TETHYS RESEARCH INSTITUTE

EUROPEAN CETACEAN SOCIETY

Proceedings of the workshop

COLLISIONS BETWEEN CETACEANS AND VESSELS: CAN WE FIND SOLUTIONS?

15th Annual Meeting of the European Cetacean Society,

Roma, Italy, 6 May 2001

Editors: Giovanna Pesante, Simone Panigada and Margherita Zanardelli

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ECS NEWSLETTER NO. 40 - SPECIAL ISSUE

March 2002

ICRAM

ISTITUTO CENTRALE PER LA RICERCA SCIENTIFICA E TECNOLOGICA APPLICATA AL MARE

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INTRODUCTION

Simone Panigada

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On Sunday the 6th of May 2001 the Tethys Research Institute organized a workshop entitled **"COLLISIONS BETWEEN CETACEANS AND VESSELS: CAN WE FIND SOLUTIONS?"** during the 15th Annual Meeting of the European Cetacean Society in Rome.

Aim of this workshop was to make an update on this problem within the Mediterranean Sea and to provide inputs from different scientists for possible solutions.

Collisions between ships and whales occur world-wide (Laist *et al.*, 2001) and are not uncommon in Mediterranean waters (Pesante *et al.*, 2000). The recent review prepared by Laist and colleagues coupled with evidences from Tethys fin whales photo-identification catalogues, collected over the decade 1990-2000 in the Ligurian Sea, were the leading forces which brought to the organization of this workshop.

In particular, how underlined by Laist and colleagues, sources of concern were:

- 14% (58 of 407) of the analyzed records indicates a vessel collision;
- 33% (31 of 92) were fin whales, representing the species hit most frequently;
- all sizes and types of vessels can hit whales;
- most lethal injuries are caused by ships longer than 80 m and traveling at 14 kn (26 km/h) or faster.

After this picture the situation in the Mediterranean Sea appears extremely worrisome, since the fin whale is the only mysticete occurring regularly in this Basin, and the species belongs to a genetically and reproductively isolated population with limited gene flow with the North Atlantic conspecifics. Moreover, given the increased number of ferries and fast ferries crossing daily the waters of the Mediterranean Sea and in particular those of the recently established International Sanctuary for marine mammals in the Ligurian Sea, an update on the situation was urgently needed.

Around 80 persons participated to the workshop, while 8 invited speakers covered different themes, from a review of the situation in particular areas to possible solutions and personal witnesses of collisions with whales (see programme).

Our special thanks go to Alstom Marine, SNCM Ferriterranée, Corsica and Sardinia Ferries for funding the organization and the logistics of the workshop. The International Fund for Animal Welfare (IFAW) provided the funding to collect data and to analyze exiting datasets, to them goes our gratitude. We are grateful to ICRAM and in particular to Giuseppe Notarbartolo di Sciara for hosting the workshop and the ECS Conference in Rome, and to the Conference organizers Fabrizio Borsani and Giancarlo Lauriano for their help and support. We wish to thank all the participants and the speakers who provided useful and interesting contributions and comments. Last but not least we would like to extend our gratitude to the European Cetacean Society and in particular to Peter Evans for offering to print these proceedings as a special issue of the ECS Newsletter.

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WORKSHOP PROGRAMME

Session one
OVERVIEW OF THE PRESENT SITUATION

Mediterranean Sea

9:10 Giovanna Pesante, Tethys Research Institute
Review of collisions in the Mediterranean Sea

North Atlantic Ocean

9:30 Phillip J. Clapham, Northeast Fisheries Science Centre
Are ship-strikes mortalities affecting the recovery of the endangered whale populations off North America?

9:50 Nick Tregenza, Institute of Marine Studies
Notes on a simple model of collision risk

10:00 Cpt. Frédéric Capoulade, Société Nationale Maritime Corse Méditerranée
Whales and ferries in the Ligurian Sanctuary: captain's experience and owner's actions

10:20 Coffee break

Session two
POSSIBLE SOLUTIONS

10:40 Joseph E. Bondaryk, SACLANT Undersea Research Centre
Benefits and limitations of active sonar for marinè mammal ship collision avoidance

11:00 Michel André, Universidad de Las Palmas de Gran Canaria
A passive sonar system to prevent ship collisions with cetaceans

11:20 Darlene R. Ketten, Woods Hole Oceanographic Institution
Ships strikes and sensory systems: what we know and what we need

11:40 Peter L. Tyack, Woods Hole Oceanographic Institution
Use of a digital acoustic tag to document response of the North Atlantic right whale

Session three
12:00-13:00 PLENARY SESSION

REVIEW OF COLLISIONS IN THE MEDITERRANEAN SEA

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INTRODUCTION In recent years the problem of collisions between cetaceans and vessels has come to the attention of both the scientific community and the general public, since ships strikes with odontocetes and mysticetes occur world-wide. Even if all types and sizes of vessels can be implicated, most lethal or severe injuries are usually caused by ships travelling 14 knots (26 km/h) or faster and 80 meters long or more (Laist *et al.*, 2001).
However, information on frequency and place of collisions and on the different species involved are rather scarce and uneven. This is particularly true in the Mediterranean Sea, which supports very high levels of naval traffic, especially in the Corso-Ligurian Basin and during the summer months (Notarbartolo di Sciara and Gordon, 1997). The purpose of this work was to fill all the gaps on collisions matter in the Mediterranean Sea in order to describe accidents locations and to understand which species are involved.
Due to a sample bias however, the maximum effort has been done on fin whales (*Balaenoptera physalus*), since more data on this species were available. Furthermore, this paper represents merely a review, with no statistical analysis.

MATERIALS AND METHODS This paper presents most of the information presently available on cetaceans species threatened by collisions in the Mediterranean Sea. These data were gathered by:
- checking all the cetaceans stranding databases to find out information on the causes of death of stranded cetaceans; in countries where stranding networks are not established, we contacted local vets;
- contacting Research Institutes which run photo-identification projects and asking for data on the occurrence and frequency of animals with scars derived from impacts with boats;
- reviewing the scientific literature actually available;
- searching historical and anecdotal records (early stranding records, Harbour Offices reports, inquiries to marine biologists and ferries captains, internet sources).

RESULTS
Stranding data
In the Mediterranean Sea there are three cetaceans stranding networks with accurate and complete databases: Centro Studi Cetacei (CSC) in Italy, Groupe d'Etudes des Cétacés En Méditerranée (GECEM) and Centre for Research on Marine Mammals (CRMM) both based in France. The first one has data from 1986 to 1999, while the others two from 1972 till 2000.
Between the 2665 cetacean specimens which stranded along the Italian and Mediterranean French

coasts during these years, 44 (1.2%) died because of a collision with a boat.
Evidence of ship strikes was found for 6 of the 13 species of stranded cetacean. An analysis for each species revealed that 28.6% of the stranded minke whales (*Balaenoptera acutorostrata*) died as a result of boat crash, 18.8% of the fin whales, 4.3% of the sperm whales (*Physeter macrocephalus)*, 1.1% of the pilot whales (*Globicephala melas*), 0.6% of the bottlenose dolphins (*Tursiops truncatus*) and 0.5% of the striped dolphins (*Stenella coeruleoalba*). These data are presented in Table 1.
Among the 44 cetaceans stranded because of ship strikes, 50% were fin whales, 20% striped dolphins, 11% sperm whales, 7% bottlenose dolphins, 5% minke whales, 2% pilot whales and 5% unidentified species.

Fin whales.
Photo-identification
a- From 1990 to 2000 the Tethys Research Institute conducted a long-term photo-identification study on fin whales in the offshore waters of the western Ligurian Sea. Pictures of 379 identified whales were analysed in order to find evidence of collisions with boats.
The 24 whales (6.4%) which presented injuries or scars were divided in two categories:

1. 10 (2.7% of the total number) were animals that undoubtedly had an accident with a ship. Among these animals:
- 7 (70%) showed a well healed over lesion (Fig. 1);
- 1 (10%) presented a big non cicatrised wound (Fig. 2);
- 2 (20%) had propeller scars, clearly recognisable from multiple, parallel and evenly spaced cuts (Fig. 3).

2. 14 (3.7%) presented signs of possible collisions, although causes of scars or injuries remain uncertain:
- 3 (21%) showed a cut fluke (Fig. 4);
- 4 (29%) had a cut dorsal fin (Fig. 5).
  These two categories are not considered as certain collisions since cut fins can result from entangled fishing lines (Green *et al.,* 1991);
- 7 (50%) presented white spots (Fig. 6), light and almost circular stains which can be natural markings or old scars; since spots are found frequently (86%, 6 of 7 cases) on the back (particularly near the dorsal fin), the whale's most exposed area, the collision hypothesis seems convincing (Pesante *et al*., 2000).

b- Among the 12 fin whales that the associations StudioMare photo-identified in 1998 in the Tyrrhenian Sea, 1 (8.3%) animal showed a mark (a white spot) that can possibly be the result of a ship strike.

c- The analysis of fin whales pictures took by other Research Institutes that we contacted (ALNITAK in Spanish waters and Pelagos Research Institute in Greece) revealed no evidence of collided animals.

Strandings, historical records, literature
A review of the scientific literature, standings information and historical records on fin whales revealed that among 207 whales that stranded along the Mediterranean coasts, 36 (17.4%) animals died because of a collision with a vessel. Analysed data range from 1897 to 2000 (Notarbartolo di Sciara *et al.,* submitted).

Harbour Offices reports

Genova Harbour Offices informed us of two collisions involving fin whales that are not reported in stranding records:

1- in 1998 a fin whale was found in Genova harbour with large wounds;

2- in 1999 in French waters a fast ferry stroke a whale, the carcass floated for 4 days and then it reached Genova harbour.

Sperm whales

Photo-identification

a- The Pelagos Cetacean Research Institute has been running since 1998 a photo-identification study on sperm whales in the waters Southwest the Island of Crete (Greece). Among the 39 individuals identified 3 (7.7%) present injuries. Two (5.1%) of them surely collided with a ship (Fig. 8), a third individual (2.6%) presents a smaller but clear wound at the end of the dorsal side of the tailstock. The location of this lesion makes a ship-strike probable, although it cannot be confirmed (Fig. 9).

b- Among the 22 sperm whales that the Tethys Research Institute photo-identified from 1990 to 2000 during a long-term study conducted in the Corso-Ligurian basin, 1 animal (4.5%) presents two clear parallel slashes behind the dorsal fin that are certainly propeller wounds (Fig. 10).

Strandings

Data on sperm whales are greatly dissimilar in different areas. The Italian stranding network (CSC) reports that from 1986 to 1999 5 of the 99 sperm whales (5%) found dead deceased for accident with ships, while the French one (GECEM, 1972-2000) has no evidence of collided individuals among the 16 stranded sperm whales. In Greece (Pelagos Cetacean Research Institute) the situation appears quite different, since from 1982 to 2001 2 (16%) of the 12 stranded specimens died after a ship-strike. However the differences recorded in percentages could be partially explained by the relatively smaller sample size in Greece and France.

Other species

In order to obtain information on the entity of collisions problem in the Mediterranean Sea we contacted several Research Institutes or individual researchers in Italy, France, Spain, Croatia, Slovenia and Greece. These are most of the countries where projects on cetaceans are currently running.

Excluding information already presented from the cetaceans stranding networks and data on fin and sperm whales, we collected only one picture presenting sure evidence of a ship strike. The animal involved was a bottlenose dolphin with deep propeller scars just behind the dorsal fin. This picture was taken in the Tyrrhenian Sea near the Island of Ischia (40°47'N and 13°52'W) by StudioMare in 2000.

DISCUSSION AND CONCLUSIONS The data we could gather from different sources allowed to stress how in the Mediterranean Sea some cetaceans species are at high risks of collisions, while the problem is not pressing for many others.

The fin whale inarguably presents the highest percentage of collided animals between the stranded individuals, and a worrying number among the photo-identified ones. Furthermore, the number of injured whales may be underestimated since photo-identification of fin whales focuses on the dorsal fin and the right side of the animal, while the rest of the body can present scars as well. Considering the small size of the Mediterranean fin whales population, estimated around 3500 individuals (Forcada *et al.*, 1996), its reproductive segregation from the Atlantic stocks (Bérubé *et al.*, 1998) and the low calf production of mysticetes (Gambell, 1985), this level of collided whales represents a source of concern

and precautionary measures are required in order to reduce human caused mortality and accidents.
Evidence of high risk of collisions was found also for sperm whales, although data from distinct areas are greatly different. In Italy and in Greece the amount of collided sperm whales among both the stranded and the photo-identified animals is worrying, especially considering that the number of ferries and high-speed vessels is constantly increasing. On the contrary in French waters no collided sperm whales has been found among the stranded, despite the high number of boats that regularly cross this area.
Also minke whales seems to suffer because of accidents with boats, but since this species is not common in the Mediterranean Sea and there are few records of strandings and sightings, these data can be misunderstood because of the sampling bias.
Regarding the other species of Mediterranean cetaceans, we found few evidences of collisions among the stranding records and the photo-identification catalogues. Species involved were striped, bottlenose dolphins and pilot whales. Comparing this low number of collided animals to their population sizes, it is evident that these species don't run high risk of collisions. However, since the number of ship strikes may be underestimated (Laist *et al*, 2001) and cetaceans in the Mediterranean Sea are threatened by many other dangers (Notarbartolo di Sciara and Gordon, 1997), the level of injured animals should be constantly monitored.

ACKNOWLEDGEMENTS We are especially grateful to the International Fund for Animal Welfare (IFAW) which supported part of data collection and analysis. We also would like to thank all the people and Institutes which provided us data for this review and helped in gathering the information: Alex Aguilar (University of Barcellona), Sabina Airoldi (Tethys Research Institute), Jean-Michel Bompar (GECEM), Ana Cañadas (ALNITAK), Caterina Fortuna, Giancarlo Lauriano (ICRAM), Barbara Mussi (StudioMare) and Luca Riva. A particular acknowledgement to Michele Manghi from CIBRA for providing us a picture of a collided whale. We are grateful to all Tethys collaborators who helped in collecting pictures of fin whales. Many thanks to Albert Sturlese and Barbara Nani for their collaboration in the photo-identification research. Special thanks to Portosole, Sanremo, Italy, for support and hospitality. The eco-volunteers supported our research cruises onboard of *"Gemini Lab"*.

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Table 1 - Species stranded due to collisions along the Italian (1986-1999) and French coasts (1972-2000).

Species	Stranded	Collided	Percentage
Balaenoptera acutorostrata	7	2	28.6
Balaenoptera physalus	117	22	18.8
Physeter macrocephalus	115	5	4.3
Globicephala melas	87	1	1.1
Tursiops truncatus	516	3	0.6
Stenella coeruleoalba	1823	9	0.5

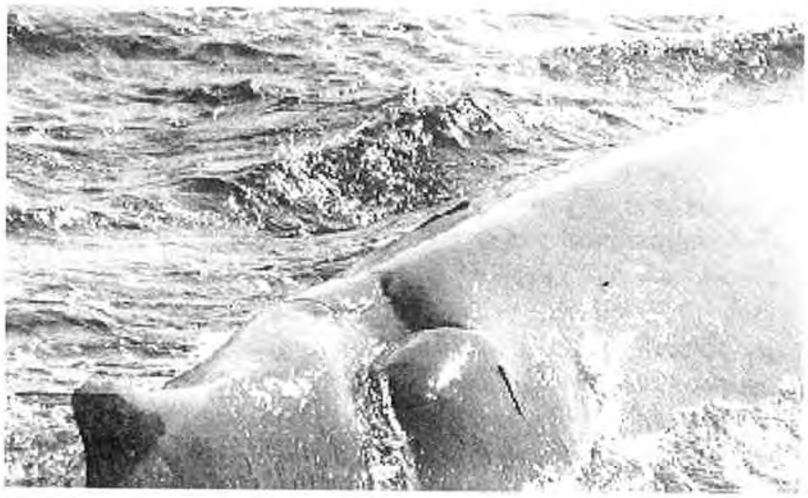

Fig. 1 - Fin whale with a well healed over lesion.

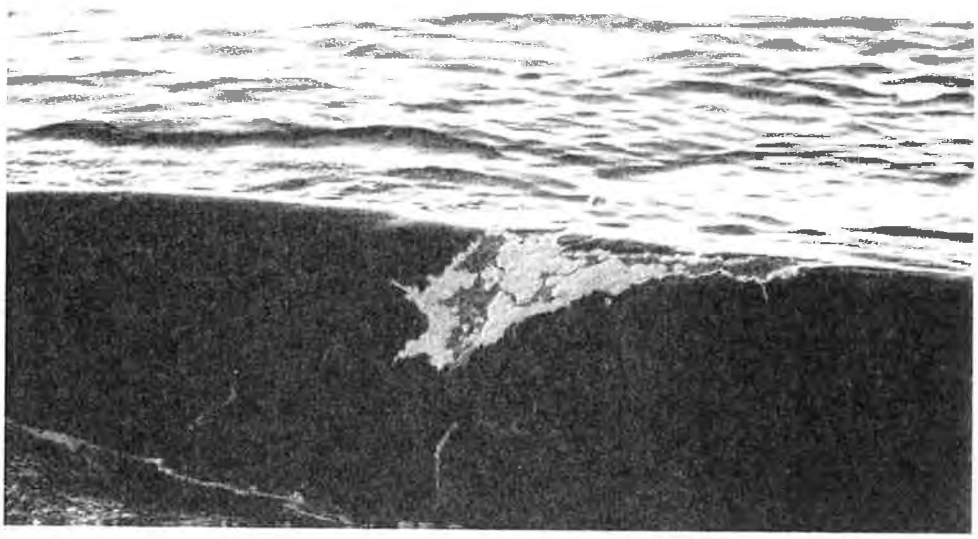

Fig. 2 - A non cicatrised wound (picture by Michele Manghi, CIBRA).

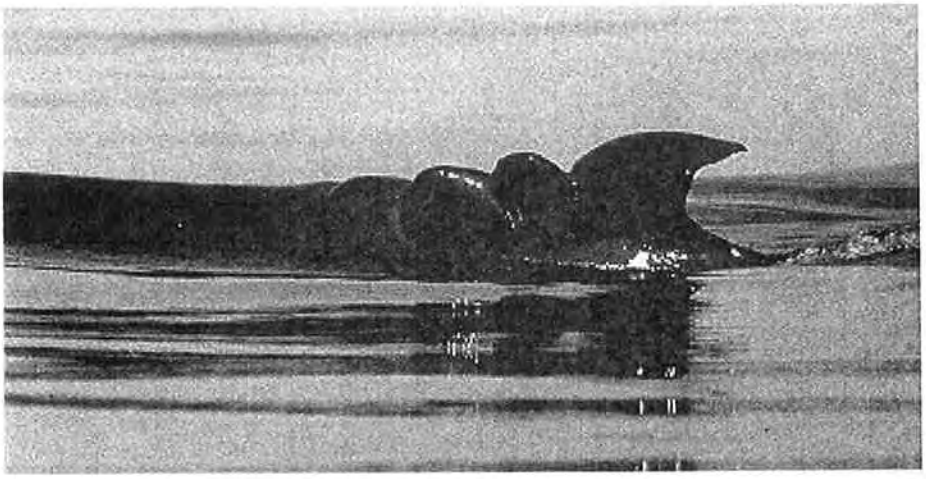

Fig. 3 - Fin whale with propeller scars.

Fig. 4 - Fin whale with cut flukes.

Fig. 5 - Fin whale with cut dorsal fin.

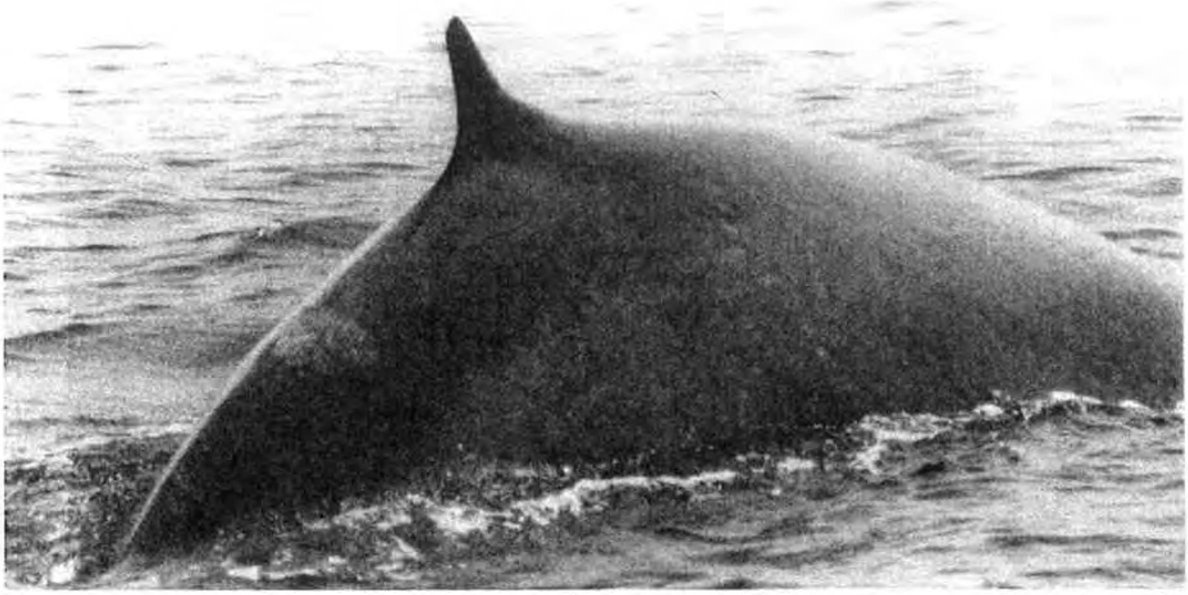

Fig. 6 - Fin whale with a white spot.

ARE SHIP-STRIKES MORTALITIES AFFECTING THE RECOVERY OF THE ENDANGERED WHALE POPULATIONS OFF NORTH AMERICA?

Phillip J. Clapham

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INTRODUCTION Ship collisions affect many or most species of large whales in North American waters and elsewhere. A comprehensive review by Laist *et al.* (2001) found records of collisions involving 11 species, with an evident increase from 1950. The most common events concern fin whales (*Balaenoptera physalus*), North Atlantic right whales (*Eubalaena glacialis*), humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter macrocephalus*) and gray whales (*Eschrichtius robustus*). However, the frequency with which these incidents are reported is probably strongly biased by the abundance and distribution of the whales: coastal species and animals from large populations are more likely to be both struck and observed. In addition, reporting is affected by morphology: a significant number of reports involve a vessel bringing a whale carcass into port across its bulbous bow, a phenomenon which is likely to occur predominantly in sleek rorquals (such as fin whales). Moreover, increased observer coverage with time and inadequate necropsy are further sources of bias in the reported number of struck whales.
Laist *et al.* suggested that ship strikes are likely to be fatal, particularly if the vessel concerned is 80 meters or more in length and/or if vessel's speed exceeds 13 knots.

RESULTS Although ship collisions are probably not significantly affecting population growth in most North American large whale species, a clear exception is the North Atlantic right whale, for which human-related mortality is high, and ship strike is the largest cause of non-natural deaths. Location of right whales habitats near or in shipping lanes, slowness in swimming and a high proportion of time spent at surface are probable causes of frequent ship strikes. Of 49 reported right whale deaths between 1970 and 2001, at least 17 (34.7%) were the result of ship strikes; 29 of the remaining 32 mortalities were either neonatal deaths, deaths of unknown cause, or deaths in which the carcass was not recovered (Table 1). In light of this, and with the certainty that many right whale mortalities pass unreported, the actual rate of ship collisions with right whales is likely much higher than the data indicate.
Several models and demographic analyses have been applied to evaluate changes in North Atlantic right whale population size, and all concluded that survival declined during the 1990's. In 1996 we calculated that only 263 animals were known to be alive, and in 1998 the International Whaling Commission concluded that the estimate of about 300 whales is likely to be accurate.

DISCUSSION AND CONCLUSIONS Given that the remaining North Atlantic right whale population, one of the most endangered of all whale population world-wide, is small and apparently declining, every cause of mortality is significant; however ship strike must be considered the single most important factor in this species' failure to recover.
Several mitigation measures have been recently proposed or implemented in U.S. and Canadian waters to prevent incidents. These management options include:

3. aerial surveys to report to mariners real-time data on the presence and position of right whales. Although this is a necessary educational tool, it is expensive and inefficient as a mortality

mitigation method. Vessel captains may not change their route or speed even if informed of the presence of whales;

- introduction of a ship reporting system, which requires vessels over 300 tons to report into an automatic system before entering certain areas particularly frequented by right whales. This system is now in place in two major U.S. right whale habitats and it gives important data on the distribution and movements of shipping;
- moving shipping lanes from right whales' critical habitats to less frequented areas; this solution will probably be applied in the Bay of Fundy in the near future. Lanes shifts could be permanent or temporary and dynamic, in relation to whales movements and migrations.
- restrictions of ships speed is a solution that would likely help to reduce the number and severity of collision; however this is likely to be difficult to introduce since it is not popular among shipping companies. Indeed, the trend in the industry is actually towards use of high-speed vessels.

Many problems frustrate efforts to mitigate ship strike. These include:

- presence of a great number of ships;
- occurrence of ships with many different flags and registries;
- protection of so-called "innocent passage" (the right to travel freely) by maritime law ;
- lack of a single central governing authority, with the exception of the International Maritime Organization (IMO);
- factors constraining ship movements, such as tide, bathymetry, schedule and port costs.

Future research may help to reduce vessel-related deaths. Areas of investigation include:

- acoustic tags placed on whales in order to study behavioural responses to playbacks of vessel sounds;
- forward-looking sonar set on ships in order to detect in time the presence of a whale;
- hydrodynamics modeling to examine the interaction of whales and ships at close range;
- passive acoustics to detect the presence of right whales through their vocalizations;
- GIS analyses/predictive modeling of whales distributions.

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Many thanks to Amy Knowlton, Bruce Russell, David Laist, the Marine Mammal Commission and Lindy Johnson.

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Table 1 - North Atlantic right whale death causes between 1970 and 2001.

CAUSE	DEATHS	PERCENTAGE
Ship-strikes	17	34.7
Entanglement	3	6.1
Neonatal/Unknown	29	59.2
Total	49	100

NOTES ON A SIMPLE MODEL OF COLLISION RISK

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NOTES

This model is a geometric 2 dimensional representation of collision risk. It is available as a simple 'calculator' that can be run under Windows (www.chelonia.demon.co.uk).

The model depends on the parameters entered and on 4 assumptions:

1. the vulnerable parts of the whale can be represented as a line of the same length as the whale;
2. the whale's orientation relative to the direction of travel of the ferry is random;
3. the whale does not tend to move into or out of the ferry's path, actively or passively;
4. ferries do not avoid whales.

Applying it to short-fin pilot whales *(Globicephala macrorhynchus)* in the Tenerife/la Gomera channel in the Canary Islands gives –

Ferry transects per year	2920
Length of ferry transect in km	11.1
Hull width in m	7
Mean N of whales per sq.km	3.1
Length of whale in m	4
Percentage of whale time very near surface	34

Whales in path of ferry each year =	**327**
Percentage of whales in a square of side D crossed by the specified transect in path of ferry each year =	**85.5**

The comments I wish to make are –

Clearly the collisions suffered by these whales are far fewer than those they risk. The assumption violation or parameter error that seems most likely to explain this is a high level of whales avoiding ferries. This focuses attention on that process and in particular on how it may be affected by the presence of a calf with its mother. Will they both behave in the same way as other whales, and be as successful in reducing their risk of collision?

Neither time or speed are required in this model (except to sum distance travelled) because assumption 3 implies that a whale is as likely to move into the path of the ferry at the point just reached by the ferry as out of it. The model simply gives the number of whales that would come into contact with the ferry if the assumptions were correct. However there is evidence that lower speed vessels have lower collision rates, perhaps because animals can avoid them more successfully, and perhaps because near- or actual collisions are less likely to be fatal. As such factors are quantified more complex and accurate models can be developed.

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WHALES AND FERRIES IN LIGURIAN SANCTUARY: CAPTAIN'S EXPERIENCE AND OWNER'S ACTIONS

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INTRODUCTION In the same year, 1998, two collisions with whales occurred on two different ships of French company SNCM, "Monte Cinto" and "NGV Asco" (Cpt Capoulade for the two). These incidents suggested studies related in this proceeding. After a short presentation of SNCM and High Speed Ferries, this paper describes circumstances of last collisions, SNCM collision history, then owner's actions and my captain's experience.

SNCM is a state owned society founded in 1976, she was successor of two owners (Compagnie de Navigation Mixte since 1850 and Compagnie Générale Maritime five years later). She operates today 13 ships, 6 car-ferries, 4 roll on/roll off passengers ships and 3 high speed car-ferries (we called it HSS High Speed Ships, in French NGV Navire à Grande Vitesse). All SNCM routes are shown on figure 1, most of them are inside or are crossing the new Ligurian Sanctuary waters. 2000 traffic is following:

- passengers 1 700 000;
- cars 600 000;
- rolls 800 000 ml;
- 4000 crossings (1423 for HSS).

HIGH SPEED SHIPS (Table 1 and figures 2 and 3). Distinctive feature of our NGV is the stabilisation system with six (for NGV Asco type) or eight elements (for NGV Liamone). These elements are (Figure 4):

- two flaps or tabs on the aft part just down the jets for the pitch;
- two aft fins for roll and steering;

4. two fore fins for roll;

- one inverted T-Foil for roll with special design and equipments to resist at a big impact (fusible bolts, stopper and radio beacon if lower part is lost). It is a fragile element against all floating objects near surface like whales and containers.

There is 9 others HSS of similar type sailing in the same area: 6 for Tirrenia (Italian state owned company), 3 for Corsica-Sardinia Ferries. New big car-ferries at high speed (28 knots) are operating this year, two for Corsica-Sardinia Ferries and two for Moby Lines.

COLLISIONS

COLLISION 1. First one on 4th of June 98, occurred on the roll on/roll off passenger ship Monte Cinto (L=136 m, 111 passengers). She was in route from Marseilles to Ajaccio, at 11.00 pm South of Cap d'Armes (Porquerolles Island), at a speed of about 18 knots and 13 knots after impact. The engine was stopped and on the forecastle an object was seen on the bulbous bow like a big black tarpaulin. But just one moment later, we clearly saw the throat grooves of a fin whale (*Balaenoptera physalus)*. Fate of whale: killed. No damage to the ship was observed.

COLLISION 2. Same year, two months later, on 6th of August 98, on the HSS NGV Asco, in route from Ajaccio to Nice, at 10.48 pm, position 43°05 N 007°48 E, at a speed of 35 knots, wind NE 6, sea 1,5m, moonlight. I was on duty with my mate and I saw a blow just ahead (typically of a fin whale). A strong impact happened, like a big wave and we noted T-Foil damages with leak in bow thrusters compartment and command jack out of order. We finished the trip to Nice at 20 knots. One day stop at Nice and ten days later the ship was in dry-docks in Marseilles for two days. A crash box has been made just rear the T-Foil shaft. Extended bolts of lower part of the foil indicated an impact of 163 mt (MDI internal report).

COLLISION 3. Next year on the 2nd of august 99 at 11.00 pm , with HSS NGV Aliso, in route from Ajaccio to Nice, position 42°28 N 008°13 E, at a speed 35 knots, calm wind and sea, black night and heavy fluorescent sea. A strong impact happened with again the same damages with leak in bow thrusters compartment and command jack out of order. Captain decided to deviate to Ile Rousse harbour and divers observed lower part of T-foil lost.
Species struck: fin whale? Fate of whale: killed and seen by fishermen several days later.

COLLISION 4. On the 15th of April 2000, daytime, same ship, another collision with an object (surely a whale) occurred but nobody have seen something on the sea. Also damage to hydraulic jack and to T-Foil shaft were observed.
Grouping of HSS collisions are in figure 5. Common points of these three last SNCM collisions: all are with HSS and on the return trip from Corsica to Nice.

SNCM COLLISIONS. Historical records of SNCM collisions are shown in Table 2. In November 1998 a quick report about this problem have been made and the evaluation risk for SNCM was approached to one collision per year. The difference between traditional car-ferries and high speed car-ferries is the consciousness of the collision. In the first, collision knowledge happens generally at the entrance of the harbour or inside. In the others, collision knowledge is immediate because of the impact due to the speed and the low weight of the ship.

CALCULATION RISK Nick Tregenza calculation risk (Tregenza *et al.*, 2000) gives 25 whales per year in the path of our high speed car-ferries but some questions remains: all whales on day time are supposed detected, but how many whale can we meet by night in the evening between 8 and 12 pm?

ACTIONS

- Just after first collision, after scientists contacts in autumn 1998 ship sightings were reactivated. Then an internal report have been written.
- August 1999: " Short detectability study on HSS " (Beaubrun *et al.*, 2001), which main conclusions are
  -up to the speed of 36 knots, fin whales could correctly be detected from the HSS, but only in the condition that one specially affected observer covers a total angle not exceeding 100° wide forward;
  - the fact that fin whales are more often detected early in the morning than in the middle of the day has no explanation. It is possible that whales move away from the road after the first shuttle service, but we have to confirm this particular behaviour.
- November 1999 a R&D action Alstom Shipyards – SNCM is implemented. Its goals are:
  -find detection or repulse system (sonar proposal, ladar presentation);
  -ship protection (crash box, new foil design);

-T-foil recovery if lower part lost (Lift bags are a solution in search by stabilization supplier MDI, Maritime Dynamics Inc. USA).

- In spring 2000: night vision system is installed on our three HSS.
- April to December 2001: a longer study about " Detectability study on HSS " (Beaubrun and EPHE) is in progress.
- In Summer 2000, R&D action supports the " Studies about abundance, distribution and activity of fin whale in the international marine sanctuary " by Gannier (2001), with some interesting parameters for characterization of each activity class. Main recommendations are:
  -a continuous follow-up of whale distribution from other ship sighting have to be done with a cartography software on board;
  -large concentration of whales have to be detected for captain 's decision to avoid this area.
- In May 2001, collisions workshop sponsorship.

We received some proposals as sound emission B flat minor for repulse whales and more seriously, a sonar from Rhode Island University scientists who founded the society PYRCON. Sonar specifications are following:
Detection range 2000 m, Frequency 30 kHz, Reception Channel number 75, Height 2,5m, Width 1,25m, Resolution 3m, Vertical 2°, Horizontal 4°, Visual sector Vertical 20°, Horizontal 85°.

FLOW CHART STUDY (Figure 6) For detection, we can list actual and future systems: Night Vision System, Sonar, Ladar and WACS (Whale Anti Collision System).
NIGHT VISION SYSTEMS
Actual specifications are:
-in Hong-Kong (For a HSS at 40 knots), detection, then 10 s of thought for decision, then action hard over port or starboard, for crossing object at 20 m. For NGV Liamone minimum detection range 347 m for HK rules;
-for European Iso/Imo: ratification in progress, for a box such that when at least 50% is immersed, 1,5 m long, 1,5 m wide and 0,5 m high remains above the water, the range of detection have to be at least 600 m, it's independent of ship performance.
There are two distinct principles: light amplifier and infrared system.
Light amplifier operates on the contrast between coefficients of reflection of the targets and those of the environment illuminated by local lights. Additional near infrared projectors can improve the system by dark night.
Infrared camera is sensitive to the temperature of the object. Accuracy is less than one degree night and day. A floating timber may be detected at 1 km but not identified because of a too small number of pixels. On the contrary even if the contrast of temperature with the one of the sea is low, a cetacean should be seen and detected.
But mains default are poor performances by bad atmospheric conditions. Canaria trials on Fred Olsen HSS (Infrared System) are not very conclusive. Our system is a light amplifier and we have not now many field experiment return.
Two others kinds of devices are approached for detection of submerged obstacles.
SONAR AND LADAR
(Thomson Marconi Petrel and Ladar advertising presentation)
•SONAR = Sound Navigation Ranging
It's an acoustic emission at 1500 m/s with a good detection performance in depth > 10 m. Frequencies are between 50 and 200 kHz . Between 0 and 10 m detection is probable but non-relevant echoes *(Sonar PETREL of Thomsom max speed 12kn)*
•LADAR Laser Detection And Ranging

It's a system with a blue-green laser associated with an infrared system used to detect mines. Two frequencies for sea surface and for entering water. A 10 m circle window is scanned. In Mediterranean Sea, this system can detect 20 m down. But impact environmental studies have to be engaged because of eye sensitiveness.

SIGHTINGS (Table 3) Sighting sheets on board have been made earlier in 80's for La Rochelle and for Denise Viale (Corte University). They have been reactivated in 1998 for CIESM in a simplified format.

EXPERIENCE On our NGV there is, due to HSS rules, 2 officers on duty during all the trips. We see in summer time many cetaceans, dolphins, pilot whales, fin whales and we are often manoeuvring. But on night it is a matter of chance. Our three NGV are equipped now with a NVS light amplifier to try to detect floating objects and whales because our last trip return arrives at Nice about midnight. Another idea is to take exactly the same route for the return. HSS makes special wake who remains a certain time and so could form a barrier.

CONCLUSION To reduce collision risk, an integrated approach is necessary with scientific partnership. Research is needed to obtain a reliable detection system. WACS system could offer good opportunities if "ambient noise imaging" works correctly.

ACKNOWLEDGEMENTS To all organisers, specially Giovanna Pesante and all sponsors.

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Table 1 - SNCM High Speed Car-Ferries main specifications.

Name *In service*	**NGV ASCO- NGV ALISO** 1996	**NGV LIAMONE** Juin 2000
Length/Beam/Draught in meters	102 / 15,4 / 2,5	134 / 19,8 / 3,35
Passengers / Cars	500 / 148	1116 / 250
Max speed	37 knots	42 knots
Stabilization	**T-foil** /2 fins/ 2 flaps	**T-Foil**/4 fins/2 flaps
Routes	Nice-Corsica Bastia-Livorno	Nice or Toulon-Corsica

Table 2 - SNCM Collisions records.

Traditionnal ships Speed < 24 kts	High Speed Car-Ferries Speed > 35 kts
1972 September 3 C/F Corse 1973 C/F Corse 1983 C/F Napoléon 1993 September 9 C/F Ile de Beauté 1996 July 26 C/F Danielle Casanova 1998 June 4 M/S Monte Cinto	1998 August 6 NGV Asco 1999 August 2 NGV Aliso 2000 April 15 NGV Aliso HSS trips 1996-2000 5 563
Consciousness of collisions -Harbour entrance -Impact ?	Consciousness of collisions -Impact with (no) sight

Table 3 - Sighting sheet (20 observations by sheet).

Date	*Hour TU*	*Latitude* °		*″*		*Longitude* °		*″*		*True Course*	*V. Kts*	*Météo Wind*	*Météo Sea*	*Obs RB*	*Obs D*	*SIGHTINGS Specie*	*Number*	*Course*	*Remarks*
12/08/01	*06H33*	*43*	*08*	*44*	*N*	*7*	*38*	*01*	*E*	*150*	*41*	*ESE2*	*2*	*030*	*3600 m*	*F.Whale*	*2*	*225*	*Blows*
12/08/01	*17H58*	*43*	*21*	*01*	*N*	*8*	*24*	*42*	*E*	*115*	*41*	*E2*	*2*	*000*	*3000 m*	*F.Whale*	*>2*	*N*	*Many blows*

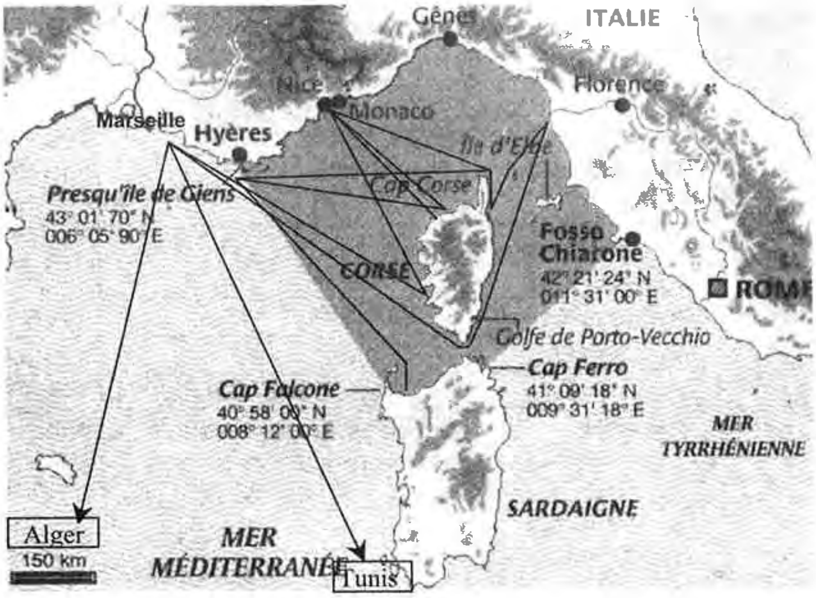

Fig. 1 - SNCM routes and Sanctuary (Le Monde 27 nov 99).

Fig. 2 - SNCM High Speed Ship NGV ASCO.

Fig. 3 - SNCM High Speed Ship NGV LIAMONE.

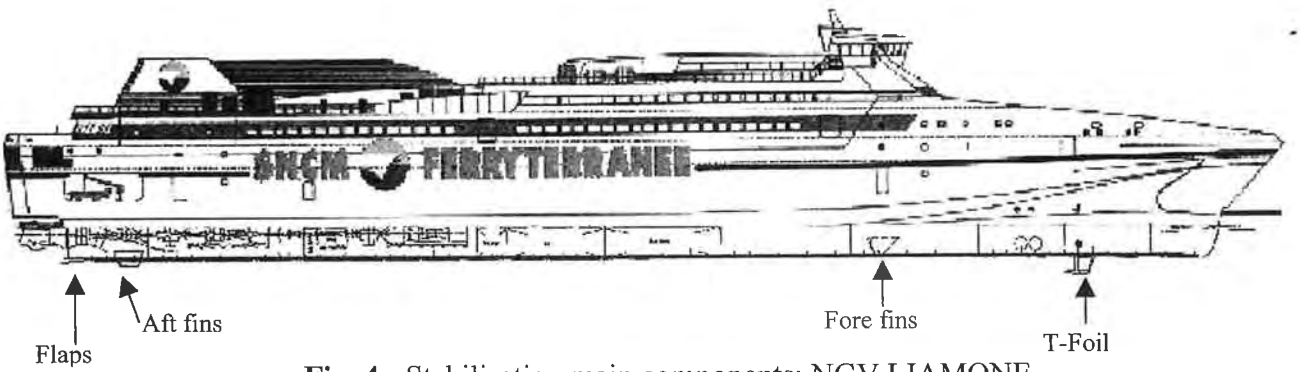

Fig. 4 - Stabilisation main components: NGV LIAMONE.

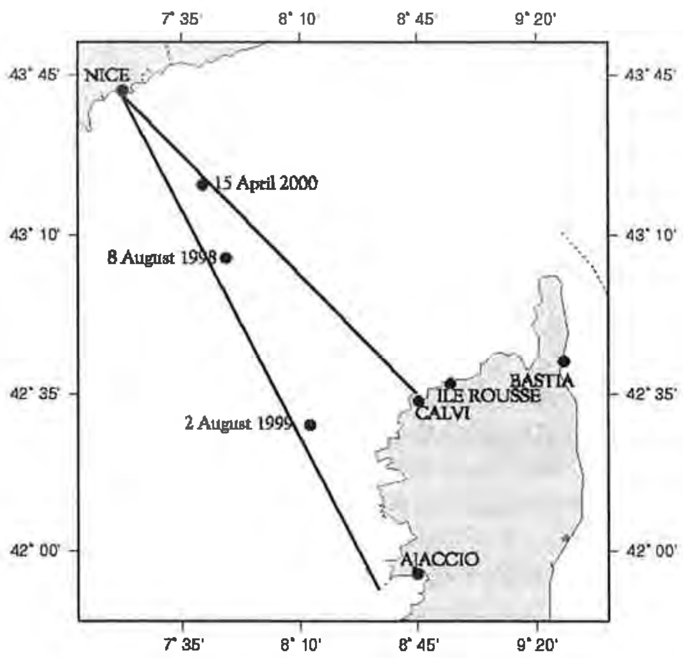

Fig. 5 - Positions of the collisionswith HSS.

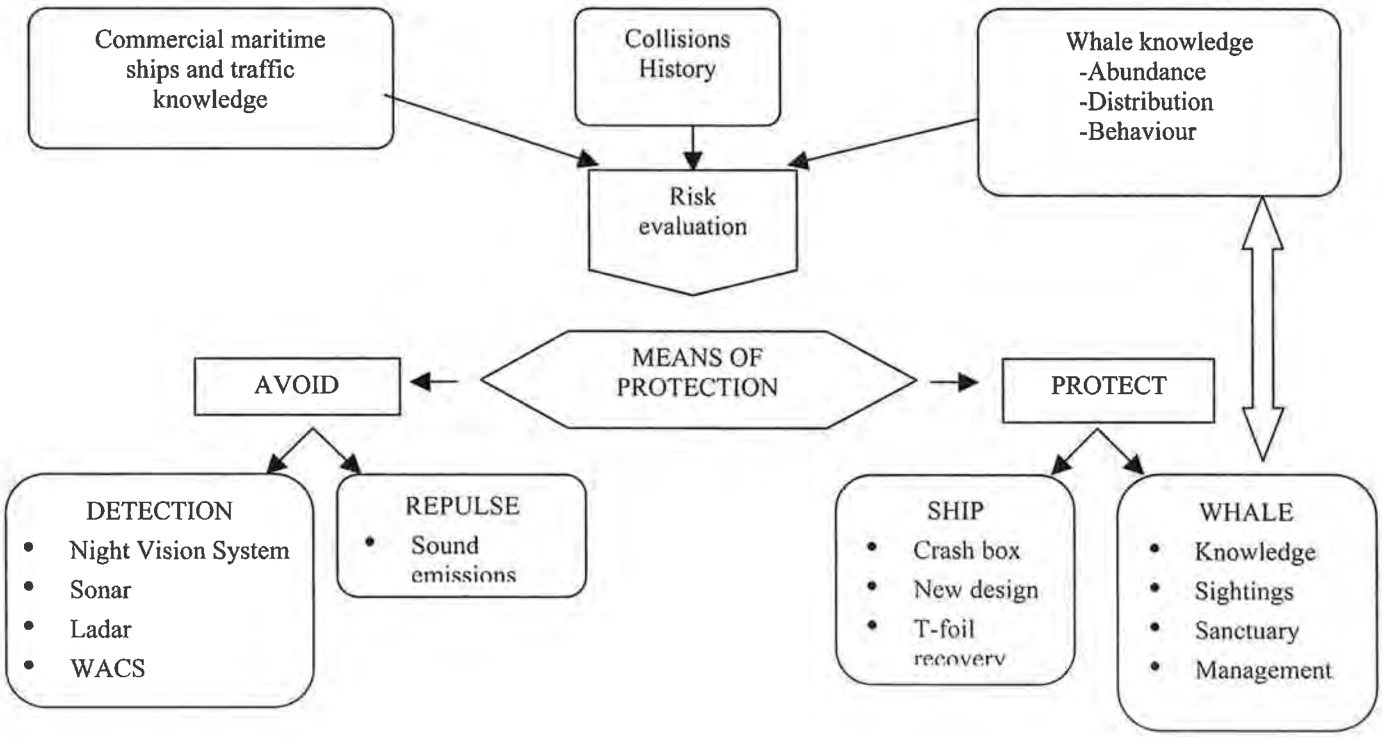

Fig. 6 - Flow chart study.

BENEFITS AND LIMITATIONS OF ACTIVE SONAR FOR MARINE MAMMAL SHIP COLLISION AVOIDANCE

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INTRODUCTION Currently, researchers are looking into the effects of ship collision on marine mammal populations. For some species, such as the Northern Right Whale, the problem is significant enough that technology solutions are being sought. Consider a fast ferry traveling at 40kts, and a Fin whale crossing its bow at 12kts some distance ahead, shown in Fig.1. To allow this ship to maneuver with 2 minutes of warning, detection would have to be made at 2.5km over an angle of 30 degrees forward. Within this cone, a fin whale could potentially swim into the direct path of the ship. Thus, a "mammal free zone" of this size must be maintained forward of the ship. For this application, an animal's presence must be detected and his location determined. One possible technology that could fulfill these requirements is forward-looking active sonar.

ACTIVE SONAR CONCEPT AND BENEFITS As shown in Fig. 2, the sonar measures the two-way travel time of a pulse emitted from the sonar and reflected from an object in the water column. This time multiplied by the sound speed, approximately 1500m/s in seawater, divided by 2 gives a very accurate estimate of the range to the object. This concept is employed by the military to detect and locate submerged submarines.
In that application, sound projectors in excess of 220dB re 1μPa, 1m and several-second pulses are used to extend the detection range to many miles. Since only short ranges are needed for the collision mitigation sonar, lower power sources, around 200dB, and sub-second pulses can be used, vastly improving the safety of the device for animals.

The main benefit of the system is its ability to give exact position information about animals in the water column whether or not they are visible or vocalizing. The coverage of the system is specified in the design and could either be a full 360 degrees or restricted to forward looking. Multiple returns over time could be used to track animals and provide their course information to allow maneuver planning. This information is not subject to light or weather conditions so the system can run day or night, in sun, fog, haze or rain. Unlike visual observations, the active sonar system is completely computerized. It could be fully automated and provide an alert to the ship's crew on detection of significant sonar returns, which eliminates the issues of observer fatigue and watch standing. The system should work for all marine mammal species and be able to give size information, e.g. large, medium, small animal, based on the strength of the return.

A sonar system was tested aboard the Alliance during Sirena '00 for concept feasibility. It was comprised of a towed omni-directional source and a line array of hydrophones as a receiver as shown in Fig 2. The line array "looks" in all directions with a "beam" every 4 degrees. Thus, returns can be separated in direction as well as range. An example of the data from this system is shown in Fig 3. The horizontal axis is time of the return or equivalently range in meters. The outgoing pulse and reflections from the nearby surface are seen at 0-300m. The bottom is about 2600m deep and is seen as strong returns. Visual observers identified the origin of the return centered at 600m as a striped dolphin.

ACTIVE SONAR EQUATION AND DESIGN The following discussion is meant to give the reader a broad and intuitive understanding of the steps of sonar design. Further detail can be found in (Urick, 1983). One version of the Active Sonar Equation is given by SL - 2TL + TS + AG + PG > N + DT. All the terms are given in some form of decibels, for example PL = $20\log_{10}(p/pref)$, where p is a physical measurable quantity like pressure in Pascals and pref is a chosen reference, say 1□Pa. The entire left side of the equation is the strength of the reflected pulse at the sonar. This received level is equal to the source level (SL), i.e. the sound put into the water, minus the loss (2TL) that occurs as sound travels through the water two ways, plus the strength of the target (TS), plus any array gain (AG) and processing gain (PG) afforded by the sonar system itself. Intuitively, this received level must be some amount (DT) greater than the ambient noise (N) at the sonar receiver to be detected. The sonar design proceeds with this equation as a guide.

The sonar design begins with the selection of the most critical parameter, which is the operating frequency.
Though not seen explicitly in the active sonar equation, many of the terms, in particular TL, are functions of frequency, so it does in fact drive the entire design. A very simple model of Transmission Loss (TL) at a given range R is given by TL = $20\log_{10}R + aR$, where the first term accounts for geometric spreading and the second accounts for absorption of sound by water. This model of geometric spreading is known as "spherical spreading" as it models the effect of a making a sound at a point in space and having the energy expand in a 3D sphere away from that point. The term "a" in the model for the absorption of sound energy is generally given in units of dB/km. This absorption is a process caused by the chemical relaxation of mineral compounds contained in seawater (Urick, 1983) and is frequency dependent. Higher frequencies are absorbed more quickly. This is why sonars and animals that want their signals to travel long distances use low frequency. A good rule of thumb for sonar design is that one-way absorption should be no greater than 10dB at the maximum range. In order to allow 2 minutes warning for 40kt vessel, the detection range we choose is R = 2500m. The frequency dependent absorption curves (Urick, 1983) show that in order for a = 10dB/2.5km = 4dB/km, that the frequency must be f = 20kHz. At this range $20\log_{10}(2500)$ = 68dB. Thus, total one-way transmission loss is TL = 68 + 10 = 78dB. The two way loss is 156dB. Note that this is where most of the initial sound energy is lost. TS is the target strength in dB re 1m, the amount of signal reflected by the target. The few estimates of TS for large whales vary from –8 to +7dB (Love, 1973; Dunn, 1969). For large ships and submarines this number varies with aspect, typically in the range +10-25dB; for a swimmer this number is -15dB (Urick, 1983). For this exercise, we take TS = 0dB.

The array gain (AG) is a function of how much the array can shut out noise from other directions when looking in one particular direction. It is related to the angular extent of the sonar "beam." A sonar putting out a 30 degree cone-like beam would have a gain of AG=18dB. The transducer, which could produce such a beam at 20kHz, would be a piston about 20 cm across its face, which is not an unreasonable size for mounting to the bow of a ship. For a system using match filter processing, PG is the processing gain from the source signal given by $10\log_{10}(T)$, where T is the length of the pulse in seconds. A short pulse must be used to reduce blanking of the early time or short-range returns by the outgoing direct pulse. Here we use T = 0.1s for PG = -10dB. Note that since the time is less than a second, the PG is negative, so this term is actually working against detection.

N is a frequency dependent ambient noise spectrum level in dB re 1□Pa/Hz, given, for example, by a classical set of measurements known as the Wenz curves (Wenz, 1962). The Sea State controls noise in the 20kHz regime. Using SS4, we find that N = 43dB. DT is the detection threshold in dB, which varies with performance, e.g. for Gaussian theory with 50% probability of detection and 10e-4% probability of false alarms, DT = 12dB.

SL is the actively emitted source level in dB re 1□Pa, 1m. With the above numbers inserted into the active sonar equation, the required source level for detection is SL = 203dB re 1□Pa, 1m. Notice that in this process there is actually very little leeway for a designer. Once the range of the sonar is specified, this determines the operating frequency and the rest of the design, including source level, follows from it. The various terms of the active sonar equation provide insight into the limitations of the sonar to detect marine mammals. Simple expressions that are generally valid were assumed for the initial design. However, when these terms deviate from their accepted values for whatever reason, the sonar performance can be degraded or completely ruined. The following sections discuss limitations imposed by each of the terms.

LOW TARGET STRENGTH OF MARINE MAMMALS The target strength (TS) of marine mammals is fairly low, due to the fact that, to an impinging sound wave, the density and elasticity of their bodies are not much different than those of the water that they inhabit. Thus more sound tends to pass through them rather than reflect. Beam aspect TS of a large whale is expected to be 0dB (Love, 1973). During Sirena '00, striped dolphins were measured in situ at an average level of TS = –20dB. Compare this to a ship or submarine, the traditional sonar target, which has TS on the order of +25dB. This difference translates directly into more SL needed to illuminate this poor target. Another problem is the aspect dependence of marine mammal TS. Au (Au, 1994) found that the head and tail aspect of dolphin measured 20dB lower than its beam aspect. Thus, it may be possible only to detect "crossing" targets, those presenting broadside aspect to the forward-looking sonar. This may be acceptable performance, since these are the most likely candidates for ship collision.

OCEANOGRAPHY DEPENDANT TRANSMISSION LOSS The model of transmission loss used in the design above is a simplification that is valid when the water is isovelocity, i.e. of uniform sound speed, over all space. This is not true in the open ocean since sound velocity is a function of water pressure, temperature and salinity, which vary with depth. Fig. 4 shows a winter sound velocity profile (SVP) which is close to the ideal isovelocity situation. The TL plot, which was generated by a model (Weinberg, 1996) using this SVP, shows approximately a $20\log_{10}R$ range dependence, roughly independent of depth.

As the sun heats the water surface in summer, a thermal gradient is formed and likewise a sound velocity gradient as shown in Fig. 5. This is known as a downward refracting profile. Sound at the surface travels faster than sound at depth, causing the wavefronts to travel downwards. The TL plot of Fig. 5 shows that after about 0.5km, all of the sound has dived down. This leaves the collision sonar blind to anything at the surface, rendering it essentially useless after 0.5km. This is the basic physics of sound propagation in the ocean. There are no parameters of the design that the sonar designer can modify to overcome this problem. Conversely, even if the ferry is making noise, under these propagation conditions, a whale will not be able to hear the ship approaching until it is within 0.5km. This fact may explain why many ship strikes occur in summer. The existence of poor sound propagation conditions, which could be identified from CTD measurements, should be compared with the times of ship strike incidents to see if a correlation exists.

NON-AMBIENT SOURCES OF NOISE In the active sonar equation, it was assumed that the noise competing against the sonar return was simple ambient noise. In the frequency regime of 20 kHz, this is ocean wave noise and is Sea State dependent. Unfortunately, this is often an over-simplification.

There are several other sources of noise which fall into two categories: active reverberation and nearby acoustic sources.

Active reverberation is made up of true sonar returns from uninteresting targets, namely patches of the sea surface and sea floor. The effect of surface reverberation is familiar to ship operators looking at their ship's radar on a stormy day. In close to the ship, reflections from sea surface waves create a dense clutter field. This is the same for the sonar, the operating range is on the order of R > 300m for SS4. Bottom reverberation is a problem when the depth is sufficiently shallow that returns from the bottom, see Fig. 3, move into the detection range.
For our 30 degree design and a range of R = 2500, the bottom can be no shallower than 2500 tan(30) = 1450m before bottom reverberation causes false alarms. Thus, the sonar can only be used in deep water to get the full range, operationally this is probably acceptable. Since the reverberation is from the sonar signal itself, increasing signal power only worsens the problem. Designing a transducer with a narrower beamwidth in elevation would reduce the bottom reverberation problem.

There are a number of non-ambient noises, which have nothing to do with the sonar reverberation. These are passive acoustic transients and continuous signals from other nearby noise sources. Other sources of noise could be nearby ships. Their spectra are generally random and do not leak badly through the match filter, though very loud, close noise sources could essentially blank the sonar. The most serious source of noise however, is the ship carrying the sonar itself. Self/own ship noise has always been a problem for hull mounted sonar systems. Navy propeller-driven destroyers at 25kts have as much as an additional 30dB of noise above ambient (Urick, 1983). No one has ever measured the noise on the hull of a modern water-jet propelled fast ferry traveling at 40kts. It is imperative that this study be done before meaningful design can be approached. Increased source level (SL) is the only way to overcome this noise.

SOURCE LEVEL AND ANIMAL SAFETY A simple solution to low Target Strength and high nearby noise sources is to raise the source level (SL) to compensate. This raises the issue of animal safety, since loud sonar-type sound has been implicated in several marine mammal mass strandings (Frantzis, 1998). What is a safe SL to use is debatable. It is clear that other factors, like frequency, length of pulses and the directionality of the transducer, must also be considered, not simply SL. The animals themselves make noise of up to 180dB (Richardson, 1995). However, there are high-frequency Fishfinders and Bottom Profilers used routinely by ships that transmit in the 200-230dB regime without apparent incident. These generally use very narrow beams that point at the bottom and sub-second pulses. The military and research sonars that have been suspected of causing problems work in the 1kHz, 220+ dB regime, have multi-second pulses and point outward in wide beams, often with omni-directional coverage or scanning. The collision sonar at 20kHz, 203dB with sub-second pulses, being projected in a 30deg restricted beam is certainly much safer than one of these military sonars in all design aspects.

As always, when considering animal safety, one must be careful to make the distinction between SL, which is the level 1m from the source and the received level at the animal which is RL = SL – TL. At 20 kHz with an SL = 203dB, our collision sonar would have the following received levels: R=1m: RL=203dB, R=10m: RL=183dB, R=100m: RL=163dB, R=1000m: RL=139dB. Note that at a range of 10m, the received level is down to the levels that the animals make themselves, so is probably not physically harmful, though it may be psychologically or behaviorally significant (Richardson, 1995). At a range of 10-100m within 30degrees of the bow of a fast ferry, an animal has a much greater potential for harm from collision than from the sonar. Fig. 6 shows the ferry routes in the Ligurian Sea in summer. Consider collision avoidance sonars mounted to each of these vessels. It must be decided among ship operators, regulators and environmental interest groups whether the number of collisions avoided over time justifies the introduction of many additional acoustic signals into the marine environment.

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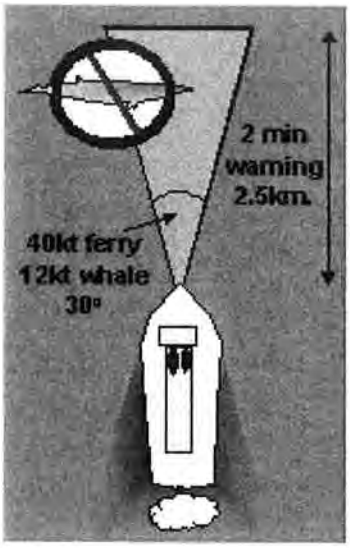

Fig. 1 - Drawing of a fast ferry.

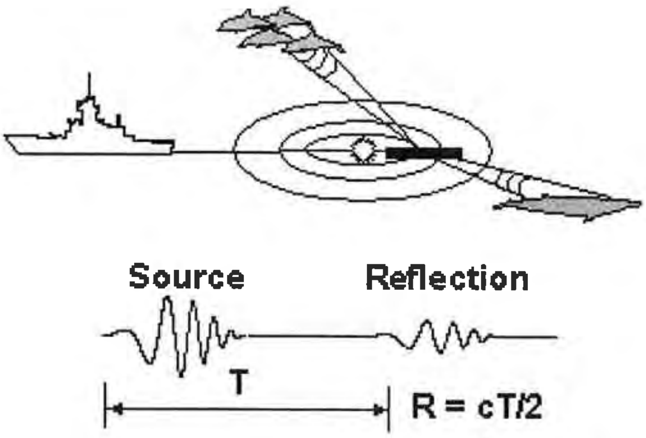

Fig. 2 - How the sonar works.

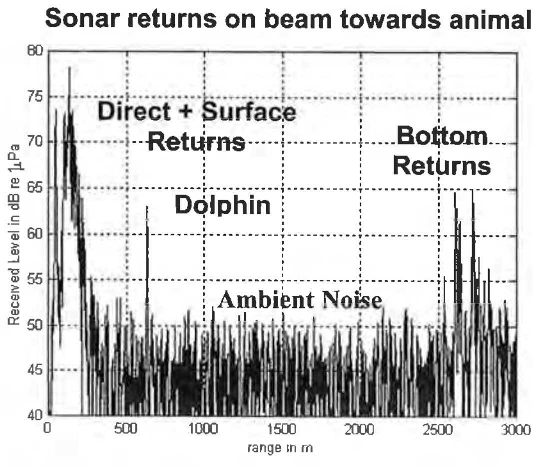

Fig. 3 - Example of sonar data.

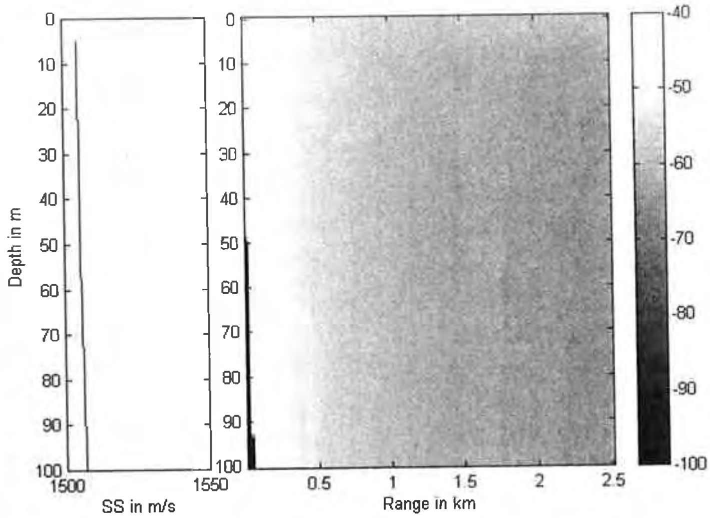

Fig. 4 - Winter sound velocity profile (SVP).

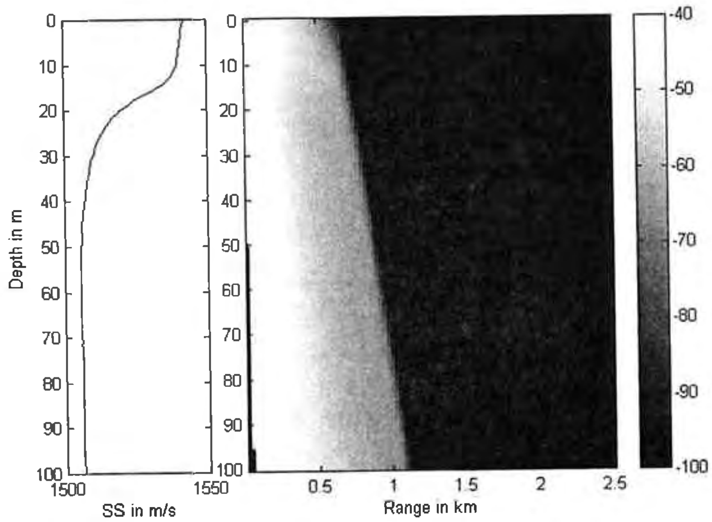

Fig. 5 - Summer sound velocity profile (SVP).

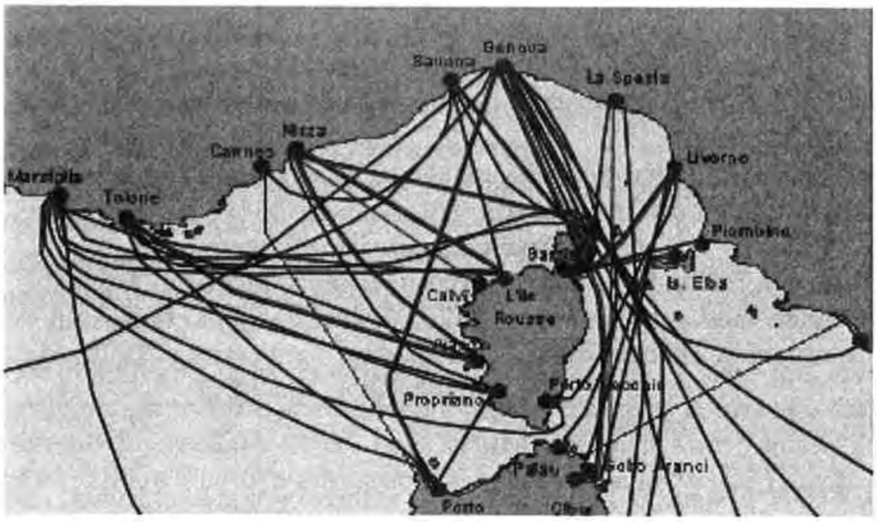

Fig. 6 - Ferry routes in the Ligurian Sea in summer.

A PASSIVE SONAR SYSTEM TO PREVENT SHIP COLLISIONS WITH CETACEANS

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INTRODUCTION Noise and other natural or anthropogenic loud sounds can have a detrimental effect on cetaceans, as well as on other animal species. They can cause stress and increase risk of mortality by interfering with their use of sounds in communication (social behaviour and reproduction) and in navigation (echolocation or bio-sonar to orientate, look for food and avoid ship collision). Acoustic overexposure, for example in an area of heavy shipping, can lead to hearing loss (Richardson *et al.*, 1995). Although the impact of low frequency acoustic pollution from shipping with regard to cetacean disorientation and death remains poorly understood, available evidence is strongly suggestive of some negative effects (André *et al.*, 1997a; Gisiner, 1998). There is an increasing mortality rate from shipping collisions that is also often implicated in strandings of dolphins and whales, indicating that cetaceans may suffer from irreversible hearing loss.

The Canary Islands are continuously exposed to heavy maritime traffic, with a daily average of over 120 ships entering and leaving the two main ports of the Archipelago, Santa Cruz de Tenerife and Las Palmas de Gran Canaria. Cetaceans, and specially sperm whales (*Physeter macrocephalus*), are present throughout the year in these waters. Collisions with whales and small cetaceans in this area have frequently been reported including some well documented accidents, specially after the recent creation of additional fast ferry services (André, 1997).

Preliminary results (lack of reaction in a middle term before playback experiments, André *et al.*, 1997b and possible hearing loss of the over-exposed cetacean populations, André *et al.*, 2001) showed that acoustic deterrents or alarm devices aboard fast-ferries should not be considered as potentially efficient nor suitable to solve the problem of unfortunate encounters with whales.

There is a strong and urgent need to find a solution to stop or dramatically reduce the collision rates in specific areas before the conservation of some cetacean populations is threatened beyond recall. This paper discusses the planned development of a passive system which would combine the necessary implementation of modern shipping with the reduction of violent interactions with cetaceans.

PRINCIPLE OF OPERATION The proposed system is termed the Whale Anti-Collision System (WACS). The specific situation of the sperm whale in the Canary Islands will be used as an example to illustrate the proposed solution, bearing in mind that WACS would be adaptable to any vocalising cetacean species endangered in an area of concentrated shipping by adapting the reception/transmission parameters.

The WACS concept is to instrument a corridor of safety for marine mammals, within which cetaceans can be detected, classified, localised and their positions notified to vessels using the corridor to permit timely course alterations. WACS consists of the following elements (Fig.1):

- A set of fixed, passive acoustic buoys forming a two-dimensional spatial aperture.
- Buoy-to-buoy and buoy-to-shore communication system.
- Automated acoustic detection, classification and localisation software.
- A 3D geographic location software.
- Land station-ship communication system.
- A ship individual geographic data reception system.

Each buoy would be bottom-anchored, mooring a vertical array of at least four hydrophones which would span an appreciable part of the water column while remaining below any surface vessel draft. Such vertical arrays can be used to detect and localise cetacean vocalisations by matched field inversion (Thode *et al.*, 2000). The two-dimensional spatial coverage would permit such localisations to be carried out over a "security corridor" and over a larger area than a single array could monitor and would additionally provide redundant estimates to improve reliability and reduce false alarm rates. Buoys could be equipped with surface flotation, which would permit solar powering, GPS and acoustic data transmissions by VHF and ease of maintenance. The disadvantage is that of interference and wear-and-tear by surface wave action. Alternatively, the buoys could be entirely sub-surface, powered and communicated with by seabed cable. The data from all buoy systems would be collected and processed at a central shore station. Automated detection algorithms, based on cross-correlation techniques developed on small odontocete species and adapted to sperm whale acoustic signals (Kamminga *et al.*, 1993; André & Kamminga, 2000), as well as on wavelet decomposition and neural network identification routines developed and successfully tested on humpback (*Megaptera novaeangliae*) and blue whale (*Balaenoptera musculus*) vocalisations (Delory & Potter, 1999; Delory *et al.* 1999), would be applied to generate a 3-D estimate of cetacean presence in or near the corridor. The result of this analysis would be visualised and transmitted to vessels equipped with WACS receivers. Ideally, this information would be integrated with current radar and collision avoidance equipment on board.

The original concept of this system is based on the possibility to have access, 24 hours a day and in real time, to accurate visual information on the presence and movements of cetaceans in shipping routes. A change of heading of a fast ship cannot be improvised nor can a ship be expected to change its course drastically over several kilometres to avoid a diffuse group of cetaceans. The system would be required to discriminate individual cetaceans by means of their acoustic vocalisations and to follow the movements of each individual separately rather than the collective movement of a whole group. WACS would provide an acoustic highway of security where ships are constantly aware of the presence, location, heading and speed of cetaceans as long as the ship remains in the acoustic range of the buoys.

NUMERICAL FEASIBILITY TESTING As a starting point to investigate the feasibility of a WACS in terms of oceanographic propagation, the source level of a sperm whale click was considered to be 130 dB ref 1μPa/1m. This value is probably well below the actual sperm whale click source level, and there is evidence that acoustic levels in the main transmit beam may be some 60 dB higher, but this lower limit was chosen on purpose to model the minimum requirements of the system (Mohl *et al.*, 2000). To avoid controversy, the directivity of the source was considered to be omni-directional. Should it prove to be the case that sperm whale transmissions are highly directional, as seems likely from the presumed function and morphology, then considerable additional information would be available, indicating the approximate heading of the animal from intensity variations received at different buoy arrays.

Detection Environment, Ray Tracing and Detection Probability

Due to the importance of correctly characterising the propagation environment, numerical experiments were conducted to test the viability of the system (SAES, 1998). A model of the sound velocity profile year round (taking as the sound source a sperm click with a source level of 130 dB ref 1μPa/1m) was constructed by SAES, Sociedad Anónima de Electrónica Submarina, from a world-wide data base including temperature, salinity and sound speed profiles at any month for any geographic location (latitude and longitude). The chosen geographic location corresponded to a point between Gran Canaria and Tenerife (N28°W15°). The sea state was considered to be Beaufort 4 (wind speed: 11-16 knots). Fig. 2 shows the sound velocity profiles measured for February and August, representing the two extreme values encountered during the whole year.

The maximum energy of a sperm whale click is centred around 3kHz, so it was decided to filter the input of the signal and work between 2 and 4 kHz, where there is enough energy not to loose crucial information. The choice of this frequency band allowed virtual elimination of background noise from shipping (<2kHz) and the high frequency components from the ship echo-sounders, etc., situated well above 5kHz.

The Ray Tracing model (Sonar Prediction System, SPPS, developed by SAES) placed a 'virtual sperm whale' at 50m depth, in an intermediate point between the islands of Tenerife and Gran Canaria, over the 3000m slope. The source produced omnidirectional clicks with a source level of 130 dB re 1μPa/1m. The bottom was considered to be sandy. The rays produced by the sperm whale click were reflected by the bottom and the water surface (Fig.3). The detection mode integrated a spectrogram analysis with a FFT analysis every 25 ms, considering that the background noise level was 55dB ref 1microPa, and reducing the frequency band to 2-4 kHz to get rid of the ship echosounders, etc., since they can be found well over 5 kHz. This would reduce the system sampling frequency and make easier to transmit the communication band to the land station. The probability of detection was measured as a function of the seasonal oceanographic conditions, taking into account the salinity and the water temperature in the region. The sea state was considered to be Beaufort 4 with intense maritime traffic. Finally, the directivity index and the processing gain of the buoy were considered to be respectively 4 and 8 dB.

RESULTS In spring conditions (May), the probability of detection (Pd) is greater than 99% up to 4.5 km and 1000m deep from the buoy. In summer (August), Pd > 99% up to 2.8 km and 1000m deep from the buoy (Fig.4). In fall (November), Pd >99% up to 2.5 km and 1000m deep from the buoy. In winter (February), Pd > 99% up to 6.7 km and 1000m deep from the buoy (Fig.4).

These results indicate that the most unfavourable conditions are to be found in spring and fall, when the maximum distance between any two buoys has to be 5km, and the array can be placed up to 1000m deep. The most favourable situations were found in winter, when the distance between two successive buoys could be 13.5 km.

From these results and to guarantee the year round coverage, the proposed acoustic security highway for ships and cetaceans would be 5km wide and would have a length corresponding to the distance between Tenerife and Gran Canaria, i.e. 65km. In this acoustic highway, the median line would consist of 12 buoys, one every 5km.

DISCUSSION These preliminary investigations indicate that a WACS is viable in terms of biology, computer, physics and electronics requirements. Detection and tracking by passive acoustical methods is a particularly suitable approach given the fact that cetaceans are below the surface much of the time, call often, and can be heard over long distances. In order to demonstrate that this system is efficient in real detection situations at sea, a mobile prototype should be built as an initial step. This prototype would include a single acoustic buoy connected with a cable to a portable computer aboard a research vessel. The experiments with the prototype would allow interested parties from different parts of the world to get a precise picture of the WACS potential and decide whether it might suit their local requirements.

The advantages of the WACS are that, once installed in a specific region, it would operate for all the ships present in the area, with no limit on number, providing an instrumented acoustic corridor for all. It would also be completely non-invasive, acting as a permanent "ear" able to detect and track cetacean movements 24 hours a day. However, even the most vocal cetacean species can be silent at some times, making them impossible to detect by conventional passive systems. To solve this problem, the system could be extended to include ambient noise imaging techniques (Potter & Chitre, 1999). These novel passive techniques use background noise, including cetacean vocalisations and vessel noise, as the illuminating source to obtain acoustic images of the environment. Interpreting the ambient noise scattered by non-vocal cetaceans could give the position of all animals encountered within the range of the sonobuoys, whether actively vocalising or not.

Therefore, the use of passive techniques to avoid collision would definitively constitute a first step towards a sustainable development of modern shipping, dramatically reducing marine mammal mortality without increasing anthropogenic noise in the marine environment. But, a similar effort would have to be put into the assessment of the impact of a long term acoustic pollution on the cetacean capabilities to orientate, look for food and avoid ship collision. This necessary future approach should clarify the problem limits from the cetacean perception of its own environment. Although the proposed system would be a challenging undertaking, no other passive solution has yet been found, and there remains little time to prevaricate.

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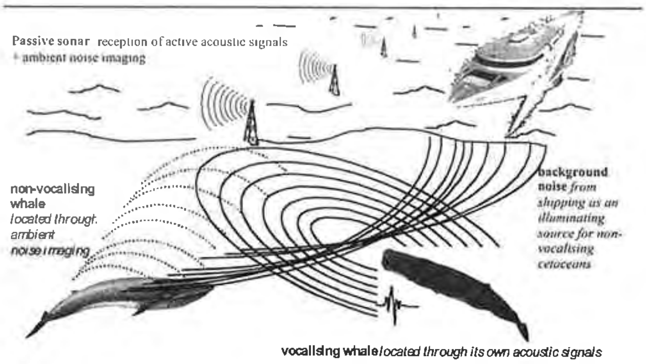

Fig. 1 - The Whale Anti-Collision System.

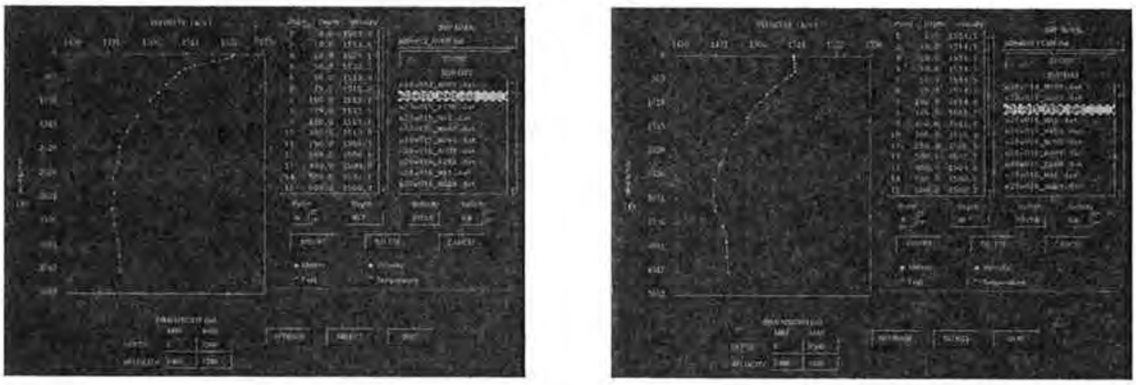

Fig. 2 - Sound velocity profiles for February and August (SAES, Sociedad Anónima de Electrónica Submarina). These profiles were calculated from a world-wide data base including temperature, salinity and sound speed profiles at any month for any geographic location (latitude and longitude), taking as the sound source a sperm click with a source level of 130 dB ref 1μPa/1m.

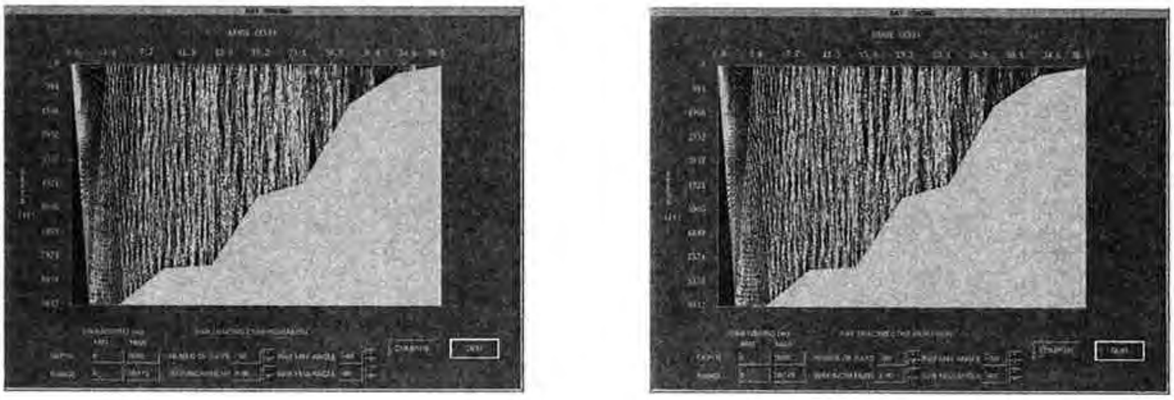

Fig. 3 - Ray Tracing for February and August (SAES, Sociedad Anónima de Electrónica Submarina). A virtual sperm whale was placed at 50m deep, producing a click with a source level of 130 dB ref 1μPa/1m. The rays emitted from the click are reflected on the sandy floor and water surface. The abscises represents the distance from the Tenerife coast, the ordinate shows the depth.

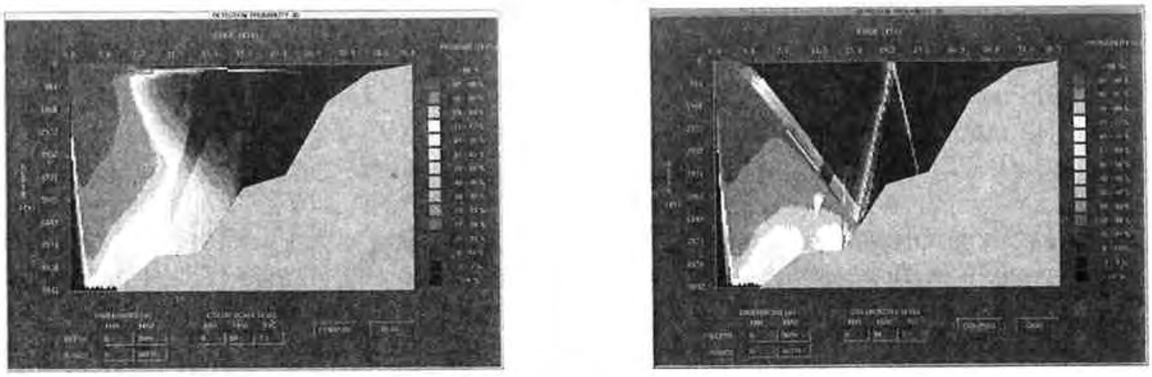

Fig. 4 - Detection Probability for February and August (SAES, Sociedad Anónima de Electrónica Submarina). To calculate the probability, a DIFAR passive sonobuoy was used as a sensor. The bandwidth allowed detection between 2-4 kHz and an incident angle of ± 60°. This buoy divides the detected signal in four hydrophones to achieve maximum energy in 8 sectors (0-45, 45-90, ..., 315-360). The sea state was considered Beaufort 4 with intense shipping. The directivity index and the processing gain of the buoy were considered to be 4 and 8 dB respectively.