Background information on marine mammals relevant to Strategic Environmental Assessment 5

P.S. Hammond, S.P. Northridge, D. Thompson, J.C.D. Gordon, A.J. Hall,
R.J. Sharples, K. Grellier & J. Matthiopoulos

Sea Mammal Research Unit, Gatty Marine Laboratory
University of St Andrews, St Andrews, Fife KY16 8LB

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MARINE MAMMALS

Non-technical summary

Distribution and abundance

Eight marine mammal species are known to occur regularly in this area: grey seal, harbour seal, harbour porpoise, white-beaked dolphin, bottlenose dolphin, Atlantic white-sided dolphin, killer whale, and minke whale.. Long-finned pilot whales and Risso's dolphins are regularly seen in waters around Shetland. There are occasional at-sea records of at least a further five cetacean species (humpback whale, fin whale, sperm whale, striped dolphin and short-beaked common dolphin) and four pinniped species (hooded seal, bearded seal, ringed seal and walrus).

There is extensive information on the distribution and abundance of grey and harbour seals around Britain from annual aerial surveys of breeding colonies and from satellite telemetry studies. There is also extensive information on cetacean distribution in the North Sea from a number of summer sightings surveys (SCANS-94, NASS-89, NILS-95). Estimates of abundance are available from these surveys for some species. There are also many records from year-round surveys by the European Seabirds at Sea Consortium (ESAS) since 1979, from cetacean observations made during seismic surveys from 1996, and sightings by voluntary observers compiled by the Sea Watch Foundation. Acoustic studies using towed hydrophone arrays, pop-up sonobuoys and the US Navy's passive underwater monitoring system (SOSUS) have been used to monitor the distribution and in some cases the density of fin whales, sperm whales and dolphins in the wider area (Swift *et al* 2002).

Minke whales occur throughout the SEA5 area, especially in summer. The harbour porpoise is the commonest cetacean in the region. The area to the north and east of Scotland has some of the highest densities of porpoises recorded. Sightings rates are highest in summer. White-beaked dolphins are restricted to the North Atlantic. In the SEA5 area they are widely distributed on the continental shelf to the south and east of Orkney and Shetland. The SEA5 area is a particularly important area for minke whales, harbour porpoises and white-beaked dolphins.

Killer whales have been observed throughout the northwestern North Sea in all months except October, and especially in deeper water. There are regular sightings around Shetland.

The Moray Firth and the coast of eastern Scotland is home to the only resident population of bottlenose dolphins in the North Sea. Dolphins are seen year round in the Moray Firth and off Aberdeen; in the latter area the rate of sightings is highest in November-May. Peak sightings occur in St Andrews Bay in June-August. This population is small (estimated 129 individuals) and geographically isolated. Population models have predicted that the Scottish east coast population is likely to be declining at a rate of around 5% per annum. However, recently calculated estimates of abundance from 1990 to 2002 show no clear trend and the effect of the recently documented range expansion is currently being investigated. Bottlenose dolphins from eastern Scotland have a high prevalence of several different types of skin lesion in comparison with similar data from other parts of the world. This appears to be mainly related to exposure to water of low salinity and/or temperature but it is possible that increase in physiological stress may make the animals more prone to other factors, such as contaminants or infections from viruses, bacteria or fungi.

Harbour seals are found throughout the year on haul-out sites in Orkney, Shetland and along the east coasts of Scotland (adjacent to the SEA5 area). Approximately 15,000 harbour seals have been counted in surveys of these sites during the annual moult, around 50% of the UK total. During the pupping and moulting seasons in June to September they spend more time ashore than at other times of the year. New information indicates that harbour seal distribution at sea is more extensive than previously believed. They are found across most of the SEA5 area and preliminary analysis shows that they are densely distributed to the east of Shetland and Orkney and off southeast Scotland.

Grey seals are restricted to the North Atlantic. The population in the northeast Atlantic has been increasing at around 6% annually since the 1960s; its current size is estimated at around 110,000 individuals, of which approximately 60,000 are associated with the colonies in Orkney, Shetland, and the east coast of Scotland. During the pupping season in October-November and the moulting season in February-April they spend more time ashore than at other times of the year. Extensive telemetry information from British grey seals at sea shows that they are widely distributed in the SEA5 area.

Ecological importance

Grey seals are important marine predators in the SEA5 area. Their diet comprises primarily sandeels, whitefish and flatfish, in that order of importance, but varies seasonally and from region to region. Grey seal foraging movements are on two geographical scales: long and distant trips from one haul-out site to another; and local repeated trips to discrete offshore areas. A modelling framework that uses satellite telemetry and other data to generate predicted distributions of where grey seals spend their time foraging around the British Isles shows that almost all grey seal activity off the coast of northeast Scotland is contained within the SEA5 area. The model estimates that approximately 50% (figure to be confirmed) of foraging effort by the UK grey seal population occurs in the SEA5 area. The SEA5 area is clearly an extremely important area for UK grey seal foraging activity.

The harbour seal is the smaller of the two species of pinniped that breed in Britain and is also an important predator in the SEA5 area. The diet is composed of a wide variety of prey including sandeels, whitefish, herring and sprat, flatfish, octopus and squid. Diet varies seasonally and from region to region. Recent telemetry studies show that there is dense foraging activity in the southern part of the SEA5 area from the population of harbour seals hauling out in St Andrews Bay and that animals tagged in Orkney and Shetland are foraging along around the northwest boundary of the SEA5 area. The SEA5 area is clearly an area of particular ecological importance for UK harbour seals.

There is relatively little information on the ecology of cetaceans in British waters. Harbour porpoises feed mainly on fish found on or near to the seabed. A recent analysis indicates that the main species consumed is whiting, with smaller amounts of herring, sandeels, sprat and cod. Animals recovered from Shetland have also been found feeding on Argentines. There is some evidence that the diet has changed during the past 40 years from one composed mainly of herring to the current diet dominated by whiting. The harbour porpoise is the most numerous marine mammal in the region and total annual fish consumption is likely to run into hundreds of thousands of tonnes for the region (North Sea and UK northern Shelf) as a whole. The significance of this species' predation from an ecological perspective has not been assessed.

Relatively little information is available for other cetacean species. Minke whales feed on a variety of fish, including herring, cod, haddock, sandeels. Fin whales consume pelagic crustaceans as well as some fish. White-beaked dolphins take whiting and other cod-like fish, sandeels, herring and octopus. Killer whales are known to feed on herring, mackerel and seals around haul-out sites. Pilot whales, sperm whales and Risso's dolphins feed mainly on squid and Atlantic white-sided dolphins on pelagic schooling fish such as mackerel and also squid

The abundance and availability of fish, especially those species mentioned above, is clearly of prime importance in determining the reproductive success or failure of marine mammals in this area, as elsewhere. Changes in the availability of principal forage fish may therefore be expected to result in population level changes of marine mammals. It is currently not possible to predict how any particular change in fish abundance would be likely to affect any of these marine mammal populations.

Sensitivity to disturbance, contamination and disease

Noise

Offshore oil and gas production is noisy. Each stage of the oil extraction process produces loud and potentially disturbing or even damaging sounds. Exploration entails seismic surveys that produce intense low frequency impulse noise, extraction includes drilling, increased vessel traffic, pipeline laying and seismic site surveys, and decommissioning can involve explosive removals.

There is an increasing awareness of the importance of sound to marine mammals. Any man-made noise could potentially have an effect on a marine mammal. The effects could range from mild irritation through impairment of foraging or disruption of social interactions to hearing loss and in extreme cases may lead to injury or even death. Most of the noise generated by offshore oil operations is low frequency, mostly <1kHz, although higher frequency sounds are also generated. Seals are known to be sensitive to those frequencies whereas small (toothed) cetaceans are relatively insensitive to low frequencies. There are no direct measurements of either the frequency range or sensitivities of hearing in large whales, but circumstantial evidence suggests that they may have good low frequency hearing.

Seismic surveys have been shown to cause avoidance behaviour in grey and harbour seals, and in a range of large cetacean species. Seismic survey work may affect foraging behaviour of seals and large whales in the SEA5 area. Current mitigation methods are probably generally effective in preventing physical damage. The development of 4D or time lapse seismic surveys means that areas with intense oil extraction activity may be subjected to repeated disturbance. The effects of such repeated surveys are not known, but minor or even insignificant transient effects may become important if disturbance is repeated and/or intensified.

There are no reliable data to suggest that vessel noise or drilling noise adversely affect seals or small cetaceans but there are indications that large whales may avoid areas of intense activity.

Decommissioning work that involves the use of explosives is likely to impact animals in the vicinity. Explosives can cause injury and death and may cause hearing damage at substantial ranges. Difficulties in observing and monitoring behaviour and the apparent attractiveness of submerged structures means that some marine mammals, especially seals, are likely to be damaged in blasts. Current mitigation methods are unlikely to be totally effective.

Contaminants

A substantial amount of information is available on the uptake of lipophillic contaminants by marine mammals, such as polychlorinated biphenyls, DDTs and chlorinated pesticides. Other studies on captive and wild populations have shown that these compounds probably have toxic effects on the reproductive and immune systems. Certain heavy metals such as mercury, lead, cadmium, copper and zinc are taken up by marine mammals although there is little evidence that these cause substantial toxic responses, except at high concentrations. Cetacean species which feed lower down the food chain may be at risk from exposure to polyaromatic hydrocarbons, although very little is known about current exposure levels or the effects of chronic exposure in marine mammals.

Oil spills

Direct mortality as a result of contaminant exposure associated with major oil spills has been reported, e.g. following the *Exxon Valdez* oil spill in Alaska in 1989. Many animals exposed to oil developed pathological conditions including brain lesions. Additional pup mortality was reported in areas of heavy oil contamination compared to unoiled areas.

More generally, marine mammals are less vulnerable than seabirds to fouling by oil, but they are at risk from hydrocarbons and other chemicals that may evaporate from the surface of an oil slick at sea within the first few days. Symptoms from acute exposure to volatile hydrocarbons include irritation to the eyes and lungs, lethargy, poor coordination and difficulty with breathing. Individuals may then drown as a result of these symptoms.

Grey and harbour seals come ashore regularly throughout the year between foraging trips and additionally spend significantly more time ashore during the moulting period (February-April in grey seals; August in harbour seals) and particularly the pupping season (October-December in grey seals; June-July in harbour seals). Animals most at risk from oil coming ashore on seal haul-out sites and breeding colonies are neonatal pups, which are therefore more susceptible than adults to external oil contamination.

Oil dispersants

There have been no specific studies on the direct acute or chronic toxicity of oil dispersants to seals and cetaceans.

Disease

A small-scale survey of anthropogenic bacteria, including *Salmonella* and *Campylobacter*, has been conducted in seals but there is no information on the occurrence of anthropogenic viruses, such as enteroviruses.

Bycatch and other non-oil related management issues

Bycatch

The accidental capture (bycatch) of marine mammals in fishing gear is an issue of current concern throughout EU waters and beyond. Bycatch in gill and tangle nets represents a significant source of mortality for harbour porpoises in many areas. The bycatch in the SEA5 area and adjacent areas has not been explicitly assessed, but gillnet fishing effort is not thought to be particularly high in this region.

Bycatches of other cetacean species in the area has only rarely been recorded and is not known to be an issue of concern.

Ship collisions

A potential source of mortality to cetaceans in this and other areas is through collisions with shipping. In other areas, where ships are numerous and cetacean numbers are depleted, this is a serious cause for concern. The frequency of such events in the North eastern Atlantic is unknown and consequently this has not been identified as a significant source of additional mortality in this region.

Conservation frameworks

Marine mammals are included in a wide range of conservation legislation. All species are listed on Annex IV (Animal and Plant Species of Community Interest in Need of Strict Protection) of the European Commission’s Habitats Directive. Under Annex IV, the keeping, sale or exchange of such species is banned as well as deliberate capture, killing or disturbance. The harbour porpoise, bottlenose dolphin, grey seal and harbour seal are also listed in Annex II of the Habitats Directive. Member countries of the EU are required to consider the establishment of Special Areas of Conservation (SACs) for Annex II species. Candidate SACs have been established for the bottlenose dolphin in the Moray Firth and in Cardigan Bay. No candidate SACs have yet been established for the harbour porpoise. A number of terrestrial candidate SACs have been established for grey and harbour seals around the coast of the UK; there are currently no marine candidate SACs for seals.

Under the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) provision is made for protection of specific areas, monitoring, research, information exchange, pollution control and heightening public awareness. Measures cover the monitoring of fisheries interactions and disturbance, resolutions for the reduction of by-catches in fishing operations, and recommendations for the establishment of specific protected areas for cetaceans.

In UK waters, all species of cetacean are protected under the Wildlife and Countryside Act 1981 and the Wildlife (Northern Ireland) Order 1985. Whaling is illegal under the Fisheries Act 1981. Guidelines to minimise the effects of acoustic disturbance from seismic surveys, agreed with the oil and gas industry, were published by the then Department of the Environment in 1995 and revised in 1998. In 1999, the then Department of the Environment, Transport and the Regions produced two sets of guidelines aimed at minimising disturbance to cetaceans. Grey and harbour seals in the vicinity of fishing nets can be killed to prevent damage to the nets or to fish in the nets under the Conservation of Seals Act 1970. Both species are protected during the breeding season; however, licences to kill seals may be granted for any time of the year for specific listed purposes.

Conclusions

- The SEA5 area is an important area for common and grey seals, and for minke whales, harbour porpoises, bottlenose dolphins and white-beaked dolphins. At least four other pinniped species and at least ten other cetacean species are also recorded in the area; some such as killer whales and white-sided dolphins are seen on a regular basis especially around Shetland. There is very little information on seasonal distribution of these species within the area, though minke whales at least are though to migrate into the area in the summer months.
- Based on satellite telemetry data and distribution models, approximately 50% of the foraging effort of the UK grey seal population is expended in the SEA5 area. Recent telemetry data also show that the SEA5 area is of particular importance for harbour seal foraging. There is therefore

considerable potential for interactions between industrial activities and seals throughout the SEA5 area.

- Marine mammals are important predators in this region, feeding on a wide range of prey types including a number of important commercial species. Because of the link between the abundance and availability of fish prey and the reproductive success or failure of marine mammals, changes in the availability of principal forage fish may be expected to result in population level changes of marine mammals. It is currently not possible to predict the extent of this.
- Seals are sensitive to the low frequency sounds generated by oil exploration and production. Small cetaceans are relatively insensitive to low frequencies. Circumstantial evidence suggests that large whales may have good low frequency hearing.
- It is likely that seismic survey work will affect foraging behaviour by any seals and large whales in the SEA5 area. Current mitigation methods are probably generally effective in preventing physical damage.
- There are no reliable data to suggest that vessel noise or drilling noise adversely affect seals or small cetaceans but there are indications that large whales may avoid areas of concentrated activity. This is particularly relevant in deeper water areas where larger whales are more numerous and may be involved in seasonal migrations.
- Decommissioning work that involves the use of explosives is likely to impact animals in the vicinity, potentially causing injury and death at close range, and causing hearing damage at substantial ranges. Difficulties in observing and monitoring behaviour and the apparent attractiveness of submerged structures means that some marine mammals, especially seals, are likely to be damaged in blasts. Current mitigation methods are unlikely to be totally effective.
- Contaminants, such as polychlorinated biphenyls, DDTs and chlorinated pesticides probably have toxic effects on the reproductive and immune systems of marine mammals. There is little evidence that heavy metals cause substantial toxic responses, except at high concentrations. Cetacean species which feed lower down the food chain may be at risk from exposure to polyaromatic hydrocarbons, although very little is known about current exposure levels or the effects of chronic exposure in marine mammals.
- Major oil spills are likely to result in direct mortality. More generally, marine mammals are less vulnerable than seabirds to fouling by oil, but they are at risk from chemicals evaporating from the surface of an oil slick at sea within the first few days. Individuals may drown as a result of associated symptoms. Neonatal seal pups are at risk from oil coming ashore.
- It is not possible to say how many marine mammals are subject to fisheries bycatch in the SEA5 area, but the fact that gillnet fisheries play a relatively small role in overall fishing activity in this area probably means that bycatch rates are lower than in many other parts of the North Sea.

1. DISTRIBUTION AND ABUNDANCE

1.1 Introduction

This section summarises information on the distribution and abundance of marine mammals occurring to the north and east of Scotland, with particular reference to the SEA5 area.

Eight marine mammal species are known to occur regularly in this area: grey seal, harbour seal, harbour porpoise, white-beaked dolphin, Atlantic white-sided dolphin, killer whale, bottlenose dolphin and minke whale. There are occasional at-sea records in the vicinity of at least eight further cetacean species (humpback whale, fin whale, sperm whale, northern bottlenose whale, long-finned pilot whale, Risso’s dolphin, short-beaked common dolphin and striped dolphin) and four pinniped species (hooded seal, bearded seal, ringed seal and walrus).

Quantitative information for this area comes from a variety of sightings surveys including the Small Cetacean Abundance in the North Sea (SCANS) survey in July 1994 (Hammond *et al.* 1995; 2002), the North Atlantic Sightings Surveys (NASS) in July 1989 (Bjørge and Øien, 1995), and the Norwegian Independent Line transect Surveys (NILS) in July 1995 and 1998 (Schweder *et al.* 1997; Skaug *et al.* 2003). Figure 1 shows the cruise tracks of these surveys in the SEA5 area. There are also published cetacean observations made during seismic surveys in 1996 to 1999 (Stone, 1997; 1998; 2000; 2001; 2003). Acoustic recordings have also been used to determine the general distribution and seasonal patterns of movement of some cetacean species by Cornell University, Aberdeen University and the Joint Nature Conservation Committee using the US Navy’s SOSUS hydrophone array and low frequency sonobuoys (Swift *et al* 2002).

Cetacean sightings data from SCANS 1994 have been combined with those from the European Seabirds at Sea database (maintained by JNCC at Aberdeen) and those of the Seawatch Foundation into a Joint Cetacean Database, from which has been generated an atlas of cetacean distribution around the British Isles using sightings per standardised unit of time (Reid *et al.* 2003). Maps from this database have been used below to show the context of the information presented for the SEA5 area.

Extensive studies of bottlenose dolphins by the University of Aberdeen and the Sea Mammal Research Unit at the University of St Andrews provide detailed information about this species in the SEA5 area.

Extensive information on the distribution and abundance of grey seals around Britain is available from studies carried out by the SMRU. These include annual aerial surveys of breeding colonies to estimate pup production and population size, and data from over 100 animals fitted with satellite-relayed data loggers (McConnell *et al.* 1999; SMRU unpublished data). There is less information on harbour seals; the most detailed data are from aerial surveys conducted during the moult by SMRU (SMRU unpublished data) and satellite telemetry studies in NE Scotland (SMRU unpublished data), including ongoing work off Orkney and Shetland supported by DTI.

In the following sections, each of the more abundant species is described with particular reference to its distribution and abundance in the SEA5 areas

1.2 Baleen Whales

1.2.1 Minke whale *Balaenoptera acutorostrata*

Minke whales are widely distributed in the world’s oceans. There are three distinct populations: Southern Hemisphere, Northern Pacific and North Atlantic. Their physical characteristics vary geographically, and several sub-species have been proposed; Antarctic minke whales are now considered a separate species (*B. bonaerensis*). In the North Atlantic the International Whaling Commission recognises three stocks for management purposes: NE Atlantic, west Greenland and Canadian east coast. Minke whales in the SEA 5 area are part of the NE Atlantic stock.

There is no direct evidence that minke whales in the Northern Hemisphere migrate, but in some areas there appear to be shifts in latitudinal abundance with season. This is true for the area around northern Britain. Minke whales appear to move into this area at the beginning of May and are present throughout the summer until October (Stephenson, 1951, Northridge *et al.* 1995). Figure 2 (from Reid *et al.* 2003) shows crude sightings rates (numbers of animals per hour), corrected for different probabilities of detecting minke whales in different sea states, from a wide variety of sightings platforms from around Britain over a 20 year period. Figure 3 shows the locations of sightings made during systematic surveys and some platforms of opportunity off NE Britain. Figure 4 shows predicted density of minke whales modelled from the SCANS 1994 data, but excluding the aerial survey block immediately around Orkney and Shetland.

The estimated summer abundance of minke whales in SCANS block D and J (around Shetland and Orkney) was 2,920 (approximate 95% confidence interval = 630 - 5,210). The estimate for the whole North Sea was 7,200 (approximate 95% confidence interval = 4,700 - 11,000). Schweder *et al.* (1997) generated estimates of the number of minke whales in the North Sea, north of 56°N, of 5,430 (SE=1,870) for 1989 and 20,300 (SE=5,240) for 1995. These estimates are approximately 8-18% of the estimated size of the northeast Atlantic stock of 67,000 whales in 1989 and 112,000 whales in 1995 (Schweder *et al.* 1997). The abundance estimate for the North Sea from the most recent Norwegian surveys in July 1998 is 11,700 (SE=3,460) (Skaug *et al.* 2003).

Summarising all available information, it is clear that the SEA 5 area is an important area for minke whales in summer.

1.2.2 Other species

There are a few records of other baleen whales in the northern North Sea. Some of these are shown in Figure 5. There are also additional incidental records of humpback and fin whales.

1.3 Toothed whales

1.3.1 Harbour porpoise *Phocoena phocoena*

Harbour porpoises are found in temperate and sub-arctic waters of the Northern Hemisphere, mainly on the continental shelves. They are distributed around the fringes of the North Atlantic Ocean basin, extending from North Carolina, off the United States, to Greenland and northern Norway and south through European waters as far as North Africa. Walton (1997) found significant genetic differences between female porpoises from the North Sea collected north and south of 56ºN, and between these animals and those from the west coast of Scotland. Tolley *et al.* (1999) found some evidence for a cline in genetic variation from northern Scotland, through Shetland to the Norwegian coast. There was a significant difference between porpoises from Scotland and Norway if the Shetland samples were removed from the analysis. Animals in the eastern North Atlantic are not known to perform long migrations, but satellite-tagged animals in Canada and Denmark have been shown to move some hundreds of kilometres within a year. Recent satellite-tracking data from Denmark have shown animals moving from northern Denmark to the northern North Sea and Shetland (Jonas Teilmann, personal communication).

Figure 6 (from Reid *et al.* 2003) shows sightings rates of harbour porpoises (numbers sighted per hour), corrected for probability of detection under different sea states around Britain. These data represent several thousand sightings made on hundreds of different platforms over a 20 year period. Harbour porpoises are abundant in the SEA5 area. Figure 7 shows the location of porpoise sightings made during systematic surveys and some platforms of opportunity. There are many observations in the SEA5 area. Harbour porpoises are also frequently observed in the Moray Firth where there is relatively little formal survey effort. Figure 8 shows predicted density of harbour porpoises modelled from the SCANS 1994 shipboard data, but excluding the aerial survey block immediately around Orkney and Shetland.

The estimated summer abundance of harbour porpoises in blocks D and J (around Shetland and Orkney) of the SCANS survey was around 61,000. Estimated density in block J (waters immediately adjacent to Shetland and Orkney) was 0.784 porpoises per square kilometre, one of the highest observed in the whole survey area. The SCANS estimate for the whole North Sea was 268,500 (approximate 95% confidence interval 210,000 – 340,000). Bjørge and Øien (1995) estimated that there were 82,600 porpoises in the North Sea north of 56ºN. This estimate is known to be biased downwards because the probability of detection on the transect line was assumed to be one. There are no other harbour porpoise abundance estimates for this area of the northeastern North Atlantic, although a second SCANS survey is planned for July 2005.

SAST data from 1979 to 1991 show the highest rate of porpoise sightings in the northern North Sea including the SEA5 area in April to June (the calving season), and July to September. These changes may be the result of porpoises moving into the northern North Sea from Norwegian waters (Northridge *et al.* 1995).

Summarising all available information, it is clear that the SEA5 area is an important area for harbour porpoises, at least in summer.

1.3.2 White-beaked dolphin *Lagenorhynchus albirostris*

White-beaked dolphins are restricted to the North Atlantic. In the eastern North Atlantic their range extends from the British Isles to Spitsbergen. They are mainly distributed over the continental shelf and in the North Sea they are much more numerous within about 200 nm of the Scottish (and north-eastern English) coasts than anywhere else (Northridge *et al.* 1995) and are commonly sighted in the SEA5 area (Figures 9 and 10).. White-beaked dolphins are present year round in the North Sea including waters of Shetland and Orkney (Northridge *et al* 1997).

The summer abundance of white-beaked dolphins in the North Sea was estimated from the North Sea blocks of the SCANS survey as 7,856 (approx. 95% confidence interval 4,000–13,300). This estimate includes shelf waters around Shetland and Orkney (SCANS blocks D) in which there were an estimated 1,157 animals; there was only one sighting of a white-beaked dolphin in block J (waters immediately adjacent to Shetland and Orkney).

1.3.3 Atlantic white-sided dolphin *Lagenorhynchus acutus*

Atlantic white-sided dolphins are confined to the North Atlantic. They share most of their range with the white-beaked dolphin, but in the eastern North Atlantic they adopt a mainly offshore distribution. At sea, the two species can be difficult to distinguish and there is sometimes a tendency for them to be recorded simply as *Lagenorhynchus spp*. Around Britain, Atlantic white-sided dolphins have been recorded mainly in the north and there are very few observations actually in the SEA5 area (Figures 11 and 12). A comparison of Figures 9 and 11 highlights the difference in the distributions of these two species in the SEA5 area, with Atlantic white-sided dolphins being generally distributed further northwest in deeper waters. In the North Sea, their presence is seasonal, with the majority of sightings occurring between May and September (Northridge *et al* 1997).

The SCANS survey estimated 11,760 *Lagenorhynchus* dolphins (white-beaked plus white-sided) in the North Sea (approx. 95% confidence interval 5,900 - 18,800). This estimate includes shelf waters around Shetland and Orkney (SCANS blocks D and J) in which there were an estimated 1,569 animals. Atlantic white-sided dolphins are occasionally involved in mass stranding events. 1,097 were taken in the Faroese drive fishery in the period 1995 to 1999.

1.3.4 Killer whale *Orcinus orca*

Killer whales are found in all oceans and most seas. In the eastern North Atlantic they occur in most areas from coastal fjords to oceanic waters. Any movements appear to be driven by prey abundance and are therefore region-specific. Killer whales have been observed throughout the northern North Sea (Figures 13 and 14) including being seen around commercial trawlers during discarding of fish (Couperus, 1994). There have been sightings north of approximately 58ºN (Reid *et al.* 2003) in all months except October. There are relatively few records within the SEA5 area itself, except around Shetland. Association of killer whales with oil platforms has been reported.

1.3.5 Bottlenose dolphin *Tursiops truncatus*

The bottlenose dolphin is a cosmopolitan species occurring in warm and temperate waters throughout much of the world. It is mostly known as a coastal species but there are also regular sightings offshore. It is not particularly common in the northeastern North Atlantic but there are a number of well-documented and, in some cases, well-studied coastal populations along the Atlantic margin of Europe. One of these has its main range in the SEA5 area.

This resident population of bottlenose dolphins inhabits coastal waters of eastern Scotland from north of the Moray Firth to the Firth of Forth (Figure 15). The few observations offshore in the North Sea may indicate that these animals are also distributed offshore at least for part of the year. In the 1980s, the core of this population's range was in the Inner Moray Firth but since the mid 1990s, in particular, the population's range has expanded south to waters off Aberdeen, St Andrews Bay and the Firth of Forth (Wilson et al. in press). Dolphins are seen year round off Aberdeen but the rate of sightings is highest in November-May. Peak sightings occur in June-August in St Andrews Bay. Within the inner Moray Firth, there are three areas where sightings are concentrated: the Kessock Channel, Chanonry narrows, and around the mouth of the Cromarty Firth. These areas were originally identified by Wilson et al. (1997a), using data from 1990-1992, but have since been confirmed through analysis of data from 1990 to 2000.

From genetic studies it appears that Scottish east coast bottlenose dolphins are more closely related to the Welsh population in Cardigan Bay and to individuals stranded around the southern coast of England than to individuals encountered in the Scottish Western Isles (Parsons et al. 2002).

A baseline estimate of abundance using mark-recapture analysis of photo-identification data collected during 1992 was calculated as 129 individuals (95% confidence interval: 110-174) (Wilson et al. 1999a). Data collected up to 1997 were analysed to estimate rates of survival and reproduction, which were incorporated in a population viability analysis (PVA) to predict likely future population trends (Sanders-Reed et al. 1999). These models predicted that, if conditions remained the same, the Scottish east coast population was likely to decline at a rate of around 5% per annum. However, recently calculated annual estimates of abundance from 1990 to 2002 show no clear trend and the effect of the recently documented range expansion on the PVA results is currently being investigated.

Post-mortem analyses of stranded animals have identified that some fishery by-catch occurs and that at least some calf mortality results from infanticide (Patterson et al. 1998). Bottlenose dolphins from eastern Scotland have a high prevalence of several different types of skin lesion (Thompson & Hammond 1992; Wilson et al. 1997b). In comparison with similar data from other parts of the world the prevalence and severity of lesions are high but mainly related to exposure to water of low salinity and/or temperature (Wilson et al. 1999b). The causal links underlying these patterns remain unknown, but it is possible that they are related to an increase in physiological stress, potentially making the animals more prone to other factors, including anthropogenic agents such as contaminants (McKenzie et al. 1997) or infections from viruses, bacteria or fungi. Subsequent studies have shown that severity and prevalence of lesions vary among individuals in the Moray Firth and that variation patterns can be related to the behaviour of infectious diseases (Wilson et al. 2000).

1.3.6 Other species

There are several other toothed whale species present in the northern North Sea. Figure 5 shows only common dolphins and Risso's dolphins in the SEA5 area in addition to the five species already mentioned, but there are additional sightings or strandings records of at least five other odontocete species from the SEA5 area.. For all these species, the SEA5 area is only a marginal part of their habitat, and is likely to be inhabited only during a restricted part of the year.

1.4 Pinnipeds

1.4.1 Grey seal *Halichoerus grypus*

Grey seals are restricted to the North Atlantic and adjacent seas. There are three recognised populations: the northwest Atlantic (breeding primarily on Sable Island, Canada and in the Gulf of St Lawrence); the Baltic Sea; the northeast Atlantic (breeding primarily on offshore islands around the British Isles but also in Iceland, the Faroe Islands, France, the Netherlands, central and northern Norway, and around the Kola peninsula in Russia). Grey seals haul out on land between foraging trips and for pupping and moulting, when they can form large colonies or aggregations. Timing of pupping differs throughout the range of the species. In Northern Britain pupping occurs from October to late November. Moulting occurs February - April.

The British grey seal population has been increasing by around 6% annually since the 1960s. Its current size is estimated at around 110,000 individuals, of which approximately 60,000 are associated with the colonies in Orkney, Shetland, and the east coast of Scotland. Table 1 summarises information taken from SCOS (2003) on the estimated population size of grey seals breeding in areas within or adjacent to the SEA5 area.

Table 1. Estimated grey seal population size in areas within or adjacent to the SEA5 area.

Area	Population size (not including pups of the year)	Year(s) when latest information was obtained	Population status
Mainland Scotland and Shetland	12,000	1998-2002	Possibly increasing
Orkney	44,300	2002	Increasing but rate may be slowing
Scottish North Sea coast	5,900	2002	Increasing

Note that most animals spend the majority on time on land for several weeks from October to November, and again from February to April during the moult. Densities at sea are therefore lower during this period than at other times of the year. Further information on distribution and movements of grey seals comes from using numbered tags attached to the flippers of pups. These indicate that young seals disperse widely in the first few months of life. Pups marked in the UK have, for example, been recaptured or recovered along the North Sea coasts of Norway, France and The Netherlands, mostly during their first year of life (Wiig, 1986).

Extensive information on the distribution of British grey seals at sea is available from studies of animals fitted with satellite relay data loggers. Figure 16 shows the tracks of 108 grey seals recorded over a period of about 10 years. Figure 17 shows locations at which it has been determined that the seals were foraging (McConnell *et al.* 1999). Figure 18 shows a distribution of predicted relative density of grey seals around the British Isles (Matthiopoulos 2003a, b, in press). A more detailed description of these data is given in section 2.1.3.

1.4.2 Harbour (or common) seal *Phoca vitulina*

Harbour seals are one of the most widespread pinniped species and have a practically circumpolar distribution in the Northern Hemisphere. In the North Sea, harbour seals haul out on tidally exposed areas of rock, sandbanks or mud. Pupping occurs on land from June to July during which time females and pups spend a high proportion of their time ashore. The moult is centred around August and extends into September. Moulting seals also spend a high proportion of their time ashore so from June to September harbour seals are ashore more often than at other times of the year.

There are four sub-species. Only the eastern Atlantic harbour seal, *Phoca vitulina vitulina*, occurs around Britain. Approximately 20% of this subspecies breeds in Orkney and Shetland and along the east coast of Scotland . Table 1 shows the minimum estimates of population size for these areas, taken from SCOS (2003), based on aerial counts of animals hauled out on land during the annual moult or the pupping season. Approximately 15,000 harbour seals are associated with the SEA5 area, around 50% of the UK total. Counts of seals hauled out on land during the moulting season (August) represent no more than about two-thirds of the total population so the true population size is likely to be at least 50% greater than these counts.

Table 2. Counts of harbour seals in Orkney, Shetland and the east coast of Scotland.

Area	Count	Years when latest information was obtained	Population status
Shetland	4,900	1996-2001	Possibly decreasing
Orkney	7,800	1996-2001	Possibly decreasing
Scottish East Coast	1,800	1996-1997	Stable

Harbour seals are widely distributed around most of the coasts of Orkney and Shetland and along the east coast of Scotland. Figure 19 depicts the distribution of harbour seals in the north-western North Sea as it was believed to be before satellite telemetry studies (after Reijnders et al. 1997). At-sea sightings from Pollock et al. (2000) are also shown.

Recent unpublished data on harbour seal distribution obtained through satellite telemetry in Scotland, Denmark and the Netherlands have found that this species is distributed far more widely offshore than previously thought. As a result, further telemetry work on the populations of harbour seals found in Orkney and Shetland is being conducted. These data, combined with those obtained previously from the seals hauling out in St Andrews Bay and the Moray Firth, show that harbour seals are found across most of the SEA5 area (Figure 20). Preliminary analysis shows that they are densely distributed to the east of Shetland and Orkney and off southeast Scotland (Figure 21). The distribution shown for the Moray Firth is likely to be considerably curtailed because of the limitations of the land-based VHF telemetry methods used. These data are described further in Section 2.2.3.

1.4.3 Other species

There are occasional records of hooded seal, bearded seal, ringed seal and walrus in the SEA5 area and adjacent waters.

2. ECOLOGICAL IMPORTANCE

2.1 Cetaceans

The six most frequently seen species of cetacean in the SEA5 area are the harbour porpoise, white-beaked dolphin, Atlantic white-sided dolphin, killer whale, bottlenose dolphin and minke whale.

2.1.1 Harbour porpoise

The main fish species consumed by porpoises (identified in samples recovered mainly from fishing nets) from the Scottish east coast between 1959 and 1971 were herring, sprats, whiting, sandeels, cod, Norway pout and other gadoids; decapod shrimps were also present (Rae 1965, 1973). Between 1989 and 1994, animals sampled from throughout the UK North Sea were found to have been eating mainly small gadoid fish such as whiting, poor cod, Norway pout and pollock, as well as herring, sprats, sandeels and gobies (SMRU/IoZ unpublished data). Greater Argentines were also recovered from at least 6 animals around Shetland (Martin 1995). Samples from 50 animals stranded or bycaught in the North Sea between 1995 and 2002 showed the diet to comprise 90% whiting, and small amounts of herring, sandeel, sprat and cod (SMRU/IoZ unpublished data).

Recently published analyses of the prey remains in harbour porpoise stomachs recovered in Scottish waters (mainly in the SEA5 area) from 1992-2003 show that overall the diet here too is dominated by whiting (>50% by weight) and sandeels (25% by weight) (Santos & Pierce 2003; Santos *et al.* 2004). Other significant components of the diet included other gadid species and octopus. Regional, seasonal and inter-annual differences in diet composition were identified.

For most of the past 40 years, the contents of North Sea porpoise stomachs has been dominated by much the same range of species, namely small gadoids, clupeids and sandeels. However, there is some evidence that the diet has changed during this period from one composed mainly of herring to the current diet dominated by whiting (SMRU/IoZ unpublished data; Santos *et al.* 2004). The harbour porpoise is the most numerous marine mammal species in the SEA5 area and adjacent waters. It is not possible to calculate total fish consumption per annum in the SEA5 area but this is likely to run into hundreds of thousands of tonnes for the North Sea as a whole. The significance of this species' predation from an ecological perspective has not been assessed.

2.1.2 Minke whale

Minke whales are known to feed on a variety of fish species, including herring, cod and haddock in Norwegian waters. In past decades minke whales were associated with herring in the North Sea and were presumed to feed on them (Northridge 1988). Stephenson (1951) reported that most minke whales taken by commercial whaling in the UK waters of the North Sea during 1948 had been feeding on herring, with some mackerel and sand eels also reported. At least one animal in recent years has also been recorded feeding on sandeels (Santos *et al.* 1994).

2.1.3 White-beaked dolphin

White-beaked dolphins have been reported to eat whiting and other small gadoids, sandeels and octopus in Scottish waters (Santos *et al.* 1994), but the sample size for this study was small (3 animals). Previously both herring and whiting have been mentioned as prey items of this species in the North Sea (Harmer 1927, Fraser 1974). Elsewhere in the North Atlantic herring and gadoid fishes also appear to be the main diet items (Reeves *et al.* 1999b).

2.1.4 Atlantic white-sided dolphin

The diet of Atlantic white-sided dolphins in the SEA5 area and adjacent waters is unknown. Elsewhere, herring, mackerel, horse-mackerel, silvery pout and squid have all been recorded as diet items (Reeves *et al.* 1999a), suggesting pelagic feeding.

2.1.5 Killer whale

Killer whales are recorded fairly frequently around Shetland, and in all months. The diet in British waters is little known, but in Norway, herring is a major diet item. Killer whales are thought to prey upon seals around haul outs in Shetland at least, and possibly offshore, as well as at least one porpoises, and have also been reported to feed on mackerel around Shetland (Fisher & Brown 2001).

2.1.6 Bottlenose dolphin

Despite the large amount of information on bottlenose dolphins in the SEA5 area, little is known about their diet. The best information comes from an analysis of the prey remains in ten stomachs from animals that were stranded and by-caught around Scotland (UK) between 1990 and 1999 (Santos *et al.* 2001). Cod, saithe, and whiting, were found to be the main prey eaten although several other fish species were also found, including salmon and haddock, as well as some cephalopods.

2.1.7 Other species

Short-beaked common dolphins are occasional summer visitors to area. An influx of the squid *Todarodes sagittatus* to the North Sea during 1937 was accompanied by an influx of common dolphins that same year, and it was assumed that the common dolphins were feeding on these squid (Fraser 1946). In the Channel and Biscay area, where common dolphins are more numerous, the main food items are mesopelagic fishes, squids and pelagic crustaceans in the offshore region (Hassani *et al.* 1997), and sardines, horse mackerel and mackerel over continental shelf waters (SMRU/IoZ unpublished data). In the SEA5 area, small pelagic schooling fishes and squids are the likely main food items.

The feeding habits of humpback whales and fin whales in this area are unknown, but elsewhere these species consume planktonic crustaceans and small schooling fish (herring, capelin, sandeels, etc).

Long-finned pilot whales, Risso's dolphins, sperm whales and northern bottlenose whales are predominantly squid feeders.

2.2 Grey seal

Grey seals are large marine predators. Adult males may weigh up to 350 kg and grow to over 2.3 m in length. Females are smaller at a maximum of 250 kg in weight and 2 m in length. The species is abundant in the North Sea (see Section 1) and is thus an important marine predator in this region. Grey seals have no significant natural predators in this area.

2.2.1 Diet composition

The diet of grey seals has been studied extensively throughout their range, although much of the information is nearly 20 years old. Updated information on grey seal diet in 2002 will be available next year from an ongoing study supported by Defra, SEERAD and SNH.

There is no information on grey seal diet in Shetland but studies in 1985 showed that in Orkney sandeels accounted for almost 50% of the diet; the remainder was mostly cod, ling and plaice (Hammond, *et al.* 1994). In the central North Sea, studies covering a longer period have shown that the diet was dominated by sandeels, cod and whiting (Hammond and Prime 1990; Hall and Walton 1999). Overall, a clear picture emerges of grey seal diet comprising primarily sandeels, gadoids and flatfish, in that order of importance, but varying seasonally and from region to region.

2.2.2 Prey consumption

The average daily energy requirement of a grey seal has been estimated as 5,500 Kcals (Hammond & Fedak 1994). The equivalent weight of prey depends on the fat content of the prey but equates approximately to 7 kg of cod or 4 kg of sandeels per day. The grey seal population associated with breeding colonies within and adjacent to the SEA5 area would be expected to consume approximately 120,000 tonnes of fish per annum. Almost 50% of this total is likely to be sandeels.

These current estimates are based on seal diet data collected mainly in 1985 and thus assume that diet composition has not changed since then. However, the sizes of fish stocks in the North Sea are known to have changed markedly during this period and it is likely that grey seal diet composition has also changed. The results from the ongoing study mentioned in Section 2.1.1 will be used to update grey seal prey consumption for the entire grey seal population around northern Britain for 2002.

2.2.3 Foraging movements and distribution

As mentioned in Section 1, grey seal distribution and movements have been extensively studied in the North Sea and around Scotland using satellite-linked telemetry. In a study of animals captured at the Farne Islands and Firth of Tay, McConnell *et al.* (1999) found that movements were on two geographical scales: (a) long and distant travel (up to 2,100 km away); and (b) local, repeated trips to discrete offshore areas. Long-distance travel included visits to Orkney, Shetland, the Faroes, and far offshore into the Eastern Atlantic and the North Sea. Most of the time, long distance travel was directed to known haul-out sites. The large distances travelled indicate that grey seals that haul out at the Farne Islands are not ecologically isolated from those at the Firth of Forth, Firth of Tay, Orkney, Shetland and the Faroes.

In 88% of trips to sea, individual seals returned to the same haul-out site from which they departed. The durations of these return trips were short (typically 2-3 days) and their destinations at sea were often localized areas characterized by a seabed of gravel/sand. This is the preferred burrowing habitat of sandeels, an important component of grey seal diet (see section 2.1.1). This, and the fact that dives in these areas were primarily to the seabed, implies that these were foraging areas. The limited distance from a haul-out site of return trips (about 40 km) indicates that the ecological impact of seal predation may be greater within this coastal zone, rather than further offshore.

This is confirmed by recent work at the SMRU in which a modelling framework has been developed that uses satellite-linked telemetry and other data to generate predicted distributions of where grey seals spend their time foraging around the British Isles (Matthiopoulos 2003a, b, in press). Figure 18 shows such a distribution overlaid on the SEA5. All the major grey seal activity off the coast of NE Scotland is contained within the SEA5 area. The model estimates that approximately 39% of foraging effort by the UK grey seal population occurs in the SEA5 area.

In summary, the SEA5 area is clearly an extremely important area for UK grey seal foraging activity.

2.3 Harbour seal

The harbour seal is the smaller of the two species of pinniped that breed in Britain. Adults typically weigh about 80-100 kg. Males are slightly bigger than females. As described in Section 1.4.2, harbour seals are not as abundant as grey seals in the western North Sea (along the coasts of Britain) but they are more so in the eastern North Sea (along the coasts of Denmark, Germany and the Netherlands). This species is an important predator in the North Sea. They have no significant natural predators in this area.

2.3.1 Diet composition

Harbour seal diet has been studied in Shetland and there have been comparable studies in the Moray Firth and The Wash. There are also unpublished results from the Firth of Tay.

In Shetland, Brown and Pierce (1998) found that gadids accounted for an estimated 53.4% of the annual diet by weight, sandeels 28.5% and pelagic fishes 13.8%. The dominant gadid fishes were whiting and saithe. There were strong seasonal patterns in the contribution of sandeels and gadids, with sandeels being important in spring and early summer, and gadids in winter. Pelagic species (mainly herring, garfish and mackerel) were important in late summer and autumn. Observed seasonal patterns are similar to those recorded for harbour seal diets in the Moray Firth.

In the Moray Firth, Tollit &Thompson (1996) found the key prey during 1989-1992 to be sandeels, lesser octopus, whiting, flounder, and cod. Significant between-year and seasonal fluctuations were evident. In another study in the same area, Tollit, Greenstreet & Thompson (1997) compared the diet composition of harbour seals feeding in the Moray Firth with the abundance of their fish prey estimated from dedicated fishery surveys in 1992 and 1994. Diet composition was almost totally dominated by either pelagic species or species dwelling on or strongly associated with the seabed, depending upon the relative abundance of pelagic schooling prey.

In the Firth of Tay, unpublished SMRU data from 1998-2003 show that the diet comprised primarily sandeels, gadids and flatfish. Gadid prey were dominated by whiting, followed by cod and haddock. Plaice was the main flatfish consumed followed by dab, flounder and lemon sole. Strong seasonal patterns in prey consumption were evident.

Harbour seal foraging can be summarised as taking a wide variety of prey including sandeels, whitefish, flatfish, herring and sprat, octopus and squid. Diet varies seasonally and from region to region.

2.3.2 Prey consumption

There are no published estimates of prey consumption by harbour seals around Britain. Harbour seals probably require around 3-4 kg per day depending on the prey species. The minimum population estimate of harbour seals within the SEA5 area is 14,500 based on counts during the moult. As described above, this probably under-represents the true population size and based on studies in other areas we would expect the total population to be greater than 20,000. A very rough estimate of prey consumption by harbour seals in the SEA5 area is therefore about 30,000 tonnes.

2.3.3 Foraging movements and distribution

Until recently, direct information on foraging movements and the distribution at sea of harbour seals in the SEA5 area was limited to small-scale land-based VHF radio telemetry studies in Orkney and the Moray Firth. These results are summarised by Thompson *et al.* (1989), Thompson & Miller (1990), Thompson *et al.* (1991) and Thompson *et al.* (1996). They showed that harbour seals moved to alternative haul-out sites within a range of 75 km and that all harbour seals appeared to forage within 60 km of their haul-out sites.

With recent technological advances reducing the size of tags, harbour seals can now be tracked using satellite relay data loggers (SRDLs). In the SEA5 area, there are accumulating data from SRDLs deployed by SMRU on 55 harbour seals.

Preliminary analyses of these data have highlighted different foraging behaviour off southeast Scotland and around Orkney and Shetland. Off southeast Scotland, animals were found to be very faithful in their use of haul-out sites on land, and moderately site-faithful in the areas individuals used to forage. Distance travelled to areas where seals were assumed to be foraging ranged from 10 km to 120 km, with a mean of 46 km. Duration of trips ranged from less than one day to 23 days, with a mean of 4.5 days. Foraging in the Moray Firth was mostly closer to the shore. Around Orkney and Shetland there are indications that seals tend to move between haul-outs sites within a 40 km radius of where they were captured with one animal hauling out as far as 200 km from where it was initially tagged. Foraging behaviour is also much more variable both in distance travelled and in the duration of trips. Most foraging trips are within 40 km of haul-outs but there are also longer distance trips to areas more than 200 km from haul-out sites.

There is dense foraging activity in the southern part of the SEA5 area from the population of harbour seals hauling out in St Andrews Bay and animals tagged in Orkney and Shetland are foraging along around the northwest boundary of the SEA5 area (Figures 20-21). When the modelling methods described above for grey seals are applied to these data, the predicted usage of this north-western part of the SEA5 are will be much greater than the density shown in Figure 21 because of the large number of seals associated with haul-out sites throughout Orkney and Shetland (Table 2).

In summary, the SEA5 area is clearly an area of particular ecological importance for UK harbour seals.

3. SENSITIVITY TO DISTURBANCE, CONTAMINATION AND DISEASE

3.1 Noise

Marine mammals spend most or all of their lives at sea, and spend the majority of that time submerged. Light is absorbed quickly in salt water and in many marine habitats visibility will be restricted to a few metres: thus vision may be of limited use. Sound, however, propagates efficiently through water and marine mammals use sound for a variety of purposes eg. Finding prey, detecting predators, communication often over great ranges and probably navigation.

Many human activities generate sound in the water, e.g. shipping, ice breaking, oil and gas exploration, sonars and explosions, and some of these sounds are extremely intense. Often anthropogenic noise is in the low to mid frequency bands that propagate well and as a consequence anthropogenic noise can be detectable at substantial ranges. Recent technological developments have introduced many new sources of noise in offshore waters. For example, shipping is the dominant noise source at low frequencies in most locations yet this sound source was completely absent before the introduction of mechanised shipping. Ross (1976) estimated that shipping had caused levels of ambient noise to rise by 10dB between 1950 and 1975 and he predicted a rise of another 5dB by the end of the 20th Century. This perturbation of the acoustic environment may have profound implications for marine mammals that evolved to function efficiently in a very different, rather quieter acoustic environment.

3.1.1 Effects of man-made sounds on marine mammals

Any man made noise could potentially have an effect on a marine mammal that is sensitive to it. Effects could range from mild irritation through impairment of foraging or disruption of social interactions to hearing loss and in extreme cases physical injury or even death.

Richardson *et al* (1995) defined a series of zones of noise influence as the ranges within which certain acoustic effects can be expected. They recognised four zones, three of which are generally thought of as occur at increasing sound level: the zone of audibility; zone of responsiveness; and the zone of hearing loss, discomfort or injury. The extent of a fourth zone, the zone of masking, depends on the characteristics of sounds that might be masked. When one is considering the detection of very faint sounds the zone of masking could be almost as great as the zone of audibility. Recent research that hints at the possibility that disruption of normal diving behaviour, which may be noise induced, could lead cetaceans to develop decompression sickness (Jepson et al, 2003) suggests that in some cases severe physical effects could be caused by sound at levels lower than those required for direct physical effects.

3.1.1.1 Zone of audibility

This zone is defined by the range at which an animal can just detect the sound. For a sound to be detected it must be both above the absolute hearing threshold for that frequency and be detectable against the background noise level in that frequency band.

Both conditioned behavioural responses to sound playback and electrophysiological measurements have been used to measure hearing sensitivities for a number of marine mammal species (see Richardson *et al* 1995). Such research has been confined to pinnipeds and small odontocetes that can be maintained in captivity. The resulting audiograms are typically U shaped with sensitivities declining rapidly at high and low frequencies. Absolute sensitivity and hearing range varies markedly between marine mammal groups and also between individuals.

Information on the hearing sensitivity of those species likely to be encountered in the SEA5 area is summarised below.

<u>3.1.1.1.1 Hearing sensitivity of pinnipeds</u>

Underwater audiograms have been derived for a range of phocid species and all show a similar pattern over the range of frequencies tested (Richardson *et al*. 1995). The audiograms for harbour seals are typical, indicating a fairly flat frequency response between 0.1 and about 40kHz, with hearing thresholds between 60 and 85 dB re 1 μPa. Sensitivity decreases rapidly at higher frequencies, but in the one animal tested at low frequency, the threshold at 0.1 kHz was 96 dB re 1 µPa. indicating good low frequency hearing (Table 3). No behavioural audiograms are available for grey seals, but electro-physiological audiograms (based on auditory evoked potentials) showed a typical pinniped pattern over the range of frequencies tested (Ridgeway and Joyce 1975). The fact that grey seals make low frequency calls suggests that they also have good low frequency hearing (Table 4). There are no audiograms for hooded seals. While it might be considered likely that their pattern of hearing sensitivity will be similar to that of grey and harbour seals, there is evidence that the hearing of another deep diving species, the Northern Elephant seal, is better-adapted for low frequency hearing than are grey and harbour seals (Kastak & Schusterman 1999). It is possible, therefore, that the hooded seal's hearing may be similarly adapted.

In-air sensitivities have been determined behaviourally for the harbour seal (Table 5). Pinnipeds appear to be considerably less sensitive than humans to airborne sounds below 10 kHz.

Table 3. Hearing sensitivity of the harbour seal from underwater audiograms (Richardson *et al*., 1995).

Species	Low Freq. (kHz)	Threshold (dB re1µPa)	Best Freq. (kHz)	Threshold (dB re1µPa)	Upper Freq. (kHz)	Threshold (dB re1µPa)
Harbour seal	0.1	96	10-30	60-85	180	130

Table 4. Characteristic frequencies of vocalisations produced by grey seals.

Species	Frequency range of vocalisations (kHz)
Grey seal	0.1 – 3

Table 5. Hearing sensitivity of pinnipeds from in-air audiograms (Richardson *et al*., 1995).

Species	Lower Frequency (kHz)	Threshold (dB re 1 µPa)	Upper Frequency (kHz)	Threshold (dB re 1 µPa)
Harbour seal	0.1	95	20	85

<u>3.1.1.1.2 Hearing sensitivity of baleen whales</u>

There are no published audiograms for baleen whales. It is assumed that they are sensitive to sound of low and medium frequencies because they predominantly emit low frequency sounds, primarily at frequencies below 1 kHz and in many cases predominantly infrasonic (<20Hz) sounds. Baleen whales react behaviourally to low frequency calls from conspecifics. However, these observations do not provide accurate indications of hearing thresholds.

Estimates of the frequency range of vocalisations of those species present in the SEA 5 area are shown in Table 6. The high upper frequencies quoted here often represent unusual outliers. Most baleen whale sounds are concentrated at frequencies less than 1 kHz, but sounds up to 8 kHz are not uncommon. The dominant call from fin whales is an infrasonic 20Hz pulse and in many oceans their calls are a prominent feature of ambient noise at these frequencies in certain times of the year.

The anatomy of baleen whale ears also indicates that they are most sensitive to low frequencies (Ketten, 1997).

Table 6. Characteristic frequencies of vocalisations produced by baleen whales (Richardson *et al*., 1995).

Species	Frequency range of vocalisations (kHz)
Minke whale	0.06 – 20
Humpback whale	0.02 – 8.2
Fin whale	0.01 – 28
Sei whale	0.012 – 3.5

3.1.1.1.3 Hearing sensitivity of toothed whales

Behavioural audiograms have been reported for some odontocete species (Table 7). The hearing thresholds have been measured in the smaller toothed whales (dolphins and porpoises). These are most sensitive to sounds above about 10 kHz and below this sensitivity deteriorates. High frequency hearing is good; upper limits of sensitive hearing range from about 65 kHz to well above 100 kHz. This reflectsthe use by these species of high frequency sound pulses for echolocation and moderately high frequency calls for communication.

Within the range of middle frequencies, where odontocetes have their best sensitivity, their hearing is acute. Frequencies at which the species in Table 7 had best sensitivity ranged from about 8 to 90 kHz. Below the frequency range of optimum sensitivity, thresholds increase gradually with decreasing frequency.

Hearing sensitivity has not been measured in the majority of the larger odontocetes including sperm whales, pilot whales and all of the beaked whales.

Table 7. Hearing sensitivity of toothed whales from underwater audiograms (Richardson *et al*., 1995).

Species	Lowest Frequency tested (kHz)	Threshold (dB re 1 µPa)	Most sensitive Frequency 9kHz)	Threshold (dB re 1 µPa)	Upper Frequency (kHz)	Threshold (dB re 1 µPa)
Killer whale	0.5	100	16	30	120	85
Beluga whale	0.04	140	30	41	100	105
Bottlenose dolphin	0.075	130	60	47	150	135
Risso’s dolphin	2	120	80	74	100	120
Harbour porpoise	0.25	115	100	32	180	106

For those species occurring in the SEA 5 area for which data on hearing sensitivity are not available, the frequency range of assumed reasonably acute hearing (for species with data on characteristic frequencies of vocalisations) is shown in Table 8.

Table 8. Characteristic frequencies of vocalisations produced by toothed whales.

Species	Frequency range of vocalisations (kHz)
Long-finned pilot whale	1 - 18
Sperm whale	0.1 - 30
Northern bottlenose whale	3 - 16
Sowerby’s and Cuvier’s beaked whale	0.3 - 11
White-beaked dolphin	2 - 20
Common dolphin	2 - 18
Harbour Porpoise	100-150kHz

Small odontocetes are more sensitive at high frequencies than are phocid seals. At their best frequencies, odontocetes are around 20-30 dB re 1µPa more sensitive than phocids. However, below about 2 kHz phocids become relatively more sensitive than small odontocetes, eg. At 2kHz harbour porpoises and juvenile bottlenose dolphins had estimated hearing thresholds of 50-70 dB re 1µPa, similar to estimates for a range of phocid seal species. At 100Hz, dolphin hearing thresholds had risen to 130 dB re 1µPa. At 100Hz, harbour seal threshold was estimated to be 95dB re 1µPa, approximately 35dB better than the dolphin. Many of the man-made sounds in the sea are in this low frequency range.

3.1.1.2 Zone of responsiveness

This is defined as the region around a source within which a marine mammal shows an observable response (Richardson *et al*. 1995). Behavioural responses are always inherently variable. Whereas the physical process of detecting or being damaged by a sound can be predicted from combinations of empirical studies and acoustic models, this is not the case for behavioural reactions to sound. The reactions of an intelligent marine mammal to a particular stimulus may be affected by several factors, e.g. nutritional state (hungry or satiated), behavioural state (foraging, resting, migrating etc.), reproductive state (pregnant, lactating, juvenile, mature), location and previous exposure history.

To date there have been a number of observational studies of changes in patterns of distribution and movement of marine mammals in the presence of acoustic stimuli. For practical and political reasons, these have usually involved studies of large cetacean species. Thus, in their comprehensive review of marine mammals and sound, Richardson *et al* (1995) devoted 15 pages to the responses of cetaceans to ships and boats and only two pages to the reactions of pinnipeds.

Available information on behavioural and physiological responses of seals and cetaceans, to each of the potential noise sources in the SEA 5 area are described below.

3.1.1.3 Zone of masking

To be audible, a sound must be detectable against the background noise. Thus, the level of background noise will often determine whether a sound is detectable or not, especially at frequencies where the animal’s hearing is highly sensitive. As a rule of thumb, Richardson *et al* (1995) suggest that a mammal can barely detect a sound signal if its received spectrum level[1] is equal to the level of noise in the 1/3 octave band in which it lies.

[1]Spectrum level is the level in dB re $1\mu Pa^2/Hz$.

Critical ratios, i.e. the ratio of sound level to background level at which detection is masked, have been estimated for a range of species. These have so far involved high frequency or continuous tone sound sources (Southall *et al* 2000, Richardson *et al* 1995). For harbour seals, Turnbull and Terhune (1993) showed that increasing repetition rate decreased hearing threshold for pulsed sounds above 2kHz irrespective of the level of masking, i.e. faster repetition decreased the critical ratio. This implies that critical ratios for irregular short pulses will be higher than for continuous tones. To date there are no useful data on the masking effects of background noise on ability to detect low frequency pulsed sounds.

The efficient detection of a wide range of sounds is biologically important for marine mammals. These will include sounds made by conspecifics, prey and predators, ambient noise useful for orientation and navigation, and for echo-locators the echoes returning from ensonified objects. Masking by noise will decrease the maximum range at which these activities can take place. A useful way to think about the significance of masking for an animal is in terms of the reduction it causes in the efficiency with which these activities can be performed. Where a directional sound beam is produced, in the case of echolocation for example, the proportional decrease in effective range will be the most appropriate metric. For other acoustic tasks the decrease in effective area or volume should be considered. Mohl (1981) modelled masking effects in these terms. He found that proportional decrease in detection range was independent of the signal to noise ratio necessary for a particular task and that it was inversely related to the amount of background noise already in the environment. Even low levels of anthropogenic noise can significantly decrease the efficiency with which acoustic tasks can be performed, especially in regions that have low levels of "natural" background noise.

Masking effects have not been studied in large cetaceans. However, as they tend to produce lower frequency vocalisations we can assume that they will be most affected by low frequency noise.

3.1.1.4 Zones of hearing loss and injury

In terrestrial mammals, exposure to loud sounds can lead to temporary threshold shifts (TTS), permanent threshold shifts (PTS) and even non-auditory tissue damage, which may be fatal. For continuous sound sources, the intensity of the signal relative to the hearing threshold at that frequency, and the duration of the exposure can both affect the timing of the onset of TTS and PTS. As a general rule, if a sound can cause a TTS, a prolonged exposure to it will lead to a PTS. For impulsive sounds, the intensity, rise time, pulse duration, pulse repetition rate and duration of exposure can all affect the timing and extent of TTS and PTS (Richardson *et al*. 1995). In the case of extremely loud sounds there may be an instant PTS and even damage to non-auditory organs.

<u>3.1.1.4.1 Hearing loss</u>

Only recently have experiments to induce threshold shifts been conducted on captive marine mammals. Schlundt et al. (2000) measured the levels of intense tones required to cause a 6dB reduction in masked hearing threshold in two beluga and five bottlenose dolphins. To provide a more or less constant noise floor in the uncontrolled study location, San Diego Bay, an environment with significant and variable ambient noise levels, masking noise was broadcast as a background during experiments. Hence "masked thresholds", not absolute thresholds were measured and it should be noted that shifts in masked thresholds are generally smaller than the non-masked TTS that would be induced by the same level of fatiguing noise. 1 second tones centred at 0.4, 3, 10, 20, and 75 kHz were used as fatiguing noises used in this experiment. At 10 and 20kHz received levels of 192dB were required to cause a 6dB mTTS.

Au *et al.* (1999) subjected individuals to a 5-10kHz, octave band, fatiguing source for at least 30 minutes over a one hour period to explore the effects on bottlenose dolphins of longer exposures to broader band noise. They found no TTS at a received level of 171dB but a threshold shift of 12-18dB occurred at 179dB re 1µPa.

TTS has been induced, experimentally, in three pinniped species, harbour seal, northern elephant seal and Californian sea lions (Kastak & Schusterman, 1996, Kastak *et al* 1999). All three species showed a similar TTS of 4.6-4.9 dB, after 20-22 minutes of exposure at 65-70 dB above threshold level in the frequency range 0.1-2 kHz.

With the absence of reliable information on the levels of sound likely to cause hearing damage in most marine mammal species, it has been common practice to apply human Damage Risk Criteria (DRC) to other mammals (Richardson *et al*., 1995). Empirical studies have shown that humans exposed, in air, to continuous sound levels 80dB above their absolute hearing thresholds are likely to suffer TTS and eventual PTS. If this DRC is applied to marine mammals we would predict that at low frequencies (<500 Hz) TTS would occur at around 165-180 dB re 1µPa . in phocids and at around 180-210 dB re 1µPa . in small odontocetes.

These represent the DRC for exposure to continuous noise. For intermittent sounds, e.g. airgun blasts, the sound levels may be significantly higher, and will depend on the length and number of pulses received. Richardson *et al* (1995) estimated the DRC for 100 pulses to be 138 dB above absolute hearing threshold. This would be approximately 208 dB for a harbour seal and would be higher for small odontocetes. Such levels could be encountered within 100m horizontally from a large commercial airgun array.

It must be stressed that the validity of applying DRC derived from human studies to seals and odontocetes is unproven, though the recent TTS studies mentioned above suggest that this is not an unduly conservative assumption. Given the lack of information on threshold levels for large cetaceans it is not possible to suggest reliable DRCs for this group.

One example of noise induced damage highlights the problem of our lack of knowledge. Mass strandings of Cuviers's beaked whales linked to the use of powerful sonars had suggested that this species, and perhaps beaked whales generally are particularly vulnerable to being damaged by such sound sources (Frantzis *et al.* 1997). Whales killed in two recent well documented, but so far incompletely reported, standing in the Bahamas and the Canaries exhibited physical damage to a variety of structures associated with hearing and/or adjacent to air spaces and symptoms consistent with decompression sickness (Balcomb, 2001, Evans and England, 2001; Jepson et al. 2003)). It now seems likely that military sonar has been causing beaked whales to strand regularly since the sixties. This phenomenon is a cause for more general concern for several reasons:

1. Our knowledge of the anatomy and vocal behaviour of beaked whales provide no indications to their apparent vulnerability to noise;
2. Other species may be equally vulnerable, and this group may be vulnerable to other intense noise sources;
3. The mechanism that led to the injury and damage in these animals remains unknown.
4. Although with hindsight mass strandings appear to be linked in time and space with sonar deployments, it has taken 40 years for the association to be accepted.

<u>3.1.1.4.2 Non-auditory effects</u>

<u>Blast injury</u>

Very intense pressure waves, e.g. blast waves from explosions, have the potential to cause damage to body tissues. Damage is most likely to occur where substantial impedance differences occur, e.g. across air/tissue interfaces in the middle ear, sinuses, lungs and intestines.

Blast damage in marine mammals has been investigated using both submerged terrestrial mammals (Goertner,1982; Richmond, Yelverton *et al*., 1973; Yelverton, Richmond *et al*., 1973) and dolphin cadavers (Myrick, Cassano *et al*. 1990). Goetner (1982) estimated distance at which slight lung and intestinal injuries would occur in various marine mammals. Marine mammals are at greatest risk of injury when they are at the same depth as, or slightly above, the explosion. Risks drop off quite sharply above and below this depth. E.g. a harbour porpoise within 750m of an explosion of a 545kg charge at 38m is likely to suffer injury if it is at the same depth. But 30m above, or 43m below it, range for injury is predicted to have reduced to 500m "Safe" distances for larger animals are expected to be shorter than for smaller ones (Richardson *et al*. 1995). Young (1991) estimated safe ranges for marine mammals of three different sizes and for human divers. However, the "safe" distances for humans are substantially greater than those for an equivalent sized marine mammal. Richardson *et al.* (1995) have suggested that a precautionary approach would involve applyng the human value for all marine mammals. This would give a safe distance of 600m for a 1kg explosion, 900m for a 10kg explosion and 2km for a 100kg explosion.

Small explosive charges have been used to try to keep seals and small whales away from fishing gear, but with limited success. Humpback whales did not apparently move away from a construction site off the coast of Newfoundland where very large charges (200-2,000 kg) were used in construction work (Lien *et al*., 1993). However, two whales with severely damaged ears became entangled in fishing gear during this time, and it seems very likely that the explosions were at least partly responsible for their deaths (Ketten *et al*., 1993). Five of eleven Weddell seals sampled in the vicinity of blasting sites showed signs of inner ear damage (Bohne *et al* 1985,1986) and various otariid seals have been observed to be killed directly by explosives (Fitch & Young 1948, Trasky 1976). It would seem that although the behaviour of marine mammals is not much affected by explosions, and they don't seems to move out of areas where blasting is taking place, they are nonetheless damaged by them.

It isn't clear whether intense sound sources, such as seismic airguns or military sonar, could cause tissue damage. If so, this would be at very short range and small numbers of animals would be affected so severely.

<u>*Other effects*</u>

Air filled cavities within the body may be made to vibrate by intense, continuous wave underwater sound. Effects will be most marked at frequencies close to their resonant frequencies, which may vary with dive depth.

Human divers exposed to intense low frequency sound report feelings of vibration, discomfort and disorientation which may be linked with over stimulation of the vestibular system. It is likely that some of the effects reported by divers also occur in marine mammals. If so, they are likely to be evinced as behavioural disruption and disorientation.

Intense sound fields may also cause gas bubbles to develop around micronuclei within tissues. This could be a major concern for human divers whose body tissues become super-saturated from breathing compressed gasses during dives. Marine mammals do not breath compressed air, but the repetitive nature of their diving may lead to super-saturation (Ridgway and Howard, 1982). Crum and Mao (1996) modelled the process of bubble growth in sound fields and concluded that a few minutes of exposure to 190 dB re 1μPa in the frequency range of 250-1000 Hz, could induce bubble formation which might lead to occlusion of capillaries. Thus, exposure to intense sound could be the critical factor triggering the bends in human divers or marine mammals with super-saturated tissues.

The observation of symptoms consistent with decompression sickness in beaked whales that stranded during a sonar related incicent in the Canaries, and in other strandings around the British Isles has led to speculation that sound may lead to decompression sickness in cetaceans at lower received levels, perhaps by disrupting patterns of diving behaviour (Jepson et al., 2003).

3.1.2 Responses of marine mammals to different types of noise

Offshore oil and gas exploration and production is noisy. Each stage process produces loud and potentially disturbing and or even damaging sounds.

- **Exploration** (Seismic Survey, sidescan sonar),
- **Extraction** (Drilling, FPSO vessels, dynamically positioned vessels, sonar surveys, seismic site surveys, increased boat traffic, pipeline laying)
- **Decommissioning** (Explosive removals)

We very briefly describe some of the known and potential effects of noise and how these relate to various stages in the life of offshore oil and gas fields. We then try to identify the key knowledge gaps and prioritise the research needed to close them.

3.1.2.1 Seismic surveys

Exploration for oil and gas reserves usually requires a series of seismic surveys to characterise the sub-surface rock formations. This involves generating a series of high energy acoustic pulses in the water column. Sound pressure waves penetrate the seabed to produce seismic waves. By measuring the strength and time of arrival of reflected signals geophysicists can map the patterns of the reflective boundaries between different rock strata.

Airgun arrays are the commonest high energy source used for seismic survey; by 1985 more than 97% of marine seismic surveys used airguns (Turnpenny & Nedwell, 1994). Airguns produce sound pulses by rapidly venting high pressure gas from a chamber. The resulting oscillating bubble produces a series of pressure waves with a waveform that can be described as a damped cosine, with a reduced amplitude and slight delay in the initial peak (Malme *et al* 1986, Turnpenny & Nedwell, 1994; Barger & Hamblen, 1980). Airgun arrays are towed behind purpose built survey vessels. Guns are suspended at depths of 1 to 10 m and fired at intervals of a few seconds, depending upon the speed of the survey vessel and the depth of the water. In general the boats travel at 4-5 knots (2-2.5 $m.s^{-1}$) and guns are fired at roughly 10 s intervals. The length of any firing sequence is dictated by the individual survey requirements, but it is not unusual for firing sequences to continue for many hours.

With the exception of explosives, airgun arrays are the most intense man made sound sources in the sea. The peak levels of sound pulses are much greater than the RMS levels from continuous sources such as ship noise or other industrial sources (Richardson *et al.*1995). However, because the sound pulses are short relative to the inter-pulse intervals, the total energy transmitted to the water may be lower than from some continuous sources. Direct comparisons between different types of sources are therefore difficult to interpret. Their ability to cause hearing damage will of course depend on the characteristics of the receiver (marine mammal ears) which in many cases are poorly known. Broadband source levels of 248-259 dB re 1μPa @1m are typical of large arrays (Richardson *et al*. 1995).

Airgun arrays are designed so that signals from individual guns interact to maximise the downward transmission of the acoustic energy. Pressure fronts from different points in the array, which constructively interfere in the vertical plane, are unlikely to do so in the horizontal plane. So, effective source levels for horizontal transmission will generally be lower than for vertical transmission and will depend critically on the geometry of the array and the position of the receiver relative to it. A linear array of guns will generally have a much lower effective source level along its axis than to the side.

While these horizontal transmissions are lower than the directed vertical levels, they are very loud in absolute terms and relative to background levels. Estimated source levels for a 28.7 litre array at 'end-fire' aspect were 217dB re 1μPa@1m, and would be expected to be greater at the sides (Malme *et al.* 1983). Thus, significant amounts of acoustic energy may be transmitted horizontally through the water column (Richardson *et al*. 1995). Goold and Fish (1998) detected sound levels above background, at ranges up to 8km from a 37 litre array and detection ranges of 100s of miles are not uncommon.

Most of the energy in airgun blasts is below 200 Hz. Barger & Hamblen (1980) reported a bandwidth of 40Hz centred about 120 Hz. The peak spectral level (the SPL in 1Hz steps) occurred between 35 and 50 Hz, and decreased monotonically with increasing frequency; spectral level at 200Hz was 48dB down on the peak at 40Hz.

Source levels at higher frequencies are low relative to that at the peak frequency but are still loud in absolute terms and relative to background levels. Goold and Fish (1998) recorded 8 kHz sounds above background levels at a range of 8km from the source, even in a high noise environment.

The now extensive literature on the effects of seismic surveys on marine mammals have recently been reviewed by Gordon et al. (2004).

The reactions of some baleen whales (bowhead, grey, blue, fin, minke and humpback) to airgun noise have been studied in the field (summarised in Gordon et al. (2004) table 2). Clear behavioural responses, in terms of changes in surfacing patterns and movement away from the source when it was within 5 km of the whales, have been observed on a number of occasions (Malme *et al* 1983, 1984,1988, Richardson *et al* 1995). Reactions have been most pronounced when the whales were to the side of the arrays long axis. McCauley *et al*. (1998) showed consistent avoidance of airguns by humpback whales during a series of careful observations made in Australia. They found that mothers and calves were more vulnerable to disturbance than single animals. Fin and blue whales continued to call in presence of airgun noise (McDonald *et al* 1993). But McDonald also showed apparent avoidance by fin or blue whale. In UK

waters, minke whales were sighted significantly further away from seismic vessels during periods of seismic array activity, suggesting active avoidance (Stone 1997,1998).
The hearing ability of toothed whales is relatively poor at low frequencies; nevertheless there is sufficient high frequency energy in the output of airgun to make them audible at distances of >10km. In addition seismic arrays carry a network of high frequency transponders for positioning. Goold (1996) presented evidence which he interpreted as showing large scale, long term changes in abundance and distribution of common dolphins during a survey and shorter term changes in behaviour between periods when guns were on and off within a survey block. In a later paper (Goold, 1998), seasonal changes in the distribution of dolphins in the same area at the same time were revealed that may explain some, or all, of the larger scale changes previously attributed to seismic surveys. If nothing else, this shows the difficulty of interpreting correlational studies made from platforms of opportunity.

Stone (1997, 1998, 2000, 2001) summarised reports from seismic vessels operating around the British Isles in which white-beaked and white-sided dolphins were seen less often during periods of seismic array activity. Conversely, more pilot whales were seen during periods of activity. This may indicate different avoidance strategies for deep diving animals like pilot whales. Sperm whales have been reported to stop calling and/or move away from distant airgun noise (Mate *et al* 1994, Bowles *et al* 1994). However, other observations suggest that sperm whales indicate rather little response to airguns (Swift et al., 1999; Madsen et al. 2002).

Both harbour and grey seals showed short-term avoidance behaviour during controlled exposure experiments with small airguns (Thompson *et al* 1998). In both cases seals abandoned foraging sites and swam away from airguns but returned to forage in the same areas on subsequent days. By contrast, Harris et al. (2001) making observations from a seismic vessel operating in a shallow lagoon system in the Canadian Arctic, found no significant change in sightings rate between firing and non firing periods. Mean radial distance to sightings did increase, suggesting some local avoidance behaviour.

4D or time lapse seismic is rapidly becoming an accepted tool for reservoir management (Bouska *et al.* 2000, Koster *et al.* 2000). Data from sequential seismic surveys are compared, and differences between these “time lapse” datasets can be interpreted in terms of changes in the reservoir due to extraction activity. Such methods have proven to be economically valuable and are likely to be widely adopted in the aging North Sea fields. There is therefore a potential for increase in the level of marine seismic survey activity in particular parts of production areas such as the North Sea. In addition, smaller scale “site surveys” may be made throughout the life of some oil fields. The effects of such repeated surveys are not known, but minor or even insignificant transient effects may become important if disturbance is repeated and/or intensified.

3.1.2.2 Vessel noise

The area is already regularly transited by large bulk carriers moving to and from the Shetland,Orkney and Firth of Forth oil terminals. There is also substantial medium sized commercial and military shipping activity in the approaches to the Firth of Forth and ferry routes between Aberdeen and the Northern Isles and between Edinburgh and Belgium. The increased shipping associated with oil developments in the SEA 5 area will be mainly smaller ships such as support vessels and tugs. There are also regular movements of rigs into and out of the construction, repair and storage facilities in the inner Moray Firth and the Tay and Forth. Noise from shipping is roughly related to vessel size; larger ships have larger, slower rotating propellers, which produce louder, lower frequency sounds. Various models for predicting shipping noise on the basis of speed and hull length have been developed and are summarised and compared in a review by Heitmeyer et al. (2004). Broadband source levels of ships between 55 and 85m are around 170-180 dB re 1 µPa@1m (Richardson *et al*., 1995), with most energy below 1 kHz. Use of bow thrusters increases broadband sound levels, in one case by 11 dB and includes higher frequency tonal components up to 1 kHz (Richardson *et al*. 1995).

Richardson *et al*. (1995) reviewed the published literature on the response of marine mammals to vessel noise. Many toothed whales appear to be tolerant of vessel noise and are regularly observed in areas where there is heavy traffic. Sperm whales have been reported to react to vessels with powerful outboard engines at distances of up to 2 km. Humpback whales and right whales are also reported to avoid large vessels in some areas. Fin whales are reputed to ignore large vessels, but they respond to close (< 100 m) approaches by whale-watching vessels by spending less time at the surface and by making shorter dives. In general, whales show very little response to slow approaches by vessels, but they may swim rapidly away from vessels producing sound which changes in intensity or head directly towards them. There is little or no data on the response of seals to vessel noise out at sea. The fact that so many large whales are struck and killed by shipping, indeed this may be a major factor preventing the recovery of North Atlantic right whale populations, is testament to the fact that these animals don't always detect and respond appropriately to shipping (Laist et al 2001, Nowachek et al. 2004). Increased shipping associated with offshore activities will increase the risk of ship-strike mortality for larger cetaceans.

3.1.2.3 Drilling noise

Drilling noise is generally low frequency, with highest levels being recorded from drill ships. Conventional drill platforms produce very low frequency noise, with strongest signals at around 5 Hz whereas drill ships produce noise with tonal elements up to 600 Hz (Richardson *et al* 1995, Greene, 1987).

There are few data on the reactions of marine mammals to drilling noise. Studies of grey and bowhead whales during migration suggest that they are generally tolerant of low level drilling noise from drill ships, but show some avoidance behaviour when sounds are loud (>20 dB above background) (Richardson et al 1985, 1990, Wartzok et al. 1989). Bowhead whales apparently reacted more to play backs than to real operational sounds. Migrating Grey whales have been shown to change course to avoid drilling noise (Malme et al 1983,1984).

There is no clear evidence of avoidance behaviour by small odontocetes to drilling noise. Bottlenose, Risso's and common dolphins were seen close to oil platforms in the North West Atlantic, and sightings rates were similar in areas with and without rigs (Sorensen et al 1984).

There is no evidence that phocid seals avoid drilling platforms. Both bearded and ringed seals approached a simulated drilling sound source, coming within 50m of the source (Richardson et al. 1995).

Construction activities associated with establishing new platforms and pipelines will also generate noise. The loudest sounds are likely to be impulsive hammering sounds, associated with pile driving and pipe installation. Source levels can be high; levels of 131-135 dB re 1 μPa. were measured 1km from a hammer used for pipe installation on an artificial island (Richardson et al 1995). Such impulsive sounds have similar frequency components to those generated by airguns. There are no available data on effects of pile driving noise on marine mammals.

3.1.2.4 Decommissioning

In the latter stages of an oilfield's life, decommissioning of fixed structures, eg. large numbers of redundant well heads, becomes a frequent requirement. Decommissioning may involve some increase in shipping noise, in particular when noisy, dynamically positioned diving support vessels are used. Although there are alternative methods of installation removal, the use of explosives for underwater cutting and demolition is still common practice and poses a serious risk of inducing PTS, or tissue damage, and is probably the greatest potential cause of acute mortality for marine mammals related to oil and gas exploration and production activities.

Ranges at which animals may suffer damage can be estimated using the models described above.

For cetaceans, risk of damage can be reduced by blasting only when observations indicate that there are no cetaceans within the danger area. However, probabilities of seeing cetaceans, especially small ones such as porpoises, may be low even in good weather. Decommissioning often takes place when sightings conditions are poor, and blasting may occur at short notice during the night or day. In sub-optimal sightings conditions such precautions will be ineffective. Passive acoustic monitoring used in addition to visual observation can very significantly increase detection probabilities for most cetaceans during some activities, such as seismic surveys(Gordon *et al*., 2000). Acoustic monitoring is compromised by the high noise levels produced by DP vessels however (J. Gordon pers. comm.).

Such observational methods are even less appropriate for seals. Even in good sightings conditions seals are rarely seen at the surface. This problem is exacerbated by the fact that seals and possibly small cetaceans may be attracted to offshore structures, probably because they cause fish to aggregate and are good foraging locations.

Current demolition practices probably injure and may even kill seals regularly. No effective mitigation practices have been developed.

3.1.3 Research Requirements

It is clear from earlier sections that current understanding of the effects of noise on marine mammals and the risks that this may cause is in most cases rudimentary. In most scenarios the main uncertainty is in the form of the relationship between observable responses and population consequences. However, there are legitimate grounds for concern and appropriate application of the precautionary principle will be required. From an industry perspective, applying the precautionary principle in a situation with great uncertainty results in a restrictive management regime. Reducing uncertainty with focused research should allow the development of management schemes which achieve conservation objectives while producing controls within which industry can operate. An appropriate risk assessment framework developed by Harwood (1999) for cetacean by-catch reduction can be applied to the marine mammal noise issue (Tyack et al. 2004) Without pre-judging the outcome of individual risk analyses we can identify broad areas of research, which are feasible and likely to be valuable.

- **Dose Response**. Research, often in the form of controlled exposure experiments, to address key uncertainties about marine mammal acoustics, sensitivities and effects of sound. The practical and ethical issues involved in designing and conducting controlled exposure experiments have been widely discussed within the marine mammal scientific community. An in-depth analysis of these issues has recently been presented by Tyack et al (2004).
- **Exposure Risk.** Targeted surveys together with telemetry based studies of movements and behaviour of selected species should be linked with oceanography and monitoring of other components of the ecosystem to identify important habitats and explore why they are important and improve our ability to predict marine mammal distributions at sea, year round.
- Assessing **medium** or **longterm consequences** of particular activities will require long term monitoring of status and distribution of populations of interest. To be useful this must be in place before new activities develop, i.e. managers must be pro-active in establishing monitoring. There are currently no monitoring schemes for any offshore cetacean populations in UK waters that would be capable of detecting even large changes in population levels. Achieving this cost effectively will require the development of new methods, passive acoustic techniques are one promising possibility for some species. Even with such programs, establishing direct cause and effect will be difficult and necessarily retrospective.
- **Development of effective mitigation**. Current mitigation practices are largely based on "common sense" measures and little work has been done to establish whether they work and/or could be made more effective. It will always be prudent to utilise effective mitigation measures, if they are easy to apply, even when harmful effects of noise have not been proven.

This will require a substantial research program. Partnerships with other noise producers (e.g. shipping, military) should be established. While this may seem a daunting scientific task, it is iin reality trivial compared to the engineering challenges that the oil industry faces and overcomes every day.

3.2 Contaminants

3.2.1 Background

Marine mammals are exposed to a variety of anthropogenic contaminants. The main route for exposure is through the food chain and as these mammals are top predators they are at particular risk from contaminants which biomagnify through the food chain (i.e. are found at increasing concentrations at higher trophic levels). Most research has focussed on two main groups of contaminants: the persistent organic pollutants (POPs) and the heavy metals. However, there is some information on other contaminants including the polyaromatic hydrocarbons (PAHs) and the butyl tins.

3.2.1.1 Persistent organic pollutants

This group of chemicals includes the organohalogenated compounds (such as the polychlorinated biphenyls - PCBs), the dichlorodiphenyltrichloroethanes (DDTs), polybrominated biphenyls (PBBs), polybrominated diphenyl ethers (PBDEs), chlordane, toxaphene, the cyclodienes (such as aldrin and dieldrin), and polychlorinated terphenyls (PCTs). Of these the occurrence and potential effects of the organochlorine compounds (OCs) are by far the best investigated. Many chlorinated pesticides are also included in this group. The significance of these compounds for marine mammals is that:

- they are highly lipophilic and hydrophobic.
- they are differentially accumulated in the lipids of animals and are therefore sometimes found at high concentrations in marine mammal blubber.
- they are chemically very stable and persistent, many compounds being resistant to metabolic degradation.
- they are present as many different isomers and congeners, and comprise hundreds of different chemical formulations which may have different behaviours and toxicities.
- they have reproductive and immunosuppressive effects, and many are 'endocrine disrupters' - acting as hormone agonists or antagonists.

In marine mammals most of these compounds are sequestered into the blubber so much of the determination of POP residues has concentrated on this tissue. Between 90 and 95% of the total burden of many POPs, particularly PCBs and DDTs, are found in the blubber because of its high lipid content (Aguilar 1985). The compounds are essentially bound away in this tissue until the tissue is mobilised for energy requirements or for the production of milk. This aspect of the life cycle of marine mammals means they may be re-exposed to the contaminants when they call upon their blubber reserves during periods of natural fasting. This is particularly the case for animals that do not feed during the breeding season, and means that females can offload a large proportion of their contaminant burdens to their offspring (Debier *et al.,* 2003). Other POPs may behave slightly differently and recent studies have shown PBDEs to be at high concentrations in the adrenal glands as well as the fat stores (Klasson Wehler *et al.* 2001). These compounds, particularly the tetra and penta group, are now found in the blubber of seals and cetaceans from UK waters (Allchin *et al.,* 1999) and in studies on juvenile grey seals, larga and ribbon seals are associated with thyroid hormone disruption (Hall *et al.,* 2003, Chiba *et al.,* 2001).

Many factors can affect the occurrence and distribution of POPs in marine mammals. These include diet, foraging strategy, age, species, sex, and nutritional condition. These confounding variables need to be considered when interpreting the significance of reported tissue concentrations (Aguilar *et al.* 1999). The large majority of persistent organic pollutants do not arise from oil exploration and production.

3.2.1.2 Heavy metals

The heavy metals are a heterogeneous group of compounds. Some are bioaccumulative (such as mercury) whereas others appear not to be (such as cadmium, chromium, nickel and copper). Data on zinc and lead in various species in the marine food web are equivocal (Muir et al. 1992). The liver, kidney and bone are the main target organs for heavy metals and levels can vary widely depending on the geographical location of the species. Marine mammals appear be protected against the effect of many heavy metals because of the presence of metallothioneins (Bowles, 1999). These are proteins whose production is induced by the occurrence of divalent cations such as Hg++, Cd++, Cu++ and Zn++. These proteins have a high affinity for binding such cations, which sequester the metals to form biochemical complexities with reduced toxicities. High levels of liver cadmium have been reported in a number of cetacean species and this probably reflects dietary preferences. High concentrations of cadmium are accumulated in the liver and gonads of cephalopods (Hamanaka *et al.,* 1982) and Antarctic krill (Honda *et al.,* 1987), the prey species of many cetaceans.

3.2.1.3 Polyaromatic hydrocarbons (PAHs)

The potential for biomagnification of PAHs is low, because fish (the main food of marine mammals) are good metabolisers of PAHs compared with molluscs. Bioaccumulation of these compounds will be lower in fish-eating marine mammals than those that feed on cephalopods or small crustaceans and plankton. Seals and cetaceans also have a detoxification enzyme system in the liver, which is induced in response to various xenobiotic compounds, including PAHs. This system (known as the mixed function oxidase, MFO or cytochrome P450 system) can convert parent compounds to excretable metabolites largely by the addition of a hydroxyl group (Sipes and Gandolfi, 1991). This biotransformation of compounds may, however, be toxic if the metabolites produced are bioactive. In addition the rate at which transformation occurs is critical. If the non-toxic pathway is saturated, minor pathways, which produce further toxic intermediates, become involved. One isoform of the cytochrome P450 enzyme system is also called aryl hydrocarbon hydroxylase because it plays a role in the metabolism of PAHs. The regulation of certain cytochrome P450 enzymes involves a ligand-activated transcription factor known as the Ah (aromatic hydrocarbon) receptor (Timbrell, 1991). This has been investigated in a very limited number of marine mammals but induction and activity of the cytochrome enzymes is widely used as a marker of exposure to inducers such as PAHs and PCBs (Troisi and Mason 1997, Mattson *et al.* 1998, Wolkers *et al.* 1999).

In 1995 the North Atlantic Marine Mammal Commission held a conference on Marine Mammals and the Marine Environment in Lerwick, Shetland. The papers from this meeting were published in a Special Issue of Science of the Total Environment (Vol 186, Nos 1 and 2, 1996). This included studies resulting from the impact of the 1993 *Braer* oilspill. Hall *et al* (Hall *et al.,* 1996) found an increase in respiratory symptoms among the grey seals hauled out in the area of the spill compared to a control site. However, this finding was correlative and causal relationship with exposure to oil on the surface of the sea was not established. An ecological steering group was also established to monitor the environmental impact of the *Braer* spill (Ritchie & O'Sullian, 1994). Their conclusions were that the impact on the environment and ecology of South Shetland had been minimal and adverse impacts that did occure were both localised and limited. A recent study on PAHs in blue mussels from the coastal waters of Shetland and Orkney (Webster *et al.,* 2003) reported that the bioavailability of these compounds from the sediment was low.

3.2.1.4 Butyl Tins (Tributyl tin (TBT), Dibutyl tin (DBT) and Monobutyl tin (MBT))

These groups of compounds have only quite recently been identified in marine mammals, despite knowledge about their toxicity and endocrine disrupting effect in invertebrates and fish having been available for a number of years (Iwata *et al.* 1994). Results of analysis in liver samples from stranded animals have indicated a widespread contamination around the coasts of England and Wales; indeed TBT and DBT have been found in open ocean cetacean species, which indicates a wider contamination of the sea by these compounds (Law *et al.* 1999). However, recent data on temporal trends of DBT, TBT and MBT in harbour porpoises from Norwegian waters (Berge *et al.,* 2004) have found a decrease in tissue concentrations following the restrictions on the use of TBT on small boats in the late 1980s.

3.2.2 Sources of Data

There is a huge body of literature on contaminants in marine mammals worldwide. For example, the US Marine Mammal Commission (Long, 2000) recently issued a bibliography containing over 1,200 references. In addition, there are many good reviews on the levels of contaminants found, the patterns of different compound groups in various species and the temporal changes in concentrations. The most comprehensive are: Aguilar and Borrell (1997), Geraci and St. Aubin (1990), Hall (2001), Law (1996), O'Shea (1999), Reijnders, Aguilar and Donovan (1999).

3.2.3 Knowledge

Our knowledge of the effects of contaminants on marine mammals remains limited. This is largely due to the difficulties involved in investigating the responses in wild animals. Whilst it is relatively easy to determine the tissue concentrations of various compounds in dead and live-captured animals, the significance of these concentrations for the health and ultimate survival of the individuals remains difficult to assess. A few studies have investigated the responses to exposure on animals in captivity, comparing responses in exposed and control groups and some associations between dysfunction and contaminant exposure have been reported in free-living individuals and populations.

3.2.3.1 Persistent organic pollutants

Two observations on wild populations suggested that the uptake of POPs by marine mammals could have toxic effects similar to those reported in laboratory species. The first was the report that a serious decline in the population of harbour seals in the Wadden Sea might be due to the reproductive effects of contaminant exposure (Reijnders 1980; Reijnders 1984). Reijnders (1986) addressed this more directly in an experiment using captive harbour seals. Two groups of female harbour seals were fed fish from different areas one contaminated with OCs the other much cleaner. Reproductive success was significantly lower in the group fed contaminated fish and failure was thought to occur at the implantation stage of pregnancy. The second effect was investigated following the outbreak of phocine distemper among harbour and some grey seals in European waters, in which differential mortality rates were reported among harbour seal populations around the UK coast (Hall *et al.* 1992a). This observation led to a study of the OC contaminant burdens among animals that were victims and survivors of the epidemic. The results suggested that animals that died of the disease had higher blubber levels of OCs than survivors, although it was not possible to control for all potential confounders (Hall *et al.* 1992b). Interestingly this finding was also repeated in a study of contaminant burdens in striped dolphins following a similar outbreak of dolphin morbillivirus in the Mediterranean Sea in 1990 (Aguilar and Borrell 1994). Later studies by Ross *et al.* (1995) and DeSwart *et al.* (1994) found evidence for immunosuppression in a group of captive harbour seals fed contaminated fish compared with animals fed clean fish. Natural killer cell activity (white blood cells that are particularly required in the defence against viral infection) in particular was depressed and lymphocyte function measured *in vitro* was lower in the exposed group.

Bergman and Olsson (1985) also reported the occurrence of adrenocortical hyperplasia, hyperkeratosis and other lesions in grey (*Halichoerus grypus*) and ringed (*Phoca hispida*) seals from the Baltic. The pathologies seen were indicative of a disease complex involving OCs and hormone disruption, a finding also demonstrated in laboratory animals (Fuller and Hobson, 1986). Other abnormalities associated with high exposure to PCBs include skull and bone lesions in grey seals (Bergman *et al.* 1992); (Zakharov and Yablokov 1990) and harbour seals from the Baltic (Mortensen *et al.* 1992).

More recently a study by Jepson *et al.* (1999) indicated that harbour porpoises (*Phocoena phocoena*) stranded along the coast of England and Wales which had died of infectious diseases had significantly higher concentrations of PCBs in their blubber than those which died from trauma, such as by-catch in fisheries or ship strikes.

3.2.3.2 Heavy metals

Of the toxic elements studied those of most importance are cadmium, lead and mercury.

Cadmium can sometimes be found at high concentrations in the livers of marine mammals (Law *et al.*, 1991), but there does not appear to be any published information on cadmium-induced pathology in marine mammals. These high levels are probably due to naturally high cadmium concentrations in prey species such as squid (Bustamante *et al.* 1998). Metallothionen sequestration appears to protect marine mammals from cadmium toxicity.

Lead is also found in many marine mammal tissues, particularly liver and kidney, but not at concentrations that are cause for concern (Law *et al.* 1991). Bone is a long-term storage target organ for lead, although again no associated histopathological lesions have been reported. Smith *et al.* (1990) used isotopic ratios to show that the source of lead in some marine mammal species has shifted from naturally derived lead to anthropogenic aerosol-dominated forms.

Mercury can bioaccumulate through the food chain and is a well-recognised neurotoxin. Its interaction with selenium appears to be protective and various laboratory studies have shown that toxic effects of mercury were prevented or reduced by simultaneous exposure to selenium (Cuvin-Aralar and Furness, 1991). Some of the concentrations of mercury in the liver of marine mammals have exceeded those known to be toxic to other mammals but lethal effects have not been observed (Britt and Howard, 1983). Marine mammals seem able to metabolise mercury from its toxic methyl form found in fish. Although marine mammals can tolerate high concentrations of mercury immobilised as the selenide, methylmercury poisoning has been reported in a ringed seal an area of heavy industrialisation (Helminen *et al.* 1968).

Copper is an essential dietary element for mammals and a wide range of concentrations has been reported in marine mammals. In the UK levels of between 3 and 30 mg/kg have been measured in the liver of stranded animals and it has been suggested that this may represent the normal range of homeostatic control in marine mammals (Law, 1996).

3.2.3.3 Polyaromatic hydrocarbons (PAHs)

Polyaromatic hydrocarbons have rarely been studied in the tissues of marine mammals but where measurements in muscle tissue, liver and blubber have all generally been below 1µg/g. Law and Whinnett (1992) investigated PAHs in the muscle tissue of harbour porpoises stranded around the UK coast and found total PAH concentrations ranging from 0.11-0.56 ug/g wet weight and 0.47-2.4 µg/g wet weight Ekofisk crude oil equivalents. Specific PAHs were 2-4 ring compounds (naphthalenes, phenanthrenes, anthracene, fluoranthene and pyrene). Bond (1993) found similar compounds in the blubber of seals from the Moray Firth. The PAH levels in this species displayed large variations, with grey seals having higher levels than harbour seals (mean 15.78 (SD 25.54) µg/g dry weight in grey seals 2.67 (SD 5.77) in harbour seals).

The effects of PAHs on marine mammals are reviewed in Geraci and St Aubin (1990) and various responses from effects on the central nervous system, eyes and mucous membranes, thermal regulatory effects from fouling of fur, to induction of metabolic enzyme systems and effects on hormone levels were reported. These effects are largely observed following short-term acute exposure. Less is known about the effects of long-term chronic exposure. Although studies have shown that fish readily convert aromatic hydrocarbons to metabolites such as dihydrodiols and phenols (Krahn *et al.* 1984) and therefore fish-eating mammals may receive lower doses of parent PAHs, cetaceans which feed lower down the food chain are likely to be most at risk. The carcinogenic nature of certain PAHs, such as benzo(a)pyrene has been a concern for example (Beland *et al.* 1993) reported the detection of benzo(a)pyrene adducts in DNA from Beluga whales in the Gulf of St Lawrence, but there is little evidence for the substantial exposure of marine mammals in UK waters to this compound. One of 27 UK harbour porpoises examined by (Law and Whinnett 1992) between 1988 and 1991 was considered to have died as a result of a tumour.

Butyl tin compounds, largely tri- and di-butyl tin have now been reported in the liver and blubber of pelagic cetaceans and marine mammals in UK waters (Law *et al.* 1999), but no reports on their effects have been published.

3.2.3.4 Oil spills

Direct mortality from contaminant exposure has rarely been reported, and has usually been associated with major oil spills such as the *Exxon Valdez* in Alaska in 1989. High concentrations of phenanthrene (PHN) and naphthalene (NPH) were reported in the bile of oiled harbour seals (*Phoca vitulina*) collected following the spill (up to 23 times higher than in control seals) and high concentrations of PAHs in the blubber (up to 400 ppb) (Frost and Lowry 1993). Due to the condition of many of the carcasses examined it was difficult to attribute cause of death to oil toxicity, but many animals exposed to oil did develop pathological conditions including brain lesions. Additional pup mortality was also reported in areas of heavy oil contamination compared to unoiled areas.

More generally, marine mammals rely on their blubber for insulation and are thus less vulnerable than seabirds to fouling by oil (Geraci and St Aubin, 1990). However, they are at risk from hydrocarbons and other chemicals that may evaporate from the surface of an oil slick at sea within the first few days. Seals often barely raise their nostrils above the surface of the water when they breathe, so any seal surfacing in a fresh slick is likely to inhale vapours. Cetaceans also typically inhale close to the surface. Symptoms from acute exposure to volatile hydrocarbons include irritation to the eyes and lungs, lethargy, poor coordination and difficulty with breathing. Individuals may then drown as a result of these symptoms.

Grey and harbour seals come ashore regularly throughout the year between foraging trips and additionally spend significantly more time ashore during the moulting period (February-April in grey seals; August in harbour seals) and particularly the pupping season (October-December in grey seals; June-July in harbour seals). Animals most at risk from oil coming ashore on seal haul-out sites and breeding colonies are neonatal pups. These animals are born without any blubber and rely on their prenatal fur (the white lanugo in grey seals) and metabolic activity for thermal balance. They are therefore more susceptible than adults to external oil contamination (Ekker, Lorentsen and Rov, 1992). Grey seals pups remain on the breeding colonies until they are weaned and unlike adults or juveniles, would be unable to leave the contaminated area. Females may also abandon contaminated pups during an oil spill, leading to starvation and premature death.

3.2.3.5 Oil dispersants

There have been no specific studies on the direct acute or chronic toxicity of oil dispersants to seals and cetaceans. The toxicity of oil spill dispersants to aquatic organisms under laboratory conditions appears to relate primarily to the chemical composition of the individual dispersant. For example, the type of solvent, aromatic content (is oil based dispersants), functional group(s) and molecular structure of the surfactants, chemical stability, and the concentration. Other factors that are important in oil spill dispersant aquatic toxicity are the duration of exposure of the organism, water temperature of the sea, oxygen content of the seawater, organism species/type, organism age, organism stage of growth/development, organism health. Indirect effects may occur if the prey items of marine mammals further down the food chain are affected.

3.2.4 Gaps in knowledge

With respect to the impact of oil exploration activities on contaminant exposure in marine mammals, no recent studies on the uptake of PAHs by marine mammals around the UK or pelagic cetaceans exist, and there is no information on the potential effects of longterm chronic exposure. Further studies are needed to determine current and background exposure levels in a variety of species and their prey, particularly prior to oil exploration and production activities within marine mammal foraging areas. In addition we have no information on alkylated phenols in marine mammals. PAH sources from exploration and production are not now very significant (100 t/yr, OSPAR 2000) and most North Sea PAHs come from terrestrial combustion sources (> 7000 t/yr).

Further work on the uptake and effect of polybrominated diphenyl ethers (the brominated flame retardants) on marine mammals is clearly needed, particularly as higher levels of these compounds, in a variety of invertebrates and fish as well as marine mammals, have been reported in the UK than elsewhere in Europe (Zegers et al. 2001). However, these compounds are not linked to oil exploration and production.

Few investigations on contaminants in marine mammals have been able to address the effects at the population level. This is particularly important where, from dose-response studies, contaminants or mixtures of contaminants are likely to have effects on survival or fecundity. In particular we need to develop a framework in which the *population* risks can be evaluated. This is been investigated to some extent (Harwood *et al.* 1999) but more detailed empirical information is required. Early simulations suggest that mathematical and statistical models would be of great benefit to any risk assessment procedure.

3.3 Disease

3.3.1 Background

It has long been known that marine mammals harbour large numbers of macroparasites, such as nematodes and cestodes as well as various ectoparasites (Margolis 1954, Reijnders *et al.* 1982, Baker and Martin 1992). However, these parasites usually do not cause severe harm unless the animals have an underlying primary disease or are stressed for other reasons.

There have been outbreaks of viral disease epidemics among seals and cetaceans worldwide and these seem to have increased in frequency, particularly in the US, in recent years (Harvell *et al.* 1999). In UK and European waters major epidemics from phocine distemper in harbour and grey seals (PDV) and morbillivirus (DMV) in Mediterranean striped dolphins were widely documented in 1988 and 1990 respectively (Dietz *et al.* 1989, Aguilar and Raga 1993). These were followed by other mass mortalities in the late 1990s, such as among Mediterranean monk seals, whose cause was disputed although some evidence pointed to PDV as the primary cause (Osterhaus *et al.* 1997, Harwood 1998, Hernandez *et al.* 1998). More recently a second major PDV outbreak occurred in Europe and the UK in 2002. This has led to a number of studies in which the grey seal, less susceptible to the disease than harbour seals, are being investigated as potential vectors for PDV.

Apart from such high profile, large-scale epidemic diseases, seals are known to suffer from a range of viral and bacterial infectious diseases.

3.3.2 Sources of data

A number of reviews of infectious diseases in marine mammals have been published and the major sources are given below: Dierauf and Gulland (2001), Van Bressem, Van Waerebeek and Raga. (1999), Harwood and Hall (1990), Visser, Teppema and Osterhaus (1991) (Gulland & Hall, In Press).

3.3.3 Knowledge

3.3.3.1 Viruses

Table 9 indicates the viral infections that have been reported among marine mammals. The morbilliviruses and influenza viruses have accounted for large scale mortalities around the world.

3.3.3.2 Bacteria

A range of organisms has been cultured from healthy and sick marine mammals and many are secondary infections in malnourished and starveling animals, particularly juveniles. (Baker 1984) found that 40% of the grey seal pups died of infections such as peritonitis and septicaemia. *Corynebacterium* and *Streptococcus* accounted for the majority of infections and during the 1988 PDV epidemic *Bordetella* organisms were isolated from a large proportion of the sick animals but was not found in healthy individuals (Munro *et al.* 1992). *Mycoplasmas* were also isolated in sick animals from the Wadden Sea and are thought to be the causative organism of seal finger (Baker *et al.* 1998).

More recently *Brucella maris* has been isolated in seals and cetaceans from the North sea (Patterson *et al.* 1998). Bacteriological investigations have shown these organisms to be significantly different from other Brucella species. Serological studies of seals in particular have shown evidence of widespread infection in ten species of cetaceans and four species of seal. However, pathological changes associated with B. maris solations have only been found in a total of nine cetacean and two seals, largely sub-blubber abcessation and pneumonia. A laboratory worker was infected with one isolate indicating that this is a potential zoonotic agent (Patterson *et al.* 1998). However, in 1999 a report of Brucella inducing abortions in Bottlenose dolphins was reported. The causative organism was specific to this species and was name *Brucella delphini* (Miller *et al.* 1999). It is not known how these two isolates are related or if they are indeed the same organism.

Leptospira pomona has also been found in some marine mammals but has not been reported in those from UK waters. This organism can be highly pathogenic and has been associated with episodic outbreaks among California sea lions in which it causes abortion (Buck and Spotte 1986).

Tuberculosis (*Mycobacterium tuberculosis*) has been diagnosed in various fur seal and sea lion species, largely in Australia, New Zealand and on the Argentine coast (Cousins *et al.* 1990, Forshaw and Phelps, 1991, Bastida, 1999). To our knowledge it has not yet been reported among European or North Sea marine mammal species.

Anthropogenic pathogens are largely found in marine mammals from the discharge of untreated sewage or effluent from facilities, which contain domestic animals. Salmonella species associated with man or his domestic animals have been cultured from marine mammals directly or their faeces, particularly *Salmonella bovis-morbificans* and *S. enteriditis* (Baker *et al.* 1995). In some cases these have been associated with pathologies and septicaemia. It was found that between 1.4 and 11.8% of grey and harbour seals in the East coast of England taken into rehabilitation centres were positive for Salmonella. Although the origin of some of these organisms is not known, *S. bovis-morbificans* is generally specific to cattle and may indicate contamination of marine mammals by anthropogenic organisms.

3.3.3.3 Toxic Algae (Harmful Algal Blooms)

There have been a number of incidents in the US, and more recently on the west coast of Africa, where toxins produced by algae have been associated with mortalities of marine mammals. Incidents include dinoflagellate toxins in Florida manatees and Humpback whales (Geraci *et al.* 1989, O'Shea *et al.* 1991), brevetoxins in Bottlenose dolphins (Geraci 1989), saxitoxin in sea otters (DeGange and Vacca 1989), and ciguatoxin in Hawaiian monk seals (Gilmartin *et al.* 1987). More recently a mass mortality among

California sea lions was linked to *Pseudo-nitzschia australis* that produces domoic acid, a neurotxin, which was found in fish and in the body fluids of the sea lions that died (Scholin *et al.* 2000).

3.3.4 Gaps in Knowledge

Whilst there has been a considerable amount of recent research on infectious and pathogenic diseases in marine mammals, particularly in the 10 years following the morbillivirus outbreaks of the 1980s, we know surprising little about the incidence of infection in European seal populations. Strandings schemes designed to determine mortality rates and causes of death of marine mammals around the UK have been forced by limited funding to concentrate their efforts on cetaceans rather than seals. Serological surveys could provide invaluable data on the exposure and immunity of populations to various diseases and this approach was proved useful in estimating the size of the susceptible harbour seal population in the UK before the recent outbreak of PDV in Europe (Thompson *et al.*, 2002).

A small-scale survey of anthropogenic bacteria such as *Salmonella* has been conducted in seals but we have no information on the occurrence of anthropogenic viruses such as enteroviruses. Indeed some pilot work suggested that other sewage related organisms such as *Campylobacter* may be a risk for marine mammal health but this study has not been followed up.

Table 9. Viruses in marine mammals – From Visser *et al.* (1991).

Virus Family	Virus	Species
Adenoviridae	Sea Lion Hepatitis Virus	California sea lion Sei whale
Herpesviridae	Alphaherpesvirinae Phocine herpesvirus-1 Uncharacterised herpesvirus	Harbour seal California sea lion Beluga whale Harbour porpoise
Poxviridae	Seal poxvirus Parappoxvirus Orthopoxvirus	Harbour seal Grey seal California sea lion Northern fur seal S. American sea lion Bottlenose dolphin White sided dolphin Harbour porpoise Grey seal
Picornaviridae	Picornavirus	Harbour seal Grey whale
Caliciviridae	San Miguel sea lion virus Calicivirus	California sea lion Northern fur seal Northern elephant seal Pacific walrus Stellar sea lion Grey seal Bottlenose dolphin Fin whale Grey whale Bowhead whale Sperm whale
Orthomyxoviridae	Influenzavirinae H7N7 Influenza A virus H4N5 H13N9 H13N2	Harbour seal Pilot whale Striped dolphin
Paramyxoviridae	Canine Distemper Virus (CDV) Phocine Distemper Virus (PDV) Porpoise Morbillivirus Dolphin Morbillivirus	Crabeater seal Baikal seal Harbour seal Grey seal Ringed seal Harp seal Harbour porpoise Striped dolphin
Coronaviridae	Coronavirus	Harbour seal
Rhabdoviridae	Rabies virus	Ringed seal
Retroviridae	Spumavirus	California sea lion
Papovaviridae	Papillomavirus	Burmeister’s porpoise Cetacean spp.

4. BYCATCH AND OTHER NON-OIL MANAGEMENT ISSUES

4.1 Bycatch

The accidental capture of marine mammals in fishing gear is an issue of some current concern throughout EU waters, and beyond. Work by the SMRU since 1993 has been targeted at determining accidental catch (‘bycatch’) rates of marine mammals in several fisheries in UK waters. Similar work has been conducted by DIFRES for Danish vessels fishing in the North Sea (Vinther 1999, Vinther and Larsen 2002).

The SEA 5 area is exploited by fishing vessels from several EU and other states, and there is a lack of detailed information on the activities of these vessels that hinders any assessment of the overall scale of bycatches in this area. There are known to be pelagic trawl fisheries for mackerel, herring and other species, much demersal trawling for prawns and for whitefish, potting for crustaceans, as well as some gillnet fishing for various demersal fish, but the overall extent of these operations is poorly known.

The primary gear types that have been associated with marine mammal bycatch elsewhere are gill and tangle nets and certain specific types of trawling. Although trawling for pelagic species, in particular, has been linked to marine mammal bycatch in some parts of the world, an ongoing study of cetacean bycatch in pelagic trawling in the North Sea and to the west of Scotland has not so far revealed any potentially significant conservation issues (SMRU unpublished). There are a few records of marine mammals being taken in demersal trawls in the SEA5 area, but such incidents are usually rare enough that they are not considered a conservation issue. Similarly, there are a few records from the wider region of minke whales becoming entangled in pot lines, but again the rarity of such events means that on their own such entanglements are unlikely to be a conservation concern.

It is likely that the greatest numbers of marine mammals caught in fishing gear in this region (as in most other areas) are taken in static nets, mainly gillnets and tangle nets. These nets ensnare bottom feeding seals and cetaceans almost wherever they are used.

(Hall *et al.* 2001) used the SMRU seal tagging database to estimate the minimum level of seal mortality from tags returned from seals found in fishing gear. They estimated that a minimum of around 2% of all seals tagged were subsequently killed in fishing gear, and it is thought that most such mortality is in gill and tangle nets.

Harbour porpoises are also taken in bottom set gill and tangle nets. This species is predominantly bottom feeding, and appears to be particularly vulnerable to accidental entanglement in such nets. Typical bycatch rates are about one porpoise in every 70-420 net hauls, depending on the type of fishery. Gillnet fisheries in the SEA 5 area are limited in scale compared with some other areas of the Northeast Atlantic. There are local small scale gillnet fisheries for groundfish in Scottish east coast waters between Arbroath and Aberdeen, some limited gillnetting in the Moray Firth, and occasional visits by English and Danish gillnetters throughout the SEA5 area. There are also Norwegian gillnetters working the area between Shetland and Norway, but the scale of their activities in the SEA5 area, close to Shteland, have not been reported.

4.2 Other issues

Another potential source of mortality to cetaceans may be through collisions with shipping. Whales are occasionally reported to be struck and killed, especially by fast-moving ferries, in other parts of the world, and smaller cetaceans can also be impacted by propeller strikes from small vessels. In some areas, where ships are numerous and cetacean numbers are depleted, this can be a serious cause for concern. There are very few data with which to estimate the frequency of such events, and consequently this has not been identified as a significant source of additional mortality in this region.

5. CONSERVATION FRAMEWORKS

5.1 Cetaceans

5.1.1 Europe

All cetacean species are listed on Annex IV (Animal and Plant Species of Community Interest in Need of Strict Protection) of the European Commission's Habitats Directive. Under Annex IV, the keeping, sale or exchange of such species is banned as well as deliberate capture, killing or disturbance.

The harbour porpoise and the bottlenose dolphin are also listed in Annex II of the Habitats Directive. Member countries of the EU are required to consider the establishment of Special Areas of Conservation (SACs) for Annex II species. Candidate SACs have been established for the bottlenose dolphin in the Moray Firth and in Cardigan Bay. No candidate SACs have yet been established for the harbour porpoise.

The Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) was formulated in 1992 and has been signed by seven European countries including the UK. Under the Agreement, provision is made for protection of specific areas, monitoring, research, information exchange, pollution control and heightening public awareness. Measures cover the monitoring of fisheries interactions and disturbance, resolutions for the reduction of by-catches in fishing operations, and recommendations for the establishment of specific protected areas for cetaceans. The UK applies the provisions of ASCOBANS to waters under its jurisdiction.

All cetacean species are listed on Annex A of EU Council Regulation 338/97 and are therefore treated by the EU as if they were on CITES Appendix I, thus prohibiting commercial trade.

5.1.2 UK

In British waters, all species of cetacean are protected under the Wildlife and Countryside Act 1981 and the Wildlife (Northern Ireland) Order 1985. Whaling is illegal under the Fisheries Act 1981.

Guidelines to minimise the effects of acoustic disturbance from seismic surveys, agreed with the oil and gas industry, were published by the then Department of the Environment in 1995 and revised in 1998. Members companies of the UK Offshore Operators Association (UKOOA) have indicated that they will comply with these Guidelines in all areas of the UK Continental Shelf. Under the Guidelines there is a requirement for visual and acoustic surveys of the area prior to seismic testing to determine if cetaceans are in the vicinity, and a slow and progressive build-up of sound to enable animals to move away from the source.

In 1999, the then Department of the Environment, Transport and the Regions produced two sets of guidelines aimed at minimising disturbance to cetaceans. The first, Minimising Disturbance to Cetaceans from Whale Watching Operations, is aimed at tour operators and members of the public involved in whale, dolphin and porpoise watching activities. The second, Minimising Disturbance to Cetaceans from Recreation at Sea, is aimed at anyone involved in any recreational activity in UK coastal waters who may incidentally encounter cetaceans.

5.2 Seals

5.2.1 Europe

The grey and harbour seal are listed in Annex II of the Habitats Directive under which member countries of the EU are required to consider the establishment of Special Areas of Conservation (SACs). A number of terrestrial candidate SACs have been established for grey and harbour seals around the coast of the UK; there are currently no marine candidate SACs.

All seal species are listed on Annex A of EU Council Regulation 338/97 and are therefore treated by the EU as if they were on CITES Appendix I, thus prohibiting commercial trade.

5.2.2 UK

Under the Conservation of Seals Act, 1970, grey and harbour seals in the vicinity of fishing nets can be killed to prevent damage to the nets or to fish in the nets. Both species are protected during the breeding season: September-December in the case of grey seals; June-August in the case of harbour seals. However, licences to kill seals may be granted for any time of the year for specific listed purposes.

Under the Act, the Natural Environment Research Council (NERC) has a duty to provide scientific advice to government on matters related to the management of seal populations. NERC has appointed a Special Committee on Seals (SCOS) to formulate this advice so that it may discharge this statutory duty. Formal advice is given annually based on the latest scientific information provided to SCOS by SMRU. SMRU also provides to government scientific review of applications for licences to shoot seals, and information and advice in response to parliamentary questions and correspondence.

6. CONCLUSIONS

- The SEA5 area is an important area for common and grey seals, and for minke whales, harbour porpoises, bottlenose dolphins and white-beaked dolphins. At least four other pinniped species and at least ten other cetacean species are also recorded in the area; some such as killer whales and white-sided dolphins are seen on a regular basis especially around Shetland. There is very little information on seasonal distribution of these species within the area, though minke whales at least are though to migrate into the area in the summer months.
- Based on satellite telemetry data and distribution models, approximately 50% of the foraging effort of the UK grey seal population is expended in the SEA5 area. Recent telemetry data also show that the SEA5 area is of particular importance for harbour seal foraging. There is therefore considerable potential for interactions between industrial activities and seals throughout the SEA5 area.
- Marine mammals are important predators in this region, feeding on a wide range of prey types including a number of important commercial species. Because of the link between the abundance and availability of fish prey and the reproductive success or failure of marine mammals, changes in the availability of principal forage fish may be expected to result in population level changes of marine mammals. It is currently not possible to predict the extent of this.
- Seals are sensitive to the low frequency sounds generated by oil exploration and production. Small cetaceans are relatively insensitive to low frequencies. Circumstantial evidence suggests that large whales may have good low frequency hearing.
- It is likely that seismic survey work will affect foraging behaviour by any seals and large whales in the SEA5 area. Current mitigation methods are probably generally effective in preventing physical damage.
- There are no reliable data to suggest that vessel noise or drilling noise adversely affect seals or small cetaceans but there are indications that large whales may avoid areas of concentrated activity. This is particularly relevant in deeper water areas where larger whales are more numerous and may be involved in seasonal migrations.
- Decommissioning work that involves the use of explosives is likely to impact animals in the vicinity, potentially causing injury and death at close range, and causing hearing damage at substantial ranges. Difficulties in observing and monitoring behaviour and the apparent attractiveness of submerged structures means that some marine mammals, especially seals, are likely to be damaged in blasts. Current mitigation methods are unlikely to be totally effective.
- Contaminants, such as polychlorinated biphenyls, DDTs and chlorinated pesticides probably have toxic effects on the reproductive and immune systems of marine mammals. There is little evidence that heavy metals cause substantial toxic responses, except at high concentrations. Cetacean species which feed lower down the food chain may be at risk from exposure to polyaromatic hydrocarbons, although very little is known about current exposure levels or the effects of chronic exposure in marine mammals.
- Major oil spills are likely to result in direct mortality. More generally, marine mammals are less vulnerable than seabirds to fouling by oil, but they are at risk from chemicals evaporating from the surface of an oil slick at sea within the first few days. Individuals may drown as a result of associated symptoms. Neonatal seal pups are at risk from oil coming ashore.
- It is not possible to say how many marine mammals are subject to fisheries bycatch in the SEA5 area, but the fact that gillnet fisheries play a relatively small role in overall fishing activity in this area probably means that bycatch rates are lower than in many other parts of the North Sea.

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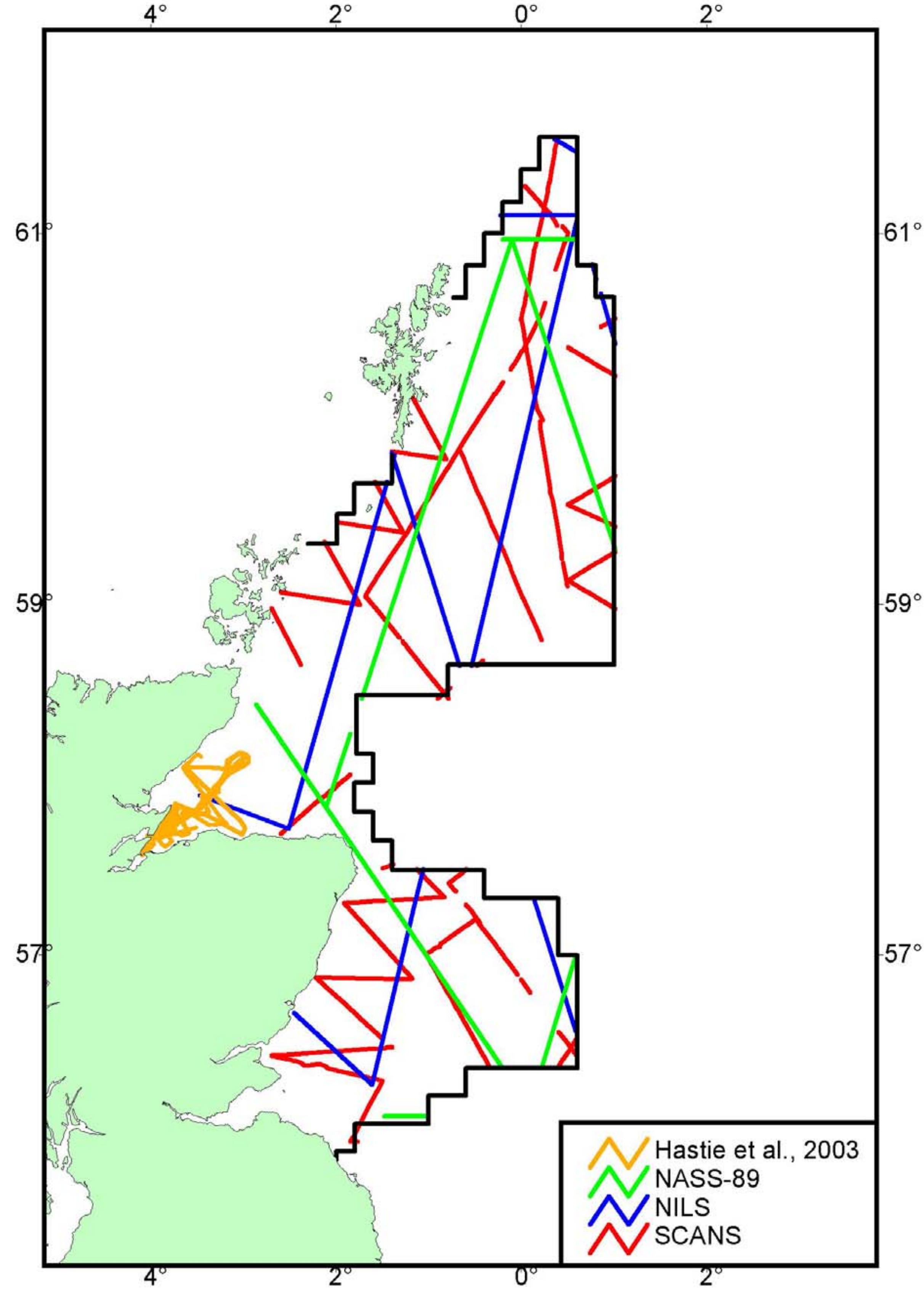

Figure 1. Cruise tracks from various surveys conducted in the SEA5 area, including SCANS (Hammond *et al*. 1995; 2002), NASS-89 and NASS 89 (Øien, 1991), NILS-95 (Schweder *et al*. 1997) and Hastie *et al.* (2003)

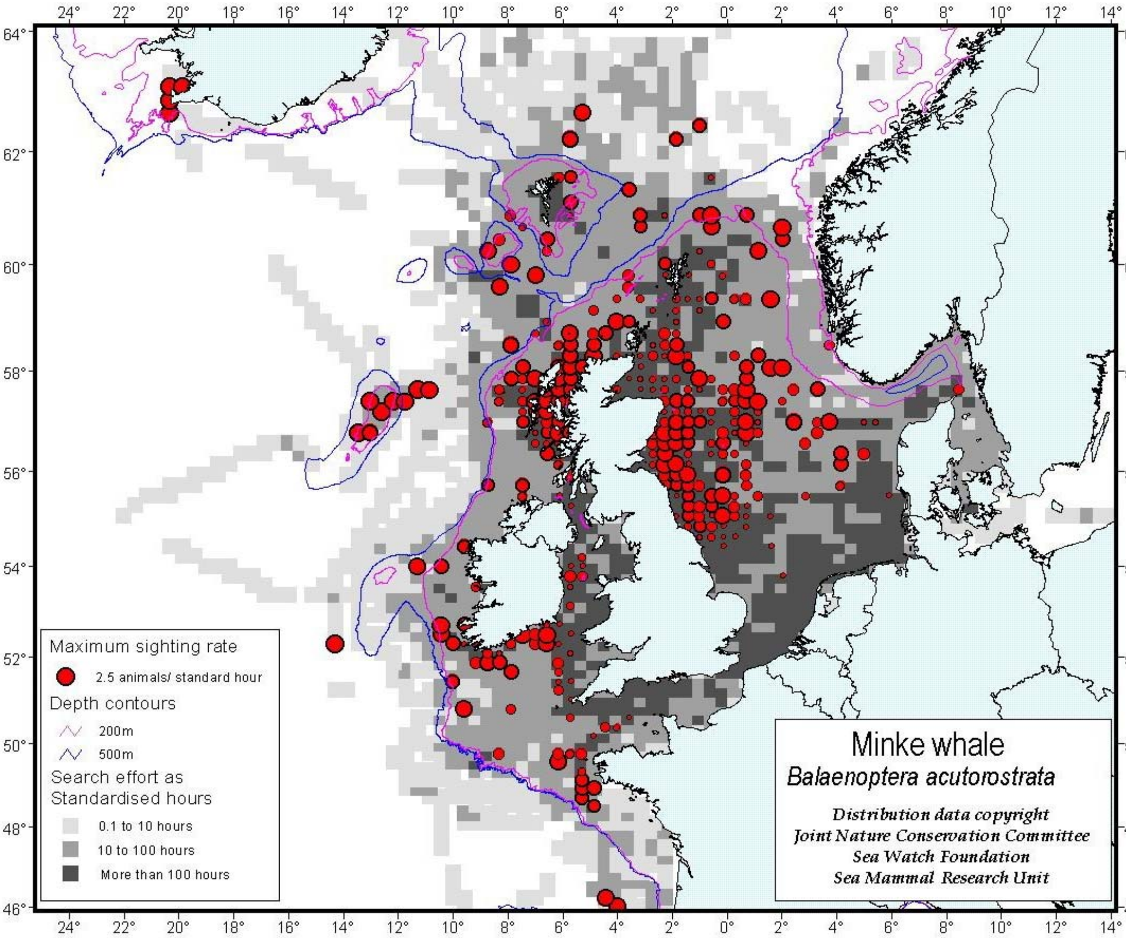

Figure 2. Sightings rates (numbers per standard hour) of minke whales reproduced from Reid *et al.* (2004). Data collected over a 20 year time period, all months, from numerous platforms. Search effort (hours of observation) is indicated by shaded squares, sightings rates by red circles with area proportional to rate. Gross corrections for the effect of sea state have been applied.

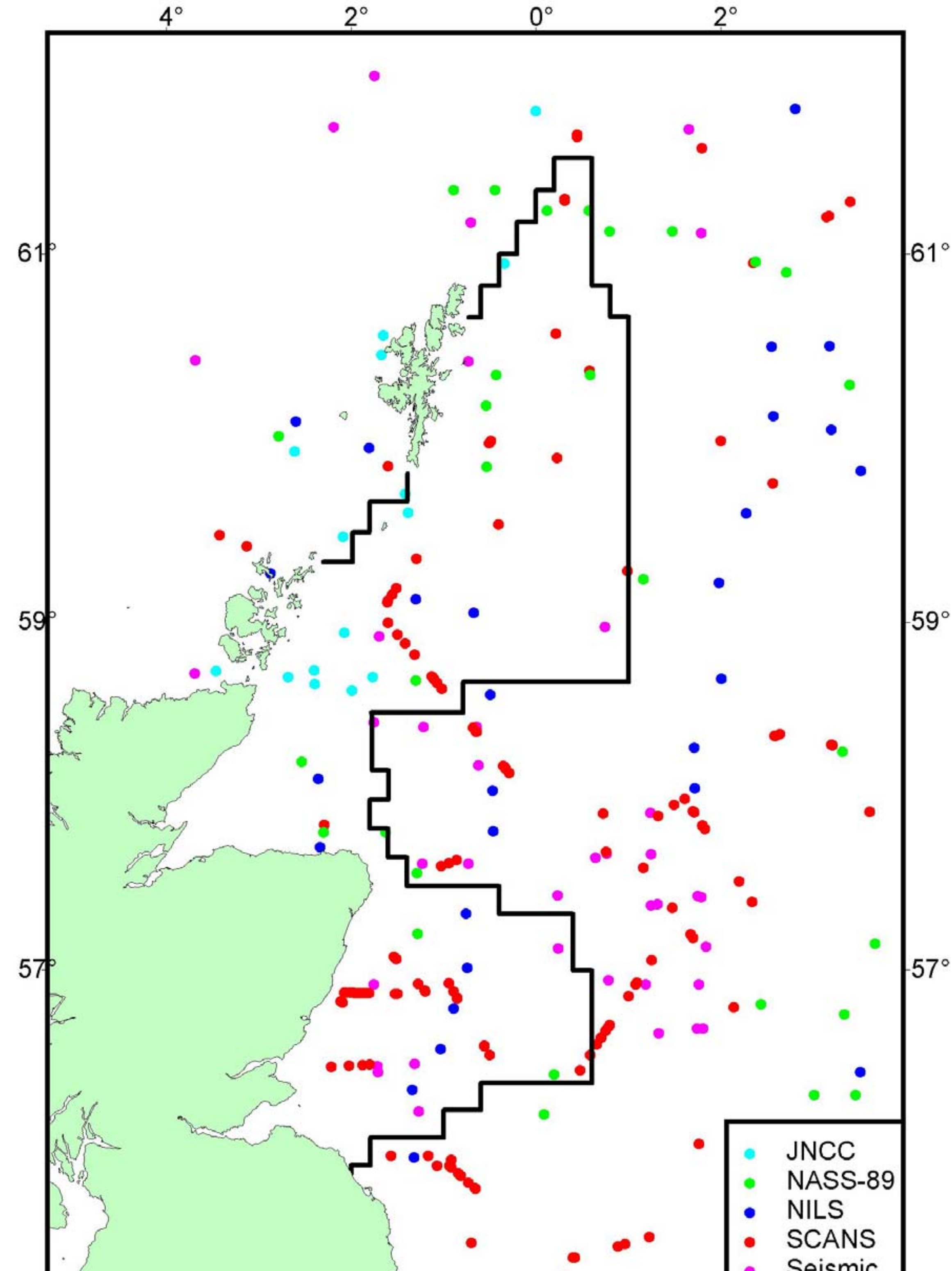

Figure 3. Minke whale sightings made during SCANS (Hammond *et al*. 1995; 2002), NASS-89 (Øien, 1991), NILS-95 (Schweder *et al*. 1997), JNCC (Pollock *et al*. 2000) and seismic (Stone 1997, 1998, 2000, 2001) surveys.

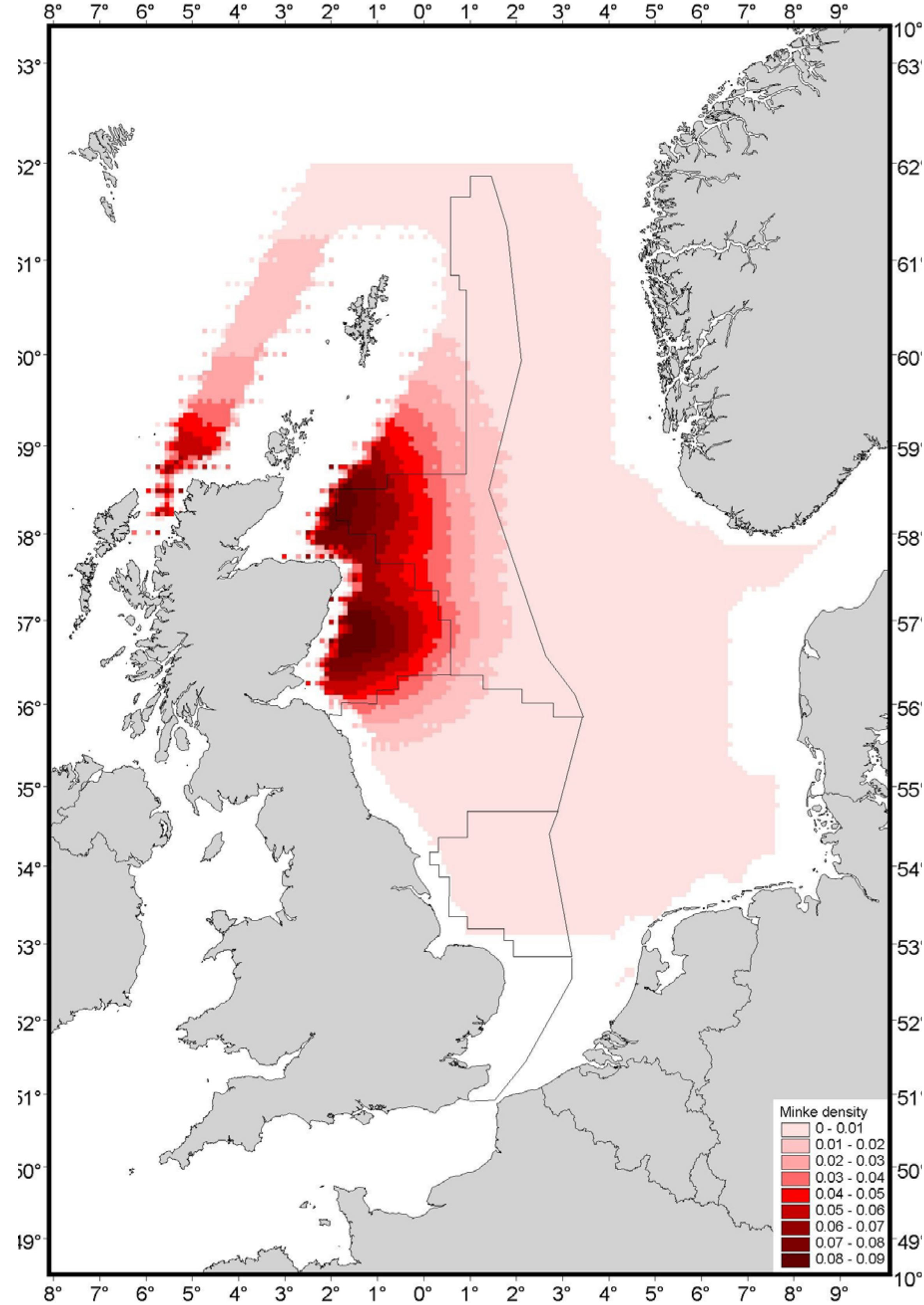

Figure 4. Minke whale density (schools.km^{-2}) predicted from spatial modelling of the SCANS data (Burt *et al*. 1999; Hammond *et al*. 1995; 2002). Mean school size is approximately 1.0.

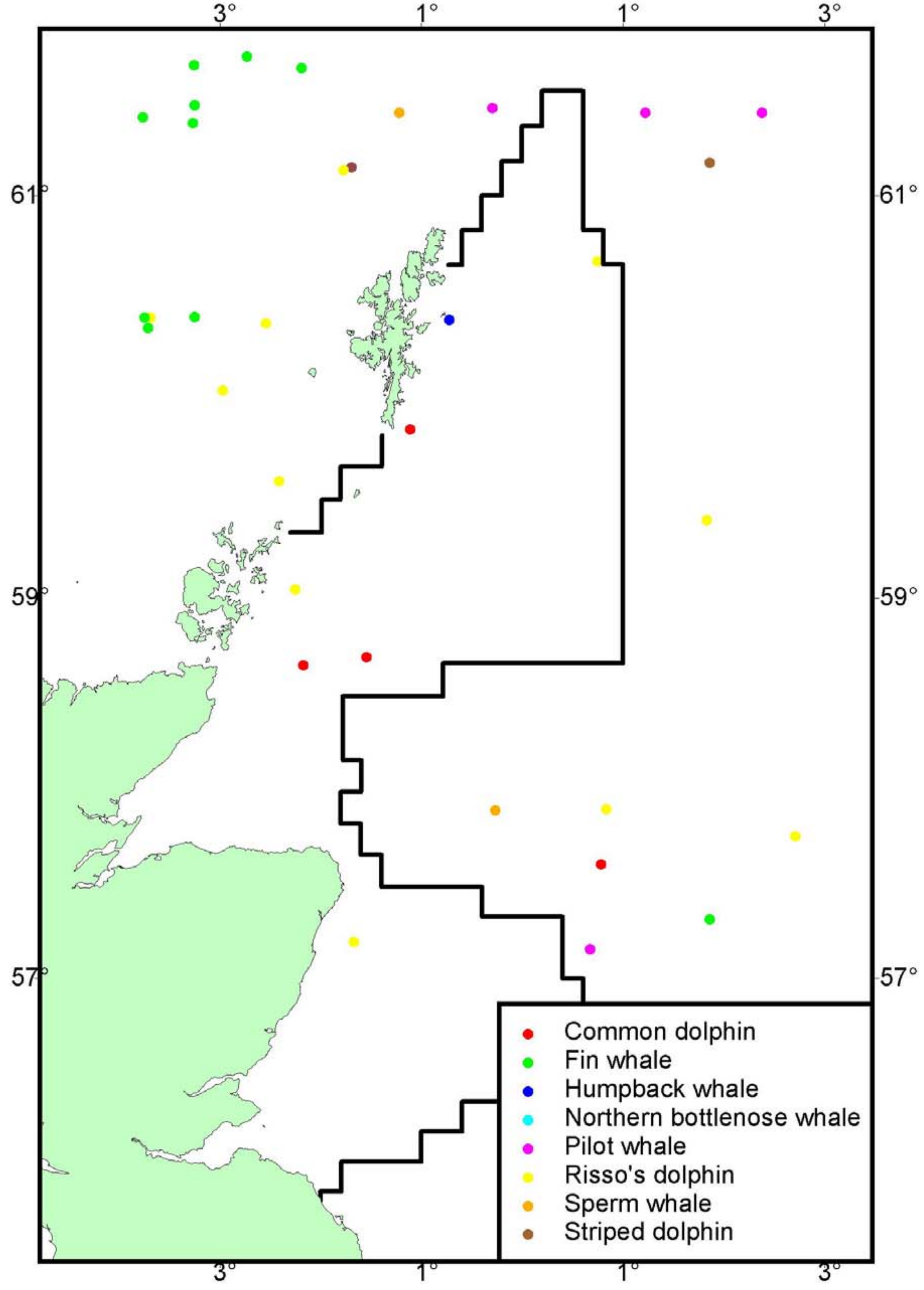

Figure 5. Sightings records of common dolphins, fin whales, humpback whales, northern bottlenose whales, pilot whales, Risso's dolphins, sperm whales and striped dolphins made during NASS-87 (Øien, 1991), NILS-95 (Schweder *et al*. 1997), JNCC (Pollock *et al*. 2000), seismic (Stone 1997, 1998, 2000, 2001), and other surveys.

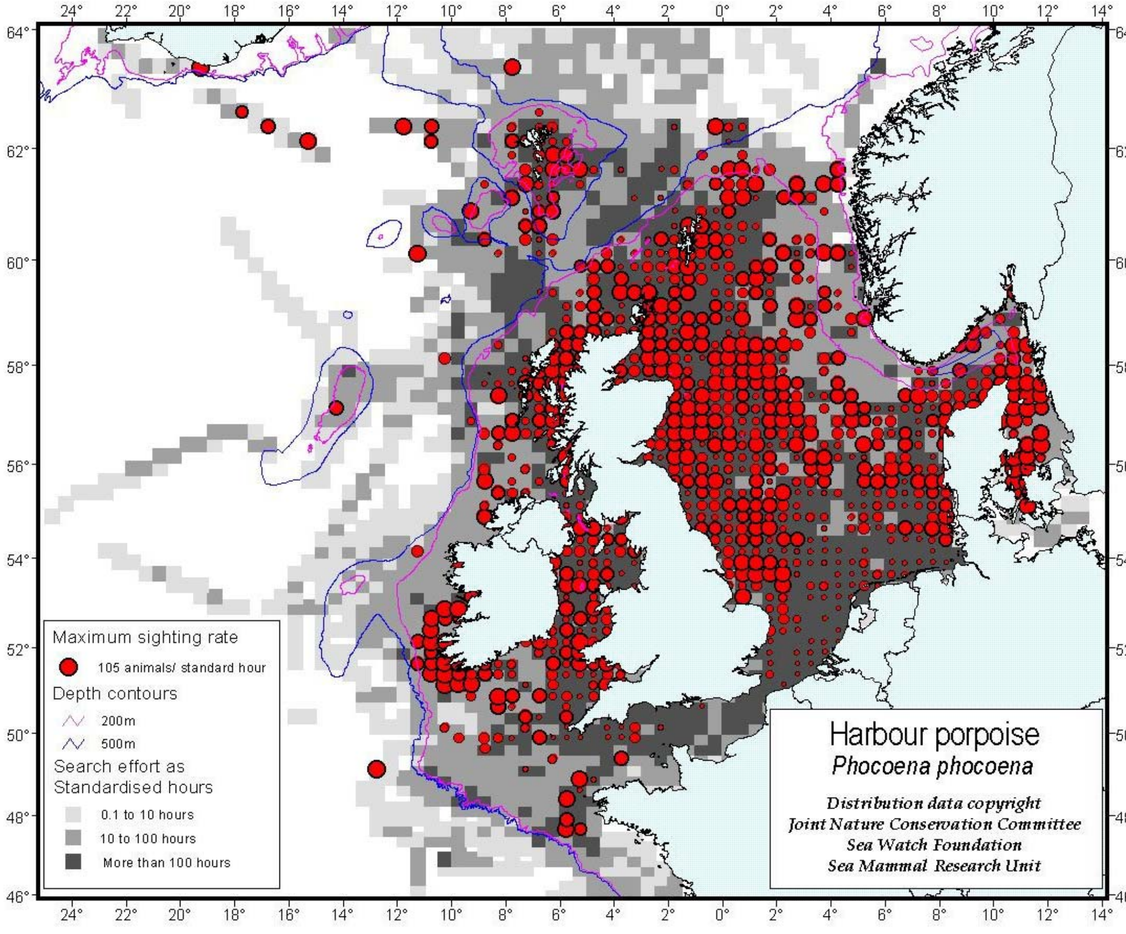

Figure 6. Sightings rates (numbers per standard hour) of harbour porpoises reproduced from Reid *et al.* (2004). Data collected over a 20 year time period, all months, from numerous platforms. Search effort (hours of observation) is indicated by shaded squares, sightings rates by red circles with area proportional to rate. Gross corrections for the effect of sea state have been applied.

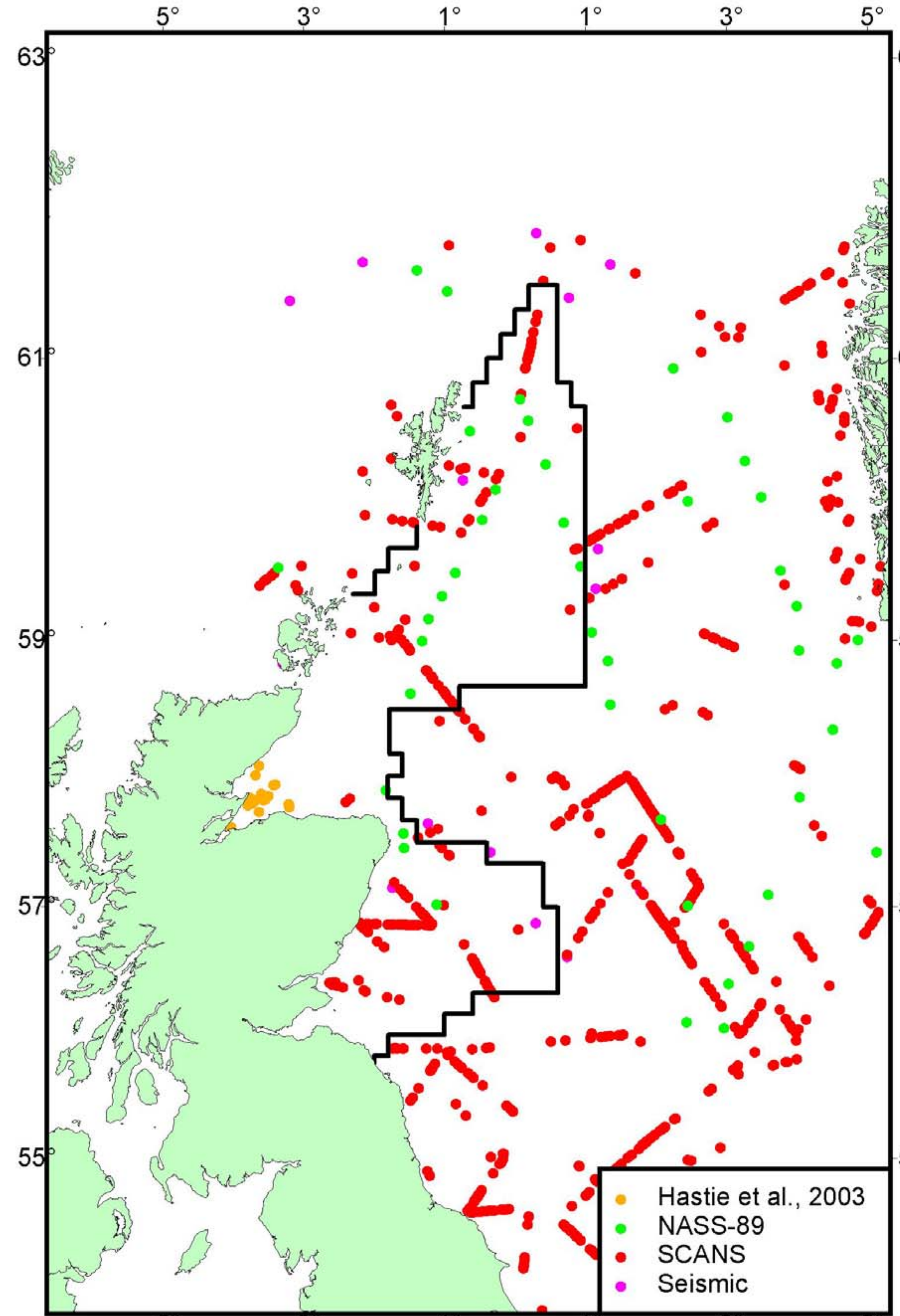

Figure 7. Harbour porpoise sightings made during SCANS (Hammond *et al*. 1995; 2002), NASS-89 (Øien, 1991) and seismic (Stone 1997, 1998, 2000, 2001) surveys and Hastie *et al.* (2003).

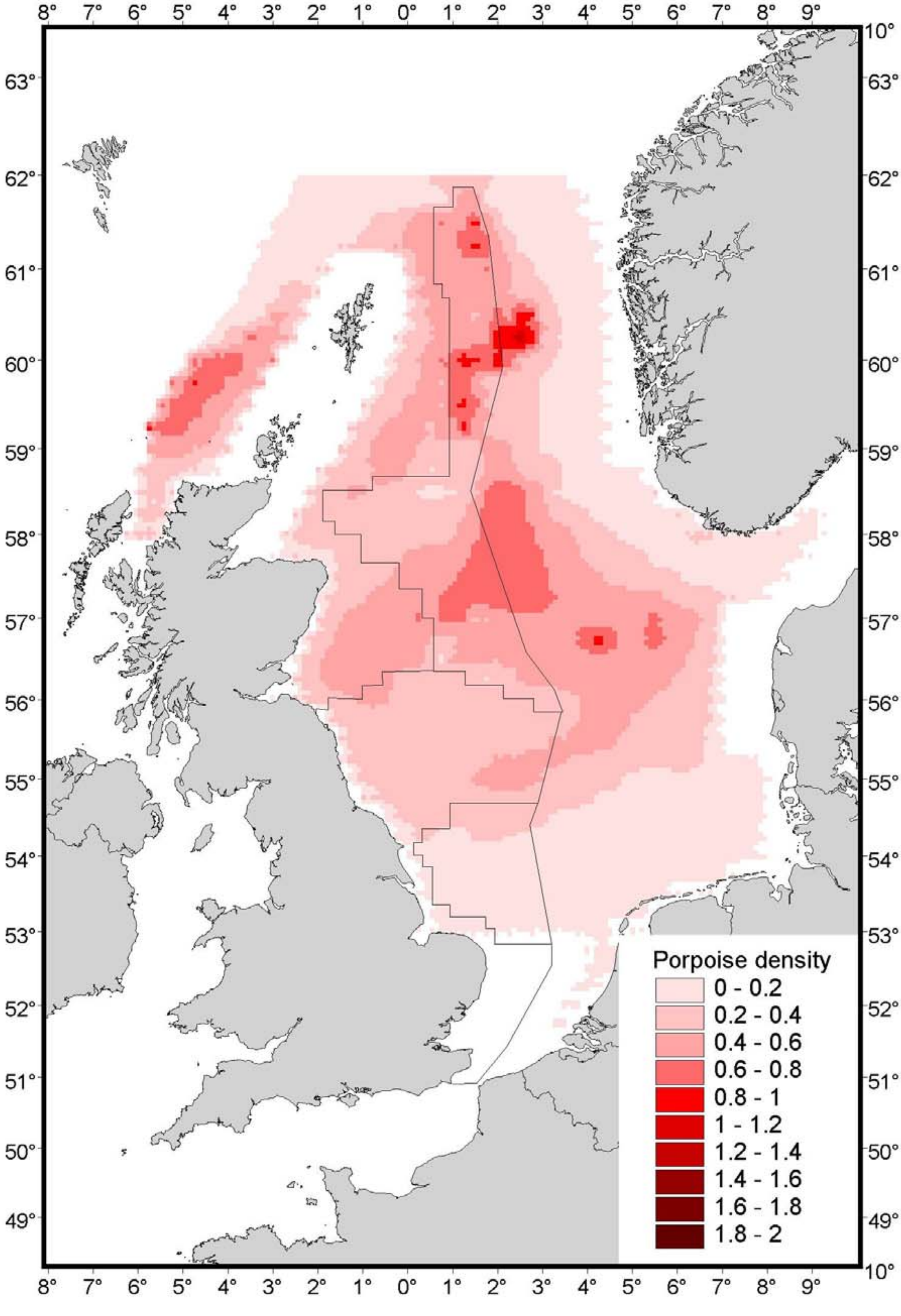

Figure 8. Harbour porpoise density (schools.km^{-2}) predicted from spatial modelling of the SCANS data (Burt *et al*. 1999; Hammond *et al*. 1995; 2002). Mean school size is approximately 1.5.

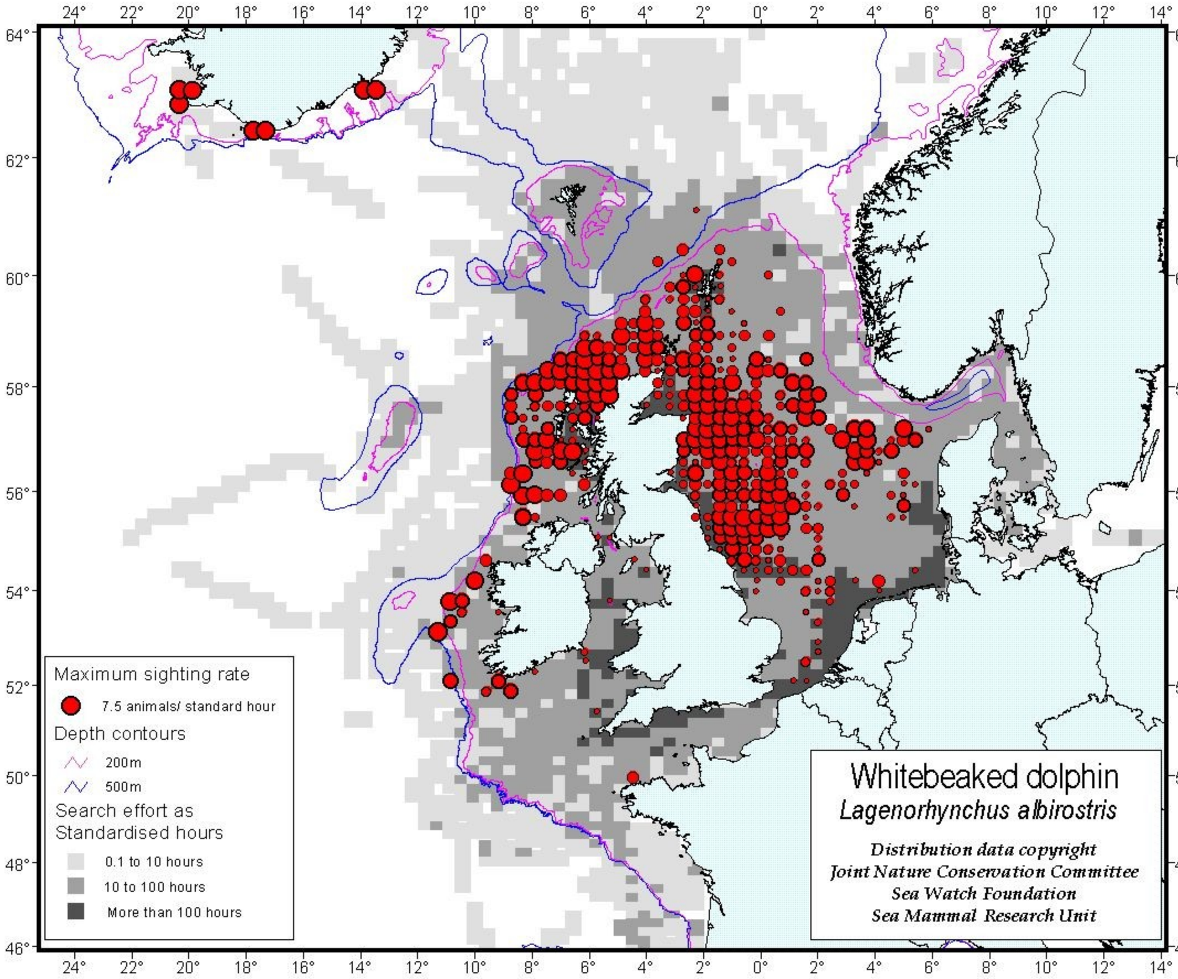

Figure 9. Sightings rates (numbers per standard hour) of white-beaked dolphins reproduced from Reid *et al.* (2004). Data collected over a 20 year time period, all months, from numerous platforms. Search effort (hours of observation) is indicated by shaded squares, sightings rates by red circles with area proportional to rate. Gross corrections for the effect of sea state have been applied.

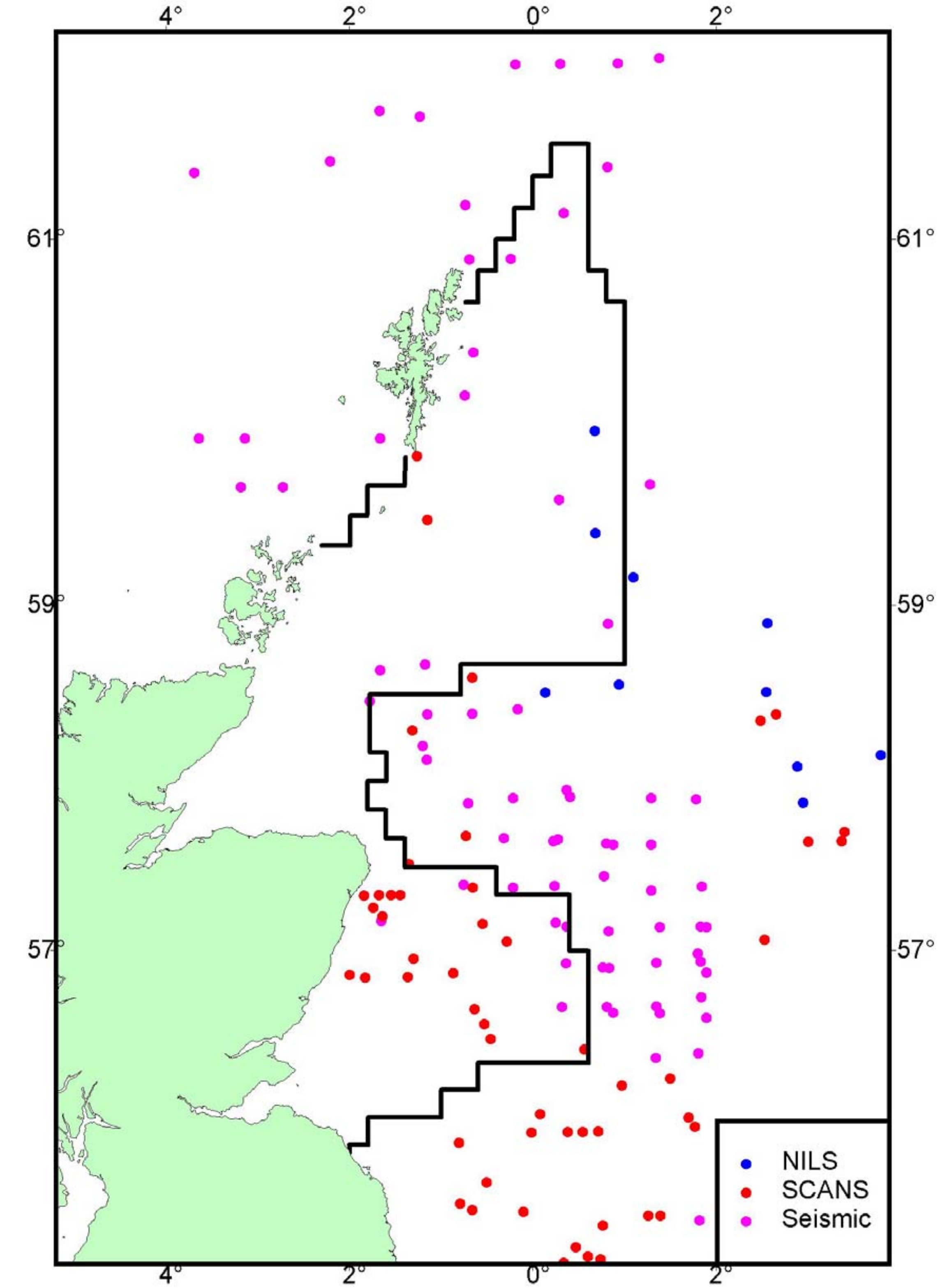

Figure 10. White-beaked dolphin sightings made during SCANS (Hammond *et al*. 1995; 2002), NILS-95 (Schweder *et al*. 1997) and seismic (Stone 1997, 1998, 2000, 2001) surveys.

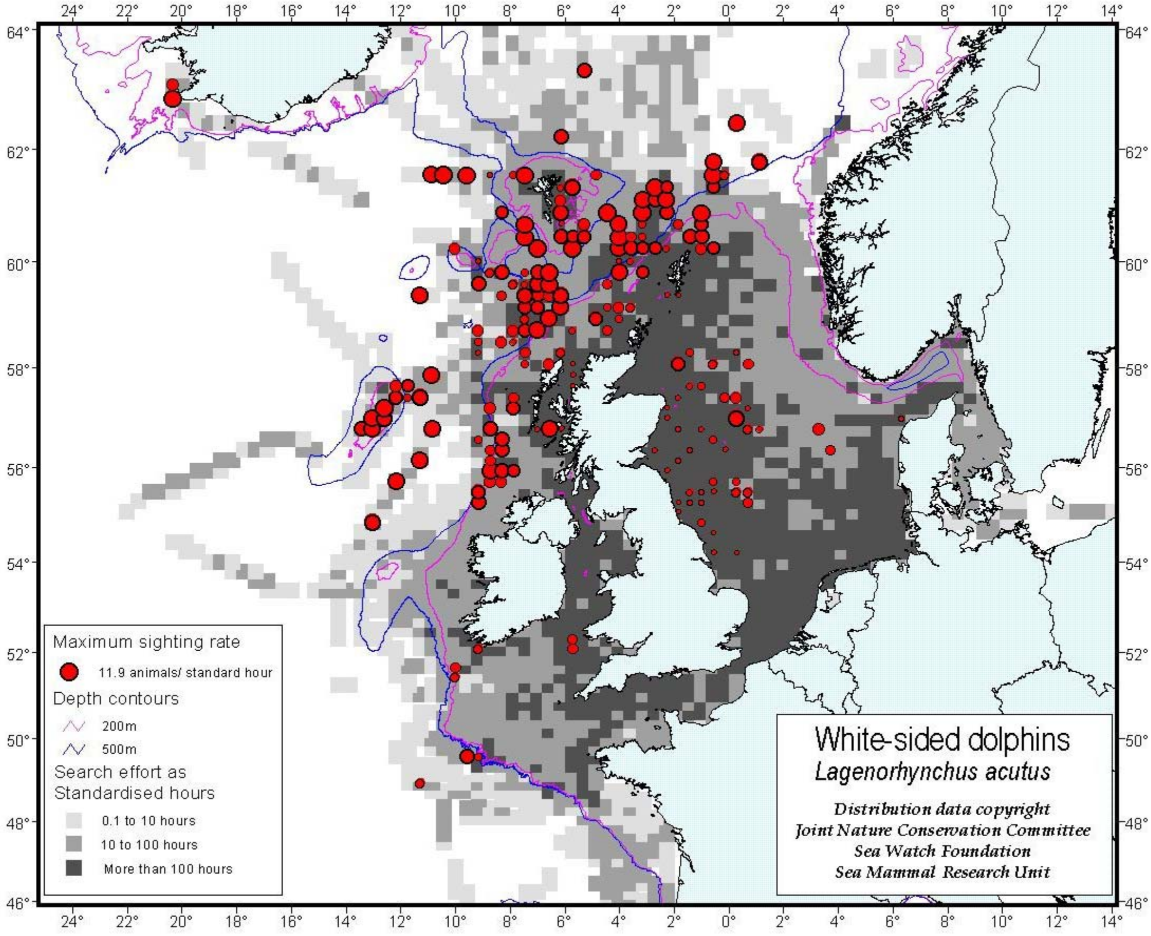

Figure 11. Sightings rates (numbers per standard hour) of Atlantic white-sided dolphins reproduced from Reid *et al.* (2004). Data collected over a 20 year time period, all months, from numerous platforms. Search effort (hours of observation) is indicated by shaded squares, sightings rates by red circles with area proportional to rate. Gross corrections for the effect of sea state have been applied.

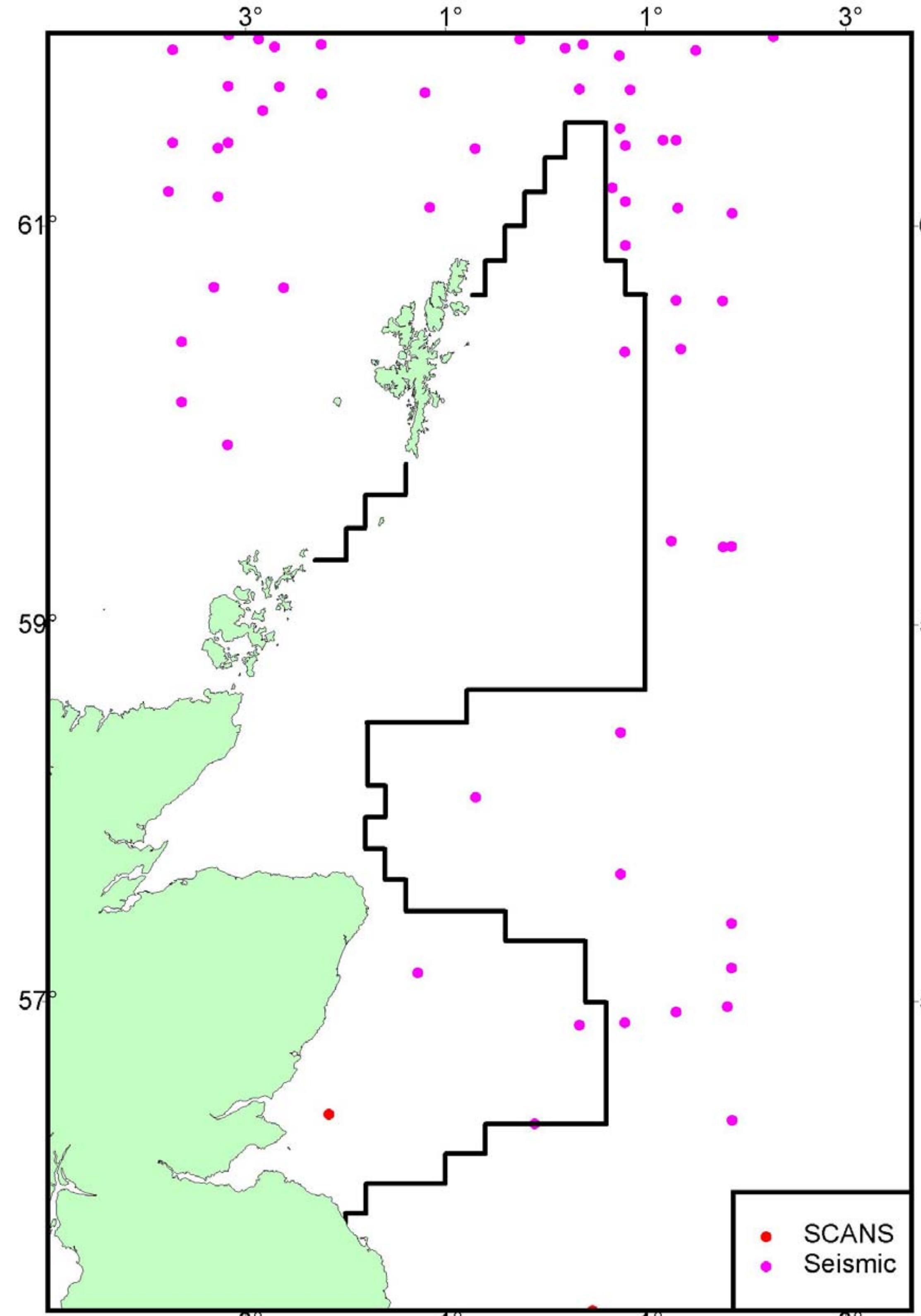

Figure 12. Atlantic white-sided dolphin sightings made during SCANS (Hammond *et al*. 1995; 2002) and seismic (Stone 1997, 1998, 2000, 2001) surveys

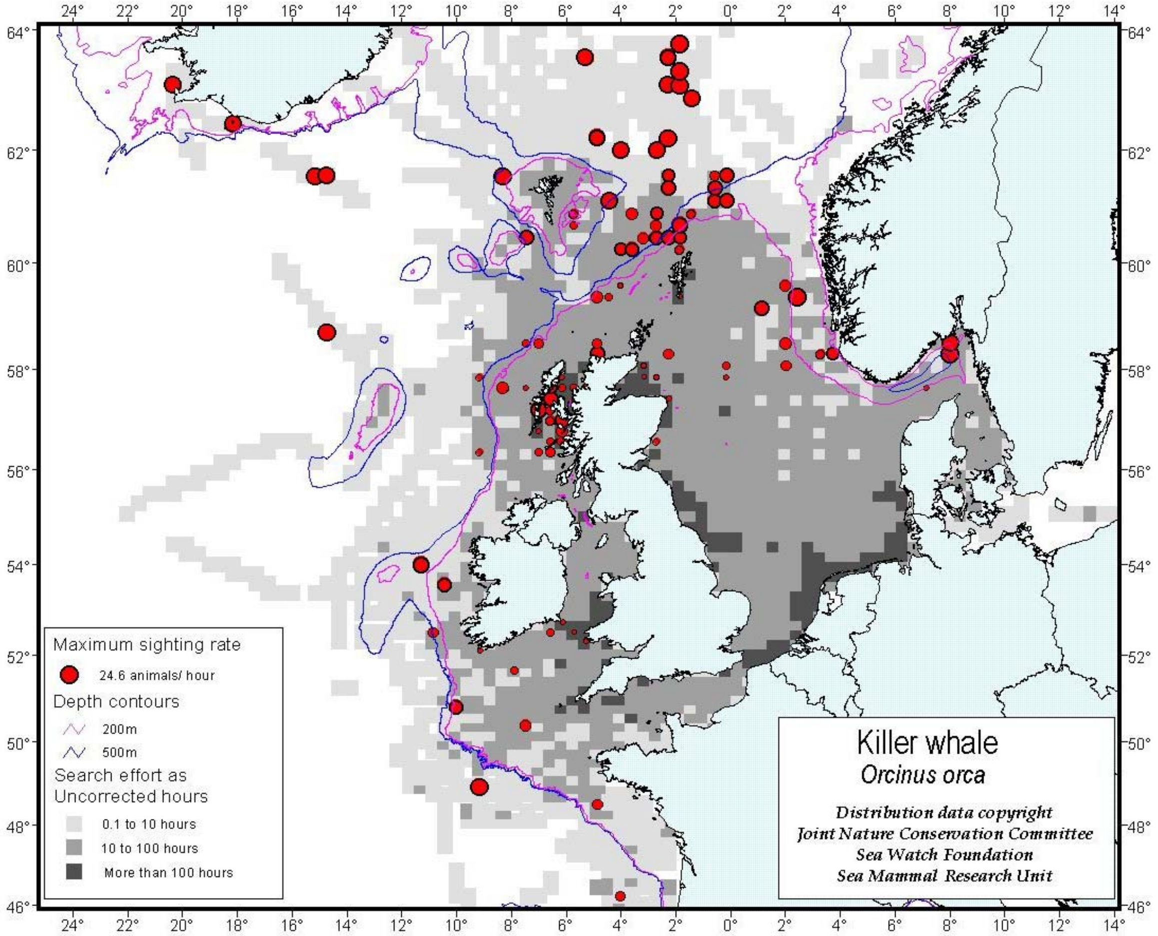

Figure 13. Sightings rates (numbers per standard hour) of killer whales reproduced from Reid *et al.* (2004). Data collected over a 20 year time period, all months, from numerous platforms. Search effort (hours of observation) is indicated by shaded squares, sightings rates by red circles with area proportional to rate. No corrections for the effect of sea state have been applied.

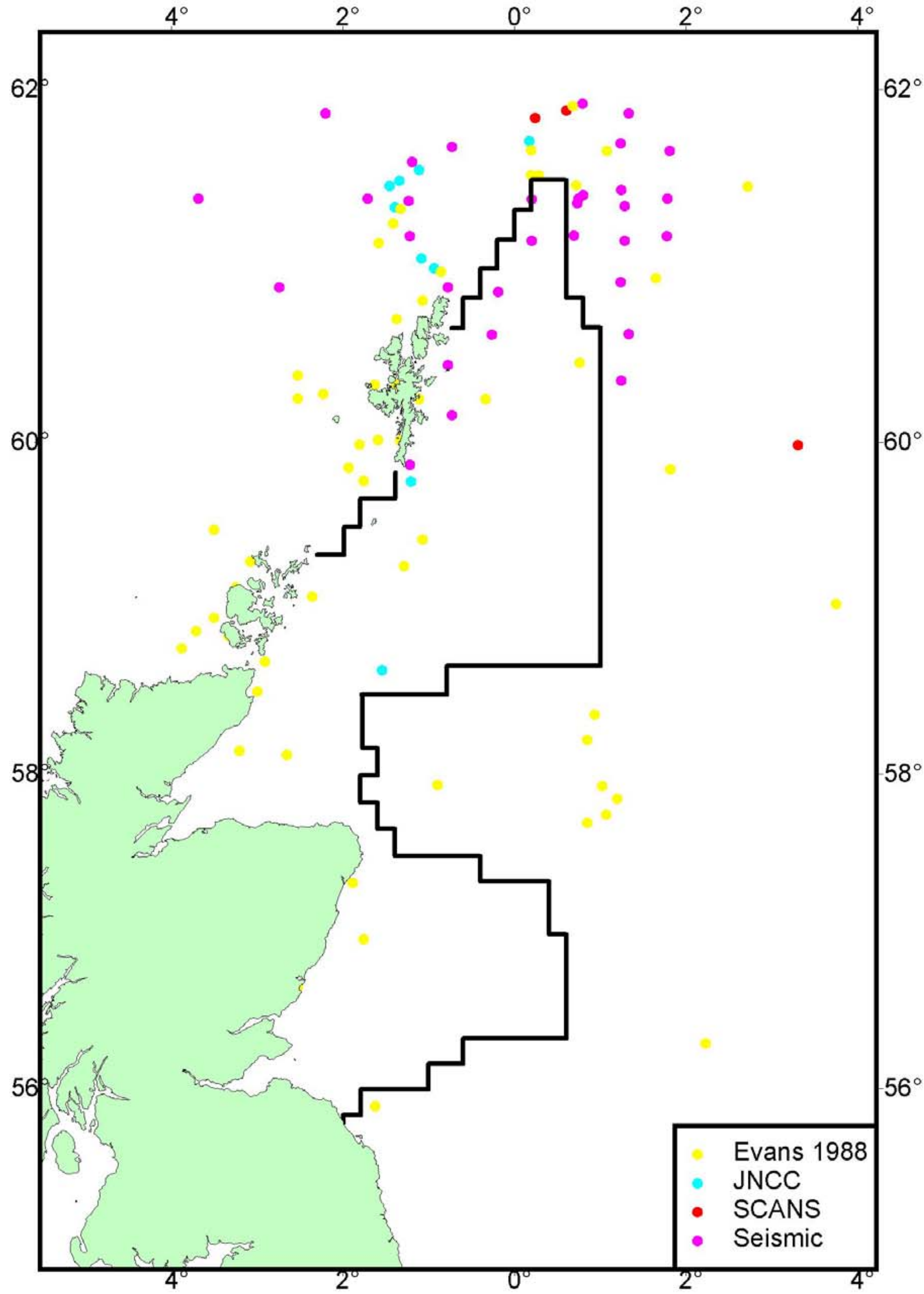

Figure 14. Killer whale sightings made during SCANS (Hammond *et al*. 1995; 2002), JNCC (Pollock *et al*. 2000) and seismic (Stone 1997, 1998, 2000, 2001) surveys, and from Evans (1988).

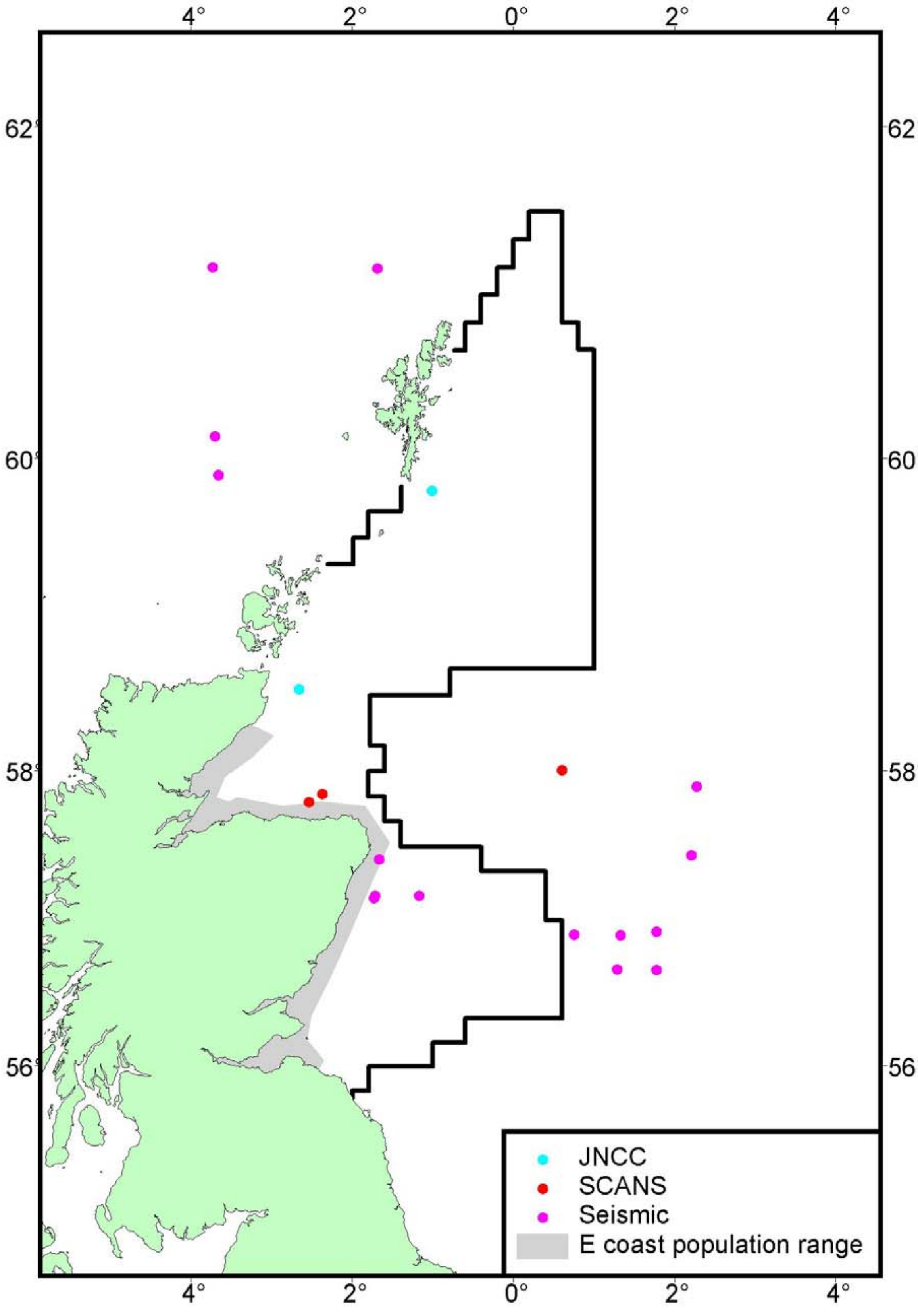

Figure 15. Scottish east coast range and sightings of bottlenose dolphins made during SCANS (Hammond *et al*. 1995; 2002), JNCC (Pollock *et al*. 2000) and seismic (Stone 1997, 1998, 2000, 2001) surveys.

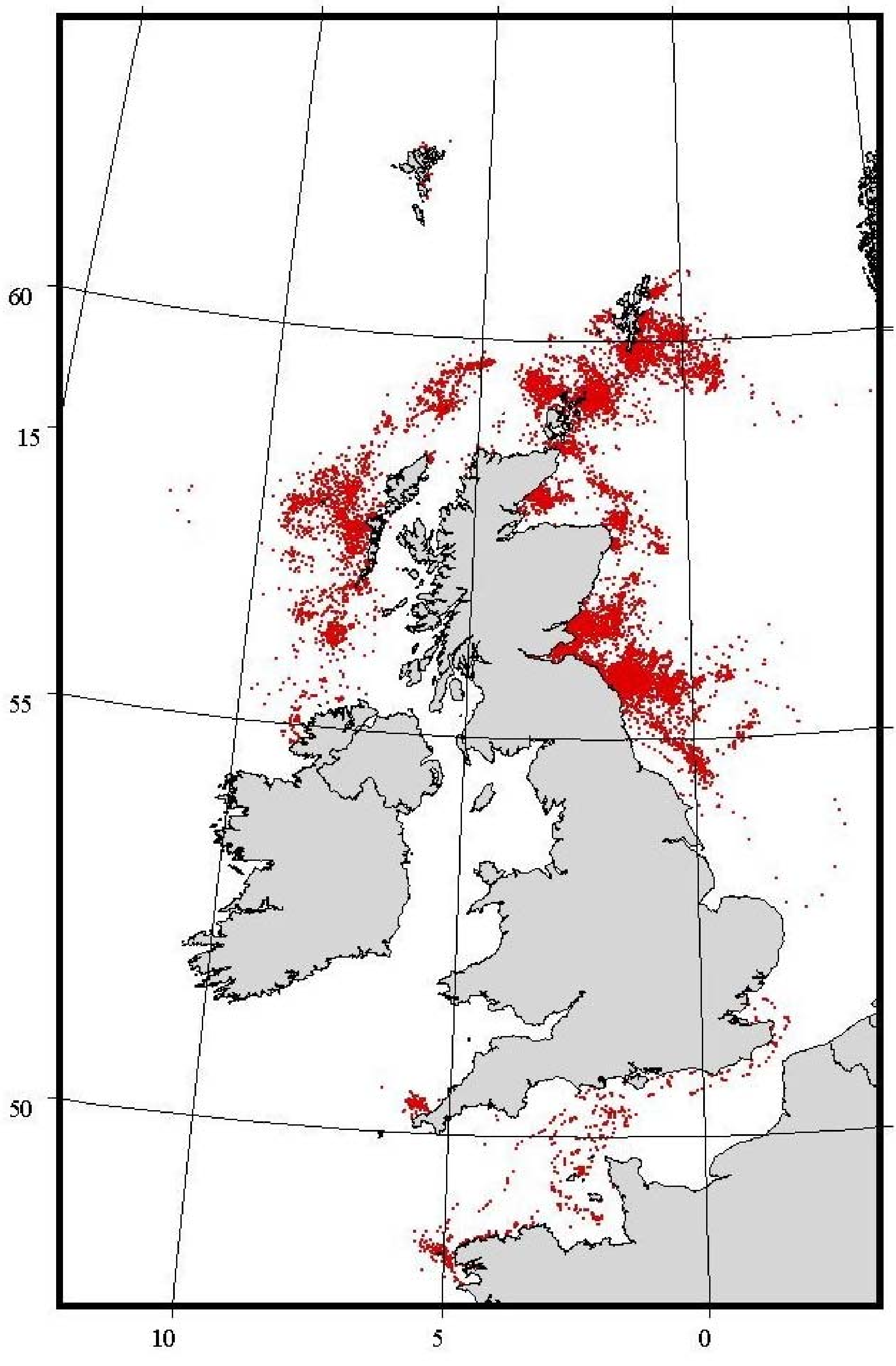

Figure 16. Tracks of 108 grey seals fitted with satellite-relay data loggers over a period of about 10 years (McConnell *et al*. 1999; SMRU unpublished data).

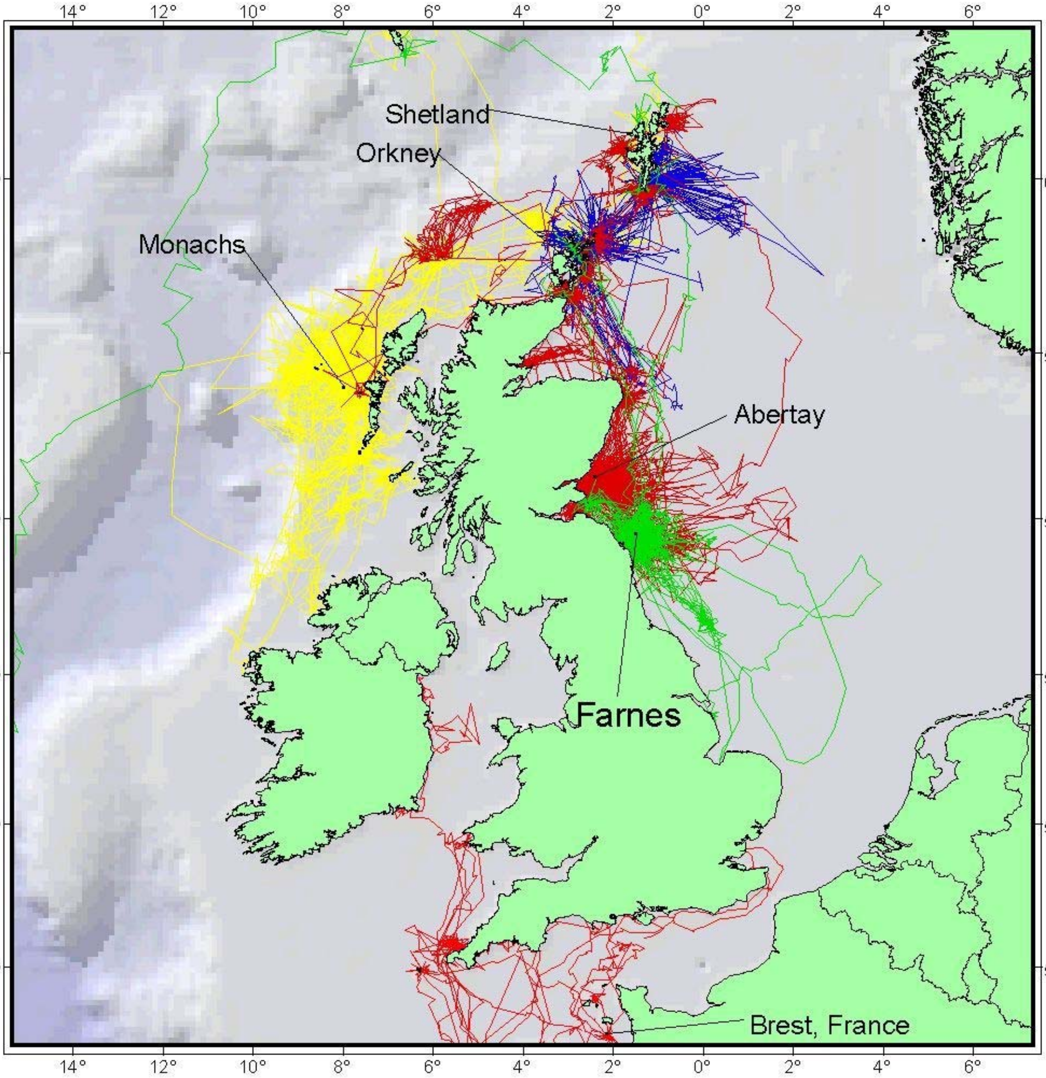

Figure 17. Locations of 108 grey seals fitted with satellite-relay data loggers over a period of about 10 years (see McConnell *et al.* 1999 for details).

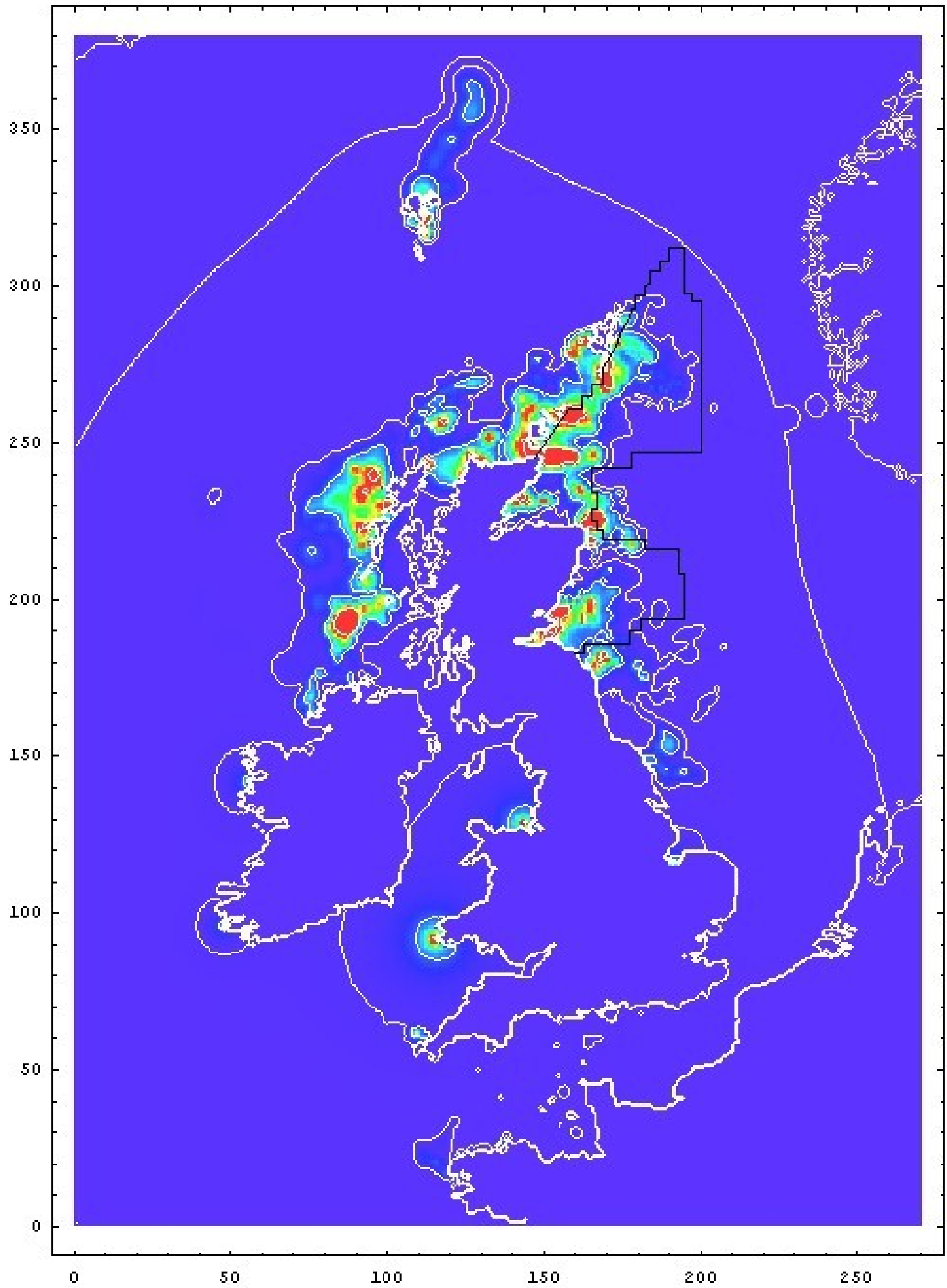

Figure 18. Distribution of where grey seals spend their time foraging around the British Isles predicted by a spatial model using the satellite-linked telemetry data shown in Figures 16 and 17 and other unpublished SMRU data (Matthiopoulos *et al.* in press).

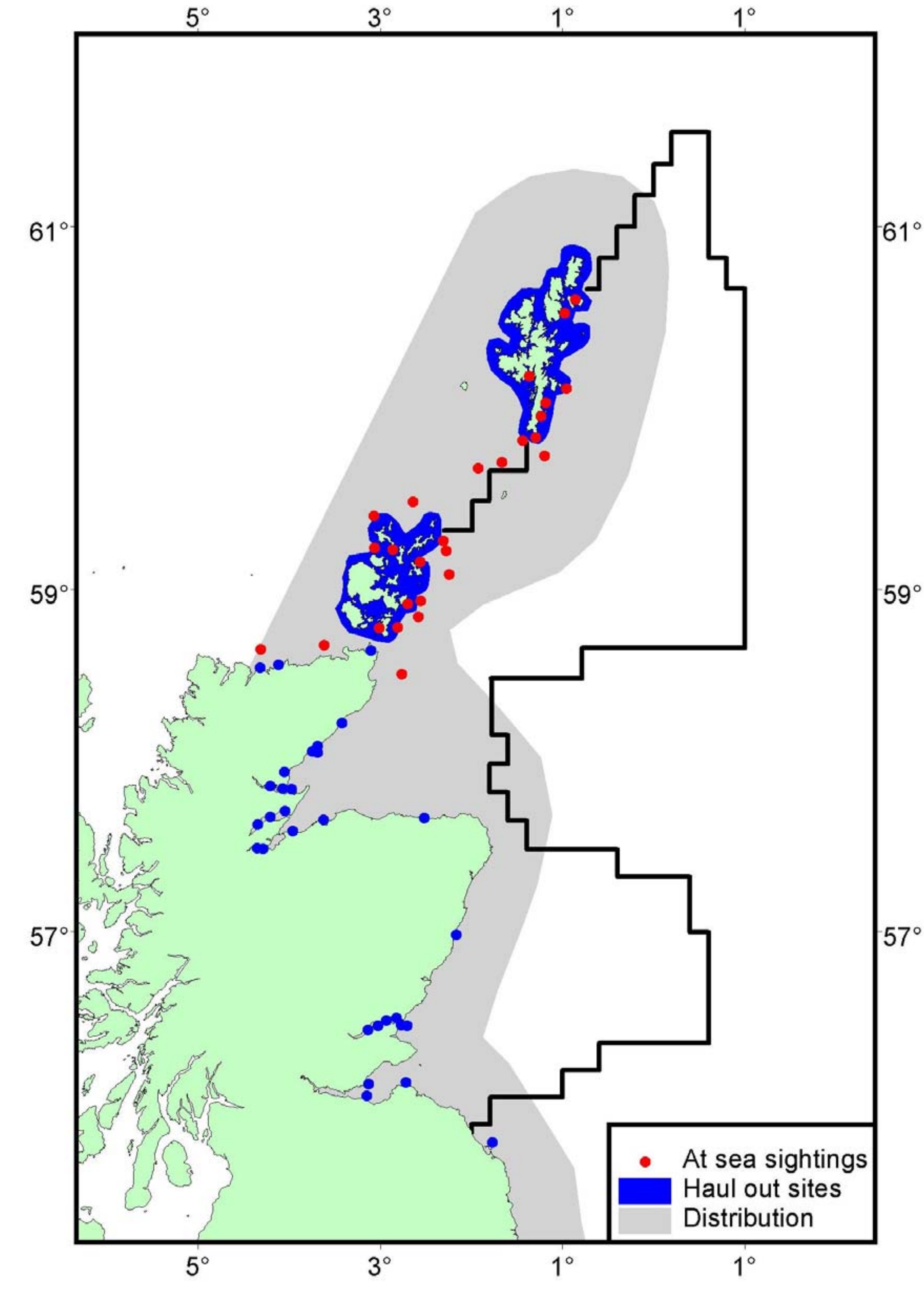

Figure 19. Harbour seal distribution in the northwestern North Sea after Reijnders *et al*. (1997). Also shown are haul-out sites during the moult (SMRU unpublished data) and at-sea sightings from JNCC surveys (Pollock *et al*. 2000).

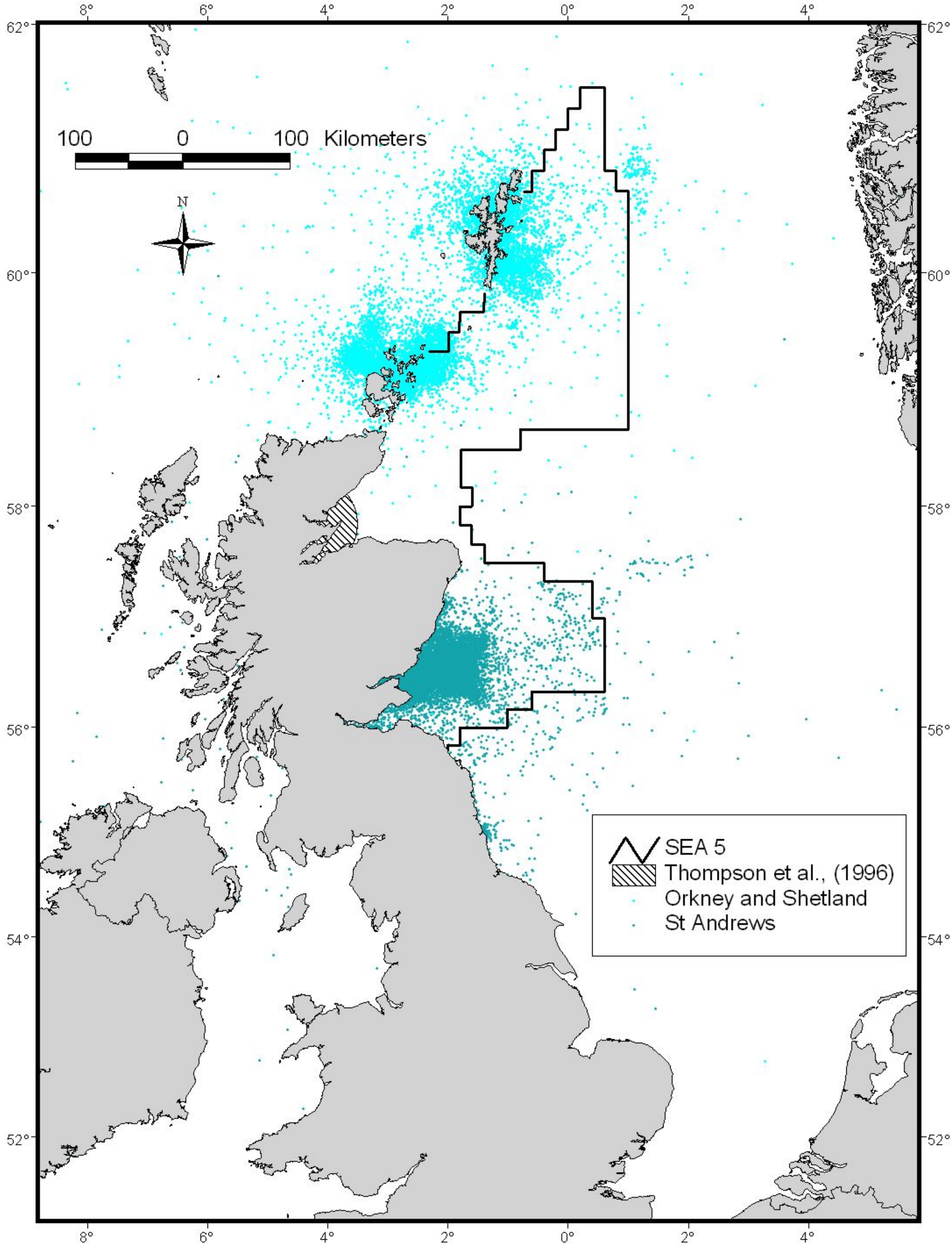

Figure 20. Locations of 55 harbour seals fitted with satellite-relay data loggers covering the period 2002-2004 (SMRU unpublished data) and the area used by VHF-tagged harbour seals in the Moray Firth (Thompson *et al.* 1996).

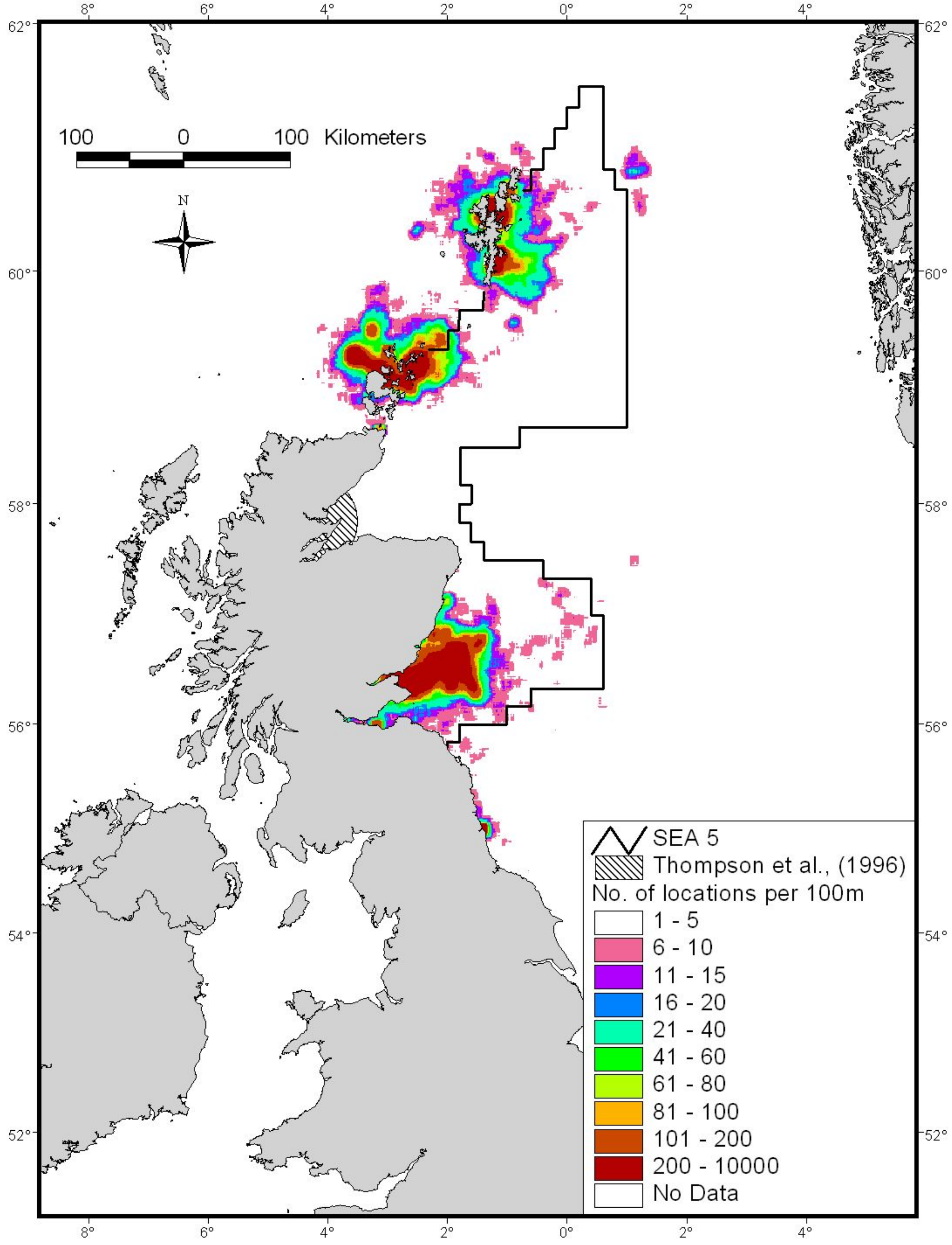

Figure 21. Density of locations of 55 harbour seals at sea from satellite telemetry studies in 2002-2004 (SMRU unpublished data), and the area used by VHF-tagged harbour seals in the Moray Firth (Thompson *et al.* 1996).