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Agenda Item 9.2: **Interactions with shipping**

Peter G. H. Evans, *Shipping as a possible source of disturbance to cetaceans in the ASCOBANS region*

Submitted by: **Secretariat**

ASCOBANS

NOTE:
IN THE INTERESTS OF ECONOMY, DELEGATES ARE KINDLY REMINDED TO BRING THEIR OWN COPIES OF THESE DOCUMENTS TO THE MEETING

Secretariat's Note

The Conservation and Management Plan annexed to the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas stipulates that ASCOBANS work towards "the prevention of other significant disturbance, especially of an acoustic nature". In recent years, there has been increasing evidence that shipping may be a source of disturbance to cetaceans, causing physical damage and possibly behavioural changes due to noise.

Consequently, the 3rd Meeting of the Parties to ASCOBANS, held in Bristol, United Kingdom from 26 - 28 July 2000, invited Parties and Range States to support research into the effects of shipping and particularly high-speed ferries and into possible ways of mitigating any adverse effects (MOP 3 Resolution No. 4). The ASCOBANS Triennial Workplan 2001 - 2003 adopted by MOP 3 calls for the definition of terms of reference for a report on disturbance to cetaceans by shipping by the 9th Meeting of the Advisory Committee (AC 9), and for a report to be commissioned in time for AC 10. A Shipping Working Group convened by AC 9 outlined these terms of reference.

The present report was prepared by Dr. Peter G. H. Evans, of the Department of Zoology, University of Oxford.

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SHIPPING AS A POSSIBLE SOURCE OF DISTURBANCE TO CETACEANS IN THE ASCOBANS REGION

Report to ASCOBANS

Peter GH Evans[1, 2]

[1] Sea Watch Foundation, 11 Jersey Road, Oxford 0X4 4RT, UK
[2] Department of Zoology, University of Oxford, South Parks Road, Oxford 0X1 3PS, UK

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BACKGROUND

The Conservation and Management Plan annexed to the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas stipulates that ASCOBANS work towards “the prevention of other significant disturbance, especially of an acoustic nature“. In recent years, there has been increasing evidence that shipping may be a source of disturbance to cetaceans, causing physical damage and possibly behavioural changes due to noise.

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OBJECTIVES

The aim of this report is to review available evidence for possible effects of shipping upon cetaceans in the ASCOBANS region, either by direct physical damage to the animals or behavioural changes caused by sound disturbance, and to propose possible mitigation measures.

For the purpose of this report, the term “shipping” covers high-speed ferries, other shipping (including military activities), and recreational activities (including jet skis). It does not cover acoustic harassment devices (e.g. seal scarers), stationary platforms (e.g. wind farms, fixed oil rigs), or activities relating specifically to the oil & gas industry (e.g. seismic exploration). The term “ASCOBANS Region” refers to the Agreement Area (North Sea, English Channel and Baltic Sea) plus UK territorial waters (to which, for all practical purposes, the UK government has applied the Agreement).

SHIPPING AND CETACEANS

Nature of the problem The ASCOBANS Region contains some of the busiest waterways in the world. The North Sea receives more than 400,000 ship movements a year, with particularly heavy traffic through the traffic separation scheme in the Strait of Dover where approximately 150 ships per day pass in each direction, in addition to an average 300 ferry crossings daily (North Sea Task Force, 1993). The dredged entrance route to Rotterdam/Europort and its connecting route through the Channel permits navigation of vessels of up to 400,000 tonnes with a maximum depth of 24 m. There is also a heavy flow of shipping from the North Sea to the Baltic via the Kiel Canal, with c. 47,000 vessel movements (as recorded in 1988). Most of the European Community's largest ports are on the North Sea coasts and rivers: Hamburg, Amsterdam, Rotterdam, Antwerp, Le Havre and London. Rotterdam/Europort is by far the largest port, followed by Antwerp, Hamburg, and London. Approximately half the shipping activity in the North Sea consists of ferries and roll-on/roll-off vessels on fixed routes, while, for example, in United Kingdom ports, tanker traffic represents about 10% and chemicals around 4% of ship departures (North Sea Task Force, 1993). These large vessels not only may pose a direct threat of physical damage by collision with cetaceans, they can also significantly raise ambient sound levels by the noise generated from their engines which itself may cause disturbance to cetaceans, and possible habitat displacement (Evans, 2002).

In the last 30 years, recreational activity has increased markedly in coastal areas of Northern Europe, as people turn to waterborne sports involving canoes and sailboats, jet skis, rigid inflatables and hard hulled speed boats. Another burgeoning marine activity is that of whale and dolphin watching with centres developing at Andenes in Norway, Cromarty, Inverness and Cullen/Spey Bay in East Scotland, Gairloch, Mallaig, Arisaig, Oban, and the islands of Mull, Skye and Lewis in West Scotland, and New Quay in West Wales. Although these tend to involve persons already with an interest in cetaceans, they can nevertheless pose a hazard both by physical damage from the propeller, and by stress and disturbance of daily activities.

Finally, it has only recently become clear that the use of "low" or "mid" frequency active sonar as used for oceanographic surveys and military exercises may also present a threat to particular cetacean species. In the ASCOBANS Region, naval and other military activities tend to be concentrated around northern areas such as West Scotland (from the Mull of Kintyre westward and northward to Rockall and the Wyville-Thomson Ridge) and southern Scandinavia, although the testing of particular sonars has also taken place in the South-west Approaches to the English Channel and the Bay of Biscay. Otherwise, most peacetime military activities involve routine fishery protection patrols or weapon testing in restricted areas.

BIOLOGICAL FEATURES OF CETACEANS IN THE ASCOBANS REGION

Twenty-nine species of cetaceans have been recorded in the ASCOBANS Region (see Table 1 in Appendix 1). Sixteen of those species occur regularly, and their status, distribution, and seasonal occurrence are summarised in Appendix 1.

Of the regular species, four are baleen whales (Mysticeti) and the remaining twelve are toothed whales, dolphins, or porpoises (Odontoceti). The majority of species live mainly in deep waters beyond the European continental shelf. These include: sei whale, fin whale, Sowerby's beaked whale, northern bottlenose whale, sperm whale, striped dolphin, killer whale and long-finned pilot whale. The humpback whale also lives mainly in deep waters but also frequently occurs close to the coast. Species favouring the continental slope include: Atlantic white-sided dolphin and short-beaked common dolphin. Those living primarily on the continental shelf include: minke whale, harbour porpoise, white-beaked dolphin, Risso's dolphin, and bottlenose dolphin. These designations are only to be taken as generalisations. A number of species living primarily in deep waters may come onto the continental shelf at certain times of the year (usually April – September), often in relation to feeding opportunities.

All baleen whale species and the larger toothed whales and dolphins (sperm whale, beaked whales, killer whale, and long-finned pilot whale) tend to give birth between October and March whereas the smaller dolphins and the harbour porpoise give birth between April and September.

COLLISIONS WITH CETACEANS

There have been records of vessels colliding with cetaceans dating back at least to the middle of the last century. However, it is only in the last decade that it has been recognised as a potential conservation issue. With the ever greater speeds exhibited by shipping – tankers, ferries, yachts, and a wide variety of small craft, it is a problem likely to increase. In a wide-ranging review of the topic, Laist *et al*. (2001) noted that although all types and sizes of vessels can be involved, most lethal or severe injuries are usually caused by ships travelling 14 knots (26 km/h) or faster and of 80 metres length or more. Damage in the form of cuts to the dorsal fin and back tend to be the result of strikes from small craft, although larger vessels can also cause similar damage.

Species known to be affected Evidence of vessel collisions has been reported for at least 21 cetacean species. Reviewing causes of mortality in 98 cases reported from the strandings schemes of the US Atlantic coast (1975-96), France (1972-98), Italy (1986-97), and South Africa (1963-98, southern right whales only), and 74 other reports of collisions, Laist *et al*. (2001) found that fin whales were struck most frequently (30%), followed by southern right whales (13%), northern right whales (12%), humpback whales (12%), minke whales (6%), sperm whales (3%), and sei whales (2%). Other species recorded by them included gray whale, blue whale, Bryde's whale, and bowhead whale, whilst, from French and Italian strandings data, Pesante *et al*. (2002b) added long-finned pilot whales, bottlenose dolphins, and striped dolphins to the list of affected species, although in low numbers compared with their likely population sizes. In an investigation of the impact of high-speed ferries in the Canary Islands, Aguilar *et al*. (2000) attributed collision with vessels as the cause of death for seven animals including a probable Bryde's whale, sperm whales, Cuvier's beaked whale, and a probable short-finned pilot whale. Honma *et al*. (1999) investigated the death of a Stejneger's beaked whale after a collision with a high-speed ferry in the Sea of Japan. Kiszka and Jauniaux (2002) necropsied a Sowerby's beaked whale found in France and considered a ship strike the cause of death. From the UK, reports have been received of direct observation of collisions with minke whale, sperm whale and long-finned pilot whale, and evidence of non-fatal propeller cuts observed in killer whale, bottlenose dolphin, short-beaked common dolphin, white-beaked dolphin, and harbour porpoise (Evans, unpubl. data).

The relative frequency of records of collisions for different cetacean species is probably strongly biased, reflecting the abundance and distribution of that species: coastal species and animals from large populations are more likely to be both struck and observed. The occurrence of strikes may be under-estimated if animals experience internal injuries that may be overlooked in stranded carcasses, or if they die at sea and sink to the bottom (Kraus, 1990). However, injuries may also be wrongly attributed to ship strikes if whales floating on the surface are hit after death, and internal examination has not taken place that enables haemorrhaging to be detected (Laist *et al*., 2001; Pesante *et al*., 2002a).

Although vessel collisions may not be significantly affecting population growth in most cetacean species, there is good evidence that in eastern North America, 35% (at least 17 out of 49 reported deaths between 1970-2001) of mortality in the endangered northern right whale population (estimated at c. 325 individuals) is caused by vessel strikes (Clapham, 2002). This represents by far the largest cause of non-natural deaths, and is attributed to the location of right whale habitats near or in shipping lanes, their slow swimming speed, and a high proportion of time spent at the surface. Although the fin whale population occupying the Ligurian Sea in the Mediterranean is much larger (estimated at c. 3,500 individuals), 17.4% (36 out of 207) of the strandings records from the Mediterranean (1897-2000) could be attributed to ship collisions, thus indicating a potentially serious problem for the conservation status of this species (Pesante *et al*., 2000b). Other cetaceans that appear to be more vulnerable include minke whale, sperm whale, long-finned and short-finned pilot whales. The sperm whale typically may spend periods of time asleep at the surface (termed “logging”) and is a comparatively slow swimmer, whilst the other species are known to associate with vessels.

Types of Injuries Injuries that lead to death mainly involve major physical damage to the animal – fractured skulls, jaws or vertebrae along with extensive haemorrhaging (Laist *et al*., 2001). In extreme cases, the entire body may be split in two. Less severe injuries tend to be wounds caused by propeller damage. These take the form of long parallel deep cuts into the back of the animal, or cuts to the dorsal fin or tail. In severe cases, the dorsal fin or tail may be severed completely.

Photo-identification studies reveal that many more cetaceans may experience a vessel strike than actually die. Twenty-four out of 379 (6.4%) identified fin whales in the Ligurian Sea had injuries or scars believed to be caused by a vessel strike. Of these, ten (2.7%) were animals that had definitely had an accident - seven showed a well healed lesions, two had propeller scars (clearly recognisable from multiple, parallel and evenly spaced cuts), and one had a big unhealed wound (Pesante *et al*., 2002b). The remaining fourteen animals (3.7%) presented signs of possible collision, although causes of scars or injuries remained uncertain. Four of these had a cut dorsal fin, three had a cut tail fluke, and seven had white spots, mainly on the back close to the dorsal fin, which were believed to be old scars, although it could not be ruled out that these were natural markings (Pesante *et al*., 2002b). Similarly, four out of 61 sperm whales (6.6%) showed injuries of a similar nature – one animal had a clear wound at the end of the dorsal surface of the tail stock, another had two clear parallel slashes behind the dorsal fin, and the other two had more severe damage to the back (Pesante *et al*., 2002b). Over 7% (12 out of 168) individually recognisable northern right whales showed major wounds on the back, caused by the propellers of large ships (Kraus, 1990).

Vessel types involved & Areas most at risk Almost every type of vessel has been reported as being involved in collisions with cetaceans. These include small and large vessels with inboard or outboard engines, and engaged in a wide variety of activities – tankers, ferries (including high speed ferries such as hydrofoils), yachts, cruise ships, Naval ships, research vessels, fisheries and environmental protection vessels, whale-watching vessels and a variety of other recreational craft. High-speed vessels were involved in six (15%) out of 40 accounts reported since 1975 by Laist *et al*. (2001), and those authors concluded that most serious or lethal injuries were caused by vessels travelling at speeds of 14 knots or more. In this context, the proliferation of high-speed ferries which typically travel at 35-45 knots (see Appendix 4), gives cause for concern.

Some localities already have experienced repeated collisions. The French ferry line SNCM, for example, operating three high-speed car ferries between mainland France and Corsica at a cruising speed of 35 knots, reported three collisions with whales in as many years (1998-2000) (Capoulade, 2002). High-speed ferries operating in the Canary Islands since April 1999 are believed responsible for the deaths of at least seven whales (Aguilar *et al*., 2000). Two different types of ferry operate in this region: a catamaran-type travelling at a cruising speed of 40 knots in the channel between Tenerife and Gran Canaria; and a monohull-type with a cruising speed of 30 knots, operating in the channel between La Gomera and Tenerife. Both high-speed and other ferries operate regularly across the Strait of Gibraltar, and in September 2002, a sperm whale was struck and killed by a 95 m long ferry (De Stephanis *et al*., 2003). In all these cases, the ferry routes inevitably cross at right angles to the normal movement paths of cetaceans travelling up and down the channels.

In the ASCOBANS region, high-speed ferries (defined as those ferries travelling at speeds of 30 knots or more) have started operating in the Baltic, North Sea, English Channel and Irish Sea (see Appendix 4 for details of ferries and maps of ferry routes). Due to the low densities and diversity of cetacean species (see Appendix 1), the risk of collisions in the Baltic, southernmost North Sea and eastern sector of the English Channel is low. However, in the northern part of the North Sea, in the Irish Sea and western English Channel, a number of species are potentially at risk – notably minke whale, killer whale, bottlenose dolphin, white-beaked dolphin, short-beaked common dolphin, and harbour porpoise. In Swedish and Danish waters, the harbour porpoise is the principal species at risk. Although high-speed ferries have not yet started in the Northern Isles of Scotland, West Scotland and the Hebrides or in the Bay of Biscay, should they do so then additional species at risk would include fin whale, sperm whale, beaked whales, long-finned pilot whale, Risso's dolphin, and striped dolphin. The most important areas for cetaceans in the ASCOBANS region lie close to the European continental shelf, to the north, west and south of the British Isles. If one assumes that the larger slower-moving whales like fin and minke whale, humpback, sperm whale and long-finned pilot whale are the species most vulnerable to mortality from ship strikes, then the most sensitive areas will be localities adjacent to the Agreement area like the Faroe-Shetland Channel, the Northern and Western Isles of Scotland, and the Bay of Biscay.

Another potentially important threat to cetaceans comes from sailing craft. Racing yachts in particular may now attain speeds of 30 knots, and when under sail, present an obvious danger by nature of their silent progress through the waves. There have been several anecdotal reports of yachts striking cetaceans, including sperm whales and pilot whales (Evans, unpubl. data; Koschinski, 2003). Some of these have resulted in serious injury to the whale, and in others, serious injury to the vessel. In six out of nine yachts participating in the *Whitbread Round the World Race* in 1997/98, collisions or dangerous interactions were reported (T. Kroger, *pers. comm.* in Koschinski, 2003).

VESSEL UNDERWATER SOUND

Since the industrial era, humans have developed a number of highly intense sources of sound (Wenz, 1962; Ross, 1976; Urick, 1982, 1983, 1986). Indeed, Ross (1976) estimated that between 1950 and 1975, ambient noise had risen by 10 dB in areas where shipping noise dominates, and he predicted it would rise a further 5 dB by the end of the 20th century as shipping traffic increased further. Sound levels generally increase with ship size and speed. The more powerful the engine that a vessel possesses, the greater the amount of sound (at least at low frequencies) it will produce. Supertankers (c. 340 m length), in particular, produce sound intensities of between 187 dB (at 50 Hz) and 232 dB (at 2 Hz) re 1 µPa, at very low (particularly <10 Hz) frequencies, resulting in them being audible to cetaceans some 80 km away, whilst infrasound components of propeller noise of a supertanker could be measured at a distance of some 463 m (Cybulski, 1977; Leggat *et al.*, 1981; Richardson *et al.*, 1995; Arveson and Vendittis, 2000; Erbe and Farmer, 2000). Likewise, large (274 m) container ships produce sounds of 181 dB (at 7.7 Hz) to 198 dB (at 23 Hz); smaller tankers or freighters (c. 135 m length) produce sounds around 170 dB at frequencies ranging from 40-400 Hz, whilst fishing trawlers (c. 30 m length) have sound source levels of 158 dB at frequencies of 100-250 Hz (Richardson *et al.*, 1995). A summary of the sounds produced by maritime activities is given in Appendix 2.

The noise of a large ocean-going vessel is a combination of narrowband sounds at specific frequencies and broadband sounds with energy spread over a range of frequencies. Narrowband sounds include tonal components from propeller blade rate (up to 100 Hz) or resonant characteristics such as 'propeller singing' (between 100 Hz and 1 kHz). Broadband sounds are caused by propeller cavitation and water flow along the hull and may extend to 100 kHz, peaking at 50 to 150 Hz (Richardson *et al*. 1995). Very little information exists on sound generated by sailing ships. It is assumed that their sound is relatively faint and may mainly contain frequency components of up to several kHz from water flow along the hull (Koschinski, 2003).

Acoustic oceanographers also use intense sounds mainly in the low-frequency range (<1 kHz) both to study the physical properties of the ocean (Spindel and Worcester, 1990; Worcester *et al.*, 1993) and marine organisms such as zooplankton in the deep scattering layers (Mauchline, 1980). Recently, there has been much debate over the potential impact upon cetaceans and other marine life that could arise from a project referred to as the Acoustic Thermometry of Ocean Climate (ATOC) project which proposed to repeatedly measure the speed of sound in the ocean over time in order to determine whether the oceans, which are the main heat sink, were warming (Mulroy, 1991; National Research Council, 1994). For that project, high intensity (c. 190 dB re 1µPa) low-frequency sound (mainly 60-90 Hz) is generated at depths of around 900 m over long-distance undersea paths such as the SOFAR channel.

Besides propeller and engine sound generated by vessels during commercial, military and recreational activities, surface vessels and submarines employ active sonar which uses sonic or ultrasonic waves to locate submerged objects, at the same time introducing brief, high-intensity pulses into the marine environment that sometimes may be transmitted over great distances. Source levels of sound are c. 200-250 dB re 1 µPa at frequencies up to 200 kHz. High resolution side-scan sonar (generally below 14 kHz) is also used in geophysical seismic surveys particularly during oil and gas exploration, along with lower resolution explosive techniques (airguns, sleeve exploders, etc.) mainly at frequencies below 500 Hz (Richardson *et al.*, 1991).

Most of the sounds generated from maritime activities referred to above (with the exception of sonar) are at frequencies lower than 1 kHz. However, when a surface vessel travels at high speed, the propeller may cavitate and produce much higher frequency sound (between 2 and 20 kHz) (Evans *et al.*, 1992). Measurements of various small craft (up to 15 m length, 240 hp engine) indicated source levels ranging from 100-125 dB re µPa at 2 kHz and 60-105 dB re µPa at 20 kHz. Cavitation is also more likely to occur when the propeller is damaged.

CETACEANS AND SOUND

Our knowledge of the hearing capabilities of cetaceans and the mechanisms they use for receiving and interpreting sounds remains very limited. Underwater hearing abilities have been studied experimentally in only a few odontocete species and in no mysticetes (Nachtigall *et al.*, 2000; Au *et al*., 2000). Subjects have been studied in controlled conditions and this imposes constraints upon the species and size of cetacean involved. Where experimental data do not exist, some inference of the sound frequencies which are important to cetaceans can be made from the characteristics of the sounds they produce (see Richardson *et al.*, 1995), and from the structure of their hearing organs. (Ketten, 1994, 1997).

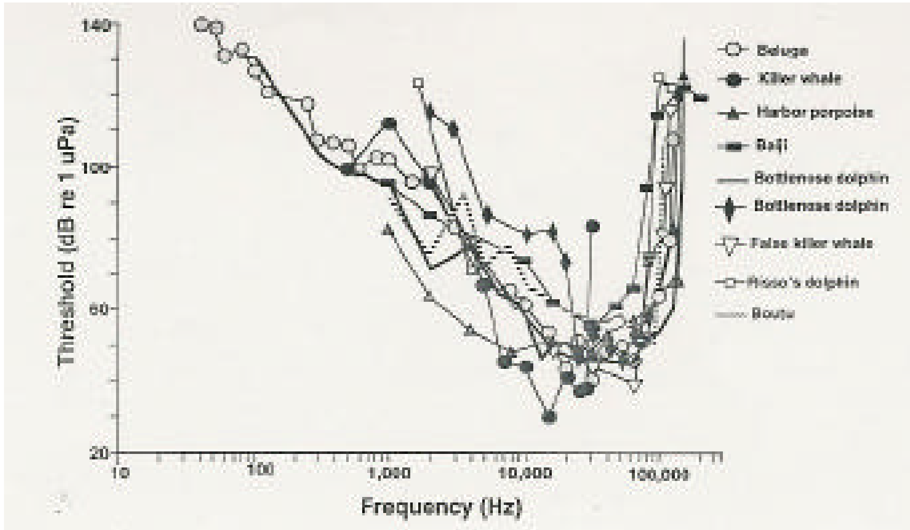

Figure 1. Audiogram for selected odontocetes (from Wartzok and Ketten, 1999)

Odontocete Hearing The audiograms of those porpoises, dolphins and smaller toothed whales that have been examined reveal typical mammalian, U-shaped, broadband curves that are, by comparison to humans and other terrestrial mammals, shifted to higher frequencies with greater sensitivity. Their auditory sensitivities are greatest at very high frequencies - between 10 and 150 kHz, with a hearing threshold of about 40 dB at those frequencies, increasing to around 100 dB at 1 kHz and 120 dB at 100 Hz, at least for those species for which data are available (Richardson *et al.*, 1991; Figure 1 - note that sound frequencies associated with the lowest threshold levels, i.e. at the bottom of each curve, are those for which the hearing of that species will be most sensitive: in this instance, all eight species can hear sounds as low as 40-50 dB at frequencies between 10^4 and 10^5 Hz but, at a frequency of 10^2 Hz, the sound must be at least 120 dB to be heard).

It is thought, however, that small cetaceans do have the ability to detect low frequency sounds (50–150 Hz) as demonstrated through playback experiments to captive bottlenose dolphins who instead appeared to respond to the movement of water particles over their sensitive skins (Turl, 1993; see also Nachtigall *et al*., 1996). Killer whales have recently been shown to have a hearing range from 100 kHz down to 100 Hz (Szymanski *et al*., 1998).

Mysticete Hearing Although there is no quantitative information on the auditory sensitivities of mysticetes, tentative audiograms for the gray whale and bowhead whale are presented by Moore *et al.* (1984) and Dahlheim and Ljungblad (1990). They suggest that greatest hearing sensitivities occur between 100 Hz and 5 kHz, on the assumption that whales will hear approximately over the same frequency range as the sounds they produce. Using this argument, we would expect fin whales to be most sensitive to frequencies around 20 Hz and blue whales to 10-20 Hz. Until actual electrophysiological measurements are made, however, these should be viewed as hypothetical.

Baleen whales may also hear sounds in the ultrasonic range. High-frequency clicks have been recorded near blue (21-31 kHz), fin (16-28 kHz), Bryde's (3-30 kHz), and minke whales (5-20 kHz), and lower frequency clicks or pulses have been reported from sei (1.5-3.5 kHz) and humpback whales (2-9 kHz) (see review in Richardson *et al*., 1995, also Appendix 2). The recent unusual live stranding of two minke whales in the Bahamas in March 2000 in the presence of 2.6-8.2 kHz active sonar sounds generated during military exercises (Balcomb and Claridge, 2001; Stewart and Gentry, 2001) suggests that this species likely heard these sounds and responded negatively to them.

Odontocete Sound Production The sounds produced by odontocetes (see Popper, 1980) may conveniently be divided into: (1) pure tone whistles generally in the frequency range 500 Hz to 20 kHz, used mainly for communication; and (2) pulsed sounds or clicks varying from 500 Hz to 150 kHz, used mainly for echolocation (Appendix 3). Source levels for both types of sound are estimated usually to be 150-200 decibels, although pulsed sounds for non-echolocatory purposes may be produced at source levels of 115 dB, mainly in the frequency range below 20 kHz. Most of these measurements were made in captivity and it should be noted that animals can modify their sound production (particularly its intensity) in confined situations, and indeed do so also in open water.

Mysticete Sound Production Mysticetes tend to produce lower frequencies of sound, usually below 1 kHz and reaching down into the infrasonic range (<20Hz) in fin and blue whales (Thompson *et al.*, 1979; Clark, 1990; Ketten, 1992; Appendix 3). They may be classified into four types (see Thompson *et al*., 1979): (1) low-frequency moans, typically with frequencies of 12-500 Hz and of 0.4 to 36 seconds duration; (2) gruntlike thumps and knocks with most sound energy concentrated between 40 and 200 Hz; (3) chirps, cries and whistles at frequencies between 1 and 10 kHz; and (4) clicks or pulses at frequencies up to 20-30 kHz and lasting from 0.5 to 5 msec. Sound source levels range between 150 and 200 decibels, at frequencies of 500 Hz or less.

Summary Most odontocetes can hear sounds over a wide range of frequencies from 75 Hz to 150 kHz, with greatest sensitivity around 20 kHz (although low frequency hearing of odontocetes has not been fully investigated), whereas the hearing of mysticetes probably ranges from frequencies of 10 Hz to 10 kHz, with greatest sensitivity usually below 1 kHz (this is based on sound production levels since no audiograms exist). Major differences in hearing between baleen and toothed whales are further supported by anatomical differences between the hearing organs of these two groups (Ketten, 1992, 1997).

One might question whether the level of sounds that these animals can produce is indicative of the levels that they would be able to tolerate. Communication sounds of many odontocetes and mysticetes have source levels of 160 to 180 dB re 1 µPa @ 1m distance (Würsig and Richardson 2002). The clicks of bottlenose dolphins and sperm whales can be much more intense, >220dB in the same units (Au *et al.*, 2000; Møhl *et al.*, 2000). Gisiner (1998) points out, however, that recorded intensity of sounds produced by these animals may have little to do with sensitivity.

Most of the man-made sounds in the sea are between the frequencies of 10 and 500 Hz. However, multibeam, parametric, side-scan and other scientific sonars as well as military sonar generate sounds between 1 and 500 kHz (see section on Active Sonar). Baleen whales are thought to be more sensitive to frequencies below 5 kHz and are therefore more likely to be affected by large vessels, geological and geophysical activities including e.g. seismic surveys, and drilling, marine dredging, and construction (e.g. pile driving and decommissioning). Toothed whales and dolphins are likely to be mainly susceptible to noises above 1 kHz and so will be affected particularly by speedboats and most forms of active sonar. However, the sensitivity of the odontocete ear to intense low-frequency sounds has not been investigated (Gisiner, 1998).

IMPACTS

This section reviews the variety of impacts that underwater sound may have upon cetaceans, and is drawn largely from a review of the topic by Gill and Evans (2002).

Zones of Influence In assessing the levels to which an animal can be harmed, it is important to set some criteria and this can be done by estimating zones of influence such as the "field of awareness", "field of modified behaviour, "field of potential impact", and "field of probable/certain impact" related to hydro-acoustical variables/criteria. Figure 2 (Richardson *et al.,* 1995) shows the zones of influence around a sound source.

In the ocean, the maximum detection distance is the distance at which a sound is audible above the ambient noise in the area. The maximum reaction distance is the distance at which animals exhibit overt behavioural changes. The measure of zones of influence varies depending on the level of ambient noise, the animal’s hearing and behaviour, the source level of the equipment, and the decay of the signal intensity with distance, which will be affected by the characteristics of the medium. At distances closer than the maximum reaction distance, injury to body tissues and hearing becomes more likely with decreasing distance to the sound source. In many cases the distance of an animal to the source sound which may cause bodily and auditory harm is impossible to measure and we can only learn from previous incidences reported unless controlled experiments are conducted, the ethics of which is much debated (Gordon *et al*., 2003).

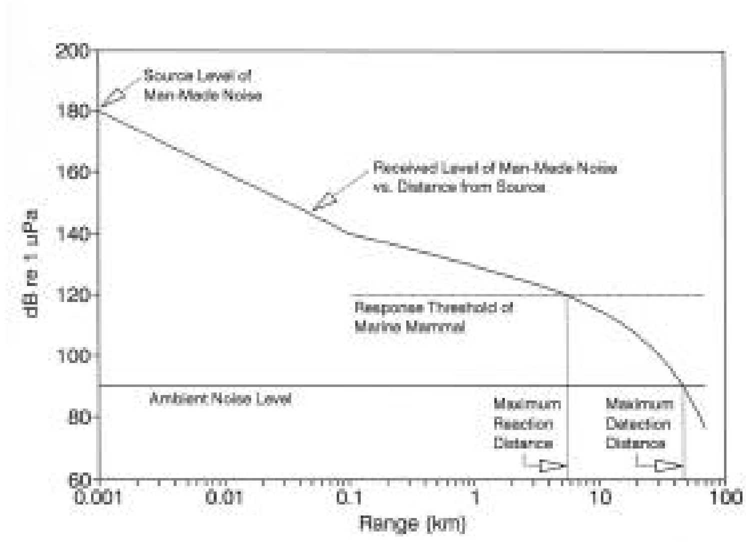

Figure 2. The zones of influence around a sound source in the ocean (Richardson *et al.*, 1995).

Received sound levels to the animal depend upon the strength of the sound at source (termed the source level), the frequency of the sound, and the physical properties of the environment through which the sound propagates. The standard unit of source level in underwater acoustics is the µPa–m for a reference distance of 1m (quoting source levels as dB re µPa at 1m). The received sound level tends to diminish with increasing distance. The received levels 10, 100, 1,000 m from a source are often 20, 40 and 50-70 dB less than the corresponding source level, although this varies depending upon the characteristics of transmission loss (Würsig and Richardson 2002).

In assessments, we need to ask whether the shipping activity under review may actually cause physical damage to the animal's body tissue or hearing and, if so, over what range. We then need to assess over what range it affects the behaviour of the species, and what level of disturbance is acceptable for the individual and population both in the short term and over the long term. Also important is whether there might be effects upon the prey significant enough to affect the population of a cetacean species. Finally, an assessment of the area covered by the activity is needed and, if disturbance is unavoidable, how important this area is to the species under consideration and what proportion of the local population might be affected.

Behavioural Responses to Noise An animal can only show a behavioural response to a sound that it can detect, and the extent to which a sound damages an animal's auditory system is closely correlated with its sensitivity to that sound's frequency. As Richardson *et al*. (1991) have pointed out, it is important to note in assessing the behavioural response of cetaceans to noise that this may vary according to:

a) "physical" factors such as the characteristics of the noise in question, its attenuation rate, and the background noise level;

b) real differences in sensitivity between individuals, or in the sensitivity of the same individual at different times; and

c) differences in activity, age and sex, habitat or degree of habituation.

For these reasons, it is very difficult to define "criteria of responsiveness" of individuals and species to noise.

Harassment is presumed to occur when cetaceans in the vicinity of the acoustic source (or vessel) show a significant behavioural response to the generated sounds or visual cues. However, even where there is no measurable behavioural response, it cannot be assumed that no biological consequences are resulting from exposure to loud noises, and evidence of hearing damage has been found in humpback whales exposed over a period of time to industrial (drilling) activity (Ketten *et al*., 1993).

Gisiner (1998) suggests that when measuring an animal's response to a sound, effort should be made to look for a distribution of possible responses, and not merely provide a listing of specific types. It should then be possible to infer which of the possible responses are the most significant. For this, it is important to know the behavioural repertoire of the species by sex and age, and this should include the repertoire of sounds used in communication.

We can recognise seven categories of behavioural response:

1) *No detection of noise* The noise may be too weak to be heard at the animal's location either because it is lower than the prevailing ambient noise level, or lower than the hearing threshold of the animal at relevant frequencies, or both.

2) *Tolerance and habituation* There is always a certain amount of ambient sound in the oceans and cetaceans will not always react to exposure to a new sound. Mammals will often become alert to low intensity sounds but ignore these sounds after a while when no danger is associated with this sound (Würsig and Richardson, 2002). It is not known if animals tolerate this sound so as to remain in the area and if so, what the effects of this tolerance are, or whether the animals really are unaffected by the sound. Habituation occurs usually on repeated exposure to noise, where animals may exhibit diminishing responsiveness to that sound. They do not usually become habituated to sounds that are highly variable in characteristics and unpredictable in occurrence. Different species show differing levels of tolerance to sound. At Heard Island, hourglass dolphins were observed to approach a sound source of 209-220 dB at 57 Hz within several hundred metres, whereas sightings of pilot whales, southern bottlenose whales and minke whales in the area were lower than during silent periods (Bowles *et al.*, 1994). Richardson *et al.* (1995) noted that some species tolerated continuous sound at received levels above 120 dB re 1 µPa but others avoided sounds at around 120 dB, although they considered that none would remain for long in areas with received levels of continuous underwater noise of 140+ dB at frequencies to which the animals are most sensitive.

3) *Slight alterations in behaviour* Some alterations in the normal behaviour of cetaceans may be evident on exposure to noise, ranging from very subtle changes in dive rates, respiration, and surfacing, to more obvious behavioural changes such as a change from feeding or resting to obvious vigilance and investigation of the sound (Richardson *et al*., 1995; Würsig and Evans, 2001). Some of these behavioural changes may only be detectable by detailed statistical analysis. The reaction threshold and degree of response are related to the activity of the animal at the time of the disturbance. Whales engaged in active behaviours such as feeding, socialising or mating are less likely than resting animals to show overt behavioural reactions, unless the disturbance is directly threatening. Generally, the short-term and long-term effects of changes in behaviour are poorly known.

4) *Avoidance behaviour* Avoidance behaviour occurs when the animal actively seeks to avoid the noise and in so doing changes its usual behaviour pattern, such as migration, feeding, and socialising. Bowhead whales, for example, have been shown to deflect from their usual course of migration to avoid noises from seismic or drilling operations, positioning themselves at least 20 km away from the noise source (Würsig and Richardson, 2002). The received level of sound at this distance from the strongest airgun was near 130 dB (averaged over pulse duration). They also showed an increased rate of surfacing and altered their dive patterns. Bowhead whales in other studies have also been shown to react to high-intensity, low frequency airgun blasts when the sound source was less than 5 km away, although avoidance began consistently at any distance less than 10 km (Reeves *et al*., 1984; Richardson *et al.*, 1986; Ljungblad *et al*., 1988). They reported that the bowhead whales' behaviour returned to normal within an hour after the airgun activity stopped. Ljungblad *et al*. (1988) noted that the whales reduced their submergence times during close exposure to seismic sounds and they suggested that this could be due to the fact that received levels of airgun blasts are lower near the surface than at depth. This is called the "pressure release effect". At the surface the level can drop by as much as 30 dB depending on the particular frequency, the depth of the animal, and the local oceanographic conditions (Jensen, 1981). In less extreme cases, seismic pulses received within 3 m of the surface were confirmed to be several decibels weaker than at 9 m and especially at 18 m depth (Greene and Richardson, 1988). Bowhead whales migrating past Point Barrow, Alaska, have been shown to change their distribution, and Eskimo hunters believe that this is due to seismic operations (IWC, 1987). Aerial surveys failed to note any significant shift in their usual route although the tests could not detect changes of less than 12 km (Moore and Clarke, 1992).

Gray whales show similar deflections from their migration routes, when exposed to seismic or LFA sonar, but can tolerate higher sound levels than bowhead whales (Würsig and Richardson, 2002). Malme *et al.* (1984) reported that migrating gray whales off California consistently deflected their swimming course to increase separation distance from the airgun blasts, only when received levels were at least 160-170 dB re 1µ Pa 1m. They noted that the whales sometimes tolerated surprisingly strong intermittent noise pulses during the seismic playbacks. Migrating humpback whales in Western Australia showed localised avoidance of an airgun array, standing off when received sound levels were 157-164 dB re 1µPa at ranges of 1.8-4.6 km (McCauley *et al*., 2000). Avoidance manoeuvres were more likely to occur in resting pods containing cows, with avoidance starting at received sound levels of 140 dB (range 1.8-4.6 km). Sperm whales have been reported to be sensitive to airguns at Heard Island in the Southern Ocean and in the Gulf of Mexico at greater distances than are reported for bowheads. However, observers from British waters reported that sperm whales did not react to the use of airguns (Gordon *et al*., 1998).

Although the examples above relate to the transmission of loud sounds during seismic exploration, the presence of a large vessel like a ferry, tanker or container ship may elicit a marked negative response. Au and Perryman (1982) observed avoidance behaviour in spinner dolphins and spotted dolphins from approaching ships even when the vessel was still on the horizon. Early responses to an oncoming vessel have also been noted in beluga whales (Blane and Jackson, 1994; Richardson *et al*., 1995: 241-324), killer whales (Kruse, 1991), and harbour porpoises (Evans *et al*., 1994).

5) *Effects on social structure* Scattering of whales, and disruption to their social structure, lasting for a few hours, has been shown for bowhead whales from the approach of a supply ship within 2-4 km of the group (Würsig and Richardson, 2002). The effects of this are unclear but repeated disruption would undoubtedly be detrimental to the well-being of the animal or the group. Whales do not have to be in physical contact to be socially bound. They are known to communicate over great distances so that masking of their vocalisations over large distances could have a harmful effect on their ability to stay in social contact with one another.

6) *Habitat displacement* If noise forces whales to move away from an area that is important to them, this could be detrimental to the local population, especially if the area is important for feeding or breeding. Perry (2000) reports many documented cases of cetacean abandonment of areas that have been subjected to a high level of anthropogenic noise. On the other hand, although it is known that whales do move away from sources of sound, it is not known whether changing locations actually affects the survival of the individual or population. If animals are displaced from preferred feeding grounds, for example, they may experience difficulties that ultimately could affect reproduction or survival. Some species may have particular specific habitat requirements, and displacement may have an effect upon life history parameters like survival and reproduction. Beaked whales, for example may depend upon particular deep canyons (cf the Gully, a canyon on the Scotian Shelf, near Nova Scotia, used by northern bottlenose whales - Gowans and Whitehead, 1995), whilst for large baleen whales, Atlantic white-sided dolphin and short-beaked common dolphin, the continental shelf slope may be an important habitat.

The geographical layout and duration of any activity involving the generation of loud sounds may have important implications for the possibility of habitat displacement. A small seismic survey, for example, may comprise only some thousand signals spread over several days in a comparatively large area, whereas an intense 3D program may involve several hundred thousand signals spread over weeks to months in a comparatively small area. For this reason, it is probably more appropriate to consider the estimated total received energy over time in addition to the more traditional measure of received sound pressure (see McCauley *et al*., 2000 for further discussion of this).

7) *Alterations to vocal behaviour* Masking occurs when sounds that are of interest to the animal such as the communication calls of another whale, predator calls, or important environmental noises, are masked by the noise. This may interfere with the animal's ability to hunt prey, avoid predation, navigate, or hear the vocalisations of conspecifics. Such sounds may be important for migration, aggregation, spacing and breeding, and for odontocetes, the detection of returning echoes whilst echolocating.

It has been suggested that gray whales, belugas, and bottlenose dolphins shift the primary frequencies of their sounds when confronted with noise that overlaps with their usual frequency ranges, so reducing the negative effects of noise masking (Würsig and Richardson, 2002). Playback experiments have shown that artificially increased noise levels may cause increases in the call rate of gray whales, and changes in their call structure (Dahlheim, 1987). The level of the whales' response was strongly influenced by the manner in which the stimulus was presented. Rapid or sudden onset of a sound caused a more pronounced response than did the gradual introduction of a sound (Dahlheim and Fisher, 1983; Dahlheim, 1987). However, bowhead whales are known to continue calling in the presence of seismic survey sounds, and their calls can be heard between seismic pulses (Richardson *et al.*, 1986). Miller *et al.* (2000) found that male humpback whales continued to sing during controlled LFAS (Low Frequency Active Sonar) transmission, where no whale was exposed to sound pressure levels greater than 150 dB re 1µ Pa (42 sec at 6 min intervals). However, humpback whales were shown to lengthen the duration of their songs to compensate for the acoustic interference. Au *et al.* (1985) report that captive beluga whales shifted to using echolocation signals with higher frequencies and greater intensities when they were in an area with increased ambient noise levels of 12-17 dB. This only slight increase in noise was enough to mask the beluga vocalisations and elicit a shift in vocal behaviour (Gordon and Moscrop, 1996). The ranges at which animals can communicate will be affected by masking frequencies, and it should be realised that some cetaceans communicate over great distances and so the effect may not always be on those animals that are nearest to the source of noise. Masking of these sounds can disrupt the normal breeding social behaviour of the population (Payne and Webb, 1971) as well as affecting co-operative feeding behaviour and group cohesion. Edds and Macfarlane (1987) found that fin whale vocalisations were masked by low frequency vessel sound, and minke whale vocalisations were masked by high frequency outboard motor noise in the St Lawrence estuary.

Richardson *et al.* (1995) note that masking of sounds that are important to cetaceans, will result primarily from continuous noise rather than the short pulses associated with seismic exploration. Some species of whales such as the bowhead whale may indeed continue to call in the presence of seismic pulses although others such as sperm whales can exhibit variable reactions (Richardson *et al.*, 1995).

During a study of the use of sound transmission time to monitor global temperature change, low frequency (c. 57 Hz) sounds were transmitted from underwater projectors near Heard Island (southern Indian Ocean) to a set of globally distributed receiving sites up to 17,500 km away. During the study, sperm and pilot whales stopped communicating when exposed to high levels of sound although it was not apparent at what received levels the whales became quiet (Bowles *et al.*, 1994). Responses can vary between species. Belugas are vocally active when they detect ship sounds, whereas narwhals fall silent (Würsig and Richardson, 2002). Dusky dolphins have been shown to react differently depending on their activity at the time of the noise, falling silent if they are resting but remaining vocal if they are socialising or mating (Würsig and Richardson, 2002). Silence could signify that the animal is listening and choosing to remain quiet in response to the sound, as opposed to signifying that the animal has left the area or lost the ability to maintain effective vocal communication (Gisiner, 1998).

Physical damage to hearing

a) *Loss of hearing* Exposure to noise can significantly alter hearing in mammals depending upon the extent of inner ear damage. The level of damage to hearing also depends upon the power spectrum of the signal in relation to the sensitivity of the animal (Wartzok and Ketten, 1999). Temporary hearing loss (TTS, temporary threshold shift) usually occurs when the duration of intense sound is short and the noise is narrow band and not impulsive. The hearing loss in this case is near the signal's peak frequency, and hearing is recoverable. The potential for a pressure wave to cause physical damage is related to its rise time, which is much greater for an explosion than, for example, a seismic pulse (see Simmonds and Dolman, 1999, for a further discussion of this). Bottlenose dolphins and beluga whales, exposed to a single one second pulse of strong sound (192-201dB), experienced mild TTS (Schlundt *et al*., 1999). However, hearing thresholds were recoverable 12 hours after the last exposure. Studies with small odontocetes reveal that sound levels necessary to cause TTS are correlated with the duration of exposure. However, the TTS thresholds have not been quantified for repeated sounds such as seismic and sonar pulses. The sound levels that are necessary to cause TTS and PTS in baleen whales are not known (Würsig and Richardson, 2002). Richardson *et al*. (1995) consider that TTS is only a possibility when animals are within a few hundred metres if the sound pressure level is of sufficient intensity, such as with large seismic airgun arrays. Normally, full hearing abilities can be expected to return 24 hours after exposure (Kastak *et al*., 1999).

Permanent hearing loss (PTS), particularly in the higher frequencies, can occur when exposure is long or if the signal is broadband with a sudden onset (Wartzok and Ketten, 1999). Repeated exposure to TTS-inducing signals without adequate recovery times can lead to PTS (Wartzok and Ketten, 1999). However, it is not known how much additional exposure causes PTS for marine mammals (Würsig and Richardson, 2002). Superimposed noise levels of a number of whale watching boats following killer whales were close to the critical level assumed to cause permanent hearing loss during prolonged exposure (Erbe, 2002).

Most mammals incur hearing losses when the signal is 80 dB over the animal's threshold (Wartzok and Ketten, 1999). Although it is not possible at present to determine the TTS and PTS exposure guidelines for marine mammals, it has been argued that cetaceans are adapted to tolerate much higher sound levels than humans before experiencing TTS, and that they are not injured by such levels (Balcomb and Claridge, 2001). It is believed that cetaceans may flee from loud sounds before they are injured (Richardson *et al*., 1995) but only in situations where the intense sonar pressure waves travel at speeds slower than that at which the animal can move away (Balcomb and Claridge, 2001). A stranded neonatal sperm whale was exposed to pulses ranging from 2.5 kHz to 60 kHz and its auditory brainstem responses were recorded (Carder and Ridgway, 1990). Its highest amplitude responses were in the range of 5-20 kHz, with a weak response at 60 kHz pulses. This is reported to be similar to other odontocetes (Ridgway *et al.*, 1981). When using sonar to track sperm whales, Moore and Watkins (1985) selected frequencies in the 40-60 kHz range because they believed that these frequencies were above the animal's hearing threshold.

In humans, it has been shown that TTS has been produced for frequencies between 700 Hz and 5.6 kHz from underwater sound sources when received levels were 150 to 180 dB re 1 µPa (Smith and Wojtowicz, 1985; Smith *et al*., 1988). Sharp rise-time signals produce broad spectrum PTS at lower intensities than slow onset signals both in air and in water (Lipscomb, 1978; Lehnhardt, 1986).

The cumulative effects of repeated incidents of temporary shifts in hearing threshold are uncertain, but in humans long-term exposure to high sound levels can accelerate the normal process of gradual hearing loss with increasing age (Kryter, 1985), resulting in premature age-related permanent threshold shift. Gordon and Moscrop (1996) comment that this might be expected to occur in other mammals such as cetaceans, and they believe that the loss of the ability to detect a variety of faint sounds could be of substantial survival significance.

b) *Damage to the organs of hearing* There have been a few reports of direct damage to the auditory apparatus of marine mammals from anthropogenic noise. Lien *et al.* (1995) reported ear damage during humpback whale post-mortem examinations from two individuals found dead in the vicinity of Trinity Bay, NE Newfoundland, where industrial noises of underwater drilling, blasting and dredging occurred at high sound levels, mainly between 20 and 400 Hz. The two humpbacks that had died in fishing gear near blasting both had damaged ears: ruptures of round windows, ossicular chain disruption, and haemorrhages, whilst two autopsied individuals similarly killed in gear from areas where there was no industrial activity, showed no signs of ear damage (Ketten *et al*., 1993). CT scans of the humpback ears showed multiple fractures throughout the periotic, consistent with intracochlear blood. Blood, serum, and cellular debris of both intra- and extra-cochlear origin filled the middle ear and surrounding peribullar region (see Figure 6 in Würsig and Evans, 2001: 580).

At least 15 beaked whales (Cuvier's beaked whale and Blainville's beaked whale), two minke whales, and a spotted dolphin stranded in the Bahamas in March 2000 following the use of mid frequency (3.5 kHz and above, 235 dB re 1µPa @ 1 m) active sonar by the US Navy (Balcomb and Claridge, 2001; Evans and England, 2001). The necropsy findings revealed significant cranial lesions among the beaked whales but not in the spotted dolphin. Haemorrhages were found in the inner ears and some cranial spaces. Acoustic fats also showed varying degrees of haemorrhaging. These pathologies were consistent with impulse trauma that may have compromised hearing or the vestibular system, but was not immediately or directly fatal. The Blainville's beaked whale had intra-cochlear and subarachnoid haemorrhages with clots in the lateral ventricles, as well as renal capsular haemorrhages, possible lung haemorrhaging, bruising of the larynx, and heart lesions (often seen in strandings) (Rowles *et al*., 2000).

c) *Damage to body tissue* There is now growing evidence to show that damage to body tissues can occur from exposure to underwater sound. Tests carried out by the US Navy determined that vestibular dysfunction (affecting balance) in immersed laboratory animals occurred at 160 dB RL at lung resonance frequencies (Jackson and Kopke, 1998). Haemorrhaging occurred in lungs and liver and other organ systems at 170-184 dB at lung resonance frequencies (Dalecki, 1998; Dalecki *et al*., 1998). Terrestrial animals exposed to strong noise have reduced sperm production, menstrual irregularities, abortions and stillbirths (Würsig and Richardson, 2002). It has also been suggested that strong sound may cause bubbles to form in blood or tissues which could then become lodged in the brain or elsewhere (Crum and Mao, 1996). Explosive blasts, with a sound pressure level of 170 dB re µPa at 1m can cause generalised damage to tissues in the human body in air (EPA, 1974). Human divers exposed to intense low frequency sound have experienced resonance of the lungs and other body cavities and dizziness, nausea and visual disruption (Cudahy and Sims, 1998, cited in Davis *et al*., 1998). Crum and Mao (1996) calculated that certain sound frequencies and levels could theoretically cause bubble growth and therefore the " bends" (decompression sickness) in marine mammals, given that due to low frequency diffusion, bubbles will continue to enlarge until they reach their resonant frequency, i.e. the lower the frequency the larger the resonant size. A 250 Hz signal, for example, will result in a theoretical bubble growth up to 1 cm. The large size of these bubbles increases the potential for blocking medium sized arteries. Theoretical modelling by Crum and Mao (1996) demonstrated that bubble growth in the frequency range of 250 Hz – 1 kHz requires supersaturation and high sound pressure level to reach large diameters. Bubble growth theoretically reaches capillary-diameter size (10 µm) within a few minutes at sound pressure levels above 190 dB (Gisiner, 1998). There is evidence that this may be the cause of bubbles observed in the heads of some stranded animals (P. Jepson, *pers. comm*.). Furthermore, post-mortem studies of seven beaked whales stranding in the Canaries at the end of September 2002, following military exercises using active sonar, revealed fat embolisms suggestive of decompression sickness (Fernández, 2003; see also section on Active Sonar).

d) *Stress* Stress is also of potential importance since this could affect the normal behaviour of an animal (Curry, 1999). Unfortunately, there are no data available for noise-induced stress in marine mammals. In terrestrial animals, noise has been demonstrated to stimulate increased activity in the adrenal cortex and other endocrine defence organs (Welch and Welch, 1970), and long exposure may affect digestive and reproductive functions. Seyle (1973) reports that there are harmful physiological effects in a variety of animal species, caused by the chronic activation of the hormonal complexes produced in response to stress.

Active Sonar Simple depth sounders emit a focused, downward-pointing, high frequency (100-200 kHz) beam whereas very powerful lower frequency sonar (1-80 kHz) may be used for fish-finding, charting and military activities. Some military and fish-finding side-scan sonars can operate up to a frequency of 500 kHz, however (Richardson *et al*., 1995: 147). Table 1 summarises the characteristics of the various sonars currently in operation.

Table 1. General characteristics of various Active Sonars[a]
(from Richardson *et al*., 1995; Gill and Evans, 2002; Zimmer, 2003; Evans and Miller, 2003)

Sonar Type	Frequency (kHz)	Duration (ms)	Source Level[b] (dB re 1µPa @ 1 m)
Environmental Sonar			
Echo sounders	12-200	0.3-3.0	180-245
Bottom profilers	0.4-30	0.1-160	200-230
ADCP[c]	0.075-1..2		216
ATOC[d]	0.06-0.09	20 mins	195
Short-range Imaging Sonar			
Side-scan	50-500	0.01-0.1	220-230
Multi-beam	15.5	20	237
Navigation (transponders)	7-60	3-40	180-200
Long-range detection sonar			
a) Tactical (Military)			
Search & surveillance	2-57	4-1000	230+
Mine & obstacle avoidance	25-500	1-30	220+
Weapon-mounted	15-200		200+
b) LFAS	0.05-0.5		200+
Examples of long-range detection sonar:			
SURTASS LFA	0.1-0.5	6000-100,000	240 (18*215)
SLC TVDS LF[e]	0.45-0.65, 0.7	2000+2000	214-228
SLC TVDS MF[e]	2.8-3.2, 3.3	2000+2000	223-226
AN/SQS-53C[f]	2.6, 3.3	500-2000	235+
AN/SQS-56[f]	6.8, 7.5, 8.2		223

[a] Based mainly on information in Watts (1994), DOEIS (1999), Zimmer (2003), and manufacturers' literature
[b] Root mean square pressure
[c] ADCP = Acoustic Doppler Current Profiler
[d] ATOC = Acoustic Thermometry of the Ocean
[e] Linked to mass stranding, Greece
[f] Linked to mass strandings in Bahamas & Canaries

Typically, pulsed high-frequency (kHz) signals are used over relatively short ranges (km) for echo sounding, bottom imaging (side-scan and multibeam sonars), bottom- and surface-scattering studies, fish-finding, navigation, communication and Acoustic Harassment Devices (AHDs). Their output ranges from 180 to 230dB re 1 µPa @ 1 m (Richardson *et al*., 1995). High frequencies are rapidly attenuated in range and the sound emitted by even high source level devices diminishes quickly (Gisiner, 1998). For example, the absorption at 100 kHz is 0.01 dB/m, so that by absorption alone, a 200 dB emission at 1m is reduced to a 100 dB level at a range of 10 km. Geometrical (spherical) spreading loss reduces this by an additional 80 dB at that range (Richardson *et al*., 1995; Gisiner, 1998).

Long-range detection sonar (LFAS and tactical sonar) are characterised by long pulse repetition rates (360-900 secs for SURTASS LFA sonar, 60-90 secs for SLC TVDS sonar as used in Greece in 1996, and 26 secs for AN/SQS-53C and AN/SQS-56 sonar, as used in the Bahamas in 2000 and Canaries in 2002. They have a small vertical beam width ($5.5^o/11^o$ in SURTASS LFA, 23^o-24^o in SLC TVDS, and 30^o-40^o in AN/SQS), but a large horizontal aperture (360^o, mostly omni-directional in azimuth). LFAS has been deployed at depths of 100-1,000 m, whereas in Greece in 1996, the SLC TVDS was deployed at 60-90 m, and in Bahamas in 2000, the AN/SQS was deployed at depths of 6.1-7.9 m (Zimmer, 2003).

In the last century, Norwegian whalers discovered that sonar caused a dramatic flight response from whales and they developed a special ‘whale scarer’ which used six oscillators to generate ultrasonic pulses in three directions. The effect of this was to scare the whale to the surface “inducing panic and panting, fatiguing the whale as quickly as possible” (Mitchell *et al.*, 1981). This was found to be effective for baleen whales as it made them swim fast and near the surface. Watkins *et al* (1985) observed that on one particular occasion, sperm whales were scattered, difficult to approach and silent, contrary to researchers’ experience in previous years. They supposed that this was due to the intense, local sonar signalling from military submarines operating in the area, which were in the frequency range of 3.25-8.4 kHz. The behaviour was normal again in 1984 when the submarines were absent. Sonars and calibration pingers operating at 36-60 kHz elicited no obvious response from the whales. Papastravrou *et al.* (1989) reported that sperm whales did not react to a depth sounder that pinged at a frequency of 50 kHz. Thiele (2001) observed that minke whales were sighted within the sea ice to the south of Marguerite Bay in close proximity to the vessel *Polarstern* throughout which time the EK 500 echo sounders were operating. They stated that the whales appeared not to be disturbed by the echo sounders. This observation was noted again when the moving vessel approached and passed minke whales, since none of them appeared to move away, although these echo sounders are audible to them several miles away from the vessel.

Sperm whales have been shown to react to military sonar in the south-east Caribbean at distances of 20 km or more from the source (Watkins *et al.*, 1985). There has been concern expressed over the incidence of beaked whale mass strandings concurrent with or following naval manoeuvres (Van Bree and Kristensen, 1974; Simmonds and Lopez-Jurado, 1991; Frantzis, 1998; Evans and England, 2001; Martin, 2003). These strandings generally seem to coincide with the development of powerful mid-frequency (MF) military sonar (J. Mead, *pers. comm*. to Balcomb and Claridge, 2001).

In 1996, there was a mass stranding of Cuvier's beaked whales on the coast of Greece and a study of the event concluded the cause was not a natural phenomenon. There was strong evidence to suggest that the stranding was a result of acoustic testing by NATO in that area, but no examination was made of the heads of the whales (Frantzis, 1998). Groups of pan-tropical spotted dolphins have been seen to move away from a Navy source vessel with an active sonar, whereas common dolphins were reported to bow-ride the same vessel (T. Fetherston, NUWC, *pers. comm*. to Lawson *et al*., 2000). Lawson *et al.* (2000) suggest that these dolphins may have become habituated to some sonar sounds in the Gully area to at least distant transmissions. The possibility of either a 'sound shadowing' effect close to the noise generation or a 'pressure release' effect near the surface accounting for observations of bow-riding dolphins, is discussed later.

On 15 March 2000, a mass stranding of cetaceans, predominantly beaked whales, in the northern Bahamas occurred, coincident with US and Allied naval transit through the area (Balcomb and Claridge, 2001; Evans and England, 2001). In this case, the warships were operating standard, hull-mounted tactical sonar within normal mid-range frequencies (MF), power outputs and duty cycles - 3.5 kHz and above, 235 dB re 1 µPa at 1 m, pings of one tenth of a second or less on a duty cycle of 24 seconds (CHINFO, June 2000). The US Navy reported that within a range of 1,000 m from the ship's sonar that the sound level dropped in intensity to less than 180 dB re 1µ Pa and therefore was within the "safe" limits. However, this "safe" level is based in part upon US Navy experiments with bottlenose dolphins and white whales which showed that TTS varies from 182 to 193 dB received level (RL) in the 20 to 75 kHz range, where their best hearing threshold is 40 - 45 dB (Schlundt *et al.*, 1999). There is no information on whether these values can be applied to other species, particularly those which are deep divers like the beaked whales. Balcomb and Claridge (2001) suggest that in the case of multiple ships operating in the area, the sound pressure level is likely to have exceeded levels of 150 (dB re 1µPa) <u>throughout</u> the NE and NW Providence Channels (from North Eleuthera to Abaco and Grand Bahama) even if levels were below 180 dB. Either way, post-mortem examination of six of the beaked whales showed evidence of injuries consistent with an intense acoustic or pressure event (Evans and England, 2001). The injuries consisted of haemorrhaging in the inner ear and some cranial spaces, and in the acoustic fats.

In the same year as the Bahamas stranding, three Cuvier's beaked whales stranded in the Madeira archipelago, coinciding with NATO Naval Exercises in the area surrounding Porto Santo Island, including the channel between Madeira and Porto Santo (Freitas, 2003). Pathological studies revealed haemorrhages in the inner ear and sub-arachnoidal spaces consistent with a temporary acoustic induced trauma (Ketten, 2003).

Physiological damage has also recently been found in seven beaked whales (mainly Cuvier's beaked whale) examined after a mass stranding early in the morning of 24th September 2002 on the coast of Fuerteventura in the Canaries, and in neighbouring Lanzarote on 25th September, following use of military sonar (3-8 kHz frequency)

(Martin, 2002; Fernández, 2003). In this latest incident, 11 carcasses were examined, including nine Cuvier's beaked whales (two mature males, one mature female, and six immature males), one mature female Blainville's beaked whale, and one mature female Gervais' beaked whale; a further 5-6 animals were refloated, at least one of which later stranded; one carcass was seen floating offshore, and two other animals were sighted. The heads of the seven individuals (six Cuvier's beaked whales, and one each of Blainville's beaked whale and Gervais' beaked whale) were examined and indicated that a decompression-like sickness was responsible (Fernández, 2003). The lesions of this syndrome were characterised by severe disseminated microvascular hemorrhages localised in vital organs including the brain, kidneys, and lungs and specialised acoustic organs of the whales. The type of injury and pattern of lesions were caused by widespread, fat emboli. Most of the carcasses examined showed animals in otherwise healthy condition, with stomachs full of cephalopods and crustaceans. Live animals were clearly disoriented. The strandings occurred immediately following a Naval acoustic exercise involving at least 58 vessels, six submarines and 30 aeroplanes co-ordinated by Spain but involving the Navies of several countries. The naval exercises were suspended on the request of the Canary Islands government. Fernández (2003) concludes that fat embolism supports the hypothesis (Crum and Mao, 1996; Houser *et al*., 2001) that sonic sonar signals generated during the naval exercise could be responsible for the development of intravascular bubbles in nitrogen-supersaturated whale tissues, and that this was an initiating factor in the patho-physiological process. Once the whales became stranded due to the "bends", death due to cardiovascular collapse followed.

These incidents suggest that beaked whales may be more susceptible to injury from powerful sonar systems than other cetaceans, and that they have a particular sensitivity to sonar acoustic stimuli at received levels well below 180 dB. D'Amico (1998) reported that a flight response in beaked whales is initiated at levels well below 180 dB re 1 µPa, at somewhere around 140 dB re 1 µPa. The NATO equipment was in this case transmitting 4 seconds of HFM and CW 450-700 Hz, and 2.8-3.3 kHz every 60 seconds. Balcomb and Claridge (2001) also found that avoidance behaviour was apparent for beaked whales and other cetaceans at received levels (RL) of 140 to 180 dB re 1 µPa of the mid frequency sonar signals (1/10 second at 3.5 kHz, transmitted every 24 seconds from multiple ships). Balcomb and Claridge (2001) also calculated that the frequencies of powerful low and mid frequency sonars precisely matched the equivalent bubble resonance frequencies of these cranial airspaces in beaked whales at predictable depths from the surface to the benthos of the water column. They predicted that ensonifying the whales at levels of 160 to 170 dB re 1 µPa of resonant frequency would cause vertigo and haemorrhaging. They also hypothesised from anatomical evidence that beaked whales have a greater hearing sensitivity than other cetaceans due to having a larger pterygoid sac (airspace). It is shown that the aversive and injurious impacts of intense low and mid frequency sonar, either of standard (1/10 sec MF, Bahamas) or long duration (4-6 second, LFA and MF, as in Greece) may still occur for beaked whales at distances of 20 km or more which is well beyond the current mitigation distance of 1 km used by the US Navy.

Balcomb and Claridge (2001) recommended that sonar exercises should be avoided in relatively confining canyons and areas of high acoustic reflectivity where the sound field may behave unexpectedly and boundary effects dramatically increase the local received level. They also suggested that the mitigation distance for high source level LF and MF sonar operations should be increased from 1 km to the distance coinciding with the first or second caustic, provided that the RL at that distance does not exceed a demonstrably safe level for precluding injury to cetaceans that inhabit the area.

The water column can be described by two layers. Where the surface layer has a positive sound speed gradient, and the lower layer a negative one, sound energy may be trapped in this surface channel. In the Bahamas incident, the presence of a surface channel where sound propagation was enhanced appears to have played an important role. Conversely, if the surface layer exhibits a negative sound speed gradient, and the lower layer a positive one, a deep sound channel develops. The sound energy in this case is channelled around the depth of minimum sound speed, and over long distances follows the model of cylindrical (rather than spherical) spreading. The depth of sound channel depends mainly on the minimum water temperature. The lower this temperature, the deeper this sound channel will be. Over much of the Atlantic, a deep sound channel (at c. 600-1,000+ m) tends to develop, and this appears to have been the case during the Canaries stranding. In the Mediterranean Sea, the sound channel is at a depth of c. 100 m (Zimmer, 2003). At the time of the Greek stranding in 1996, the sound source was within this sound channel. A convergence zone develops in a deep sound channel when the source is close to the surface and the water depth is greater than the critical depth where the sound speed equals the maximum sound speed above this depth. In this case, the acoustic energy will be first refracted from the surface and then back to the surface where a convergence zone develops. Shadow zones may develop between these convergence zones.

The position of the sound channel may thus be of particular importance in determining the type of impact experienced by deep diving cetaceans such as beaked whales – whether the whales are likely to have been trapped within the sound channel, or to have been above or below it may determine whether they suffer direct acoustic trauma or experience a form of decompression sickness as they attempt to escape from the loud sound.

It has been suggested that some very powerful sonar may ensonify large volumes of water and thus potentially affect cetaceans over significant distances (Gordon and Moscrop, 1996). Particular concerns were expressed about the ATOC (Acoustic Thermometry of Ocean Climate) Project, designed to repeatedly measure the speed of sound in the ocean over time in order to determine whether the oceans, which are the main heat sink of the planet, are warming.

An experiment was conducted to test for any effects upon cetaceans in open oceanic waters in relation to the ATOC sound source at Pioneer Seamount, 85 km west of San Francisco. For that experiment, 20-minute sequences of high-intensity (195 dB re 1µPa@1m), low-frequency (mainly 60-90 Hz) sound pulses were transmitted at depths of around 900 m every four hours for more than 24-hours (Calambokidis *et al.*, 1998).

Aerial surveys were conducted in 1995-97 in a 80 by 80 km box centred around the sound source. Experimental surveys (within 20 hours after the end of a 24-hour cycle of sound transmission) were compared with control surveys (flown at least 48 hours after the end of a sound transmission cycle). A total of 22,117 marine mammals were sighted during 34,095 km of control effort, and 23,068 marine mammals were sighted during 34,808 km of experimental effort. No significant differences in numbers of marine mammals of any species were detected between control and experimental surveys. However, there were significant differences in how two cetacean species, humpback whales and sperm whales, were distributed in relation to the sound source. Both species were on average further from the sound source during experimental periods (Calambokidis *et al.*, 1998).

The US Navy marine mammal research programs have investigated the effect of Low Frequency Active sonar (LFAS) on the behaviour of blue, humpback, fin and gray whales. Gray whales have been shown to be displaced from their migration paths when exposed to sonar playback levels of 120 dB (Tyack, 1999, Tyack and Clark, 1998). For blue and fin whales, active sonar transmissions (LFAs) caused them to cease vocalising (see, for example, Clark *et al.*, 1998; 1999a,b).

Recreational Activities In the last 25 years, the amount of sound generated by both commercial and recreational vessels in certain regions must have increased enormously, given the increase in quantity of traffic in many areas. As noted earlier, this will not only have increased ambient noise levels at frequencies below 1 kHz, but, particularly in coastal areas where speedcraft operate, it will have introduced significantly higher levels of high frequency sound. This potentially could affect the daily lives of inshore toothed whales and dolphins such as the bottlenose dolphin and harbour porpoise.

During the 1970s, concern was expressed that gray whales were being displaced from their breeding lagoons in Baja California, Mexico by the large numbers of speedboats and low-flying aircraft visiting the area for whale-watching purposes (Reeves, 1977). Although later studies found no correlation between changes in whale distribution in Baja California and that of human activities (Jones and Swartz, 1984) nor any difference in swimming speeds or respiration patterns of migrating whales in the presence of boats in Southern California (Sumich, 1983), a longer-term impact upon biological parameters such as reproductive success could not be excluded.

In Hawaii, Kaufman and Wood (1981) found that the presence of humpbacks varied inversely with the amount of daily boat traffic and with days on which military bombing practice took place. In Alaska, clear and graded changes in the behaviour of humpbacks in response to vessel traffic were observed even at distances of over 3 km (Baker and Herman, 1989). These included longer dives, shorter periods at the surface, movements away from the paths of vessels, and temporary displacement of individuals from preferred feeding areas (Baker *et al.*, 1982, 1983). With a single approaching vessel, aerial behaviours and surface-feeding patterns did not change, but with several vessels in the area, the number of breachings was reduced. Short-term negative reactions to small boats observed in Hawaiian humpbacks included increased frequencies of surfacings without blows and of dives initiated without raised tail flukes (Bauer and Herman, 1986). The various effects often occurred when vessels were 0.5-1.0 km away. Smaller pods and pods containing a calf were more affected than were larger pods (Bauer *et al.*, 1993).

In the Gulf of Maine, fin whales are often approached by whale-watching vessels, and a shore-based study investigated whether this affected their respiration rates and time spent at the surface (Stone *et al.*, 1992). Although no differences were found in the overall percentage of time spent at the surface, fin whales made significantly shorter dives in the presence of boats, and on surfacing, the number of blows made was fewer, resulting in shorter surfacing sequences.

In the Ligurian Sea (Western Mediterranean), fin whales, humpback whales, and sperm whales have all demonstrated shorter surfacings and fewer blows in response to whale-watching craft (Notarbartolo di Sciara *et al*., 1996).

Most studies of reactions of cetaceans to vessels have concentrated upon baleen whales. However, in recent years, increasing attention has been paid to the possible impact that ecotourism and other recreational activities may be having upon odontocetes (toothed whales and dolphins). Because of the higher sound frequencies at which species of this group operate, one might expect rather different responses if sound alone was the stimulus eliciting a reaction. In Kaikoura, New Zealand, sperm whales are visited frequently by whale-watching vessels. A study by Gordon *et al.* (1992) in this area found that resident sperm whales had shorter surface times and made fewer blows in the close presence of motorised whale-watching vessels compared with their own relatively silent sailing vessel. On disturbance, the whales were also more inclined to dive without throwing their tail flukes up into the air and to change their acoustic behaviour on diving. In Western Norway (off Andenes), Eberhardt (1993) found that lone sperm whales (but not groups of 2-5 animals), resting at the surface, were affected by boats approaching to within 50 metres, showing avoidance behaviour and changes in the intervals between blows.

Of large odontocetes, one of the species most exposed to whale-watching activities is the killer whale, particularly in the vicinity of Vancouver Island (Canada) and Puget Sound, Washington State. Shore-based studies by Kruse (1991), Duffus and Dearden (1992) and Otis (*in* Phillips and Baird, 1993) have generally found little if any effect of the presence of boats on killer whale behaviour. The only possible influence occurred on occasions when several boats came within 400 metres of the whales which then tended to increase their swimming speed by around 50% above that of their undisturbed speeds (Kruse, 1991). On the other hand, in a recent study, Erbe (2002) calculated that a temporary threshold shift (TTS) of 5 dB is likely in killer whales after 30-50 minutes of exposure within a radius of 450 m to whale watching vessels. Close to major shipping lanes, exposure time to similar sound intensities might even be longer.

A study of reactions by bottlenose dolphins to the presence of speedboats in Cardigan Bay, West Wales also showed shorter periods at the surface, longer dives, and movements away from vessel paths (Evans *et al.*, 1992). These occurred over a range of 150-300 m at sea states 3-4. A noise transmission simulating a motor boat rapidly approaching at a distance of 150 metres produced the most marked negative response, presumably the result of a startle effect, but this may reflect the rather artificial mode of sound transmission. Sound characteristics of various craft were also measured and indicated that dolphins should first hear a jet ski 450 metres away, an inflatable at 1 km, and larger motorised vessels (up to 240 hp engine) between 1.1 and 3.1 km distance (above a background sea state of 3). For a naive juvenile dolphin faced with a jet ski moving rapidly towards it in an erratic manner, that probably represents a serious danger.

Despite long-term exposure to high levels of marine traffic, bottlenose dolphins in Sarasota Bay (Florida) continue to demonstrate short-term behavioural changes, showing decreased inter-individual distances, increased swimming speeds and directional changes in response to an approaching vessel (Nowacek *et al*., 2001).

Those studies in which cetaceans appear to tolerate or are unaffected by the presence of boats conclude that they have habituated to them. This has occurred in areas of relatively light boat traffic, or where particular vessels maintain a predictable course, such as passenger ferries (Shane, 1990; Evans *et al*., 1994; Janik and Thompson, 1996; Bristow and Rees, 2001; Gregory and Rowden, 2001). In Mexico, in an area where bottlenose dolphins were exposed to frequent boat traffic, Acevedo (1991) found that they altered their behaviour only when a boat had approached to within c. 5 m, at which point they would dive and resume their previous behaviour elsewhere.

A number of other studies indicate that habituation to the presence of vessels may have taken place. A study by Gordon *et al.* (1992) of the effects of whale-watching activities on the behaviour of sperm whales off Kaikoura, New Zealand found that transient individuals were less tolerant (spending shorter periods at the surface and having shorter blow intervals) than residents. In Johnstone Strait (British Columbia) and Puget Sound (Washington State), the resident killer whale pods appear to have habituated to the presence of boats and either ignore or even approach vessels (Phillips and Baird, 1993). Likewise, Erbe and Farmer (2000) report that beluga whales in the St. Lawrence estuary (an area with very high shipping activity) approach ships to much shorter distances than in the quieter Beaufort Sea. They assume that the animals have become more accustomed to heavy traffic, but do not discount the possibility that these animals have experienced hearing loss following continuous exposure to loud sounds. They calculated that a TTS of 4.8 dB in the hearing sensitivity of belugas could occur if exposed to cavitation noise from an icebreaker (broadband source level of 205 dB) within a 3-4 km radius for more than 20 minutes. A TTS of more than 12 dB would seem unlikely since this would require a stay of 30 minutes within a 120 m radius of the sound source.

In the Gulf of Maine (NE United States), Beach and Weinrich (1989) found that humpback whales were less inclined to respond negatively to whale-watching boats than in South-east Alaska where they experience much lower levels of boat traffic. On the other hand, bowhead whales in the Beaufort Sea where they experience about three times as much shipping as in Baffin Bay, exhibit shorter dives and surfacings on feeding grounds, with less tail fluking, and fewer sexual interactions (Richardson *et al*., 1995). Although these differences in behaviour may reflect adaptive changes by individuals, it is difficult to determine the long-term effects on survival and reproductive success given all the other environmental variables prevailing.

At Cape Cod (NE United States), whale-watching of humpbacks, fin, minke and right whales has seen an enormous growth since the late 1970's. A study of around 12,000 logbook entries from research boats over the 25-year period 1957-82, carried out by Watkins (1986), indicated systematic changes from a situation where whales generally ignored or avoided vessels in the years prior to the development of whale-watching, to positive reactions with whales actually approaching vessels in the later years. Following repeated contact with boats, most species have changed their reactions from avoidance behaviour and reduced vocalisation to showing general disinterest. Resting whales were more difficult to approach without being disturbed, whilst actively feeding or socialising animals tended to ignore the presence of boats. However, responses did vary between species. Humpbacks tended to respond positively to the increasing presence of whale-watching vessels, sometimes changing their behaviour to make an approach or engage in predictable surface behaviours. Fin whales changed from strongly negative reactions to ships to ignoring them, continuing to feed unless approached to within 30 metres, although usually they would fall silent. Minke whales were more inquisitive in the early years, changing later to little or no reaction with increased exposure to vessels, whilst right whales showed little change in behaviour over the years, except for becoming more silent in the more coastal areas. Some of the more positive changes in behaviour may of course reflect the more careful behaviour of whale-watching operators once guidelines were introduced. However, the frequent reports of cetaceans of various species (e.g. bottlenose dolphins, gray, humpback and minke whales) behaving in a "friendly" manner may reflect an increasing acceptance by them of the close presence of humans and their vessels. In the Hebrides of Scotland, the author has observed that, even allowing for a local population increase, a much greater number of minke whale individuals approach and associate with whale watching vessels now than when the industry started twelve years ago.

Bottlenose dolphins and other small odontocetes not infrequently bow-ride vessels including jet skis, and have been observed even at the bow of seismic vessels. Minke whales may ride either the bow or the stern of boats. These regular occurrences suggest that the sounds produced by those vessels is certainly not always aversive.

A study of reactions by harbour porpoises to a variety of craft in the Shetland Islands showed different responses depending upon various factors (Evans *et al.*, 1994). Porpoises were more likely to respond negatively to speedboats and a large ferry both of which they experienced only infrequently, compared with sailing boats and a small daily ferry. They were also more likely to respond negatively when occurring singly or as adult-calf pairs than when in groups. Finally, whereas porpoises tended to move away from vessels early in the summer, as the season progressed their reaction changed, so that by early autumn the majority of individuals actually approached vessels, possibly reflecting the lower vulnerability of their growing young, or their greater curiosity as they became more actively social, or perhaps to some degree of habituation as the summer season progresses.

Besides whale-watching and other recreational activities, the other form of human disturbance that should be considered is that of researchers themselves, either by close approach to one or more cetaceans for purposes of individual photo-identification, or for taking biopsy samples by darting.

Photo-identification requires a vessel to approach cetaceans closely, and may necessitate spending lengthy periods with the animals so as to secure good photographs of as many individuals within the group as possible. Some encounters are not amenable to photo-identification, for example when the group is actively foraging for food or pursuing prey. Repeated pursuit of individuals constitutes harassment and should be avoided. Most persons with experience of photo-ID, however, know that the success of their activity depends very much upon how their vessel behaves around the animals, and just as with whale watching generally, following codes of conduct such as no rapid changes of course or speed of the vessel, are pre-requisites. Noting negative changes in behaviour of the animals (e.g. repeated avoidance of the boat, or a marked change in the dive patterns) and responding accordingly is also very important.

Where studies have examined the effect of biopsy darting upon humpbacks, little or no observable reaction was observed in 35-60% of cases (35% on feeding grounds, and 60% on breeding grounds), the remaining showing little more than a temporary moderate response in the form of hard tail flicks and trumpet blows (Weinrich *et al.*, 1991; Clapham and Mattila, 1993). Generally, a marked behavioural response was observed on 5% or less of occasions, and the researchers concluded that darting results in only a brief disturbance of the animal's behaviour. Minke whales are more likely to respond: one individual darted from behind responded strongly by tail slapping; most others either responded by diving or simply flinched (Evans, *pers. observ*.). Reactions appeared to be of a short-term nature, and the individual could readily be approached again or itself would approach the vessel. If the animal was darted during a feeding lunge amongst balls of sprat or herring, it showed no reaction at all. It is possible that with flocks of seabirds hovering close to its back, the minke whale was already expecting some contact.

MITIGATION MEASURES

The implementation of appropriate mitigation measures may help to minimise the chances of cetaceans being exposed to activities that can cause physical damage or overt behavioural responses. These will be considered under three main headings: vessel collisions, active sonar, and recreational activities. Other shipping activities like seismic testing, drilling, dredging, etc will not be considered, nor overall increases in ambient noise caused by routine traffic.

Vessel Collisions It is important first to understand the various reasons why cetaceans may be struck by vessels rather than take avoidance action. Koschinski (2003) has reviewed these in detail, and lists six possible reasons:

1) *High probability of encounters* Those species, like the sperm whale and northern right whale, which spend a higher proportion of time at the surface, will have a higher probability of a ship strike. Tregenza (2002) has modelled this for short-finned pilot whales in the Canaries, and calculated (on the basis of a number of assumptions which may or may not apply) that 327 whales are likely to be in the path of a ferry every year. This is much higher than the actual number of strikes observed, and he concludes that active avoidance by the whales probably accounts for this.

It is likely that juvenile or sick individuals and slow-swimming species as well as those that typically rest, feed or court at the surface, will be more vulnerable to collisions (Terhune and Verboom, 1999; Laist *et al*., 2001; Clapham, 2002; Kiszka and Jauniaux, 2002).

Laist *et al*. (2001) showed that a high proportion of struck northern right whales (75%; n=8), southern right whales (55%; n=11) and humpback whales (80%; n=10) were calves or juveniles (juveniles spend more time at the surface than adults). On the other hand, Panigada (2002) did not find a greater number of fin whale deaths from ship strikes amongst juveniles compared with adults.

2) *Reduced perception* Under certain circumstances, whales may not be able to readily perceive an approaching vessel or be confused as to how far away it is or the direction from which the vessel is travelling. A downward refracting sound profile may become established in temperate or warm stratified waters, caused by a thermal gradient building up in summer (Terhune and Verboom, 1999; Bondaryk, 2002). Sound will travel faster in the warm surface water compared with the cooler layers further down, and this sound velocity gradient causes the sound path to be bent away from the surface, thus decreasing the time at which the whale would hear an approaching vessel.

The hull of a large ship (as well as minute air bubbles surrounding it) may also shield engine and propeller noise in front of the vessel (Terhune and Verboom, 1999). Sound directionality around ships depends largely on the type of ship and the method of propulsion it uses, and is frequency dependent. Ships radiate a lot of energy specially from their sides. To the front, the hull absorbs a large part of the acoustic energy from propeller cavitation noise (especially at lower frequencies). Injected air bubbles behind the ship absorb part of the energy from higher frequencies such as cavitation noise >1 kHz (cf. Urick, 1983).

Sound levels radiated by ships build up only over some distance. In the "near-field" of a ship where a whale would be in greatest danger of a collision, the sound perceived by its ears is likely to be low compared with other ships some distance away (Urick, 1983; Richardson *et al*., 1995). Although sound radiation from ships is not fully understood, the range over which a near-field effect can occur is likely to depend strongly upon the size of the sound source. One particular near-field effect is that referred to as the Lloyd mirror effect or image interference effect, where at close quarters, the sound source (the ship) and the receiver (whale's ears) are very close to the surface and close together. Under these conditions, the reflection of the ship's sound from the surface strongly interacts with direct sound radiation so that the reflected sound is out of phase with the direct sound. If the source has strong tonal or narrow bandwidth components (as in ships' noise), this phenomenon produces an interference pattern in these frequencies. It may be observed as range-dependent fluctuations in sound level at receiving locations along a horizontal radial line from the source. The Lloyd mirror effect is strongest with low frequency components and only occurs in calm sea conditions. However, the interference pattern created by this effect will be distorted by a downward refracting sound profile (Urick, 1983).

This effect occurs when the range from source to receiver is sufficiently long that the direct and reflected path lengths are comparable. An interference field develops with alternating maxima and minima in received level. Theoretically, with a pure tone source and a smooth surface, constructive and destructive interference could lead to pressure doubling at the maxima and total cancellation at the minima. However, because of wave roughness and finite bandwidth effects, variations in received level are more commonly <6 dB from maxima to minima for narrow band components (Urick, 1983, Richardson *et al*., 1995). Broad band components of ships' noise will probably not be affected by the Lloyd mirror effect. Unfortunately, no information on interference of broad band noise is available so far.

In the area beyond the range of the Lloyd mirror effect, the received level can be reduced quite substantially. This is especially true for shallow radiation angles. Arveson and Vendittis (2000) calculate a reduction of ships' noise by 21 dB for a radiation angle of 5^{o}. They estimate the reduction with the following equation:

$$received\ level = SL + 20\ log(sin\ \alpha)$$

with SL = source level and α = radiation angle.

In conclusion, the Lloyd mirror effect may contribute to a reduction in received levels in a horizontal line from the ship and confusion of the whales about the ship's range and danger level. These effects are likely to be greatest directly in front of a vessel and just below the surface (Terhune and Verboom, 1999).

At mid-depth, especially in coastal waters with a rocky bottom with good reflecting properties, whales may experience shallow water acoustic effects, the echoes from the bottom and surface creating an interference pattern (Richardson *et al*., 1995; Terhune and Verboom, 1999). This may also lead to confusion in locating the sound source.

3) *Distraction by other activities* Individuals may pay less attention to an approaching vessel or a sound impulse if they are preoccupied in another activity – this may be sleeping at the surface, as in logging sperm whales (André *et al*., 1997) or active feeding, as in humpbacks, blue, fin, and sei whales (Richardson *et al*., 1995).

4) *Impaired hearing* As described in an earlier section, cetaceans exposed over the long-term to high levels of noise, may undergo hearing loss through either temporary or permanent threshold shifts. Although direct evidence for this has yet to be found, small

cochlear changes relating to low frequency hearing observed in two autopsied sperm whales in the Canaries were believed to be caused by the continuous presence of high levels of engine and propeller noise from ships in the area, and thus may make them specially vulnerable to ship strikes (M. André, *pers. comm.* in Koschinski, 2003).

The most obvious cause of impaired hearing is that of high levels of ambient noise already in the area. Distant shipping generally dominates ambient noise at frequencies of 20-300 Hz up to about 80 dB re 1µPa @ 1 m (Richardson *et al.*, 1995). This potentially could confuse the whale or mask the sound of individual ships until they are too close to the whale (Terhune and Verboom, 1999), although the sounds generated by large vessels (180-200 dB) are so much greater than ambient noise levels that it seems unlikely that a whale would not perceive the vessel at a sufficient range to take avoiding action (Richardson *et al*., 1995). Likewise, although ambient noise from natural sources, such as wave action, occurs within a similar frequency range as ship noise (90 dB re 1µPa @ 1 m maximum at frequencies of 20-300 Hz), in those circumstances, cetaceans are most likely to avoid the more turbulent surface layers.

5) *Lack of recognition of the threat posed by ships* If individual animals do not perceive ships as a threat, they may allow them to approach closer than is safe. This could apply specially to young animals that have yet to learn by experience (assuming they survive that experience!). Terhune and Verboom (1999) conclude from observations of northern right whales swimming directly into the path of ships without noticeable reaction (at assumed received levels of 92 to 105 dB re 1µPa @ 1m), that acoustic information may not be the major stimulus to alert them to imminent danger. It is assumed that reaction thresholds will depend on the perceived relevance or threat. Koschinski (2003) has pointed out that noise levels received close to the surface will increase immediately after the stern of a ship has passed, so that a whale surviving a strike may find it difficult to associate the threat of a ship with the presence of the faint noise just before the accident. If that were the case, one way to mitigate against it might be to chase young calves with a boat to ensure that they learn to associate boats with the presentation of a threat, as suggested by N. Tregenza for the local eastern North American northern right whale population (Koschinski, 2003), although it is debatable whether that experience would be generalised to other vessels.

6) *High tolerance to traffic noise and habituation* Cetacean populations living in areas exposed to heavy maritime traffic may habituate to ship noise (Richardson *et al*., 1995). An earlier section gives several examples of this. In those cases, that population may no longer view vessels as a threat, although obviously that perception is likely to change if some individuals experience a strike, and survive.

Possible reasons for lack of reaction by ships' crews In most cases, whales hit by ships were not seen beforehand (40%; n=43) or were seen too late to be avoided (53%; n=43) (Laist *et al*., 2001). In some cases, bad sighting conditions were responsible for collisions. For example, out of 37 incidents investigated by Laist *et al.* (2001), 27 collisions (73%) occurred in daylight, nine (24%) at night and one at dusk (3%). High sea states also affect sightability.

Finally, ships may simply be travelling too fast to be detected within the reaction time of officers on duty. Laist *et al*. (2001) suggested that although collisions with motorised vessels appear to have started in the late 1800s, they remained infrequent until the 1950s when a sharp increase was observed. This corresponded with a period when the maximum speed of most large ocean-going vessels started to exceed 14-15 knots. The severity of lesions also seems to be a function of speed. Among collisions with lethal or severe injuries, 89% of the 28 vessels investigated were moving at 14 knots or faster (Laist *et al*., 2001). Collisions with hydrofoils and other fast ferries have also increased with the number of vessels in operation (Capoulade, 2002). The success of any flight response will depends also on the speed of the whale relative to the vessel (Laist *et al.*, 2001; Koschinski, 2003).

Mitigation measures A number of collision incidents leading to damage of the vessel and risk to human life have led shipping companies to invest money in mitigation measures, mainly of a technological nature. The French shipping company SNCM, for example, has been involved in various technical developments including forward-looking SONAR (sound navigation ranging), LADAR (laser detection and ranging), and night vision systems (light amplifier or infra red camera), as well as certain ship protection measures (Capoulade, 2002).

Capoulade (2002) reports that, for night vision systems, a detection distance of at least 600 m is required by European ISO. The drawback of night vision systems is their bad performance in poor atmospheric conditions (i.e. vapour saturated atmosphere). A detection distance of 600 m allows a maximum reaction time of 30 seconds at a speed of 40 knots. However, only the parts of the cetacean above the surface would be detected (i.e. notably the back and fin, and in some cases, the blow), and, even then, the animal would have to rise reasonably far above the surface to be detected by this system.

Sonar and ladar were therefore proposed for inconspicuous and submerged obstacles. Bondaryk (2002) calculated that a 20-kHz sonar with a source level of 203 dB (re 1µPa @ 1 m) would have a sufficient resolution and power to detect a whale at a distance of 2.5 km (which would allow a warning time of 2 minutes). However, active reverberation of the forward projected sound from the water surface and the sea floor may interfere with the echo from the target (the whale), and inhibit detection. Especially in shallow waters, where the water depth is within detection range, a sonar with a broad beam width in elevation is useless. Furthermore, short ranges (e.g. less than 300 m) cannot be covered with most sonars due to multiple reverberation from waves at the surface. Many commercially available sonars can only be operated at low speeds, such as 12 knots for the *Thomson Petrel* (Capoulade, 2002). Another drawback of an active sonar when used in warm stratified waters would be the downward refracting sound profile. This effect contributes to additional transmission loss, although it can be partly overcome with a higher source level of the sonar, but then this may itself pose a problem to whales (Bondaryk, 2002).

Ladar tests revealed a detection range of 400 to 800 m for objects 3 to 10 m below the surface (or up to 20 m in the Mediterranean Sea), but questions remain regarding the sensitivity of the eyes of marine animals to the laser (Capoulade, *pers. comm.*, in Koschinski, 2003).

Other mitigation measures have been proposed or implemented in US and Canadian waters, primarily aimed at preventing collisions of ships with endangered northern right whales. Some of these may also be management options in other regions and for other species. These include:

- aerial surveys with real-time reports of right whale positions to mariners (e.g. Clapham, 2002). This is an expensive management tool that might be ineffective if vessel captains refused to change their route or speed even if informed on whale presence.
- an automated ship identification system (AIS) in combination with a long range radar which enables the coastguard to identify each vessel within critical right whale habitat. Although an expensive measure, an AIS is an important tool to minimise the risk of any unwanted incident (e.g. oil spills) in coastal waters, and it may actually become mandatory in many highly-frequented shipping areas world-wide.
- moving shipping lanes away from critical habitat, such as calving and nursing areas. This solution will probably be applied in the Bay of Fundy in the near future (Clapham, 2002). This is presumably the most efficient management option although it may not be appropriate for other species or in other regions, especially when little is known of the use, size, and location of their habitat.
- general speed limits for ships in high-collision-risk areas. This could be a very effective measure. Laist *et al.* (2001) have suggested a speed limit of 14 knots to vessels operating in high-use whale habitats or in areas inhabited by highly endangered species. However, this measure may be difficult to introduce since it is not popular among shipping companies. Indeed, there is a counter trend in the shipping industry to use faster vessels, and for passenger transport in particular, to establish more ferry lines using high-speed catamarans.

Additional measures proposed include:

- introduction of a 'whale anti collision system' – *WACS*, a row of sonobuoys along a shipping corridor equipped with a passive listening system for whale vocalisations could provide real-time information on whale positions. This information could be relayed from the land to all vessels equipped with a WACS receiver (André *et al.*, 2002), in combination with ambient noise imaging techniques – *ANI*, taking advantage of reflection of ambient noise from any given target, e.g. a large cetacean, and visualised to show whale positions (André *et al.*, 2002; Potter *pers. comm.*, in

Koschinski, 2003). However, these measures need additional testing. One problem is that whales resting at the surface generally are not vocalising so they would not be detected by these means.

· flexible management zones.

Some of the above mentioned measures could only be implemented in coastal areas (under a country's national jurisdiction). The International Maritime Organisation (IMO) (as a central governing authority for ship travel) would have to implement additional management measures in international waters.

Acoustic mitigation measures such as pingers have also been proposed, but these require cetaceans to associate the sounds with an approaching danger (Terhune and Verboom, 1999). Pingers have been very effective at reducing harbour porpoise by-catch in fishing gear (Kraus *et al*., 1997), and to prevent humpback whales colliding with fish traps (reduction of 70% observed, using pingers emitting sound at a centre frequency of 4 kHz and source level of 135 dB re 1µPa @ 1 m – Lien *et al*., 1992). However, this approach has not yet been tested on moving objects like vessels. It might prove effective, for example, on racing yachts that otherwise produce little sound through the water if cetaceans hear the pinger in time to take avoiding action. High or mid frequency pingers mounted on the lowest point of a ship's bow would counteract near field effects such as the Lloyd mirror effect and shallow water effects (which only occur at low frequencies). Furthermore, there would be no absorption of their sound to the front by the massive hull (see above). Additionally, there would be less masking by natural sounds since these occur at a different frequency range (i.e. at lower frequencies).

The most obvious mitigation measure would be for shipping to avoid cetacean-rich areas or at least to follow the main course of a Channel or Sound. Unfortunately, most ferries tend to cross Channels or Sounds at right angles since they take the shortest possible route from the coastline of one island to that of another. This greatly increases the chances of collisions. In most cases, changing shipping routes is unlikely to be acceptable economically, although this is what has been done to some extent off eastern North America to protect northern right whales.

Although many cetacean species have been reported as having been struck by vessels, it is the slower moving species and those with a tendency to rest at the surface that appear to be particularly vulnerable. The sperm whale is an obvious candidate along with pilot whales, but most baleen whale species also seem to be vulnerable. In the ASCOBANS Region, cetacean interactions with vessels are therefore likely to be greatest along the continental shelf edge to the north, west and south of the British Isles. A number of ferry routes cross such areas. These include the Smyril Line ferries from Aberdeen (UK) to Iceland via the Northern Isles and Faroes, and the P&O ferries from Plymouth (UK) to Santander (Spain) and Portsmouth (UK) to Bilbao (Spain). At present, none of these can be classified as high-speed ferries. Minke whales, and the smaller toothed whales and dolphins can be found in high numbers around the Hebrides and Northern Isles of Scotland, in the northern North Sea, southern Irish Sea and St George’s Channel, and Celtic Sea and western Approaches to the English Channel south to the Bay of Biscay. Although ferry routes bisect a number of these regions, only in the Irish Sea are high-speed ferries currently operating, and here, baleen whales and large odontocetes are comparatively rare. However, if high-speed ferries were introduced in the Hebrides or Northern Isles of Scotland, the minke whale in particular might be affected, and the same applies to routes crossing the northern North Sea.

Smaller cetacean species like dolphins and porpoises clearly suffer boat strikes, but these usually involve small vessels and are more likely to lead to injury than death. Possible mitigation measures for this group will be considered in the section on recreational activities.

Active Sonar Although active sonar has widespread use amongst fishing fleets, these are generally of high frequency (50-500 kHz) so that the sounds generated are rapidly attenuated with distance. No mortality has yet been associated with their use, although it should be noted that this would be difficult to establish given the fact that almost every large fishing boat is equipped with side-scan sonar of some sort. Low frequency (50-500 Hz) active sonar has been used in oceanographic research, and to a limited extent by the military. Although negative behavioural responses have been observed in some whale species, no long-term effects or direct mortality have been demonstrated (Calambokidis *et al.*, 1998; Jackson and Kopke, 1998; Clark *et al.*, 1998; 1999a,b; Tyack and Clark, 1998; Tyack, 1999; Rendell and Gordon, 1999).

This is not the case, however, for mid-frequency (2-10 kHz) tactical sonar used by the military particularly for detecting submarines, to which a number of cetacean mass-strandings have been linked (Evans and England, 2001; Evans and Miller, 2003). Beaked whales (e.g. Cuvier's beaked whale, Sowerby's beaked whale, Blainville's beaked whale) in particular appear to be affected, although sonar has been implicated in the deaths of other species, such as minke whale. Unfortunately, our general knowledge of the status, distribution and biology of beaked whales is rudimentary, beyond the fact that they typically occur in deep (500-3,000 m) ocean canyons or abysses, live in small groups, and feed upon cephalopods (Heyning, 1989; Mead, 1989a, b). Limited information on vocalisations suggests that they do use similar frequencies to the military sonar (i.e. 1-10 kHz). Much of the ASCOBANS Region lies on the European continental shelf where beaked whales are rare. On the other hand, any military activities in the Norwegian Sea, Faroe-Shetland Channel, Rockall Trough, Porcupine Seabight, and Bay of Biscay would likely encounter beaked whales.

Most of the ASCOBANS Region is less than 100 metres depth. However, there are some parts which are deeper and may attract species like beaked whales. Notable amongst these is the Norwegian Trough which regularly goes to depths in excess of 300 m, whilst other areas that frequently attain depths of 100-300 m include the Inner Sound, Minches, and Sea of Hebrides off the west coast of Scotland, the North Channel between Northern Ireland and South-west Scotland, and the Celtic Deep south of Ireland. At present, one of these (the Inner Sound, Minches, and Sea of Hebrides) is used for military exercises, and concern has been expressed for local cetacean populations there (mainly harbour porpoises and minke whales) (Parsons *et al*., 2000). Military mid-frequency sonar has been used in this area for the last sixty years, but usage is currently believed to be at a low level compared with previous operations (E. Harland, *pers. comm.*). Minesweepers operating in the area use very high frequency, short-range sonar and their effects are likely to be limited to small areas.

Following the Bahamas mass stranding, the U.S. government proposed the following mitigation measures (Evans and England, 2001; Gentry, 2003):

1) The most obvious mitigation measure is to avoid areas where beaked whales are known to concentrate, or to avoid them in the seasons when whales are present. Military sonar exercises are held where submarines could lie in wait for surface ships while being concealed from detection by an acoustically complex environment. Deep, submarine canyons with steep walls are ideal for these so-called “chokepoint” exercises. Unfortunately, such places are often ideal for beaked whales as well. Navies should survey each canyon for beaked whales immediately before each exercise begins. The military could sponsor marine mammal surveys of all chokepoints to be used for sonar operations to determine whether and at what seasons they contain beaked whales.

2) The second mitigation measure is to plan sonar operations so as to avoid the confluence of factors, other than beaked whales and submarine canyons, that was believed to have contributed to the Bahamas stranding. These include surface ducts that trap sonar signals near the surface, and the use of multiple sonars. Surface ducts tend to form in winter. No one is yet certain of the extent to which they contribute to stranding events. But for now they can generally be predicted so they should be avoided. In terms of sonar, often an SQS-53C sonar is used in combination with an SQS-56 sonar (called a DE 1160 in Europe), and the two sonars ping alternately as often as every 15 seconds, sometimes for hours on end. Multiple pairs of 53C’s and 56's may be used in an operation. Planners should avoid this set of factors (that is, beaked whales, submarine canyons, surface ducts, and multiple sonars) until the actual route of tissue damage is known. At that point the mitigation measures could become more sharply focused.

3) The following mitigation measures are applied at the scene of an operation: ships should establish safety zones around the sonars and be prepared to shut down the sonar if animals are detected breaching them. In the near term, navies should use visual observers and passive acoustic detection to locate animals.

4) Visual observers and passive acoustic detection both fail to detect all submerged animals. Navies do not yet have, but need to develop, a foolproof method of detecting animals. High frequency sonar is the most promising technology for this purpose (see below).

5) After a sonar operation has ended, navies need to always conduct surveys for injured animals. These surveys are essential because unless one systematically looks for injured animals one will never know which mitigation measures work, and which do not but only seem plausible.

Gentry (2003) considers that ramp up, or soft start, which is used as a mitigation measure with airgun arrays (Pierson *et al*., 1998), and has been used in the US Navy's LFA sonar research (Marine Acoustics Inc., 1997), would be of questionable value with most sonar operations. In the Bahamas event, and probably others, beaked whales could have heard sonars approaching from a great distance and the increasing received levels would have had the same effect as a ramp up procedure. Nevertheless, animals stranded and some died, suggesting that whales did not vacate the area, which is the purpose of ramp up. On the other hand, if it was the sudden introduction of a loud sound that had the major impact, as may have been the case in the Canaries event, then ramp up or soft starts might still be effective in giving animals a chance to move away.

Whale-finding sonar may be the mitigation measure of the future (Gentry, 2003). Two different research groups in the U.S. are developing high frequency, low power sonars. They are similar to fish finders except that they look horizontally as well as downward. These sonars have a limited detection range (about 2 km) because the high frequencies they use (20 to 50 kHz) do not propagate well. Their source levels are low (210 dB re 1µPa @ 1 m) and their pings are brief (40 milliseconds), so the total acoustic energy they produce is too small to cause injury. Any behavioural avoidance they cause among marine mammals is local because of the limited propagation range.

This high frequency sonar, called IMAPS, is a prototype being developed by Scientific Solutions, Inc. It looks both down and horizontally in 360 degrees, and produces a new image every four seconds. It has not yet been field tested. The same company made the High Frequency Marine Mammal Monitoring sonar (HFM3) that the U.S. Navy uses as a mitigation measure for its low frequency sonar. In field trials, the HFM3 detected dolphins with great success out to about 2 km. It has been used in operations this year for a few months, but no report of its success rate is yet available. HFM3 and IMAPS are alike in signal characteristics but they differ in the way they scan: HFM3 is mechanically steered whereas IMAPS is a phased array (no moving parts).

Some new method will have to be devised to use high frequency sonar as a mitigation measure for mid-frequency sonar. The main problem is that the ships that carry mid-frequency sonar operate at very great speed, possibly too fast for them to detect whales and react appropriately. A separate survey ship might be needed to scan the operation area beforehand. Clearly research is still needed. But high frequency sonar is the most promising new mitigation tool in a decade, so the effort would be worthwhile.

We still do not know the mechanism by which beaked whales are affected by mid-frequency military sonar. We do not know which part of the acoustic signal causes the problem, or whether it acts through whale behaviour, physiology, or tissue trauma. In the case of the Bahamas stranding, the indication was that the sonar directly damaged the auditory system, destroying hair cells and causing haemorraging. In the case of the Canaries stranding, although auditory damage clearly occurred, death may have been caused by animals changing depths too fast to avoid the sound and experiencing fat embolisms in the process. In either situation, it is not known whether the alternative was the causative mechanism. Once a general mechanism is known, it may be possible to manipulate just the implicated variables. Some of the variables occur at the level of the whole operation, such as the number of sonars used, frequency with which pairs ping, and the duration of pinging. Other variables deal with the characteristics of individual sonars, such as source level, rise time, and frequency composition. Until one knows the causative mechanism, planners should reduce their total acoustic output to the very minimum that is required to accomplish their goals (Gentry, 2003). More research is clearly needed and for this to be effective, scientists and navies need to work cooperatively to devise, implement, and evaluate the efficacy of various alternative mitigation measures (Evans and Miller, 2003).

Recreational Activities The ASCOBANS Region borders coastlines that in many areas contain high human population densities. During summer, in particular, large numbers of people spend time by the sea engaged in recreational activities – water-sports, sailing, and, in some areas, whale and dolphin watching. Most such activities involve small craft less than 15 m length, although some boats engaged in eco-tourism can be larger. The sounds that these vessels generate are usually of moderate or low intensity (SL = 130 dB re 1µPa @ 1 m or less), and they tend to possess planing hulls that travel at high speeds producing most of their sounds by cavitation of the propeller, at frequencies ranging from 800 Hz to 20 kHz. By their nature and the fact that most recreational activities occur in relatively shallow waters, such sounds attenuate rapidly and so are less likely to cause major noise disturbance, at least by comparison with large ships. Their main danger to cetaceans probably comes from their perception as a threat of physical damage through a collision. This in turn may lead to increased stress levels, and disrupt important activities like feeding, socialising, or caring for their young (IFAW *et al.*, 1996; Würsig and Evans, 2001).

Coastal localities where general marine recreation is important and most likely to conflict with cetaceans include: Danish Kattegat and Belt Sea (with harbour porpoises), German Frisian Islands (with harbour porpoises), Southern and South-west England (with bottlenose dolphins), Cardigan Bay, Wales (with bottlenose dolphins and harbour porpoises), and the Channel Islands and coasts of Normandy and Brittany (with bottlenose dolphins). Other areas either have low levels of recreational activity or few cetaceans.

In North-west Europe, with the exception of commercial trips to look at sperm whales and killer whales from western Norway, whale and dolphin watching is concentrated in the British Isles, with bottlenose dolphin watching centred upon the Moray Firth (East Scotland), Cardigan Bay (west Wales), and, more casually, scattered ports along the south coast (such as Poole, Paignton, and Brixham). Trips to see minke whales in particular are centred around the Hebrides and west coast of Scotland (Isle of Mull, Arisaig, Mallaig, Isle of Skye, Gairloch, and Isle of Lewis), and to see common dolphins, off the west coast of Pembrokeshire.

There is one major difference between most recreational activities and whale and dolphin watching operations: whereas the former tends not to pay close attention to the animals;

in the latter, boats directly orient towards, and stay with, their subjects - the marine mammals themselves. As a result, the animals may not have the chance to habituate as they might with other maritime activities, and instead may become irritated (or “sensitised”) to constant or near-constant day-time approaches (Würsig and Evans, 2001). In both cases, however, they may become habituated to “constant” human presence. There are few good data on sensitisation or habituation, but, overall, whales and dolphins who wish to avoid boats can generally do so in remarkably efficient fashion. As noted earlier, Watkins (1986) found that baleen whales in Cape Cod Bay, an area with much industrial as well as commercial tourism activity, have become generally quite habituated to boats around them. Their main responses included diving or increased surface activity (such as flipper slapping or leaping) when boats approached rapidly and “head-on”, or when there were rapid shifts in engine speed and direction.

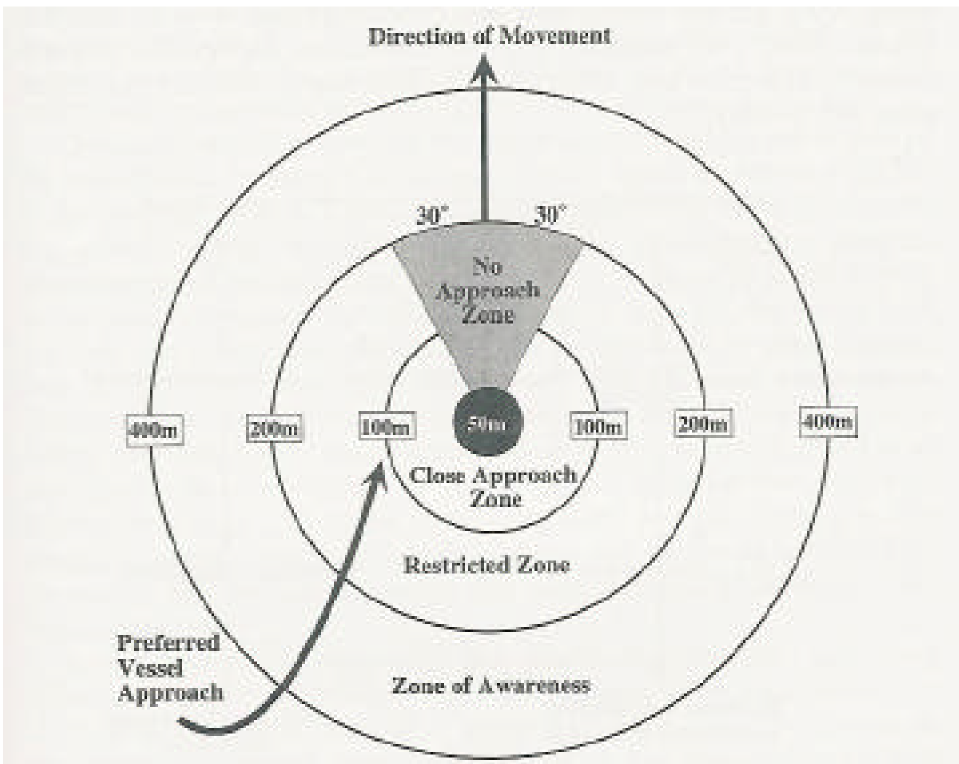

Figure 3. Vessel approach diagram. The 50 m “bull’s eye” is a no approach zone. Note that circle diameters are not to scale. (from Würsig and Evans, 2001, modified from Beach and Weinrich, 1989)

Much has been written about whale and dolphin watching and potential disturbance, especially for gray, humpback, right, and sperm whales; as well as for dusky, common, Hector’s and bottlenose dolphins (see, for example, reviews by IFAW *et al.*, 1996; Evans, 1996; Constantine and Baker, 1997; Constantine, 1999; Würsig and Evans, 2001). The general conclusion for the present appears to be that common sense should prevail when approaching marine mammals: do not have more than two boats within 1 km of the animals, do not approach rapidly, avoid sudden changes in direction and engine speed, do not cut into a group so as to separate group members (Würsig and Evans, 2001). Many codes of conduct exist in different countries, and most share the same features. The main elements of these are included in Appendix 5, whilst Beach and Weinrich (1989) provide a useful figure of distances and boat operation to keep in mind (see Figure 3).

Whales and dolphins may also be in different "moods" relative to their general behavioural mode; and depending on such things as whether they have recently fed, are composed of a nursery unit of mothers and calves, or are sensitised by other human actions or by predators such as killer whales nearby (Würsig 1996). Normally approachable animals can be quite "skittish" at times, and it is up to the experience of the whale-watching skipper to recognise these traits (Figure 4).

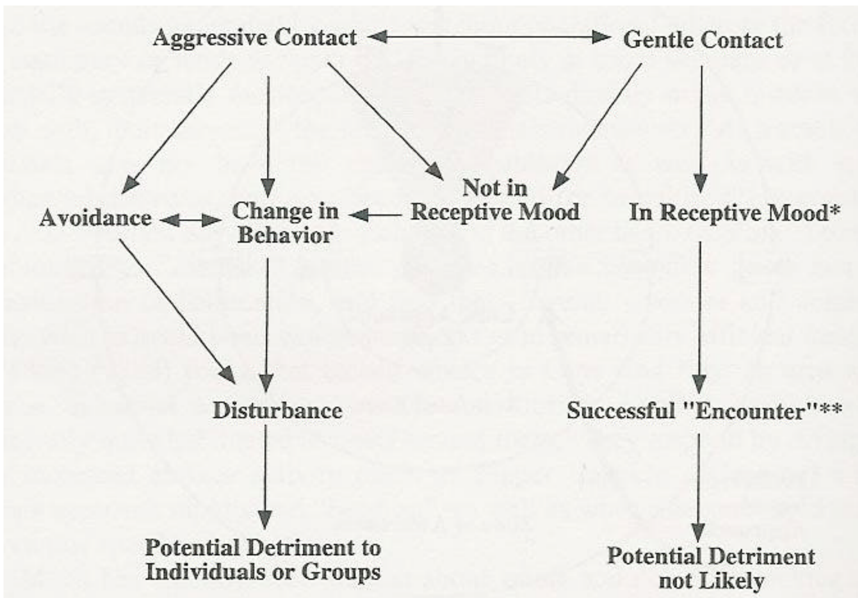

Figure 4. A schematic of how to approach cetaceans for best "whale-watching results. The schematic includes dolphin and porpoise watching, and swimming-with-dolphins. Aggressive contact is defined as rapid approach by the vessel, or rapid changes in speed and direction. Gentle contact means careful appraisal of the animals, their behavioural state, and how best to approach them, usually slowly and not head-on. Note that even gentle contact can result in unacceptable potential detriment if the animals are not in a receptive mood. *Receptive means that the animals are in a behavioural state to likely cause least disturbance. **Successful Encounter refers to both the animals not being disturbed, and the humans being happy with the situation (from Würsig and Evans, 2001).

It was mentioned previously that whales and dolphins may react differently not only by different types and cadences of sounds, but also by other factors of general behaviour, group disposition, etc. This concept is expanded upon in Figure 4, with the understanding that these are generalities gleaned from personal experience, and there will always be exceptions. In general, however, more gregarious large groups of whales and dolphins tend to be less easily disturbed than small grouped ones or "loners". Animals close to shore or surrounded by islands may be particularly shy and skittish. Pelagic "open ocean" dolphins in general are least disturbed, but here caveats must be made. For example, striped dolphins are often very shy of vessels from even a large distance, but the congeneric spinner, spotted and clymene dolphins come up to ride the bow of vessels during a majority of encounters (Würsig *et al.*, 1998), and the same applies to the common dolphin. Likewise, the white-beaked dolphin commonly bow-rides vessels on the European continental shelf but its close relative, the Atlantic white-sided dolphin, rarely does (Evans, 1990). It is also likely, although few data exist on this point, that whales and dolphins are most "skittish" or easily disturbed, when they are not in their usual, or most familiar, surroundings. To my knowledge, this possibility has not been investigated. Dolphins and whales also react differently whether they are socialising, looking for food, resting, or taking care of young (Würsig and Würsig, 1980).

Constantine (1999) discussed long-term effects of whale and dolphin watching in New Zealand, where five species of dolphins and six species of whales are targeted commercially. New Zealand tourism operations are generally quite well regulated and appear to be "sustainable" without chasing animals away from their near-shore haunts, although Constantine considered that too many permits were being issued too rapidly, resulting in the potential to harm individuals and populations in future.

There are certainly opposite extremes of potential disturbance: gray whale mothers and their newborns in Baja California calving lagoons are probably much more easily disturbed than when the same animals (with slightly older calves) are feeding along Vancouver Island, British Columbia. Dusky dolphins that rest and socialise in a bay south of Kaikoura, New Zealand, appear to be much less easily disturbed than are spinner dolphins of Hawaii that spend their daytime in deep rest in small bays (Norris *et al.*, 1994; Würsig, 1996). While tourism has not driven spinner dolphins out of these bays (perhaps because of the potentially great importance of the bays to the dolphins), the dolphins are constantly forced by human presence to change their activity levels, from rest to a heightened level of alertness (Forest, 1998). Presently, there is no information on how this frequent change in behaviour may affect levels of stress, and in turn how this might affect survival.

Mitigation measures such as the obvious tour-operator rules of approaching slowly, changing engine speeds with care, staying at a respectable distance, etc (see Appendix 5), can be externally enforced, but are also self-trained since tourism on animals can only be conducted when animals are not scared, skittish, and evasive (Würsig and Evans, 2001). However, other marine users such as those engaged in water sports may not always have the same inherent reasons to act responsibly, and for these education and enforcement are likely to be specially necessary. In sensitive areas, a licensing system for vessels has some merit, so long as it is run in conjunction with regular education and monitoring in an even-handed manner. Otherwise, local politics may cause the system to break down. In general, it will be only isolated individuals and less aware newcomers that break the rules.

There are also some technological modifications that can also be effective. These include the fitting of propeller guards to prevent accidental physical harm, and keeping propellers in good order to reduce cavitation noise.

SUMMARY AND CONCLUSIONS

As a general rule, the larger the mammal, the more probable it is to have sensitive low frequency hearing, usually at the expense of acute high frequency hearing. We humans hear reasonably well from about 20 Hz (cycles per second) up to as high as 15-20 kHz. The lowest frequency that we can hear is called the upper limit of infrasound; and the highest frequency is the lower limit of ultrasound. In general, human females have higher frequency hearing capability than males. Everybody loses some high frequency hearing with age, and men tend to do so more rapidly and drastically than women. Elephants and rhinoceroses have low frequency hearing, stretching into infrasound. Large whales, especially blue and fin whales, produce such sounds and are probably sensitive to them as well; we have no evidence for infrasound production or hearing in any toothed whale species (see review by Richardson *et al.*, 1995). On the other hand, toothed whales have sensitive hearing at mid and very high frequencies but not at low frequencies. They make and receive clicks that reach far into ultrasound and that are used largely for echolocation. We have no good evidence that any baleen whales can make ultrasounds or can echolocate.

The higher the frequency, the more sound attenuates with distance. In other words, a sound of a particular intensity at 100 Hz might reach to a distance of one kilometre, while a sound of the same intensity but at 10 kHz might only reach for 150 metres (for a more thorough review, see Malme, 1995). So, we expect to find low frequency sounds being used as long-distance communication or contact calls, and higher frequency sounds being used for short-range communication and echolocation. This is exactly what happens, with blue and fin whales emitting moans that reach into infrasound and that can be heard for up to several hundred kilometres in some situations in deep water (Payne and McVay, 1971); and with dolphins whistling to each other and echolocating at relatively close distances within generally one kilometre (Au, 1993, Norris *et al.*, 1994). Large toothed whales, such as pilot whales and beaked whales, appear to have lower frequencies of sound projection and optimum-hearing (in the region of 1-30 kHz) than do the smaller dolphins and porpoises, but there is much variability in this among species.

Anthropogenic noises can disrupt the lives of animals in several ways, and cetaceans are no exception: sounds can 1) frighten them or make them curious, but in either way change their behaviour; 2) compete with communication signals or echolocation, by sound masking, and thus decrease the efficiency of finding food, mating, caring for young, or avoiding predators; cause 3a) physical effects such as stress leading to changes in hormone levels and perhaps lowered immunity from diseases, 3b) a temporary loss of hearing (or temporary threshold shift) or permanent damage to hearing, or 3c) - in the worst of cases with explosions or other loud noises that also send shock waves - possible death (Richardson and Würsig, 1997; Würsig and Evans, 2001). We have tentative information about the first, at least for changes in behaviour in the short-term. We know even less about long-term behavioural changes, such as thresholds of sound intensity that might cause abandonment of an area. And almost nothing is known about noise-induced stress in marine mammals. Information about hearing losses, and more debilitating chronic or catastrophic effects is limited, but various examples of this have come to light in recent studies, as reviewed in earlier sections.

Richardson and Würsig (1995) spelled out basic noise mitigation techniques, and these largely apply today:

1) design of equipment to be as silent as possible. Propeller shrouding that has been used to silence ships of war is an example; as are also acoustic uncoupling of generators from hulls, engine trains from drive shafts and propellers, and other engineering techniques. [But note that this must be counterbalanced against increased risk of ship strikes.]
2) Seasonal and hourly timing of activities can help to mitigate against detrimental effects. Many cetaceans show strong seasonal patterns of occurrence in coastal areas, and may also have diurnal patterns of activity.
3) Changes of locations can help to mitigate sounds, so that industrial supply vessels, for example, do not move directly through near-shore feeding grounds, but actually route around the main concentration of animals with only minimal increase in expense of fuel and time.
4) Adjustment of operational procedures can help to mitigate against adverse effects. One way to help is to monitor the area for marine mammals before projecting loud sounds. If mammals are present, the activity has to be delayed. Such monitoring is widely practiced now with respect to seismic activities (see, for example, JNCC, 1998), but should also be applied whenever active sonar is being used. Monitoring presently tends to rely on visual, not acoustic, methods, and may certainly miss animals. It is important to conduct both simultaneously since each has its own advantages and limitations. In this context, passive acoustic monitoring can additionally be applied not only to monitor the presence of cetaceans but also of anthropogenic sounds including active sonar.
5) Other operational changes include keeping vessel speed down, slowly ramping up sounds, staggering sound production so that it does not occur throughout the day, and providing lower-charge warning blasts before projecting intense sounds needed for the job. Except for vessel speed, Richardson and Würsig (1995) considered these latter operational procedures questionable, possibly doing more harm than good, if, for example, whales or dolphins are attracted to ramping up sounds, to low-level blasts, or to changes in duty cycles. Even reduced vessel speed may act conversely if animals are less disturbed by a vessel moving rapidly through an area in 20 minutes than if it lingers and takes twice as long.

One technique that has not been thoroughly investigated but which shows promise for the future is a way of shrouding sound once it has been projected into the water (Würsig and Evans, 2001). The best method of reduction may be to create an impedance mismatch by a curtain of air bubbles. Air is about 800 times less dense than water, and air bubbles therefore effectively "swallow up" much sound energy moving from water to the bubbles. The technique has recently been investigated in some detail for shrouding around a stationary, very loud percussive hammering ("pile driving") activity for creating a wharf in Hong Kong (Würsig *et al.*, 2000). A curtain of bubbles was created by running air into a perforated rubber hose surrounding the pile driver. Sounds that were bubble-screened were reduced at 250 to 1,000 m distances in the broadband (from 100 Hz to 25.6 kHz) by about 3-5 dB, with greatest reduction at 400-6400 Hz. Indo-Pacific humpbacked dolphins that occurred in the area were therefore subjected to less noise than without the bubble curtain operating. Nevertheless, more experimental studies need to be carried out to ascertain if and how bubble screening can become a commonplace reality both for stationary and moving sources of noise.

Finally, developments in active sonar may pose not only a threat to some cetaceans but also a solution, if the technology can be found to use this to detect the presence of cetaceans at least at close range.

We still have very much to learn both about the effects upon cetaceans of different shipping activities and how best to mitigate against those that are detrimental. Research is badly needed to address the newly identified problems of active sonar in military exercises and risk of collisions from high-speed vessels. For progress to be made it is very important that scientists work closely with industry and appropriate authorities. That will require initiatives at government level.

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APPENDIX 1. STATUS & DISTRIBUTION OF CETACEANS IN THE ASCOBANS REGION

Twenty-nine species of cetaceans have been recorded in the ASCOBANS Region, but of these only 16 species occur regularly (Table 1). A brief review of the status and distribution of those 16 species is given below (from Evans, 1998; Evans *et al*., 2003):

Minke Whale (*Balaenoptera acutorostrata*) Widespread in small numbers along the Atlantic seaboard of Norway and Scotland south to the western English Channel (usually on the continental shelf in depths of 50-200 m), with numbers greatest on the west coast of Scotland and around the Hebrides; also occurs regularly in the northern and central North Seas. Present in the region year-round but mainly seen near the coast from May to October, with numbers peaking in July to September.

Sei Whale (*Balaenoptera borealis*) Uncommon, mainly in deep Atlantic waters off the edge of the continental shelf (500-3,000 m) from North Scotland south to the Western Approaches to the Channel. In coastal waters of Northern Europe the species occurs mainly between June and December. Numbers vary between years but generally rarer than the fin whale.

Fin Whale (*Balaenoptera borealis*) Uncommon, mainly in deep Atlantic waters off the edge of the continental shelf (200-2,000 m) from North Scotland south to the Western Approaches to the Channel. In coastal waters, the species occurs mainly between June and December, although at least a segment of the population over-winters and may breed south of Ireland and in the Western Channel Approaches. Sightings surveys indicate a general movement northwards off North-west Scotland from June to October, although acoustic studies show the species to be present in the region year-round.

Humpback Whale (*Megaptera novaeangliae*) Rare, mainly on or near the continental shelf (100-2,000 m) from North Scotland south to the Celtic Sea south of Ireland and western Channel. In coastal waters, the species occurs mainly from April-September, but some sightings also in December and January. Acoustic studies indicate a late winter/early spring southward migration from higher latitudes.

Sowerby's Beaked Whale (*Mesoplodon bidens*) Apparently rare, but likely to be under-recorded, in deep Atlantic waters such as ocean trenches off the edge of the continental shelf (700-3,000 m), with most records between North Scotland and the Faroe Islands, although also recorded west of Ireland and in the Western Approaches to the Channel.

Northern Bottlenose Whale (*Hyperoodon ampullatus*) Uncommon, mainly in deep Atlantic waters such as ocean trenches off the edge of the continental shelf (1,000-3,000 m), although it occasionally enters more shallow waters (300 m or less depth), between April and September. A latitudinal migration northwards in spring and southwards in late summer has been postulated.

Table 1. Cetacean Species Recorded in ASCOBANS Region

SUBORDER MYSTICETI (baleen whales)	
Family Balaenidae	
*Northern right whale	*Eubalaena glacialis*
Family Balaenopteridae	
Minke whale	*Balaenoptera acutorostrata*
Sei whale	*Balaenoptera borealis*
*Blue whale	*Balaenoptera musculus*
Fin whale	*Balaenoptera physalus*
Humpback whale	*Megaptera novaeangliae*
SUBORDER ODONTOCETI (toothed whales)	
Family Ziphiidae	
Sowerby's beaked whale	*Mesoplodon bidens*
*Blainville's beaked whale	*Mesoplodon densirostris*
*Gervais' beaked whale	*Mesoplodon europaeus*
*Gray's beaked whale	*Mesoplodon grayi*
*True's beaked whale	*Mesoplodon mirus*
*Cuvier's beaked whale	*Ziphius cavirostris*
Northern bottlenose whale	*Hyperoodon ampullatus*
Family Kogiidae	
*Pygmy sperm whale	*Kogia breviceps*
Family Physeteridae	
Sperm whale	*Physeter macrocephalus*
Family Monodontidae	
*White whale	*Delphinapterus leucas*
*Narwhal	*Monodon monoceros*
Family Phocoenidae	
Harbour porpoise	*Phocoena phocoena*
Family Delphinidae	
White-beaked dolphin	*Lagenorhynchus albirostris*
Atlantic white-sided dolphin	*Lagenorhynchus acutus*
Risso's dolphin	*Grampus griseus*
Bottlenose dolphin	*Tursiops truncatus*
Striped dolphin	*Stenella coeruleoalba*
Short-beaked Common dolphin	*Delphinus delphis*
*Fraser's dolphin	*Lagenodelphis hosei*
*Melon-headed whale	*Peponocephala electra*
*False killer whale	*Pseudorca crassidens*
Killer whale	*Orcinus orca*
Long-finned pilot whale	*Globicephala melas*

(* = Very rare or accidental in ASCOBANS Region;)

Sperm Whale (*Physeter macrocephalus*) Uncommon, mainly in deep Atlantic waters off the edge of the continental shelf (200-2,000 m), north and west of the British Isles and Ireland, and in the Western Approaches to the Channel. Most sightings in the region have been between July and December, although the species has been detected acoustically in mid-winter. There is some evidence for a general northwards movement in early summer and a southwards movement in the latter part of the summer.

Harbour Porpoise (*Phocoena phocoena*) The most common and widely distributed cetacean in the ASCOBANS Region, found mainly over the continental shelf (20-200 m). It is most abundant around North-west and North-east Scotland, in western and southern Ireland, parts of Wales, in the eastern Skagerrak and southern Kattegat of Denmark, and the German and Dutch Frisian Islands. It is uncommon in the southernmost North Sea and English Channel. Although present in the region year-round, in many coastal localities around the UK there is a distinct seasonal peak between July and October whilst in the south-western North Sea and western Channel, numbers are greatest in January-February; in the eastern North Sea, between January and July; and in the Danish Skagerrak and Kattegat, apparently between May and November (although winter coverage is poor).

White-beaked Dolphin (*Lagenorhynchus albirostris*) Common over a large part of the northern European continental shelf (50-200 m), occurring at greatest abundance in the central and northern North Sea across to north-west Scotland. Less common off western Ireland, and rare in the Irish Sea, western Channel and southern North Sea. Although present in the region year-round, it is most common in coastal waters between June and September, with numbers peaking in August, especially in the northern North Sea.

Atlantic White-sided Dolphin (*Lagenorhynchus acutus*) Common, mainly offshore along the continental shelf edge (100-300 m), but also coming onto the shelf around the Hebrides, Northern Isles and northern North Sea, as well as western Ireland and the Western Approaches to the Channel. Rare in the Irish Sea, eastern Channel and southernmost North Sea. The species comes onto the continental shelf between June and November, with numbers peaking in September.

Risso's Dolphin (*Grampus griseus*) Widely distributed in small numbers (though locally common in a few regions) along the Atlantic European seaboard from the Northern Isles of Scotland to the Southern Ireland and the Brittany coast of France. Although usually a species of continental slopes (400-1,200 m), in the ASCOBANS region, the species is frequently found at depths of 50-100 m, where it occurs mainly between May and October. The major populations in the UK occur in the Hebrides but the species is regular also in the Northern Isles, and in the Irish Sea around the Lleyn Peninsula of North Wales.

Bottlenose Dolphin (*Tursiops truncatus*) Locally fairly common along the Atlantic European seaboard from the Hebrides of West Scotland to the Channel Islands and coasts of North-west France. It is rare in the central and southern North Sea and the eastern Channel. Resident communities exist in the Moray Firth, Eastern Scotland (with seasonal movements east and south to North-east England) and in Cardigan Bay, West Wales, with additional groups seasonally moving around South-west England and along the Channel coasts of England. Numbers at most UK coastal localities are greatest between July and October with a secondary peak in certain areas in March-April, although some animals are present near-shore in every month of the year. The species also occurs offshore particularly along the continental shelf edge where it frequently associates with long-finned pilot whale.

Striped Dolphin (*Stenella coeruleoalba*) Uncommon in the ASCOBANS region, its main distribution being to the south and west, where it occurs mainly offshore beyond the continental shelf edge (1,000-3,000 m depth). Most records of the species in the region come from the South-west Approaches to the Channel and off southern Ireland, although in recent years it has occasionally been recorded in northern Britain and the northern North Sea. Most sightings occur between July and December.

Short-beaked Common Dolphin (*Delphinus delphis*) Common and widely distributed in fairly deep waters (mainly 200-500 m) along the Atlantic European seaboard, coming seasonally onto the continental shelf (50-100 m depth). In the ASCOBANS region it is common in the western Approaches to the Channel and the southern Irish Sea (particularly around the Celtic Deep) and around the Inner Hebrides north to Skye. It is also common west of Ireland, and off the continental shelf it can be found north to a latitude of about 65^{o} N (though rare north of 60^{o} N). In the UK, there appears to be a seasonal movement onto the continental shelf between May and October, whilst further south it occurs year-round with peak numbers between July and December.

Killer Whale (*Orcinus orca*) Uncommon though widely distributed in deep waters (mainly 200-1,000 m) along the Atlantic European seaboard, coming seasonally onto the continental shelf (20-100 m depth). In the ASCOBANS region it is most common off south-west Norway round to southern Sweden, and in northern and western Scotland. It is rare in the Irish, central and southern North Seas, and the English Channel. Occurs year-round but in coastal localities in Britain, it is seen mainly between April and October, with peak sightings in June to September; in Norway it is seen mainly between October and January in the Lofoten area, and in February and March off the coast of Møre.

Long-finned Pilot Whale (*Globicephala melas*) Fairly common and widely distributed in deep waters (mainly 200-3,000 m depth) seaward and along the edges of continental shelves, occasionally coming into coastal waters in North Scotland, Western Ireland, and the South-west Approaches to the Channel, with greatest numbers in June – September, except in the northern North Sea where the species is recorded frequently between November and January.

Summary In the context of potential interaction with different types of shipping, we may divide cetaceans into three groupings: 1) all baleen whales, with likely low frequency hearing (on the basis of their vocalisations), and therefore most vulnerable to noise disturbance from large vessels (and seismic) as well as physical damage from large ships; 2) all large odontocetes (sperm whale, beaked whales, pilot whales and killer whale), with mid-frequency hearing, and thus most vulnerable to noise disturbance from military sonar as well as physical damage from large ships; and 3) all small odontocetes (dolphins and porpoises), with high-frequency hearing, and therefore most vulnerable to noise disturbance and physical damage from smaller planing vessels with cavitating propellers. Sightings for each of these groupings are plotted here on maps 1-3. These plots derive from the UK sightings database held by Sea Watch Foundation. They have not been corrected for effort, and are presented here simply as a rough guide to the main distribution of the three groupings. It should be noted that coverage is best for UK waters, with declining effort on the eastern side of the North Sea, and little effort in Danish waters and the Baltic. Nevertheless, they do give a picture of the relative frequency of the different cetacean groupings, with baleen whales and large odontocetes most common in the northern North Sea and European Atlantic seaboards, and small odontocetes widely distributed on the continental shelf, occurring rarely only in the eastern English Channel and southernmost North Sea. Although not depicted here, small odontocetes are the main group present in Danish waters, whilst in the Baltic, only one species, the harbour porpoise, occurs and then only in very small numbers.

APPENDIX 2. SOUND SOURCES FROM VARIOUS MARITIME ACTIVITIES

(from Evans, 1996)

Activity	Frequency Range (kHz)	Av. Source Level (dB/1 µPa/1m)	Estimated Received Level at different ranges (km) by spherical spreading			
			0.1	**1.0**	**10.0**	**100**
Geophysical seismic surveys						
a) High resolution						
- pingers, side-scanner, fathometer	10-200	<230	190	170	149	128
b) Low resolution						
- airguns[1]	<0.5	230-250	190-210	170-190	149-169	128-148
- airguns[2]	0.008-0.2	248	210*	144*	118*	102†
- sleeve exploder	0.005-0.5	225-270	185-230	165-210	144-189	123-168
- vibroseis	0.02-0.07	260	220	200	179	158
- explosives (TNT)	-	270	230	210	189	168
c) Drilling Exploration						
- jack-up	0.005-1.2	85-127	45-87	25-67	4-46	<25
- semi-submersible	0.016-0.2	167-171	127-131	107-111	86-90	65-69
Drilling Production	0.25	163	123	103	82	61
d) Dredging						
- gravel island	-	130	90	70	49	28
- suction dredge	0.38	160	120	100	79	58
Vessels						
- 650 cc jet ski	0.8-20.0	75-125	35-85	15-45	<25	<25
- 6 hp outboard inflatable	0.8-20.0	105-130	65-90	45-70	24-49	<25
- 90 hp outboard speedboat	0.8-20.0	110-130	70-90	50-70	29-49	<25
- 240 hp inboard fishing boat	0.1-20.0	110-135	70-95	50-75	29-54	<25
- large merchant vessel	0.05-0.9	160-190	120-150	100-130	79-109	58-88
- supertanker	0.02-0.1	187-232	147-192	127-172	106-151	85-130
- oceanographic vessel	<0.1	170-230	130-190	110-170	89-149	68-128
- icebreaker	0.01-1.0	183-191	143-151	123-131	102-110	81-89
- military vessel	-	190-203	150-163	130-143	109-122	88-101

[1] = Beaufort Sea, Canada, early 1980's; [2] = St George's Channel, Irish Sea, 1993; * = actual measurements; † = extrapolated

APPENDIX 3. Sound production characteristics for the cetacean species regularly recorded in the ASCOBANS Region (from Richardson *et al*., 1995; Evans and Nice, 1996; Wartzok and Ketten, 1999, with recent additions)

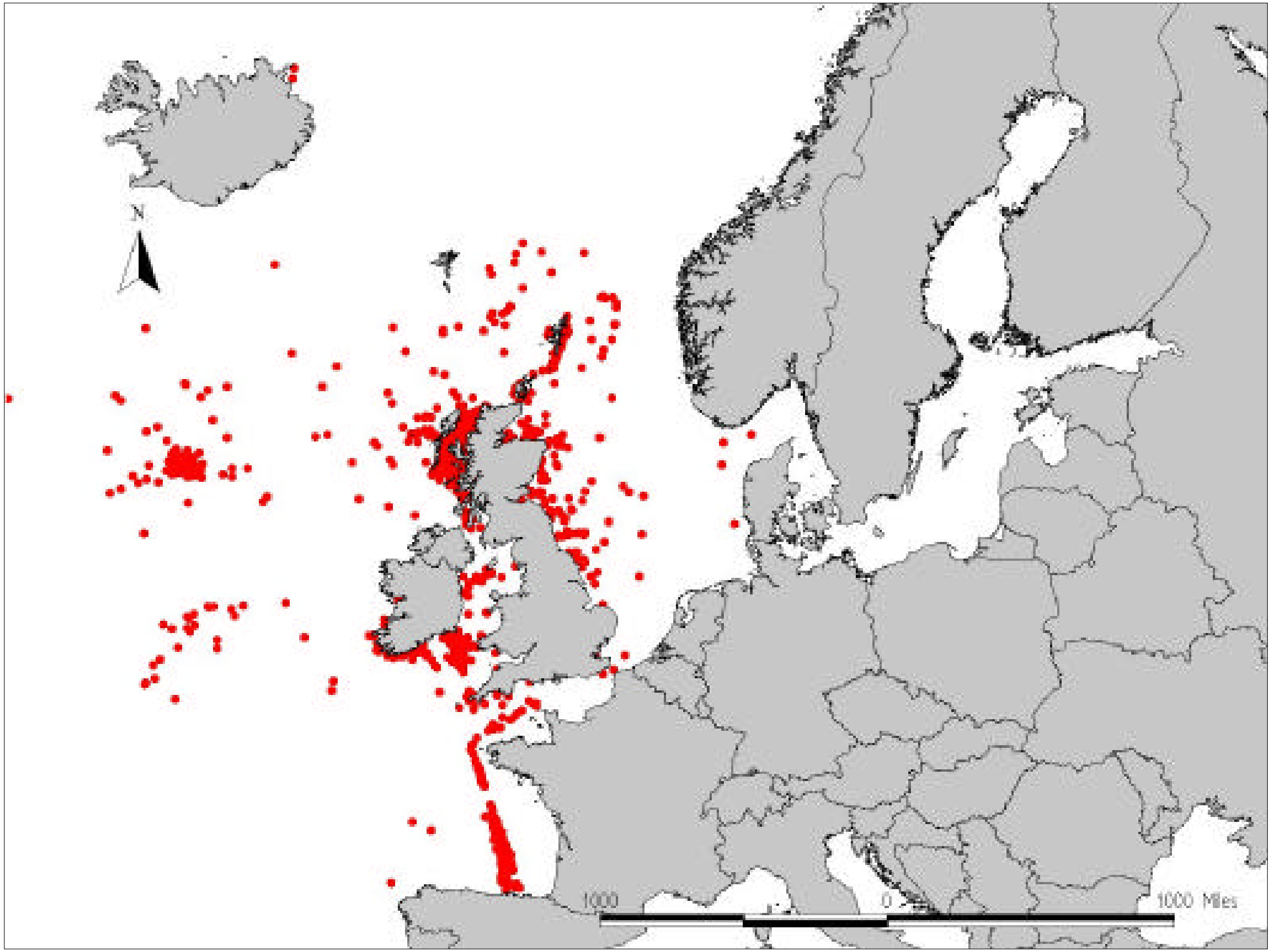
Scientific Name	**Common Name**	**Signal Type**	**Frequency Range (kHz)**	**Frequency Near Max. Energy (kHz)**	**Source Level (dB re 1 µPa)**	**References**
B. physalus	Fin whale	Moans	0.016-.0750	0.020	160-190	Thompson *et al*. 1979, Edds 1988
		Pulse	0.04-0.075			Clark 1990
		Pulse	0.018-0.025	0.020		Watkins 1981
		Ragged pulse	<0.030			Watkins 1981
		Rumble		<0.030		Watkins 1981
		Moans, down-sweeps	0.014-0.118	0.020	160-186	Watkins 1981, Watkins *et al*. 1987, Edds 1988, Cummings & Thompson 1994
		Constant call	0.02-0.04			Edds 1988
		Moans, tones, upsweeps	0.03-0.75		155-165	Watkins 1981, Cummings *et al*. 1986, Edds 1988
		Rumble	0.01-0.03			Watkins 1981, Edds 1988
		Whistles[a], Chirps[a]	1.5-5	1.5-2.5		Thompson *et al*. 1979
		Clicks[a]	16-28			Thompson *et al*. 1979
B. borealis	Sei whale	Fm sweeps	1.5-3.5			Thompson *et al*. 1979, Knowlton *et al*. 1991
B. acutorostrata	Minke whale	Sweeps, moans	0.06-0.14		151-175	Schevill & Watkins 1972, Winn & Perkins 1976
		Down sweeps	0.06-0.13		165	Schevill & Watkins 1972
		Moans, grunts	0.06-0.14	0.06-0.14	151-175	Schevill & Watkins 1972, Winn & Perkins 1976
		Ratchet	0.85-6	0.85		Winn & Perkins 1976
		Thump trains	0.10-2	0.10-0.20		Winn & Perkins 1976
		Clicks? Clicks?	5-20 3.3-3.8, 5.5-7.2, 10.2-12	4.0-7.5 5.0-6.0		Beamish & Mitchell 1973 Winn & Perkins 1976
Megaptera novaeangliae	Humpback whale	Songs	0.03-8	0.1-4	144-186	Thompson *et al*. 1979, Watkins 1981, Edds 1982, 1988, Payne *et al*. 1983, Silber 1986, Clark 1990
		Social	0.05-10	<3		Thompson *et al*. 1979
		Song components	0.03-8	0.120-4	144-174	Thompson *et al*. 1979, Payne & Payne 1985

Megaptera novaeangliae	Humpback whale	Shrieks		0.750-1.8	179-181	Thompson *et al*. 1986
		Horn blasts		0.410-0.420	181-185	Thompson *et al*. 1986
		Moans	0.02-1.8	0.035-0.360	175	Thompson *et al*. 1986
		Grunts	0.025-1.9		190	Thompson *et al*. 1986
		Pulse trains	0.025-1.25	0.025-0.080	179-181	Thompson *et al*. 1986
		Slap	0.03-1.2		183-192	Thompson *et al*. 1986
		Clicks	2-9			Thompson *et al*. 1986
		Pulsive			181-186	Clark (in Wursig *et al*. 1982)
Physeter macrocephalus	Sperm whale	Clicks	0.1-30	2-4, 10-16	160-180	Backus & Schevill 1966, Levenson 1974, Watkins 1980a, b
		Clicks in coda	16-30			Watkins 1980a, b
Orcinus orca	Killer whale	Whistles	1.5-18	6-12		Steiner *et al*. 1979, Ford & Fisher 1983, Morton *et al*.1986
		Clicks	0.25-0.5			Schevill & Watkins 1966
		Screams	2			Schevill & Watkins 1966
		Clicks	0.1-35	12-35	180	Diercks *et al*. 1971, Diercks 1972
		Pulsed calls	0.5-25	1-6	160	Schevill & Watkins 1966
Hyperoodon ampullatus	Northern bottlenose whale	Chirps		3-16		Hooker & Whitehead 2002
		Whistles		4		Hooker & Whitehead 2002
		Clicks		2-22 (mean 11); 20-28 (mean 24)		Hooker & Whitehead 2002
Globicephala melas	Long-finned pilot whale	Whistles	1-8, 0.5-5.0	1.6-6.7[b]		Busnel & Dziedzic 1966a, IFAW web site
		Clicks	1-18			Taruski 1979, Steiner 1981
		Clicks		6-11		McLeod 1986
		Clicks		30-60	180	IFAW web site
Grampus griseus	Risso’s dolphin	Whistles		3.5-4.5		Caldwell *et al*. 1969
		Rasp/pulse burst	0.1->8.0	2.0-5.0		Watkins 1967
Lagenorhynchus acutus	Atlantic white-sided dolphin	Whistles		6.0-15.0		Steiner 1981
Lagenorhynchus albirostris	White-beaked dolphin	Squeals		8.0-12.0		Watkins & Schevill 1972
Delphinus delphis	Short-beaked common dolphin	Barks		<0.5-3.0		
		Whistles	4.0-16.0			Busnel & Dziedzic 1966
		Chirps		0.5-18.0		Caldwell & Caldwell 1968, Moore & Ridgway 1995

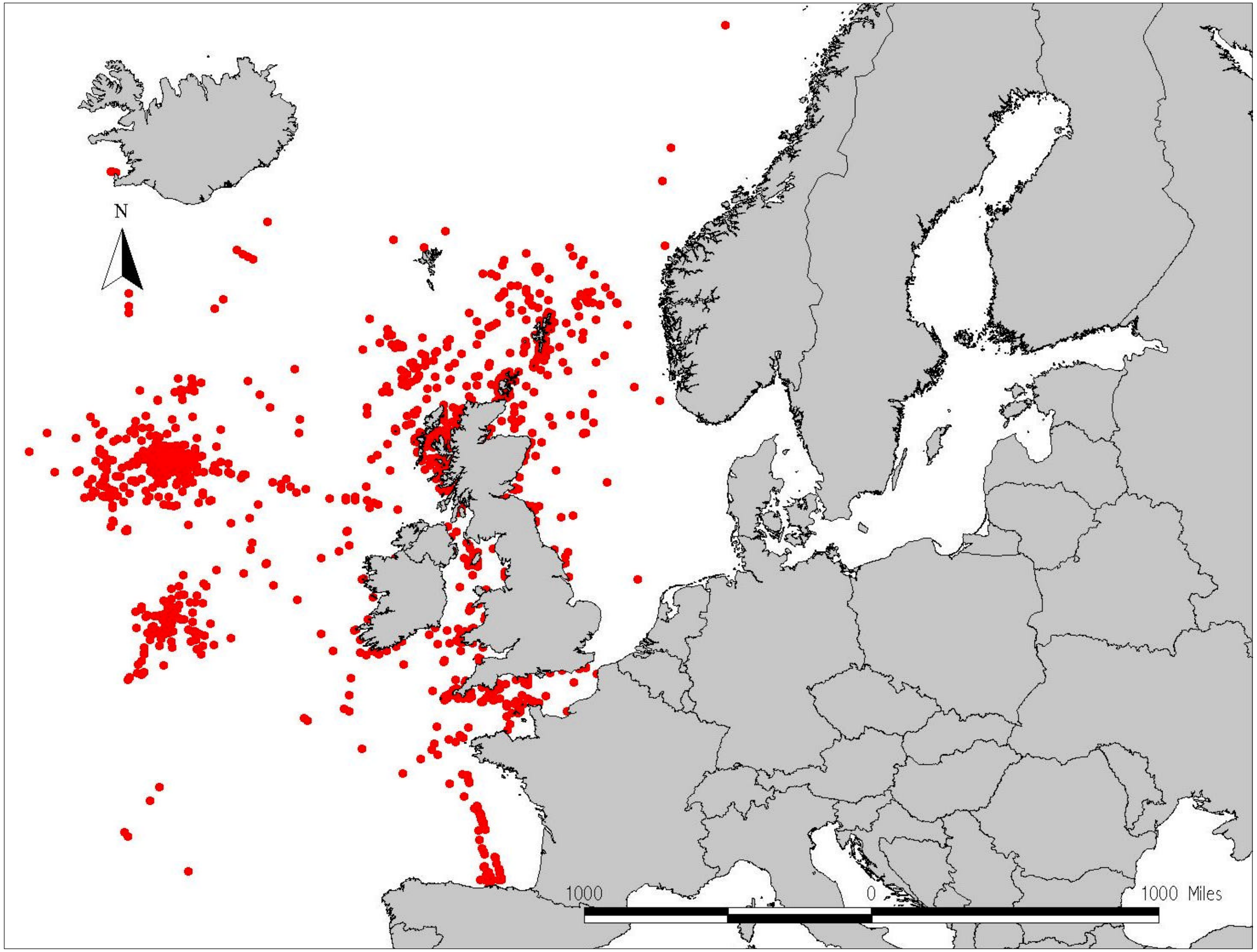
		Clicks	0.2-150	30-60, 23-67	140	Busnel & Dziedzic 1966, Dziedzic 1978
Tursiops truncatus	Bottlenose dolphin	Barks	0.2-16.0			Evans & Prescott 1962
		Whistles	4.0-20.0	3.5-14.5	125-173	Caldwell & Caldwell 1967, Evans & Prescott 1962
		Clicks	0.2-150	30-60		Diercks *et al*. 1971, Evans 1973
		Clicks		110-130	218-228	Au *et al*. 1974, Au 1993
Phocoena phocoena	Harbour porpoise	Pulses	100-160	110-150		Møhl & Anderson 1973
		Clicks		110-150	135-177	Busnel *et al*. 1965, Møhl & Anderson 1973, Kamminga & Wiersma 1981, Akamatsu *et al*. 1994

[a] Few recordings or uncertain verification of sound for species

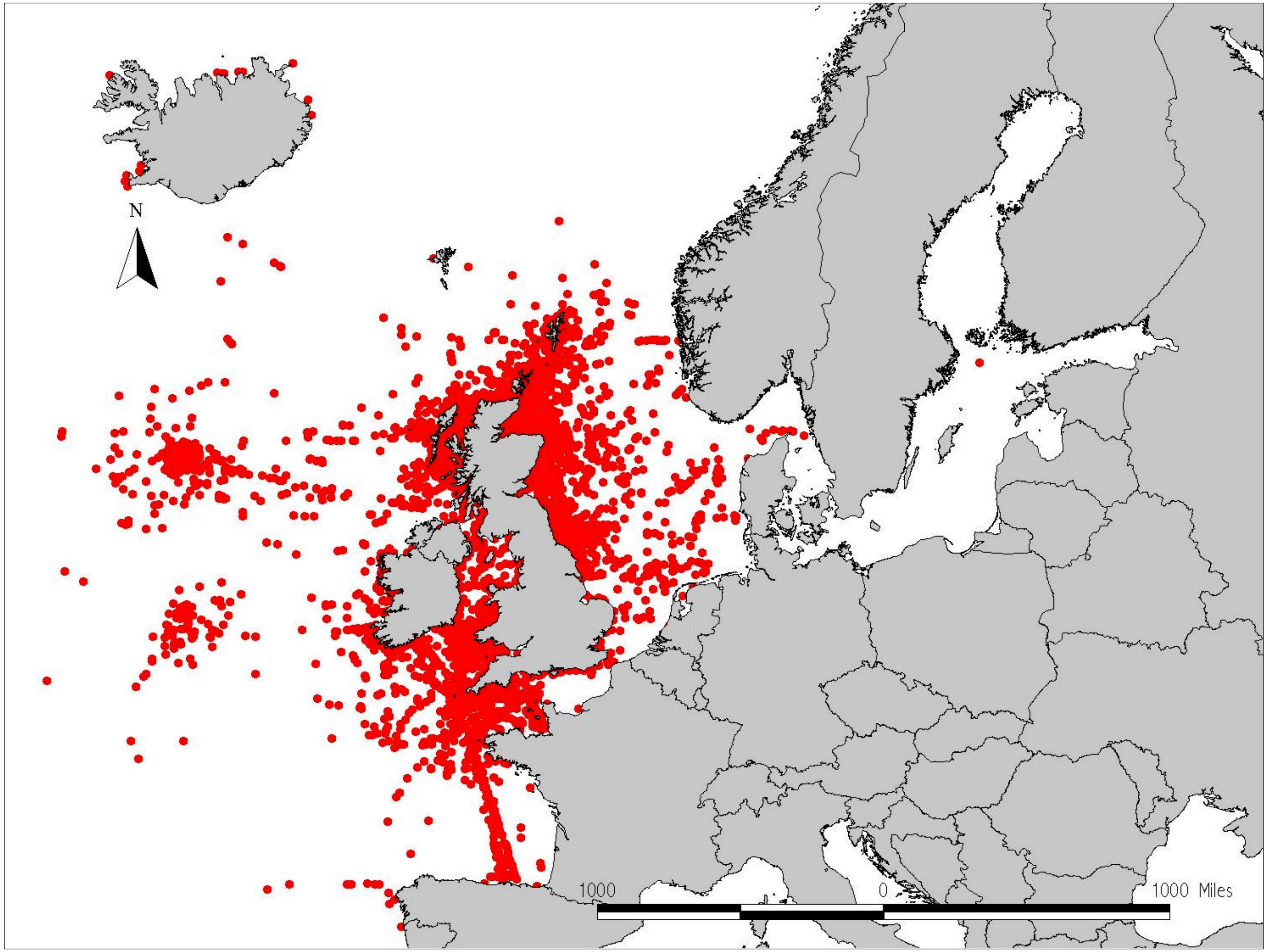
[b] Frequency determined as “mean minimum frequency minus 1 sd…to. Mean maximum frequency plus 1 sd (***sensu*** Richardson ***et al***., 1995)



Map 1. Distribution of baleen whales in the ASCOBANS region



Map 2. Distribution of large odontocetes in ASCOBANS region



Map 3. Distribution of small odontocetes in the ASCOBANS region

APPENDIX 4. Overview of High-Speed Ferry routes in the ASCOBANS area and adjacent waters in 2002 (from Document AC10/Doc. 33)

Name/type of craft	Route (return)	Round trips/day	Speed (kph/knots)	Capacity (passengers/cars)	Size/tonnage	Engine power
Baltic Sea						
Tallink Autoexpress 1/catamaran	Helsinki ⇔ Tallinn	3	38 knots	556/150		
Tallink Autoexpress 2 / catamaran	Helsinki ⇔ Tallinn	3	34 knots	660/175		
Nordic Jet / catamaran	Helsinki ⇔ Tallinn	3	38/40.5 knots	428/55 or 38 cars +2 buses	120 tons	2 x 7 200 kW
Baltic Jet / catamaran	Helsinki ⇔ Tallinn	3	38/40.5 knots	428/55 or 38 cars +2 buses	120 tons	2 x 7 200 kW
Super Sea Cat Four / catamaran	Helsinki ⇔ Tallinn	5-7 (plus Super Sea Cat One)	38 (max. 42) knots	722/140 cars + 4 buses		
Finnjet / ship	Summer: Helsinki ⇔ Tallinn ⇔ Rostock Winter: Helsinki ⇔ Tallinn	0.5	30.5/16.8 knots	1781/395		55 000 kW/11 520 kW
Jaanika / hydrofoil	Helsinki ⇔ Tallinn	6-7 (together with Laura	38 knots	192		2 x 2 200 kW
Laura / hydrofoil	Helsinki ⇔ Tallinn		38 knots	190		2 x 2 200 kW
Linda Express / foilcat	Helsinki ⇔ Tallinn		55	286		4 x 1700 kW
Superfast	Helsinki ⇔ Rostock	0.5	27.1/max. 30.4	626/661 cars or 82 cars + 98 18m-trailers or 110 16m-trailers	30/285 GRT	
HSC Gotland	Nynäshamn ⇔ Visby		35 knots	700/140	5632/450	28 000 kW
Delphin	Rostock ⇔ Trelleborg		37.5 knots	600/175	5541/346	32 172 hK
HSC Villum Clausen	Ystad ⇔ Rönne		41 knots (max 50)	1037/186	6402/485	36 000 kW
Superfast VII and Superfast ViIII	Rostock ⇔ Hanko	1	56/30	626	30 285 GRT	46 080 HP
Superfast IX and Superfast X	Rostock ⇔ Södertelje	1	56/30	626	30 285 GRT	46 080 HP

Name/type of craft	Route (return)	Round trips/day	Speed (kph/knots)	Capacity (passengers/cars)	Size/tonnage	Engine power
Baltic Sea (cont.)						
HS Merlin (hydrofoil)	[1] Gdynia ⇔ Hel	5, 2-R (1 May-15 Sept only)	32 knots	70 passengers	20 tons	736KW
As above	[2] Gdynia ⇔ Jastarnia	2, 4-R (1 May-15 Sept only	As above	As above	As above	As above
As above	[3] Sopot ⇔ Hel	3 (1 May-15 Sept only	As above	As above	As above	As above
As above	[4] Sopot ⇔ Jastarnia	3 (1 May-15 Sept only)	As above	As above	As above	As above
Delfin I (hydrofoil)	[5] Kolobrzeg ⇔ Nexo	1 (10 Apr-31 May: Wed,Sa,Su; 1Jun-31 Aug: all week; 1 Sept-31 Oct: Wed,Sa,Su)	36 knots	130 passengers	31.9 m/60 tons	2 x 960 KW
Polesie (hydrofoil) (pod bandera rosyjska)	[6] Elblag ⇔ Krynica Morska	1 (1 May-15 Sept)	28 knots	43 passengers	31 BRT	736 KW
As above	[7] Frombork ⇔ Kaliningrad	1 (1 May-15 Sept)	As above	As above	As above	As above
As above	[8] Frombork ⇔ Krynica Morska	1 (1 May-15 Sept)	As above	As above	As above	As above
HSC Baltic Spirit (high speed catamaran)	[9] Kolobrzeg ⇔ Nexo	1 (26 Feb-31Aug: Wed,Th)	30 knots	240 passengers	286 BRT	2 x 1500 KW
As above	[10] Ustka ⇔ Nexo	1 (22 Jun-31 Aug: Sa,Su, Mo)	As above	As above	As above	As above
As above	[11] Darlowo ⇔ Nexo	1 (25 Jun-31Aug: Tu,Fr)	As above	As above	As above	As above
As above	[12] Ustka ⇔ Darlowo	1 (22 Jun-31 Aug: Mo-return-Fr)	As above	As above	As above	As above
As above	[13] Darlowo ⇔ Kolobrzeg	1 (22 Jun-31 Aug: Tu-return-Th)	As above	As above	As above	As above

Name/type of craft	Route (return)	Round trips/day	Speed (kph/knots)	Capacity (passengers/cars)	Size/tonnage	Engine power
Tornado –I (hydrofoil)	[12]Ustka ⇔ Nexo	1 (19 Jun –31Aug, Wed)	32 knots	124 passengers	130 BRT	2 x 960 KW
As above	[11]Darlowo ⇔ Nexo	1 (19 Jun –31Aug, Thu)	As above	As above	As above	As above
As above	[9]Kolobrzeg ⇔ Nexo	1 (1-4 May, Thu, Fr, Sat, Sun)	As above	As above	As above	As above
As above	As above	1 (5 May – 18 Jun Fr, Sat, Sun)	As above	As above	As above	As above
As above	As above	1R (5 May – 18 Jun, Tue, Wed, Thu)	As above	As above	As above	As above
As above	As above	1 (19 Jun – 4 Jul, Fr, Sat, Sun)	As above	As above	As above	As above
Tornado –I (hydrofoil)	[5] Kolobrzeg ⇔ Nexo	1R (19 Jun – 4 Jul, Mon, Wed)	32 knots	124 passengers	130 BRT	2 x 960 KW
As above	As above	1 (5 Jul – 5 Aug, Mon, Sun)	As above	As above	As above	As above
As above	As above	1 (5 Jul – 5 Aug, Tue, Fr, Sat)	As above	As above	As above	As above
As above	As above	1 (1-30 Sep, Fri, Sat, Sun)	As above	As above	As above	As above
As above	As above	1R (1-30 Sep, Tue, Wed, Thu)	As above	As above	As above	As above
Tornado –I (hydrofoil)	Gdynia ⇔ Hel ⇔ Kaliningrad	20 Jun to 30 Sept	32 knots	124 passengers	130 BRT	2 x 960 KW
Raketa (hydrofoil)	[14] Gulf of Gdansk (Gdynia ⇔ Hel and others)		26 knots	64 passengers	77 BRT	730
Zodiak or Pogwizd (hydrofoils)	[15] Gdynia ⇔ Hel	2 (?) (01 May-30 Oct.)	32 knots*	116 passengers	35 m / 60 tons	1000 KM

Skagerrak, Kattegat, and Belt Sea						
HSS Stena Carisma	Gothenburg ⇔ Frederikshavn		40 knots	900/210	8631/480	44 000 HK
Cat-Link IV / Incat 046	Arhus ⇔ Odden		42-44 knots			
Mai og Mie Mols SWATH-type	Odden ⇔ AEbeltoft		45-48 knots	450/120	984 tons	16 860 HK
Stena Line / HSS 900	Göteborg (Sweden) ⇔ Frederikshavn		40 knots	900/210	450 tons	44 000 HK
Silvia Ana L / DNV, 1A1 HSLC Car ferry AR1 EO	Hirtshals ⇔ Kristiansund (Sweden)		40 knots	1036/238	1846 tons	46 100 HK
Max Mols & Mads Mols, Incat 91 m 1a1 HSLC R1 Car Ferry “A” EO	Køge ⇔ Rønne		44 knots	800/225		4 x 7080 KW
Max Mols Incat 91 m 1a1 HSLC R1 Car Ferry “A” EO	Rønne ⇔ Ystad (Sweden)		44 knots	800/225		4 x 7080 KW
Super Seacat One / MDV1200	Göteborg (Sweden) ⇔ Frederikshavn		40 knots		1250 tons	4 x 6875 KW
Villum Clausen	Rønne ⇔ Ystad (Sweden)		40 knots			
MS Salten / LIRM	Nexø ⇔ Kolbrzeg/Ustka		32 knots	200		640 KW
Hansa/Baltin Jet DQLN/DQVB	København ⇔		36 knots	342	466 BRZ	

North Sea						
Cat No. 1	Sylt ⬄ Helgoland	1 (30 days/yr Mar-Sep)	74/40 knots	432	-	12 633 HP
Cat No. 1	Amrum ⬄ Helgoland	1 (31 days/yr Mar-Sep)	74/40 knots	432	-	12 633 HP
Cat No. 1	Langeoog ⬄ Helgoland	1 (17 days/yr Mar-Oct)	74/40 knots	432	-	12 633 HP
Cat No. 1	Norderney ⬄ Helgoland	1 (60 days/yr Mar-Oct)	74/40 knots	432	-	12 633 HP
Cat No. 1	Norddeich ⬄ Norderney ⬄ Helgoland	1 (4 days/yr Jun-Sep)	74/40 knots	432	-	12 633 HP
Cat No. 1	Hooksiel ⬄ Helgoland	1 (58 days/yr Mar-Oct)	74/40 knots	432	-	12 633 HP
Cat No. 1	Hooksiel ⬄ Sylt	1 (2 days/yr - 18 Aug + 19 Sep)	74/40 knots	432	-	12 633 HP
Hanse Jet II	Hamburg-Wedel ⬄ Cuxhaven ⬄ Helgoland	1 (28 Mar - 27 Oct only)	67/36 knots	342	-	6 600 HP
M/S Vargoy	Hamburg ⬄ Cuxhaven ⬄ Helgoland	1 (Mar-Oct)	65/36 knots	230	-	5 400 kW
M/S Nordlicht and M/S Polarstern	Emden ⬄ Borkum	2 (27 Feb - 17 Mar) 3 (18 Mar - 27 Oct) 2 (28 Oct - 6 Jan)	70/38 78/42	272 402	- -	5 548 HP 10 000 HP
MS Polarstern	Ditzum ⬄ Emden ⬄ Eemshaven ⬄ Borkum ⬄ Helgoland	2/week (5 May - 3 Jun and 25 Sept - 20 Oct) 3/week (4 Jun - 24 Sep)	78/42	402		10 000 HPPS

English Channel						
Catalonia Incat 91	Portsmouth ⇔ Cherbourg (France)	2	40 knots	360/200	91m	28 800 kW
Red Jet 1 Red Jet 2 Red Jet 3	Southampton ⇔ Cowes (IoW)	2/18 18/2 16	36 knots	138 138 190	32.5/168 GRT 32.5/168 GRT 33.5/213 GRT	1 360 kW 1 360 kW 1 500 kW
SuperSeacat I Fincantieri HS Ropax Monohull	Newhaven ⇔ Dieppe (France)	2	37 knots	700/140	100m/GT4662t	4 x Ruston 16RK270M, each 4964 BHP (3650 kW) each driving LIPS water jets type IRC 115 DA, 4 of which are steering jets
Hoverspeed Great Britain INCAT 74m HS Ropax Catamaran	Dover ⇔ Calais (France)	4	36 knots	340/85	74m/GT3003t	4 x Ruston 16RK270M, each 4964 BHP (3650 kW) each driving LIPS water jets type IRC 115 DA, 4 of which are steering jets
Seacat Danmark INCAT 74m HS Ropax Catamaran	Dover ⇔ Calais (France)	4	36 knots	430/85	74m/GT3003t	as above
Seacat France INCAT 74m HS Ropax Catamaran	Dover ⇔ Calais (France)	4	36 knots	430/85	74m/GT3003t	as above
Seacat Diamant INCAT 81m HS Ropax Catamaran	Dover ⇔ Calais (France)	4	35 knots	654/140	81m/GT4305t	4 x Ruston 16RK270 Mk2, 555 500 kW each driving LIPS water jets type LJ1 35/8DL, 4 of which are steering jets

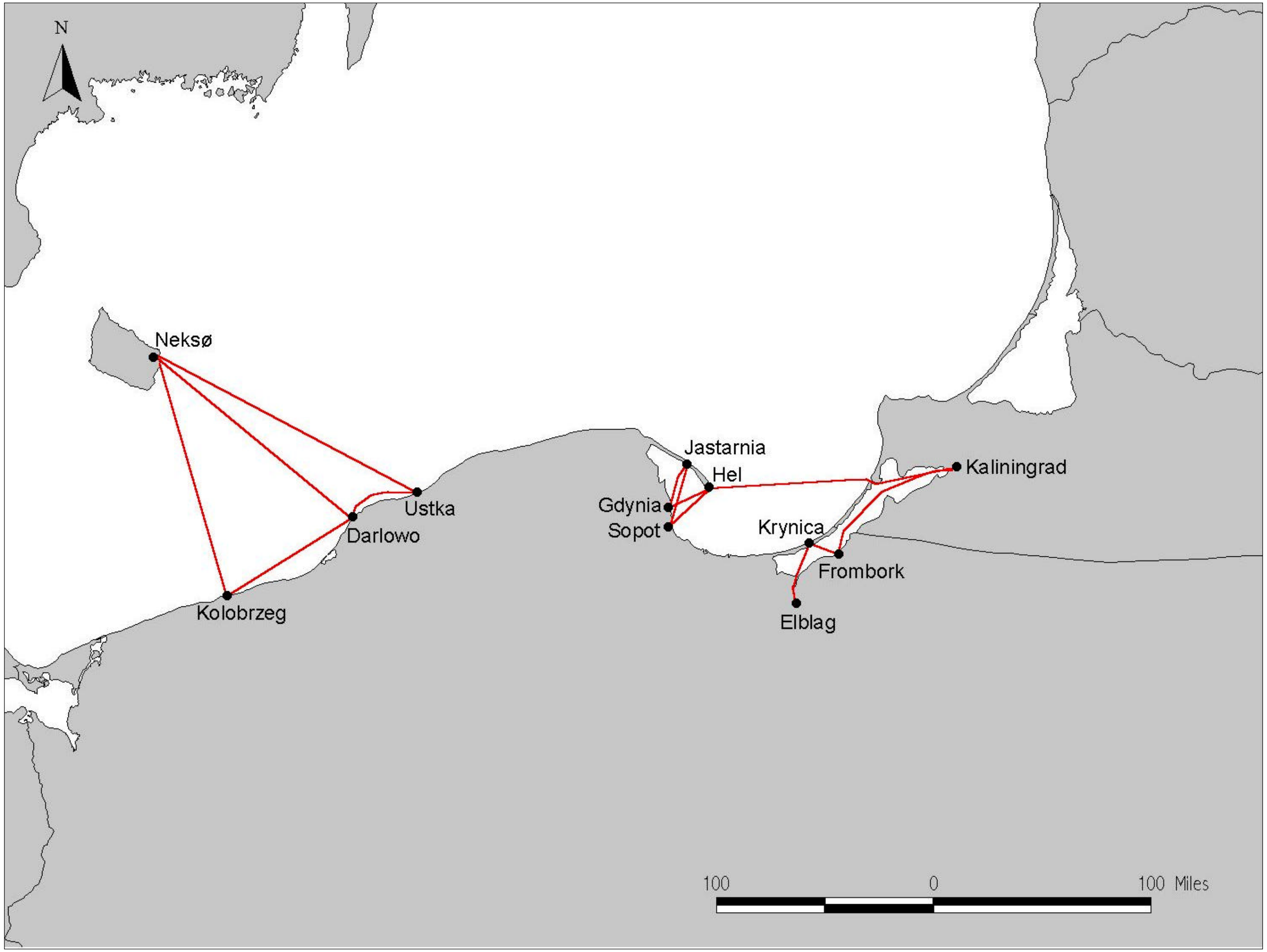
Condor Express Incat 86m Wavepiercer	Weymouth ⇔ Guernsey ⇔ Jersey ⇔ Poole	2 winter operating Weymouth/Channel Islands/Weymouth	40 knots	800/185	86m	29 mw
Condor Vitesse, Incat 86m Wavepiercer	Poole ⇔ Cherbourg (France) Guernsey ⇔ St Malo (France) Guernsey ⇔ Poole	1 summer only	40 knots	800/185	86m	29 mw
Condor 10, Incat 74m Wavepiercer	St Malo ⇔ Jersey ⇔ Guernsey ⇔ St Malo (France)	3 summer only	35 knots	600/84	74m LOA	20 mw
Double O Seven Hovercraft	Ryde ⇔ Isle of Wight ⇔ Southsea, Hampshire	70 summer, 60 winter	max. 45 knots	95 passengers	LOA 24.5m, Beam 11.2m, 1011.95gt	4 x 386 kW
Island Express Hovercraft	Ryde ⇔ Isle of Wight ⇔ Southsea, Hampshire	As above	As above	As above	LOA 25.4m, Beam 11.2m, 102.92gt	2 x 613 kW, 2 x 386 kW
Freedom 40 Hovercraft	Ryde ⇔ Isle of Wight ⇔ Southsea, Hampshire	As above	As above	As above	LOA 25.4m, Beam 11.2m, 102.92gt	2 x 613 kW, 2 x 386 kW
Fastcat Ryde Catamaran	Portsmouth ⇔ Ryde (IoW)	33 trips collectively	34 knots	361 passengers	GRT 478 LOA (m) 40	4 000 kW
Fastcat Shanklin Catamaran	Portsmouth ⇔ Ryde (IoW)		34 knots	361 passengers	GRT 482 LOA (m) 40	4 000 kW

Irish Sea						
Rapide INCAT 81 m HS Ropax Catamaran	Belfast ⇔ Heysham	2	34 knots	650/140	81m/GT4112t	4 x Ruston 16RK270 Mk2, 5 500 kW, each driving LIPS water jets type LJ1 35/8DL, 4 of which are steering jets
SuperSeacat III Fincantieri HS Ropax Monohull	Liverpool ⇔ Douglas (IoM) Liverpool ⇔ Dublin	1 1	37 knots	700/140	81m/GT4663t	4 x Ruston 16RK270M, each 4964 BHP (3650 kW) each driving LIPS water jets type IRC 115 DA, 4 of which are steering jets
Sea Cat Scotland INCAT 74 m HS Ropax Catamaran	Troon ⇔ Belfast	3	34 knots	431/80	74m/GT3003t	As above
Sea Cat Isle of Man catamaran	Douglas ⇔ Liverpool Douglas ⇔ Heysham Douglas ⇔ Belfast Douglas ⇔ Dublin	1 weekly 2 weekly 2 weekly 3 weekly	34 knots	516/80	74m/GT3003t	As above
Stena HSS 1500	Holyhead ⇔ Dun Loaghaire	3/4	40 knots	1500/375	19638 GRT	2 x 21 200 kW 2 x 13 700 kW
Stena Line HSS 1500	Stranraer ⇔ Belfast	5	40 knots	1500/375	19638 GRT	2 x 21 200 kW 2 x 13 700 kW
Stena Line Incat 81m	Fishguard ⇔ Rosslare	2/3	37 knots	627/140	4113 GRT	4 x 5 500 kW
Irish Ferries HSC Jonathan Swift Austal 86m Catamaran	Dublin ⇔ Holyhead	3	39.5 knots	768/200	86m x 24m GT5989	28 000 kW
Superstar Express 82m Catamaran	Larne ⇔ Cairnryan	5	35	850	82m, 1256mt, full load displacement	26 mw

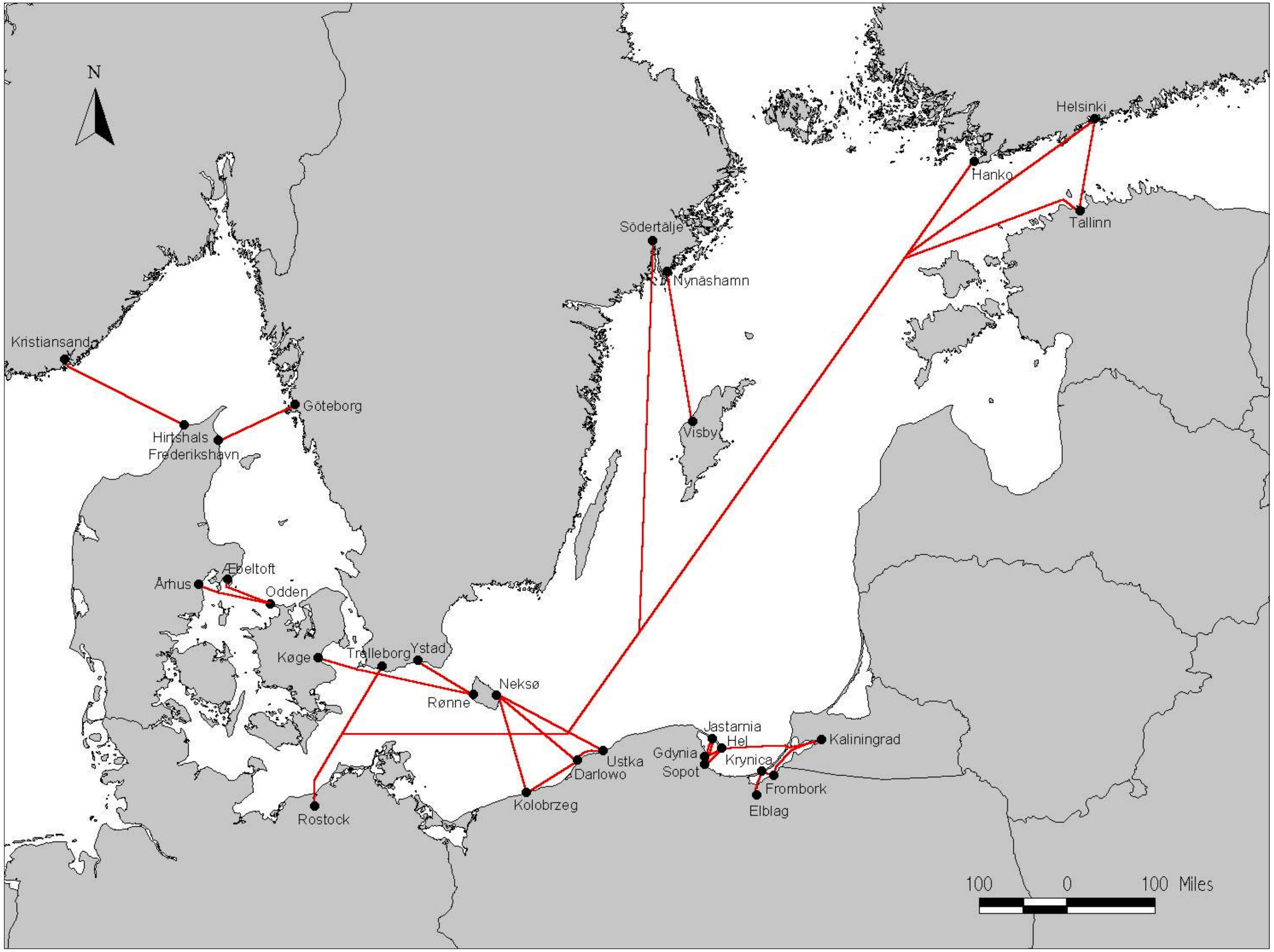
All types of vessels (including hovercraft) capable of travelling at speeds in excess of 30 knots.

LEGEND (for Polish high-speed ferries):

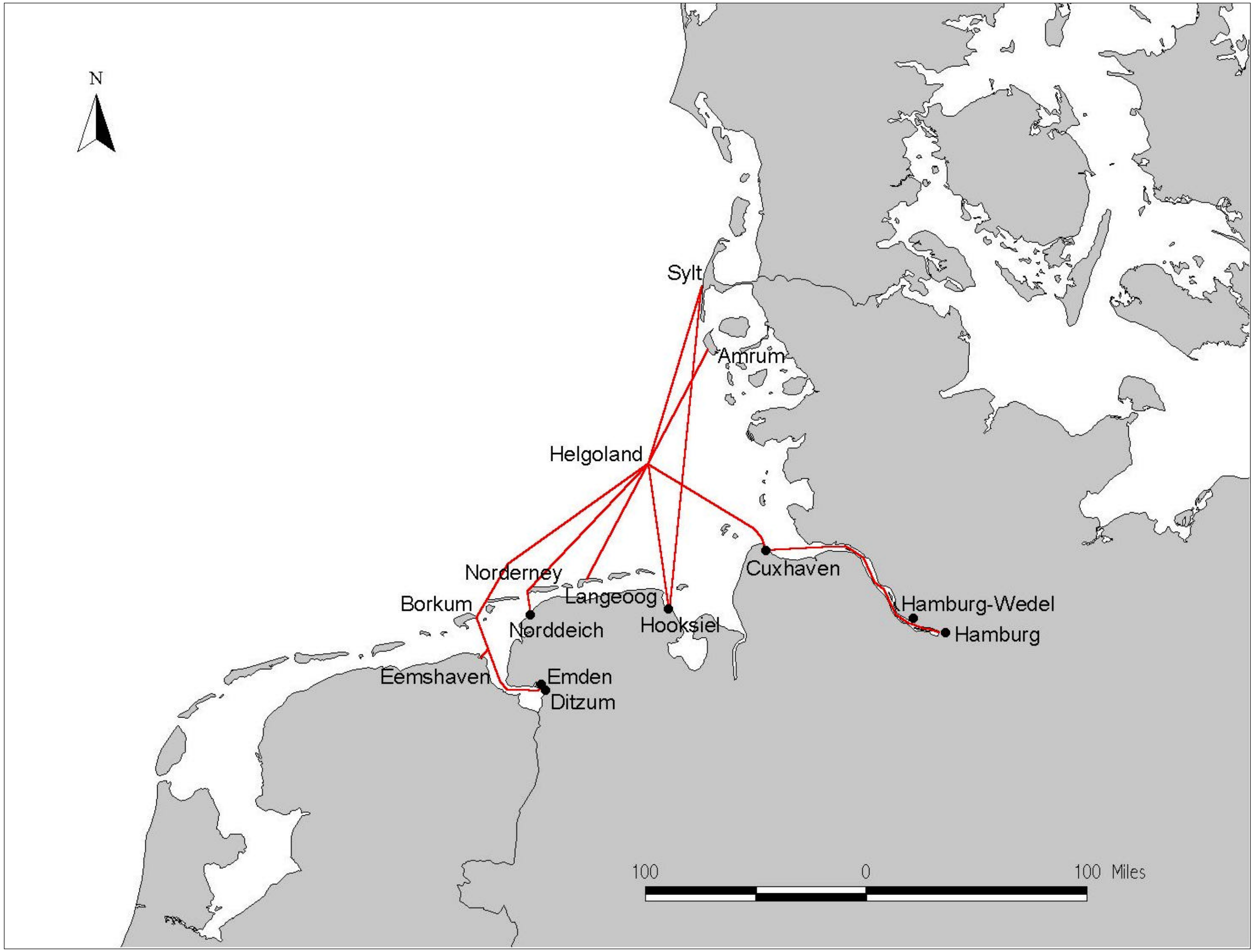
***R* - additional reserved trips; *?* - data has not been rendered accessible by the ship owner;**
***** - according to the navy experts' opinion these craft can reach a maximum speed of 26-27 knots nowadays;**
***?** - data has not been rendered accessible by the ship owner; however, it is presumed that this hydrofoil made c. 5 round trips a day in the period 15 Jun- 31 Oct**
***1-15* - these numbers relate to the numbers in Map 1.**



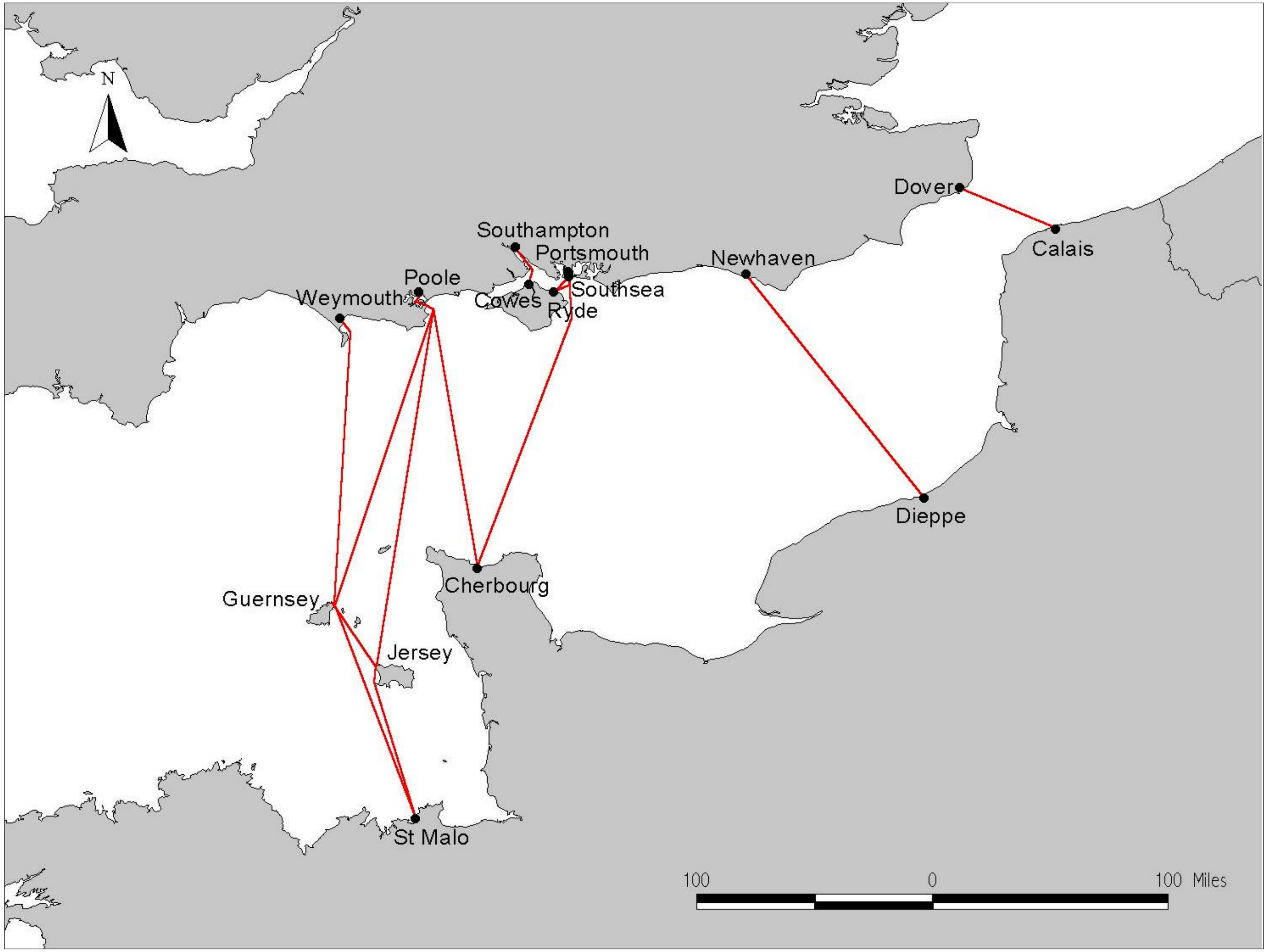
Map 1. Routes of high-speed ferries operating in Poland in 2002
[from I. Kuklik & K. Skora, 2003. ASCOBANS Document AC10/Doc. 33a (S)]



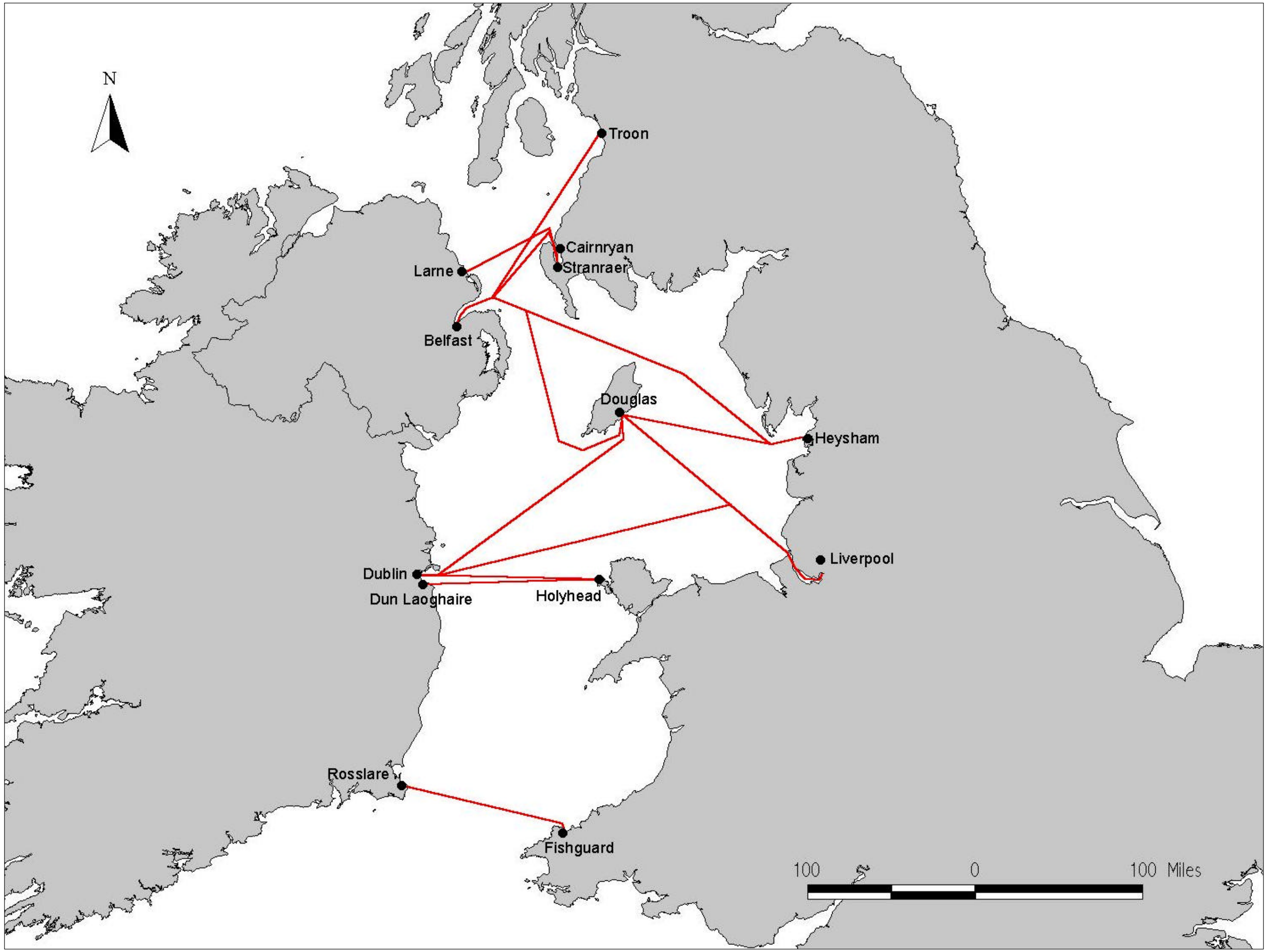
Map 2. Routes of high-speed ferries operating in the Skagerrak, Kattegat, Belt and Baltic Seas in 2002
[from ASCOBANS Secretariat, 2003. ASCOBANS Document AC10/Doc. 33 (S) & Doc. 33a (S), with addenda]



Map 3. Routes of high-speed ferries operating in the North Sea in 2002
[from ASCOBANS Secretariat, 2003. ASCOBANS Document AC10/Doc. 33 (S)]



Map 4. Routes of high-speed ferries operating in the English Channel in 2002
[from ASCOBANS Secretariat, 2003. ASCOBANS Document AC10/Doc. 33 (S)]



Map 5. Routes of high-speed ferries operating in the Irish Sea in 2002
[from ASCOBANS Secretariat, 2003. ASCOBANS Document AC10/Doc. 33 (S)]

APPENDIX 5. GENERIC CODE OF CONDUCT FOR WATCHING WHALES AND DOLPHINS (as applied in the United Kingdom)

Increasingly, dolphins around the world are facing modern pressures upon their environment – pollution, accidental capture in fishing nets, and disturbance from vessels, particularly high-speed craft.

Recreational activities in inshore waters have burgeoned recently, and can pose a major threat to cetaceans (whales and dolphins) either by direct injury when animals are accidentally cut by the boat's propeller, or by interference or stress caused from the high frequency sounds made by the vessel's motor.

There is no reason why boats and cetaceans should not be able to co-exist if care is taken to observe the following rules:

IF YOU SIGHT CETACEANS AT A DISTANCE, MAKE FORWARD PROGRESS MAINTAINING A STEADY SPEED, SLOWING DOWN TO SIX KNOTS OR LESS WHEN YOU ARE WITHIN A KILOMETRE OF THEM

DO NOT CHASE CETACEANS, DRIVE A BOAT DIRECTLY TOWARDS THEM, OR ENCIRCLE THEM; WHEREVER POSSIBLE, LET THEM APPROACH YOU. IF THEY CHOOSE TO BOW-RIDE, MAINTAIN A STEADY SPEED AND COURSE

DO NOT RESPOND TO THEM BY CHANGING COURSE OR SPEED IN A SUDDEN OR ERRATIC MANNER; SLOWING DOWN OR STOPPING SUDDENLY CAN CONFUSE AND ALARM CETACEANS AS MUCH AS SUDDEN ACCELERATION

ALLOW GROUPS OF CETACEANS TO REMAIN TOGETHER. AVOID DELIBERATELY DRIVING THROUGH, OR BETWEEN, GROUPS OF CETACEANS

AVOID CLOSE APPROACH TO CETACEANS WITH YOUNG. YOU RISK DISRUPTING MOTHER-CALF BONDS AND EXPOSE INEXPERIENCED YOUNG TO STRESS AND POSSIBLE BOAT STRIKES

DO NOT SWIM WITH, TOUCH OR FEED CETACEANS, FOR YOUR SAFETY AND THEIRS. BESIDES THE STRESS YOU CAN CAUSE THEM, REMEMBER THAT, JUST AS IN HUMANS, DISEASES CAN BE SPREAD BY CLOSE CONTACT, AND CETACEANS ARE LARGER THAN HUMANS AND CAN CAUSE UNWITTING INJURY

DO NOT THROW RUBBISH OR FOOD NEAR OR AROUND CETACEANS

ALWAYS ALLOW CETACEANS AN ESCAPE ROUTE. AVOID BOXING THEM IN BETWEEN VESSELS

ENSURE THAT NO MORE THAN TWO VESSELS ARE WITHIN A KILOMETRE OF CETACEANS AT ANY ONE TIME AND NO MORE THAN ONE BOAT WITHIN CLOSE PROXIMITY. REFRAIN FROM CALLING OTHER VESSELS TO JOIN YOU

IF OTHER VESSELS IN THE VICINITY ARE INTERESTED IN WATCHING THE CETACEANS, LIMIT YOUR PRESENCE TO 15 MINUTES. (NOTE: THE WILDLIFE AND COUNTRYSIDE ACT MAKES PROVISION FOR LICENSES TO BE ISSUED TO ALLOW CERTAIN ACTIVITIES SUCH AS RESEARCH AND SURVEY TO TAKE PLACE)

MOVE AWAY SLOWLY IF YOU NOTICE SIGNS OF DISTURBANCE, SUCH AS REPEATED AVOIDANCE BEHAVIOUR, ERRATIC CHANGES IN SPEED AND DIRECTION, OR LENGTHY PERIODS UNDERWATER

POSSIBLE SOURCES OF NOISE DISTURBANCE CAN BE AVOIDED BY ENSURING SPEEDS ARE NEVER GREATER THAN TEN KNOTS, AND BY KEEPING THE ENGINE AND PROPELLER WELL-MAINTAINED. ON THE OTHER HAND, CARE SHOULD BE TAKEN TO AVOID COLLISION WITHG DOLPHINS WHEN USING SAILING BOATS OR BOATS WITH A LOW ENGINE NOISE AS THE ANIMALS ARE LESS LIKELY TO HEAR THE VESSEL UNTIL IT IS CLOSE

PEOPLE REGULARLY USING VESSELS IN AREAS WHERE CETACEANS ARE KNOWN TO OCCUR SHOULD CONSIDER FITTING PROPELLER GUARDS TO MINIMISE THE RISK OF INJURY TO THEM

PLEASE NOTE THAT UNDER UK LAW, IT IS AN OFFENCE TO INTENTIONALLY KILL OR INJURE CETCEANS. IT IS ALSO AN OFFENCE TO DISTURB CETACEANS AND BASKING SHARKS. TO DO SO INTENTIONALLY OR RECKLESSLY* MAY RESULT IN A PRISON SENTENCE.

* Recklessness is a legal term. A person who is heedless of the consequences of his actions or of danger will be reckless.

Remember that whales, dolphins and porpoises use sound as a daily part of their life, for locating and capturing food, locating and communicating with one another, detecting predators, and forming a picture of their underwater environment in often very dim light. Many of the sounds made by craft directly overlap the frequencies used by dolphins and porpoises, particularly those caused by cavitation of the propeller blade, producing a very loud broadband, high frequency noise. This causes interference with their daily activities, sometimes excluding them from preferred feeding or nursery areas. It can also lead to undue stress, particularly when mothers are pregnant or with small young. Scientific studies have shown that dolphins respond negatively to craft moving directly at them, increasing the time they spend underwater and often swimming rapidly away from the sound source.