographers attribute a greater importance to the 'non-subject' educational areas such as personal and social development, and recruitment to their subject[3].

The declining levels of fieldwork have long term impacts. Relatively few trainee and newly-qualified biology/science teachers are entering the teaching profession with fieldwork experience (Christine Harrison, pers.comm.) and they are increasingly dependent on in-school training to develop this expertise as the responsibility for initial teacher training has shifted from university education departments to placement training in schools. As a result of a long-term shift away from whole-organism biology towards molecular and cellular disciplines in bioscience education, and increasing numbers of non-specialists teaching science topics, fewer schools will have biology teaching staff who are able to provide such training and mentoring support to new recruits. If this continues, the fieldwork legacy will weaken further and the flight from fieldwork will accelerate.

2.4. Cost

Cost is often cited as a major influence, and is likely to have contributed to the shortening of courses and the move towards more local experiences (see above). There is also some evidence that fieldwork has declined in the state compared to the private sector[4], possibly due to differences in availability of financial and other resources. A contributory factor to this trend may be the absence of a compulsory requirement for science fieldwork, which means that there is a heavy reliance on financial support from parents and guardians for non-statutory activities. However, as described above, the evidence from lower secondary groups from London schools shows that other subjects which also lack statutory support for fieldwork are still able to offer more residential experiences, often to overseas locations.

2.5. Health and safety

There is a perception of an increasing number of accidents and incidents on out-of-school trips and a surge in litigation against teachers. This has eroded confidence which has been undermined further by strong recommendations from one of the major teaching unions for its members to avoid out-of-school activities and trips[7]. These perceptions, and the subsequent advice, are not founded on fact. Evidence collected by the Health and Safety Executive (HSE) and outdoor activity insurers indicates that very few accidents, and subsequent claims, occur as a result of science fieldwork and that litigation is decreasing[7]. Unpublished FSC data for its 17 field centres in 2004 show that a notifiable accident occurred once for every million hours of fieldwork contact time – the equivalent of one accident per year in a medium sized secondary school with 850 pupils. Most head teachers would welcome a similar safety record.

3. Impacts on conservation biology

The weakening of fieldwork provision in science education has both direct and indirect impacts on conservation biology. As seen above, there are relatively few newly-trained teachers who are able, or inclined, to deliver fieldwork themselves[1,6]; the lack of practical experience probably contributes to the comparatively low level of interest shown by A level teachers to environmental and whole-organism biology and this probably reinforces the opinions of their students[4]. The reservoir of practical environmental knowledge and skills amongst school and university students – sometimes called environmental literacy – may already be low[11], but no historical comparison is possible in the absence of comparable previous or archive data.

The lack of interest in whole-organism and environmental biology is also seen amongst biosciences undergraduates[4], who themselves are also being offered declining levels of fieldwork[6]. Logically, this should result in a shortfall in undergraduates with experience of, interest in, and commitment to jobs in the environmental sector and this has been demonstrated in difficulties in recruitment seen by environment sector employers in the past five years[12]. The longer term impacts of a decline in the educational and academic fieldwork base on conservation biology are more difficult to describe, particularly their possible link to the widely-reported decline of interest and competencies amongst volunteers who are essential to the majority of biodiversity related surveys and projects in the UK. Over 71% of the 67 UK biodiversity monitoring programmes listed by the UK's Joint Nature Conservation Committee have a dependency on volunteers, with 52% being totally reliant on their work[13]. The links between the decline in educational fieldwork and the 'health' of biodiversity-related interest and competencies in the voluntary sectors are still unknown, but they may prove fundamental, culturally deep-seated and long-lived.

4. Solutions

There is reasonable consensus – historical and contemporary – about the action which is needed to reverse the decline in fieldwork provision (eg.[1]). The following areas are critical:

Curriculum change. The inclusion of stronger statements supporting fieldwork is an obvious solution, but this would need to be accompanied by clear intellectual and practical integration into the rest of the biology and science curriculum so that the outdoor experience does not become an irrelevant 'skills and techniques' ghetto with little relevance to biology and the wider application of science; students should recognise the importance of fieldwork and its applications to everyday life and career prospects.

Teacher training. The potential of the curriculum will not be exploited fully without interested, competent and committed teachers. Both initial teacher training and continuing professional development should ensure that teachers will lead fieldwork.

Health and safety. The protocols for visits and trips should provide support, rather than erecting barriers, for teachers who are organising fieldwork. In particular, guidance should be consistent and 'fit for purpose'; a fieldwork trip to a nearby woodland is not the same as a climbing expedition to the Alps.

Resources. Biology fieldwork need not be expensive, particularly if carried out locally. The lack of money is an excuse which often fails close scrutiny; in fact, ecology teachers could make more of the fact that theirs is a science research discipline which can deliver high quality work – very similar to that carried out at the forefront of science research - with basic equipment. Fieldwork can also be undermined by inappropriate and dated resources; they should recognise that interests and experience have changed in the past 30 years. For example, systematic monographs which may have been appropriate as fieldwork teaching aids some time ago will fail to enthuse contemporary aspirants and yet they still appear – perhaps regarded as part of a rite of passage – as teaching tools. Similarly, ecology texts, exemplar data and 'worked examples' all too frequently refer to situations which have little relevance to contemporary lives. By working more closely together, science teachers and research scientists could help to overcome these major obstacles.

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CRUMBLING FOUNDATIONS: THE EROSION OF THE TAXONOMIC BASE OF BIOLOGY

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The ability of 'someone' to provide names for any organism of interest, or the ready availability of a suitable field guide, is often taken for granted. Underlying this view are assumptions that all species have already been given names, that identifications are by and large 'easy', that taxonomic information and support are effectively free and, increasingly, that it's all on the web. The evidence supports none of these assumptions, but instead indicates a large number of species yet to be described and named, and a continuing decline in the number of taxonomists available to do this job. The seriousness of this situation is underlined by numerous case studies that demonstrate the vital contribution of taxonomy to other sciences and activities. Not only is the capacity of the taxonomic sector to provide the taxonomic component of non-taxonomic work unsustainable, but the agenda of understanding global biodiversity is itself threatened. The decline in taxonomic expertise and infrastructure, and the difficulty of obtaining taxonomic information, has been dubbed the 'taxonomic impediment' by the Convention on Biological Diversity, which has set up the 'Global Taxonomy Initiative' in response. The only tenable solution to the taxonomic impediment is to support taxonomic work in a sustainable way. Taxonomic work and products could be better integrated with other environmentally-linked activities, and this requires partnerships to be formed across sectors. Taxonomy is poised to become more effective and efficient using developing digital and analytical techniques, and now is a good time to develop new models of cross-discipline interaction. In the short term greater dialogue is needed to develop synergies, identify priorities, and gain clarity on costs by both taxonomists and non-taxonomists. Methods must also be found to revive taxonomic elements in UK curricula from KS1 to University levels.

1. Introduction

Much of what people do is built on sets of assumptions. Unfortunately, some of these are so ill founded as to threaten the ability to carry out the activities which are predicated upon them. Such assumptions underlie the practice of much of environmental science both in the UK and elsewhere. The assumptions in question are to do with taxonomy – the source of the names of the organisms we study, and the custodian of a vast amount of biodiversity information.

Biologists are used to having names for organisms as a means of communication and comparison, even if they do not always apply them rigorously. However, there is an unspoken assumption that such names will always be available as and when wanted, that field guides will be on the bookshelves, that taxonomists will be on hand to produce an identification at short notice, and that no specimen is unidentifiable.

Author's biography. Chris Lyal is a researcher at the Natural History Museum in London. His major interest is the systematics of weevils, with the major themes of producing a catalogue to the 65,000 species of this hyperdiverse group, working out the higher classification, and studying host specificity and coevolution of seed-feeding weevils with rainforest trees in South East Asia. In addition to his research, Chris has a strong interest in the state and role of taxonomy globally, and in this arena has worked for the Convention on Biological Diversity as Programme Officer for the Global Taxonomy Initiative, and is currently associated with the Global Biodiversity Information Facility as a member of the Governing Board and its Science Committee, and with BioNET-INTERNATIONAL as an advisor and co-opted member of the Board.

Moreover, most of the reference specimens supporting UK and tropical taxonomy is housed in the UK and other industrialised countries, and workers in the countries of origin, be they foreign nationals or UK researchers, may assume that access to this material and the expertise to interpret it will always be available as and when desired. Any project in the environmental arena that incorporates assumptions such as these in its design is building in the potential to fail.

Taxonomic capacity in the UK for most animals and plants is deteriorating although, except for a few taxa, it has not quite reached crisis point. However, the UK is in a better state than most other countries, particularly those in the tropical areas, where the assumptions listed are wholly unsound.

2. Picking up a field guide

Field guides are a major resource for non-taxonomists to identify species[1]. In a recent UK survey of the taxonomic needs of conservation bodies, some 70% identified field guides as very important to their work[2]. In teaching, routine identification and fieldwork they are a familiar tool, since in the UK and the USA, at least, they have been published for many years. The assumption that must be questioned is the expectation of the continued ready availability of field guides to provide researchers with identifications, whatever the taxon to be identified.

Unfortunately, some of field guides in current use were published a worryingly long time ago and thus their reliability today must be questioned, a point that was picked up by a number of the respondents to the UK Survey (Taylor, 2005). The age of publication is also of significance in terms of availability, since many guides are out of print. Of a small sample of field guides recommended by one British naturalist group[3], one book was produced in the 1950's and is now out of print, and of the others a large proportion was produced in the 1980's, with declining numbers appearing since (Fig. 1). A similar story is true for an important source of UK insect identification: the *Handbooks for the Identification of British Insects* produced by the Royal Entomological Society. Since the series began, the Society has published 80 *Handbooks*, although the rate of publication has dropped in the past two decades (Fig. 2). Of these handbooks, 33 are now out of print, although 10 have been superseded by works from other publishers, leaving about 23 insect groups (Order, or Superfamily within a larger Order) not covered in any available handbook.

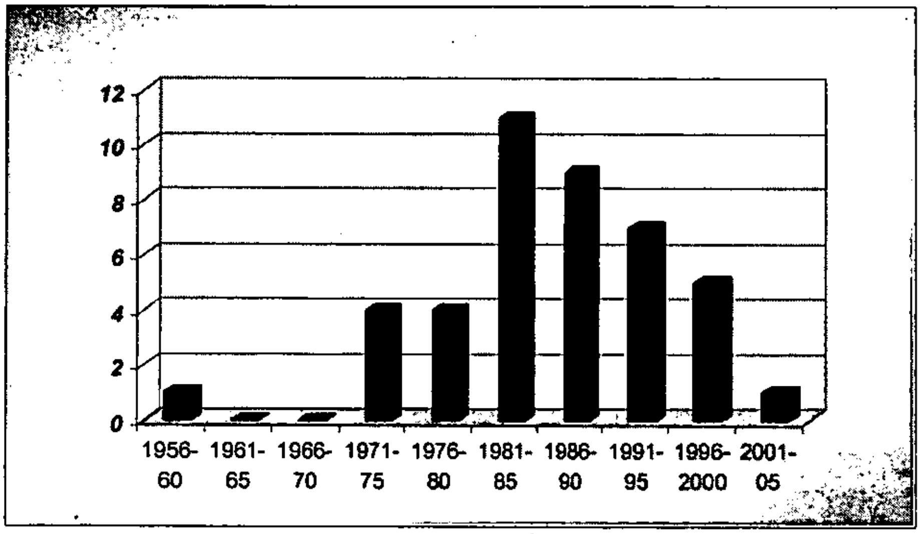

Fig. 1 - Publication dates of a recommended selection[3] of UK field guides published between 1956-2005.

Further, the original 80 handbooks only covered about half of the British insect fauna. Some groups such as the Lepidoptera have been covered outside the RES handbook series, but others such as the parasitic Hymenoptera have not been treated by any publication at all. For the 104 families of British flies, 52 have been covered by handbooks and 24 by other publishers, leaving about 25% which do not have recent or available keys for identification (P. Barnard, *pers. com.*). There are significant gaps in the Hemiptera and Coleoptera. Even the *Handbooks* that we have tend to cover only one life-history stage, so larvae of beetles, flies, Hymenoptera and even of many Lepidoptera are not treated.

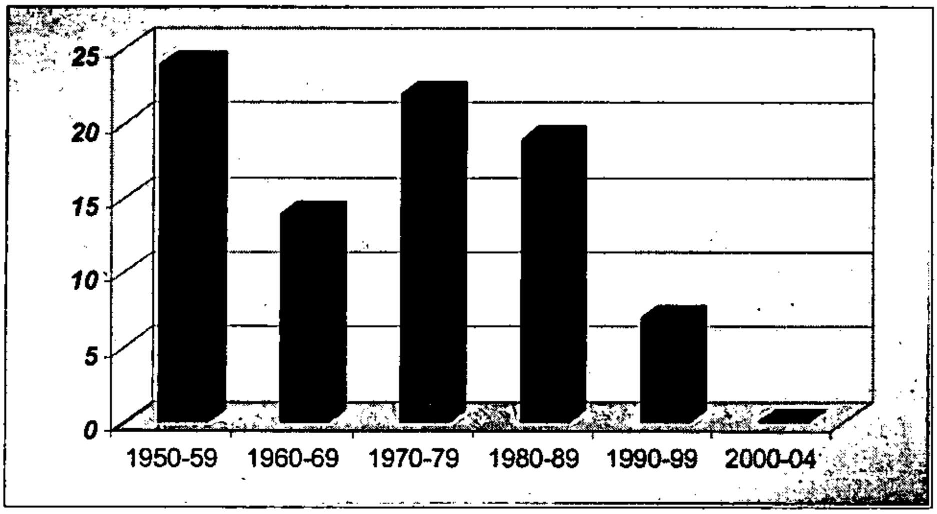

Fig. 2 - Publication dates of the RESL 'Handbooks for the Identification of British Insects'.

These figures point out a set of concerns. If there are no field guides, then the effectiveness of our biodiversity monitoring and assessment work insofar as it covers the groups concerned must be limited, as is our capacity to carry out ecological or other studies. For groups where guides have been produced but are out of print, the situation is similar, other than for institutions and individuals that have sufficiently good libraries. These lacunae in coverage are not, of course, dictated by scientific decisions on the taxa that demonstrate particular biological features of interest, or are good biodiversity indicators, but rather by factors such as taxonomist interest and publishers' perception of the market. Field guide availability may well dictate areas of study, or at least preclude some components of the ecosystem being examined. This is especially important in areas such as community ecology, where significant portions of the community may be inaccessible, and in general field biology, in that the resources which new field biologists need are simply unavailable. Examination of field guide production and availability suggests that this effect will increase.

The age of a field guide is important not only because of its effect on availability, but on the content. There is a gradual change in the scientific names applied to organisms, due to changing taxonomic understanding. Identifying the magnitude of this change is not simple. In fish about 10% of names in any given work may be outdated after 10 years[4,5,6]. The *Zoological Record* included 502,281 new animal names at all ranks for the years from 1978 to 2002. In the same period they recorded 96,137 new synonyms – an average of approximately 4,000 per year. An older guide may therefore provide names that cannot be assigned with confidence to modern concepts of species, and consequently cause some confusion.

A third issue with both older and newly-published field guides is completeness. Older guides may omit species that have colonised since publication; a potentially serious issue in an age when invasive alien species are accounted the second most serious threat to biodiversity globally. Newly-published guides suffer from an analogous problem. In recent years there has been a growth of field guides that cover not only the UK but also Western Europe. Such guides often include excellent images and brief descriptions, and it is possible to name specimens through their use. However, many of them also include only some of the species actually present in the area they cover, a selection that in some cases is not noted explicitly. For example, Chinery's (1993) *Insects of Britain and Northern Europe* illustrates fewer than 800 of Britain's approximately 23,500 species[7]. This can clearly lead to incorrect identifications or, perhaps preferably, no firm identification at all. It will certainly leave the user (if the user notices) with a nagging suspicion that their identification might not be as absolute or useful as they might like.

A feature of field-guides is the many illustrations, often with key characters indicated, enabling the user to identify an observed specimen easily[1]. However, for many taxonomic groups, particularly the ones comprising smaller organisms or which are more speciose such as the insects, field guides are in most cases either unavailable or the key characters are more difficult to observe. The RES *Handbook* series deals with organisms more in this 'difficult' category than field guides proper, as do non-UK series such as the *Fauna of New Zealand.* Such texts tend to be reasonably illustrated, but employ more technical terms and the illustrations frequently require more expert knowledge to interpret. As has been pointed out, even such works as the *Handbooks* by no means cover the whole of the UK insect fauna, although the UK is still in a favourable position globally. In the absence of handbooks identification must fall back to the primary taxonomic literature, which treats groups at a finer scale – often genus or species group - and is very much aimed at the professional user. A complaint which is often heard at this level is the complexity of the terminology and the need to examine obscure organs on the specimen being identified. Here is another assumption, there are 'easy' characters available for all taxa, even though taxonomists for some reason do not use them. Although, it must be confessed, taxonomists do not always employ the most accessible characters, there are generally reasons for this – many species can only be separated through the use of features that are very difficult to see and understand and the apparently 'easy' ones do not serve to distinguish taxa. The difficulty is sometimes overcome to some extent through the use of pictorial keys, so that the user does not have to be familiar with detailed terminology. However, even these cannot deal with differences that use ratios of measurements or other complex characters; if the organisms to be identified display no simple characters, the author cannot invent them. There is a concomitant issue that identification of species is not necessarily simple even for the subject specialist, and a taxonomist may have to dissect minute organs from a specimen before being able to identify it.

There are increasing numbers of resources on the web that will assist in species identification, such that it is tempting to think that the web has filled the gap left by the decline in field guide production. However, web sites are often woefully incomplete in their coverage, and sometimes unreliable. There are few if any cases of UK fauna and flora where the web can be seen as a reliable source of identifications, although the resource is improving in some areas.

Recently there has been much discussion about the development of genetic 'barcodes' for use in identifications[7,8,9,10]. This may come to be a functional reality, and the technology is certainly developing rapidly. However, the days of the hand-held 'barcoder' are still quite far off and, more significantly, there is still relatively little clarity on whether the entities that are identified using analysis of barcodes are the same as the biological species currently recognised. There is currently nothing approaching a barcode 'library' of UK species, and a significant amount of taxonomic expertise will need to be engaged to create such a thing. Until these issues (as well as those of cost) are resolved, barcoding is not a valid alternative to field guides and will not do away with the need for expert taxonomic support. In any case, many identifications are performed on the basis of a sighting rather than a capture, a situation which is unlikely to change. The barcoding approach has vast promise, but will not reach its goals unless there are sufficient resources put into the taxonomic enterprise in the short and long terms.

The discussion above focuses on guides to the UK fauna and flora. The situation with regard to many of the places elsewhere in the world where UK biologists now work is of course far worse. Even in the UK Overseas Territories, where one might expect some production of identification aids, the lacunae are great. For the biodiversity-rich tropics, there are virtually no complete guides to the fauna and flora other than larger vertebrates and perhaps butterflies. Instead, there are scattered taxonomic treatments of genera or other units, which may or may not have keys within them, and are rarely illustrated to the full extent needed for identification by the lay user. Much of the biota, in any case, has not been named by science.

3. Calling in the expert

If there is no field guide, or the guide available does not assist in providing an unequivocal identification, the next port of call for many scientists is the expert in the group of organisms concerned. The dangerous assumptions here are first, that there are experts in place to assist, and second, that they will be able to undertake the work within the necessary timescale.

Two House of Lords select committees have debated UK taxonomy. Both have concluded that there has been a decline in the numbers of taxonomists employed in the UK, and in support for taxonomic institutions[12,13]. There is no indication that this trend is being reversed, raising the spectre of the effective end of expert taxonomic activity in the UK and, with it, necessary support for conservation and other sectors. In this the UK is part of a global trend, which has alarmed taxonomic, conservation and other organisations[14,15,16,17]. Teasing apart the background for this is perhaps a futile exercise, although it is in part linked to misperceptions addressed in this paper – that taxonomy is effectively complete, for example, and that taxonomic problems may be simply solved or circumvented. Other misperceptions are also involved: that systematics is descriptive rather than hypothesis driven, that other, newer sciences and technologies are more worthy of interest, and that conservation action rarely requires taxonomic input. Whatever the reasons, systematics is a shrinking discipline, and a declining area in UK universities, as elsewhere, and without corrective action fewer and fewer students are likely to be trained in its techniques and understand the issues that this decline raises. This poses major problems for humanity's ability to manage its environment.

That taxonomic expertise is always available to provide answers for those in other sectors, that it can be called upon at short notice, and that it should not be charged for, are fairly common perceptions. Not all taxonomic organisations have a statutory duty to undertake identifications, although the major museums and herbaria will attempt to do so. If the need for taxonomic engagement is more extensive than a single identification (and even this may be very time-consuming), the assumption of availability is even more questionable. It cannot be assumed that identifying specimens for the casual enquirer, or even a fellow professional body, will automatically supersede the core work and research agenda of a taxonomist, or a taxonomic department. In many cases the performance indicators on which taxonomists and their parent institutions are judged include identifications for, and work with, other sectors, but they also include elements such as peer-reviewed taxonomic papers[18]; one cannot expect either individuals or institutions without prior planning to set aside their priorities for those of another institution within the timescale dictated by the latter.

Taxonomic institutions are as short of funds as any others and there is a limit to how much even the most well-endowed can bear the cost of producing outputs for workers in other sectors when this does not further their own priorities. If charges for such outputs are requested (and some institutions are prevented from charging by their mandate) and there are no funds within a project budget to pay them, this further produces a barrier between sectors and can militate against the support needed by taxonomists from other sectors. This has not prevented grant-giving bodies from cutting out the costs of taxonomic components of environmental projects on the grounds that the taxonomic elements cannot or should not be charged for (Anderson, *pers. com.*; Oberprieler, *pers. com.*). The take-home message to funders and applicants must be that taxonomy is not free, and needs to be budgeted for in project design.

In many cases the professional taxonomist serves as a back-up to the amateur enthusiast in their support for conservation and other activities[2]. The UK in particular makes great use of amateur expertise, and amateurs perform a pivotal role in supporting activities at local and national level, as was discussed by a number of contributors to Taylor (2005) and is discussed by Gates in this volume. However, this is not necessarily a sustainable resource[15], nor is this resource automatically available for all groups of organisms. The recent House of Lords report on systematics and taxonomists[13] heard that the volunteer community was 'aging'. Unless we take steps to ensure that the next generation of amateurs is equipped with basic whole-organism knowledge during their education, and with the tools to develop their interest and enthusiasm, this unpaid and often unappreciated resource will no longer be available. In that case a major resource used by the UK conservation bodies will have vanished[13]. Given the scenario already outlined, the expert community left will be insufficient to fill this gap.

4. Names for all?

Adam, apparently, was given the task by God of naming the birds and beasts[19]. There seems to be an assumption that he finished this task. Unfortunately, this is far from being the case. In the past 250 years, since the time of Linnaeus, taxonomists have named somewhere in the region of 1.78 million species of animals, plants and micro-organisms. Estimates for actual numbers of all species of organisms range from 3 million[20] to approximately 100 million[21], with much of the uncertainty in the arthropods, protists and prokaryotes. In terms of the distribution of these named organisms amongst the unnamed, the majority are in the vertebrates and the seed plants, and the lowest proportion in the smaller organisms (Fig. 3). The highest absolute numbers of unnamed species are in the prokaryotes, fungi and insects (the estimated total number of insects used in Fig. 3 is 4,000,000, but this is likely to be too low; Häuser (2004)[22] cites 15 million, for example). Although a few new species are found in the UK every year, the vast majority of new species are found in the tropics. Much of the work undertaken to understand and conserve biodiversity in the tropics involves surveying organisms in some way. The proportion of unnamed species taken in any survey is huge, and poses a real problem to analysts. Several methods have been devised to deal with this issue, in the absence of sufficient taxonomists to address it. The simplest, of course, is to ignore it, and sample only those organisms for which there is a good chance of identification. Thus some criteria by which indicator taxa are selected include that the group must be well-known taxonomically. This criterion is, of course, based on an unscientific and biased selection rather than on any tested hypothesis as to the organisms' power to 'indicate'.

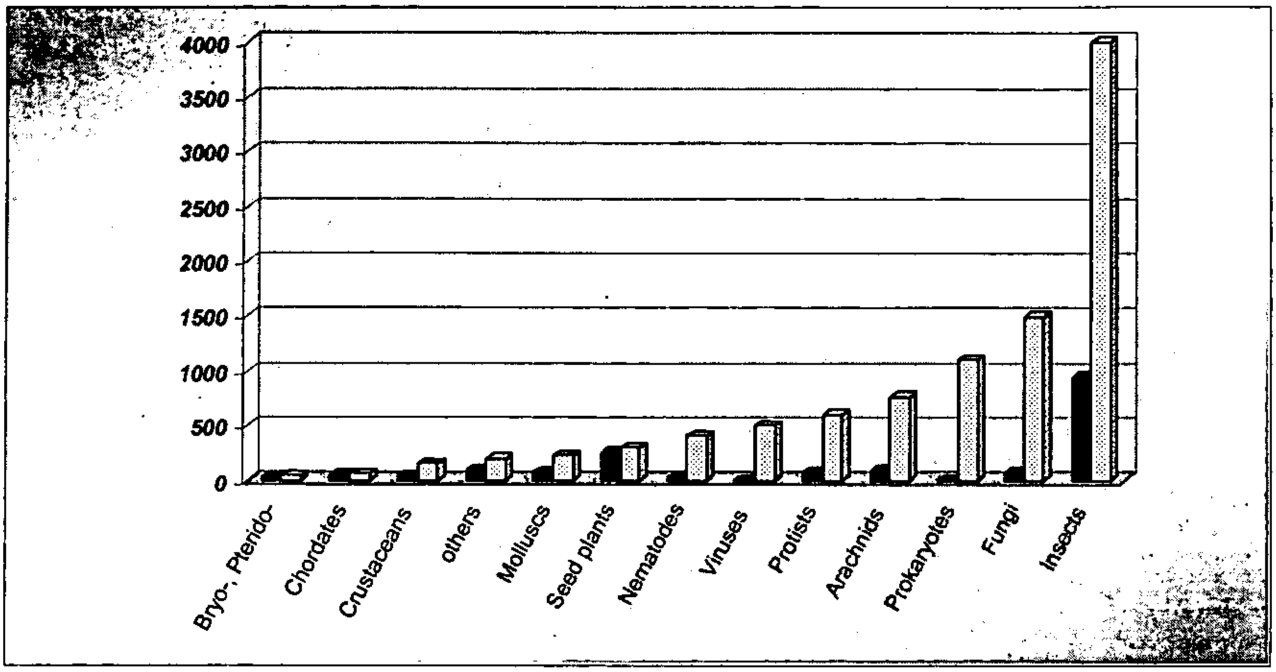

Fig. 3 - Numbers of described species (black bars) and estimated total numbers of species (white bars) (numbers in thousands). The total numbers of insect and micro-organism species are probably underestimates.

Another method is to sort all specimens collected to 'morphospecies' ('Recognisable Taxonomic Unit' or 'Parataxonomist Unit'). While this superficially reasonable solution has been adopted by many projects, it suffers from the disadvantages that it is not easily transferable between sites. Thus assessments cannot be compared, and even monitoring a single site through time is rendered extremely difficult. Moreover, reporting observations can only be in terms of project-specific identifications, and there are very limited possibilities of placing those observations in any other context without the associated voucher specimens being formally named. Finally, the accuracy of morphospecific sorting, both in terms of correspondence with biological species and the absolute numbers of taxa present, has been shown to be questionable[23].

One further way in which the issue has been addressed is to treat taxa at a hierarchical level higher than species, and work on the basis of genus or family present. Unfortunately, while there is a 'species concept' that is predicated on some (presumed) biological reality, there is no similar theoretical or observational basis for an objective taxon at any more general hierarchical level, and thus no clarity on how one assigns biological or any other meaning to them.

5. Does it matter?

In the previous sections some indication of the importance of taxonomic expertise to work in other sectors has been given. However, the demonstration of taxonomy's significance need not depend on abstract examples; numerous case studies are available. For example, detailed surveys and taxonomic identification of samples around New Zealand coasts revealed an area of about 20 × 10 square km near Spirits Bay to be a significant marine biodiversity hotspot, the most diverse known for the New Zealand region, with high levels of local endemism. The hitherto unsuspected species diversity of macrobenthos in this small area of seafloor, and its importance as a spawning ground for the surrounding fishing industries, resulted in the New Zealand Ministry of Fisheries closing the area with the greatest number of species (in the 50-70 m depth zone) to trawling, Danish seining, and commercial scallop dredging, to allow areas of affected habitat to regenerate. As a further result of the work testable hypotheses based on geography, tectonics, hydrography, and the biology of the organisms themselves could be erected to explain this diversity. The preliminary taxonomic work thus identified an extremely important area both ecologically and economically. This example is one of thirty-five case studies of 'Why Taxonomy Matters' made available on the web by BioNET-INTERNATIONAL[24].

Another example of the need for taxonomy is highlighted by the Census of Marine Life project[25]. In 2004, 106 new species of marine fish were found as part of this project, an average of over two new species a week. An accumulation curve of marine fish species descriptions suggests that some 5,000 marine fishes remain to be discovered and identified[26]. A graph of all marine species discovered in Europe reveals a trend line with no end in sight[27]. The Ocean Biographic Information System (OBIS) database shows that near-surface records account for 95% of all existing observations of ocean life; less than 0.1 percent are from the bottom half of the water column. A specimen collected below 2000 m (6,000 ft) is about 50 times more likely to be new to science than one found at 50 m.[25] In order to have any sort of handle on this diversity, and to enable further work on these organisms, taxonomic attention is vital.

So far the focus of the discussion has been on the services taxonomists provide through identification and naming of specimens. This by no means covers the contribution of taxonomy to environmental studies or, indeed, the significance of taxonomy's own research agenda. At a basic level are lists of species by their most up to date name, and with synonyms so that out-of-use names can be properly associated[22,28]. In addition to streamlining taxonomic activity, up to date checklists of the fauna and flora can be of immense value for conservation and many other environmental and legal activities at subnational, national and global levels[29,30,31]. As Valdecasas and Camacho (2003)[32] put it, "without a good, constantly updated taxonomy, biodiversity studies and conservation science become pure 'number crunching' and 'meaningless'." There are numerous efforts to produce such a resource, many of these being coordinated by the Integrated Taxonomic Information System[33], Species 2000[34] and the Global Biodiversity Information Facility (GBIF)[35].

Beyond names, taxonomic institutions house myriad specimens. This is far from being a static resource. Specimens are loaned between museums to enable taxonomists around the world to examine them, carry out identifications and build local reference collections. Increasingly specimens are being imaged and these, made available on the web, are used by a wide variety of people, including those in the environmental sector. The data associated with the specimens, also being digitised and made available, have direct applicability to environmental issues[36,37,38,39]. One of many possibilities is Ecological Niche Modelling. This technique uses specimen locality data, dates of collection, and climatic and other data from the localities, to create an 'envelope' indicating the likely distribution of the species[40,41]. This not only indicates where species may be found naturally, but also other geographical areas where they could survive, thus offering the potential to predict distributions of Invasive Alien Species, or of native species under different models of climate change. Taxonomy's own agenda to describe all the Earth's biota, discover its phylogenetic interrelationships, understand species' distributions and how these change over time, is of great relevance directly and indirectly to environmental science[42].

Taxonomy, despite its problems, is currently undergoing a revolution in the way in which it does things. The advent of the internet and increasingly powerful computers have enabled taxonomic and related biodiversity information to be shared to an extent never before possible[22,43,44]. Currently data associated with nearly fifty million specimens and observations, from more than 400 collections, are accessible through the GBIF web portal[35]. These data can be downloaded and analysed, and very soon there will be a dynamic link to species catalogues so that the names can be authoritatively checked, and data stored under synonymic names associated confidently. Plans are under way to extend the interoperable system of data to images, molecular data, morphological characters, and taxonomic literature itself, so that an increasing amount of taxonomic information will be accessible directly by the user. This will enable taxonomists to be far more productive by removing some of the rate limiters, and should facilitate communication between taxonomists and those in other sectors. This revolution, however, will not fulfil its potential unless there are sufficient taxonomists to manage the system and adequate support to populate it with data.

6. What is to be done?

The scenario of decreasing taxonomic expertise and information availability is threatening for environmental studies, conservation, sustainable development and, indeed, continued human use of biodiversity. Not only has this been identified as an issue by the UK House of Lords and other national bodies, but the Convention on Biological Diversity (CBD), which the UK and 185 other countries have ratified, recognises a 'taxonomic impediment' to its implementation. This the CBD sees as a rate limiter in establishing suitable mechanisms for conservation and sustainable use of biodiversity and fair and equitable access to its genetic benefits. As a response they have put in place a 'Global Taxonomy Initiative' (GTI)[45]. Much of the activity under the GTI so far has been at the policy level. As policy, the Parties to the CBD have agreed[46] that, for example, there needs to be capacity building in taxonomy around the world, including training and employment of taxonomists and the other staff that are required for a taxonomic institution to function effectively. They have also agreed that taxonomic institutions need to be financially stable, and they have argued for the proper housing of biological collections. On the science side, they have asked for greater stability in taxonomic nomenclature, support for monitoring and assessment of biodiversity in a variety of ecosystems worldwide, and specific products such as a list of plant names, keys to freshwater fish and genera of bees, taxonomic toolkits to soil organisms, and much else. Although the GTI is considered by some to apply only to developing countries, this is a misperception, and it applies to the UK as much as to any other Party to the CBD.

Despite the clarity of the international political support through the documents produced, translating the words into action is far from simple. The CBD has asked for financial support for the GTI, and so far several million dollars has been provided, mostly directed at developing countries since the main funding body, the Global Environment Facility (GEF), is not mandated to provide funding to industrialised nations. In the UK the Darwin Initiative has provided funds for projects aligned with the GTI, again directed primarily at developing countries but providing funds for UK taxonomists. However, none of these activities supports the regeneration of taxonomy in the UK in any sustainable manner. Within the UK NERC responded to the first House of Lords Report on Systematic Biology[12] with the NERC Taxonomy Initiative, implemented in 1994. It had the purpose of regenerating taxonomy in universities, and funded research fellows to pursue work attempting to define evolutionary relationships in three Universities. The initiative was seen by NERC as short-term only, and NERC informed the 2002 House of Lords committee that it would not run again. The initiative certainly had some success, and led, according to one respondent in the second report, to five taxonomists in university posts "who would not otherwise have been there"[14]. On the other hand, since the initiative focussed on evolutionary relationships, there was not an immediate pay-off for environmental or conservation work and the development of the type of skills that would support these.

At the simplest, one might say that the problem could be solved by training and employing more taxonomists. This means we need to ensure whole-organism biology, including systematics, is taught in universities, and that institutions that employ taxonomists are financially enabled to increase the number and taxonomic scope of those they employ. Details of the actions that need to be taken have been provided in a number of papers and documents, of which only a few need be cited[12,13,22,31,46]. However, although the actions and steps set out in these documents are vital, the evidence shows that they do not provide solutions that can immediately be implemented. The situation we are in has come about because people have taken value judgements as to whether to support taxonomy or not. The reasons for these decisions, and the personal and institutional drivers that have supported them, need to be addressed at a wide variety of levels and places. Without this attention, there is unlikely to be any lasting change.

A first step in resolving the problem is for both taxonomists and those in the environmental sector to develop between them greater clarity about user needs and priorities for taxonomy, and how to address these. This needs a greater dialogue and degree of collaboration than is often the case[31,47]. Through the GTI the most highly emphasised needs are for user-friendly identification aids, species lists, and relevant information produced in a timely manner. In the UK field guides have been emphasised, as have checklists and information on the distribution of species, at local, regional and national levels[2]. Prioritisation is clearly possible and necessary within these highlighted outputs.

Not only does there need to be improved dialogue and a developed working relationship between the various biodiversity sectors, but this must extend to the funding bodies and political decision-makers[48]. The current gaps in communication and understanding have led, and continue to lead, to misunderstandings and misperceptions that hamper the work of all concerned. For example, members of the environmental sector tend to phrase questions in the language used by that sector, and expect answers using the same format and lexicon. Taxonomists, in contrast, tend to look at problems within a taxonomic framework and produce output in taxonomic publications using terminology and construction suitable for other taxonomists[18]. The intersection of these two communication loops is relatively weak, so that taxonomists do not always comprehend the environmental problems being addressed and how taxonomy fit into them, and environmentalists do not fully understand the extent of any taxonomic problem raised, the need for extensive research, or indeed the answer that is provided. Because the timescale of taxonomic work can be rather different from that of environmental projects, delivery of a taxonomic result within the project life may be an issue. Funding bodies in the environmental sector will tend to respond to only the non-taxonomic loop, and not necessarily perceive the frailty of the assumptions made on availability of taxonomic information. This may be because the applicants themselves do not see it, and may in any case have had adverse experience with taxonomists who do not perceive the needs of the environmental sector users. Clarity on both sides, and a mutual understanding of the scope of the scientific problems to be solved, and the method of output delivery, is necessary[49]. With this understanding can develop project design that takes all of the issues into account, and makes clear the extent of the taxonomic research that may need to be done and specifies the outputs needed. Only with this clarity, including the identification of the necessary work, outputs and their cost, can appropriate funding be sought.

Such clarity and dialogue does not happen overnight. There are, of course, many instances where the two sectors are working well together, the UK National Biodiversity Network being a good example of this. However, mutual comprehension may have to be developed more at the level of the individual practitioner and the department than at the level of institutional management.

Solving the problem of greater synergy between environmental and taxonomic sectors is only one element of the puzzle. Ensuring a greater level of teaching of taxonomy is another. Science, like every other human activity, is susceptible to fashion shifts, and this, coupled with the false perception that taxonomy is not relevant or needed by other scientific endeavours, has adversely affected taxonomy worldwide. In order to reverse this trend taxonomists themselves (and those in the environmental sector who realise taxonomy's importance) need to be more proactive in telling people about their work and its importance. Not only do we need to be more vocal about the good stories we can tell, but also we need to become more involved in the education system itself. Taxonomists have a fund of examples that mesh well with aspects of the National Curriculum, and which can be used to assist teachers deliver their subject. A useful strategy might be to make such resources more available to the educational establishment, so that students become used to seeing taxonomy intermeshed with other aspects of biology and environmental science as they progress through school. As taxonomy becomes more open to the world through increased presence on the web, and more integrated with other aspects of environmental study and biology, we can hope that the demand for tuition in universities becomes more vocal, encouraging universities to put it back on the curriculum. In the interim the dialogue between sectors should include the development of curriculum items for universities.

The need for taxonomy in the environmental sector can scarcely be clearer. The current diminution of taxonomic expertise is nothing short of a disaster that will, unless reversed, lead to a scientific community that is unable to identify much of the biota of the UK, let alone the rest of the world. The organisms used as a basis for decision-making and scientific study will decrease in number and phylogenetic range because of identification difficulties, making the results less predictive and useful. The tools and insights available from taxonomists and their collections will become unavailable. The situation can be redressed, but it will take understanding and action from all partners in the biodiversity world to do so.

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THE USE OF LOCAL KNOWLEDGE TO MAP THE DISTRIBUTION OF ENDANGERED BIRDS ON PACIFIC ISLANDS

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In the Pacific islands where community-based systems of management have operated (or still operate) in managing natural resources at sustainable levels, they are under-pinned by good environmental knowledge in local people. The value of such knowledge as an important resource in modern environmental planning processes cannot be underestimated. This paper describes studies of environmental knowledge (i.e. knowledge of local bird life) of people from Vanuatu and the Suva region of Fiji. In Vanuatu environmental knowledge is well developed and it was used to develop a rapid appraisal technique to map the distribution of birds. However, in Fiji environmental knowledge was generally poor and did not permit a similar study of birds to be undertaken. A comparison of environmental knowledge is made in people from the island of Santo in Vanuatu and those of Viti Levu in Fiji. In Vanuatu this knowledge appears to be acquired at an early age because it was as good in children of 10 years old, and younger, as in adults. Fijian children had poorer environmental knowledge than adults suggesting that it is being 'progressively' lost. It is argued that this loss is associated with 'western' influence and that environmental education initiatives are required to reverse the trend.

1. Introduction

There is no doubt that local or environmental knowledge was once an important environmental resource. It was well developed in communities that operated at subsistence level[1], and was used by them to managing natural resources[2]. Fishermen in such communities provide one example in which environmental knowledge was particularly well developed. Such knowledge included the behaviour, precise locations and timing of fish spawning[3,4], the behaviour of biology of crabs[5], and information on fish ectoparasites[6]. Johannes[3] stated that the knowledge of Palauan fishers in Micronesia far surpassed the current base of scientific knowledge. Regrettably, environmental knowledge has been largely ‘lost’ in modern society and it is generally regarded that it is now poor[7]. Nevertheless, there are still cases in which its importance is recognised. Christie and White[8] have argued that local knowledge when combined specialist knowledge of the outside researcher is considered more potent than either knowledge alone in understanding reality. Not surprisingly, local ‘non-scientific knowledge’ has been incorporated into the development of environmental management plans. It has especially been successful in fisheries management in Japan[9], Denmark[10] and Canada[11]. Similarly, environmental knowledge of farmers’ has also been included in environmental planning processes[12]. Harrison[13] showed how farmers’ are knowledgeable experts who can provide valuable inputs into policy decisions and argue for their inclusion in the setting and delivering of Local Biodiversity Action Plans. Environmental knowledge has been increasingly used in environmental impact assessments (EIA). This includes Inuit environmental knowledge used in Arctic EIAs’[2]. In Canada, federal environmental guidelines now require that developers incorporate traditional knowledge (including environmental knowledge) into EIAs[14].

Author’s biography. Dr. **Andy Birchenough** is currently Marine Environmental Impact Adviser at CEFAS, Burnham-on-Crouch. His wide research interests include community-based science, the ecology of estrildid finches and the impacts of anti-fouling paints on marine life.

This paper describes two studies relating to environmental knowledge in the Pacific islands. The first study relates to the value of environmental knowledge as a resource. It is used to develop a rapid appraisal technique to map the distribution of birds in the islands of Vanuatu. The technique is based on the abilities of the people of Vanuatu to recognise species of birds that occur locally. It was developed on one group of birds the estrildid finches, but as a model for more general use. However, while environmental knowledge is especially well developed in people from Vanuatu, in people from the Suva region on the island of Viti Levu in Fiji environmental knowledge was generally poor and did not permit a similar study of birds to be undertaken. A second study compares environmental knowledge (knowledge of local bird life) in these people with those from the island of Santo in Vanuatu.

2. Methods

(i) Mapping the distribution of birds in Vanuatu

The study was carried out during the period June - September 1999.

Study area

Vanuatu consists of about 80 islands, and has a population of about 140,000 people. The main centres of population are the towns of Port Vila and Luganville, on the islands of Efate and Santo (more fully Espirito Santo) respectively (Fig.1). There has been some urban and agricultural development on these two islands but most people (ni-Vanuatu) live in small villages and farm at subsistence level, tending partly cleared areas of forest, known as village gardens. These gardens are cultivated mostly by the men, and may be at distances of several km from the villages themselves.

Surveys were made on 12 of the larger islands in the central and southern parts of Vanuatu: Aneityum, Tanna, Efate, Emae, Tongoa, Epi, Ambrym, Malakula, Pentecost, Ambae, Maewo and Santo (Fig.1).

Knowledge of bird life.

Interviews were conducted at a total of 61 villages (between 4 and 8 on each island), and approximately 10 adults were interviewed (range 8 to 12) at each of them. The interviewers were always accompanied by a local guide who spoke English and the local language, bislama. The guide explained the procedure to those interviewed.

The first step in the procedure was to distinguish between those interviewees who had 'good knowledge' of local birds and those who had 'poor knowledge'. Interviewees were tested on a 1:1 basis and asked to respond 'yes' or 'no' when they were shown colour illustrations of 35 birds, depending on whether or not they believed that the species occurred on the island. Some species shown to them were resident on their island others were not. A ' yes' response was considered to be correct answer to the sight of an illustration of a resident species. A 'no' response to a non-resident species was also correct. Conversely, 'no' responses to residents, and 'yes' responses to non-residents, were incorrect responses. An interviewee was considered to have 'good knowledge' based on the satisfaction of two criteria: >50% correct answers to resident species and >50% correct answers to non-resident species.

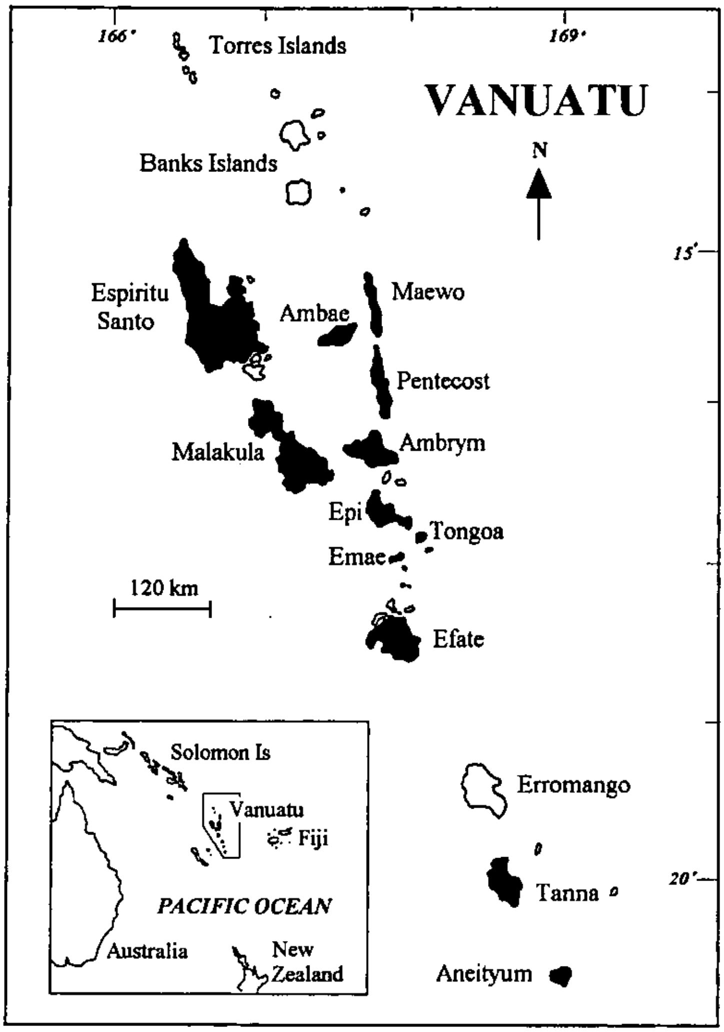

Figure 1 - A map of Vanuatu. Islands, which were surveyed, are shown in black.

The second stage of the procedure was to obtain information on the local presence or absence of the target group of birds, the estrildid finches. They included two endemic sub-species the Blue-faced Parrot Finch *Erythrura trichoa cyaneifrons* and the endangered Royal Parrot Finch *Erythrura cyaneovirens regia* and three introduced species the Common Waxbill *Estrilda astrild,* Chestnut-breasted Mannikin *Lonchura Malacca* and Black-headed Mannikin *Lonchura Malacca.* Each interviewee was shown colour illustrations of each of the five estrildids and asked to respond in the same way (as above). In the subsequent analyses, only data from those people who achieved the criteria for 'good knowledge' were included. Statistical comparisons were made using the Chi-square Test between the proportions of 'yes':'no' responses for each species on each island with the proportions for the same species for those islands (summated) on which the species had never been recorded. Only information from those interviews, which were conducted with adults on their own, without the possibility of collusion, were included in the analysis of data. Finally to ground-truth the data obtained formal field counts of estrildids were made on each of the islands visited. .

(ii) Environmental knowledge in Vanuatu and Fiji.

The study was carried out during the period September – November 2000.

Study Areas.

Santo (more fully Espirito Santo) is the largest island in Vanuatu. It has an area of 3,677 square kilometres and a population of 30,000. There is a large town, Luganville (the second largest in the country) and there has been some agricultural development on the island. However, most people still live in small villages throughout the island and are engaged in subsistence farming. Interviews were held at 9 villages on the island. A total of 102 males were interviewed, ages ranged from 10 to 75.

Viti Levu is Fiji's largest island, with an area of approximately 10,400 square kilometres and a population of around 580,000. It is the main political and administrative centre in Fiji and most of the countries principal industries are located there. The island is divided by a mountain range into two distinct regions, the drier western side where the flora consists of mainly open grassland and the wetter eastern side predominately covered by greener vegetation and rainforest. Also on the eastern side is the country's capital and largest city, Suva. The city and its surrounding urban area have a population of around 140,000 people, one-fifth of Fiji's urban population. Away from the urban areas many Fijian's still live in small villages. The interviews on Viti Levu were carried out at 6 villages on the eastern side of the island all within 150km of Suva. A total of 57 males were interviewed, aged between 10 and 67.

Knowledge of bird life.

Knowledge of bird life was tested by showing people colour illustrations of species that occur locally (i.e. occur on their island) and illustrations of non-native (Australian) species The interviews themselves were conducted (on a 1:1 basis to deter collusion) with male members of the villages because the previous study on Vanuatu had shown men to have better knowledge of bird life than females (see results and discussion). They were shown, one at a time, illustrations of 29 birds, 21 of which were local species (either Vanuatuan or Fijian) and 8 non-native Australian species. Interviewees were asked to respond 'yes' or 'no' to whether they thought each bird occurred on their island. In order to determine whether or not common species were better known to the islanders than rarer ones, each species was categorized as either common (including abundant) or uncommon (including rare) based on the available literature.

3. Results

(i) Mapping the distribution of birds in Vanuatu

The majority of ni-Vanuatu interviewed were familiar with the resident birds on their islands. They usually responded to the colour illustrations of them quickly and confidently, and frequently offered additional information about the precise locations of particular species. Conversely, they mostly responded to illustrations of non-resident species by indicating that they were not present on the island. Most people, who were interviewed, satisfied both criteria for good knowledge (responding correctly to most of the illustrations of both resident and non-resident species). However, the proportion of males reaching these criteria (87.2%) was higher than that in females (58.0%). This difference was evident in data for each of the islands considered separately ($P<0.001$; $N = 12$; Wilcoxon Matched-Pairs Signed-Ranks Test) (Table 1).

There was close conformity between the results obtained from analyses of local knowledge and sightings of estrildids from field observations. They suggest that each species has a patchy distribution and is restricted to relatively few of the islands. Where there were actual sightings of species on the following islands during formal field counts of birds, in each case, high proportions of local people (>37%; $P<0.001$ in each case) claimed that they were present on the island concerned (Table 2):

Common Waxbill on Efate;

Royal Parrot Finch on Efate, Emae, Tongoa, and Epi;

Blue-faced Parrot Finch on Efate;
Chestnut-breasted Mannikin on Santo;
Black-headed Mannikin on Malakula and Santo.

Table 1 - Numbers of men and women who were categorised as having either 'good knowledge' (GK) or 'poor knowledge' (PK) of local bird life.

	Males			**Females**		
Island	**Sample size**	**GK**	**PK**	**Sample size**	**GK**	**PK**
Aneityum	27	23	4	13	9	4
Tanna	42	33	8	15	12	3
Efate	62	50	12	22	8	14
Emae	34	29	5	11	6	5
Tongoa	39	38	1	15	10	5
Epi	34	31	3	15	9	6
Ambrym	25	24	1	13	10	3
Malakula	35	34	1	14	9	5
Pentecost	36	32	3	12	7	5
Ambae	36	32	4	15	7	8
Maewo	32	28	4	16	8	8
Santo	38	33	5	20	10	10
Total	**444**	**387**	**57**	**181**	**105**	**76**
Percent		**87.2**	**12.8**		**58.0**	**42.0**

*Table 2 - Percentages of positive ('yes') responses to colour illustrations of 5 estrildids in people with 'good knowledge'. Statistical comparisons were based on proportions of yes : no answers on each of the islands separately with those summated for all of the islands on which the species had not been recorded: * = P<0.05; ** = P<0.01; *** P < 0.001; Chi-square Test.*

Island	**N**	**Common Waxbill**	**Royal Parrot Finch**	**Blue-faced Parrot Finch**	**Chestnut-breasted Mannikin**	**Black-headed Mannikin**
Aneityum	32	9.4	12.5	**21.9***	9.4	12.5
Tanna	45	11.1	13.3	**28.9*****	15.6	15.6
Efate	58	**48.3*****	**37.9*****	**46.6*****	8.6	6.9
Emae	35	0	**60.0*****	2.9	2.9	2.9
Tongoa	48	4.2	**68.8*****	10.4	4.2	0
Epi	40	10.0	**50.0*****	5.0	20.0	15.0
Ambrym	34	2.9	**38.2*****	8.8	14.7	14.7
Malakula	43	8.7	16.3	9.3	14.0	**20.9***
Pentecost	39	9.0	12.8	7.7	20.5	10.3
Ambae	39	0	10.3	7.7	10.3	2.6
Maewo	36	11.1	5.6	8.3	11.1	2.8
Santo	43	14.0	11.6	4.8	**41.9*****	**67.4*****

(ii) Environmental knowledge in Vanuatu and Fiji.

Men from the island of Santo have superior knowledge of their local bird fauna than those from Viti Levu. Almost all of those interviewed on Santo recognised (responded 'yes' to) the majority of the illustrations of Vanuatuan species. Knowledge of common species was significantly better than that of uncommon ones (W=196, P<0.01: Mann Whitney U Test) (Table 3). Australian species were also recognised as non-native species. None of them received >25% positive responses.

Table 3 - Mean percentage of males responding positively to illustrations of species grouped according to their relative abundance on Vanuatu or Fiji.

	Common		Uncommon	
Species	**n**	**Mean ±SE**	**n**	**Mean ±SE**
Vanuatuan	16	88.5 ±2.6	5	58.6 ±6.7
Fijian	15	41.5 ±5.9	6	12.0 ±1.7

In contrast, Fijian men had difficulty in identifying resident species. Only five bird species received >50% 'yes' responses. These were all common species and, not surprisingly therefore, overall common species were significantly better known than uncommon ones ($W=175$, $P<0.01$; Mann Whitney U Test). Fijian men were more successful in providing 'correct' answers (i.e. they answered 'no' more often), than those from Santo, to illustrations of Australian species. However, this is almost certainly due to their tendency to answer 'no' to most birds shown to them (Fijian or Australian), rather than a realisation that they were not native species.

Ni-Vanuatu show no evidence of improvement in knowledge of birds with age. The scores obtained by children of between the ages of 7 to 10 was as good as that of older men. Coefficients of correlation between age and percent correct responses were small and not significant for both Vanuatuan and non-native (Australian) species. In contrast, older Fijian men were better able to recognise birds than younger ones. This was the case in responding to illustrations of both native Fijian species and Australian ones, coefficients of correlation were significant in both cases.

4. Discussion

The results of the studies suggest that local knowledge can be used as an inexpensive and effective rapid appraisal method for assessing the distribution of birds. The technique described here can be effective in habitats that are difficult to survey but are inhabited by human populations and it can almost certainly be adapted for use with other groups of organisms. However, it depends on good environmental knowledge in the participants. This was evident in ni-Vanuatu, especially men. They spend a great deal of their time hunting in the forest and tending village gardens, while most women remain within the villages. The distributions of the study species in Vanuatu assessed on the basis of local knowledge conformed closely with those derived from actual sightings of the birds (Fig. 2).

The technique may be less effective in countries where there has been significant 'western' influence. People in them have tended to lose their affinity with the environment[1] and mostly have poor knowledge of the environment[7, 16, 17]. This was shown to be the case in the Suva region of Fiji, where local knowledge was too poor to permit the technique to be used to map the distribution of birds.

The second study confirms that males from Vanuatu (from the island of Santo) have remarkably good knowledge of the local bird fauna. It is surprising that knowledge of children is as good as that of adults, and that there was therefore no improvement in it with age. They presumably acquire their knowledge on early hunting and 'gardening' visits to the forest with adult males. In marked contrast to ni-Vanuatu, male Fijians, who were interviewed, had poor knowledge of local birds.

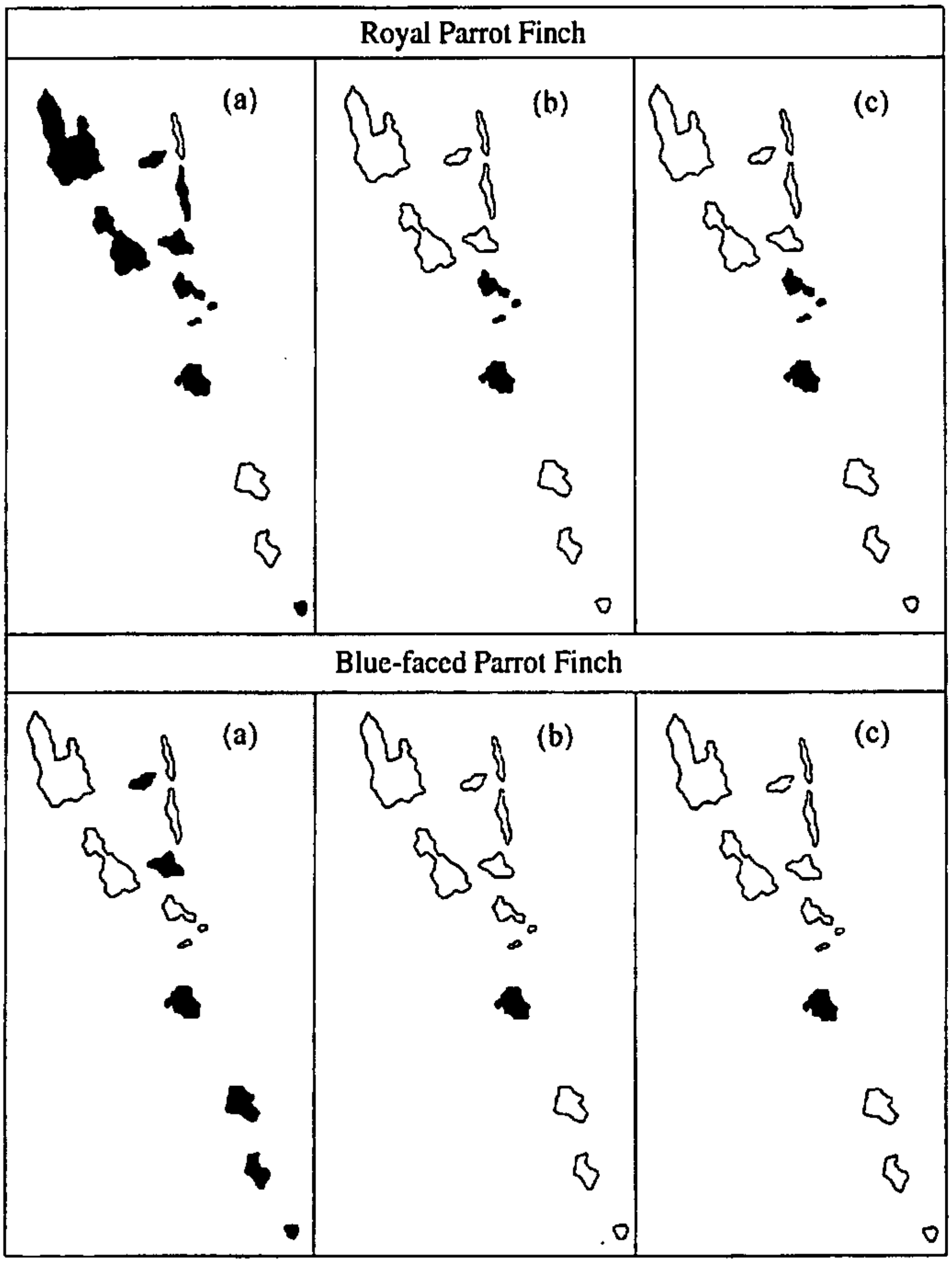

Figure 2 - Distributions of two endemic sub-species of estrildids on Vanuatu: the endangered Royal Parrot Finch and the Blue-faced Parrot Finch. Islands where the species occurs are shown in black. (a) distributions according to records in Bregulla[15]*; (b) distributions based on the analyses of local knowledge; and (c) distributions based on sightings of finches in the present study.*

Poor knowledge of the environment may not be widespread in Fiji. Interviewees in the present study were from villages within 150km of Suva, and many of them travelled daily into Suva for work. It is likely that people on more remote parts of Viti Levu and on other islands have retained a close affinity with the environment and still have good knowledge of it. However, children from the study area, as well as adults, have poor knowledge and this may reflect deep cultural changes, associated with 'western' influence. Unlike Vanuatu, children actually have poorer knowledge than adults, suggesting that there are still some adults with good knowledge but that it is being lost progressively from the society. The consequences may be serious. A number of authors have stressed the importance of local participation in environmental management[1, 18] and, given poor affinity with, and knowledge of, the environment, this is unlikely to occur. Since it is obviously unrealistic to expect people to give up their jobs in Suva in order to return to former rural ways of life, methods must be found of re-kindling environmental knowledge. Environmental education clearly has a key role to play[19].

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THE VALUE OF FISHERS' KNOWLEDGE AS A RAPID APPRAISAL TECHNIQUE TO ASSESS THE ABUNDANCE AND DISTRIBUTION OF CETACEANS IN THE NORTH SEA

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Specialist groups such as fishers have a deep understanding and knowledge of their local environment. This is acquired, in part, through their experiences working outdoors at sea, but it is also passed through successive generations of fishing families. There are indications that this knowledge is being lost progressively as the fishing industry declines. The paper demonstrates the value of fishers' knowledge in a scientific context, as a rapid appraisal technique to survey the distribution and abundance of cetaceans in the North Sea. Previous scientific surveys have often been either spatially limited and/or extremely expensive. Input from volunteer programmes has been extremely valuable and cheap, but has had relatively little contribution from fishers. Interviews were conducted with fishers from a range of North Sea ports, asking in particular for information on sightings of whales and dolphins. The findings show that the range and abundance of species found in the northern North Sea is greater than in its southern parts. There was evidence that species such as the Minke and Killer whale, are now being sighted more frequently and are therefore probably increasing in numbers. Sightings, such as that of the Sperm whale were exciting and unexpected. There were even fishers who claim to have seen Blue whales and Belugas in far northern areas of the North Sea. Corroboration from cetacean experts and data from strandings suggest that the fishers' knowledge has a high degree of reliability and therefore represents a valuable resource for environmental management.

1. Introduction

It is recognised that specialist groups such as fishers have a deep understanding and knowledge of their local environment [1, 2]. This is acquired in part, through their experiences working outdoors at sea, but it is also traditionally passed through successive generations of fishing families. There are indications however, that this knowledge is being lost progressively as the fishing industry declines [3]. Technological advances mean that younger fishers' require a different suite of skills to fish successfully and are much less reliant on learning the old ways, or 'meads'. There is a real danger that this important resource will be lost as elder generations pass away. This is particularly evident in developing countries, where traditional teaching is being replaced by Western-style education systems, which tend to ignore the value of local knowledge. For example, when documenting the traditional ecological knowledge of beluga whales held by hunters in Alaskan and Russian villages, Mymrin *et al.* [4], found that younger hunters had comparatively little understanding of the ecology of their prey than their elders. The western educational systems in place were doing little to protect traditional skills and observational techniques leading to further declines in the knowledge base.

Although in the past there has been little cooperation between fishers and environmental managers, there is increasing recognition that stakeholders can bring expert knowledge of the environment to the table, and as a result in coastal waters of the UK it is becoming more commonplace for fishers to be involved in fisheries management [5]. However it remains that, beyond the involvement of

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fishers in the management of commercial fisheries, there is little consultation on other non-target marine species, meaning that the potential wealth of fishers' knowledge is still not being fully explored [6].

This paper demonstrates the value of fishers' knowledge in a scientific context, as a rapid appraisal technique to survey the distribution and abundance of cetaceans in the North Sea. Rapid appraisals have great potential as a cost-effective tool for providing baseline data, monitoring change, and assessing priorities for future research. Recently, local knowledge has been used within rapid appraisals, encouraging the participation of local communities in resource management. For example, rapid surveys of local knowledge have been used to assess trends in biodiversity relating to forest cover in Mexico and similarly in grassland areas of Uganda [7, 8], and to map the distribution and assess conservation needs of finches on Vanuatu [9]. Fishers' knowledge in particular has been used to gain preliminary information on tropical fish prior to sampling in unfamiliar ecosystems [10].

Current data on the distribution and abundance of cetaceans come from three main sources: scientific studies, sighting surveys carried out by volunteers and strandings. Previous scientific studies have often been either spatially limited and/or extremely expensive, and many focus on only a few species. To date, the most comprehensive assessment of cetaceans in the North Sea and adjacent waters was that of the SCANS (Small Cetacean Abundance in the North Sea) project, conducted in 1994 by scientists from a number of European marine research stations [11]. This survey combined shipboard and aerial transects covering a total distance of 27,000km at great expense. The project was successful in providing estimates of abundance for the Harbour porpoise, White-beaked dolphin, Common dolphin and Minke whale. However, as the name of the survey would suggest, larger species were not included. The authors also note that the results cannot be used to determine whether species are increasing, decreasing or are stable in numbers. The largest effort-related cetacean sightings dataset is held by *The Seabirds at Sea Team* of the JNCC (Joint Nature Conservation Committee). Observations of marine mammals were collected as an ancillary role during assessments of seabirds around Britain and Ireland. These surveys have been conducted year round from 1979 to 1990 on a limited budget using a variety of 'platforms of opportunity' [12]. However, although extensive, the data collected for the North Sea is pre–1987, and as with the SCANS survey, focuses on the Harbour porpoise, White-beaked dolphin and Minke Whale.

Input from volunteer programmes is extremely valuable and provides a cheap means of collecting data over extended time frames. For example, the Sea Watch Foundation has collated opportunistic sightings and those from dedicated watches since the early 1960s [13]. Information provided by volunteers originates from both land based watches and offshore observations, utilising a variety of 'platforms of opportunity' to minimise costs. However, although these vessels have included those involved in research, fishery protection, seismic activities and ferries, very few sightings have been reported from fishing vessels. The present study establishes the contribution which can be made by fishers in assessing the abundance and distribution of cetaceans while going about their daily activities at sea.

2. Methods

2.1. Study Area

The study included 12 ports bordering the North Sea, these were: Lowestoft, Grimsby, North Shields, Blyth, Eyemouth, Fraserburgh, Peterhead, Lerwick and Scalloway (Shetlands), Hvide Sande and Thyborøn (Denmark) and Haugesund (Norway) (Figure 1). These ports were chosen to provide good coverage of the whole of the North Sea and due to the reasonable size of the remaining fishing fleets at each. However, information from some of the ports was later combined due to their proximity or the availability of fishers: these were Fraserburgh and Peterhead, and the Shetland and Danish ports. North Shields, Blyth and Eyemouth were also combined to give a 'Northumberland' dataset, as all the fishers interviewed in Eyemouth were actually based in Amble or Holy Island.

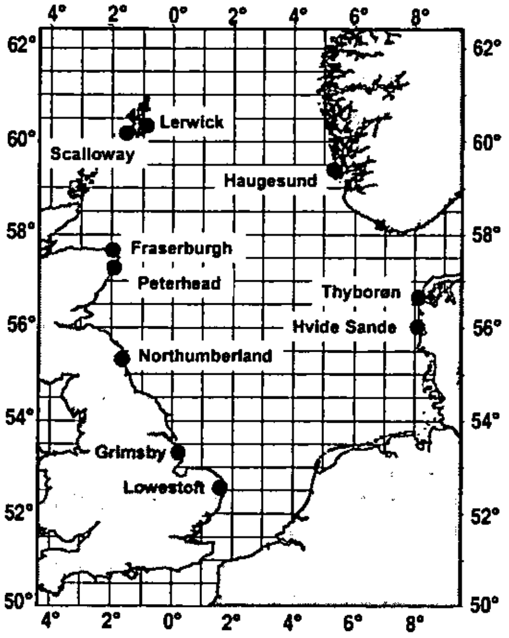


Figure 1 - Map showing the locations where interviews were held.

Initial contacts in each case were made with the Fisherman's Associations or Producers' Organisations, who often suggested names of specific skippers to target. However, most interviewees were selected randomly depending on their availability, which meant a cross section of different types of fishers was interviewed. I aimed to interview the skipper of each vessel, as the most experienced member of the crew. However, this was not always possible, in which case the crew nominated a spokesperson.

2.2. Interview Design

Interviews were conducted between 20th April and 26th August 2004, with a total of 107 participants. The majority of interviews were held onboard fishing vessels to cause the least disturbance to the fishers' business, although this was dependant on the suggestion of the fisher. Some were conducted on the quayside or after the fish auction, others were held at the Fisherman's Mission or Producers' Organisation office, or on occasions at the fisher's home. For these reasons, the length of the interviews varied from about 30 minutes to up to two hours.

Information was collected using semi-structured interviews, based around a set of predefined questions. The semi-directive method allowed the interviewer to cover the relevant topics, without the need to adhere to a particular order, and afforded flexibility for the interviewee to lead the conversation onto other issues of concern. Cetacean identification guides were available to use for those fishers who had seen specific cetaceans but were unsure of their identification, although very few actually found it necessary to refer to such guides. To minimise language barriers, the questions were translated into Danish and Norwegian, including local names for particular species.

A local interpreter was present during the interviews in these two countries. Two types of information were gathered,

i) Quantitative, factual information to allow comparisons to be made between responses of different participants. These questions related to personal information such as 'what type of fishing do you do?', cetacean abundance and distribution such as 'how regular are sightings of each species of porpoise, dolphin and whale?' (common, occasional, uncommon, not seen), 'how confident are you that your identification is correct?' (for example, 100% no doubt of correct identification, 75% fairly sure, 50% some reservations and 25% may have misidentified the species), 'what time of year do sightings occur?' and 'over the years have sightings of porpoises, dolphins and whales increased, decreased or remained the same?'

ii) Qualitative, in-depth information allowing expansion on the above questions, such as 'what has caused the changes in abundance', and particular experiences and opinions relating to management issues.

Quantitative results were tabulated to determine the number of fishers who had seen each species and how regularly sightings had occurred over the previous year. From these tables, an abundance score was calculated for each species at each port. The score was assigned depending on whether sightings had been listed as common, occasional, uncommon or not seen in the last year. A reply of 'common' was assigned a score of 3, 'occasional' a score of 2 and 'uncommon' a score of 1. The totals for each port were then divided by the number of fishers interviewed to give abundance per fisher for each species. These scores were then plotted onto maps of the North Sea to determine the distribution of species.

3. Results

3.1. Personal details

Very few fishers who were approached refused to be interviewed; those who did decline were usually involved in maintenance work prior to going to sea. Of the 107 fishers interviewed, the majority described themselves as offshore fishers (43%), 28% as inshore fishers and 29% undertook both inshore and offshore fishing (Table 1). Overall, fishers at each port had a similar number of years experience at sea, with the mean ranging from 26 years in the Shetlands and Fraserburgh to 33 years in Norway.

Table 1 - Summary of fishers' personal details at each port.

Port	**Number of Fishers Interviewed**	**Number of Years Experience Fishing (mean)**	**Type of Fishing**		
			Inshore	**Offshore**	**Both**
Shetlands	22	26	4	8	10
Norway	12	33	2	7	3
Fraserburgh	19	26	1	13	5
Denmark	17	29	1	15	1
Northumberland	15	29	9	1	5
Grimsby	11	29	7	1	3
Lowestoft	11	27	6	1	4
		Totals (%)	**28**	**43**	**29**

3.2. Abundance of cetaceans

Five species were sighted by fishers in at least some parts of the North Sea on a regular basis: Harbour porpoise, Killer Whale, Minke Whale, Long-finned pilot whale and White-beaked dolphin. A further three species were seen occasionally: Bottlenose dolphin, Common dolphin and Atlantic white-sided dolphin, with less frequent sightings of Humpback whale, Risso's dolphin, Sperm whale and Fin whale (Tables 2 and 3). There were also some interesting one-off sightings of a Striped dolphin off the coast of Northumberland, a Blue whale off Foula in the Shetlands and a Beluga spotted in waters north of the Shetlands by a Danish fisherman.

Table 2 - Abundance scores for whale species at each port.

		Species Abundance Scores					
Port	**Number of Fishers Interviewed**	**Minke**	**Fin**	**Killer**	**Long-finned pilot**	**Humpback**	**Sperm**
Shetlands	22	0.64	0.05	1.86	1.05	0.09	0.14
Norway	12	1.75	0.08	2.25	0.83	0.25	0.08
Fraserburgh	19	0.53	0.00	1.79	0.58	0.16	0.05
Denmark	17	0.12	0.00	0.41	0.00	0.00	0.00
Northumberland	15	0.33	0.07	0.53	0.73	0.00	0.00
Grimsby	11	0.36	0.00	0.18	0.18	0.00	0.00
Lowestoft	11	0.27	0.00	0.00	0.09	0.00	0.00
Totals	107	4.00	0.20	7.03	3.46	0.50	0.27

Table 3 - Abundance scores for porpoise and dolphin species at each port.

		Species Abundance Scores					
Port	**Number of Fishers Interviewed**	**Harbour porpoise**	**White-beaked**	**Bottlenose**	**Atlantic White-sided**	**Common**	**Risso's**
Shetlands	22	1.68	0.82	0.09	0.55	0.32	0.32
Norway	12	1.75	0.25	1.00	0.25	0.25	0.00
Fraserburgh	19	1.42	0.95	0.47	0.26	0.26	0.05
Denmark	17	1.18	0.47	0.12	0.00	0.29	0.00
Northumberland	15	1.47	0.33	0.53	0.07	0.40	0.00
Grimsby	11	2.00	0.27	0.55	0.00	0.00	0.00
Lowestoft	11	1.82	0.27	0.09	0.00	0.27	0.00
Totals	107	11.31	3.36	2.85	1.13	1.80	0.37

The majority of fishers did not feel the need to refer to the identification guides provided during the interviews. However, the guides were of use on occasions, to confirm that both interviewer and interviewee were referring to the same species, particularly in Denmark and Norway. On the whole, the fishers' confidence that they had correctly identified each species was high, with average confidence levels exceeding 83% for each species (Table 4). Of all the species, the distinct markings of the Killer whale made it the easiest to identify (99% confidence), followed by the Harbour porpoise (98% confidence), again, relatively easy to identify due to its small size and frequent occurrence. The fishers had the lowest confidence in their identifications of the Fin whale and White-beaked dolphin (83% and 85% respectively).

Table 4 - Fishers' confidence (in percent) of correct species identification. Key: M = Minke whale, F = Fin whale, K = Killer whale, LFP = Long-finned pilot whale, H = Humpback whale, S = Sperm whale, HP = Harbour porpoise, WB = White-beaked dolphin, B = Bottlenose dolphin, AWS = Atlantic white-sided dolphin, C = Common dolphin, R = Risso's dolphin.

	Whale Species						Porpoise and Dolphin Species					
	M	**F**	**K**	**LFP**	**H**	**S**	**HP**	**WB**	**B**	**AWS**	**C**	**R**
Shetlands	96	100	99	93	100	100	100	88	100	84	100	75
Norway	100	100	100	100	100	100	100	50	100	100	100	-
Fraserburgh	79	-	98	90	90	80	95	85	98	85	90	100
Denmark	100	-	100	-	-	-	100	100	100	-	100	-
Northumberland	100	50	98	94	-	-	92	100	81	90	97	-
Grimsby	100	-	-	100	-	-	100	75	77	-	-	-
Lowestoft	100	-	-	100	-	-	100	100	100	-	95	-
Average (mean)	**96**	**83**	**99**	**96**	**97**	**93**	**98**	**85**	**94**	**90**	**97**	**88**

3.3. Changes in Abundance

When asked whether numbers of whales had changed over the years, 27% of fishers thought numbers had increased, 17% thought they had remained the same and only 11% replied decreased (Figure 2). However, almost half of all fishers were unable to offer an answer. This figure was largest for those fishing south-eastern parts of the North Sea, with many saying that they had not seen sufficient whales during their time at sea to comment. Those fishers from Grimsby and Lowestoft that did answer thought numbers of whales had declined. The northern parts of the North Sea, Norway, Fraserburgh and the Shetlands, had seen the biggest increases in numbers, particularly of Killer whales.

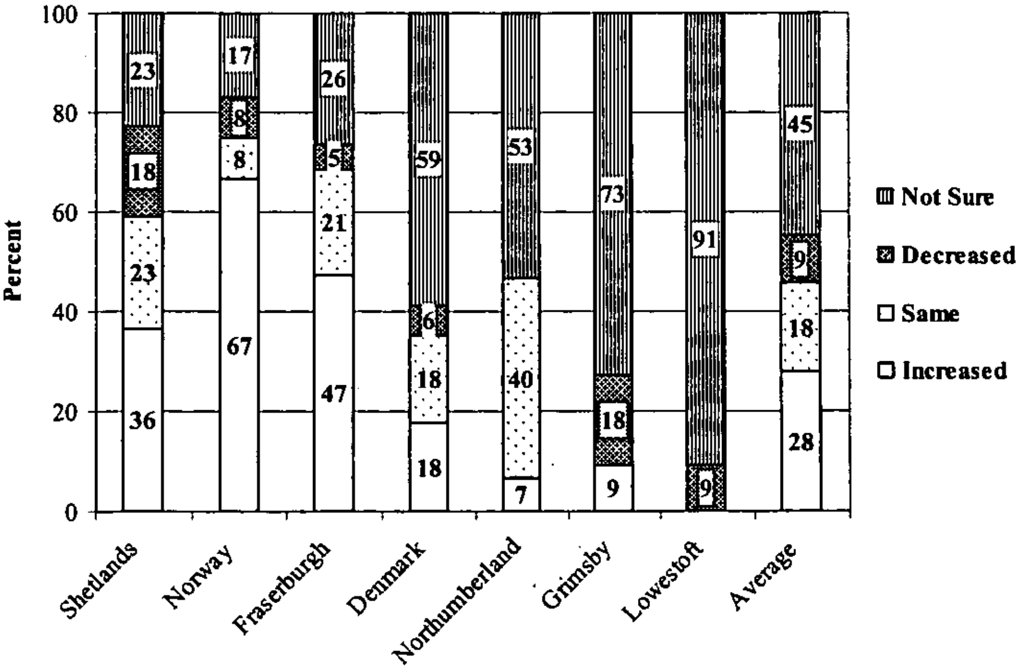


Figure 2 - Fishers perceived direction of change in whale abundance in the time they had been fishing. The percentage values are shown on each bar.

When the fishers were asked the same question about porpoises and dolphins, 33% of fishers replied that numbers had increased; a further 32% thought they had remained the same, while 14% thought numbers had decreased (Figure 3). Compared to the whales, fewer interviewees replied that they were not sure whether abundances of porpoises and dolphins had changed over the years. The abundance of porpoise and dolphins in south-eastern waters appears to have increased or remained the same, compared to the decreases noted for whale species.

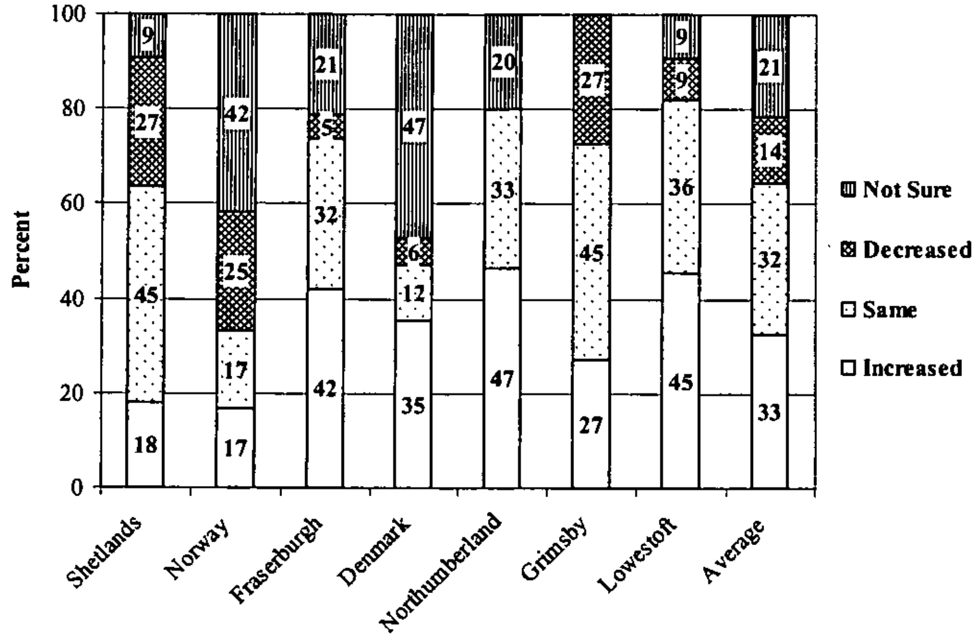
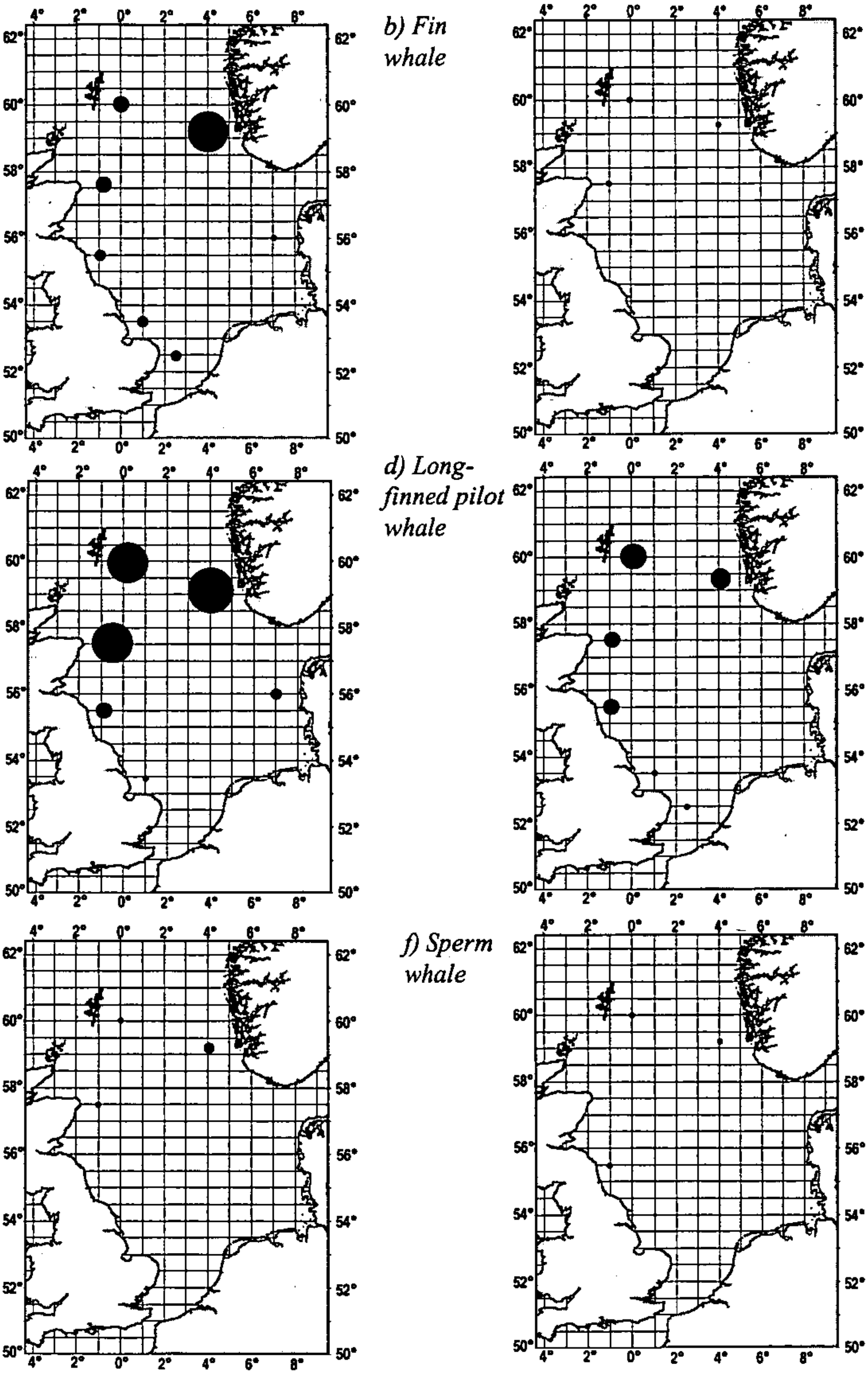


Figure 3 - Fishers perceived direction of change in porpoise and dolphin abundance in the time they had been fishing. The percentage values are shown on each bar.

3.4. Distribution of cetaceans

It is evident that there is a clear divide in the distribution of whales, with all species being more abundant in the north-western area of the North Sea than in south-eastern parts; indeed, the Fin, Humpback and Sperm whale are absent from the more southerly parts (Figure 4; b, e, f). The Killer whale (Figure 4c), by far the most frequently sighted whale species, was most common off the coast of Norway, followed by the Shetlands and off the coast of northeast Scotland. Similar patterns were noted for both the Minke and Long-finned pilot whales (Figure 4; a, d).

For the porpoise and dolphin data, the divide between north-western and south-eastern parts was less distinct. Only sightings of the Atlantic white-sided dolphin and Risso's dolphin were confined to the north-western parts of the North Sea (Figure 5; d, f). This would be expected for these 'northern' species. The White-beaked, Bottlenose and Common dolphin, are all seen throughout the North Sea (Figure 5; b, c, e), as is the most frequently sighted of all the cetaceans, the Harbour porpoise. The Harbour porpoise is ubiquitous throughout the whole of the North Sea, with the highest abundance scores at Grimsby and Lowestoft (Figure 5a).



a) Minke whale

b) Fin whale

c) Killer whale

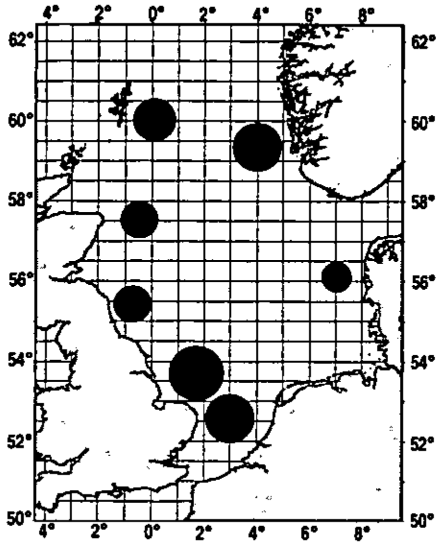
d) Long-finned pilot whale

e) Humpback whale

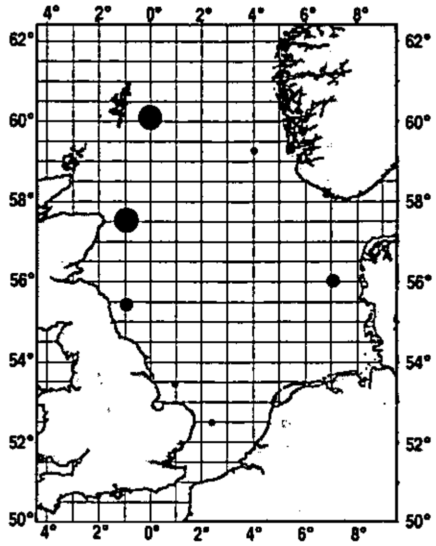
f) Sperm whale

Figure 4 - Distribution of whale species throughout the North Sea. The size of the circle represents the relative abundance score at each port. No symbol at ports at which the species had not been sighted.

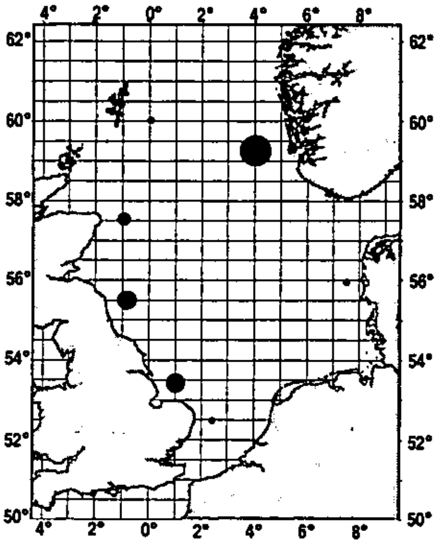
a) Harbour porpoise



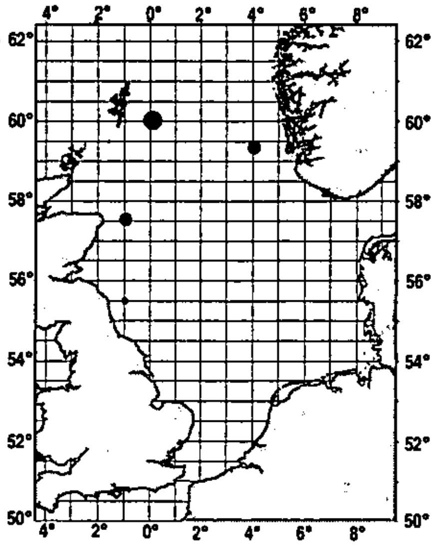
b) White-beaked dolphin



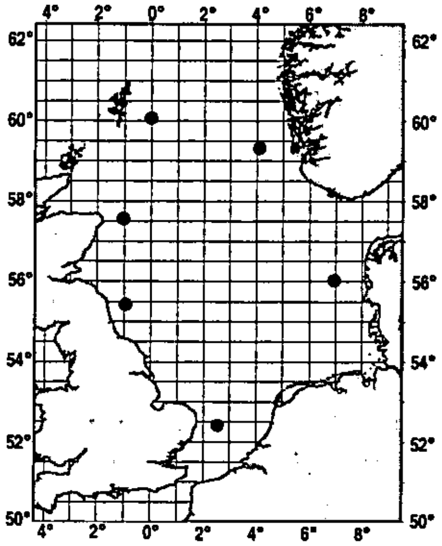
c) Bottlenose dolphin



d) Atlantic white-sided dolphin



e) Common dolphin



f) Risso's dolphin

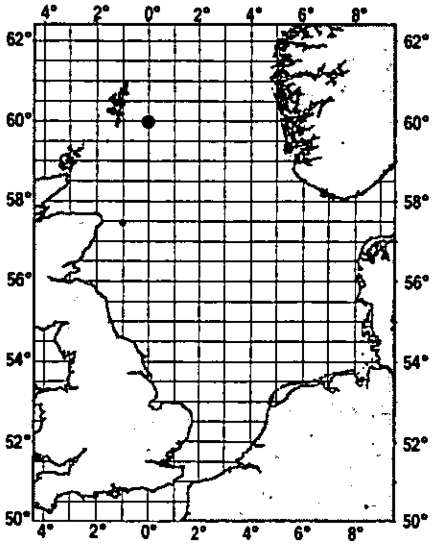


Figure 5 - Distribution of porpoise and dolphin species throughout the North Sea. The size of the circle represents the relative abundance score at each port. No symbol at ports at which the species had not been sighted.

3.5. Seasonality

Seasonality in the distribution of sightings followed the same pattern at each of the study ports. Cetaceans were seen throughout the entire year, with a peak in sightings within the summer months of June to August for porpoises and dolphins (34% of all sightings) and whale species (36% of all sightings, Figure 6). The numbers of sightings which occurred during the spring and autumn months were similar, both being less than summertime, while the winter months bore the least sightings of all (19%). For whale species, a distinction can be drawn between the north-western and south-eastern parts of the North Sea, as in the latter, sightings occur mainly in the summer months. Indeed, no sightings of whales were recorded at all in Denmark during the spring, or Grimsby and Lowestoft during the winter months (Table 5).

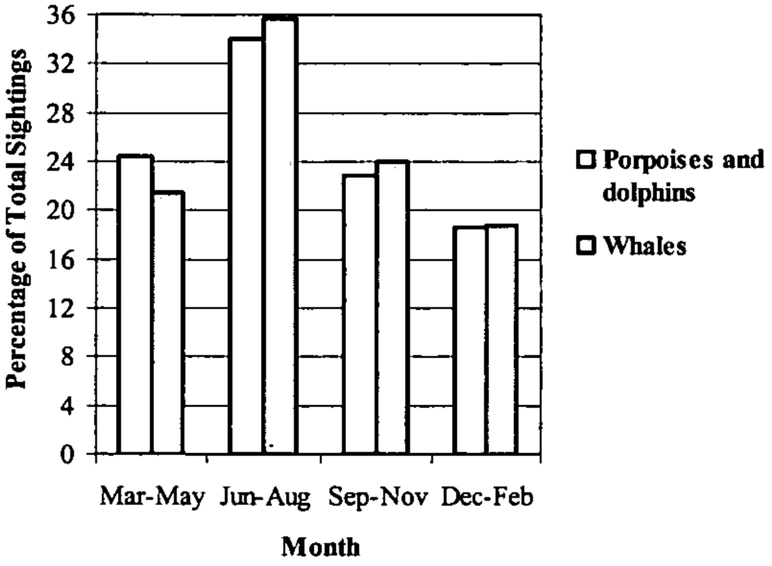


Figure 6 - The percentage of total sightings occurring over various months.

Table 5 - The percentage of fishers at each port to have seen porpoises, dolphins and whales over various months.

	Porpoises and Dolphins				Whales			
Port	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb
Shetlands	45	73	45	36	32	59	45	32
Norway	58	75	58	58	67	83	75	67
Fraserburgh	63	84	58	58	47	58	42	42
Denmark	24	59	12	12	0	18	12	12
Northumberland	67	87	73	60	40	73	40	27
Grimsby	64	73	55	27	9	36	9	0
Lowestoft	82	91	73	45	18	27	9	0

4. Discussion

The results of this study suggest that fishers' knowledge could be utilised to provide a cost-effective rapid appraisal of cetaceans in the North Sea. It is evident that North Sea fishers are familiar with a range of cetaceans, being able to determine their abundance and distribution, and comment on factors affecting different species. The fishers interviewed in this study, had an average of 28 years at sea. Indeed, the numbers of years experience at sea is important, as knowledge tends to be unevenly distributed between fishers, being concentrated among skippers, particularly those with lengthy fishing careers [14]. However, as with scientific data, it remains important to validate fishers' knowledge where practical.

Corroboration from existing data would seem to suggest that the fishers' knowledge of cetaceans has a high degree of reliability and therefore represents a valuable resource for environmental management. The abundance scores calculated from fishers' knowledge for the species they observe whilst at sea, correspond well to information in a recent report compiled by The Sea Mammal Research Unit. The report lists the Harbour porpoise, Bottlenose dolphin, White-beaked dolphin, Atlantic white-sided dolphin, Killer whale and the Minke whale as the most frequently sighted cetacean species within the North Sea [15]. The report also states that sightings of a further four species, Risso's dolphin, Common dolphin, Long-finned pilot whale and Sperm whale have been reported fairly regularly. However, these live sightings of Sperm whales tend to be from the northern North Sea, which does not correspond well with sightings further south from the Northumberland fishers. Yet there is evidence that the species does venture into southern waters, as two strandings occurred on the East Anglian and Lincolnshire coasts in 2004 alone [16]. Of the species sighted less often by the fishers, the Humpback and Fin whale have both previously been noted within the North Sea through occasional at-sea records. Data held by Sea Watch actually shows an increase in casual sightings of Humpbacks from 9 between 1980-89 to 54 between 1990-99 [13].

The majority of fishers believe that numbers of cetaceans as a whole are on the increase. A variety of possible reasons for this were put forward, ranging from changes in environmental factors, human activities, and the ban on whaling. By far the most common factor suggested as being responsible for the increase in cetacean numbers was an increase in the amount of food available and changes in prey sources. Many fishers commented that stocks of pelagic species such as herring and mackerel are on the increase, and several skippers of pelagic boats said they have observed cetaceans when they are out fishing, migrating to follow these stocks. The increases in seal populations within the North Sea since the early 1990s were thought to have had a huge influence on the numbers of Killer whales in particular. One Shetland fisher even commented that:

> *'Killer whales are even coming in the harbour here catching seals; there is plenty of food about for them.'*

Indeed, prey abundance and movement are thought to be the most important factors affecting the movement of cetaceans, with availability of the principal prey species being key to their population changes [15, 17].

When the fishers' data is plotted, the distribution of most of the species compares well to the *Atlas of cetacean distribution in north-west European waters*, compiled from data provided by the SCANS, SAST and Sea Watch surveys [13]. However, there are exceptions where the fishers' data describe wider distributions for certain species than the Atlas. For example, the Atlas states that the Minke whale and Long-finned pilot whale are rare or unseen in southern parts of the North Sea, yet we have several sightings of each species from as far south as Lowestoft. The fishers' data also suggests that Minke whales and Bottlenose dolphins are seen in the largest numbers off the coast of Norway. According to the Atlas, the Minke is less common in these eastern parts of the North Sea and the Bottlenose dolphin is supposedly absent. It may be that the change in distribution has occurred only recently since the Atlas data was collected, as commented on by a Norwegian fisher:

'We are seeing Minke whales in areas we never saw them before 2 or 3 years ago, off Haugesund and Bergen in the deep areas.'

The discrepancy could also be due to the lower search effort off the Norwegian coast within the Atlas surveys. It is important to note that this distribution of search effort, or in our study, whether fishers' activity is focused in either inshore or offshore waters, may influence the reliability of survey results. For example, the uneven distribution of whale species in the fishers' data, with large numbers seen in north-western parts of the North Sea, could be affected by the high number of offshore fishers in the northern ports. Offshore fishers are more likely to come into contact with larger cetaceans, which tend to be more common in deeper waters, than their inshore counterparts. Likewise, the more even distribution of porpoise and dolphin sightings from fishers' data, may be related to the presence of small cetaceans in coastal waters where inshore fishers from all ports work. However, this pattern does not explain why the mainly offshore Danish fishing fleet have low abundance scores for whales. Nonetheless, this highlights an issue in survey design, that by interviewing a broad cross-section of fishers, difficulties may arise in interpreting the results.

The fishers' data describes seasonality within the North Sea, with peak numbers of sightings for all species during the summer months. For the whale species in particular, sightings occur over a longer period throughout the year in northern parts compared to the south, as commented on by one Norwegian fisher:

'You see cetaceans from summer through to winter in the northern North Sea, but only summer elsewhere. We see lots here (Norway) when the herring come into the western fjords.'

This pattern could be due to cetaceans migrating into the North Sea on a seasonal basis. For example, during their seabird surveys at sea Northridge *et al.* [12] found that minke whales were most frequently observed between May and October. They suggested that Minkes travel south from Atlantic waters into the northern North Sea rather than arriving from the southern North Sea and channel. It is important to note however, another factor which could also contribute to the peak in sightings during the summer months is that better sea conditions at this time of year make it much easier to record and correctly identify cetaceans. This affects all cetacean surveys, and in the case of land based volunteer surveys, there is the added factor that effort tends to be much lower in the winter months [13].

The fact that fishers are at sea, and able to observe, throughout the entire year, demonstrates just one way in which fishers' knowledge has advantages over other survey techniques. The use of fishers' knowledge could also prove extremely beneficial in those areas where previous 'conventional' survey efforts have been unsuccessful due to logistical constraints. For example, Johannes *et al.* [1] summarise several studies where biologists have underestimated populations of Arctic whale species as information on stocks has been difficult and expensive to obtain. When the environmental managers have sought the cooperation of the local people it has led to the implementation of better survey techniques, and improved understanding of stocks, as the indigenous hunters' hold invaluable knowledge on distribution patterns, behaviour, and inter-annual abundance of arctic whale species gained through close ties with their environment. Similarly, when documenting hunters' knowledge of Beluga whales in north western Alaska, Huntington [18] found that in addition to describing feeding behaviour, migrations, calving, predator avoidance and ecological interactions, the hunters could provide in depth observations of human interactions and activities that were uncommon in scientific publications of Belugas.

It is clear that fishers' knowledge has wider applications beyond its value as a rapid appraisal technique. Fishers' observations of environmental factors are essentially linked to their fishing success. This knowledge is compiled not just from personal experience at sea, but based on that of generations before and others with whom they have fished. The incorporation of this knowledge into environmental management is required to ensure the sustainable use of marine resources such as cetaceans.

5. Acknowledgements

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MAPPING THE HUMAN LANDSCAPE

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Fishermen's knowledge in north Northumberland is changing as the industry changes, and vanishing as it declines. I have spent a number of years recording this knowledge, and will touch on three main areas of my research: first, fishermen's practical knowledge and skills; secondly, their stories and folklore; and thirdly, their dialect. I will also talk about the methods I used to collect this knowledge, and about ways of disseminating it through the collaboration of science with creative arts such as poetry. I aim to show that the fishermen's skills and stories are of enormous importance: because they contribute to a sense of place, identity and belonging; and because they embody beliefs and values which serve to emphasise that human culture is inseparable from the natural environment.

1. Introduction

I am a poet and historian living in the Northumberland fishing village of Beadnell. Between 1989 and 1996 I spent thousands of hours recording the knowledge of the generation of fishermen then in their 70s and 80s, in Beadnell and the other coastal villages from Holy Island to Amble. These villages were changing rapidly. From around 60 fishermen at the beginning of the 20th century, Beadnell had only about 12 in 1969 and eight in 1989. Now, in 2005, only two men from the village make their living from the sea. As the industry declines, the old knowledge and skills are in danger of vanishing altogether.

Much of my research centred on the knowledge of a small group of individuals, who quickly became close friends. They included Charlie Douglas and his sister-in-law May in Beadnell, Bill Smailes in Craster, and Newbiggin-born Redford Armstrong of Amble. Each of these individuals was a key memory-holder within his or her community, and it was only through their friendship, and their understanding of the urgent, reciprocal relationship of giving and receiving information that would not otherwise be passed on, that I was accepted into a community that did not readily welcome outsiders. The knowledge which they and the wider community entrusted to me was priceless. I have drawn upon it in my poetry, prose-writing and educational work, through which I aim to make others aware of the things which make this coast environmentally and culturally distinctive[1].

I did not originally intend to gather specific information about the environment. It was the fishermen's culture that interested me. But it immediately became apparent that the human history could not be separated from the natural, for the simple reason that the fishermen's livelihood, and often their very lives, depended upon sensitivity to their environment. The generation of fishermen with whom I worked relied upon their own observations, and upon knowledge and skills which were handed down. Bigger boats, more powerful engines, and technological advances such as radar, echo-sounders and Decca and satellite navigation, meant that some of this environmental sensitivity had already been lost to the younger generation of fishermen.

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At the same time, as a poet running occasional workshops in local schools, I was increasingly aware of another change: as macrocosmic environmental knowledge becomes far more widespread and easily available due to television and now the internet, local, microcosmic environmental knowledge, based on observation and oral tradition, is in decline. Children can tell you more about elephants in the Serengeti than they can about the blennies that lie under the stones in the rock-pools a short walk from where they live. We might have more information at our disposal but, because we rely less for it upon our own eyes and ears, we are in danger of knowing less; or at least of possessing that knowledge in a more passive, less personal way.

2. Human and Natural History

The environmental and cultural information which I gathered from the fishermen was indivisible; but, for present purposes, I shall divide it into three main areas: first, fishermen's knowledge and skills; secondly, stories and folklore; and thirdly, fishing language. A fourth area, beliefs and values, I will touch on at the end of this paper.

2.1. Knowledge and Skills

I asked coble fisherman Charlie Douglas of Beadnell what he thought made a good fisherman. 'Brains', he replied. By this he meant two things: observation, and memory. His father's generation had grown up relying on two staple kinds of fishing, both of which had disappeared in Charlie's lifetime: herring drift-netting and long-lining for white fish. Herring fishing depended largely upon skills of observation. The signs the men looked for when trying to identify a rising shoal at nightfall, before the invention of the echo-sounder, included diving gannets, blowing whales, and the memorable sight of 'fire' or phosphorescence on the water. Long-lining similarly involved skills of observation, but also, to a much greater degree, those of memory – of being able to remember and visualise the ground inch by inch in order not only to catch fish but to avoid snagging the 1,200 hooks on obstacles such as rocks or shipwrecks.

Every small boat fisherman carries in his head a unique map of his own fishing ground, which he knows intimately. He learns the best places for lobsters, crabs or whatever he catches, and he guards this information jealously. This knowledge was especially detailed among men who had worked the long-lines, who had, over time, almost literally come into contact with the sea-bed fathom by fathom.

How could a fisherman connect the map in his head with what lies beneath the surface of the sea? He would navigate by watch and compass, and take bearings from landmarks, lining up distinctive features on the land, each with its own local name – places such as Hebron Hill, Heiferlaw and Staggart (the Kyloe hills), buildings such as the castles of Bamburgh or Dunstanburgh, farmhouses, churches, silos and groups of trees. Thus a quick tour around Beadnell Bay would give you such places as Faggot's Rock at 'Hebron on the high sandhill and the Farne (Inner Farne) on Beadnell Point end.' Roughly north-east of Faggot's Rock is a group of rocks known as 'the Barnyards'. These lie at 'Hebron on the two silos (Tuggal Hall) and the Point ends on' (Seahouses and Beadnell Points lined up). 'Hebron on Robin Wood's Rock and the Church on the in-end of the pier' gives you a rock called 'the Bus of the Burn'. 'The Herd's House (Shepherd's Cottage) plantation on Old Weir's hut' marks hard ground, and 'the Church about the huts' gives you the north end of a piece of hard ground known as 'the Shad'.

Redford Armstrong of Amble told me a story from when echo-sounders were first introduced. A man asked him: 'Do ye have a meter in your boat?' 'No,' he replied. 'How come I'm on soft ground here and ye're right aside on us, and ye're on rock, pulling up any amount of lobsters?' 'Whae,' says Redford, 'Ye have Billy fast to the castle wall and I have Billy open the castle wall.' The old men's knowledge could be just as reliable as modern technology.

But there was more to this than geography. The men's knowledge encompassed memories of who caught what, where, when; what the weather was like, which way the wind was blowing, the condition of the tide, and other variable circumstances. While echo-sounders and navigational aids might tell you about the present, knowing the history gives you another dimension. This was a knowledge which could not be reproduced by technology. It was not just a geographical map but a map of stories.

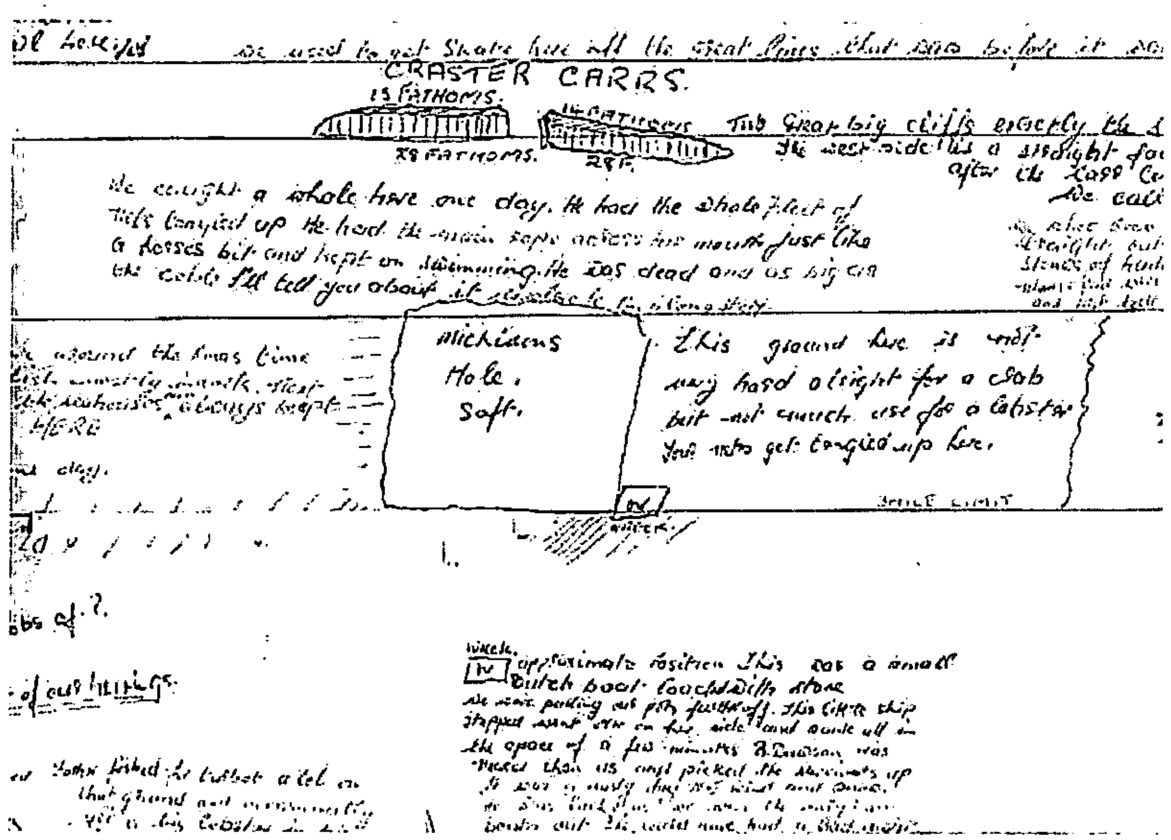

Figure 1 - Excerpt from one of Bill Smales' maps, showing fishing grounds between two miles and five and a half miles off Craster.

Several of the fishermen were willing, when I asked them, to commit at least some of this knowledge to paper in the form of actual maps. The most remarkable of these, crammed with extraordinary detail, were drawn for me by Craster fisherman Bill Smailes. They record names, places, marks, kinds of ground, hazards such as shipwrecks, usual and unusual catches, tides, directions for shooting pots and nets, and stories. Here are some examples:

At a place called 'The Castle Hole' two miles off Craster, Bill writes: 'Father fished for turbot a lot on this ground and occasionally got a big lobster in his bratt nets there. It was a favourite place for herring spawning.' Four miles off he marks a place with the note: 'We shot 5,000 mussel-baited hooks straight out…and got 133 stones of haddocks the day Jimmy Stephenson's Mam and Dad were married.' At nearby Sunderland Point Hole, also four miles off, he writes: 'Nothing but crawling buckies here.' On the shore beneath Dunstanburgh Castle, at a place called 'Cusha', he remarks: 'Plenty big winkles under the big stones. I used to pick them as a boy – 9d a stone.' South along the shore at the 'Channelly Hole' he marks a shipwreck, 'Orda, 1898,' and observes that granite ballast from the wreck still lies there. A mile out to sea he marks another wreck: 'This boat was carrying linseed oil. Hit rocks off Newton and was being towed when she sank here on a Sunday morning in the 1950s...The fulmars fed on that oil for years. You always knew where you were in the fog by the oil stream.'

Figure 2 - Bill Smailes (with Billy Patterson, left), crabbing off Craster in 1950.

The deep empirical and historical knowledge exemplified by Bill's maps, and carried to some extent in the heads of all small-boat fishermen, derived in part from direct experience, and in part from the fact that families tended to remain in the same village, or at least within the same area, for generations, and to pass their knowledge down. For this reason, Charlie Douglas could tell me that, in his great-grandfather's generation (mid-19th century), grey seals, now considered by fishermen to be a great nuisance because of their numbers, were relatively uncommon. 'Herring whales', on the other hand – mostly pilot and minke whales, which were now a rare sight – had then been a reliable method of locating herring shoals. Similarly, in Charlie's grandfather's generation (later 19th century), lobsters, a staple catch for most of Charlie's life, had been in very short supply.

Changes to what was considered normal in the old men's youth were often remarked upon: before World War II it was usual to catch large quantities of 'great muckle haddocks' on the Middle Bank at New Year. Now there were none. Similarly, birds like the corncrake and cuckoo had disappeared from the fields adjoining the shore, and it was often said that there were fewer sea-anemones in the rock-pools than there had been in the men's youth. I heard anxious comments in Craster that the amount of seaweed coming ashore at the harbour had diminished from a depth of about five foot to almost nothing in a single lifetime. Though it made boat launching easier, this was thought to denote 'something wrong with the sea'. The Beadnell men, too, watched the weed and looked for seasonal variations. They spoke of the extra quantities of weed washed ashore in spring and early summer as 'the May Tops', and remembered local farmers gathering it for the fields. They also remembered certain visitors regularly gathering a green, silky weed, although they could not recall its purpose.

Stories of unusual finds, such as albino lobsters, light blue lobsters and unusual species of birds and fish – including a sunfish off Craster in the 1950s – were remembered and handed down. Charlie Douglas recalled that his father had found a 'ribbon fish' ('red, with a tassel on his heed') in Beadnell Haven. Charlie himself remembered catching a shark (probably a basking shark) in a drift net off Dunstanburgh Castle, and knew of another – specifically identified as a basking shark – which had been caught and killed in the salmon 'heuk nets'[2] on Beadnell beach. Memories of record-sized fish and unusually large catches were particularly cherished. It was said that (probably towards the end of the 19th century) 'Old Weir' Fawcus had caught a 62 pound salmon in Beadnell Bay; and that, probably early in the 20th century, 'Baxter' had caught a 22 stone skate on the great-lines. Other unusual events were noted. Charlie remembered his grandfather's story of the 'sea-cat breeze', in which large numbers of catfish were washed ashore at Beadnell in the 19th century.

Men and women who had worked with long-lines had particular memories. Women's work baiting the long-lines was vital. May Douglas could tell you the best places to gather mussels and limpets locally, and the merits of different kinds of shellfish. Limpets from the North Rock at Beadnell, for example, were better than others, because they could be picked more easily. Men who had fished the lines spoke nostalgically of catching 'little Christmas trees' four or five inches high on certain areas of 'easy ground'; when these were brought indoors their phosphorescence glowed in the dark. They also remembered catching brilliant red 'cocks' combs' at a particular place five or six miles out from Dunstanburgh Castle Point. They had not seen these creatures since the long-line fishing ended, and I have been unable to identify them.

For men who had fished under sail or from small, open cobles with low-powered engines, knowledge of particular weather conditions and the ability to read weather 'signs' could be crucial. These 'signs' were many, and some were more grounded in science than others. Sometimes predictable astronomical occurrences could be interpreted as 'signs'. A half moon 'lying on her back', for example, was thought to be a threat of wind and stormy weather. Atmospheric conditions might be more reliable indicators. A ring or 'bruff' around the moon was considered to be a sign of rain. A 'weathergaa', or isolated spot of rainbow, indicated wind from its direction. Movements of birds were also significant. 'Little roaches' (auks) on the sea foretold a hard winter, which in turn suggested that crabs would be caught close in.

Whether shooting long-lines, drift-netting for herring or salmon, hauling pots, or simply navigating through the narrow channels between the Farne Islands, knowledge of the idiosyncrasies of local tides was essential. These varied with the lie of the land, and even with the strength and direction of the wind. Each fisherman knew what to expect in his own area. Although on the east coast the ebb tide basically runs north and the flood tide south, at spring tide and when the tides were increasing or 'puttin' up', it was said that fish worked south-west in; and that at neep or 'dead' tides and when the tides were decreasing or 'takin'off', they worked north-east out. It was important to know this when line fishing or drift-netting. The merits of fixed-net salmon berths also varied according to the tides: at Beadnell, 'Featherblaa' was considered best in a dead tide; 'the Cundy' 'alright in a spring tide;' and 'Kill Corner' best in big tides. When hauling pots in certain places, such as 'Megstone (on) the Haven' and 'Longstone (on) the Crumstone', the north end of your fleet could be in ebb tide while the south end was in flood. After high water ashore you would find no tide there at all. But farther south, at 'Heiferlaw (on) the Castle', you would find a flood tide two hours after high water ashore. This was known as a 'true tide' – a north and south running tide, unaffected by islands, rocks or the lie of the land.

Figure 3 - Charlie Douglas knits a creeve cover, Beadnell, 1993.

Besides this wealth of environmental knowledge, fishermen possessed a great armoury of manual skills, such as making cane eyes for pots, fastening particular knots, or spinning 'graithes' for snoods; all these were inevitably disappearing with the kinds of fishing that required them. Almost vanished from living memory within the last quarter century are the age-old skills involved in rigging and sailing a coble. The skills involved in building these boats are vanishing just as quickly. Skills required for making and maintaining gear have followed changing fishing practices, such as the developments in technology from 'trunks' to 'creeves', the innovation of the 'parlour' or 'trap' creeve for lobsters in the 1950s, and the recent innovation of pots with soft, wide entrances. Practical skills have changed especially with the increasing use of man-made materials, which mean that it is no longer necessary to bark and tar ropes, or to cut and bend ash sticks for pots. This also means that, when lost gear washes up on the shore, plastic pot-bows and nylon nets cause much more intrusive and long-lasting litter.

Practical skills varied from village to village, sometimes according to personal preference, but also reflecting particular conditions of place. During the long-line fishing, different ways of fastening the hook to the snood and the snood to the line depended on local conditions. In Seahouses, hooks were fastened much less freely than in Amble, due to the stronger tides around the Farne Islands. The Amble men thought the Seahouses men's hooks 'numb'. Holy Island men preferred horsehair to cotton for their snoods, for greater strength in stronger tides. Also adapting to local conditions when fishing for salmon on the beach, Boulmer and Amble men work a 'T-net' with a flood-tide and ebb-tide trap; whereas Beadnell men, fishing some distance from a river mouth, in a bay with a prevalent ebb tide, work a distinctly different 'heuk net', with only an ebb-tide trap.

The particularity of all these skills represents the practical application of the fishermen's intimate knowledge of local conditions. It is in the detail and texture of this local knowledge that its value lies.

2.2. Stories

It is obvious from what I have said about Bill Smailes's maps that the fishermen's knowledge of the sea-bed is inseparable from the stories which they told. There is no room here to explore these stories in depth, but it is worth noting that many of them are in themselves scientifically or historically interesting. Charlie Douglas, for example, maintained that, in his grandfather's day, fishermen from Beadnell sailed their cobles up the east coast and through the Caledonian canal to the Clyde to join the herring fleet, sleeping under their sails as they travelled. Although oral testimony can be notoriously fallible, it is perhaps less so when gathered from people who depended upon memory for their livelihood. Confirmation from written records such as newspaper reports and lifeboat logbooks show a high degree of reliability in the fishermen's stories. It would be interesting to look for independent corroboration of Charlie's recollection that crabs tagged at Beadnell were once recovered at Crail in Scotland. Charlie's grandfather had himself collaborated with scientists, and his relatives had worked with the Dove Marine Laboratory from its inception in the early years of the 20th century.

Stories suggested themselves through connections: by time of year (although actual dates were hazy), by particular characters, and most of all, by place. A large number of the men's stories were directly connected to features in the landscape, beneath the sea or beside it. Charlie's brother Tom Douglas showed me troughs cut in the rocks at Beadnell Haven, physical reminders of how bratt (turbot) were stored in the days before railways, when they were transported live to market in sloops with internal wells. The fish were prevented from escaping from these troughs or 'bratt holes' at high water by lids. Charlie and Tom connected another story to these holes. A piece of easy ground seven or eight miles east of Beadnell used to be called 'the Bratting Ground' because turbot were caught there. The marks for it were 'Hebron on Beadnell Trees and Staggart on the Farne House Tower'. This name has now almost slipped beyond memory; today the place is known as 'the Off Bank'. Yet to men like Charlie and Tom, the Bratting Ground was of great significance. Their father, uncle and grandfather almost lost their lives there when they were caught in a sudden blizzard while line-fishing from their 21ft coble, the Jane Douglas, in February 1895.

Stories matter: even the seemingly inconsequential stories – those about characters who were long-dead, but who were spoken of as if they were still alive. An example might be the story of old Hannah from Beadnell who could not read and write, but who, in her youth, had 'travelled the fishings', and who asked during World War I, 'Is Yarmouth on wor side?' Another is that of the scavenger who combed the shore for dead bodies. He was given his come-uppance by a fisherman who pretended to be dead and then, as the scavenger peered into his mouth for gold teeth, bit him. 'Deed man bite!' Charlie would laugh, telling the story for the hundredth time. Such shared stories are important because they helped bind together the social fabric of the village. They also give an insight into the way that people lived and thought.

Even misleading information can be interesting. Superstitions and old wives' tales, though not always founded in fact, can give valuable insights into the way people think. Why did some Beadnell fishermen maintain that a 'frone' (starfish) always carried a stone to drop into the mouth of a clam? What gave the fishermen of Holy Island their belief that barnacle geese bring plague? Why did fishermen in Beadnell – and elsewhere, all across Europe – believe that someone born with a 'caul' or membrane over his face would not drown? Why is it unlucky to say the word 'rat' in Beadnell (say 'caaldie' or 'lang-tail'), 'rabbit' in Craster (say 'conie'), and – worst and most widely-hated, from Northumberland, across Europe and beyond – the word 'p-i-g' ('guffie', 'grunt', 'article')? How old are these stories? They are a window back into the distant past.

2.3. Dialect and communication

Joanna Stockill of the Dove Marine Laboratory has already remarked that fishermen's expertise has not been sufficiently valued by policy-makers. This may be partly because it is difficult to separate hard information from stories; but it is more to do with the fact that fishermen's knowledge is extremely local – a fact which is also, of course, its strength. The tendency to undervalue it is also largely due to a lack of communication between fishermen on the one hand and scientists and policy-makers on the other. This has led in turn to severe repercussions: to regulations which, not always effective or practical, have been perceived by fishermen as interference. Day after day, I saw the anger and frustration of men in Seahouses and Amble who, obliged to throw overboard the bigger part of their catch of perfectly good cod and whiting because it was under-size or over quota, felt that they simply were not heard. They wanted the policy-makers to know: for them, the regulations were not working. The fish they threw back were dead. Such poor communication has increased suspicion of the scientific community among fishermen. Charlie would shake his head at the so-called 'experts', who would tell him what he could and could not do, but who were unable to tell a hen crab from a cock crab in the hand.

One of the great problems of tapping into fishermen's expertise is that of language. Local dialect can be so impenetrable that it causes, at least, difficulties in communication, and at worst an assumption of ignorance on either side. Would you know, for example, if you encountered a 'paddle-hush'? (a lumpsucker). Could you forget a confrontation with a 'fetther-lasher' (gurnard) or a 'swatter' (jellyfish)?

Extreme local variations of dialect add to the confusion. A porpoise may be a 'skeldy' or a 'plasher', a whale a 'finner' or a 'piker', usage and precise definitions varying according to place. Spider crabs, once found in abundance on Sandlem Bus off Beadnell in cold weather, are known to Beadnell men as 'pipers', but to Seahouses men as 'tyeds'. Squat lobsters are 'goudies' or 'tailiers' on Holy Island, 'sixpenny men' at Seahouses, 'nancies' at Beadnell and 'wiggies' at Blyth. Coal fish may be 'baggies', 'haa'f waxties', 'podlers' or 'blackjack', depending on their size. Distinctions between species are not always clear: while a 'whulk' is a winkle rather than a whelk, and a whelk is a 'buckie', a hermit crab occupying a whelk shell is distinguished simply as a 'craalin' buckie' rather than a 'slavvery buckie'.

The expressive dimension of dialect is rich and invaluable: who could fail to distinguish the dark, cumbersome flight of the 'gormer' (cormorant) from the deft, quick 'pickie' (tern)? But what is a 'pickie' at Beadnell is a 'teeram' at Seahouses, and a 'tarree' at Craster. It is all very confusing. Within a few miles, a crab pot may be a 'creel' (Holy Island), a 'creeve' (Seahouses and Beadnell) or a 'net' (Craster). When Newbiggin fisherman Redford Armstrong first visited Holy Island before World War II, he maintained that he could hardly understand a word.

The north Northumberland coastal dialect may be impenetrable to an outsider, but what it does reveal is something very interesting about its speakers' relation to their environment. The expressiveness of the fishermen's dialect is more than ornament or curiosity. The ability of the words to convey meaning through sound and rhythm – the connection already alluded to between the lightness of the word 'pickie' and the deftness of the bird which it describes; or that between the ferocity of the adjective 'gurrelly' and the roughness of the sea to which it refers – is not accidental. There are hundreds of similar instances in the fishermen's speech. What they reveal, I would suggest, is a deep and ancient connection between language and environment. Words do not merely refer to things: they evoke them. Perhaps the taboo words, 'rat' and 'p-i-g' and their acceptable dialect alternatives, reflect the remnants of a not-quite-lost belief in the power of language, not only to evoke the environment, but to influence it.

At the same time, fishermen's speech abounds in metaphors which draw on the natural environment to express abstract thoughts and feelings. Rather than describe someone as 'clever' or 'sharp', Charlie would say: 'There's no much wetter gans ower his heed'. Rather than say outright that a person was sly, he would say: 'He's like the fox that gans about among the sheep'. Like the expressive sound of the fishermen's dialect, this constant use of picture-language drawing on the natural world both indicates and affirms the closeness of their relationship to their environment[3].

3. Collection and Dissemination of Material

3.1. Collection

Before I say more about the values which I believe the fishermen's language and stories articulate, I should like to explain in a little more detail how I collected the information so far outlined. It was gathered in what might appear an extremely haphazard way. I did conduct a number of formal interviews, and in these situations I used audio-tape; but I found informal encounters far more valuable, and for these I used notebooks, which seemed less intrusive. I scribbled constantly.

Because my research was independent, I had the luxury of spending a huge amount of informal time with my 'interviewees', several of whom, as I have already indicated, became close friends. It helped that we were so different: they were old, I was young (and female); I had an academic background, they had not; they knew everything, I knew nothing. It helped, also, that I lived in the village and that my grandparents had lived there. Every day, over a number of years, I spent a couple of hours in the men's huts, as well as joining them aboard their boats, and sharing evenings in family homes. An academic might raise an eyebrow. Nothing was done in an orthodox or disciplined way. But it was only because of this very lack of structure that, over time, I was given the enormous privilege of becoming almost invisible – and, rather than imposing my own ideas by seeking answers to formal questions, I was able to follow the fishermen's own connections and to learn to think as they did.

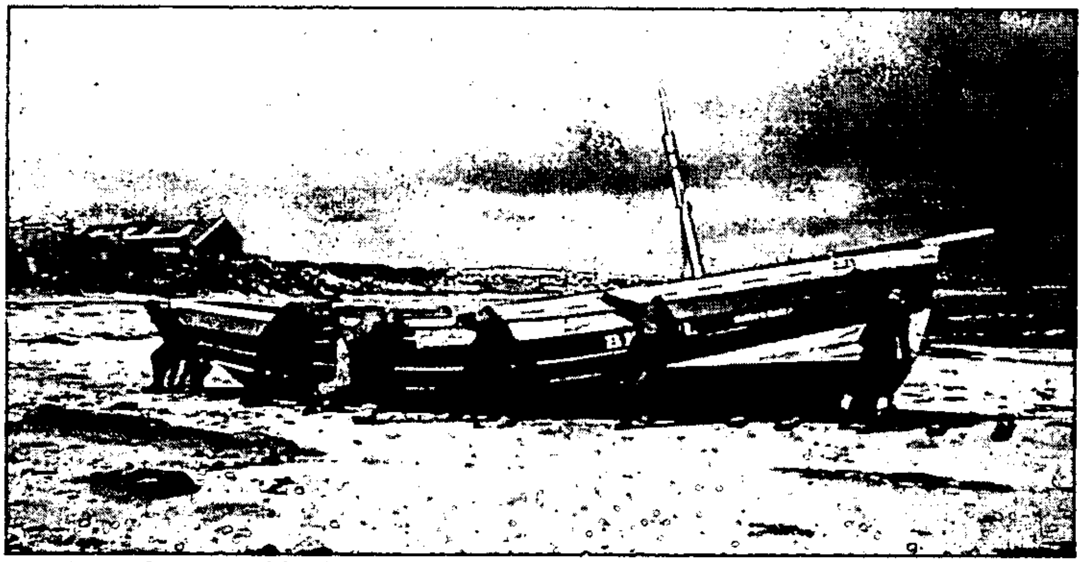

Figure 4 - Launching a coble the traditional way, using greased sticks and plenty of effort. The Golden Gate, BK 221, Beadnell, 1992.

This was true even when I started to take photographs and video. Rather than imposing itself between me and the fishermen as I feared, the camera was ignored. I was able to capture in close detail the fishermen's ordinary skills – bending bows to make creeves, knitting 'covers', preparing salmon nets, landing and launching cobles - whilst all the time they wove their intricate net of stories.

3.2. Dissemination

Notebooks, audio-tape, video, photographs and sketch-maps: these, then, were the ways I recorded the information. But how was I to pass it on? My great and as-yet unfulfilled desire is to set it all down in a book. I made a beginning with a small publication called 'The Bonny Fisher Lad', but this is only a partial and inadequate representation of the quantity of information which the fishermen entrusted to me. I owe them so much more.

Another aspect of the dissemination of the fishermen's knowledge, however, has been through my educational work as a poet in primary schools [4]. Although Malcolm Green will speak at much greater length about the importance of creative work in promoting an understanding of the environment, I should like to say just a short word about its value. I believe very strongly that any distinction between science and the creative arts is false; and that history and science – 'human and natural history' – can and should be taught through creative arts such as poetry. By creating and 'making', children and adults alike involve themselves imaginatively in the subject. They experience it personally. This is especially true when the context is local.

I usually work with children aged between seven and 11 years old, but the same techniques apply to all ages. My workshops, which I run sometimes in collaboration with an environmental scientist and sometimes on my own, begin from four main starting-points:

The first involves working from objects, such as a piece of fishing gear, an object from the seashore such as a shell, or even a living creature such as a crab. We discuss the object's origins, facts about it, what the children can tell me themselves, what the fishermen knew or stories they told about it. Then the children examine it using all their different senses, one by one. We go on to write a group poem as if that object is speaking. When small things are experienced directly through the senses in this way, the wider subject of the environment becomes immediately accessible. The children connect what their senses tell them about the object with stories and facts that their minds have absorbed about it through discussion. In that way they learn to create images.

A second workshop involves working outdoors on the seashore, dunes and surrounding land. Children might be asked to collect their own objects by beachcombing. Or they might make a visit to an area of the shore which they know well, concentrating on its landscape, investigating its stories, including both the science of its geology, flora and fauna, and stories told by the fishermen. They are encouraged to ask: how does it come to look the way it does? As well as scientific and historical stories, I always ask the children for their own associations and memories of a place. Again, factual discussion leads into imaginative writing in the voice of the place itself.

A third model involves working from old photographs. Starting again with a place which the children know well, such as a local harbour, we look at pictures of it 50 or 100 years ago. We talk about the place as the fishermen knew it, facts about it, stories; and discuss how and why it has changed. I ask the children to focus like cameras on small details, and to imagine the place using each sense in turn, as we begin to write a group poem structured around pairs of lines beginning: 'Once...But now...'

A fourth model, and my favourite, is based on cross-generational work – introducing older members of the fishing community, such as grandparents and great-grandparents, into the classroom to talk about changes in fishing, village life and the environment. Because my work recording oral history has inspired so much of my own poetry, it is easy to extend these techniques to others. Before the visitors arrive, I discuss with the children the kind of questions that they might ask. Any child whose family is not originally from the area is made familiar with the community's history. During the visits we tape all the interviews, and afterwards use quotations from them as the starting-place for group poems in which the children imagine their way into particular places and experiences using each sense in turn.

In each case the workshop begins with factual discussion and empirical observation, and goes on to group, and then individual, writing exercises which involve the imagination. This imaginative element, often requiring the children to write in the first person, encourages each child to explore his or her own sympathetic response to the environment – in other words, to develop a sense of place.

Poetry is especially effective in this. Through its powers of sound and rhythm, poetry can do more than merely describe. Just as the fishermen's dialect affirms, through its expressive sounds and use of metaphor, an intimacy with the natural environment which is lost to standard English, so poetry can, through sound, rhythm and image, evoke the physical world. 'Plodging though the claggy clarts' does not merely refer to wading through mud: it makes you feel its heavy stickiness as if you really *were* wading. That is precisely how poetry works.

Children seem to understand this connection instinctively. The exploration of scientific or historical fact through imaginative writing comes naturally to them. By experiencing a factual subject personally, by evoking it poetically, the children are fired with enthusiasm and able to 'possess' it, to make it their own. This creative process strengthens in them something which, for most, is part of their inheritance: a cultural involvement in their own environment.

4. Facts and Values

It might be possible to pass on in this way some of the factual content of the fishermen's knowledge, or indeed any factual subject; but I would also argue that, as fishing declines, without its application in daily life, the fishermen's factual and practical knowledge is in danger of becoming a dead language, of interest only to scientists or historians. What matters even more is to pass on their values.

The small boat fishermen of the generation with whom I worked were by nature conservationists. This is not a romantic assertion. It is true that they wanted to make money; and that, lacking the technological advantages of the generations which followed, they were simply unable to fish as intensively; but they were also all aware to a remarkable degree of what was going wrong. Exposed as they are in small, open boats, fishermen's lives depend upon their respect for the sea, and upon working *with* nature, not against it. As Charlie Douglas always said, 'the sea's the boss'. This gives them a particular perspective, which was augmented in Charlie's generation by a sense of time and place that extended beyond the individual. These men had relied for most of their lives upon traditions which were handed down, and they wanted to hand them on in turn. They wanted the fish to be there for their sons and grandsons. This meant that they had to be conservationists in the most practical sense.

One clear example of this is the story, preserved by Beadnell fishermen, of their grandfathers' battle with fishermen from a neighbouring village over 'berried hen' (gravid) lobsters. When lobsters became scarce in the 19th century, the Beadnell men agreed amongst themselves to a voluntary restriction on landing berried hens. The neighbouring fishermen refused to comply, so the Beadnell men cut the dans off their pots. Continuing tensions contributed to the eventual formation of the Northumberland Sea Fisheries Committee, and to proper regulation of the industry.

What that story exemplifies is that the Beadnell fishermen thought of themselves within a wider environmental and historical context. Taken as a whole, all the skills and stories touched upon in this paper support this. These shared memories built up, like landmarks, into a network which gave each community a clear sense of its own identity. This in itself was important: a strong defence against the sameness which now, increasingly, engulfs us. But it mattered in another way, too. The shared memories, and the language in which they were expressed, served as a map of the community's values – of the things that mattered to people.

What the fishermen's language and stories crucially embodied was their understanding of where they stood in relation to one another, to the past and future of their community, and to their environment. From them I learnt that the great skill of a fisherman, like that of a poet, and possibly also of a scientist, is to learn to be still – to look, and to listen – and to remember. More important even than the great library of knowledge in their heads were the skills of observation and memory which garnered that knowledge in the first place. It is these skills that I believe we need to revive and disseminate – to empower children and adults alike to discover the world at their feet, and to value and possess it through their own stories. Only then can the fishermen's inestimable knowledge remain a living tradition.

The Marks T' Gan By

I asked Charlie what a fisherman must know.
'Aal bloody things!' he answered me. 'How so?'
'A fisherman hetti hev brains, y' kna, one time;'
His fingers twisted round the slippery twine
In the stove's faint firelight. It was getting dark.
'Them days,' he said, 'w' hetti gan b' marks.

'Staggart, the Fairen Hoose; Hebron, Beadlin Trees...'
Thus he began the ancient litany
Of names, half-vanished, beautiful to hear:
'Ga'n roond the Point, keep Bamburgh Castle clear
The Black Rock, mind. Off Newton, steer until
Ye've Staggart level the Nick a the Broad Mill.'

Novice, I listened. In the gloom I saw
The rolled-up sail by the long-unopened door,
A traveller, stiff with rust, a woodwormed mast –
All the accumulation of the distant past.
'Now, keep the Chorch on Alexandra Hoose,
An' yon's the road...' 'Oh, Charlie, what's the use?'

I said. 'These memories! I know they're true,

And certainly they're beautiful. But how can you
Compete with all the science of these modern days?
The echo-sounder's finished your outdated ways.
Efficiency. That's what they want; not lore.
Why should the past concern us any more?'

I could not see his face. The stove had died.
'There's naen crabs noo,' said Charlie sadly, and he sighed,
And seeming not to hear me, sealed the knot.
'When ye see lippers comin', when t' stop
An' when t' gan – that's what ye need t' kna.
The sea's the boss. Me fatther telled me so.

'Them marks,' he said; 'he handed aal them doon
Like right an' wrang. Them buggers for' the toons,' –
He sliced the twine he sewed with, savagely –
'Th' divvin't kna what's right. Th' gan t' sea –
Their only mind's for profit. They'll no give
Naen thowt t' hoo their sons'll hetti live.'

I saw, then. 'So,' I said, 'as we embark,
The past is map and measure, certain mark
To steer by in the cold, uncertain sea?
We leave it, like the land. But all we know –
What to hang on to and when to let go –
Leads from it...' 'Aye,' said Charlie. 'Sic an' so.'

From: 'The Lost Music', by Katrina Porteous (Bloodaxe 1996).

5. Glossary

Bratt – turbot
Covers – net covers for crab and lobster pots
Creeves – crab and lobster pots
Crawling (or craalin') buckies – hermit crabs
Dan – buoy used to mark pots
Easy ground – soft sea-floor; mud, sand and pebbles
Fleet – a string of pots
Graithes – lengths of spun horsehair used on Holy Island as part of snoods for long-lines
Herring whales – probably mostly pilot and minke whales
Heuk nets – fixed trap-nets used to fish for salmon and sea trout on Beadnell beach
Lippers – waves which break on the surface
Long-lines – lines carrying 1,200 hooks, baited with mussels and limpets and traditionally shot in winter time for white fish. Long-line fishing ended in north Northumberland soon after World War II.
Salmon berths – places where fixed trap-nets could be anchored
Snoods – lengths of twine used to fasten hooks onto long-lines
Travel the fishings – to follow herring shoals down the east coast as fisher lassies did from Shetland to Yarmouth

Traveller – iron ring used to attach sail to mast

6. References

[1] I am indebted to Sue King and Angela Clifford of Common Ground for the concept of 'Local Distinctiveness'. Clifford, Sue, and King, Angela, 'Losing Your Place'(1993), *Local Distinctiveness: Place, Peculiarity and Identity*; Common Ground.

[2] 'Heuk nets' are a local variation of fixed nets used to fish for salmon and sea trout close to the shore. They resemble one half of the classic Northumberland 'T-net' rather than the older 'J-net' with which they somewhat confusingly share their name. Osler, Adrian (2004), 'The Salmon's Kingdom: net fisheries of Northumbria', *Maritime Life and Traditions*, Winter 2004, Number 25, p35.

[3] Porteous, Katrina (2001), 'Nivvor Can Be Telt: the music of language in Northumbrian Poetry, Song and Speech', Fred Reed Annual Lecture to the Northumbrian Language Society, delivered in Morpeth, October 2001.

[4] Porteous, Katrina (2001), 'Play, Pleasure and Passion: approaching non-fiction through poetry', *Writing in Education*, Autumn 2001, Number 24, pp 7-11.

TWENTY FIRST CENTURY SCIENCE

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Twenty First Century Science is an innovative GCSE curriculum, currently in pilot across 76 schools (approximately 8,000 students). This session describes the background to changes in teaching a new GCSE science. It will also examine how new regulations for 14-16 Science in England and Wales may offer greater opportunity for students' environmental literacy.

1. Introduction

Over the past two decades, science has become established as a core school subject, taken by all students aged 5 to 16. But increasingly questions have been raised about the suitability for many students of the curriculum.

From September 2006 schools in England and Wales will begin teaching a new GCSE science curriculum. This presentation describes the background to these changes, the pilot -*Twenty First Century Science*, and describes the approach to educating students about their natural environment.

GCSE Science – what is the current norm?

The majority of students follow a Double Award course. This leads to two grades in the range A*A* - GG. Double Award students spend approximately 20% of their school curriculum time studying science between the ages of 14-16. Double Award provides a balance of study across biology, chemistry and physics concepts, which is compulsory under the current National Curriculum.

Some students choose to study a less extensive, Single Award course. This leads to a single grade in the range A* - G. This enables them to broaden their studies at GCSE, perhaps developing a second foreign language, an additional arts or humanities subject, or taking a vocational course.

A minority of students study separate sciences (biology, chemistry, and physics) to GCSE level. This is significantly more common in the independent school sector, where students may also opt not to study all three sciences, since independent schools are not bound by the National Curriculum.

Why do we need a new GCSE curriculum?

School science has two jobs to do. For some students it provides the first stages of their training as scientists, or for a career that involves science. For all students, it provides the kind of scientific literacy that they need to play a full part in a modern democratic society where science and technology play a key role. Clearly knowledge of the environment should be included in this curriculum.

There are inherent tensions between these two aims, which are particularly noticeable by the time students reach the age of 14. Differences in aptitude and interest are becoming more apparent, and the same science curriculum for all does not seem to be an ideal solution. If we are to cope with the

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diversity of students' interests and aspirations, we need a curriculum model for science that offers greater flexibility and genuine choice.

Students, teachers, and parents report dissatisfaction in school science. There is also considerable concern over falling take up of some sciences, particularly physical sciences, at A-level and beyond. The House of Commons Science and Technology Select Committee on Science Education 14-19 (July 2002) condemned the current model for school science for:

- being overloaded with factual detail;
- failing to inspire students to continue with science;
- discouraging students from thinking for themselves;
- neglecting contemporary science;
- lacking flexibility;
- making practical work into a tedious and dull activity

The Committee concluded that:
'......a new National Curriculum should require all students to be taught the skills of scientific literacy and selected key ideas across the sciences. This core should form the basis of a wider and more flexible range of exam courses, reflecting the diverse interests and motivations of students.'

Twenty First Century Science
In 2002 the Qualifications and Curriculum Authority (QCA) asked the University of York Science Education Group to develop a new curriculum model for science at GCSE. The resulting *Twenty First Century Science* suite of courses began piloting in 76 secondary schools in September 2003, with over 8,000 students.

The *Twenty First Century Science* curriculum model offers greater flexibility and diversity at GCSE, by separating the core Science course from Additional Science. It enables the development of courses with real fitness for purpose. It also gives students choice, without closing doors. A student who opts to study only the core Science course at age 14-16 can more easily change their decision and study Additional Science at a later date.

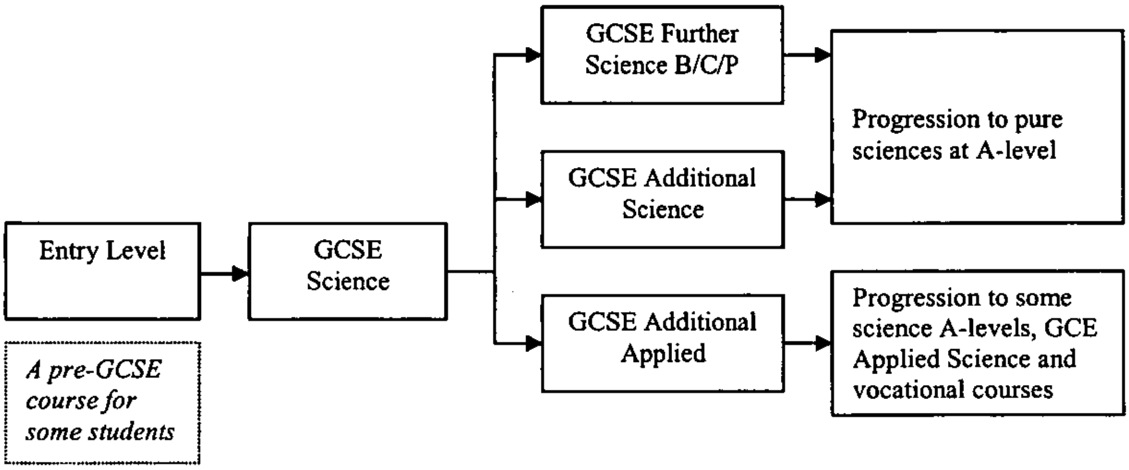

Figure 1 - The Twenty First Century Science suite curriculum model for 2006.

What is the core Science course like?

Much has been written about scientific literacy: how to define it, why it is important as an objective for schools science and, if this is accepted, how to develop a schools curriculum that addresses this need. Colin, Osborne, Ratcliffe, Miller and Duschl (2001) say that it involved:

> *'....a better understanding of the workings of science thus enabling [people] to engage in a critical dialogue about the political and moral dilemmas posed by science and arrive at considered decisions.'*

Taking a similar view, the authors of the European White Paper on Education and Training (European Commission, 1995) argue that promoting scientific literacy:

> *'...does not mean turning everyone into a scientific expert, but enabling them to fulfil an enlightened role in making choices which affect their environment and to understand in broad terms the social implications of debates between experts. There is similarly a need to make everyone capable of making considered decisions as consumers.'*

Twenty First Century Science puts scientific literacy at the heart of the schools science curriculum, because this is the only kind of science that can really be justified as a compulsory curriculum element – for *all* students.

We might think of a scientifically literate person as someone who can:

- recognise and appreciate the impact of science and technology on everyday life;
- take informed personal decisions about things that involve science, such as health, diet, use of energy resources, environmental impact of their actions;read and understand the essential points of media reports about matters that involve science;
- reflect critically on the information in, and (often more importantly) omitted from, such reports;
- take part confidently in discussions with others about issues involving science.

The foundations of the core Science course

Science Explanations

No-one can be said to be 'scientifically literate' unless they understand some science. But what matters is to have a broad understanding of the main scientific explanations that give us a framework for making sense of the world around us. Students should understand these major **Science Explanations**, not get lost in detail or unnecessary complexity for their level of study, so that many simply switch off. In Twenty First Century Science, the Core Science course aims to help students understand the **Science Explanations** shown in Box 1.

Box 1: Science Explanations (SE)

SE1 Chemicals
SE2 Chemical change
SE3 Materials and their properties
SE4 The interdependence of living things
SE5 The chemical cycles of life
SE6 Cells as the basic units of living things
SE7 Maintenance of life
SE8 The gene theory of inheritance
SE9 The theory of evolution by natural selection
SE10 The germ theory of disease
SE11 Energy sources and use
SE12 Radiation
SE13 Radioactivity
SE14 The Earth
SE15 The Solar System
SE16 The Universe

Ideas about Science

To be an informed consumer of scientific knowledge, you need more than an understanding of the major Science Explanations. You also need to reflect on scientific knowledge itself, the practices that have produced it, the kinds of reasoning that are used in developing a scientific argument, and the issues that arise when scientific knowledge is put to practical use. The **Ideas about Science** that help you understand and think critically about these aspects are an integral component of Core Science (Box 2).

So, in the Core Science course, it is an understanding of the major Science Explanations and key Ideas about Science that is central. These are the things that we want students to take away with them from the course, and 'carry with them' for the rest of their lives.

Box 2: Ideas about Science

IaS1 Data and its limitations
IaS2 Correlation and cause
IaS3 Developing explanations
IaS4 The scientific community
IaS5 Risk
IaS6 Making decisions about science and technology

What about future scientists?

The majority of students will want to study science for a greater proportion of their GCSE curriculum time. They will want to pursue their interest in science, and perhaps to progress to further study post-16. However, not all students wish to follow a pure academic route. *Twenty First Century Science* provides several options for students.

2. Additional Science

Since the core Science course meets the scientific literacy needs of all students, the Additional Science GCSE course can truly meets the needs of students seeking a deeper understanding of basic scientific concepts. Additional Science provides strong contexts for teaching scientific facts and ideas in a way that can readily be related to their applications (Box 3). A concept-led course, it develops models and explanations that provide a firm basis for study of science post-16.

Box 3: Additional Science (Ad)

Ad1 Homeostasis

Ad2 Chemical patterns

Ad3 Explaining motion

Ad4 Growth and development

Ad5 Chemicals of the natural environment

Ad6 Electricity

Ad7 Brain and mind

Ad8 Synthesis and analysis

Ad9 The wave model of radiation

Additional Applied Science

A map of the science domain produced by the Council of Science and Technology Institutes showed that there are three important strands to the work of people who apply science:

- The application of knowledge, methods, tests and trials to provide data, deliver a product or solve problems.
- The communication of knowledge, expertise, benefits and implications of scientific work both within the science community and outside.
- Management including working with others and the deployment of resources within constraints of material resources, time, budgets and the need to avoid harm to people and the environment.

These three strands are reflected in the experience of students taking the Additional Applied course. The course is set in contexts (Box 4) which are likely to be encountered by many students in their personal and/or working lives, and in which scientific procedures are involved together with scientific understanding. The focus is on the procedural and conceptual understanding that underpins authentic, science-related work.

Box 4: Additional Applied Science (Ap)

Ap1 Life care

Ap2 Agriculture and food

Ap3 Scientific detection

Ap4 Harnessing chemicals

Ap5 Communications

Ap6 Materials and performance

Separate sciences – Further Biology, Chemistry and Physics
Although not part of the original pilot, separate science courses are being developed for 2006. It is important that these courses are a distinct, relevant experience for students who wish to progress to A level science courses. Each subject area encompasses further development of Science Explanations, Ideas about Science, and elements of the Additional Applied course with particular relevance to professional scientists. The over-riding theme through Further Biology is energy flow through the ecosystem, which draws together many of the areas students have studied in core Science and Additional Science.

The new National Curriculum for students aged 14-16
A new National Curriculum for students aged 14-16 was developed by the Qualifications and Curriculum Authority (QCA) in 2004. Drawing on the *Twenty First Century Science* pilot, it encompasses a core GCSE Science course, and flexible criteria for Additional Science courses. These criteria give details of Additional Science and Additional Applied Science courses, but they also provide the opportunity for students to study a wider range of more specialised courses. For example, a student might complete GCSE Science in Year 10, and then go onto GCSE Astronomy, or Geology, for example, in Year 11.

The new curriculum will be followed by students from September 2006. *Twenty First Century Science* will be one of a number of GCSE Science course suites available to schools, each produced by a different Awarding Body.

Each suite will be different to *Twenty First Century Science*. Indeed from September 2006 there will be wider diversity between content of GCSE suites than in current Double Award. However, all courses do need to conform to the revised National Curriculum, which can be found at http://www.qca.org.uk/11881.html.

What will students experience through the new National Curriculum?
QCA describes the new National Curriculum for GCSE science as:

Breadth of study (Science Explanations in *Twenty First Century Science*)

- Organisms and health e.g. organisms are interdependent and adapted to their environments;
- Chemical and material behaviour e.g. new materials are made from natural resources by chemical reactions;

- Energy, electricity and radiations e.g. energy transfers can be measured and their efficiency calculated, which is important in considering the economic costs and environmental effects of energy use;

- Environment, Earth and universe e.g. the effects of human activity on the environment can be assessed using living and non-living indicators; the surface and the atmosphere of the Earth have changed since the earth's origin and are changing at present.

How science works (ideas about Science in *Twenty First Century Science*)
'Pupils learn about the way science and scientists work within society. They consider the relationships between data, evidence, theories and explanations, and develop their practical, problem-solving and enquiry skills, working individually and in groups. They evaluate enquiry methods and conclusions both qualitatively and quantitatively, and communicate their ideas with clarity and precision.'

'They develop their ability to relate their understanding of science to their own and others' decisions about lifestyles, and to scientific and technological developments in society.'

The pilot of *Twenty First Century Science* is being evaluated by an independent research team based at the University of Leeds, King's College, London, and the University of York. The evaluation is focusing on three key areas:

- characterising the understanding which students acquire of the foundations of Core Science, Science Explanations and Ideas about Science;

- exploring attitudes of students to school science, comparing students following current Double Award with Twenty First Century Science students;

- exploring teachers' attitudes to school science.

The evaluation will report preliminary findings later this year. A final report will be made in 2006. It is hoped that further evaluation into student curriculum choices and performance post-16 will also be carried out.

Pilot teachers have provided informal feedback on their experience of the courses to date. Perhaps these are the best way to reflect how *Twenty First Century Science* hopes to improve students' experience of school science.

'Science teachers want young people to share their love for their subject. I believe that Twenty First Century Science will provide them with a powerful new tool to do this.' Dena Coleman, Head Teacher.

'The big changes are that there are more opportunities for different teaching and learning styles. It's more relevant, and students seem to be enjoying the course more.'
Kathryn Kennedy, Head of Science.

'We are now questioning theories which in the past were just accepted when they were taught.'
Paul Graham, Head of Science.

THE AMATEUR NATURALIST: A SPECIES RECOVERY PROGRAMME

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The current phase of climate change will bring about rapid changes in the distribution and abundance of Britain's flora and fauna. These should be documented in detail but the number of staff with expertise in taxonomy and field studies who can engage in this task has declined in most UK universities in recent decades. Amateur naturalists have a long and illustrious history of documenting our native flora and fauna and could, by working in collaboration with university academic staff, make major contributions to recording the impact of climate change on species. Many conservation organisations have already successfully exploited this human resource in field-based surveys, providing models for similar collaboration between university professional biologists and amateur naturalists. Recent developments in World-Wide Web and digital technologies could be used to facilitate this collaboration, providing an accessible and user-friendly interface for training and exchange of information resources. Such technologies have already been used effectively by the UK Phenology Network, for phenological monitoring. Research collaborations between university scientists and amateur naturalists could provide a stimulus to the study of natural history in the community and could help to fulfil aims to widen access to universities. They could also, by encouraging direct public involvement in scientific research, help to build public confidence in the scientific enterprise in general.

1. Introduction: The challenge of recording rapid change

There is overwhelming evidence that we are in the early stages of the most rapid phase of climate change in documented human history. This will have profound effects on the abundance and distribution of components of our flora and fauna, and could well undo a century of wildlife conservation effort. Over the last century wildlife conservation strategy has focussed on protecting isolated examples of key habitats and species in nature reserves, which are for the most part semi-natural managed islands in an agricultural, industrial or urban landscape.

In the face of climate change species can respond in two ways: evolve to adapt to a changing climate or migrate to track the shifting margins of their existing climatic optimum. Given the rapid rate of climate change, the former strategy is only likely to be successful for those species that have short life cycles and reproduce in very large numbers, providing high levels of genetic recombination for natural selection to act upon, leading to evolutionary change. The alternative strategy requires unaided migration of species which may have highly specialised habitat requirements. This will be difficult for species with restricted mobility and will be constrained by ecological barriers in a developed landscape and a lack of suitable destinations that can be devoted to wildlife conservation in competition with other forms of land use. Local extinction will be the likely fate of species that are unable to adapt or migrate. There is little doubt that, over the coming century, there will be significant changes to the distribution and abundance of our native flora and

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fauna. There will also be an influx of adaptable or mobile alien species that will be better suited to the new prevailing climate than existing natives.

Irrespective of whether these consequences of climate change can be controlled, mitigated or ultimately reversed, it is important that they are documented, both as a scientific record of the effects of climate change on species and because of their cultural and economic importance[1]. It is regrettable that universities are now probably less well equipped to do this than at any time in their history. Changes in university funding priorities dictate that research effort is primarily focussed on those activities that score most highly in the Research Assessment Exercise (RAE), which strongly favours academic disciplines like molecular biology and biomedical sciences, with industrial links and measurable short term economic benefits. Fundamentally important but unfashionable disciplines like taxonomy, which do not support the high impact factor academic journals that are the key criterion for RAE success, have withered in many universities. It is unlikely that there will be many new university appointments in those field-based disciplines that could contribute most to monitoring effects of climate change on our flora and fauna in the near future[2].

2. Human Resources: An expanding role for the amateur

There are, however, significant pools of amateur expertise available, in the form of local natural history societies, membership of specialist conservation groups and also amongst the large numbers of the general public who belong to mass-membership, nation-wide conservation organisations.

Britain has a long tradition of skilled amateur natural historians, dating back to Gilbert White and beyond, who laid the foundations for our knowledge of our flora and fauna[3]. The word 'amateur', used in the context of natural historians, should never be considered a derogatory term; frequently it implies a highly developed specialist knowledge, keen observational skills and a meticulous approach to data recording. Local natural history societies attract field studies expertise, with members who often possess high levels of taxonomic and field identification skills. Recently there have been concerns that the number of such individuals is declining[2]. However, many of those societies listed for Northumberland and Durham in the British Association's 1959 Directory of Natural History and Field Study Societies[4] still thrive, almost half a century later, and new societies have since been formed. Societies like the Darlington and Teesdale Naturalists' Field Club and the Natural History Society of Northumbria have decades of experience in monitoring key wildlife sites in the region, while the Northern Naturalists' Union has been documenting the fluctuating fortunes of our region's flora and fauna since 1924, in its journal *The Vasculum* and in specialist monographs[5].

Nationwide, specialised field studies and conservation organisations, such as the Botanical Society of the British Isles, Butterfly Conservation and the British Trust for Ornithology, devoted to specific taxonomic groups such as plants, butterflies or birds, are focal points for professional biologists and amateur natural historians alike. They have made major contributions to documenting changes in the distribution and abundance of our flora and fauna. Notable achievements in recent years include the New Atlas of the British and Irish Flora[6], The Millennium Atlas of Butterflies of Britain and Ireland[7] and the continuing British Trust for Ornithology (BTO) Breeding Birds Survey, all of which have highlighted trends linked to climate change. Such organisations have proved adept at mobilising their membership and members of the public for surveys and recording schemes, often using World-Wide Web-based resources (Table 1).

Table 1 - Examples of some public-participation recording and survey activities in membership-based organisations.

Organisation	**Survey**
Plantlife	Various Plants Surveys [1]
BTO	Scarce Woodland Birds Survey [2]
Essex Field Club	Ladybird survey [3]
UK Glow-worms	Glow-worm survey [4]
People's Trust for Endangered species	Stag beetles [5]
Marine Life Information Network	Marine Life [6]
Seawatch Foundation	Marine Mammals [7]
Conchological Society	Slipper Limpet [8]

Web sites.

1. http://www.plantlife.org.uk/html/get_involved/get_involved_index.htm
2. http://www.bto.org/survey/special/scarce_wood_bs.htm
3. http://www.essexfieldclub.org.uk/ladybird_survey.htm
4. http://website.lineone.net/~galaxypix/
5. http://www.ptes.org/
6. http://www.marlin.ac.uk/LearningZone/LZ_rockpool.htm
7. http://www.seawatchfoundation.org.uk/
8. http://www.conchsoc.org/2index.htm?row2col1=Crep_forn_form.php

One of the most significant developments in public commitment to nature conservation in the last half-century has been the growth of mass-membership conservation organisations, exemplified by the Wildlife Trusts, the Royal Society for the Protection of Birds, and Plantlife. Their members represent a sector of society whose enthusiasm is measured in a willingness to make a regular financial commitment and includes many who would be eager to play an active role in monitoring the fate of species during the current phase of environmental change. There is much to be gained by involving amateur naturalists and conservation society members in species monitoring research undertaken in universities.

3. Enabling technology: amateur naturalists on-line

A new generation of naturalists have grown up in an information technology-literate culture, at ease with the use of the Internet, electronic information retrieval systems and digital photography. There is now a growing realisation that the World-Wide Web can be an essential tool for documenting biodiversity, providing an open-access library of life for cataloguing all living things and exchanging information. It has the potential to link amateurs with professions in a common enterprise. It can be used on a variety of scales, ranging from the established Global Biodiversity Information Facility[8] to local community efforts to document flora and fauna[9,10].

It is instructive to compare the traditional taxonomist's paper-based keys for identifying species, loaded with jargon, often difficult to follow and frequently ambiguous, with World-Wide Web or DVD-based identification resources that are now becoming available. The recently published DVD-based Interactive Flora of the British Isles[11] describes 3525 species, illustrated with 6500 photographs, 2000 line drawings and distribution maps for each species, with multiple entry keys, hot links to a glossary and rapid search facilities, all of which can be updated via the World-Wide Web. Such a resource would be impossibly expensive and unwieldy in printed format, but in future it is likely that data resources like this could be integrated into highly portable Personal Digital

Assistants (PDAs) that also incorporate digital cameras and Internet facilities, for field identification and immediate data submission. Media and devices like this will be basic tools for field biologists of the future.

The digital age is changing the nature of natural history knowledge. When taxonomic information was only found in obscure and often poorly indexed specialist publications in academic libraries, a high level of subject-specific learning was essential for naturalists engaged in field work. When information is readily available in an easily understood form at the click of a mouse button, the essential training element is to understand how to access and use this knowledge, not to memorise it.

Full implementation of this technology will require organisational effort and a great deal of money, but some components are already being developed and used (Table 2).

Table 2 - Example of web-based keys and identification guides currently available.

Organisation	**Taxon**
Biological Recording in Scotland	Bumblebees [1]
British Bryological Society	Garden Mosses and Liverworts [2]
UK Moths	Moths [3]
RAUK	Reptiles and amphibians [4]
Natural History Museum, London	Polychaete worms [5]
Natural History Museum, London	Lichens on twigs [6]
Essex Field Club	Ladybirds [7]
Seawatch Foundation	Cetaceans [8]

Web sites.

1. http://www.brisc.org.uk/bbident.php
2. http://rbg-web2.rbge.org.uk/bbs/Learning/malotag.htm
3. http://www.ukmoths.force9.co.uk/
4. http://www.herpetofauna.co.uk/identification.htm
5. http://www.nhm.ac.uk/zoology/taxinf/index2.html
6. http://www.nhm.ac.uk/botany/lichen/twig/
7. http://www.essexfieldclub.org.uk/ladybird_key.pdf
8. http://www.seawatchfoundation.org.uk/species-main.htm

4. The UK Phenology Network: a model for amateur involvement in natural history recording

The key requirements for encouraging and exploiting public involvement in natural history recording are training in accurate identification and providing remote, interactive access for those who participate in recording schemes, using computer-based technology.

One of the best existing models for this kind of participation can be found in the UK Phenology Network[12], a World-Wide Web-based phenological monitoring scheme that currently has over 12,000 active recorders throughout Britain. This web-based resource provides five key components for a mass-participation recording scheme. These are:

1. a clear exposition of what the scheme aims to achieve, and why it is important
2. clear, well illustrated instructions as to what observations must be recorded

3. easy, on-line data submission
4. easy public access to past records, which helps recorders to build an overall pictures of the changes being studied, and how their data contributes to a long-term database
5. feedback to contributing individuals on the annual progress of recording, its significance, and the importance of individuals' contributions.

The latter is especially important for maintain enthusiasm and a sense of personal commitment to a collective enterprise, and in this case is achieved by the use of interactive maps, regular analysis of results and e-mailed information to registered participants. There is nothing more dispiriting for recorders than to submit records that disappear into a void, with no feedback or indication of how they are contributing to the overall project. One of the key virtues of web-based recording enterprises such as this is the relative ease with which feedback to recorders can be delivered in an attractive, interactive, graphical form at minimal cost.

5. Community natural history: an opportunity for universities

Some commentators have described the current state of taxonomy and field-based research into our flora and fauna in universities as a crisis[2], but as with all such exigencies it has the potential to precipitate constructive action. Universities could benefit from working more closely with amateur naturalists in a number of ways:

1. By exploiting a knowledgeable and willing pool of expertise amongst amateur naturalists, university departments could increase their own research potential.
2. Universities could run training courses in taxonomic skills and the use of IT-based identification and recording techniques for dedicated amateur naturalists, using course participants that have been trained to relevant standards as reliable recorders in research programmes.
3. By engaging in such activities, universities can fulfil their aspirations in the field of community-based extension activities. They have the potential to widen-participation in higher education for people without high-level, formal educational qualifications. Gifted amateur natural historians often fall into this category, being self-taught field biologists without formal academic qualifications.
4. Extension activities of this kind form an important bridge between science departments and the wider community, encouraging active participation in the scientific enterprise. Such close, direct community links are widely considered to be essential for building public confidence in science.
5. Activities of this kind are particularly suited to collaboration on a regional scale between universities, making best use of the pool of professional taxonomic and field study skills amongst their staff.
6. One particularly encouraging national development is the recent creation of Science Learning Centres, linked to local universities, designed to enhance skills amongst school science teachers and support staff. These have the potential to extend natural history recording activities into schools, encouraging the next generation of natural historians. Science Learning Centres deliver supporting material for courses via an interactive, web-based system[13] which could be used as a very effective training tool for enhancing natural history recording skills. The North East Science Learning Centre, opened in 2004 and based at Framwellgate School in Durham, has already run a course designed to encourage primary school participation in the UK Phenology Network.

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[8]Global Biodiversity Information Facility. http://www.gbif.org/ (accessed 23/02/05)

[9]A Biodiversity Information System for all your ecological and natural history requirements in Cheshire, Halton, Warrington and Wirral.
http://www.consult-eco.ndirect.co.uk/lrc/index.htm (accessed 19/02/05)

[10]Isle of Skye Flora
http://www.plant-identification.co.uk/skye/ (accessed 23/02/05)

[11]Stace, C.A. (2004). Interactive Flora of the British Isles – A digital encyclopedia on DVD-ROM. (ed. van der Meijden, R. & de Kort, I.). ISBN 90-75000-69-3. ETI Biodiversity Centre, University of Amsterdam.

[12]UK Phenology Network. http://www.phenology.org.uk/ (accessed 23/02/05)

[13]Science Learning Centres.
http://www.sciencelearningcentres.org.uk/ (accessed 23/02/05)

BIOTECHNOLOGY – AN ENABLING TECHNOLOGY FOR INDUSTRIAL SUSTAINABILITY

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The distinguishing feature of clean technologies is that they refocus attention from the remediation to the prevention or minimisation of pollution and environmental degradation. New thinking, policies and technologies have started to catalyse such a paradigm shift such that management of wastes and pollution no longer is acceptable or sustainable. Moreover, the notion of industrial sustainability forces all the stakeholders (industry, government, public) to assume global, holistic and long time frame perspectives: global because most environmental problems have uncontained and global rather than contained and local dimensions, holistic because environmental problems require systematic analysis, and long-term because actions need to be prioritised for the sustenance of future generations rather than environmental problems being patched over by narrowly conceived, short-term, piecemeal responses. Biotechnology offers one important route to clean or cleaner industrial operations – it provides powerful and versatile tools with which it can compete with chemical and physical means of reducing material and energy consumption, and the generation of waste, emissions and effluents. And, critically, biotechnology is proving to be economically competitive in a number of industrial sectors.

The main drivers of clean (bio)technology are economic competitiveness, government policies, and scientific/technological feasibility. These drivers act in concert – none on their own are likely to propel the widespread adoption of biotechnology in this context. Two points must be emphasised: (1) biotechnology is not inevitably clean, just as chemical technology is not invariable dirty; and (2) rigorous comparisons of competing technologies can be made only by using life cycle assessment or similar tools in order to examine products/processes throughout their complete lifetimes (cradle-to-grave).

Although biotechnology has all the distinguishing features of a radical and pervasive technology, its take-up and recognition by industry as a clean technology has been patchy and perhaps slower than anticipated. While current biotechnology is dominated by the human health care and agriculture sectors, it is sometimes forgotten that the applications of biotechnology go far beyond food and human health and are penetrating a wide range of industrial sectors. A selection of case studies will be presented that demonstrate the scope of biotechnology in the progress towards sustainable industry via (1) replacement of fossil fuels, (2) replacement of traditional chemical processing, and (3) direct alleviation of environmental pollution.

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MARLIN'S EDUCATION AND OUTREACH ACTIVITIES: ENGAGING THE PUBLIC IN ENVIRONMENTAL MONITORING

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MarLIN was established in 1988 and provides information to support marine environmental management, protection and education. MarLIN is the marine node of the UK National Biodiversity Network, holding and making available records of marine life from professional surveys and volunteer recorders.

The 'Marine Life Learning Zone' is a part of the MarLIN Web site and provides marine life information and facilities for volunteer recorders including online recording and support for other recording schemes. These online resources are supported by products such as the 'Sealife Signpost', identification guides, posters, flyers and Seashore Safari stickers.

The MarLIN team with local partner organisations stage educational events around Plymouth Sound for schools and the public. These 'Seashore Safaris' are our opportunity to put our products into practice, encourage marine recording and talk to future volunteer recorders.

MarLIN, together with the National Biodiversity Network, held a one-day conference in July to bring together collectors and custodians of marine life records and address the issues of flow of data collected by volunteer recorders. We aim to build on the 2004 event with a follow-up conference in summer 2005 which will include even more volunteer recorders.

The MarLIN programme is working with volunteers and schools to help document how our marine life is changing. We collect records of climate change indicator species, non-native species and provide fieldwork training to schools. With the Dove Marine Laboratory in NE England we are working on a project to engage schools nationally to collect data from rocky shores and make it available on the Internet.

MarLIN's role is to tie-together and where needed to support marine life recording schemes in Britain and Ireland, and to promote best practice in handling the records generated.

1. Introduction

Designed to make marine life information freely and rapidly available through the Internet, *MarLIN* was established in 1998 by the Marine Biological Association and developed in collaboration with the major environmental protection agencies in the UK together with academic institutions. There are three strands to the *MarLIN* programme:

- Biology and sensitivity key information
- Data access
- Education and outreach

Author's biography. Guy Baker is the Outreach and Information Officer for the Marine Life Information Network for Britain and Ireland (*MarLIN*).

MarLIN provides the marine node for the UK National Biodiversity Network (NBN), a project to build a UK network of biodiversity information.

2. *MarLIN's* education and recording resources

MarLIN operates a Web site which includes 'the Learning Zone' (www.marlin.ac.uk/learningzone/) aimed at a non-specialist audience and volunteer recorders. The Learning Zone provides accessible information on marine life and helps promote recording schemes and events.
Elements of the Learning Zone Web site include:

- Species pages. Accessible information on marine life through pages on marine plants and animals.
- On-line marine life recording form and feedback. An easy-to-use online recording form is available at http://www.marlin.ac.uk/learningzone/recording/rec_logon.asp Users are requested to log in (so we can contact them if a record is unusual or needs verification). The form can be downloaded and printed. Feedback is provided (URL) so that recorders can view their submissions. Once validated and verified, all records are passed to the NBN.
- Marine life topic pages. Information on marine non-native species, aquaculture, dredging and so forth, aimed at 'A' level to undergraduate level.
- An interactive Tour of Firestone Bay. Takes users on a virtual dive of this fascinating site in Plymouth Sound.
- A forum for volunteer recorders.

To complement our online resources we produce identification guides (the *MarLIN* guide to selected underwater species was produced in collaboration with Seasearch), posters, bookmarks, flyers, marine life stickers and the Sealife Signpost (see 5.2 below).

3. *MarLIN*'s outreach activities

3.1. Seashore Safaris

MarLIN, with partner organisations Plymouth Young Peoples Agenda 21 (PYPA21) and British Trust for Conservation Volunteers (BTCV), holds educational events on the shore. The number of events and participation has increased each year since 2001.

3.1.1 Public Safaris

The rocky shore of Plymouth Sound has rich and diverse marine life. Direct contact with the public on the rocky shore is an invaluable way of inspiring interest and conveying information. As well as helping the public to enjoy marine life, the public events promote *MarLIN* learning resources and encourage volunteer recording. We also celebrate World Oceans Day and are participating in the first Tamar Coastal Festival.

3.1.2 School Safaris

Key Stage 2 groups explore the rocky shore, use the 'beach lab' and play games with an environmental and citizenship slant. For some of these children this will be their only visit to the shore.

In 2004 we involved around 170 members of the public and 170 schoolchildren through Seashore Safaris.

3.2. National Science Week and other British Association related activities

During National Science Week local school groups and the public are invited to come and learn about the research being undertaken at the MBA. The Marine Life and Environmental Sciences Resource Centre (constructed in what was previously the aquarium) is opened up and each research group interprets their work through interactive displays. The *MarLIN* display illustrates the impacts of environmental change using a colourful, interactive display. In 2004, over 600 children ranging from infants to 6th formers attended, and over 100 members of the public visited on the Saturday.

4. *MarLIN* helps coordinate volunteer data

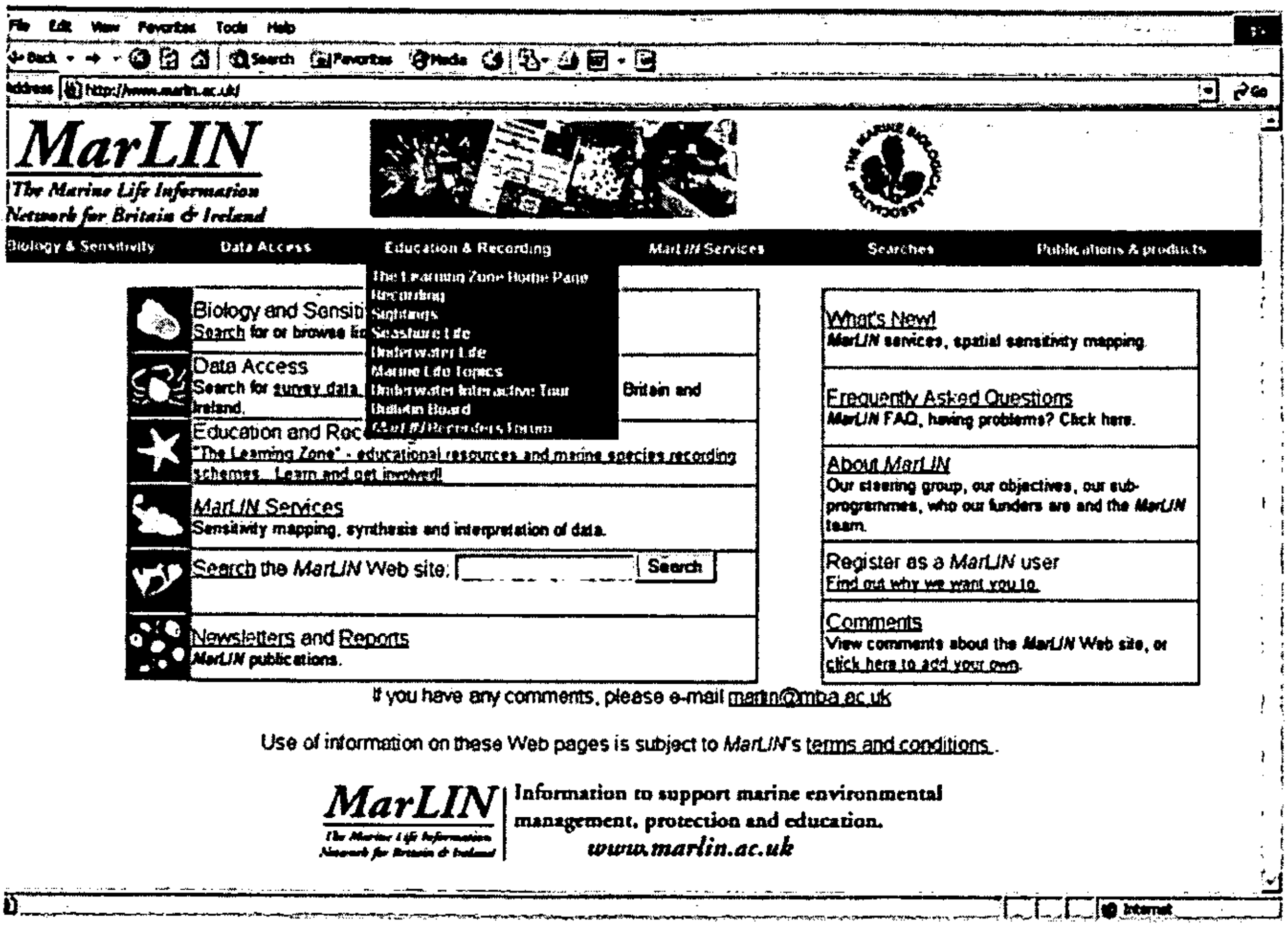
4.1. A volunteer recording conference - 'Making marine life recording work'

MarLIN, together with the UK National Biodiversity Network, held a one-day conference at Exeter University in July 2004 entitled 'Making marine life recording work'. Around 60 delegates attended, including volunteer recorders and representatives from a range of marine life societies and trusts, Local Record Centres and statutory nature conservation agencies.

The aim of the conference was to improve the flow of data collected by volunteer recorders and to promote best practice in handling volunteer data. Issues identified and discussed included data flow and management, managing volunteers and strengthening the network of data collectors and custodians. Action on these issues is encouraged through the resulting report and an on-line forum has been established to allow continued exchange of information. To visit the forum select Education & Recording from the *MarLIN* home page menu bar and select *MarLIN* Recorders Forum. See Figure 1.

Feedback from delegates suggested the content of the day was appropriate and useful, and many particularly enjoyed the networking opportunities.

We aim to hold a follow-up event next summer which will include more volunteer recorders. If you are a volunteer recorder of marine life, have any views on the subject, or would like a paper copy of the conference report, please contact *MarLIN* at marlin@mba.ac.uk. The report is also available from www. marlin.ac.uk/conference/vol_rec_conf.htm.



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The Marine Life Information Network for Britain & Ireland

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Education and Rec
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Information to support marine environmental management, protection and education.
www.marlin.ac.uk

Figure 1 - Navigating to the MarLIN on-line recorders forum.

5. Recording schemes

5.1. Seasearch

A *MarLIN* representative sits on the steering group of Seasearch. *MarLIN* provides identification guides and is involved with local Seasearch projects.

5.2. Sealife Signpost

We realised that for the interested public there is sometimes confusion on who wants what records and the Sealife Signpost was our attempt to chart some of the murky waters of marine recording. The Sealife Signpost is a simple sticker for clubhouses, bags, boats etc. that has been widely distributed. It directs people to appropriate recording schemes – including our 24-hour Recording Hotline (01752 255026). A full list of 12 recording schemes can be found on the Sealife Signpost online. All records *MarLIN* receives are passed on to the appropriate scheme, and all records of seashore and seabed wildlife are passed to the National Biodiversity Network.

Version 2 of the Sealife Signpost is in production and will direct users to facilities to upload mobile phone pictures and send text messages to the *MarLIN* Web site.

5.3. The Shore Thing

The rocky shore is a great place to learn about ecology through observations of adaptation and interaction. In partnership with the Dove Marine Laboratory at the University of Newcastle, *MarLIN* is engaging schools to provide biological survey training, collect data from rocky shores and make them available on the Internet. This national project focuses on records of species which tell us about climate change and on non-native species.

The demonstration phase – carried out in summer 2004 – has helped the project to evolve, proved that we can engage schools and tested our survey methodology, data capture and data quality procedures. Funding for a three year project run is being sought.

Intertidal surveys are backed up by preparatory lessons, experts on the shore and teacher support packs. The resulting dataset can be used as the basis for further work. Many students will take this knowledge and awareness on to further study or into an interest in natural history.

6. Volunteers

MarLIN receives valuable help from volunteers, often students or recent graduates who commit at least one day a week. We get help with basic information reviews, Seashore Safaris or database work, in return the volunteers learn about marine life, get valuable work experience and meet researchers in their fields of interest.

7. Summary

- *MarLIN* makes marine life information available on the Internet
- *MarLIN* helps the public to enjoy marine life
- *MarLIN* supports recording schemes and promotes best practice in handling volunteer data

The *MarLIN* project is funded by a Consortium. Key funders of the Learning Zone and educational activities have been the Environmental Action Fund of Defra (who fund 'Sealife Heritage'), English Nature, the Crown Estate and the British Marine Aggregate Producers Association, PADI Aware, NBN.

AWAKENING CURIOSITY IN NATURE

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A class of 7 and 8 year old children spent a term studying kittiwakes on the River Tyne. The idea was to use the inspiration of the kittiwake's life cycle to increase the pupils' understanding and curiosity of the natural world, whilst covering important parts of the national curriculum. The arts (storytelling, music and the visual arts) were the key tools in the process, both in terms of encouraging observation and as a response to what was seen or learned. This creative engagement led to a strong identification with the bird and an enthusiasm and desire for learning. It also led to sense of self-satisfaction and pride in what they had done. On the whole the children gained a good understanding of the life of the kittiwake and other life around them. They had a confidence in self-expression which was reinforced by being involved with the drawing up of a management plan and writing a leaflet. There is strong anecdotal evidence that their curiosity and interest in nature was increased beyond the life of the project.

1. Project Background

This paper is about a study of kittiwakes done with a class of 13 Year Four (7-8 year olds) pupils at Lindisfarne School in Gateshead in collaboration with the Sage Gateshead Music Centre.

The project arose out of a larger initiative at the Sage Gateshead, called Voices of the Rivers Edge (VOTRE), whose aim was to record and creatively express the stories of the people who live by the River Tyne.

As part of this it was decided that the stories of the wild creatures should also be heard. This strand of the project became known as the Kittiwake Project. The kittiwake was seen as symbolic to Tyneside because here they nest further inland than anywhere else in the world. This normally sea-cliff nesting bird has taken up residence on man-made structures right down the Tyne.

Their presence has highlighted different attitudes in people's relationship with wild creatures and brought fierce controversy. For some they are a delightful presence in the city, for others they are a dirty, noisy nuisance that should be removed. This has come to a head over colonies on the Baltic Flour Mill and the Tyne Bridge.

The kittiwake was thus an interesting bird to study both biologically and socially.

We chose to work with Lindisfarne school in a very disadvantaged area of Gateshead, situated underneath a dual carriageway and not far from the nesting colonies. The teacher in the school was very keen on the project and saw it as an opportunity to deliver parts of the national curriculum in a creative way. He thus re-organised the topics of his year's teaching to fit. Elements of Science, English, Technology, Geography, Art, Music and P.S.H.E were all covered by the project.

Author's biography. Malcolm Green is a consultant biologist with a strong interest in the arts and especially story telling. The kittiwake project was carried out in collaboration with The Sage Gateshead.

The kittiwake project lasted for one afternoon a week for a full school term, with whole days given over to field trips. It became a true collaboration between The Sage Gateshead and the school, with myself as the storyteller both working on it and planning its overall direction. Other artists involved were: musicians from The Sage and a visual artist. We were also supported by other agencies, in particular the Dove Marine Laboratory and the RSPB. The project was funded by The Sage Gateshead.

2. Introduction

Two men in a field

For many children in both inner city and rural environments their involvement in the natural environment is low. They do not play outside or make dens in the way that their grandparents or even parents did. They do not roam freely into countryside far from their home. Their understanding and knowledge of local natural history is poor. This is certainly the situation with the children of Lindisfarne School.

It is, however, also true that most children aged between 7 and 11 years are fascinated by life in all its various forms and guises. The problem is more of one of access and the basic knowledge that opens doors to further interest. At Lindisfarne School, we hoped to stimulate children's curiosity and deepen their understanding through creative and imaginative involvement in local wildlife. The kittiwake, as a special local creature, was the vehicle for doing this.

3. The Process

Much of the work of the kittiwake project was informed by previous creative work with birds in other schools, so although most of the report is based on this project, elements of other projects are also brought in to illustrate a point.

There were 5 basic stages of working that we used to develop children's understanding and involvement. These are expanded on later:

1. The children to tell their own stories of observation of nature. This was encouraged by inviting the children to write things they had seen during the week into a diary and regular 'show and tell' sessions.
2. The children were taken on field trips where they were encouraged to be curious and record their observations.
3. The children were encouraged to research further their observations back in the classroom, sometimes using knowledgeable adults as a resource and sometimes books and the Internet.
4. The children were encouraged to tell aspects of their own life stories and see how these were echoed in the life of a wild creature.
5. Creative activities were used to engage the children in the process. Traditional Stories were used to encourage questioning and stimulate interest. Poetry, story-making, music and the visual arts were all used to both make sense of information and creatively respond to it.

The teacher said on many occasions that the children's personal ownership of the project and identification with the bird was what made the project relevant and held their interest. Something that is lacking in much of the national curriculum

4. Children Telling their own Stories

Getting children to tell their own stories was an important part of the project from the beginning. Sometimes the stories were told to a partner, who then told it back to the wider group, sometimes it was told straight to the big group.

At the beginning of the project children simply talked about observations they had of nature during the week and we had a regular show and tell. We had a big diary in which these observations were recorded.

This simple observational storytelling led on to the telling of personal stories about their lives and experiences: leaving home, growing up etc...we used these stories to parallel and compare with the life of a kittiwake. This kind of storytelling contributed to their story making later in the project.

We believed that by creating parallels in life story we would create empathy without being anthropomorphic.

Something that was borne out by the writing.

5. Observing

The first thing was to see the kittiwakes.

Fortunately, near to the school is an artificial nesting tower with 60+ pairs of birds nesting on it. We walked down to the tower and the children had the chance to see, hear and smell the birds for themselves. It was a chance also for some focussed observations

We encouraged the children to think of what questions they might like to ask the birds...and then to see what they could discover by looking. Drawing channelled the looking. We then asked them to put words to the picture that might relate to things they noticed or things they were feeling. For some children these tasks were easy and helped them to see more, for others just being out and wandering around was enough.

The words and pictures created were used in creating poems with the children back in the classroom. This enabled them to reflect on what they had seen, assimilate the information and make a personal response.

Poem by Class Four:

I wonder how far a kittiwake flies?

The view of the glorious Tyne
White shining foam on the rushing waves
I saw a kittiwake, washing in water
Orange beak
Hovering
Red mouth
Shining feathers in the sky
I wonder how far a kittiwake flies?

6. Curiosity and Questioning

Curiosity and asking questions are central to any investigation. It is, however, hard to ask good questions, particularly when your background knowledge is so poor. It is harder still to ask open questions.

One way of doing this was to look at an area in which they were experts... their own lives and discuss the important questions there...to see that the answers are usually various shades of grey rather than black or white. We used these questions to think what would be relevant to the kittiwake. These were answered through book research but more importantly through role play. I became the kittiwake in the classroom (a kind of audio visual aid) and the children could ask me questions about who I was and what I did. This gave then the power to find out what they wanted to know rather than what I wanted to tell them.

It was through this process that we uncovered the life cycle of the kittiwake and created a piece of artwork in the form of a map to consolidate the learning. This became a place where information and thoughts and feelings could be displayed throughout the project.

In parallel with the factual information about the kittiwake's life, we worked with folktales. We encouraged the children to explore the language of metaphor, the language of story.

7. The Language of Story

The folktale or story using metaphor is essentially engaging because it talks about us...our aspirations and fears through a fictional character with whom we identify. People have long understood their relationship with the outside world through the vehicle of the story.

Most days of the project a folktale was told. This had a number of functions. We could present information through stories. There was a 'chill out' element...allowing the children to enter another world for a few minutes...see their own pictures in their heads...stretch their imaginations.

The more mythic stories added another dimension to the bird: the kittiwake as the reincarnation of a drowned child, the kittiwake that transforms into a woman.

At the beginning of the project, I told a story called the Jackdaw's Skull, which was about a boy who learned the language of the birds and set off on a long journey. I saw this both as stimulus for our work and a metaphor for the project.

I intended that by using stories throughout the project, the children would learn the language that would eventually enable them to create their own story at the end of the project...a story that would bring together their lives with the life of a kittiwake in both an informational and metaphorical way.

8. The Kittiwake's Journey

The Jackdaw's Skull story lead to asking the questions ...what does the Kittiwake want to tell us about her journey?

We divided the kittiwake's life into four phases:

Birth and fledging…the nest…home
Childhood…wandering the oceans
Adolescence…return to the colony
The adult…continuing the cycle

With each phase we started with what the children knew…

What's home to you…what is home to a bird…what is different, what is similar…does the word home have a meaning for a bird?

What would it be like to fly? Imagine what it would be like to be that young bird out in the middle of the oceans in a storm?

The young kittiwake returns to the colony for the first time not to breed but to hang out in gangs…what do teenagers do? How do they behave?

Some people want to remove the nesting kittiwakes from the Tyne Bridge …do we care?

With each element of the lifecycle, we used an arts activity to experience and consolidate the learning. This included storytelling, song, movement and rap. We invited in outside 'experts' to present the controversial issue of kittiwakes nesting on the bridge. They spoke for and against netting the bridge so that the kittiwakes could no longer nest. The children then discussed the issues and created roles: the city engineer, who was worried about corrosion, the woman with her daughter, who liked watching them between shopping. A fierce debate ensued and a vote taken…the kittiwakes won handsomely!

A rap artist was then brought in who helped the children turn the arguments into a rap.

9. Using the Children's Knowledge

We were then able to use the knowledge of the children in a practical way. Two scientists from the Dove Marine laboratory worked with the children on a 'citizenship day', in which the children were consulted on the management of the land around the tower, where the kittiwakes nested. This meant a second visit to the tower, at a time when no kittiwakes were present and through various activities the children used their knowledge and imaginations to suggest improvements to the area.

The children were also asked to come up with designs for a leaflet to tell people about the Tyne kittiwakes. Both these activities gave value and importance to the children's work and understanding, which was a very positive outcome for the project.

10. Creating the Story…bringing together child and kittiwake

The final activity of the project was to create a story. The idea of the story was to bring together elements of what the children had worked on in the project, with the spice of their own imaginations. I introduced a structure for the story through a few key questions. We then created the story as a whole class activity.

At key points the children broke into smaller groups to brainstorm different directions in which the story could go. The whole class then voted on the one they liked the best.

The story that emerged was very rich and personal to the group. One boy, Liam, who was semi-literate had throughout the project referred to bird book that his deceased father had left him and was clearly very important to him. This book was woven into the fabric of the story. Katy often visited Holy Island, where her grandmother lived and her experience of this influenced the kittiwake's journey.

Four children were chosen to work on the telling of the story and the others worked with the musicians to create songs and some movement to accompany the telling. I took the responsibility for remembering the overall structure by providing the link elements of the storytelling.

Performances of this were made to the school and at the Sage Gateshead and put a conclusion to the project.

A section of the children's story

"I can't row though" said Billy, as he got on the boat, "you don't need to" said Albert, his grandfather. Amazingly out of the sky came dozens of kittiwakes, who attached strands of seaweed to the boat and started to pull them out to the North Sea...

Billy would have felt cold and afraid, if he didn't have kittiwakes for company. "I think we are following the journey the kittiwakes make each year", his grandfather explained.

11. Discussion

A project like this involves constant readjustments to attune to the children. Sometimes I questioned the relevance of what we were doing given the harsh reality of life for many of the children. This idea was, soon banished by their enthusiasm. All the workers were touched and humbled by the warmth and generosity with which we were received each week. Of course why shouldn't the children want to have an engagement with the life of the outside world? They too are fascinated and touched by it if given the chance. Here I would like to quote John Innerdale the teacher:

"One of the major reasons for the children becoming so interested is that they felt a personal link to the kittiwake through the visits and taking on the role of the bird. I've noticed this so many times in primary teaching that if you give the children personal ownership, they feel more involved and it becomes relevant to them. This combined with the cross-curricular nature of the project was the key to its success...if we are to enthuse our pupils once more in our increasingly industrial; age –make it relevant to them and use as many areas of the curriculum as possible to teach it"

In terms of the long-term impact of the project on the children's curiosity and interest in nature, it is very hard to know what effect it has had. I would, however, like to finish with an anecdotal story of the teacher.

Taking the children on a trip a couple of months later. They passed a pool with the great edifice of St. James Park Football Ground, towering behind. The children immediately noticed the gulls on the pool. A new child in the class said "*they must be kittiwakes*" to which another replied "*don't be silly, they won't have come back from the sea yet.*"

It was remarkable that they even noticed the gulls!

He also said that the nature table has never been so full with things brought in.

One cannot stress enough the importance of Mr. Innerdale, the class teacher, whose enthusiasm for the project and knowledge of the children made it possible.

"Thank you for everything about the kittiwakes. I never knew anything about kittiwakes until you came along. Now I know loads and loads."
Brad Ryder.

THE 'OVERSEAS MODULE' AT NEWCASTLE UNIVERSITY PROVIDES TRAINING IN FIELDWORK AND COMMUNICATION

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Graduates in biological sciences should have broad experience, which is enhanced by travel, and also the ability to communicate effectively with other members of society. The 'Overseas Module' at Newcastle which was first introduced in 1989 was designed to meet both of these objectives. Students are asked to arrange a visit overseas, to investigate a biological problem and communicate their findings in a manner which would appeal to the general public. Each student submits a report and a poster offering them the chance to use different methods of communication. The Overseas Module is a highlight of the degree programmes and often the reason for the final selection of one of the degrees which offer it.

1. Introduction

There is an important need, not only for students to spend time in the natural environment but for them to be able to communicate information about it to other scientists and the wider public[1]. The 'Overseas Module' at Newcastle University enables students to (i) broaden their experience of environmental and other biological issues by travelling abroad during the long vacation; (ii) gather information on a chosen topic; and (iii) report their findings in a way that is comprehensible to the intelligent layman. The culmination of the experience is therefore the kind of article which appears in *New Scientist* or *Scientific American* and a poster presentation.

Students are expected to adopt the role of investigative journalists and collect information though interviews and library, archival and internet searches on a topic of their own choosing. They must also assemble illustrative materials from their own photography or other sources. The rules are flexible with one important exception. This is a communication and not a research exercise. An article or poster that describes original data in the form of a scientific paper is not permitted – the skills relating to scientific research are developed in other parts of the course. While many of the students spend most of the long vacation abroad, they are expected to allocate between 7-10 days of their time on this module.

It is well known that overseas travel is popular amongst young people preparing to go to University. A request for 'gap year' information on 'Google' reveals more than 13 million sites. The number of student applicants through the UCAS system who now prepare for university by taking a Gap year has risen so that in Newcastle almost 20% of applicants for the Marine Biology and Zoology courses plan to defer their entry and have a year devoted to travel before they begin their course.

In order to offer more opportunities for students to experience new cultures and different teaching methods the EU encourages students to spend the second year of their undergraduate course at another institution. While this Erasmus/Socrates scheme has many appealing features it has one

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stumbling block for most science students in the UK in that it depends on the ability to speak and write in another language. In effect few such exchanges take place.

Some universities across the UK recognise the value of international fieldwork.[2], and offer opportunities within their biology programmes to attract students. The schemes vary from one year placements in Scandinavia or the USA offered by Stirling[3] to short field courses in South Africa or France in the course at Plymouth [3] or Tobago with Welsh universities[4]. The value of visits to 'exotic' destinations is recognised as an effective means of student recruitment[5]. It has also been suggested that they also offer a strong motivation for taking courses[6]. Similar sentiments have been expressed by authors[7] who noted the lack of commitment of students to university study but that active participation in an 'Expedition' was a strong motivating factor. The Overseas Module offered in Newcastle hopefully encompasses all of these aims. It has been a highlight of both degree courses since its inception in 1989.

2. Module description

The module is aimed at second year students from the Marine Biology and Zoology degree courses at Newcastle. Among the planned outcomes are that field studies will be significantly promoted by allowing a free choice of subject area. In addition students will benefit from the visit by being immersed in new cultures. They will have a different learning experience, broaden their horizons, demonstrate their independence and become more confident and self reliant.

Students are asked to arrange a visit to an overseas country of their choice where they can study a biological problem which interests them. The visit, taken during the long vacation before final year, should be for 7-10 days, often it is much longer. Marine Biology/Zoology in Europe was devised by Professor Stewart Evans in 1989 as an alternative to the year abroad Erasmus/Socrates scheme. Originally students were encouraged to contact institutions in Europe many of which had been visited by Professor Evans who had made arrangements for students to use the institution as a base and have access to the library. Almost immediately students showed themselves to be more adventurous and within two years it was clear that autonomy and world-wide travel were preferred.

Financial support is offered to the students by the host department and calculated to allow the cost of rail travel to Europe, with a small amount left for camp sites and food. Once the destinations became more remote imaginative schemes to raise money were thought up and more recently student loans used for the visit of a lifetime.

The arrangements for the module begin at the start of the second academic year. Students are encouraged to organise themselves into groups for the visit as lone travel is very actively discouraged. Lists of destinations chosen previously are shown and contacts with third year students who have just made their visit are encouraged. Even this small matter of giving advice pleases final year students who relish being regarded as experts on travel plans and their chosen project.

Throughout the year meetings are held regularly to check progress with plans. Letters of introduction are provided and matters of safety and health issues are addressed. Advice concerning health issues is taken from the Foreign Office and Department of Health websites and risk assessment forms check that necessary considerations have been given to all aspects of the trip. Email contact throughout the year and tutorial meetings solve many problems along the way. While help and advice are always available the visit has to be organised by the students themselves.

Destinations chosen by the cohort of students who travelled overseas in 2004 illustrate the worldwide locations chosen for projects (Figure 1). Since one visit to the Arctic in 2002 when polar bears were the subject of the study, Newcastle students have visited locations which stretch from the tropics to the poles.

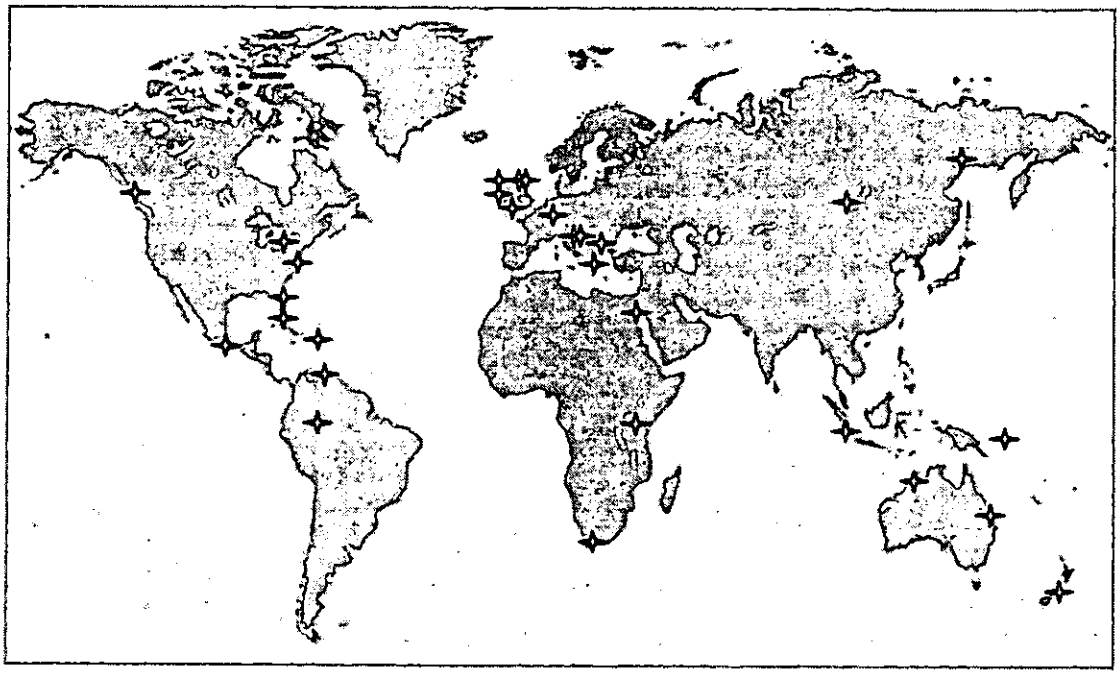

Figure 1 - Destinations chosen by Marine Biology and Zoology students for their overseas project in the long vacation 2004. Most destinations were visited by small groups of students, with the exception of UK locations which were chosen by individuals.

The topics chosen represent a wide range of interests. Although many such as turtles and dolphins are predictable others, e.g. Prezewalski horses, European Griffons, sea moss cultivation and yellow-eyed penguins, are more unusual. The projects which students take part in are also widely different. Some prefer a hands-on approach and join conservation programmes to protect turtle eggs, braving forest walks, biting insects and exhaustion from working through the night. The arrival of students as volunteers on these programmes has directly resulted in a reduction in poaching of turtle eggs. Local families can make more money by providing accommodation for students than they can from poaching. Students involved in conservation projects such as those who visit rain forests or coral reefs often describe environmental degradation. The need for natural science courses has been emphasised as these allow students to experience field work so that they are able to understand the causes of the decline they witnessed[8]

Others choose to be involved in basic ecological research such as the wolf project in a Canadian National Park. In these situations students provide a workforce along with post-docs and those on sabbatical which is valuable in helping to collect data on the natural ecosystems as well as on the effects of human activities[9,10]. A small number prefer to be involved in public education, basing themselves in countries such as Indonesia where community education programmes involve villagers in plans for 'beach clean-ups' and 'no fish zones'. It may be that field courses to 'poor' destinations could become 'development tourism' if not handled sensitively[5]. Experience from Newcastle students suggests that they are sympathetic to the culture in which they find themselves and write about their worries and concerns for people, such as subsistence fishermen and their families whom they have met.

Table 1 - Range of topics chosen by the 2004 cohort of students. Each person submitted an individual report and poster.

Marine Biologists		**Zoologists**	
North Sea Fish	UK	African Big game	Zambia
Pink River Dolphin	Brazil	Tree kangaroos	Australia
Dugong	United Arab Emirates	Golden Eagles	Ireland
Coral Reef Fish	Tobago	Jaguars	Belize
Leatherback turtles	Costa Rica	Indigenous parrots	Bahamas
Conservation	Monterey Bay	Dolphins	Croatia
Sharks	South Africa	Wolves	Canada
Horseshoe crabs	Florida	Wilderness walks	Australia
Community education	Indonesia	Amura tigers	Siberia
Orcas	Seattle USA	Griffon	Croatia
Manatees	Florida	Prezewalski horses	Mongolia
Fish farming	Shetland Isles	Gouldian finches	Australia
Sea moss cultivation	Tobago	Elephants	Florida
Yellow eyed penguins	New Zealand	Grey seals	UK
Fishing Technology	Greece	Kiwi	New Zealand

More adventurous individuals go and dive with white sharks in South Africa. Some risk sea sickness measuring fish on boats involved in net technology trials in the North Sea or survey fish populations off Canada. In 2004, 67 students took part in this module and of those only two decided to carry out a project which did not require some sort of field or practical involvement, confirming the view that students value field work[11] and enjoy field study[12].

3. Discussion

The Overseas Module is a success. It offers students the ability to make choices, to demonstrate their independence and to try out their organisational skills, within a structured and monitored teaching environment. Language abilities can be improved in an environment where some English will be spoken but where examination results will not depend on excellence in a foreign language. It is agreeable to select a travelling companion, who may be a friend from home rather than another student, and most likely extend the work related visit to a holiday at a destination which may never be revisited. The requirement of a cultural write up means that students must appreciate local cultural differences. Whether eating fermented mare's milk in a Mongolian 'ger' is enjoyable at the time is doubtful but in the report it is highlighted as 'memorable'. Even visits to apparently similar countries such as the USA reveal differences which students find surprising. Why does no one in Florida walk anywhere? And therefore by deduction: is not our public transport system in the UK excellent! Cultural observations reveal a degree of observation and empathy which is surprising. After a visit to Robben Island a student wrote:

'To see how people who were merely trying to live a fair life had been kept and punished was heartbreaking.'

Another student visiting the Far East found the levels of poverty unsettling. He wrote:

'To see people in such a state of misfortune is really upsetting, but at the same time it makes you very grateful for what you have.'

Clearly an overseas field course is enjoyable but it is arranged, taught by staff and carried out with the class. There is not the sense of anticipation our students describe during the organisation or the thrill of carrying out practical work such as seal counting from a spotter plane or tracking tigers. For a twenty year old who has never been outside Europe the experience of travelling up the Amazon in a canoe was described as seeing a river 11km across which made the largest UK rivers look like minor streams. He was 'awestruck', and saw monkeys, parrots, eagles and sloth even before the camp had been reached. Of course some students find making the arrangements a huge problem but the joy of success having overcome all the wasted emails and web searches is very special. The Overseas Module is a great bonus for students completing cv's as it allows them to show examples of their ability to organise, to be independent and to integrate with others. It is impressive to potential employers.

Comparative data is not available for any similar schemes. Suffice to say that one comment above all others demonstrated the success of the module. It was from a female student, a very beautiful and immaculately presented girl who spent a lot of time and money on her appearance. In her report she wrote 'just to be here is such a privilege, who needs electricity and warm water?' It is therefore no surprise that this module is so popular and often one of the major reasons for the final degree selection

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THE 'CITIZENSHIP DAY' AS A MEANS OF ENCOURAGING SCHOOLCHILDREN TO ACQUIRE, VALUE AND USE ENVIRONMENTAL KNOWLEDGE

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The 'Citizenship Day' has been developed as a means of introducing environmental issues into the classroom and encouraging young students to act as responsible citizens by recommending ways in which the environment can be managed effectively. Two models have been developed. Children play the roles of environmental managers in the 'Environmental Management' model and those of prosecutors, jurors and media in the 'Court Room' model. The models have been tested in three schools on Tyneside and one in Northumberland. Reactions from local authorities, industry and the media suggest that the recommendations made by the children are valuable, realistic and affordable. They have resulted in several positive outcomes, including the publication of nature trails, the development of further projects and invitations to participate in further planning initiatives.

1. Background: The Problem

The need to involve citizens in decision-making processes that relate to all social issues, including management of the environment, has been emphasised in a range of influential publications. They include, for example, the report of the House of Commons Select Committee on Public Administration[1] and, specifically in relation to the marine environment, the Defra publication *Safeguarding Our Seas: A Strategy for the Conservation and Sustainable Development of our Marine Environment*[2]. The benefits from doing so include '*better decision-making, reduced reliance on regulation, generating a positive role for people and organisations and greater inclusiveness.*' *Safeguarding Our Seas*, in particular, recognises the need to encourage '*local partnerships to deliver local solutions and develop opportunities within the Government's framework for national policies.*'

However, there are obstacles of at least three kinds that must be overcome before the general public will be in a realistic position to contribute effectively to environmental decision-making and planning processes:

First, people's knowledge and awareness of local environmental issues is poor. Most people have insufficient knowledge either of ecosystems or understanding of the problems confronting them to contribute usefully to public debate on management issues. Gigliotti (quoted in Gambro and Switzy[3]) commented that '*we seem to have produced a citizenry that is emotionally charged but woefully lacking in basic ecological knowledge*'.

Second, the personal sense of caring for, and showing a responsibility towards, the environment appears to be lacking in the lay public. Evans[4] suggests that most people in the developed world

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have 'lost' their affinity with the environment and view its management as the distant responsibility of politicians, industrialists, scientists and 'green' activists.

Third, people are reluctant to engage in the scientific process because science is undervalued and held in relatively low esteem by the public. The House of Lords' Select Committee report[5] on *Science and Technology: Science and Society* suggests that the lay public's unease, mistrust and even hostility towards science, and failure to comprehend scientific issues, has wide-reaching consequences. It is probably responsible for the under-funding of science and indirectly therefore for the shortage of resources to address environmental issues.

There is a clear need to change public perceptions of, and attitudes towards, the environment· Not surprisingly therefore, there have been several calls for more environmental education in the school curriculum[6,7]. However, Lakin and Burch[8] draw attention to the difficulties of establishing environmental education in schools and the problems faced by teachers who are prepared to include it in their courses. A particular problem is that fieldwork raises several safety issues. They, among other factor appear to be contributing to what is generally believed to be a national decline in fieldwork teaching in schools and universities[9,10,11, 12].

The introduction of *Citizenship* in each of the Key Stages of the National Curriculum provides yet further challenges for over-burdened teachers, who already suffer from 'initiatives overload', excessive administrative and teaching duties and the de-moralizing impacts of almost relentless appraisal and reorganisation. While there are major difficulties in bringing it into the classroom, its introduction does provide an opportunity for new teaching initiatives in which students are asked to consider issues concerned with management of the environment. The '*Citizenship Day*', which is described here, is one such innovation. Two models are presented. In the first, schoolchildren play the roles of environmental managers in considering issues relating to conservation and sustainable development on local habitats. This involves some fieldwork. In the second, which is confined to the classroom, the participants challenge moral and ethical values relating to specific human activities that impact on the environment by playing roles in the judicial system. Members of the public are put on trial for harming the environment, with the children playing roles of prosecutors, jurors and the media.

The 'Environmental Management Model' has been developed and tested in two schools on Tyneside and one in Northumberland. It has been adapted for children of different ages and abilities, and to suit local circumstances (e.g. in considering local habitats that are of conservation importance). The 'Court Room Model' has been developed and tested in one school on Tyneside. It too relates specifically to an environmental issue of local importance, in this case the health of wild salmon as a key indicator species of river health.

The experiences in each of the four schools are outlined below:

2. The Environmental Management Model

2.1. Management Recommendations for Blyth and Hartley Links (Sand Dunes): Cramlington Community High School

The Links have been designated as a Local Nature Reserve by English Nature. They have had an interesting but sometimes turbulent history, being used as military bases during the Napoleonic, First and Second World wars and a centre of sand extraction until the middle part of the last century. They have been, and still are an important leisure resource for the local community, with a promenade, now in poor condition, and a disused bandstand at the northern end. The dunes themselves suffer from excessive and largely uncontrolled trampling from visitors but they still support a rich diversity of plants and animals, including several species of conservation importance.

A group of 6 volunteer Year 10 students from Cramlington High School were asked to act as responsible citizens by assessing the value, health and management of an area of local conservation interest, and making recommendations for their future management. The opportunity was also taken to seek their views on the feasibility and design of a wider project, which would consider the management needs of a range of different habitats in Blyth Valley.

The dune project took part in two phases. The first was an information gathering phase, in which local naturalists (including members of the Northumberland Wildlife Trust) and scientists from Newcastle University, carried out surveys of the dunes, collated existing historical information about them and sought the views of local residents on management issues. The information was used to produce fact files that would be available to the participating students. The second phase was the citizenship day itself. This involved a programme of several different activities, each of which was led by one or more experienced adults:

- Students followed a nature trail that had been commissioned by Blyth Valley Borough Council to give them an overview of the dunes' habitat and features of special interest. They were provided with disposable cameras so that they could keep their own photographic records of the dunes.
- Students were divided into sub-groups in order to undertake brief surveys of plants, mammals, invertebrates and birds in the dunes. They were provided with Field Studies Council's Aidgap Guides and some 'in-house' identification guides. The fact files were also made available so that the students could consider their findings in the broader context of longer term surveys.
- Sub-groups of students designed their own posters depicting their views on management needs. These were illustrated with their own photographs.
- The 'Ring of Change' technique was used to determine the Group's view of management priorities for the Reserve. Each individual was asked to name one good feature, one bad feature and one feature requiring change in the dunes. These were then prioritised by the class, leading to the following recommendations:

1. Increase the number of designated footpaths.
2. Better monitoring of litter and fines imposed for dropping it.
3. More information and educational materials relating to the dunes.
4. Preservation of the historic buildings (especially wartime structures).
5. Provide additional sculptures.
6. Charge for parking as means of providing funds to support dune conservation.
7. Better provision for dog owners to clear up 'mess' from their dogs.

Recommendations were submitted to Blyth Valley Borough Council, and have become part of the exercise currently being undertaken by the Council to seek local views on the management of coastal areas. These are being formalised in the Northumbrian Coastal Authorities Group Shoreline Management Plan (Number 2) and the Blyth Masterplan for the re-development of the northern end of the dune system.

At the end of the citizenship day, the Group was given a short presentation on other habitats of conservation interest Blyth Valley. It included woodland, rocky shore, offshore, freshwater and estuarine habitats. The students were then asked for their views on the feasibility of the wider project in which young people would make recommendations on management needs of other habitats in the area. They were strongly in favour of developing the project. Their enthusiasm and guidance has led subsequently to the submission of a project '*Youth Environmental Solutions*' to the Heritage Lottery Young Roots Grants Scheme.

2.2. Management Recommendation for Pelaw Quarry Nature Reserve: St. Joseph's Roman Catholic Comprehensive School:

Pelaw Quarry is a small Reserve on the site of a disused quarry, adjacent to St. Joseph's School. Clay for use in the local brickyards was quarried from Pelaw Quarry from the latter part of the nineteenth century until the mid twentieth century. The site became derelict with the closure of the brickworks but the clay pit was filled with water and the surrounding area planted with trees and shrubs. It is managed by Gateshead Metropolitan Borough Council and has been designated as a Local Nature Reserve.

Fig. 1 - A winter's scene at Pelaw Quarry Nature Reserve.

There were three phases in the development of this project:

Phase 1 was used to establish the foundations for the project. A Focus Group, consisting of 8 of the School's sixth-formers, was recruited. It was to be their responsibility to produce the final recommendations for the management of the Reserve. This was also an information gathering phase. A range of different fact files was produced as a result of surveys of wildlife conducted by local experts, especially from Durham Wildlife Trust and Newcastle University, and some sixth-formers themselves. Members of the Focus Group surveyed the opinions of local residents and users of the Reserve and consulted representatives from Jarrow and Hebburn Historical Society about the industrial history of the area, local police about local regulations and problems of policing the Reserve, and representatives from Gateshead MBC and Durham Wildlife Trust about management issues.

Phase 2 was the citizenship day itself, although it was a misnomer in this case because it consisted of two separate days. It was based primarily on 40 volunteers from Years 7 and 8 at St. Joseph's School and the senior classes of the feeder primary schools (Year 6). The days involved surveys of important habitats in the Reserve, coupled with 'environmental games', which illustrated the concepts of food webs and the spread of pollutants through them, and opportunities to discuss the use and management of the Reserve. The class produced their own management recommendations, including an outline design of a nature trail. These were submitted to the Focus Group.

Phase 3 involved the deliberations of the Focus Group. Its recommendations included the following:

- The need to raise awareness of the Reserve, especially among local people
- The desirability of a wildlife monitoring programme undertaken by local schools
- The need for signage, leaflets and nature trails
- Bat conservation
- The need to maintain the attractiveness of the area and to provide facilities such as benches and paths.

There have been three specific outcomes arsing from the project. First, the citizenship days were covered by regional press and radio. Second, the international paint company Akzo Nobel agreed to fund the publication of a nature trail based on the School's recommendations. Third, Peter Shield of Gateshead Metropolitan Borough Council has invited the School to participate in a *'Planning for Real'* exercise for Wardley Country Park, of which the Pelaw Quarry Reserve is part.

2.3. Management Recommendations for the Kittiwake Tower Nature Reserve: Lindisfarne Primary School, Gateshead

The Kittiwake Tower is an artificial breeding site for kittiwakes. It provides a series of narrow ledges on which the birds can construct their nests. Kittiwakes nest on ledges on the Tyne Bridge and on the window sills of some warehouse buildings on Tyneside. The Baltic Flour Mill was one such warehouse but netting screens were used to prevent the birds from reaching the ledges when the building was converted to become a centre for contemporary arts in 2002. The tower was erected to provide alternative accommodation. It was immediately adopted, providing nesting places for up to 200 pairs of kittiwakes. Gateshead Metropolitan Borough Council has given the tower and the area immediately adjacent to it the status of Local Nature Reserve.

The citizenship day involved a Year 4 class of thirteen students. They had already been working with Malcolm Green (The Sage Gateshead) on a multi-stranded project that aimed to engage them with the environment creatively through music, debate, visual arts and storytelling. The students were therefore already well-motivated and knowledgeable about kittiwakes. However, the citizenship day focussed on the management issues of the Reserve itself.

The day consisted of two parts: a visit to the Reserve in the morning, followed by class work in the afternoon. The morning session, in which the class was accompanied by their class teacher and four biologists, was structured around four questions:

- What is here that you can see?

- What is here that you cannot see?
- What is here that should not be here?
- What would you like to see here?

The afternoon session involved an environmental game, which illustrated the bioaccumulation of pollutants in the food chain, and the production of model maps of the Reserve incorporating the students' own ideas for its improvement. The 'Ring of Change' technique was used to prioritise management recommendations. They were as follows:

First priorities:
- Interpretive panels
- A coin operated telescope to view the nesting kittiwakes

Second priorities:
- Planting wild flowers and trees to make a more colourful site
- A display board with a map showing other sites where nesting kittiwakes can be seen
- The publication of an information leaflet on kittiwakes in general but also including poetry and drawings produced by the children
- The installation of a CCTV camera so that the birds could be watched more closely

Third priorities:
- Picnic tables and benches
- Display boards about animals and birds on the site, including those that cannot be seen (e.g. living in the muddy banks of the Tyne, nocturnal etc.)
- Café
- Souvenir shop
- Bird hide
- Bird feeding station

Other suggestions:
- Bins for litter
- Shelter for visitors
- Re-seeding some grassless areas
- Improving the paths, especially for disabled access

There have been two specific outcomes, following the citizenship day. First, Akzo Nobel has agreed to fund an information leaflet based on the children's recommendations and including some of their art and poetry. Second, Peter Shield of Gateshead Metropolitan Borough Council has involved the class in discussions about future developments at the Reserve.

Fig. 2 - Teacher, John Innerdale, and some members of Class 4, witkittiwake information leaflets.

3. The Court Room Model: adjudication by Bill Quay Primary School, South Tyneside

The class of 26 Year 6 children was already familiar with the life cycle and biology of the salmon. They had visited the salmon hatchery at Keilder Dam, at one of the sources of the Tyne, and the class had set up an aquarium in the classroom in which the early development stages of the salmon were being studied. Salmon are a good indicator of water quality in the River Tyne. There were good 'runs' of these fish prior to the 1930s but the species became locally extinct, undoubtedly due to severe industrial and domestic pollution of the estuary, until the 1980s. However, clean-up measures have now resulted in huge improvements in water quality. Salmon have returned to the Tyne and the population is supplemented by the release of juveniles from the hatchery. The Tyne is now said to be one of the best salmon rivers in Britain.

The objective of the Court Room session was to introduce the children to the concept of threats to the salmon. In this case the 'Citizenship Day' was condensed into an afternoon session lasting for approximately three hours. It was based entirely on role play, which was 'directed' by Geraldine Ling.

A number of outsiders (including expert ecologists) and the classroom teacher were invited to play the roles of the judge and members of society whose actions pose a threat to the existence of wild salmon. They were to be tried one at a time for endangering the existence of salmon in the Tyne. Responsibilities were as follows:

The judge would direct courtroom proceedings and read out the case for the prosecution, that is, the specific threat caused by the defendant.

Fig. 3 - The Judge.

The defendants would be expected to respond to questions posed by the prosecution, justifying their actions and position. Each was asked to bring an item that symbolised their particular role and dress appropriately for it. The roles were as follows:

- Industrialist. Responsible for polluting and therefore poisoning the Tyne but at the same time contributing wealth and jobs for the local economy.

- Farmer. Allows sheep to graze down to the water's edge, leading to erosion of the banks. The river may become unsuitable for salmon due to widening and shallowing.

- Angler. Removes salmon from the river but spends on meals, hotel bills etc, as well as the fees paid to fish for a day. Anglers have also campaigned strongly to have the river cleaned up.

- Traditional fisher. Comes from a family that has depended on fishing as a livelihood for generations but removes salmon from environment before they have had chance to spawn.

- Fish farmer. The point of this issue is that, although fish farming does not directly affect the Tyne at the moment, it has major affects on west coast rivers and may be having an affect on the genetic health of the salmon population.

- Car Driver / Global Warmer. Prosecuted for contributing to global warming and the resultant imbalance in the ecosystem.

- Northumbria Water (owners of the Keilder Dam). Obstructions of the river are the one of the biggest threats to the salmon. The idea of this role was to highlight the effect of obstructions to the passage of the salmon to their breeding grounds.

Members of the class played three roles:

- The jury, consisting of 6 children.
- The prosecutors, involving 14 of the class, but operating in pairs, with each pair questioning one of the seven defendants.
- The press consisting of 6 children, who would report orally (in practice mimicking TV *Newsnight* presentations) on the outcomes of each of the seven 'trials'.

Fig. 4 - 'Oh come on! You don't really expect us to believe that?'

Decisions on which roles were played by which children were made at the start of the session by drawing names out of a hat.

Each defendant was tried in turn but time was given before each trial for class discussion about the questions that would be posed. The whole class could contribute to this discussion, not solely the prosecutors. Once the questions had been asked and the replies heard, the jury agreed on a verdict. They recommended an appropriate 'sentence' to judge and the specific actions that should be taken by the defendant to prevent or minimize their specific threats to salmon. This was an important feature: the jury was not there to simply say "you are wrong" etc. but to come up with management recommendations and sensible solutions to the issues.

At the end of the session, members of the class decided by vote on whom among the defendants posed the biggest threat to the salmon. The day's proceedings were then summed-up, with appropriate comments, by the judge.

The actions of the industrialist were regarded as the most serious threat to the salmon, almost by unanimous vote, but the fish farmer, car owner and farmer were all also found guilty as charged. There were severe recommendations on the actions that were needed to ensure the long-term survival of the salmon. For example, the fish farmer, who had suggested in his defence that escapes of his cultivated salmon into the environment were inevitable. This was because marauding seals broke into his cages in order to eat salmon. He was told that he must strengthen his cages. Similarly, the farmer was instructed to fence off fields bordering the River Tyne so that grazing sheep could not damage the fragile banks.

The traditional fisher, the angler and the representative of Northumbria Water were found not guilty. The judge and jury recognised that traditional livelihoods, important leisure activities and serious attempts to manage water quality for wildlife in general were, on the bases of the cases made out by the defendants, acceptable activities.

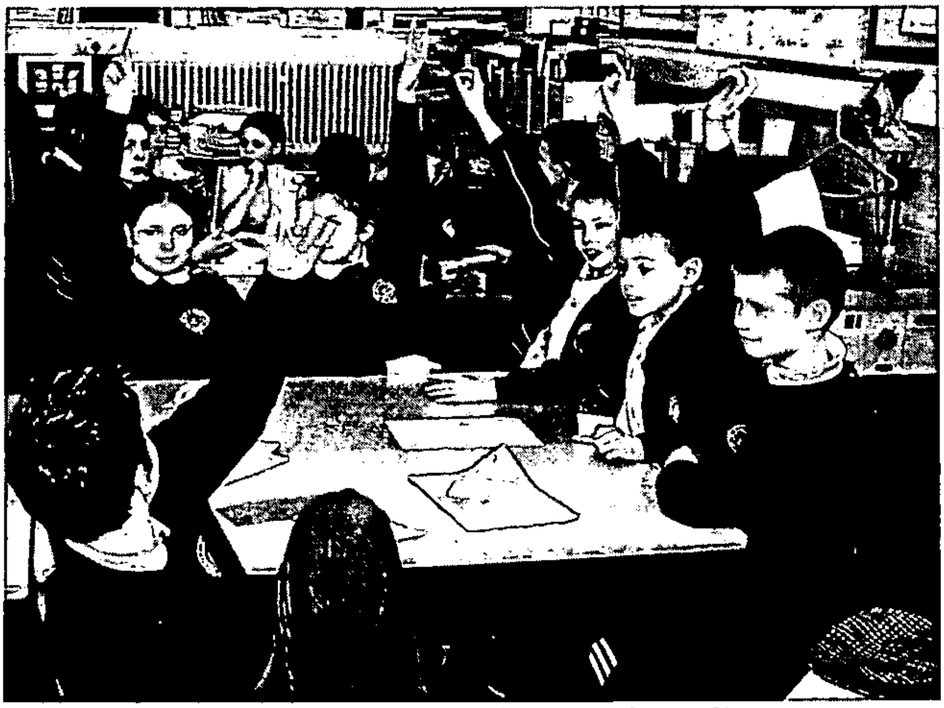

Fig. 5 - The verdict: Guilty as charged!

4. Evaluation

We believe that the 'Citizenship Day' presents an effective means of introducing environmental issues into the classroom. It: (i) ensures that students learn about the local environment (rather than rainforests or lions on African savannas[13]); (ii) raises their awareness and understanding of environmental issues; and (iii) encourages them to act as responsible citizens by considering ways in which problems can be rectified and the environment managed more effectively in the future. Since they are dealing with 'real' problems, the students are able to appreciate the complexities of environmental issues and understand that management decisions may often be a compromise between conflicting legitimate interests.

Collection of information for use by students participating in citizenship days (e.g. in preparing fact files) can be challenging but it is in itself a worthwhile exercise. There can be few wildlife areas that have been accorded the status of Local Nature Reserve that would not benefit from plant and animals surveys. Certainly the survey information that was generated in the studies described here was warmly accepted by the Reserve managers. Fieldwork is an integral part of the 'Environmental Management Model' but can be limited to a half day excursion and is probably of a relatively low risk. Citizenship days based on the 'Court Room Model' can be conducted entirely indoors, although the value of the one described here was certainly enhanced by a field trip to a salmon hatchery and studies of the early development of the salmon in the classroom.

Children from primary school age to sixth-formers have been involved in these pilots studies and, in our view, citizenship days can be adapted for students of all age and ranges of ability. We feel that the most appropriate place for them in the classroom is as part of cross-curricula studies, and not a component of biology, science or geography lessons. The cross-curriculum approach encourages children to consider the environment from a range of different perspectives, including art, poetry, leisure, sport and story-telling. Including everyone in the debate, whatever, their academic bent or aptitude, also helps young people to appreciate that all members of society have a role to play in conserving the environment. It is a 'joint responsibility' and not the sole domain of scientists, industrialists, 'green' activists and politicians.

The management recommendations made by the children who participated were, almost without exception, realistic and affordable in terms of the kinds of funding that is normally available to environmental projects. This was reflected in at least four different ways. First, the interest shown by the environmental managers from Blyth Valley Borough Council and Gateshead Metropolitan Borough Council, in considering the recommendations made by the children, and actually inviting them to be involved in further planning projects. Second, the willingness of industry, in the case the paint company Akzo Nobel, to sponsor outcomes of the projects, such as the publication of information leaflets for the general public. Third, the use of the children's advice to develop a project for Heritage Lottery funding. Fourth, the interest shown by the media in reporting on the results of Citizenship Days.

5. Acknowledgements

The 'Citizenship Day' has been developed as part of the outreach programme *The North Sea: A Sustainable Future* which operates from the Dove Marine Laboratory (School of Marine Science and Technology, Newcastle University). The overall objective of the programme is to empower lay people to participate in planning and decision-making process relating to the local environmental. We gratefully acknowledge support from the Esmee Fairbairn Foundation, the Heritage Lottery Fund, the Royal Society and Akzo Nobel.

Thanks are also due to a huge number of individuals who have helped in many different ways. We apologise that we cannot acknowledge everyone's support but the following deserve special mention: Sharon Rowe of Cramlington Community High School, Terry Gurr, Derek Hilton-Brown and Arthur Cranson of Blyth Valley Borough Council, Alison Schreiber and Richard Higgins of Akzo Nobel, Peter Shield of Gateshead Metropolitan Borough Council, Julie Fulton of Durham Wildlife Trust, Geraldine Ling of The Sage Gateshead, Ros Field ,Carol Milne and Joe Murphy of St. Joseph's School, John Innerdale of Lindisfarne Primary School and Andy Jones of Bill Quay Primary School.

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MARINE SPECIES ECOLOGY: THE VALUE AND APPLICATION OF EXISTING KNOWLEDGE OR MAKING THE MOST OF "*WHAT WE KNOW*"

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This paper was originally published in the Porcupine Marine Natural History Newsletter (Number 4, March 2000 pp 14-28) and was intended for a marine biological audience. It addresses the problem of unprocessed marine biological data and the need to make available the accumulated collective knowledge of marine species that has not been published. It describes a means of ' capturing' unpublished marine species information from those with long-term expertise using a new species recording framework. The proposed approach was tested by members of the Porcupine Marine Conservation Society at their 1998 Annual conference. The results of the trial exercise are presented. The effectiveness of the approach is assessed and the species information obtained is examined. It is concluded that a huge amount of knowledge can be obtained in the way described, but that this needs to be organised before it can be used. It could then facilitate more focussed, predictive, studies and therefore help to avoid expensive duplication of survey effort.

1. Introduction

This paper was prompted by our attendance at a successful workshop organised by Judy Foster-Smith in Newcastle on marine species recording in January 1998[1]. The purpose of species recording schemes was to help us better understand the biology and distribution of species. Whilst species recording schemes for marine species have been in use since the early 1970's the translation of the results from this work into our collective understanding of the biology and distribution of individual species has not really progressed significantly to the point where the marine biological community can easily access the current knowledge for a wide range of common marine species. It can neither do this in the traditional format of paper monographs or in ways that would be of more direct application in applied studies. Currently there seems to be an obsession with 'computer' systems' and the collection of yet more data.

The view we develop in this paper is that, as marine ecologists, we are rather too quick to go out and collect more data without making proper use of the data that we have already. More than this, however, we are rather poor at converting 'raw' data into biological 'knowledge' that is needed to *interpret* the data collected for either academic or more applied studies. This view is by no means new; the joys of field work and the incentives to undertake contract funded survey and monitoring all tend to encourage data collection at the expense of considered synthesis. It is also the case that a considerable amount of marine biological survey work is still being undertaken further compounding this situation. It is put forward here that the benefits of synthesis are likely to be

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significant and enable us to conduct both survey and monitoring work from a sounder knowledge base that will facilitate innovative approaches to both prediction and ground truthing our knowledge base.

The point is often made that data on species and habitats from the marine environment for management decisions is often lacking. In the same breath the high expense of collecting data in comparison with the equivalent information from land is also highlighted. Both these points are true and highlight the need to take much greater care of the data we collect from our marine work. Recognition of this need to better organise the data and knowledge we have is leading to important initiatives to ensure that hard won *data* is not lost and it is used to the best effect. For example, the Marine Life Information Network (*MarLIN)* and the Joint Nature Conservation Committee (JNCC) Biodiversity database for the Marine Nature Conservation Review (MNCR) data are good examples.

However, data on their own are not enough; they need to be set in the context of our broader knowledge of species biology. Doody[2] summarised this point succinctly: "*Data is the raw material from which information is produced. Information is a collection of data relevant to a recipient at a given point in time. Information is data in context – it has meaning, relevance and purpose.*"

1.1. Marine biological knowledge - what we do and do not know - the challenge

The *collective* marine biological knowledge is enormous but only a fraction of this knowledge is available. For example ask yourself these questions: -

- How many years have you been studying marine biology?
- What percentage of your marine biological knowledge is published or available for other generations?
- Is this percentage high or low?

Many Porcupine Marine natural History Society (hereafter referred to as 'Porcupine') members have 20, 30, and 40 years of knowledge locked up inside wise minds. This knowledge is of great value. It provides key links to previous generations and bodies of work and understanding. It is important that we do not loose this information. Whilst the value of this information is being increasingly discussed there seems little effort directed at actually securing it. This paper describes a useful way of collecting together existing expertise, which at the same time facilitates its publication.

The challenge we face is huge. The Species Directory[3] shows us that there are some 9,000 species in UK seas. Our knowledge of many of these species is scant. Figure 1 shows our likely knowledge of marine species ranked in terms of how much we know about them. Species like *Mytilus edulis* about which we know a great deal would be on the left side of the graph whilst there is a large tail of species about which we know very little. One of the ongoing challenges to marine biologists and ecologists is to square off the graph.

This paper has two main aims. First, to propose both a new species recording format that has been designed to capture marine biologists' collective ***knowledge*** and to enable such knowledge to be published as quickly and effectively as possible. Second, to describe a trial of this species recording framework and a process of engaging the Porcupine members to record their knowledge.

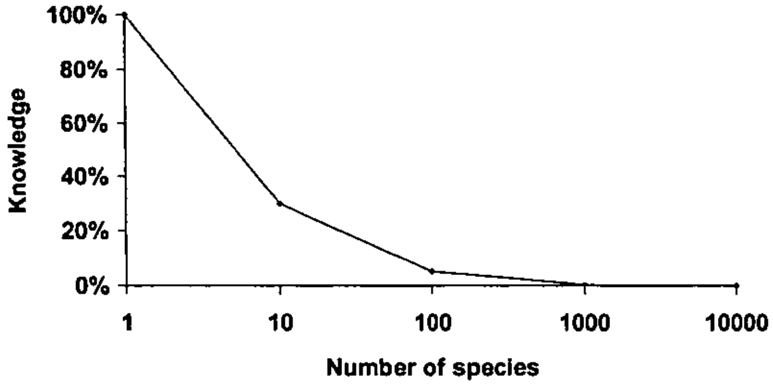


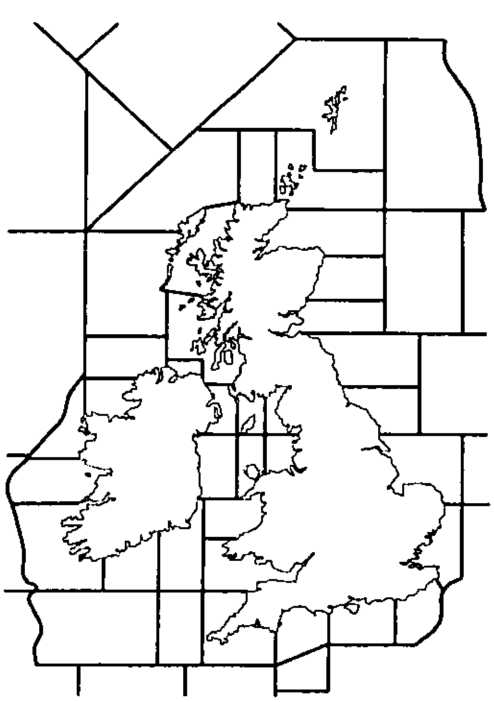
Figure 1 - A suggested knowledge curve for European marine species.

2. Methodology

This method section describes a suggested *marine species recording framework* and the ideas behind this and the *information collection process* used at the Porcupine conference (March 1998).

2.1. Species Recording Framework

UK Sea Areas



Species:______________________

Distribution rules:
What preference does the species show for seabed type, depth zone, light, salinity, siltation, temperature, other species?

Questions/Issues arising:

Contributors:

Figure 2 - The recording framework.

Recording forms and cards are a recognised way of collecting information on species distribution and ecology. A single species recording form designed to capture knowledge of the distribution of species, was developed to trial at the March 1998 Porcupine conference (Fig. 2). This framework is designed to enable both individuals and groups to record both bio-geographic and biological knowledge ***together*** in a simple way – minimising the barriers to completion by individuals or groups. It should also be noted that the format also lends itself directly to publication.

The provision of a map enables easy location of the information rather than the need to be absolutely precise about describing a particular location. This is, in effect, all that the synoptic reports of species recording schemes (especially at large scales) do anyway. For example, see the Conchological Society maps for *Calliostoma ziziphinum* (Sheet 4 results) below.

We have added a draft *number* and *date* so that people can know at what point the information was compiled. Similarly the *editor* – the last person to edit the text, and the *contributors* have been identified to enable others to follow-up the text in future.

The developing power of information technology should help us to marshal what we know (our existing knowledge) more effectively and provide access to extensive bodies of information such as is published here (The Species Encyclopaedia concept - see discussion) without the need for the production of expensive monographs.

2.2. The Information Collection Process

The *species recording framework* was tested during two sessions at the Southampton Porcupine conference in March 1998. In the first session delegates were encouraged to record their knowledge of six species. Delegates were encouraged to work in groups and six co-opted co-ordinators then collated the views on these species. The results of the exercise were then presented to the conference delegates at a subsequent session. These results have since been edited and are included in the results section as ***working drafts***.

We chose the species on the day of the conference on the basis of the experience of the members of the audience and to ensure species from a range of different phyla were included in the trial. The six species chosen were the:

- intertidal sponge '*Ophlitaspongia seriata*',
- leopard spotted goby *Thorogobius ephippiatus*,
- painted topshell *Calliostoma zizyphinum*,
- goose foot starfish *Anseropoda placenta*,
- burrowing anemone *Cerianthus lloydii* and
- fan worm *Sabella pavonia*

Delegates were given specimen recording forms (Fig. 2). They were asked to assign the probability of finding the species in the geographic areas given by assigning them to one of five categories:

Categories	**Probability**
1. Highly likely	66 - 100%
2. Possible	66 - 33%
3. Unlikely	33 - 10%
4. Highly improbable	10 - 0%

The need for a 'no information' / insufficient information category emerged during this trial and had been raised also at the marine species recording conference in Newcastle[1].

Delegates were also asked to list the ***rules*** governing the distribution of the species in question. For example:

- substratum preferences
- depth zone preferences
- salinity preferences
- siltation tolerance
- life-cycle strategy – long lived, versus opportunistic, colonisation

There is no doubt that illustrations of the species in question during the briefing process considerably aid participants in the information collection process. As we have found in preparing this paper *the process* forces people to dig out old records, references and to assess the biological and ecological context.

3. Results & Discussion

The results of this session are described in two main parts. Part 1 concerns the results of the sheets describing the species distributions and biology that we assembled during, and after, the conference and Part 2 summarises the general conclusions we have drawn from this trial.

3.1. Part 1 – The results from the trial

The results from the trial are presented for the following species sheets:

Sheet 1. The intertidal sponge '*Ophlitaspongia seriata*'
Sheet 2. The burrowing anemone *Cerianthus lloydii*
Sheet 3. The fan worm *Sabella pavonina*
Sheet 4. The painted topshell *Calliostoma zizyphinum*
Sheet 5. The goose foot starfish *Anseropoda placenta*
Sheet 6. The leopard spotted goby *Thorogobius ephippiatus*

Key to Conference output maps

Presence of viable adult populations

1. Highly likely 66-100%
2. Possible 66-33%
3. Unlikely 33-10%
4. Highly improbable 10- 0%

SHEET 1.

'Ophlitaspongia seriata' (Red sponge) Draft 1: 10/10/99

Distribution rules:
Substratum: usually under boulders
Zone: Lower eulittoral, shallow sublittoral
Salinity: Fully marine?
Geographic distribution: South-west and west coasts with rocky inter-tidal; probably not on east coast. Contributors know it from South Wales, Helford, Isle of Man, Strangford Lough and Connemara. Not seen in Orkney. The Isle of Man fauna lists it from many inter-tidal sites.

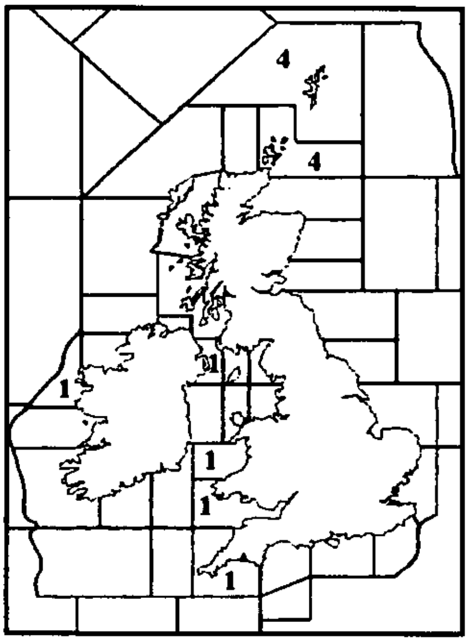
Questions/Issues arising:

- More accurate habitat data required
- Where are the preserved specimens?
- MNCR east coast specimens need to be checked

Note: At the time of this trial work this species was the subject of taxonomic work in progress (Chambers, pers. comm.) and it has since been renamed[4].

Contributors:
Susan Chambers (editor), Dale Rostron, Eleanor Murray, Bob Earll

Published information:
Habitat: "On rock, commonly under boulders on the lower shore and also in the shallow sublittoral (to 5m below chart datum); on clean rock, shells, *Fucus* and *Laminaria* stipes in areas of strong water movement (either tidal or wave action)."
Distribution: "British Isles; France and Spain." [5]



Conference output

MNCR Database

SHEET 2.

Cerianthus lloydii (Burrowing anemone) Draft 1: 18/10/99

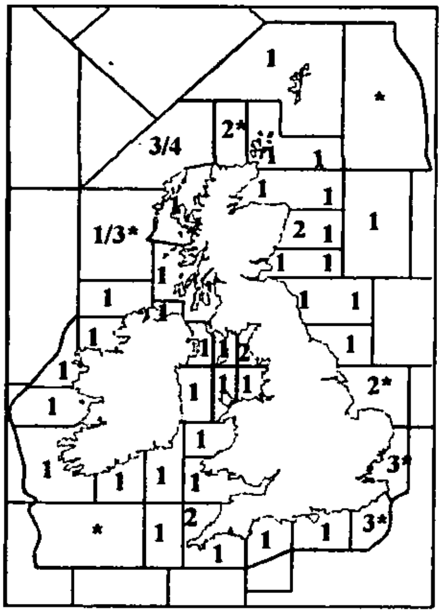
Disribution rules:
General: Uk distribution is apparently mainly restricted to south and west coasts.
Substratum: Muddy sand to muddy gravel sediment. Not found in clean sand or gravel (i.e. dynamic sediment). Most abundant ($>100/m^2$) in muddy gravel in current-swept areas.
Zone: Lower shore to deep circalittoral – at least 100m deep.

Questions/Issues arising:

- What is its abundance?
- Is it localised indistribution in the rather large areas?

Contributors:
Keith Hiscock (editor), Eleanor Murray, Bob Earll, Martin Sheader, Ivoer Rees, Robin Harvey.

Published information:
“Adults live buried in mud, sand, or gravel, from about LWST to at least 100m depth. The tube is long, up to 400mm or more, andfrewuently winds around stones if these are present in the substrate. Adults are locally abundant in many localities on all coasts of the british isles and in some areas are common on the shore. This species occurs on all western coasts of Europe from Greenland and Spitzbergen south to Biscay.”[6]



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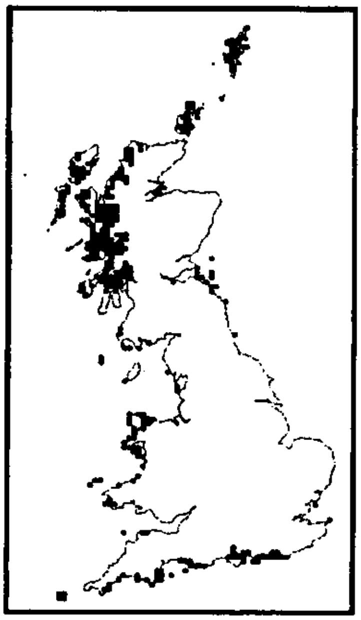


MNCR Database

SHEET 3.

Sabella pavonina (Fan worm) Draft 1: 18/10/99

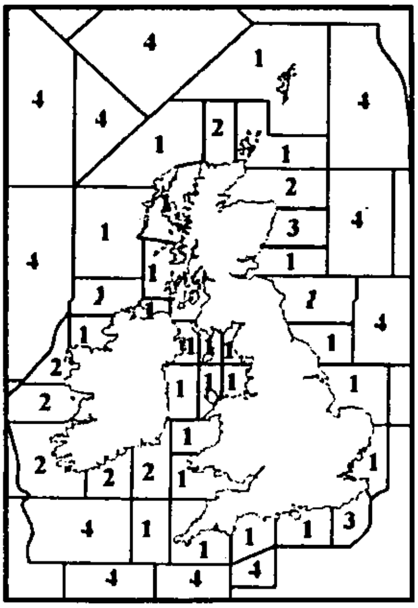
Distribution rules:
General: Widespread in all coastal areas of the UK
Inter-tidal: Fully marine, but need considerable fine sediment and organic matter to build its tube. Wave sheltered. Muddy sand, gravel, fairly stable substrata.
Distinct 'beds', often at ELWS. Sometimes present in very dense populations.
Sub-tidal: May be expected in almost any area of stable, muddy sand or gravel with high organic and sediment loading, and fully marine and fairly sheltered conditions Sometimes found on rock or floating structures in very sheltered conditions.

Questions/Issues arising:

- What is the status (presence/abundance etc) of the blank areas?
- Does the population fluctuate?
- What is the effect of climate or other influences?
- Surprisingly little information on population densities, age class sizes etc.

Contributors:
Trevor Baker (editor), Judy Foster-Smith, Helgi Gudmundsson, Ian Killeen, Andy Mackie, Jenny Mallinson, Eleanor Murray, Julia Nunn, Ivoer Rees, Shelagh Smith, Cliff Thorpe, Pamela Tompsett, Seamus White

Published information:
" Found on all coasts with big populations in Menai Strait, Swansea Bay and estuaries of Essex and Plymouth rivers. On stones in sand and mud; sub-littoral, locally abundant" [7]



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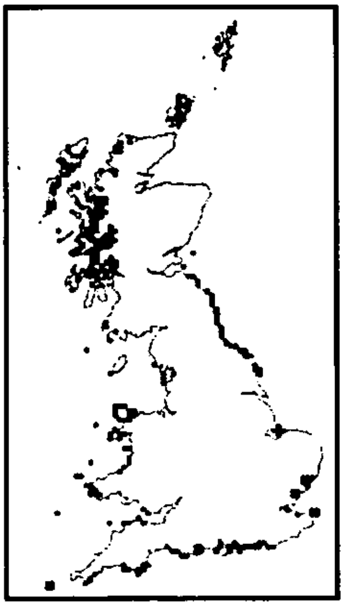


MNCR Database

SHEET 4.

Calliostoma ziziphinum (Painted topshell) Draft 1: 18/10/99

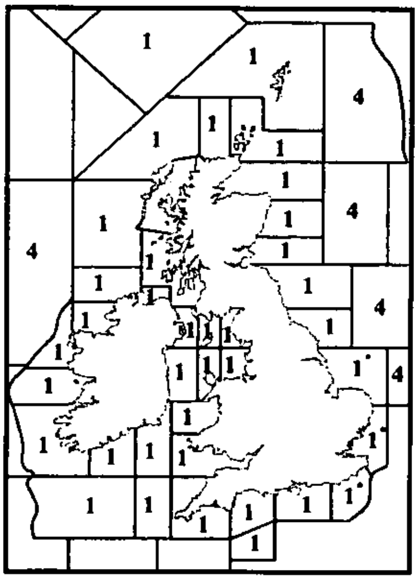
Distribution rules:
Fully saline water
Differences in requirements: (a) Sublittoral – found anywhere, but needs some kind of hard surface, not necessarily bedrock, e.g. beds of stones or bivalves; (b) Littoral – needs shelter from wave action; low on shore –restricted temperature tolerance; time of low (Spring) tides may be important; prefers sites close to, but not in, strong current; mainly hard substrate. No special food preferences; will eat many phyla – tests show a love for Devonshire cup corals!

Questions/Issues arising:

- Why uncommon on south east coast of England? Lack of habitat? Reduced salinity?
- Why are specimens 'pale' at sites near strong current?
- Why is there a white form, and what predicts its distribution?
- Time of year for breeding?

Contributors:
Julia Nunn (editor), Andy Horton, Ian Killeen, Seamus White, Shelagh Smith, Christina Vina Hebron

Published information:
"Occurs fairly commonly amongst weeds and under stones on rocky shores a little above LWST and to 300m depth. It has been found on all suitable British and irish shores, in the Mediterranean, and on western European shores north to the Lofoten Islands. It is said to eat small coloenterates but also takes vegetable matter." [8]



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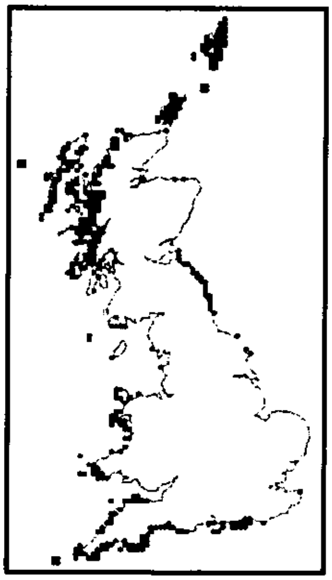

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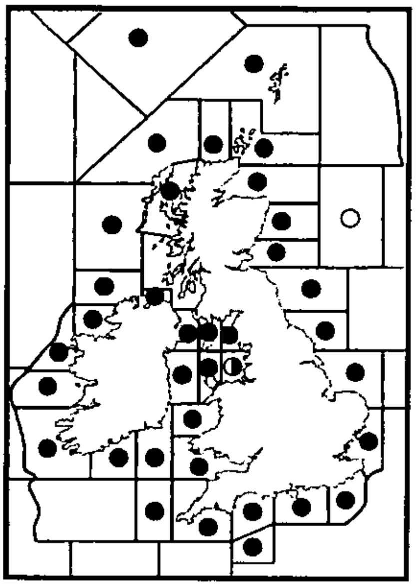


Marine Mollusc Atlas

Key: ● = Recorded live, post-1950; ◑ = Recorded live, pre-1951; ○ = Recorded as shell only

SHEET 5.

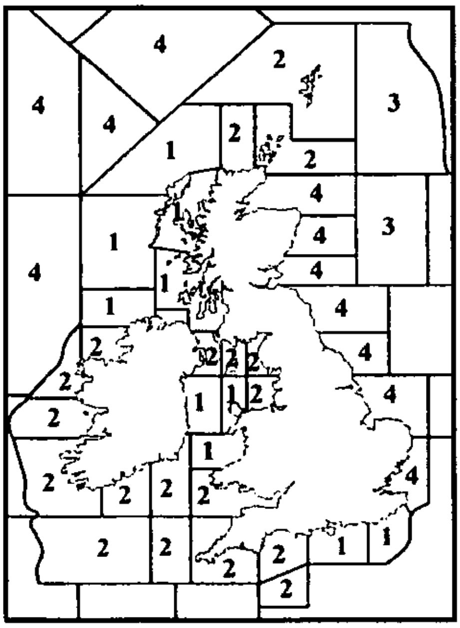
Anseropoda placenta (Goose Foot Starfish) Draft 1: 18/10/99

Distribution Rules:
Full salinity
Depth > 10m
Mixed sediment (muddy, gravely sand)
West and North ?
Low turbidity

Questions arising:
Why is sediment restricted and patchy

Contributors:
Ivor Rees (editor), Robin Harvey

Published information:
"Characteristically found on muddy sand or muddy gravel. Often covers itself with sand or gravel. Apparently feeds on small crustaceans but it is not known how these are caught. Found sporadically all around the British Isles, especially in water of 20-40m. Locally common but rarely seen by divers." [9]



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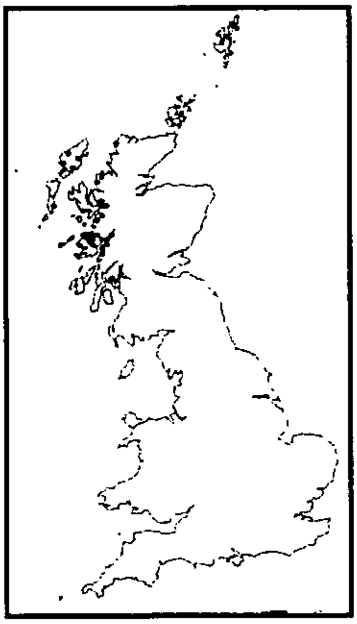


MNCR Database

SHEET 6.

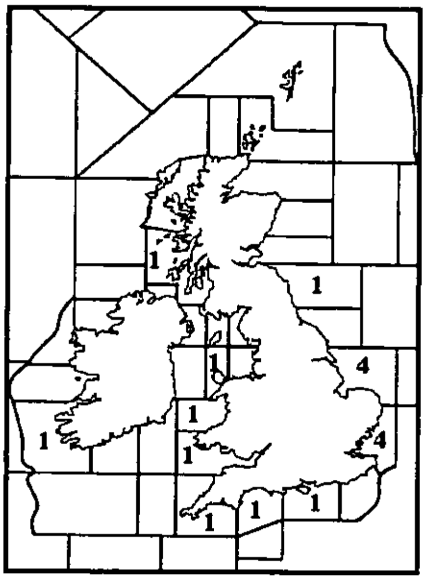
Thorogobius ephippiatus (Leopard-spotted goby) Draft 1: 18/10/99

Distribution rules:
Rocky areas with ledges and crevices, often cliffs. Usually on terraces with holes/crevices to go into.
Shallow sublittoral, often singly. Seen in summer by divers. Seen in holes in very soft clasy cliff (piddock holes)
Doesn't like brightly lit areas
Impression that young live in the same area/habitat as the adults.

Questions/Issues arising:
- Are they territorial?
- Are they in shallow water in winter?
- Are they nocturnal?

Contributors:
Frances Dipper (editor), Dale Rostron, Bob Earll, Jane Lilley, Keith Hiscock, Keith Broomfield

Published information:
"Mediterranean; Eastern Atlantic; Canaries and Azores to Skagerrak. Coastal, in/near crevices associated with vertical rock faces, from low water of spring tides to 40m; rarely in deep shore pools. Breeds from May to July (Plymouth, Connemara)." [10]



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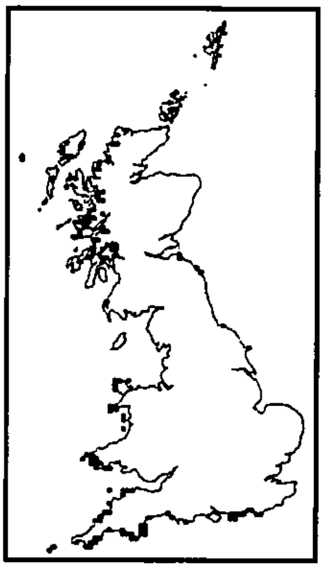

MNCR Database

3.2. Part 2 - General Conclusions

3.2.1 Abundance assessments

There is no doubt that a question focused on the abundance of species would be highly productive. It is evident from the responses that people would like to include information on abundance. However, abundance clearly depends on the spatial scales of methods used to assess it and this needs to be described in the first instance. The abundance measures and spatial scales are very species and habitat specific, for example:

- Colonies of the sponge *Ophlitaspongia* are often finite in size and cover small areas (1-10cm).
- *Cerianthus lloydii* and *Sabella* can vary in density from 1 or 2 / m^2 in sandy environments to 100's/m^2 in current swept seabeds.
- The leopard spotted goby *Thorogobius* is by and large a solitary species occupying well defined areas around small caves and underhangs in the rock, so its density may depend on the availability of this habitat.

There is no doubt that this knowledge base and information collection process would benefit from some kind of a simple abundance question such as '*describe the abundance levels of this species*'.

3.2.2 The importance of methodology – of knowing how and where to look

One of the interesting points to emerge from this exercise was how our understanding of species is often geared to rather specific methodology and knowledge of when and where species occur. In other words it is important to know (a) what to look for and (b) where and how to look. For example:

- *Anseropoda placenta* tends to be observed only by divers or dredge surveys that cover relatively large areas rather than benthic grab studies which have restricted area coverage. This is perhaps not surprising for a member of the megafauna.
- The leopard spotted goby *Thorogobius* ephippiatus can really only be studied by divers and, even then, with greater success by diving at night because of its nocturnal behaviour.
- The sponge '*Ophlitaspongia*' is likely to be found only at *very* low water or in the shallow sublittoral zone *under* boulders on boulder beaches.

3.2.3 Biogeography of UK species

The theme of the March 1998 Porcupine conference was biogeography and the biogeographic descriptions resulting from this exercise are given below.

The traditional form of '*Ophlitaspongia seriata*', which is illustrated in the classic seashore texts and guides, would appear to have a strongly western distribution. Sue Chambers at the meeting highlighted a number of difficulties with the name and authority of this species not least because of confusion with the identity of some specimens from the east coast which were actually *Halichondria panicea*. Whilst this illustrates the benefits of voucher specimens, the records for *Ophlitaspongia* from the east coast recorded by the MNCR need to be verified since Bull, in his monograph of North Eastern sponges [11], does not record this species, even though it was well know to his contemporaries. A recent detailed survey of under-boulder fauna [12] did not record this species either. There is, however, one recent report from Rumbling Kern, Craster (NU263172) in a large cave with *Dendrodoa* [13].

Sabella pavonina has a pan UK distribution based on the MNCR findings and the contributions of members to the meeting. This is in interesting contrast to *Cerianthus lloydii* which also uses fine sediment to construct a tube but for which records are noticeably scarce on the east coast (MNCR map). This may well represent the classic south-westerly distribution pattern shown by other species.

Calliostoma zizyphinium shows a UK wide distribution although the records from the Conchological Society map and the MNCR data-base suggest that it is far less common in the south-east of England. Reduced hard substrata, the preponderance of sediment habitats and reduced salinity (Mersey, Severn, Humber, and Thames) are all likely to influence its distribution. We can also see from the *Calliostoma* example why there is need to refine our descriptions, the Conchological Society map is a very crude representation of this species in areas where routine observations of this species are probably rather rare because of the prevailing physical and chemical conditions.

The leopard-spotted goby, *Thorogobius ephippiatus* was one of the species whose distributions were highlighted around the coast of UK by the use of SCUBA; these distribution maps would have been blank before 1965. This is a salutary lesson with regard to knowing where and how to look for species, i.e. effective methodology, and to those who would seek to use species distributions to track climate change. The gaps in the trial format and MNCR coverage in the still probably reflect lack of records / recording – it is highly likely to be found all around the Irish coast, Isle of Man and probably Shetland. The absence of records in the large sediment bays of the north west and below Flamborough probably reflects both lack of suitable habitat and appropriate sampling.

Anseropoda placenta has an interesting distribution with the trial experts describing its distribution in benthic dredge tows from deep water, but the MNCR data-base illustrating a high frequency of records in the Scottish sea lochs, based mainly on diving studies.

The distribution maps from the MNCR and Conchological Society were provided after the conference – you can judge for yourself the match between what the audience 'knew' about the distribution of the species and the most recent data that is available.

3.2.4 Ideas to develop for the future – the use this approach to focus on specific groups or areas

Many major synecological surveys require an autecological basis to enable results to be interpreted. This type of approach which involves the entire community engaged in the research, is a potentially powerful way of providing the autecological basis for projects on particular areas or where a particular group of species are being studied. Two possible examples are:

1. *The census of the important conservation species in Cornwall / any area* What do we know about important species – convene a meeting inviting all the local and outside experts – what are the key species we value? Decide on these and then use a regional grid map and similar question format to generate the information base that is needed to make a start. Such a synopsis might have *Zostera*, maerl, *Sargassum*, Kelp forests, key offshore reefs, *Sabella* on the low shore areas etc. Everyone then knows what it is that is important to the experts so that a new census can work from the basis of what is known and compare existing with the new knowledge gained.

2. *New project on the molluscs / any species from the channel /any area*. Again a meeting of experts can be used to collate all the existing information in this format. Field surveys could then be directed to both 'routine' and 'key' areas to ascertain whether changes in the populations have taken

place. This process could also serve to ensure that all participants in a survey were up to speed with existing knowledge and species identifications (especially for key species).

In both examples the critical driver is ownership by a body of people who can both compile the information and maintain an interest in it over time. Who should take the lead with developing such sheets: Porcupine, interested professional groups such as the Conchology Society, agencies doing project work? The scale of the task is 'large': even if 250 marine biologists worked on this project they would each need to describe/take the lead with 36 species to meet the 9000 species covered in the UK Species Directory. There is also the issue of how this information is to be made available to the widest constituency of scientists? The internet is clearly the obvious choice – but who will provide the home to the server that holds this information – MarLIN – JNCC – and will this information be provided freely?

3.2.5 A new direction for Porcupine recording, publications and field activities

Porcupine has for almost 20 years been bringing marine biologists together to discuss topics of interest. It has a strong interest in marine natural history and also the distribution of species. Indeed both the founding meeting in Edinburgh and subsequent meetings, notably one in Glasgow which reviewed marine recording schemes (1984/5), as well as the Southampton conference (1998), have placed emphasis on marine biogeography and the factors that influence it. We would suggest that in the future Porcupine could target its efforts at building and publishing the marine biological knowledge base, through work on the ecology *and biology* of species using the approach described here to help develop **Species Encyclopaedias** using this type of record format to facilitate publication. This would not only engage the membership more fully, but also begin to pool the undoubted knowledge that exists in a way that is enjoyable and produces a product which has widespread benefit to those who follow.

3.2.6 Beyond exploratory survey - to predictive hypothesis driven survey

Much marine ecological survey work is undertaken as if no research had ever gone on before.

Survey on land has moved to much more directed methods which often *ground truth* predictions based on maps or from remotely sensed images. The survey ecologist on land is now seldom going out 'blind' to explore the 'unexplored' but instead verifies and tests reasonably well-established bodies of knowledge.

In the marine environment – with some notable exceptions of tropical reef and shallow water ecologists - benthic ecologists still tend to survey 'blind', although there are long overdue signs that this is changing. Our knowledge is just not marshalled or used in way that facilitates a ground-truthing, or predictive, approach.

The relatively recent development of more versatile electronic means of visualising the seabed such as 'Roxanne', and the more routine application of side scan sonar, can provide the physical context to a survey area. They enable marine ecologists to describe the physical environment of the seabed. This knowledge, when combined with other physico-chemical data, provides a basis for starting to think about how this may be used to predict species distributions. Many benthic species are very closely distributed with the broad oceanographic features – e.g. salinity and physical seabed types and so rule- based probability distributions could provide a way of predicting likely species distributions.

4. Conclusions

In this paper we seek to illustrate a number of points: -

1. Data is important, but is only *one* part of the process to develop knowledge. Data on its own, without context or a marine biological knowledge base is virtually meaningless. Similarly species distribution maps, without their ecological context, are virtually meaningless. It is data when combined with our marine biological understanding that provides *knowledge*. This knowledge needs to be made much more widely available and information technology has an important role to play in this.

2. As a community of scientists we collectively posses a huge amount of *knowledge* but it needs to be organised effectively so that it can be used. In organising it we will be able to see what we *do* and *do not* know and will hopefully avoid expensive duplication of effort.

3. In this setting it should then be possible to ***use*** this knowledge to drive *hypothesis based* approaches to marine ecological studies - including predicting the distribution of species, so that surveys are, in effect, ground-truthing predictions.

4. In making these points we highlight:

- the challenges that still face marine biologists in understanding the ecology, including distribution, and biology, of our fauna and flora;
- the great store of *knowledge* that the marine biological community from the different generations possess – *collectively*;
- the need to engage the *entire* marine biological community directly in the process;
- how a new approach to collecting single species information would be a more productive way of collating knowledge than current multi-species record cards schemes;
- how it is possible to use conferences, workshops and focused fieldwork to help marshal such information in a way that is stimulating, enjoyable and productive;
- and the opportunities this approach could provide for Porcupine as it develops in the future.

5. Acknowledgements

We would like to thank the Porcupine conference organising committee for allowing us the freedom to develop this approach and to the facilitators for each of the species, Sue Chambers, Frances Dipper, Keith Hiscock, Julia Nunn, Ivor Rees and Pamela Tompsett for helping production of the trial maps and text. We would also like to thank the delegates of the Porcupine meeting that contributed to the information on the sheets. We would also like to thank Eleanor Murray, then of JNCC, for producing the MNCR species distribution maps of the six species. The authors would also like to thank Judy Foster-Smith (Dove Marine Laboratory) and Mike Kendal (Plymouth Marine Laboratory) for their very helpful and constructive comments on the manuscript, and special thanks to Judy Foster-Smith for re-formatting the paper so that it was in a suitable form for re-publication in the *Proceedings* of ENSUS 2005.

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