Background information on marine mammals relevant to Strategic Environmental Assessment 4

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April 2003

MARINE MAMMALS

Non-technical summary

Distribution and abundance

Twelve marine mammal species are known to occur regularly in this area: grey seal, harbour seal, hooded seal, harbour porpoise, white-beaked dolphin, Atlantic white-sided dolphin, Risso's dolphin, long-finned pilot whale, killer whale, minke whale, fin whale and sperm whale. There are occasional at-sea records of a further 11 cetacean species (humpback whale, sei whale, blue whale, Sowerby's beaked whale, Cuvier's beaked whale, pigmy sperm whale, false killer whale, northern bottlenose whale, beluga whale, bottlenose dolphin and short-beaked common dolphin) and three pinniped species (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. Information on hooded seals is available from satellite telemetry studies of seals tagged at the ice edge and from sightings during seismic survey operations. There is also extensive information on cetacean distribution in the North Sea from a number of summer sightings surveys (SCANS-94, NASS-89 and 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 in 1996-99, 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 SEA 4 area, especially in summer, and seem to move into the area in May. They are mostly distributed over the continental shelf, and one estimate for part of the area was of around 3000 animals in the summer of 1994. This is clearly an important area for minke whales.

The harbour porpoise is the commonest cetacean in the region. The area to the north of Scotland has some of the highest densities of porpoises recorded, and one abundance estimate in 1994 was for more than 60,000 animals in a part of the SEA 4 area (SCANS block D). Sightings rates are highest in summer, and it is clear that this is an important area for porpoises.

White-beaked dolphins are restricted to the North Atlantic. In the SEA 4 area they are widely distributed on the continental shelf to the west of Orkney and Shetland, and one estimate of abundance for one part of the SEA 4 area (SCANS block D) was for over 1000 animals in 1994.

The Atlantic white-sided dolphin is primarily an offshore species but does occur over the shelf, especially in summer. Most sightings in the SEA 4 area are in deep water.

Killer whales have been observed throughout the northwestern North Sea in all months except October, and especially in deeper water. Most records are from the northern and western parts of the SEA 4 area, though there are regular sightings around Shetland. Likewise, pilot whales are mostly found along the shelf edge.

Fin whales and sperm whales are regularly sighted in the deep water between the Faroe Islands and the Shetlands. Acoustic studies suggest that fin whales are present year round, and that sperm whales are fairly numerous, but for both species most vocalisations were confined to the deeper water areas north and west of the SEA 4 area. (Swift *et al* 2002) Risso's dolphins are sighted in low numbers through most parts of the SEA 4 area.

At least ten other cetacean species are reported irregularly.

Harbour seals are found, throughout the year, on haulout sites in Orkney, Shetland and along the north coast of Scotland. Approximately 13000 harbour seals have been counted in surveys during the annual moult, this represents around 18% of the eastern Atlantic sub-species. 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 seals forage widely over much of the North Sea, ranging up to 200km from their haulout sites. There are no direct data from the SEA 4 area, but assuming similar foraging patterns we could expect harbour seals to range over much of the southern half of the area. At sea sightings of harbour seals in this area are also concentrated in the south and close to Orkney and Shetland.

Grey seals are restricted to the North Atlantic; total abundance is approximately 300,000 animals. The population in the northeast Atlantic has been increasing at around 6% annually since the 1960's; its current size is estimated at around 130,000-140,000 individuals, of which approximately 63,000 are associated with breeding colonies in Orkney, Shetland, North Rona and the north coast of Scotland. Extensive information on the distribution of British grey seals at sea shows that although they do occur in the SEA 4 area, but are concentrated in the south and along the eastern edge of the area. Models of habitat preference supported by the satellite telemetry data suggest that the most important areas used by grey seals in the SEA 4 area appear to be close to Orkney and Shetland. These results are supported by the distribution of at sea sightings during cetacean surveys.

Hooded seals are seen in deeper waters along the north-western side of the SEA 4 area, throughout the year. Satellite telemetry data show that a proportion of the Jan Mayen stock moves down to forage in the Faroe-Shetland Channel, mainly foraging over deep water.

Ecological importance

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. The large distances travelled indicate that grey seals in the SEA 4 area are not ecologically isolated; seals from both the Hebrides and Farnes/Isle of May populations have been recorded foraging in the area. Foraging destinations at sea are typically localized areas characterized by a gravel/sand seabed sediment, the preferred burrowing habitat of sandeels, which are an important component of grey seal diet. The limited distance from a haul-out site of a typical foraging trip indicates that the ecological impact of seal predation may be greater coastally, rather than further offshore. Recent and ongoing mathematical modelling has generated predicted distributions of where grey seals spend their time foraging around the British Isles. The model predicts that approximately 16% of the overall foraging effort of the UK grey seal population occurs in the SEA 4 area.

Grey seals are important marine predators in the SEA 4 area. Their diet comprises primarily sandeels, whitefish and flatfish, in that order of importance, but varies seasonally and from region to region. A current estimate of annual prey consumption in the area is approximately 40,000 tonnes, of which almost 50% is sandeels. We cannot estimate confidence intervals so this consumption figure should be treated with caution.

The harbour seal is the smaller of the two species of pinniped that breed in Britain but may also be an important predator in the SEA 4 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. A very approximate estimate of annual consumption of prey by harbour seals in the SEA 4 area is around 23000-30000 tonnes. Again, it is not possible to estimate confidence intervals.

Harbour seals were previously believed to forage within 60 km of their haul-out sites but recent information indicates that they forage widely, up to 200km from haulout sites. It is likely, therefore, that much of the SEA 4 area may be visited by foraging harbour seals, All tracks to date have been in shallow shelf waters. We have no direct evidence of movements into deep waters.

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 porpoises 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 SEA 4 block. 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-January 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 SEA 4 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, and bycatch in other species, 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 SEA 4 area is an important area for cetaceans, not least because there is a relatively high species diversity found in the area. There are at least nine species regularly sighted there and another 10 that have been recorded less regularly. Little is known about the abundance or seasonal distribution of these species. Some of the offshore species, notably sperm whales and fin whales, probably migrate through the area. For some of the less frequently sighted species such as the beaked whales, this area may be more important that the number of sightings would suggest, as these are not numerous animals and are difficult to see. On the shelf, the area is important especially for porpoises, white-beaked dolphins and minke whales.

- Based on satellite telemetry data and distribution models we estimate that 16% of the foraging effort of the UK grey seal population is expended in SEA 4, concentrated in the south and east of the area. Harbour seals have recently been found to forage farther offshore than previously thought and are likely to occur over much of the southern and eastern parts of the SEA 4 area. Hooded seals occur in the deep-water areas of SEA 4 throughout the year. There is therefore potential for interactions between industrial activities and seals throughout the SEA 4 area.

- Marine mammals are important predators in this region, feeding on a suspected 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 possible that seismic survey work will affect foraging behaviour by any seals and large whales in the SEA 4 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 intense 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 SEA 4 area, but the total is likely to be lower than in adjacent North Sea areas.

1. DISTRIBUTION AND ABUNDANCE

1.1 Introduction

This section summarises information on the distribution and abundance of marine mammals occurring to the north of Scotland, with particular reference to the SEA4 block.

Twelve marine mammal species are known to occur regularly in this area: grey seal, harbour seal, hooded seal, harbour porpoise, white-beaked dolphin, Atlantic white-sided dolphin, Risso's dolphin, long-finned pilot whale, killer whale, minke whale, fin whale and sperm whales There are occasional at-sea records of a further 11 cetacean species (humpback whale, sei whale, blue whale, Sowerby's beaked whale, Cuvier's beaked whale, pigmy sperm whale, false killer whale, northern bottlenose whale, beluga whale, bottlenose dolphin and short-beaked common dolphin) and three pinniped species (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 that took place in July 1994 (Hammond *et al.* 1995; 2002) and the North Atlantic Sightings Surveys (NASS) that took place in July of 1987 and 1989 (Bjørge and Øien, 1995). Figure 1 shows details of cruise tracks for these surveys in the SEA4 block. There are also published cetacean observations made during seismic surveys in 1996 to 1999 (Stone, 1997; 1998; 2000, 2001). 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 have also been combined with those from the European Seabirds at Sea database (maintained by JNCC at Aberdeen) and those of the Seawatch Foundation to produce a combined Atlas of cetacean distribution around the British Isles using sightings per standardised unit of time, (Reid *et al.* in press). Although the data from this exercise were not available to combine with other data presented here maps from Reid *et al.* (in press) have been included.

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 information is from aerial surveys conducted during the moult by SMRU (SMRU unpublished data) and ongoing satellite telemetry studies in eastern Scotland (SMRU unpublished data). There is some information on foraging distributions of hooded seals from satellite telemetry studies (Folkow & Blix, 1995, 1999).

In the following sections, each of the more abundant species is described with particular reference to its distribution and abundance in the SEA4 block.

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 while 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: northeastern Atlantic, west Greenland and Canadian east coast. Minke whales in the SEA 4 block are part of the northeastern 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 (Northridge *et al.* 1995). Figure 2 shows the locations of sightings made during surveys and from platforms of opportunity. In the SEA4 block there are some sightings in deep water but most are within the 200m depth contour. To give a wider picture, Figure 3 (from Reid *et al.* in press) 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. From the SCANS survey the estimated abundance in SCANS block D (around Shetland and Orkney) was 2,920 (approximate 95% confidence interval = 631 - 5,209). The estimate for the 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). New abundance estimates have been calculated from more recent Norwegian surveys, but the results are confidential until after they have been discussed at the IWC Scientific Committee meeting in May/June 2003.

Summarising all available information, it is clear that the SEA 4 block is an important areas for minke whales in summer.

1.2.2 Fin whale *Balaenoptera physalus*

A cosmopolitan whale species found throughout most of the world's oceans and seas, fin whales in the Northeast Atlantic are mainly seen in deeper waters off the continental shelf edge (Figure 4). Fin whales are thought to undertake seasonal migrations in the North Atlantic as in the Southern Ocean. Passive acoustic monitoring off the shelf edge has shown that while fin whales are present throughout the year, singing activity (and possible therefore number of animals) is lowest in the area around the Shetland and Faroe Islands during the summer (May to September) (Clark and Charif 1998). Studies using sonobuoys suggest that most fin whales are found in water deeper than 500m and to the north and west of SEA 4 (Swift *et al* 2002).

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 5 (from Reid *et al.* in press) 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 shelf waters of the SEA4 block. Figure 6 shows the location of porpoise sightings made during systematic surveys and some platforms of opportunity. There are many records in the SEA4 block.

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 in the whole survey. The SCANS estimate for the whole North Sea was 268,452 (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 the northeastern North Atlantic.

SAST data from 1979 to 1991 show the highest rate of porpoise sightings in the northern North Sea including the SEA 4 block 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 SEA4 block is an important areas 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 and adjacent areas are much more numerous within about 200 nm of the Scottish (and North eastern English) coasts than anywhere else (Northridge *et al.* 1995). 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 (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 white-beaked dolphins in block J (waters immediately adjacent to Shetland and Orkney).

However, white-beaked dolphins are commonly sighted in the northern North Sea, including shelf waters of the SEA4 block up to about 60˚N (Figures 7 and 8). The SEA4 block seems to be at the northern extreme of their distribution in the eastern North Atlantic. White-beaked dolphins are present year round in the North Sea including waters of Shetland and Orkney (Northridge *et al* 1997).

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 a tendency for them to be recorded simply as *Lagenorhynchus spp.*

Around Britain, Atlantic white-sided dolphins have been recorded mainly to the north (Figures 9 and 10), including in offshore waters of the SEA4 block. A comparison of figures 8 and 10 shows the difference in the distributions of these two species in the SEA4 block, with this species being generally distributed further northwest in deeper water. In the North Sea, their presence is seasonal, with the bulk 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 (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. 1,097 Atlantic white-sided dolphins were taken in the Faroese drive fishery in the period 1995 to 1999. They are occasionally involved in mass stranding events.

1.3.4 Long-finned pilot whale *Globicephala melas*

Long-finned pilot whales occur in both hemispheres. In the Northern Hemisphere they are only present in the North Atlantic and western Mediterranean. There are an estimated 778,000 whales in the eastern North Atlantic, based on NASS-89 survey results. There has been a sustained catch of pilot whales off the Faroes for many hundreds of years, during which period more than 230,000 whales have been taken. Pilot whales are capable of diving to great depth and are also one of the most commonly mass-stranded whales.

Pilot whales are not common in the North Sea but they are commonly seen in deep waters north and west of Shetland and Orkney in the SEA4 block (Figures 11 and 12). Pilot whales are seen in Shetland waters in most months of the year; historically, there were enough whales around Shetland to support a drive fishery. The largest catch on record in this fishery was 1,540 animals caught in 1845 (Shetland Sea Mammal Group, 2001). Strandings along the UK North Sea coast have increased since 1947 (Sheldrick, 1976); there were a number of mass strandings involving more than 150 animals in total between November 1982 and January 1985 (Martin *et al.* 1987).

1.3.5 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 migrations 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.* in press) in all months except October. There are a significant number of records from the SEA4 block, particularly just north of Shetland. Association of killer whales with oil platforms has been reported.

1.3.6 Risso's dolphin *Grampus griseus*

Risso's dolphins have a wide distribution and are thought to feed mainly on squid. They are capable of deep dives and are generally found in oceanic waters. Sightings records are widely distributed with the SEA 4 block (Figure 15 & 16).

1.3.7 Sperm whale Physeter macrocephalus

Sperm whales have a wide distribution that includes most seas and all oceans. The world population of sperm whales has been recently estimated at 360,000 individuals (Whitehead 2002). Males migrate to high latitudes to feed and, as a result, all sperm whales sighted or stranded around northern Britain to date have been males.

Sperm whales are normally distributed to the west and north of the UK on, and beyond, the continental shelf break. They have also been recorded fairly regularly in Orkney and Shetland waters, with sightings and strandings reported in most months (Shetland Sea Mammal Group, 2001; Anon, 1999; Booth, 1998). Figure 17 shows that sperm whales are fairly regularly recorded in deep waters in the SEA4 block. It may be assumed that the western edge of SEA 4 covers a migratory route for some portion of the North eastern Atlantic sperm whale population at times of the year.

Acoustic studies indicate that sperm whales are numerous at least in May and October, and in deeper water to the north and west of SEA 4 (Swift *et al* 2002).

1.3.8 Other species

There are several other toothed whale species that are present in this area. For some such as common dolphins, the area is only a marginal part of their habitat, inhabited only during a restricted part of the year. For others such as the beaked whales, this could be an important part of their habitat, but for species such as these that are rarely seen and are thought to exist in small numbers only, the significance of the area is hard to determine.

1.4 Pinnipeds

1.4.1 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 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 in the SEA4 zone. A minimum estimate of population size for this sub-species based on counts at haul-out sites is around 70,000 individuals. However, counts of seals hauled out on land during the moulting season (August) represent only about 60-70% of the total population. Approximately 18% of this subspecies breeds on the north coast of Scotland, and in Orkney and Shetland. Table 1 shows the minimum estimates of population size for these areas based on aerial surveys of animals hauled out on land during the annual moult or the pupping season.

Table 1. Counts of harbour seals in Orkney, Shetland and North coast of Scotland.

Area	Count (year)
Orkney	7800 (2001)
Shetland	4900 (2001)
North Coast	265 (1997)

Harbour seals are widely distributed around most of the coasts of Orkney and Shetland. Figure 18 shows the distribution of harbour seals in the UK, extended from Reijnders *et al.* (1997) to take into account additional known haul-out sites in the south-western North Sea. At-sea sightings from Pollock *et al.* (2000) are also shown.

Harbour seal distribution at sea is constrained by the need to return periodically to land. Until recently, the available data suggested that harbour seals were unlikely to be found more than 60 km from shore but recent satellite telemetry studies have shown that harbour seals from Scotland, Denmark and the Netherlands are distributed widely across the North Sea (Figure 1 - see Section 2). There are no directly comparable data for harbour seals in the SEA 4 block, but it is likely that similar offshore movements occur around northern Scottish coasts. To date all studies of harbour seal movements have been in areas with extensive shallow water habitat. It is not known if harbour seals routinely travel out into deep water areas. If harbour seals inhabiting Orkney, Shetland and the north coast of Scotland exhibit similar foraging habits to those in the central North Sea (as should be expected), they are likely to be distributed over much of the SEA 4 block, but densities will be highest in the southern half of the block.

1.4.2 Grey seal, Halichoerus grypus

Grey seals are restricted to the North Atlantic and adjacent seas. There are three recognised populations: the northwest Atlantic (primarily on Sable Island, Canada and in the Gulf of St Lawrence); the Baltic Sea; the northeast Atlantic (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). They haul out on land between foraging trips and for breeding, when they form large aggregations. Timing of pupping differs throughout the range of the species. In Northern Britain pupping occurs from October to late November. Moulting occurs in February and March.

The British grey seal population has been increasing by around 6% annually since the 1960’s. Its current size is estimated at around 130,000 to 140,000 individuals, of which approximately 63,000 are associated with the colonies in Orkney, Shetland, the North Scottish coast and North Rona. Table 2 summarises information on the estimated population size of grey seals breeding in areas adjacent to the SEA 4 block. Abundance estimates are expressed as pup production and total non-pup population.

Table 2. Numbers of grey seal pups born in areas adjacent to SEA 4.

Area	Pup production (year)	Total population
North Coast	900 (2000)	2760
Orkney	17,500 (2001)	54000
North Rona	1,050 (2001)	3200
Shetland	1000 (1977)	3100
Faroe Islands	Unknown (some hundreds)	~4000 (1966)

Note that most of the population will be on land for several weeks from October to December, and again in February and March during the moult. Densities at sea are likely to be 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 (Wiig, 1986).

As described in more detail in section 2.2.3, extensive information on the distribution of British grey seals at sea is available from studies of animals fitted with satellite-relay data loggers. Figure 20 shows the tracks of 108 grey seals recorded over a period of about 10 years. Figure 21 shows locations at which it has been determined that the seals were foraging (see McConnell *et al.* 1999 for details).

1.4.3 Hooded seals *Cystophora cristata*

Hooded seals are medium to large sized phocid seals found throughout the northern North Atlantic. They are regarded as comprising two separate groups, the Greenland Sea stock and the North-west Atlantic stock (Reijnders *et al.* 1997). There is as yet no genetic evidence that these are completely discrete populations (Reijnders *et al.* 1997). They breed on pack ice in several locations, primarily at Jan Mayen, at the West Ice, at 64°N in the Davis Strait, on the Front off Newfoundland and in the Gulf of St Lawrence. Breeding and moulting sites are on thick drifting ice over deep water, usually further offshore than areas used by harp seals.

The world population of hooded seals is estimated to be around 500,000-600,000 (Reijnders *et al.* 1993). Around two-thirds of this population is associated with the Greenland Sea/Jan Mayen stock. There are few population estimates on which to assess the status of the populations, but surveys in 1984 and 1990 suggest that the Front stock may have increased at around 5% per yr. Counts from the Jan Mayen stock suggest a gradual decline, from 120,000 pups in 1955 to 70,000 in 1970, and recent estimates suggest a current pup production of around 50,000 (ICES 1992). In both cases the error bounds on the estimates indicate that apparent trends should be interpreted with caution. On the basis of satellite telemetry data (Folkow & Blix 1995, 1999) it is likely that hooded seals observed in SEA 4 are members of the Jan Mayen stock. We have no reliable estimate of the proportion of the population using the SEA 4 area.

2. ECOLOGICAL IMPORTANCE

2.1 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, 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 themselves in this area.

2.1.1 Diet composition

Harbour seal diet has been studied in Shetland and there have been comparable studies in the Moray Firth and The Wash.

In the Moray Firth, Tollit and Thompson (1996) found the key prey during 1989-1992 to be sand eels, lesser octopus, whiting, flounder, and cod. Significant between-year and seasonal fluctuations were evident. In another study in the same area, Tollit, Greenstreet and Thompson (1997) compared the composition of the diet 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 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 area of Scotland.

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

2.1.2 Prey consumption

There are no published estimates of prey consumption by harbour seals in the SEAS-4 block. Harbour seals probably require around 3-4 kg per day depending on the prey species. The minimum population estimate of harbour seals within SEA 4 is 13000 based on counts during the moult. This probably under-represents the true population size and based on studies in other areas we would expect the true population to be approximately 21000. We do not have direct evidence of preferred foraging areas for any of these populations, but as with grey seals, based on observations in other studies we could expect approximately half the foraging effort to be expended in the SEA 4 block. An approximate estimate of annual consumption of prey by harbour seals in the SEA 4 block is therefore 11,000 - 15,000 tonnes. We have no estimate of confidence intervals for this figure and it should be treated with caution.

2.1.3 Foraging movements and distribution

Direct information on foraging movements and the distribution at sea of harbour seals in the SEA 4 block is limited to small scale land based radio telemetry studies based in Orkney. These results are summarised by Thompson *et al.* (1996). They showed that harbour seals moved only to alternative haul-out sites within a range of 75 km and that all harbour seals foraged within 60 km of their haul-out sites. These results were confirmed by direct at sea tracking studies during the breeding season (SMRU unpublished data).

However, recent studies of harbour seal foraging distribution have revealed that this species forages much further offshore that previously thought. Figure 19 shows areas where harbour seals have been tracked using satellite-link telemetry from Scotland (SMRU, University of St Andrews) and Denmark (Fisheries Museum, Esbjerg and ELSAM, Denmark); another recent study in the Netherlands has found similar results (data not available). These studies clearly show that harbour seals may forage up to 200km from land and are therefore capable of foraging over much of the SEA 4 block. To date there are no data from harbour seals foraging over deep water.

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. They have no significant natural predators themselves in this area.

2.2.1 Diet composition

The diet of grey seals has been studied extensively throughout their range.

In Orkney, sandeels accounted for almost 50% of the diet; the remainder was mostly cod, ling and plaice (Hammond, *et al.* 1994). 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. In the central North Sea, diet was dominated by sandeels and cod, with whiting also a significant component (Hammond and Prime 1990; Hall and Walton 1999).

2.2.2 Prey consumption

The average daily energy requirement of a grey seal has been estimated as 5,500 Kcals. The equivalent weight 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 around SEA 4 would be expected to consume approximately 125,000 tonnes p.a.. However, only a proportion of that foraging effort will be expended in the block and other seals from populations in the Hebrides and Farnes/Isle of May will spend some time in the area. On the basis of the output of a population distribution model (see below) and the diet composition information presented above, the estimated consumption of prey in SEA 4 is around 40,000 tonnes, almost 50% of this total is sandeels. We cannot calculate confidence intervals for this estimate.

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. A new study by SMRU, funded by DEFRA, will update grey seal diet information for the entire North British population for 2002.

2.2.3 Foraging movements and distribution

As mentioned in section 1, grey seal distribution and movements have been studied in the North Sea using satellite-linked telemetry. In a study of animals captured at the Farne Islands and Abertay Sands, 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 Farnes are not ecologically isolated from those at 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 gravel/sand seabed sediment. This is the preferred burrowing habitat of sandeels, an important component of grey seal diet (see section 2.2.1). 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 mathematical and statistical 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 *et al.* in preparation). Figure 22 shows such a distribution overlaid on the SEA 4 block. Activity in the SEA 4 block is concentrated in the southern half, closest to the haulout sites. The size of the breeding population associated with the Northern Isles, North Rona and the North Scottish mainland, mean that the southern half of the SEA 4 block is likely to be a particularly important area for grey seals. The distribution model estimates that approximately 15.8% of foraging effort by the UK grey seal population will occur in SEA 4.

2.3 Hooded seals

2.3.1 Diet composition

There are no published data on diet of hooded seals in this area. Movement patterns and dive behaviour from satellite telemetry studies have been used to infer predation on Greenland halibut (*Reinhardtius hippoglossoides*), redfish (*Sebastes spp.*), polar cod (*Boreogadus saida*), herring (*Clupea harengus*), squid (*Gonatus fabricii*) and blue whiting (*Micromesistius poutassou*) (Folkow & Blix 1999). In the Western Atlantic population, diet has been studied directly in the Gulf of St Lawrence. The bulk of the diet (82% of energy) comprised demersal prey (Greenland halibut, redfish, polar and Atlantic cod (*Gadus morhua*)), the remainder comprised pelagic species, mainly Herring and Capelin (Hammill *et al.* 1997).

2.3.2 Prey consumption

The absence of diet data and population estimates for the SEA 4 area precludes any meaningful estimate of prey consumption.

2.3.3 Foraging movements and distribution

Pups tagged at Newfoundland and in the Davis Strait have been recovered in both West and East Greenland, but no Jan Mayen tagged seals have been recorded in Greenland. Seals tagged on the West Ice have been recorded in Iceland and along the Norwegian coast, suggesting that, as in grey seals, there may be a wide dispersal of young animals (ICES 1992).

Hooded seals were sighted in the Faroe-Shetland Channel during seismic survey operations in all seasons (Pollock, 2000). Sightings were restricted to deep water areas, along the north-western margins of the SEA 4 block. Sightings in the north-west Atlantic were also concentrated along the continental slope during winter boat surveys off Newfoundland (Stenson & Kavanagh 1993).

Satellite transmitters have been used in the North-east Atlantic to track adult hooded seals between breeding and moulting and after the moult. Previously it had been assumed that seals left their breeding areas in the West Ice and moved directly towards moulting sites at Jan Mayen (Folkow & Blix 1995). Data from 8 satellite tagged seals shows that in fact they make long range movements out into the North Atlantic. Seals moved into waters around the Faroes, off Northern Ireland and into the Norwegian Sea (Folkow & Blix 1995, 1999). Similar offshore movements were seen in North-west Atlantic seals tagged in the Gulf of St. Lawrence (Stenson et al 1993). Fifteen seals were also tagged after the moult in an area around 71ºN and 12ºW (Folkow & Blix 1995). Again these seals all performed wide-ranging movements, with trips lasting 3-7 weeks. Eight of 15 seals spent some time in waters around the Faroes. Other important areas were to the south-west and the north of Iceland, along the continental shelf break between Norway and Bear Island, and in areas of the Norwegian Sea (Folkow & Blix 1995, 1999). Based on the observed movements of this relatively small sample of hooded seals it seems likely that substantial numbers move into the north-western sections of the SEA 4 block.

Telemetry studies indicate that hooded seals are deep, long duration divers. Satellite transmitters indicate that some seals may dive regularly to over 1,000 m. 41% of dives by one seal off Jan Mayen were to more than 1,000 m. In the pooled data set from all seals, 28% of dives were over 300 m. Off the Faroes there was a seasonal change from shallow dives in autumn (100-300 m) to deeper dives in winter and spring (300-600 m) (Folkow & Blix 1995). Dive depths in the North-west Atlantic study were shallower, up to 530 m, with seals spending most of the study foraging along the shelf break (Stenson *et al*. 1993). Dive durations averaged between 5 and 15 mins, but in all studies there were some long dives, up to 52 mins. Satellite position fixes suggest that the majority of dives are performed in open-ocean over deep water, so many hooded seal dives must have been to mid-water depths, in contrast to both grey and harbour seals which are mainly benthic divers.

2.4 Cetaceans

The nine most frequently seen species of cetacean in the SEA 4 block are the harbour porpoise, white-beaked dolphin, Atlantic white-sided dolphin, long-finned pilot whale, killer whale, minke whale, fin whale, sperm whale and Risso's dolphin.

2.4.1 Harbour porpoise

Harbour porpoises in Scottish waters seem to feed mainly on fish found on or near to the seabed. The main fish species consumed by porpoises (identified in samples recovered mainly from fishing nets) from the Scottish east coast during the 1960s were herring, sprats, whiting, sandeels, cod, Norway pout and other gadoids, while 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 pollack, as well as herring, sprats, sandeels and gobies. Greater Argentines were also recovered from at least 6 animals around Shetland (Martin 1995). Samples collected from Scottish waters between 1992 and 1994 yielded mainly small gadoids and sandeels (Santos *et al.* 1994). 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).

For most of the past 40 years, the contents of North Sea porpoise stomachs have 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. Harbour porpoises are probably the most numerous marine mammals in the areas under consideration, with a total North Sea population of around a quarter of a million animals (see section 1.3.1), and densities around Shetland among the highest anywhere in the Northeast Atlantic. Total fish consumption per annum is likely to run into hundreds of thousands of tonnes for the region as a whole. The significance of this species' predation from an ecological perspective has not been assessed,.

2.4.2 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). At least one animal in recent years has been recorded feeding on sandeels (Santos *et al.* 1994).

2.4.3 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).

2.4.4 Atlantic white-sided dolphin

Atlantic white-sided dolphins tend to occur in the deeper waters of SEA 4, and their diet there is unknown. Elsewhere, herring, mackerel, horse-mackerel, silvery pout and squid have all been recorded as diet items (Reeves *et al.* 1999a), suggesting a pelagic feeding mode. Mackerel and squid would both be expected in the deeper water parts of SEA 4.

2.4.5 Killer whale

Killer whales are recorded fairly frequently around Shetland and further North and West in deeper waters. The diet in UK waters is little known, but in Norway, herring is clearly a major diet item. Killer whales are thought to prey upon seals around haul outs in Shetland at least, and possibly offshore, and are also reported to feed on mackerel around Shetland (Fisher and Brown 2001).

2.4.6 Long-finned pilot whale

Long-finned pilot whales are primarily distributed along the shelf break but are regularly seen around Shetland. The diet has been examined in the Faroe Islands by Desportes and Mouritsen (1993) who also reviewed diet information from other places, and concluded that cephalopods form the bulk of their food.

2.4.7 Fin whale

Fin whales are mainly found in the Sea-4 area in deeper water off the shelf edge. Their diet in this area is unknown, but elsewhere they are known to eat both pelagic crustaceans and small schooling fish (herring, capelin, sand eels etc) (Tomilin 1967, Jonsgaard 1966).

2.4.8 Sperm whale

Sperm whales are also mainly reported from deeper water areas, and it is generally assumed that their diet in this region is likely to consist mostly of squids. In some parts of the world deepwater fishes have also been reported in their diet, and in a few locations they also appear to have learned how to remove fish from longlines, though this is not an issue in this area.

2.4.9 Risso's dolphin

Risso's dolphin is also found mainly in the deeper water parts of SEA 4, and is presumed to feed mainly on squid. Nothing is known about its actual feeding habits or foraging strategies in this area.

2.4.10 Other species

Northern bottlenose whales are also predominantly squid feeders, and might be expected in this area occasionally. It is likely that when they do so, they would be following squid. Sowerby's beaked whale is also generally considered to be a squid-eating whale, but one animal stranded in Scotland was found to have been feeding on silvery pout.

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 SEA 4 area, squids and small pelagic schooling fishes are the likely main food items.

The feeding habits of humpback whales in this area are unknown, but like the fin whale this species also consumes both fish and planktonic crustaceans elsewhere. The fish species most likely to be consumed are those that form dense pelagic schools such as sandeels, herring, sprats and mackerel.

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 limited 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, eg. 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 ranges 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 will generally 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.

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 SEA-2 block is summarised below.

3.1.1.1.1 Hearing sensitivity of pinnipeds

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

3.1.1.1.2 Hearing sensitivity of baleen whales

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 4 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.

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). Toothed whales are most sensitive to sounds above about 10 kHz and below this sensitivity deteriorates. In contrast, high frequency hearing is good; upper limits of sensitive hearing range from about 65 kHz to well above 100 kHz in most species. This is related to the 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.

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 4 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

Small odontocetes are more sensitive to 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 area 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 4 blocks are described below.

3.1.1.3 Zone of masking

To be audible, a sound must be detectable against the background noise. 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.

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 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 areas 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, 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.

3.1.1.4.1 Hearing loss

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 study location, San Diego Bay, and 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 the 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.

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[1] Spectrum level is the level in dB re 1µPa^2/Hz.

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). 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 can be 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 impulsive, 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 estimates 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 a recent well documented, but so far incompletely reported, standing in the Bahamas exhibited physical damage to a variety of structures associated with hearing and/or adjacent to air spaces (Balcomb, 2001). 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. 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.

3.1.1.4.2 Non-auditory effects

Blast injury

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, only animals within 500m are likely to be injured. "Safe" distances for larger animals will be substantially less (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 larger than those for an equivalent sized marine mammal. Richardson *et al.* (1995) have suggested that a precautionary approach would be to use 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 were washed up dead during this work, 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 wehre they occur, 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.

Resonance effects

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.

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; 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 reaction of some baleen whales (bowhead, grey and humpback) to airgun noise has been studied in the field. 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 predictable 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 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. 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).

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.

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 increase in the level of marine seismic survey activity in the North Sea and a likelihood that activity will be concentrated in specific areas. 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 transitted by large bulk carriers moving to and from the Shetland and Orkney oil terminals. The increased shipping associated with oil developments in the SEA 4 blocks will be mainly smaller ships such as support vessels and tugs. Noise from shipping is roughly related to vessel size; larger ships have larger, slower rotating propellers which produce louder, lower frequency sounds. 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. 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 is little 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. 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. 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

    - Start by doing these in locations where conditions are optimal (good weather, adequate populations, long term studies, good logistics).
    - Assessment of accumulated impacts on populations that range widely and may migrate to other areas.
- **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. 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. This is a daunting scientific task, but in reality it is 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 (Ridgway and Reddy 1995). 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 and in a study on juvenile grey seals are associated with thyroid hormone disruption (Hall *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).

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).

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 (In Press), 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).

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).

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 which 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. For example we have no current information on the proportion of the harbour seal population in Europe that are still protected against another outbreak of PDV.

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	Harbour seal
	Phocine herpesvirus-1	California sea lion
	Uncharacterised herpesvirus	Beluga whale
		Harbour porpoise
Poxviridae	Seal poxvirus	Harbour seal
		Grey seal
	Parappoxvirus	California sea lion
		Northern fur seal
		S. American sea lion
		Bottlenose dolphin
		White sided dolphin
		Harbour porpoise
	Orthopoxvirus	Grey seal
Picornaviridae	Picornavirus	Harbour seal
		Grey whale
Caliciviridae	San Miguel sea lion virus	California sea lion
	Calicivirus	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	Harbour seal
	H7N7	Pilot whale
	Influenza A	Striped dolphin
	virus H4N5	
	H13N9	
	H13N2	
Paramyxoviridae	Canine Distemper Virus (CDV)	Crabeater seal
		Baikal seal
	Phocine Distemper Virus (PDV)	Harbour seal
		Grey seal
		Ringed seal
		Harp seal
	Porpoise Morbillivirus	Harbour porpoise
	Dolphin Morbillivirus	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.

The SEA 4 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 as well as some gillnet fishing, but the 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).

The only other current significant threat to marine mammals from fishing gear stems from the use of static nets, notably bottom set gill 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 4 area are limited in scale compared with some other areas of the Northeast Atlantic. Locally based vessels have in the past operated gill and tangle nets for dogfish, cod and monkfish in the area, and English and Danish vessels also fish on Papa Bank for cod and other species. Further offshore there are larger freezer netting vessels working deepwater areas for monkfish and certain deepwater fish species. Marine mammal bycatch has not been monitored in these offshore vessels.

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 SEA 4 block is an important area for cetaceans, not least because there is a relatively high species diversity found in the area. There are at least nine species regularly sighted there and another 10 that have been recorded less regularly. Little is known about the abundance or seasonal distribution of these species. Some of the offshore species, notably sperm whales and fin whales, probably migrate through the block. For some of the less frequently sighted species such as the beaked whales, this area may be more important that the number of sightings would suggest, as these are not numerous animals and are difficult to see. On the shelf, the area is important especially for porpoises, white-beaked dolphins and mink whales.
- Based on satellite telemetry data and distribution models we estimate that 16% of the foraging effort of the UK grey seal population is expended in SEA 4, concentrated in the south and east of the block. Harbour seals have recently been found to forage farther offshore than previously thought and are likely to occur over much of the southern and eastern parts of the SEA 4 block. Hooded seals occur in the deep-water areas of SEA 4 throughout the year. There is therefore potential for interactions between industrial activities and seals throughout the SEA 4 block.
- Marine mammals are important predators in this region, feeding on a suspected 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 SEA 4 block. . 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 SEA 4 area, but the total is likely to be lower than in adjacent North Sea areas.

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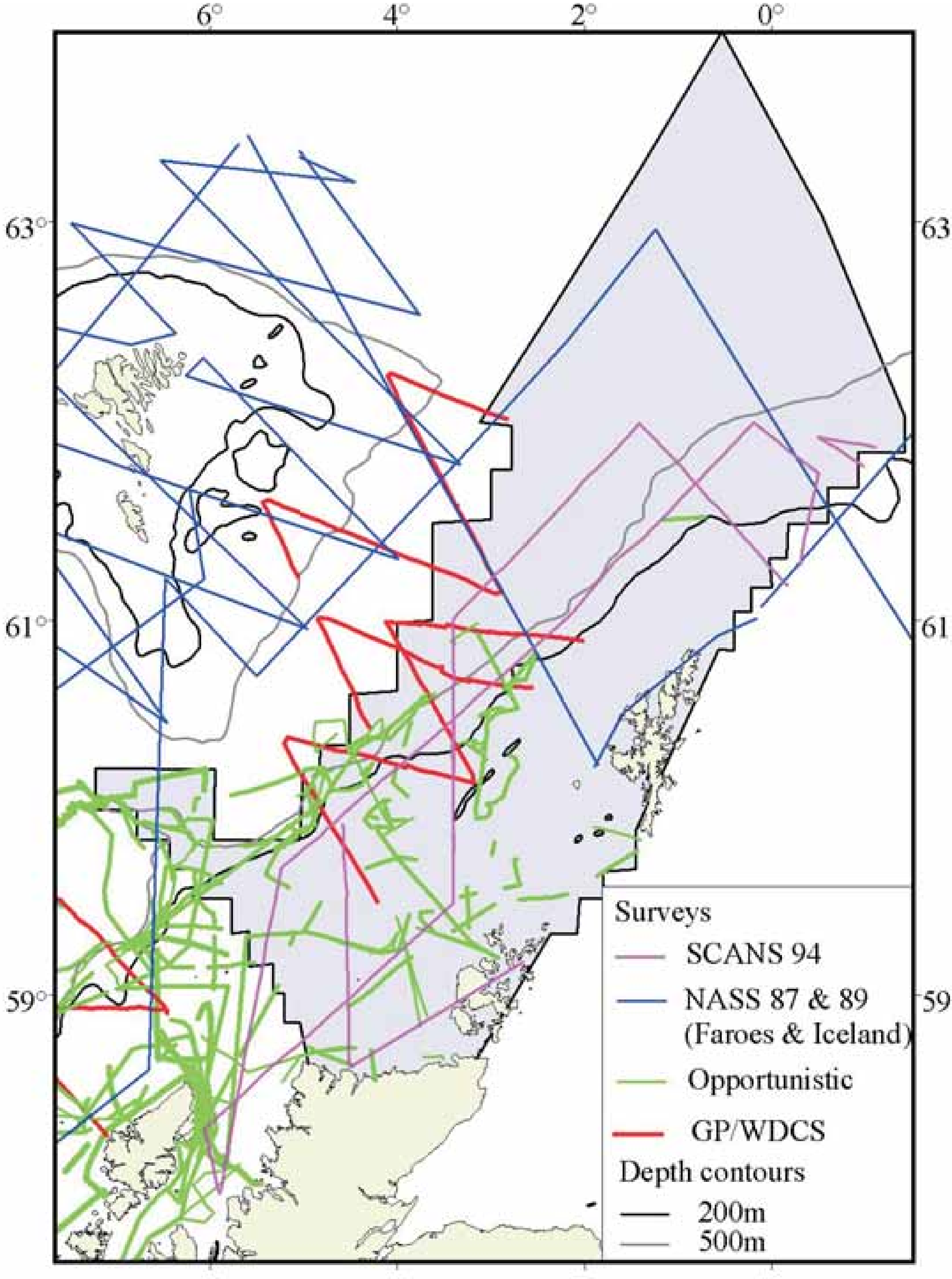

Figure 1. Boundaries of SEA-4 block, and cruise tracks from various surveys conducted in the area, including SCANS (Hammond et al. 1995; 2002), NASS-89 and NASS-87 (Øien, 1991), GP/WDCS (Macleod et al., in press) and opportunistic surveys (Macleod, 2001).

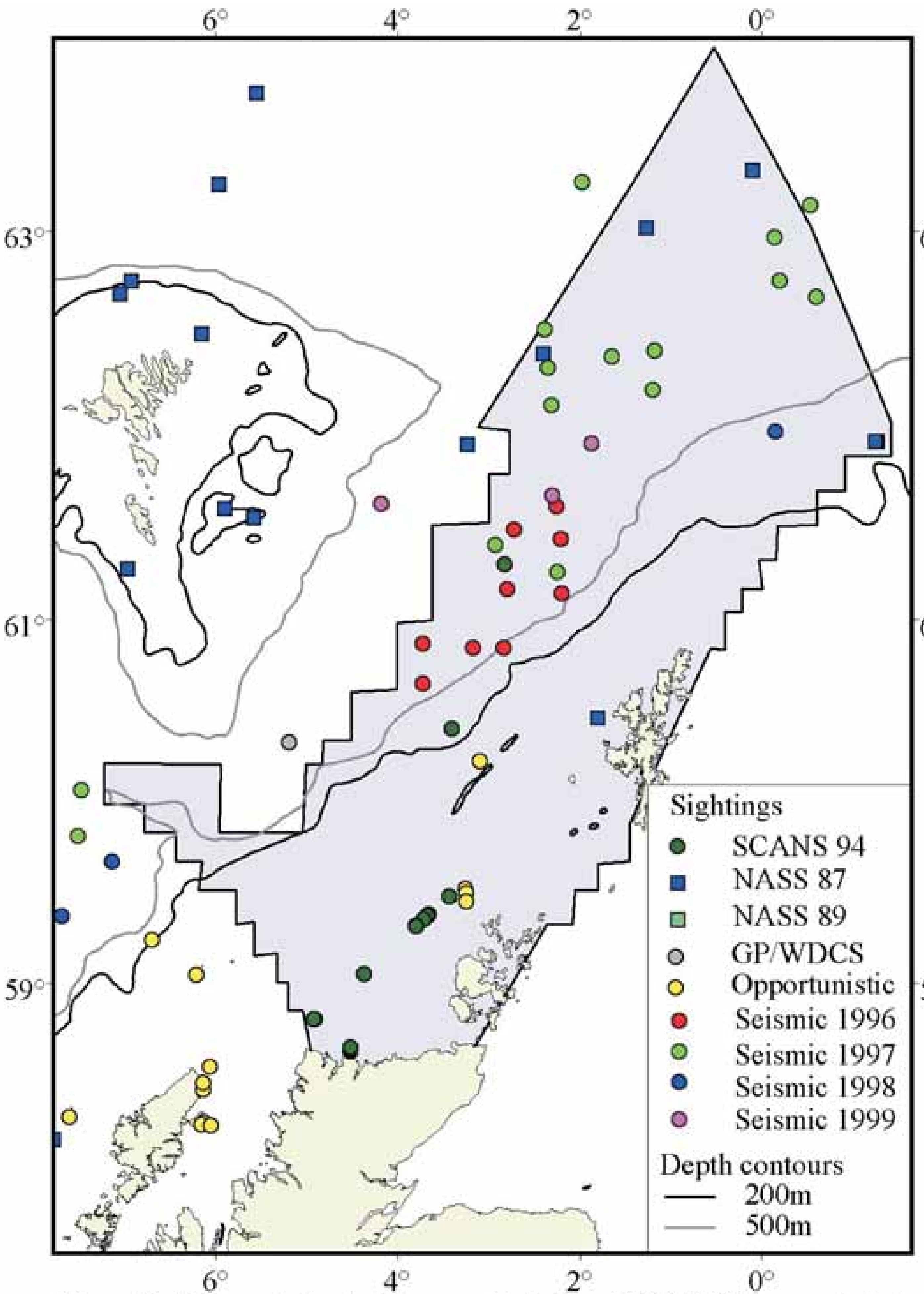

Figure 2. Minke whale sightings made during SCANS (Hammond et al. 1995; 2002), NASS-89 & NASS-87 (Øien, 1991), GP/WDCS (Macleod et al. in press), opportunistic (Macleod, 2001) and seismic (Stone 1997, 1998, 2000, 2001) surveys.

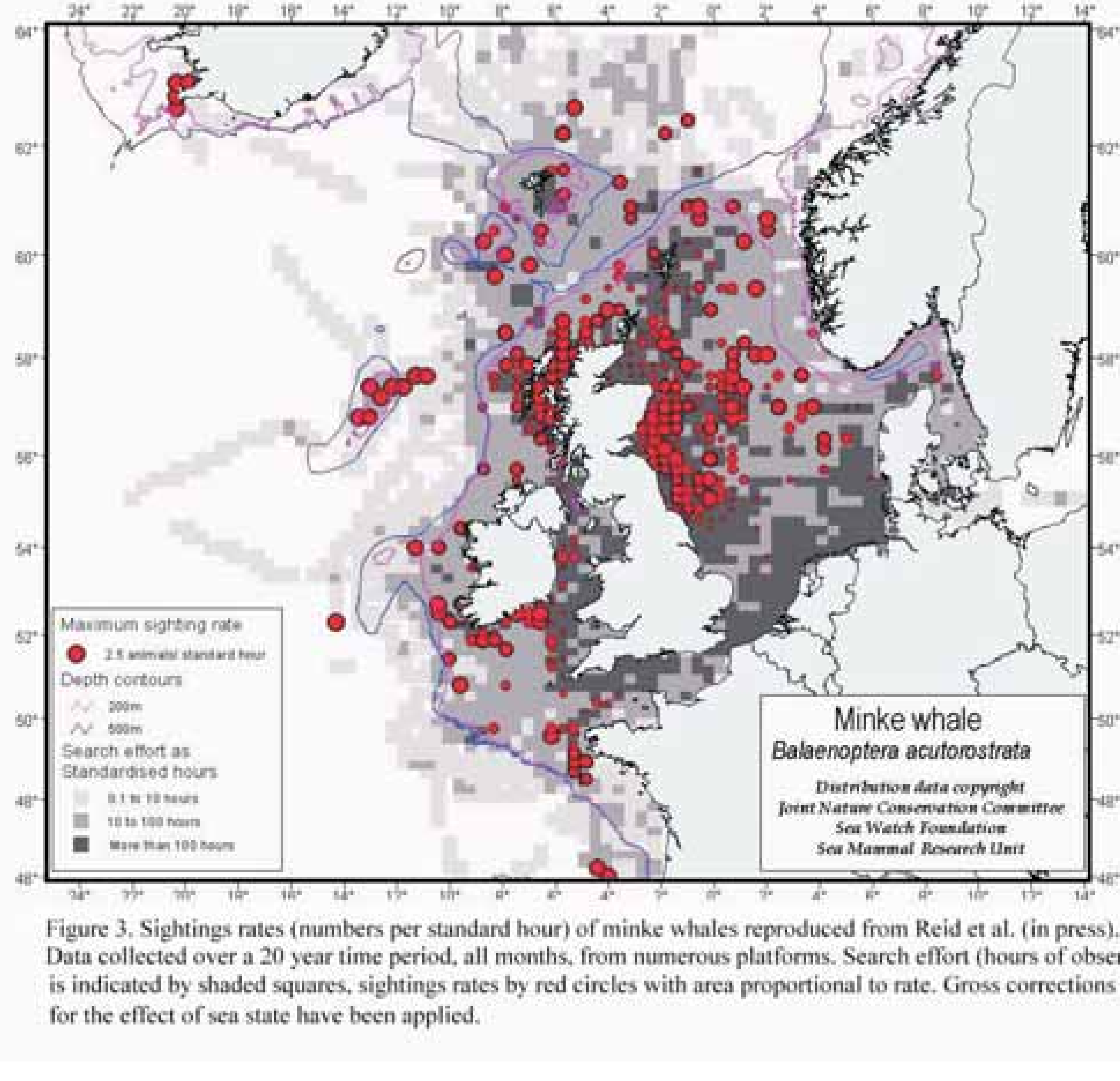

Figure 3. Sightings rates (numbers per standard hour) of minke whales reproduced from Reid et al. (in press). Data collected over a 20 year time period, all months, from numerous platforms. Search effort (hours of observation) is indicated by shaded squares, sightings rates by red circles with area proportional to rate. Gross corrections for the effect of sea state have been applied.

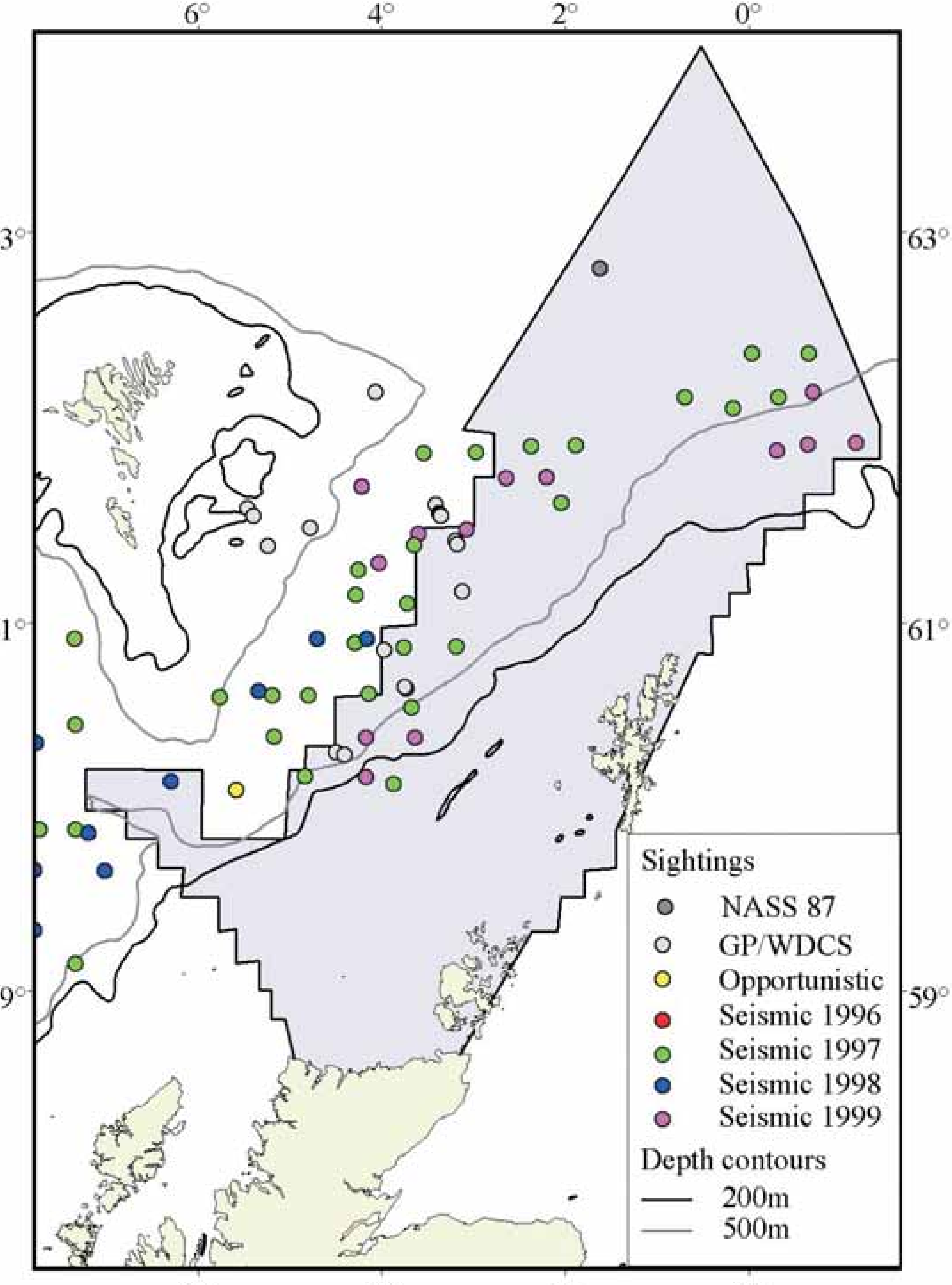

Figure 4. Fin whale sightings records made during NASS-87 (Øien, 1991), GP/WDCS (Macleod et al. in press), opportunistic (Macleod, 2001) and seismic (Stone 1997, 1998, 2000, 2001) surveys.

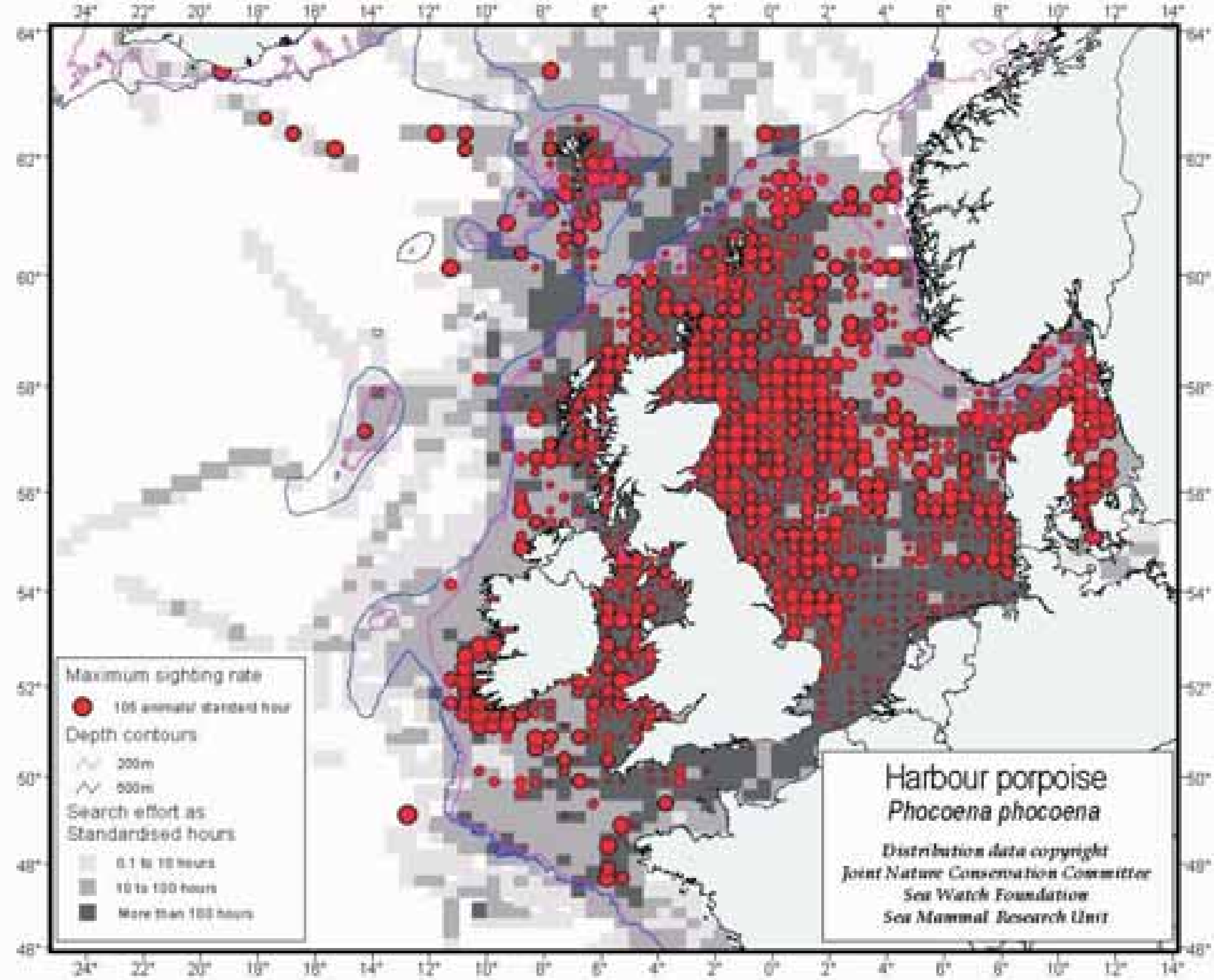

Figure 5. Sightings rates (numbers per standard hour) of harbour porpoises reproduced from Reid et al. (in press). Data collected over a 20 year time period, all months, from numerous platforms. Search effort (hours of observation) is indicated by shaded squares, sightings rates by red circles with area proportional to rate. Gross corrections for the effect of sea state have been applied.

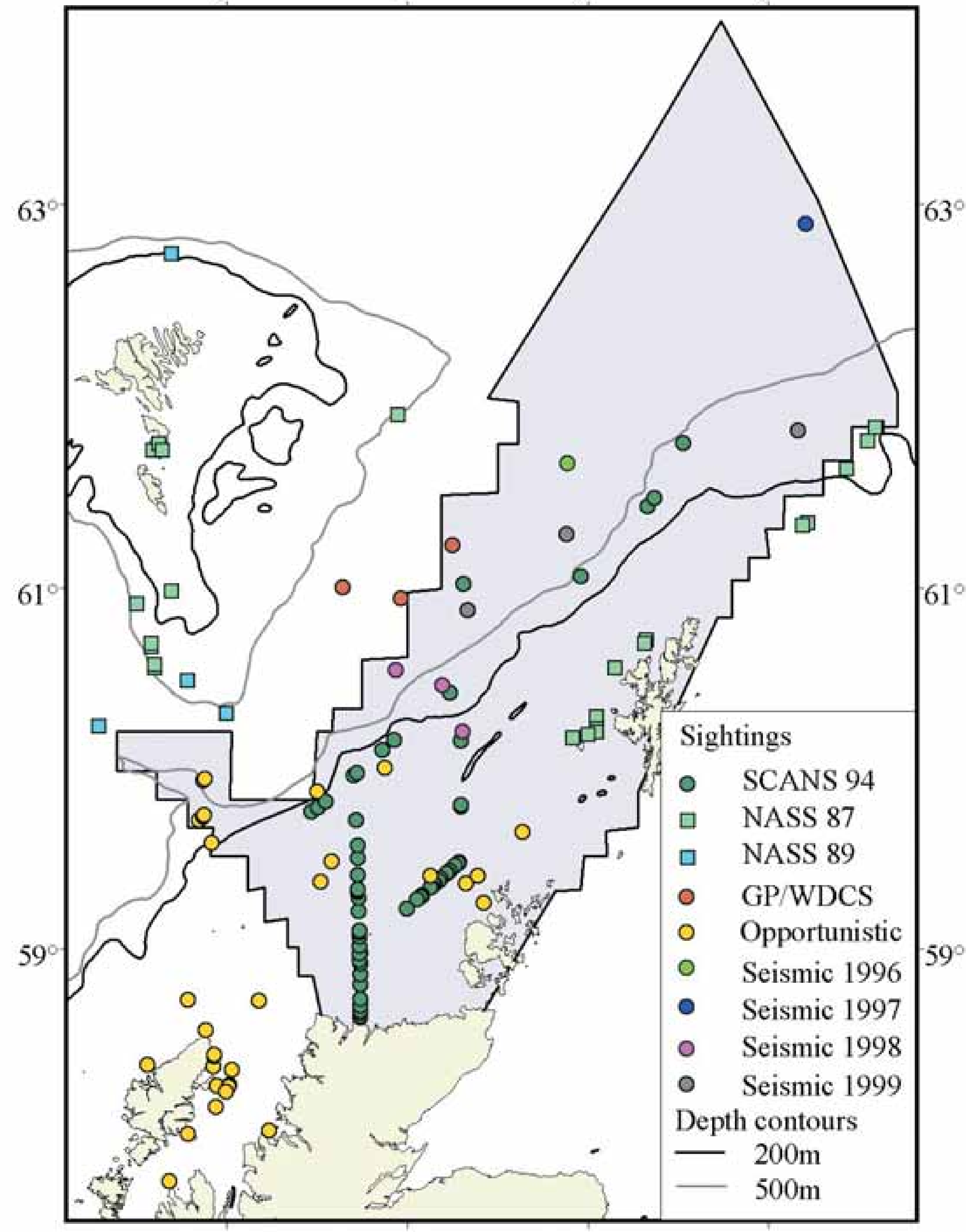

Figure 6. Harbour porpoise sightings made during SCANS (Hammond et al. 1995; 2002), NASS-89 and NASS-87 (Øien, 1991), GP/WDCS (Macleod et al., in press), opportunistic (Macleod, 2001) and seismic (Stone 1997, 1998, 2000, 2001) surveys.

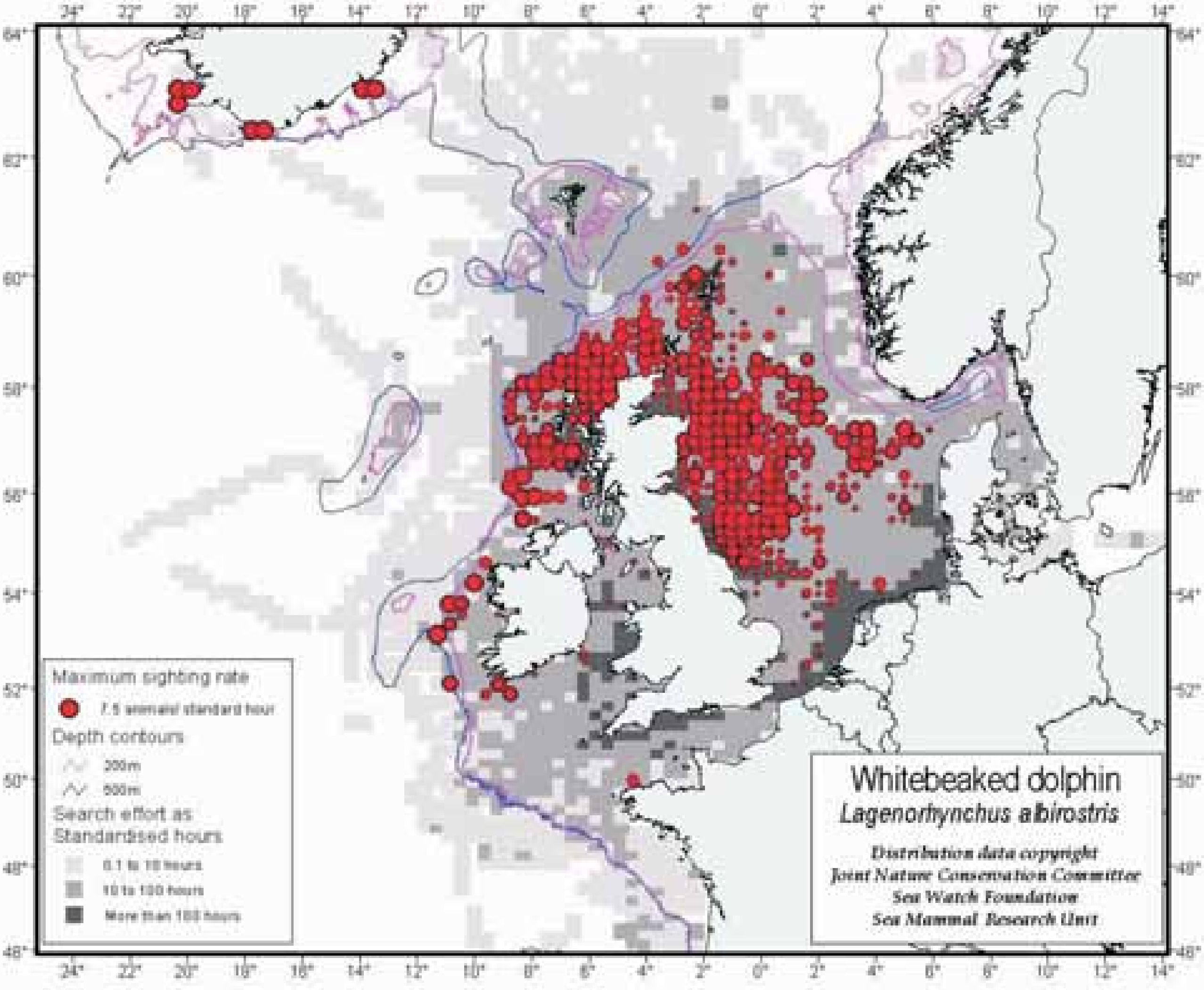

Figure 7. Sightings rates (numbers per standard hour) of white-beaked dolphins reproduced from Reid et al. (in press). Data collected over a 20 year time period, all months, from numerous platforms. Search effort (hours of observation) is indicated by shaded squares, sightings rates by red circles with area proportional to rate. Gross corrections for the effect of sea state have been applied.

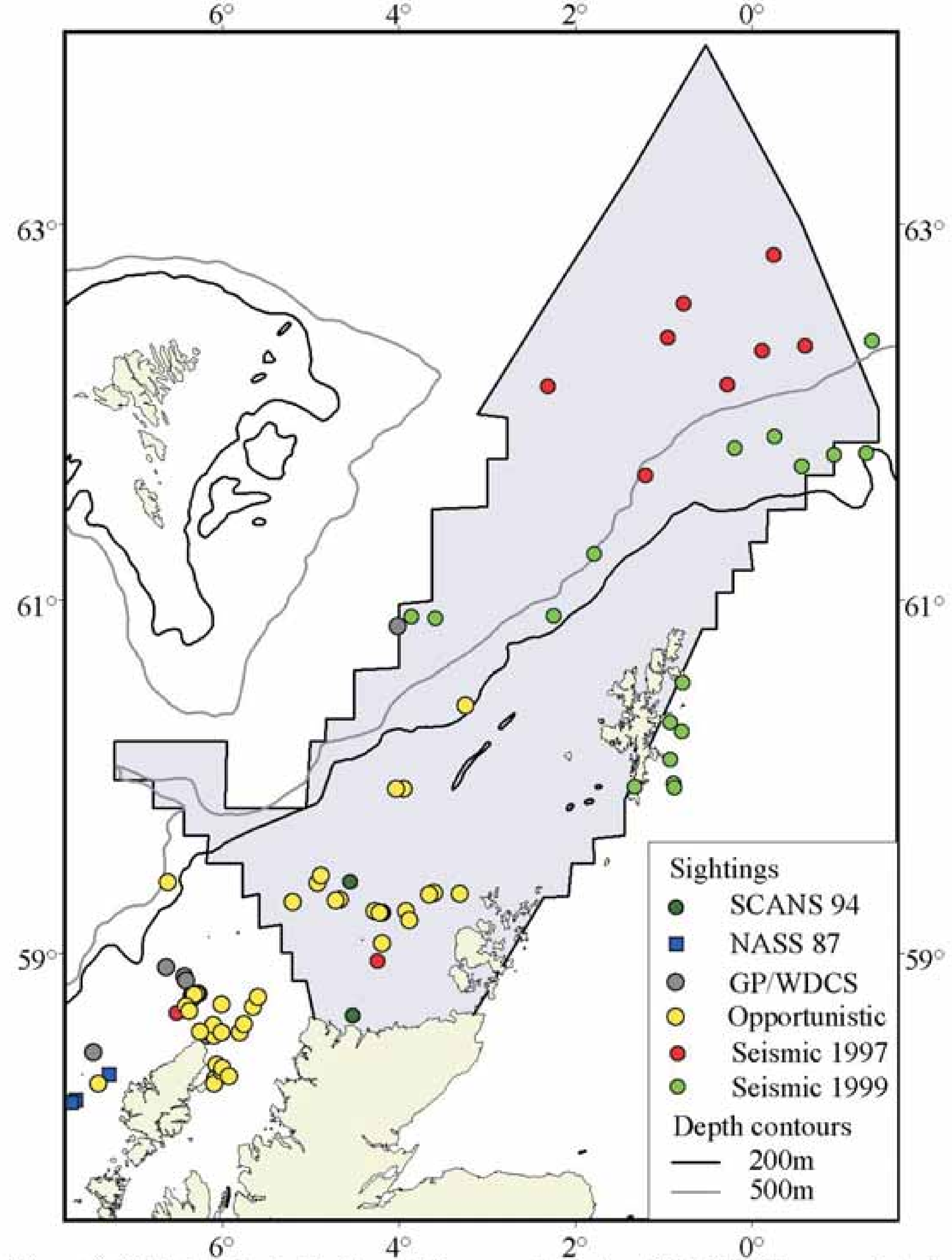

Figure 8. White-beaked dolphin sightings made during SCANS (Hammond et al. 1995; 2002), NASS-87 (Øien, 1991), GP/WDCS (Macleod et al., in press), opportunistic (Macleod, 2001) and seismic (Stone 1997, 1998, 2000, 2001) surveys.

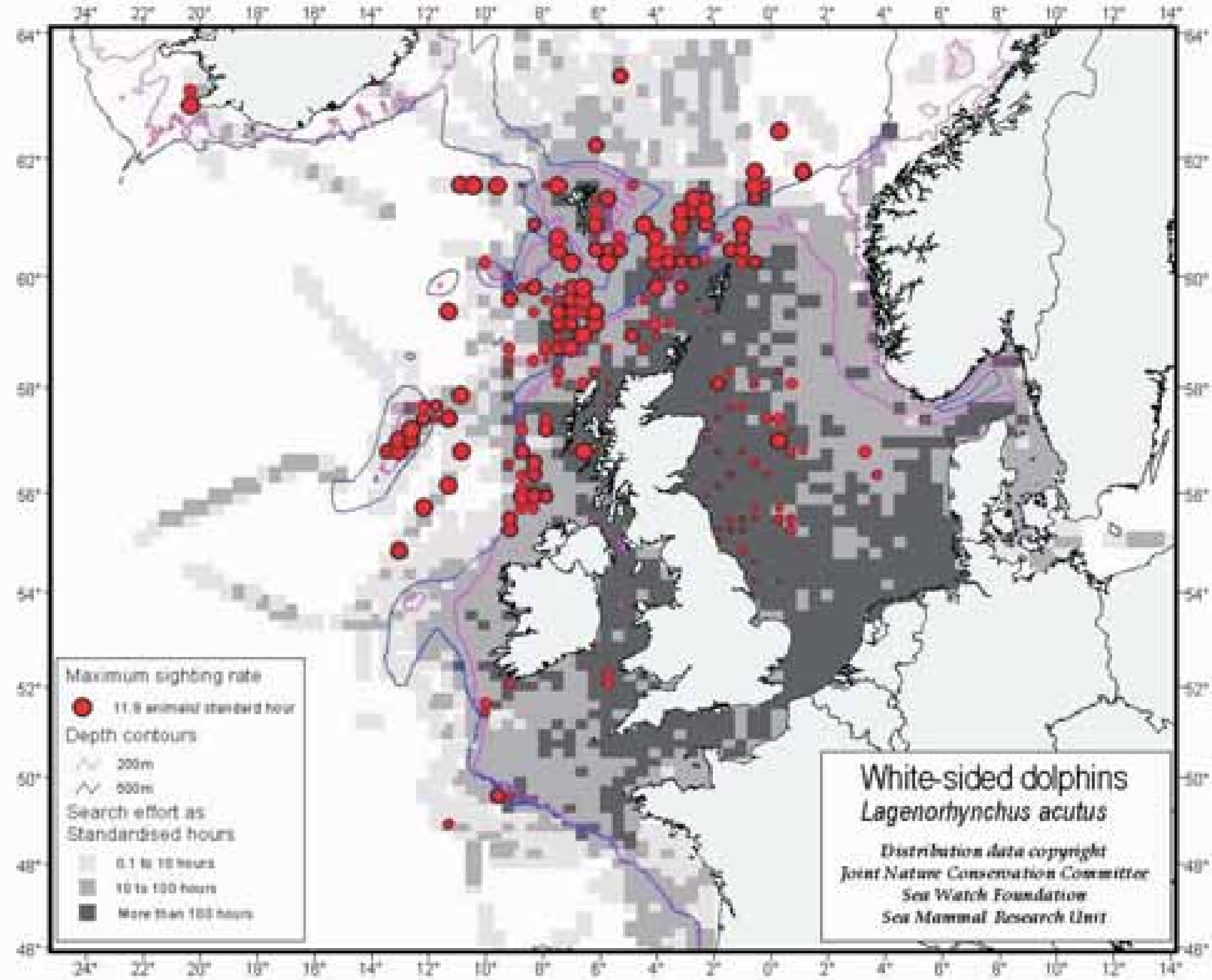

Figure 9. Sightings rates (numbers per standard hour) of Atlantic white-sided dolphins reproduced from Reid et al. (in press). Data collected over a 20 year time period, all months, from numerous platforms. Search effort (hours of observation) is indicated by shaded squares, sightings rates by red circles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

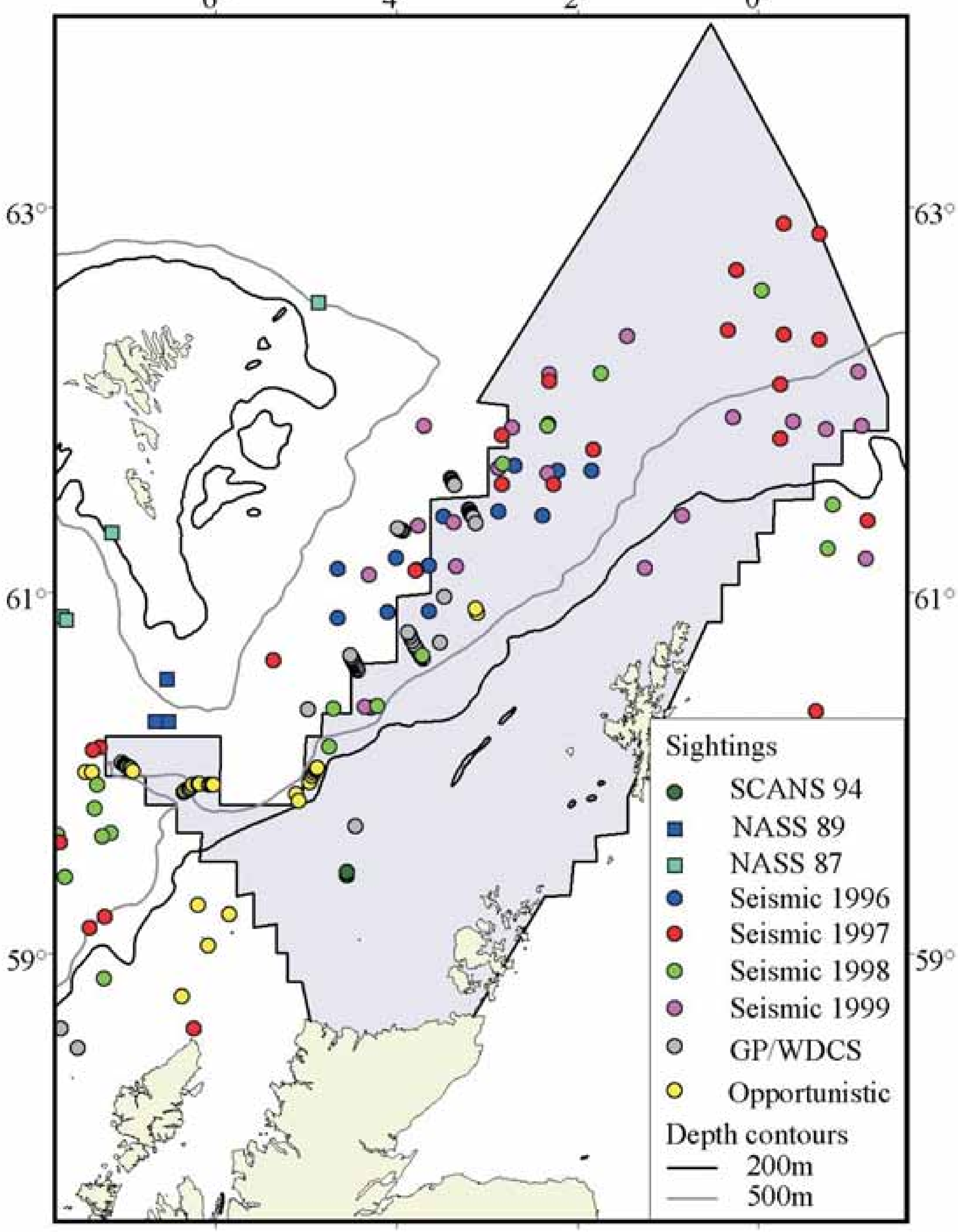

Figure 10. Atlantic white-sided dolphin sightings made during SCANS (Hammond et al. 1995; 2002), NASS-89 and NASS-87 (Øien, 1991), GP/WDCS (Macleod et al., in press), opportunistic (Macleod, 2001) and seismic (Stone 1997, 1998, 2000, 2001) surveys.

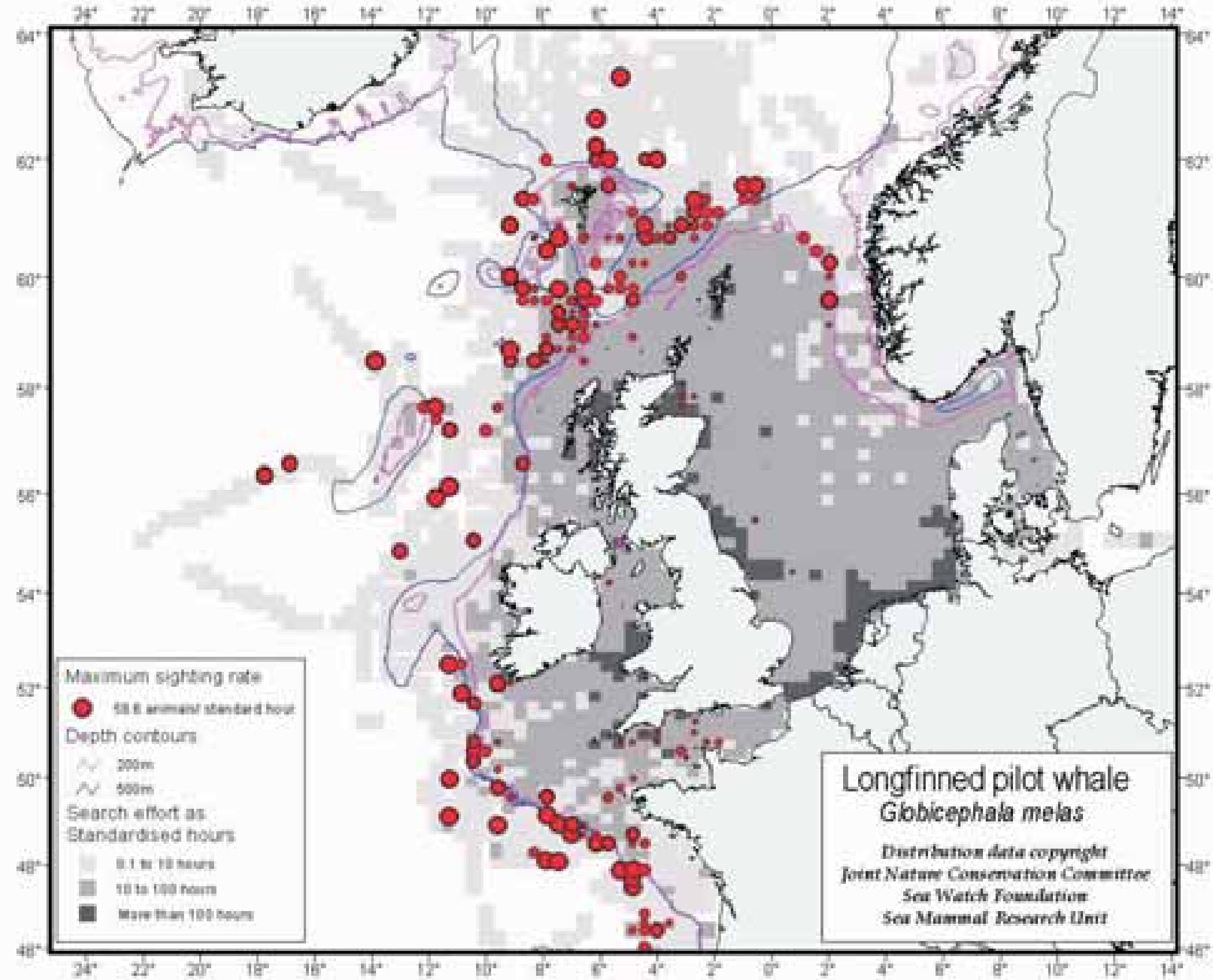

Figure 11. Sightings rates (numbers per standard hour) of long-finned pilot whales reproduced from Reid et al. (in press). Data collected over a 20 year time period, all months, from numerous platforms. Search effort (hours of observation) is indicated by shaded squares, sightings rates by red circles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

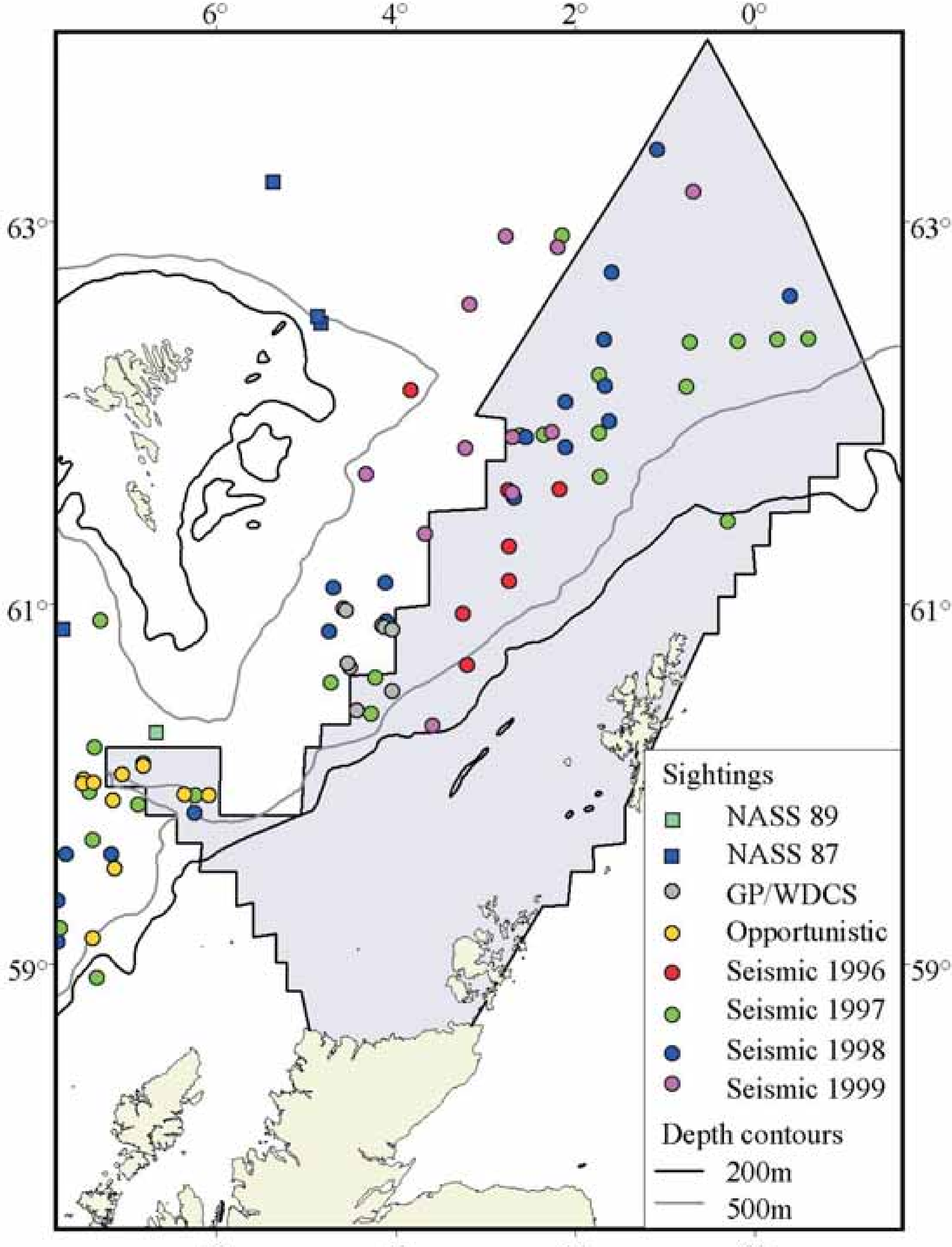

Figure 12. Pilot whale sightings made during NASS-89 and NASS-87 (Øien, 1991), GP/WDCS (Macleod et al., in press), opportunistic surveys (Macleod, 2001) and seismic (Stone 1997, 1998, 2000, 2001) surveys.

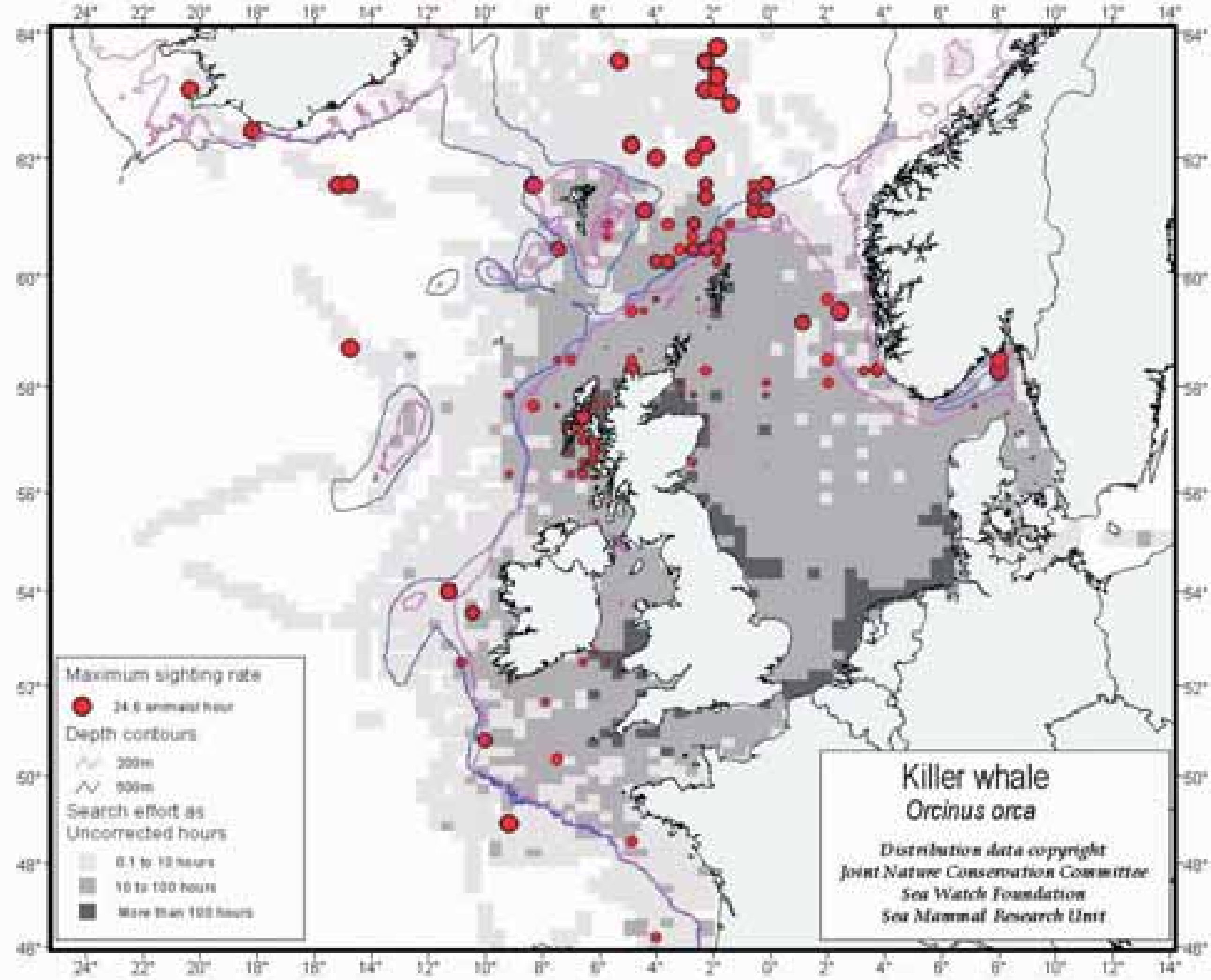

Figure 13. Sightings rates (numbers per standard hour) of killer whales reproduced from Reid et al. (in press). Data collected over a 20 year time period, all months, from numerous platforms. Search effort (hours of observation) is indicated by shaded squares, sightings rates by red circles with area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

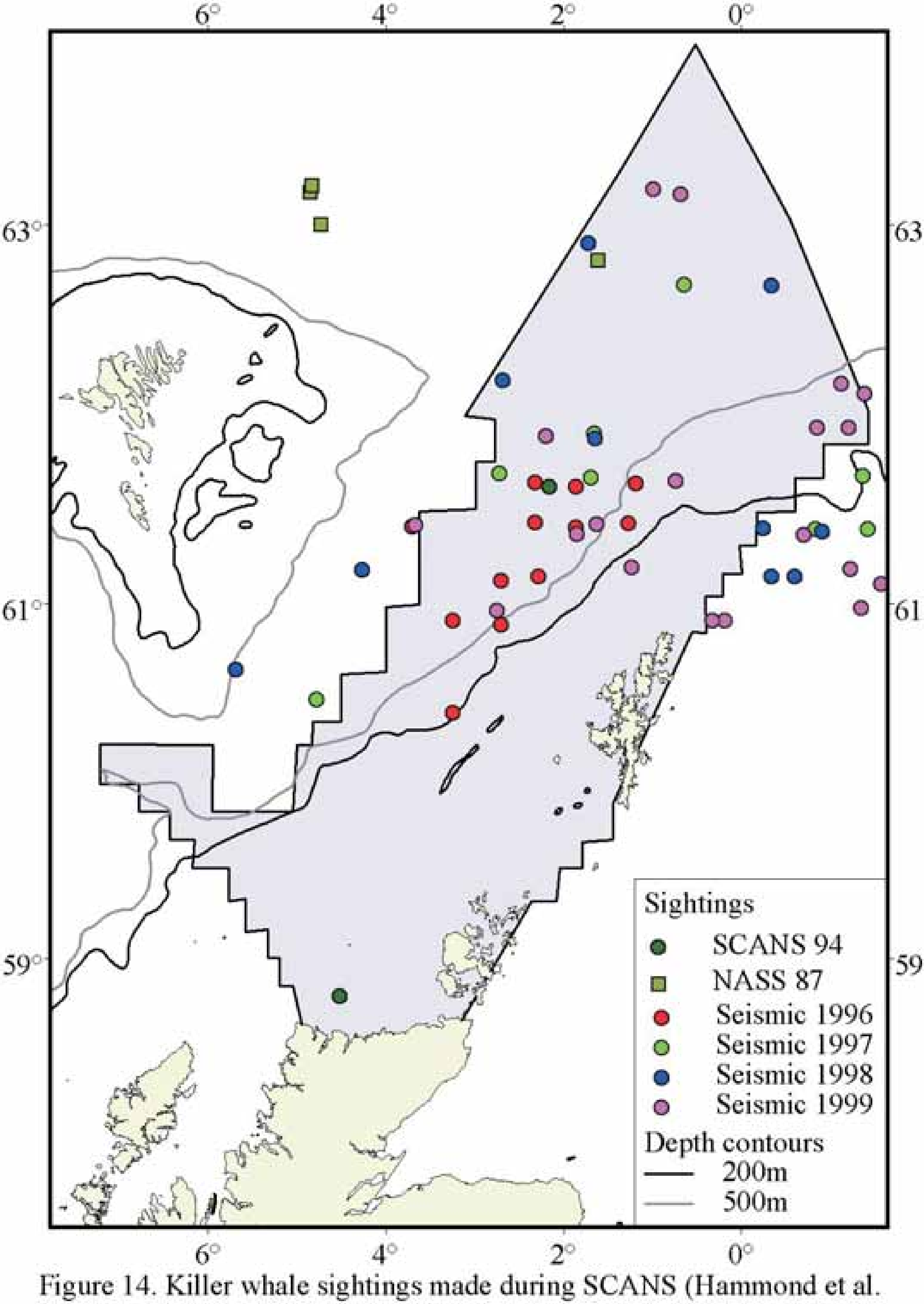

Figure 14. Killer whale sightings made during SCANS (Hammond et al. 1995; 2002), NASS-87 (Øien, 1991) and seismic (Stone 1997, 1998, 2000, 2001) surveys.

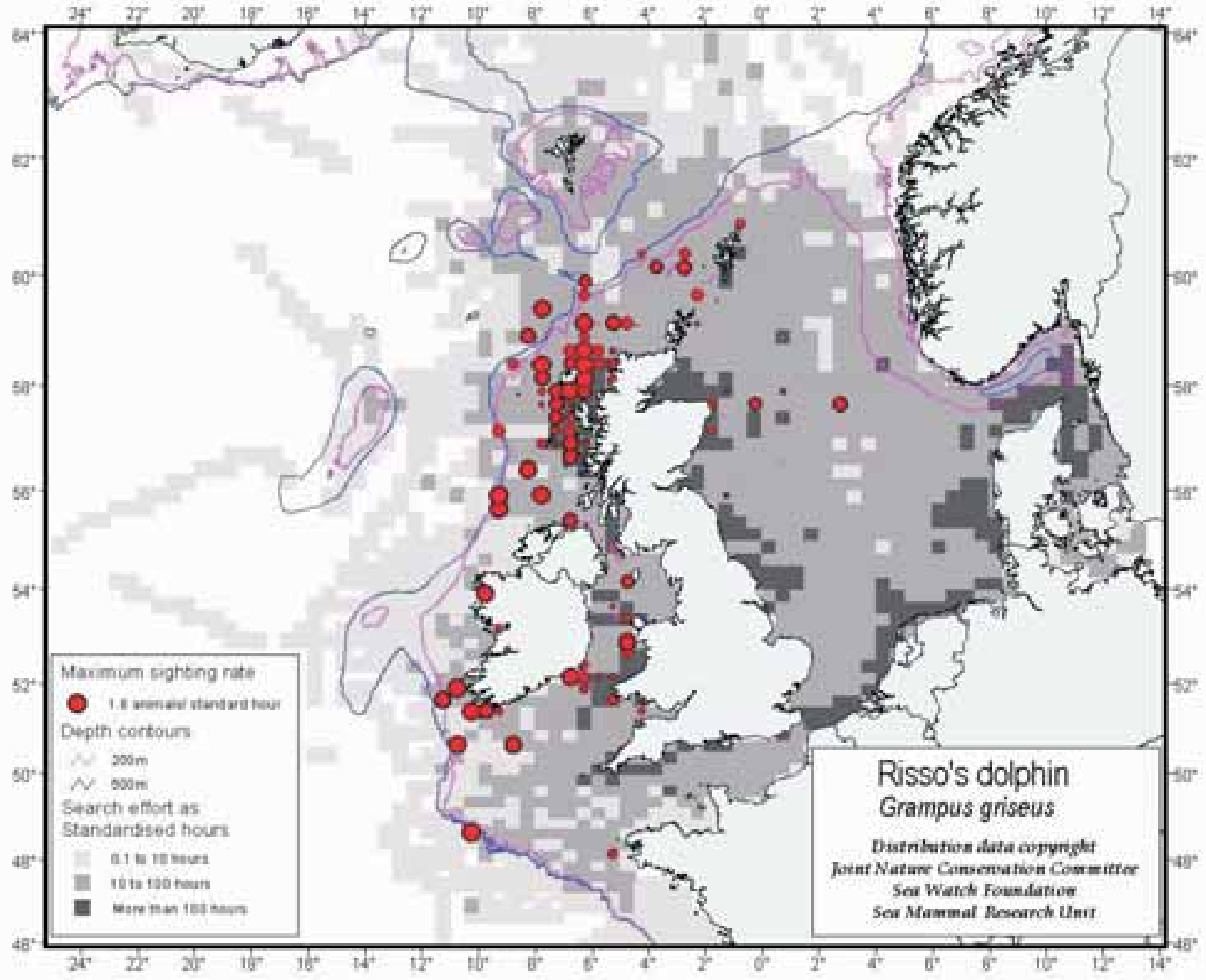

Figure 15. Sightings rates (numbers per standard hour) of Risso's dolphins reproduced from Reid et al. (in press). Data collected over a 20 year time period, all months, from numerous platforms. Search effort (hours of observation) is indicated by shaded squares, sightings rates by red circles with area proportional to rate. Gross corrections for the effect of sea state have been applied.

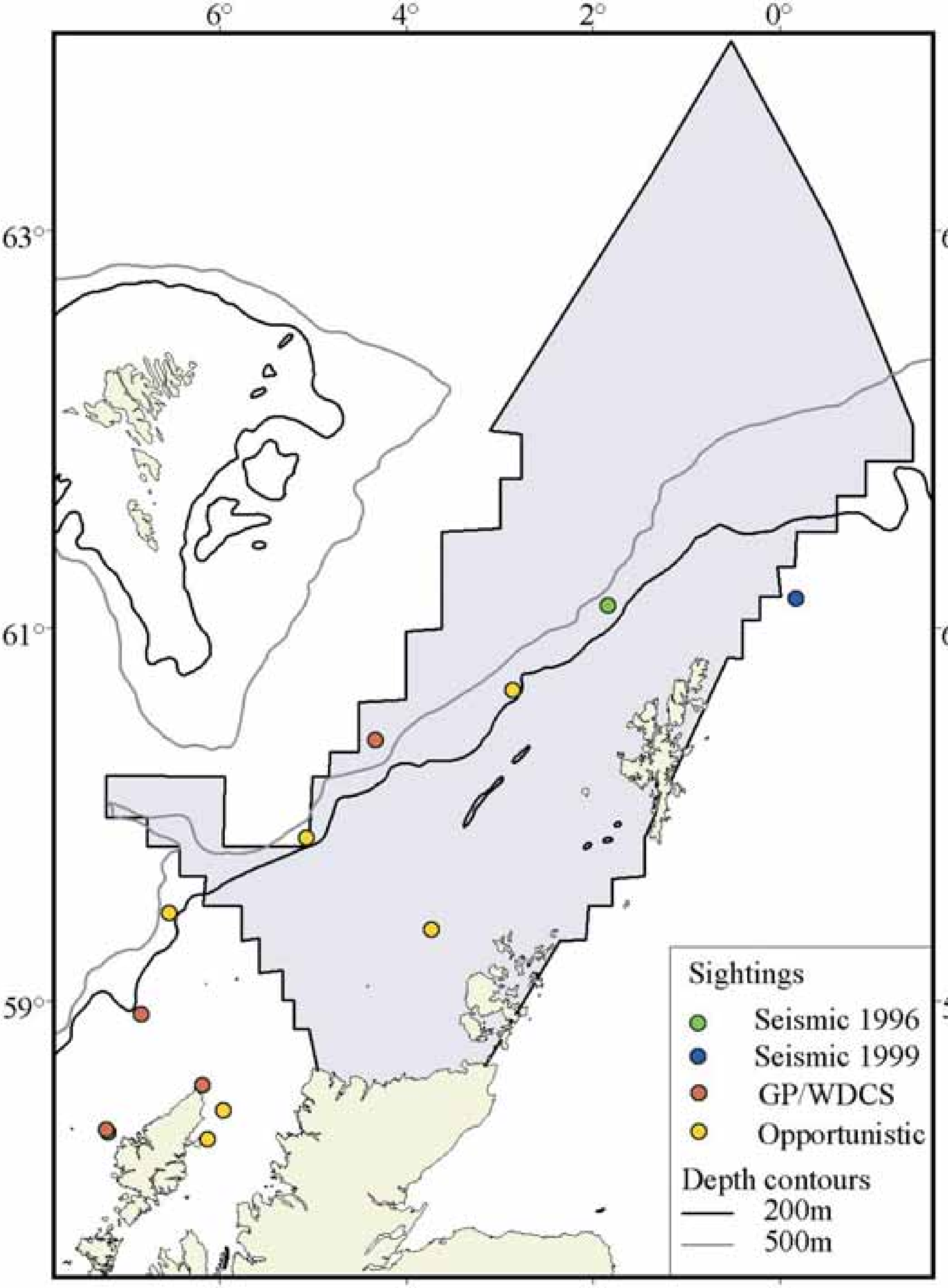

Figure 16. Risso's dolphin sightings made during GP/WDCS (Macleod et al. in press), opportunistic (Macleod, 2001) and seismic (Stone 1997, 2000) surveys.

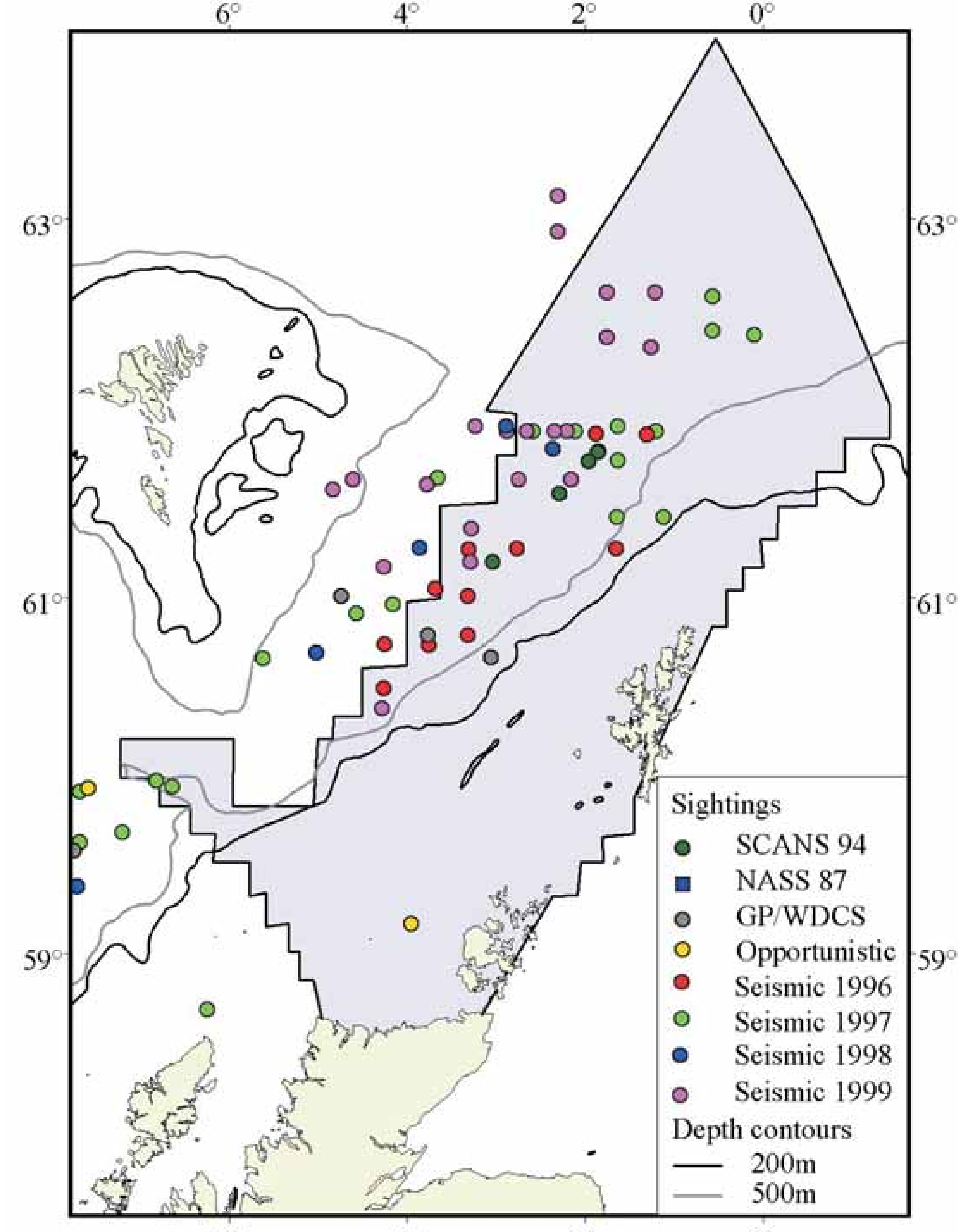

Figure 17. Sperm whale sightings made during SCANS (Hammond et al. 1995; 2002), NASS-87 (Øien, 1991), GP/WDCS (Macleod et al., in press), opportunistic (Macleod, 2001) and seismic (Stone 1997, 1998, 2000, 2001) surveys.

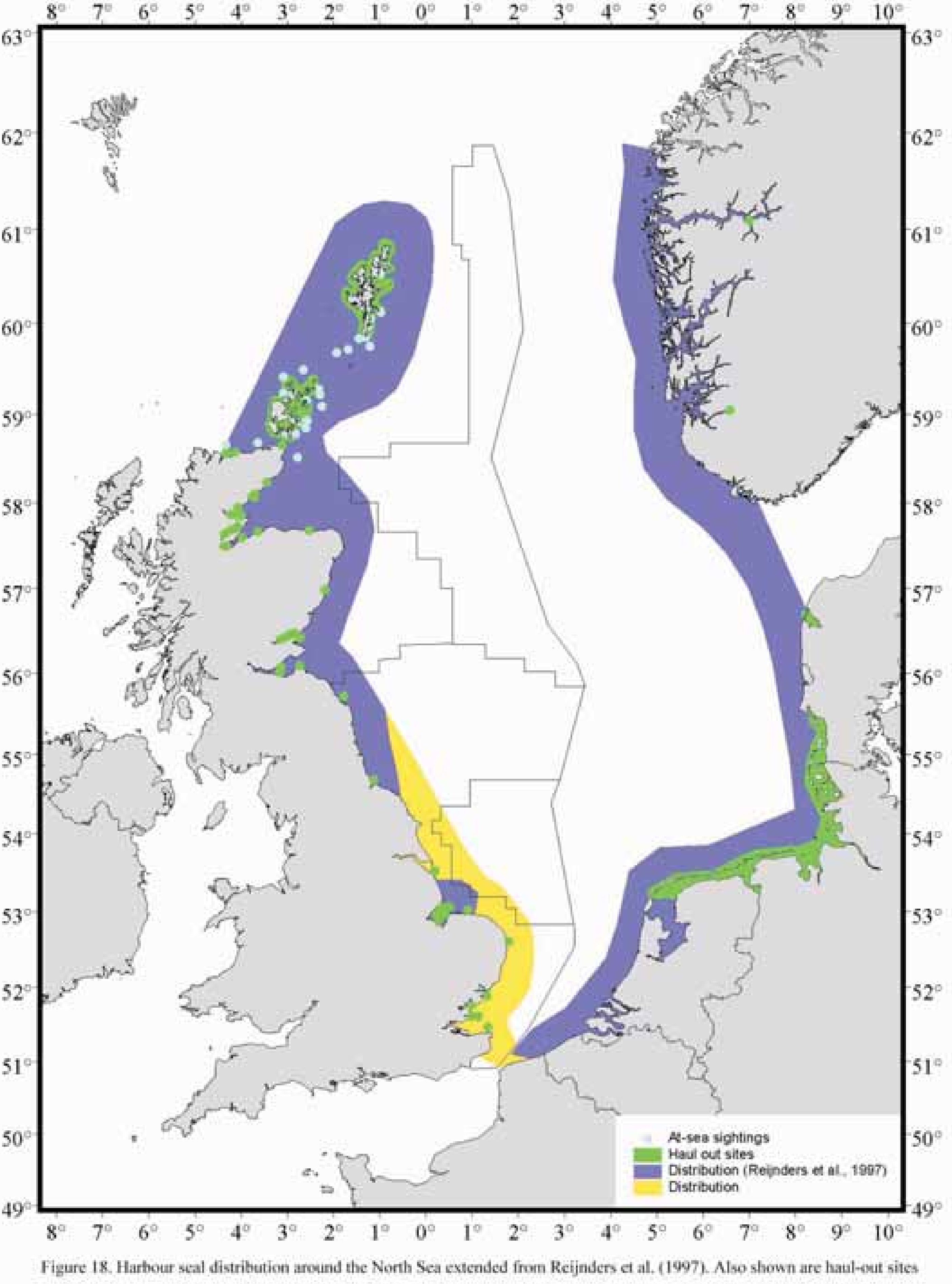

Figure 18. Harbour seal distribution around the North Sea extended from Reijnders et al. (1997). Also shown are haul-out sites during the moult (SMRU unpublished data; Bjørge 1991) and at-sea sightings from SAST surveys (Pollock et al. 2000).

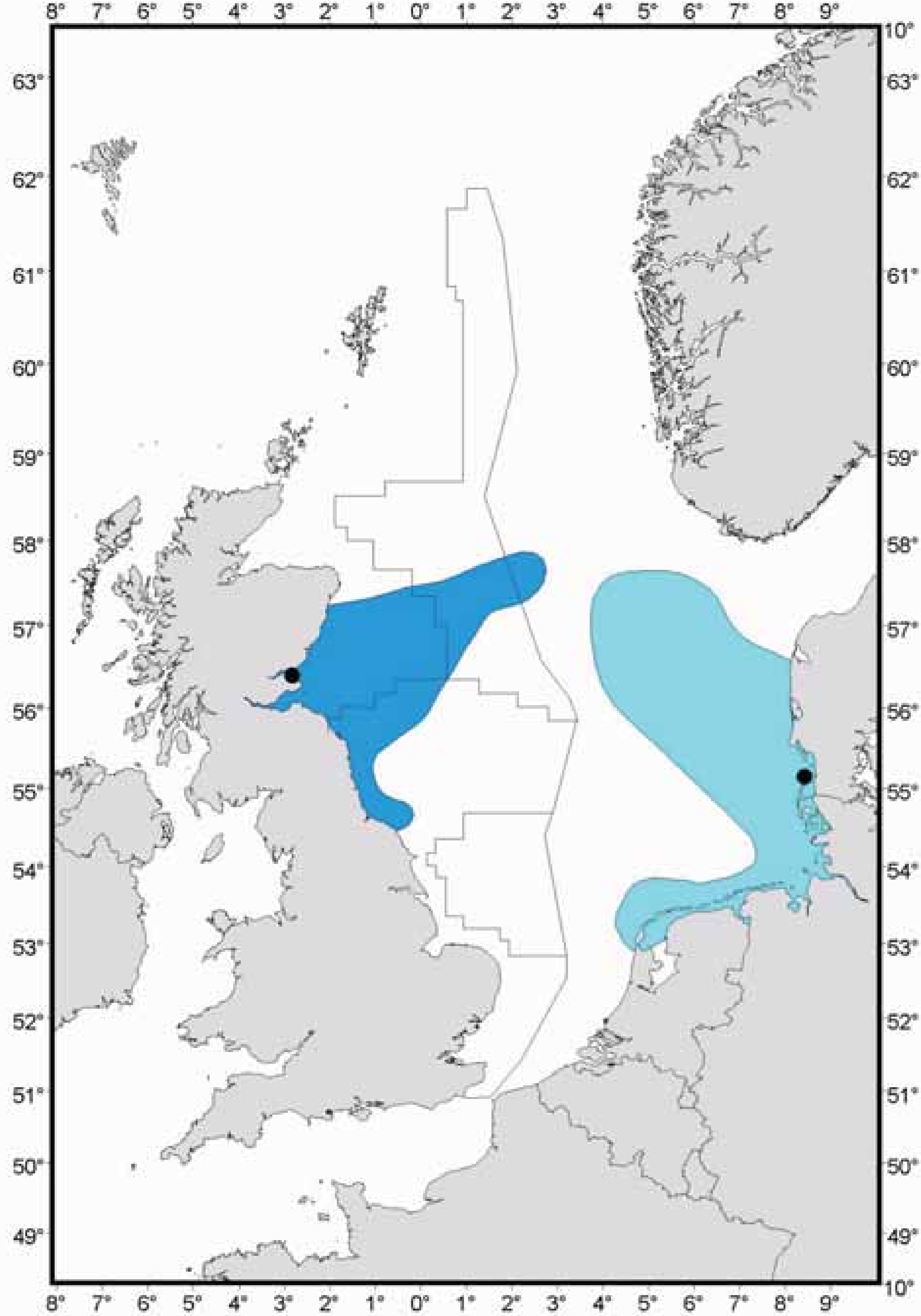

Figure 19. Distribution of harbour seals at sea from recent satellite telemetry studies. The shaded area in the western North Sea bounds the locations visited by 10 harbour seals from St Andrews Bay in 2001/02 (SMRU, unpublished data). The area in the eastern North Sea bounds the locations visited by 10 harbour seals from the island of Rømo, Denmark in 2001/02 (Fisheries Museum, Esbjerg and ELSAM Denmark, unpublished data).

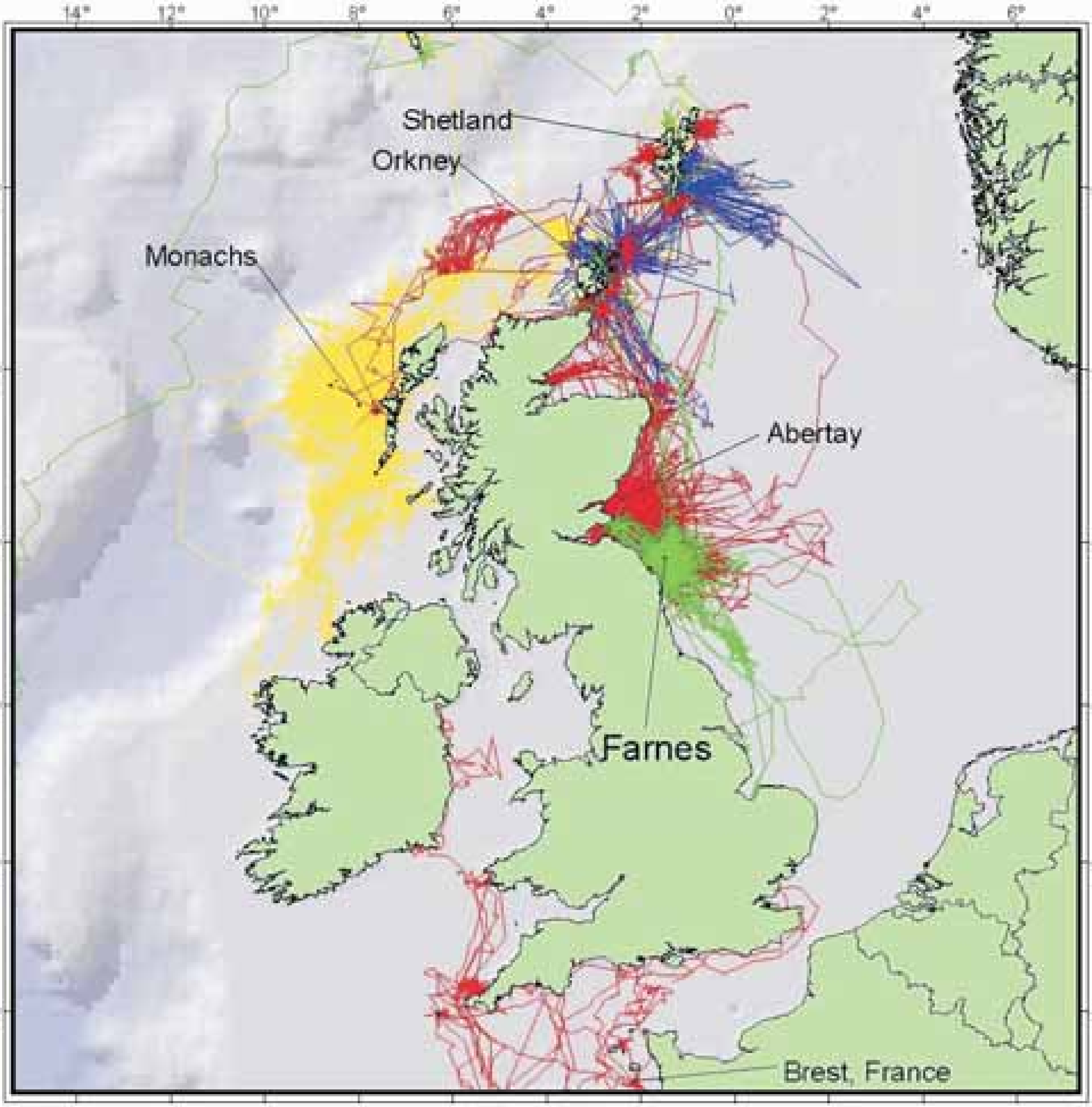

Figure 20. Tracks of 108 grey seals fitted with satellite-relay data loggers over a period of about 10 years (McConnell et al. 1999; SMRU unpublished data).

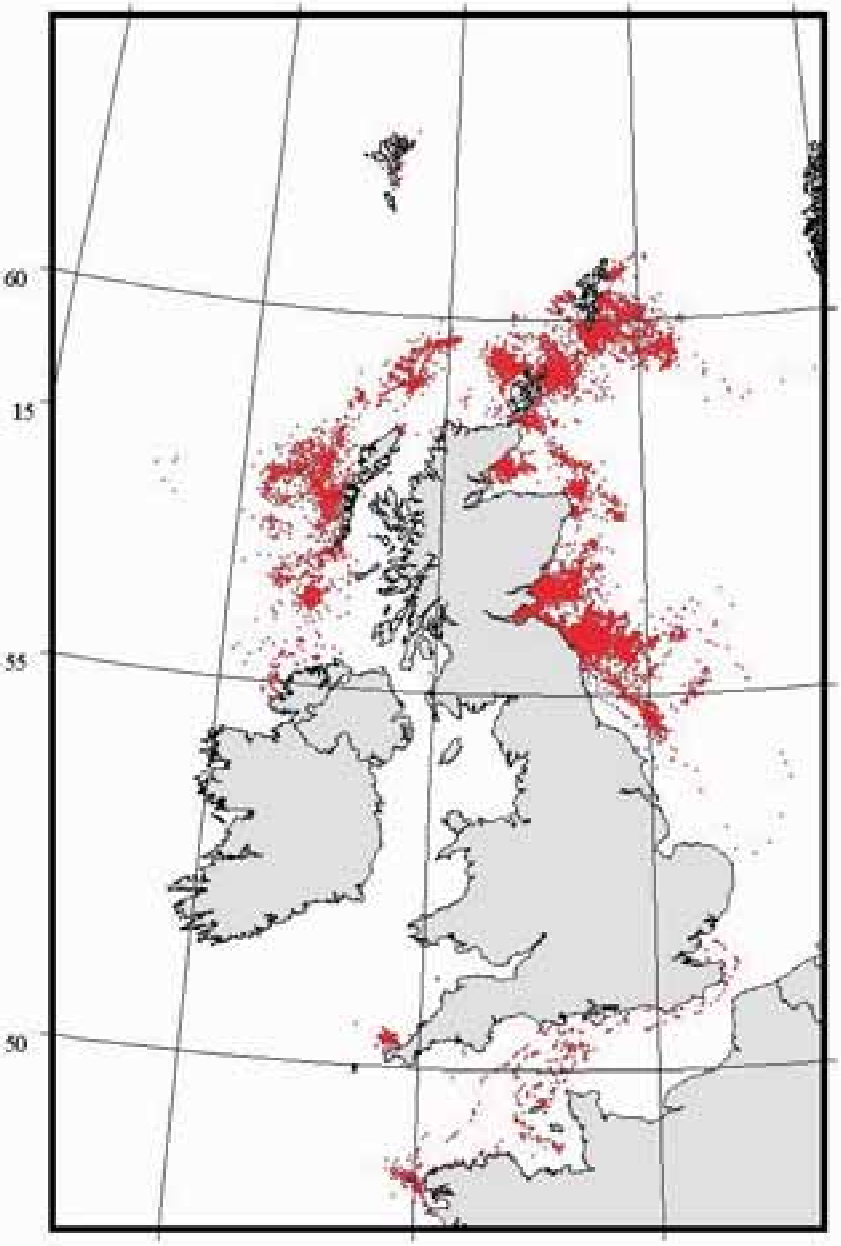

Figure 21. Locations of 108 grey seals fitted with satellite-relay data loggers over a period of about 10 years (see McConnell et al. 1999 for details).

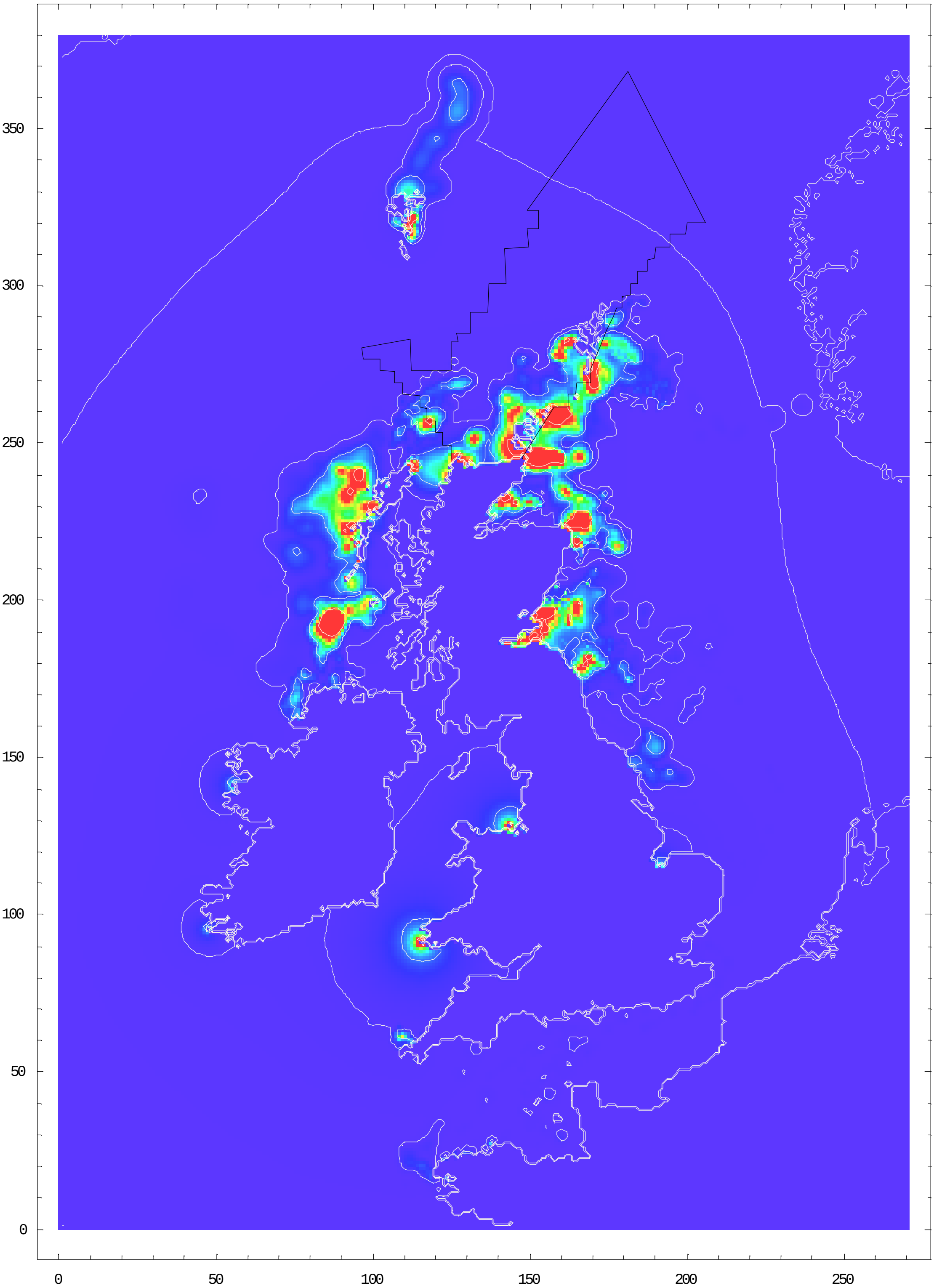

Figure 22. Distribution of where grey seals spend their time foraging around the British Isles predicted by a spatial model using the satellite-linked telemetry data shown in Figures 20 and 21 and other unpublished SMRU data (Matthiopoulos *et al.* in preparation).