Background information on marine mammals for Strategic Environmental Assessment 7

P.S. Hammond, S.P. Northridge, D. Thompson, J.C.D. Gordon,
A.J. Hall, C.D. Duck, G. Aarts, L. Cunningham, C.B. Embling & J. Matthiopoulos

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

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Non-technical summary

Distribution and abundance

Twelve marine mammal species are known to occur regularly in this area: grey seal, harbour seal, minke whale, sperm whale, bottlenose dolphin, short-beaked common dolphin, white-beaked dolphin, Atlantic white-sided dolphin, Risso's dolphin, killer whale, long-finned pilot whale, and harbour porpoise.

There is extensive information on the distribution and abundance of grey and harbour seals around Britain from annual aerial surveys of breeding colonies and haul-out sites and an increasing body of data from satellite telemetry studies. Information on cetacean distribution comes from both dedicated and opportunistic sightings surveys made by a wide spectrum of organisations, some voluntary and some funded by industry and by governmental agencies.

Harbour seals in the SEA-7 area are widely distributed along almost all island and mainland coasts. The number of animals in the area is likely to be more than 20,000, out of a total UK population of 50-60,000. Harbour seals spend more time ashore during summer when they are pupping and moulting. Information on distribution at sea is currently limited to the Inner Hebrides where 24 tracked animals have mainly remained close to haul-out sites but also made longer distance movements.

The British grey seal population has been increasing by around 6% annually since the 1960s. Its current size is estimated at around 120,000 individuals. In the SEA-7 area, the size of the population breeding in the Inner and Outer Hebrides has been estimated at 42,000 animals. During the pupping season in late summer - early autumn and the moulting season in spring grey seals spend more time ashore than at other times of the year. Grey seals are widely distributed in shelf waters of the SEA-7 area

Minke whales are frequent visitors to the coastal areas SEA-7 in the summer months, but there are also high sightings rates of the species in offshore areas such as Rockall Bank. The sperm whale is regularly recorded in deep waters beyond the continental shelf break of SEA-7. Bottlenose dolphins are common around the Hebridean Islands, but they can also be found offshore along the shelf edge and Rockall Bank. Common dolphins are recorded in large groups especially in the summer months in the Sea of Hebrides and southern part of the Minch, but also found common off the continental shelf as far north as 65°N during summer. White-beaked dolphins and Atlantic white-sided dolphins are both frequently observed to the north and west of SEA-7 (white-beaked generally more northerly than white-sided dolphins). Risso's dolphins are abundant around the Hebrides, especially around the northern end of Lewis, with sightings rates highest in summer. Killer whales are recorded regularly though infrequently, mainly in the Hebrides, and to a lesser extent along the shelf-edge. Long-finned pilot whales are mainly recorded along the continental shelf slope and in the west and north of SEA-7. The harbour porpoise is the commonest cetacean in the region, with sightings throughout much of the area throughout the year, but with highest concentrations in coastal areas during the summer months.

Ecological importance

The diet of grey seals in the SEA-7 area varies seasonally and from region to region. It is dominated by sandeels and gadoids but herring is also an important prey item. The grey seal population associated with breeding colonies west of Scotland is estimated to consume approximately 80,000 tonnes of prey per year. The shelf waters west of the Outer Hebrides are extensively used by grey seals, and there are "hot spots" on Stanton Bank to the south of Barra, and in waters to the west of Islay and Jura, and east of Lewis. The waters of the SEA-7 area are clearly very important as foraging habitat for the large numbers of grey seals hauling out in the Inner and Outer Hebrides.

Harbour seal diet has not been systematically studied around Britain and there is very limited information from western Scotland. In other areas, harbour seal diet can be summarised as a wide variety of prey including sandeels, whitefish, flatfish, herring and sprat, octopus and squid. Diet varies seasonally and from region to region. A very rough estimate of prey consumption by harbour seals in the SEA-7 area is about 25,000 tonnes per year. Recent information indicates that the waters of the Minch and the Hebridean Sea are important foraging habitat for the large numbers of harbour seals in the SEA-7 area. Studies are currently underway to provide information on the at-sea movements and distribution of seals from the Outer Hebrides.

There is relatively little information on the ecology of cetaceans throughout British waters. Minke whales might be expected to feed on herring, sprats and sandeels as they do elsewhere in UK coastal waters, and have been found in sandeel and harring pre-spawning grounds in the Hebrides. The sperm whale is known to eat deep water squids from stomachs of whales stranded on the east coast of Scotland, but have also been known to feed on deepwater fishes in other areas of the world. There are some stomach contents data for bottlenose dolphins in Scottish waters, which suggest that cod, saithe and whiting are the main prey, though they also take some salmon, haddock and squid. There are also some stomach contents data for common dolphins in Scottish waters, which suggest a diet of schooling fish such as mackerel, whiting and herring. The few stomachs from white-sided dolphins from Scotland also suggest that whiting is eaten by this species in addition to other small gadoids, sandeels and octopus. Atlantic white-sided dolphins are presumed to consume pelagic fish such as herring, mackerel, silvery pout, pearlsides and squid as they do elsewhere in Atlantic waters, while Risso's dolphins feed mainly on squid. Killer whales are known to have a very catholic diet of marine mammals and schooling fish such as herring and mackerel, but nothing is known of their diet in the SEA-7 area. Long-finned pilot whales have been shown to eat mainly squid towards the north of SEA-7, but include fish such as saithe, mackerel and blue whiting to the west of SEA-7. There is some stomach contents data for harbour porpoises in the SEA-7 area, which suggest that, as elsewhere, whiting, sandeels and other small gadoids are important. The harbour porpoise is the most numerous marine mammal in the region, and total annual fish consumption seems likely to run into tens of thousands of tonnes for the region as a whole. The significance of these species' predation from an ecological perspective has not been assessed.

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.

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. SACs have been established for the bottlenose dolphin in the Moray Firth (one) and in Cardigan Bay (two). No SACs have yet been established for the harbour porpoise. A number of terrestrial SACs have been established for grey and harbour seals around the coast of the UK, including three for grey seals in Wales. There are currently no marine 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 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 Department of the Environment in 1995 and are revised from time to time. In 1999, the 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-7 area is an important area for marine mammals. The waters of the Minch and Hebridean Sea and shelf waters west of the Outer Hebrides are very important foraging habitat for the large populations of grey and harbour seals in this area. Sperm whales and long-finned pilot whales are abundant throughout the deep waters west of the shelf edge. Bottlenose dolphins, white-beaked, and Atlantic white-sided dolphins are found both in the Hebrides and in shelf waters to the west of the Outer Hebrides. Harbour porpoises are abundant in the Hebrides year round, rarely found in deep waters, killer whales are also less frequent year round visitors to the area. Common dolphins are found throughout the area during the summer months though concentrated in the southern part. Minke whales and Risso's dolphins are also summer visitors to the Hebrides, though they, and harbour porpoises are also found in smaller numbers offshore.
- Marine mammals are important predators in this region. Because of the link between the abundance and availability of fish prey and the reproductive success 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 of seals and large whales in the SEA-7 area. Current mitigation methods are probably effective in preventing physical damage.
- There are no reliable data to suggest that vessel noise or drilling noise adversely affect seals or small cetaceans. Large whales may avoid areas of concentrated activity.
- 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-7 area, but the fact that gillnet fisheries play a relatively small role in overall fishing activity in this area means that bycatches are likely lower than in many other areas around Britain.

1. DISTRIBUTION AND ABUNDANCE

1.1 Introduction

This section summarises information on the distribution and abundance of marine mammals occurring in waters to the west of Scotland, with particular reference to the SEA-7 area.

Twenty-one cetacean species have been recorded in the region. Of these, ten species are known to occur regularly: harbour porpoise, bottlenose dolphin, short-beaked common dolphin, Risso's dolphin, white-beaked dolphin, Atlantic white-sided dolphin, long-finned pilot whale, killer whale, sperm whale and minke whale. Five further species, though not very often recorded, and primarily associated with deep water, probably also occur regularly: striped dolphins, fin whales, northern bottlenose whales, Cuvier's beaked whale and Sowerby's beaked whale. There are occasional at-sea records of a further 6 species: Sei whale, humpback whale, blue whale, northern right whale and false killer whale. Pygmy sperm whales and at least three further species of beaked whale might also be expected in the general area on occasion.

Quantitative abundance is limited to areas of overlap with the NASS surveys, conducted in North Atlantic waters by Iceland, the Faroes and Norway. The most recent NASS survey (2001) was denied access to UK waters, so there are no recent abundance estimates available for these waters. The NASS-95 survey resulted in estimates of some of the large whale species that may be relevant to this area. The SCANSII survey, conducted during the summer of 2005, covered the continental shelf zone of the SEA-7 area. Abundance estimates from this survey are not yet available, but will be by the summer of 2006. Relative abundance data are available from platform of opportunity sightings data (see Reid *et al*., 2003), as well as some small-scale coastal survey work conducted by organisations such as the Hebridean Whale and Dolphin Trust (HWDT).   In the following sections, each of the more abundant species is briefly described with particular reference to its distribution and abundance in the SEA-7 area.

Extensive information on the distribution and abundance of grey seals around Britain is available from studies carried out by the Sea Mammal Research Unit (SMRU). These include annual aerial surveys of breeding colonies to estimate pup production and population size (SCOS, 2005), aerial thermal image surveys of haul-out sites during August (SCOS, 2005), and data from around 150 animals fitted with satellite-relayed data loggers (e.g. McConnell *et al.,* 1999; Matthiopoulos *et al.,* 2004). In the SEA-7 area, new data are available from a SMRU study supported by DSTL.

For harbour seals there are detailed data from aerial thermal image surveys conducted during the moult by SMRU (SCOS, 2005) and from satellite-relayed telemetry in the Inner Hebrides. Studies of the at-sea distribution of harbour seals around the Outer Hebrides have been recently initiated.

1.2 Baleen Whales

1.2.1 Minke whale (*Balaenoptera acutorostrata)*

The minke whale is widely distributed in all the major oceans of the world from tropical to polar seas, though most abundant in relatively cool waters and on the continental shelf (in depths of 200 m or less).

It occurs in along the Atlantic seaboard of Europe mainly from Norway south to France, and in the northern North Sea, occurring less commonly in the southern North Sea and eastern Channel. Within UK waters it is most frequently sighted in the north-western North Sea and the Hebrides. Sightings rates are also high on Rockall Bank (see Figure 1- adapted from Reid *et al*., 2001). The species has been recorded in every month of the year in UK waters, but is mainly seen near the coast between May and September (Evans, 1990; Northridge *et al.*, 1995; Evans *et al.*, 2003). The minke whale population in the Inner Hebrides has been surveyed by HWDT between April-September every year since 2003 from their motor-sailor research vessel, *Silurian*. Minke whales were common in the Inner Hebrides in the summer months (April-September) with peak numbers seen around August (Figure 2). This also confirms sightings reported by the whale watching organisations off Mull (Sealife Surveys), where highest concentrations are usually found around the Small Isles (Rhum, Muck & Eigg). 2005 saw a move of minke whales out of the area, with much smaller numbers seen in all months in comparison to previous years.

Minke whales in the SEA-7 area are considered by the International Whaling Commission as part of a single northeastern Atlantic stock. There are about 150,000 minke whales in the north-eastern and central North Atlantic. (IWC website)

1.3 Toothed whales

1.3.1 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, where records exist, 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. Figure 3 shows that sperm whales are fairly regularly recorded in deep waters in the SEA-7 block. It may be assumed that SEA-7 covers a migratory route for some portion of the North-eastern Atlantic sperm whale population at times of the year.

Opportunistic passive acoustic surveys have been carried out to the north and west of Scotland from oceanographic and fisheries survey vessels since December 2000. The majority of these surveys have concentrated on the area between the Faroes and Shetland Islands, with a few surveys further south and west of the core areas in more recent years. In addition to this, passive acoustic surveys have been carried out from herring abundance surveys on the shelf waters from west of Coll & Tiree to the west of the Orkneys. During these surveys, continuous monitoring of the hydrophone was carried out and any sperm whale sounds were noted along with the number of animals heard. Sperm whales are found to be common in the deeper waters to the west of the shelf edge, with much higher numbers in May than in October between the Faroes and the Shetlands (Hastie *et al*., 2003), though large numbers were found in deep waters further south (in the Rockall Trough) in October 2005 (see Figure 4).

1.3.2 Common bottlenose dolphin (*Tursiops truncates)*

The bottlenose dolphin has a worldwide distribution in tropical and temperate seas of both hemispheres. Along the Atlantic seaboard of Europe, the species is locally fairly common near-shore off the coasts of Spain, Portugal, north-west France, southern and western Ireland, North-east and South-west Scotland, in the Irish Sea, and in the English Channel (Evans *et al.,* 2003). Sightings are fairly common around various Hebridean islands. The species also occurs offshore along the shelf edge in the eastern North Atlantic, and on Rockall Bank.

There are no abundance estimates for bottlenose dolphins in this area, though estimates for shelf areas within SEA-7 will be generated by the SCANS-II project. Relative abundance from Reid *et al*. (2003) is shown in Figure 5, while more recent and more systematic data from HWDT show greater relative densities in certain parts of the inner Hebrides. During the monthly surveys carried out by HWDT in the summer months between 2003-2005, bottlenose dolphins have been seen occasionally, mainly in coastal waters around Mull, Islay, Tiree and Skye (Figure 6). Little is known about the population of bottlenose dolphins in this area, though there have been a few dedicated studies by HWDT over the last few years. A new 3-year project studying their distribution, and carrying out photo-ID studies in order to estimate the number of dolphins and assess their residency patterns has just started this year (2006) jointly with SMRU, University of Aberdeen, SAMS and SNH.

1.3.3 Short-beaked common dolphin (*Delphinus delphis)*

The short-beaked common dolphin has a worldwide distribution in oceanic and shelf-edge waters of tropical, subtropical and temperate seas of the Atlantic and Pacific Oceans, occurring in both hemispheres. It is abundant and widely distributed in the eastern North Atlantic, mainly occurring in deeper waters from the Iberian Peninsula north to the Faroe Islands, with summer sightings as far North as the Barents Sea. Its distribution appears to be associated with Gulf Stream waters in temperatures of 8-28º C, and there appears to be an annual influx of animals to the Celtic Shelf from adjacent offshore waters during the winter months.

The species is common in the Sea of Hebrides and southern part of the Minch especially in the summer. It is also common off the edge of the continental shelf it can be found north to latitude about 65º N (though rare north of 62º N) during the summer. In some years, the species occurs further north and east in shelf seas - in the northern Hebrides, around Shetland and Orkney, and in the northern North Sea. It is generally rare in the central and southern North Sea and eastern portion of the English Channel.

The overall distribution for this species in the waters adjacent to the UK is shown in Figure 7, In the Hebrides, short-beaked common dolphins have been occasionally seen during the monthly summer surveys carried out by HWDT between 2003-2005. They appear to be absent from the southern part of the Inner Hebrides, encountered most often off the west and to the north of Coll & Tiree (Figure 8). The majority of sightings have been concentrated in July and August. Common dolphins have also been sighted occasionally during opportunistic passive acoustic surveys (i.e. no dedicated visual observations) carried out from oceanographic and fisheries survey vessels during May, July and October from 2003-2005. In these surveys, common dolphins were found in offshore areas on the continental shelf from as south as west of Coll & Tiree to as far north as west of the Orkneys.

An abundance estimate for the NASS-95 survey area of around 350,000 has been derived by Canadas *et al*. (in press), with densities of around 0.55 animals per km^2. Another survey that covered a smaller area in 2001 in Irish waters adjacent to SEA-7, yielded a density estimate of 0.039 common dolphins per km^2 (O'Cadhladh, 2001). Abundance estimates for shelf waters overlapping with SEA-7 are expected from the SCANS II survey when results are made available in 2006.

1.3.4 White-beaked dolphins (*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 numerous within about 200 nm of the Scottish (and Northeastern English) coasts than anywhere else (Northridge *et al.*, 1995). They are frequently observed especially in the northern parts of SEA-7 (see Figure 9). There are no current abundance estimates for this area, but estimates for shelf waters will be produced by the SCANS-II project. White-beaked dolphins are taken in the Faroe islands for food in a drive fishery or Grind.

1.3.5 Atlantic white-sided dolphins (*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 and west (Figure 10), including offshore waters of the SEA-7 block. There are no abundance estimates for this area.

1.3.6 Risso's Dolphin (*Grampus griseus*)

The Risso's dolphin is widely distributed in tropical and temperate seas of both hemispheres, occurring in small numbers along the Atlantic European seaboard from the Northern Isles south to northwest France, the southern Bay of Biscay, around the Iberian Peninsula and east into the Mediterranean Sea. A major concentration in northern European waters occurs in the Hebrides but the species is regularly seen also in the Northern Isles, in the Irish Sea and off southwest Ireland, while it is rare in the North Sea and all but the western end of the English Channel. Globally they are most usually seen in oceanic waters.

Within the SEA-7 region they may be most abundant around the northern end of Lewis (see Figure 11), but in the monthly summer surveys carried out by HWDT in the Inner Hebrides, Risso's dolphins are seen occasionally throughout the survey area (see Figure 12). They appear to be most frequent in the area between June-September, and are rarely found in the area before June.

1.3.7 Killer whale (*Orcinus orca*)

The killer whale has a worldwide distribution in tropical, temperate and polar seas in both hemispheres (with greatest abundance at higher latitudes). It is widely distributed on the Atlantic seaboard of northern Europe, mainly around Iceland, western Norway, and northern Scotland, but it is occasionally seen south to the Iberian Peninsula and east into the Mediterranean Sea.

In the SEA-7 area killer whales are most often sighted in the Hebrides, and to a lesser extent along the shelf edge (Figure 13). There are no abundance estimates here.

1.3.8 Long-finned pilot whale (*Globicephala melas*)

The long-finned pilot whale has a worldwide distribution in temperate and sub-polar seas of both hemispheres. It is common and widely distributed in deep North Atlantic waters. In British and Irish waters, long-finned pilot whales occur mainly along the continental shelf slope, particularly around the 1,000 metre isobath, and notably in the north of SEA-7 (see Figure 14). They are also frequently sighted, and heard among other delphinids, west of the shelf edge. Pilot whales are hunted by the Faroese, and there are thought to be around 780,000 in the central and north-eastern North Atlantic.

1.3.9 Delphinid species

Delphinid species such as white-sided dolphins, white-beaked dolphins, common dolphins, and long-finned pilot whales can be detected acoustically during passive acoustic surveys for cetaceans. It is, however, very difficult to determine species from their vocalistions. In opportunistic surveys carried out to the north and west of Scotland from oceanographic and fisheries survey vessels since December 2000, delphinid species were heard throughout the survey area, though concentrated away from shore. Opportunistic sightings during the surveys suggest that white-beaked dolphins are concentrated to the north of the Outer Hebrides, whereas white-sided and common dolphins are found throughout the area. Opportunistic sightings of long-finned pilot whales were recorded in the deep waters of the Faroe-Shetland Channel, and frequently in deep waters to the west of the shelf edge. All delphinid sounds have been grouped together due to the difficulty of distinguishing species and are shown in Figure 15.

1.3.10 Harbour porpoise (*Phocoena phocoena)*

The distribution of the harbour porpoise is restricted to temperate and sub-arctic (mainly 5-14º C) seas of the Northern Hemisphere. In the eastern North Atlantic, it is common and widely distributed on the continental shelf (mainly at depths of 20-200 m) from the Barents Sea and Iceland south to the coasts of France and Spain. It is the most frequently observed (and stranded) cetacean in British and Irish waters where it is most abundant around North-west and North-east Scotland, in western and southern Ireland, most of Wales and off South-west England (Figure 16). The harbour porpoise is comparatively rare in waters exceeding 200 metres, and therefore is primarily a species of the continental shelf.

Metrical studies using skeletal material, along with studies of tooth ultra-structure and genetics together suggest that subpopulations of harbour porpoises may exist in the North Sea and adjacent waters, with possible separate populations occurring in the Irish Sea (Wales), northern North Sea, and southern North Sea (Netherlands) (Andersen, 2003; Lockyer, 2003). Genetic evidence from the UK and elsewhere also indicates that males disperse more widely than females (Walton 1997; Andersen *et al.*, 1997; Tolley *et al.*, 1999).

The harbour porpoise is widely distributed in the SEA-7 area on the shelf- though there are also sightings on Rockall Bank and in deepwater areas suggesting some level of interchange with between Scottish, Faroese and Icelandic shelf animals.

In visual surveys carried out by the Hebridean Whale and Dolphin Trust (HWDT) from their motor-sailor research vessel, *Silurian*, in summer months between 2003-2005, it is evident that the harbour porpoise is found distributed throughout the Inner Hebrides (Figure 17), with peak numbers found in August. Acoustic surveys were also carried out simultaneously and should yield further information on distribution and abundance later in 2006.

1.4 Other Species

1.4.1 Other species occasionally sighted

Several other species of cetaceans have been recorded more than casually. These are fin whales in deep water, striped dolphins, which occasionally appear among the Hebridean Islands, and three species of beaked whales: northern bottlenose whales, Cuvier's beaked whale and Sowerby's beaked whale. All but the striped dolphin, which is generally considered a warmer water species, are probably present throughout much of the deep water area throughout much of the year, but in low numbers.

1.4.2 Rare Occurrences.

Several other species of baleen whale, namely blue whales, northern right whales, humpback whales and sei whales may also occur in low numbers occasionally in this area. Humpback whale numbers seem to have increased in recent years in Iceland waters (Pike 2005) and this may have led to increased number in the SEA-7 area too, but with no systematic sightings in offshore waters this is impossible to determine. Pygmy sperm whales and false killer whales have also been sighted in this general area, and so may occur occasionally.

1.5 Pinnipeds

1.5.1 Grey seal (*Halichoerus grypus)*

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

The British grey seal population is currently estimated at around 120,000 individuals (SCOS, 2005). In the SEA-7 area, the size of the population breeding in the Inner and Outer Hebrides has been estimated at about 42,000 animals (Thomas and Harwood, 2005). The distribution of grey seals at haul-out sites off the west coast of Scotland is shown in Figure 18.

Note that in the SEA-7 area most grey seals spend the majority of their time on land for several weeks in October/November whilst pupping and mating, and in spring during the moult. Densities at sea are therefore lower during these periods than at other times of the year.

The distribution of grey seals at sea in the SEA-7 area has been studied by tracking animals fitted with satellite relay data loggers (Matthiopoulos *et al.*, 2004; SMRU, unpublished data). Figure 19 shows the predicted area usage by grey seals tagged over the last 10 years based on these data and counts of animals at haul-out sites. A more detailed description of these data is given in section 2.2.3.

1.5.2 Harbour (or common) seal (*Phoca vitulina)*

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

There are four sub-species. Only the eastern Atlantic harbour seal, *Phoca vitulina vitulina*, occurs around Britain. The number of harbour seals around Britain is estimated to be at least 50,000, based on minimum population counts of 34,000 during the moult (SCOS, 2005). Harbour seals distribution at haul out sites in western Scotland is shown in Figure 20. Based on the counts illustrated in Figure 20, the number of harbour seals in the SEA-7 area is likely to be at least 20,000.

The distribution of harbour seals at sea off the west coast of Scotland has been studied by tracking animals fitted with satellite relay data loggers (SMRU, unpublished data). Figure 21 shows smoothed tracks from 24 animals studied in 2003-2005. A more detailed description of these data is given in section 2.3.3.

1.5.3 Hooded seal (*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 Northwest 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, at Jan Mayen, at the West Ice, at 64ºN in the Davis Strait, on the Front off Newfoundland and in the Gulf of St Lawrence.

The world population of hooded seals was estimated to be around 500,000-600,000 (Reijnders *et al.,* 1997). Around two-thirds of this population is associated with the Greenland Sea/Jan Mayen stock. Surveys in 1984 and 1990 suggest that the Northwest Atlantic stock may have increased at around 5% per year (Stenson *et al.,* 1994). Counts from the eastern stock suggest a gradual decline, from 120,000 pups in 1955 to 70,000 in 1970, and around 50,000 in the early 1990s. Recent aerial surveys suggest that pup production may have declined further.

Hooded seal pups 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. Hooded seals were sighted mainly in deep water along the continental slope during winter off Newfoundland (Stenson & Kavanagh, 1993).

2. ECOLOGICAL IMPORTANCE

The abundance and availability of fish, especially those species mentioned above, is clearly of prime importance in determining the reproductive success 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.

2.1 Cetaceans

The ten most frequently seen species of cetacean in the SEA-7 area are the minke whale, sperm whale, bottlenose dolphin, short-beaked common dolphin, white-beaked dolphin, Atlantic white-sided dolphin, Risso's dolphin, killer whale, long-finned pilot whale and harbour porpoise.

2.1.1 Minke whale

Minke whales are known to feed on a variety of fish species, including herring, cod and haddock in Norwegian waters. In past decades, minke whales were associated with herring in the North Sea and were presumed to feed on them (Northridge, 1988). Stephenson (1951) reported that most minke whales taken by commercial whaling in the UK waters of the North Sea during 1948 had been feeding on herring, with some mackerel and sand eels also reported. At least one animal in recent years has also been recorded feeding on sandeels (Santos *et al.*, 1994). There is no specific information on feeding in the SEA-7 area, however minke whales off the Isle of Mull were shown to prefer areas of sandeel habitat in early summer, and pre-spawning herring habitat in late summer (Macleod *et al.*, 2004).

2.1.2 Sperm whale

Sperm whales are mainly reported from deeper water areas, and it is generally assumed that their diet in this region is likely to consist mostly of deepwater squids, as it was from strandings of sperm whales on the east coast of Scotland (Santos *et al*., 1999). 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.

2.1.3 Bottlenose dolphin

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

2.1.4 Short-beaked common dolphin

There is very little information about the diet of common dolphins off the west coast of Scotland. However Santos (1998) – analysed 3 stomachs of common dolphins from Scottish bycatch, the main component of which was whiting (68.69%). The BIOCET project (unpublished data, 2005) analysed 9 common dolphin stomachs from Scottish waters collected between 2000-2003 and found that the most common prey consumed were mackerel, whiting and herring (25.6%, 18.5% and 13.4% of the estimated prey weight respectively).

Elsewhere in Europe, common dolphins are known to consume a wide variety of prey (fish, cephalopods and crustacea). Studies suggests that the diet of common dolphins in continental shelf waters consists of mainly epipelagic shoaling species such as sardines, horse mackerel and mackerel (SMRU/IoZ unpublished data; Santos, 1994, 1998; Brophy, 2003), while those feeding over deeper waters offshore exploit mesopelagic fishes, squid and pelagic crustaceans (Hassani *et al.*, 1997, Brophy, 2003).

2.1.5 White-beaked dolphin

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

2.1.6 Atlantic white-sided dolphin

The diet of atlantic white-sided dolphins in Scotland is unknown. Elsewhere, herring, mackerel, horse-mackerel, silvery pout, pearlsides and squid have all been recorded as diet items (Couperus, 1997; Reeves *et al.*, 1999a), suggesting a pelagic feeding mode.

2.1.7 Risso's dolphin

There are no data on Risso's dolphin feeding habits in the SEA-7 area, but they are generally assumed to restrict their feeding to squids, as they do in other areas (Clarke and Pascoe, 1985; Wurtz *et al.*, 1992; Santos *et al*., 1995). It is not possible to assess the ecological significance of this.

2.1.8 Killer whale

Killer whales have a catholic diet including marine mammals and schooling fish like herring and mackerel, but nothing is known of their diet in this area.

2.1.9 Long-finned pilot whale

Long-finned pilot whales are predominantly squid feeders (Desportes and Mouritsen, 1993). Stomach analysis of animals from the North Atlantic also suggests that they also supplement their diet with small amounts of fish such as saithe, mackerel and blue whiting (Gannon *et al*., 1997). The study carried out by Desportes and Mouritsen (1993) in the Faroe Islands found mainly squid in the diet, whereas the study carried out by Gannon *et al.* (1997) to the west of the North Atlantic found some fish in their diet. There is no other indication of diet for long-finned pilot whales within SEA-7.

2.1.10 Harbour porpoise

Although well studied in the North Sea, and to a lesser extent in the southwest of England and the Irish Sea, the diet of the harbour porpoise is less well studied to the west of Scotland. In a study of diet of harbour porpoises from Scottish waters (including 34 stomachs from the west cost), the diet was found to consist mainly of whiting, sandeels, haddock/saithe/Pollack and Norway pout/poor cod (Santos *et al.*, 2004). Elsewhere in the UK other important prey species include sprats, herring, and small gadoids (Rae, 1965, 1973; Martin, 1995; Santos and Pierce, 2003), and for smaller animals at least, gobies are an important source of food (IoZ/SMRU unpublished data).

The harbour porpoise is probably the most numerous marine mammal species in the SEA-7 area and adjacent waters. It is not possible to calculate total fish consumption per annum in the SEA-7 area but this is likely to run into tens of thousands of tonnes for the west coast of Scotland as a whole. The significance of this species' predation from an ecological perspective has not been assessed.

2.1.6 Other species

The feeding habits of fin whales in this area are unknown, but elsewhere these species consume planktonic crustaceans and small schooling fish such as herring, capelin, and sandeels (Christensen *et al*., 1992; Sigurjónsson, 1995; Sigurjónsson and Víkingsson, 1997).

There is very little information on the feeding habits of beaked whales, however analysis of the few stomach contents of stranded animals suggest that they are predominantly mesopelagic squid eaters, though do eat some mesopelagic fish species.

The feeding habits of striped dolphins in this area are unknown, but they are found to eat both squid (in Mediterranean waters) and fish (elsewhere in the world).

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 SEA-7 area (see Section 1) and is thus an important marine predator in this region. Grey seals have no significant natural predators in this area.

2.2.1 Diet composition

The diet of grey seals has been studied extensively around Scotland and the east coast of England, primarily in 1985 and 2002 (Prime and Hammond, 1990; Hammond and Prime, 1990; Hammond *et al.*, 1994a, b; SMRU unpublished data). Overall, the diet comprises primarily sandeels, gadoids and flatfish, in that order of importance, but varying seasonally and from region to region. Sandeels and gadoids dominate the diet in the SEA-7 area but herring is also an important prey item (SMRU unpublished data).

2.2.2 Prey consumption

The average daily energy requirement of a grey seal has been estimated as 5,500 Kcals (Sparling and Smout, 2003). The equivalent weight of prey depends on the fat content of the prey but equates approximately to 7 kg of cod or 4 kg of sandeels per day. The grey seal population associated with breeding colonies west of Scotland is estimated to consume approximately 80,000 tonnes of prey per year (SMRU unpublished data).

2.2.3 Foraging movements and distribution

Telemetry data from about 75 grey seals tagged in and around the SEA-7 area show much individual variability in their movement patterns west of Scotland, as has been found in other areas around Britain (McConnell, 1999; Matthiopoulos *et al.*, 2004). Some animals ranged widely and spent time in a variety of locations; others remained in one limited area for most of the time.

Figure 19 shows the modelled at-sea usage for grey seals off the west coast of Scotland and Ireland. Several areas of relatively high usage in the SEA-7 area are clear. The shelf waters west of the Outer Hebrides are extensively used by grey seals, and there are “hot spots” on Stanton Bank to the south of Barra, waters to the west of Islay and Jura, and waters east of Lewis. Because of limited data on numbers of seals around offshore islands, estimates of usage around St Kilda, the Flannan Isles, North Rona and Sula Sgeir may not be very accurate.

In summary, the shelf waters of the SEA-7 area are clearly very important as foraging habitat for the large numbers of grey seals hauling out in the Inner and Outer Hebrides.

2.3 Harbour seal

The harbour seal is the smaller of the two species of pinniped that breed in Britain. Adults typically weigh about 80-100 kg. Males are slightly bigger than females. As described in

Section 1, harbour seals are not as abundant as grey seals around Britain and are found in low numbers around Irish Sea coasts except in Northern Island. They have no significant natural predators in this area.

2.3.1 Diet composition

Harbour seal diet has been studied in Shetland (Brown and Pierce, 1998), the Moray Firth (Tollit and Thompson, 1996; Tollit *et al.*, 1997), and The Wash (Hall *et al.*, 1998). There are also unpublished results from the Firth of Tay (Sharples, 2005) but no information from the SEA-7 area. From these studies, harbour seal diet can be summarised as a wide variety of prey including sandeels, whitefish, flatfish, herring and sprat, octopus and squid. Diet varies seasonally and from region to region.

2.3.2 Prey consumption

There are no published estimates of prey consumption by harbour seals around Britain. Harbour seals probably require around 3-4 kg per day depending on the prey species. A very rough estimate of prey consumption by harbour seals in the SEA-7 area is about 25,000 tonnes per year.

2.3.3 Foraging movements and distribution

The movements of 24 harbour seals off the west coast of Scotland were tracked using SMRU SRDLs. Animals were tagged in Jura and Islay in September 2003 and April 2004, and in northwest Skye in September 2004 and March 2005. The smoothed tracks of these animals are shown in Figure 21.

Two geographical scales of movement were apparent. Most trips were short to within 25 km of the haul-out site, often (25-40% of the time) returning to the same site; thus a degree of site-fidelity and coastal foraging was apparent. However, some individuals made longer trips of over 100 km, indicating that animals from haul-out sites were not completely isolated. Longer distance movements in southwest Scotland showed some seasonality, occurring predominantly at the end of September and the end of March. Almost half of the trips lasted between 12 and 24 hours although some trips lasted several days, with the longest recorded trip lasting more than 9 days.

The waters of the Minch and the Hebridean Sea are clearly important foraging areas for the large numbers of harbour seals in the SEA-7 area. Studies are currently underway to provide information on the at-sea movements and distribution of seals from the Outer Hebrides.

2.4. Hooded seal

Hooded seals are large phocids that usually forage in deep offshore oceanic waters along and off the continental shelf. They are regularly sighted in the SEA-7 area but there is no current estimate of the size of the population using this area. Adult males may weigh up to 435 kg and grow to over 2.8 m in length. Females are smaller at a maximum of 350 kg in weight and 2.3 m in length. Females pup in loose aggregations on pack ice in March. The pups weigh around 15 kg at birth and are suckled for only 3-4 days (Bowen *et al.*, 1985), the shortest lactation period known for any mammal.

2.4.1 Diet composition

Hooded seals dive mostly to meso/bathypelagic waters, mainly to 100-600 m but with some very deep dives (>1000m) (Folkow and Blix ,1999). Greenland halibut, redfish, polar cod, herring, wolffish, squid and blue whiting are the main known prey of hooded seals (Folkow and Blix, 1995; Kapel, 2000; Potelov *et al.*, 2000).

2.4.2 Prey consumption

There are no published estimates of prey consumption by hooded seals and no estimate of population size in the SEA-7 area to calculate even crude estimates.

2.4.3 Foraging movements and distribution

Satellite tagged seals have made long range movements from Jan Mayen into waters around the Faeroe Islands, off Northern Ireland and into the Norwegian Sea (Folkow and Blix, 1995) and it is likely that hooded seals regularly forage in the SEA-7 area. Of fifteen seals tagged after the moult at around 71ºN, 12ºW (Folkow and Blix, 1995), eight spent some time in waters around the Faeroes Islands.

3. SENSITIVITY TO DISTURBANCE, CONTAMINATION AND DISEASE

3.1 Noise

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

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

A relatively new source of noise in many UK coastal waters is that associated with the construction and running of offshore wind farms, which will be mainly restricted to shallow waters. There are proposals to develop additional wind farms in the SEA-7 area. To date there is limited information on the noise generated during each of survey, construction and operation phases.

Acoustic deterrent devices (ADDS) are unusual in being an anthropogenic noise source which is specifically designed to be aversive to marine mammals and to exclude them from certain areas. ADDS are used extensively by aquaculture sites in inshore waters in SEA-7 where they are intended to exclude seals from the vicinity of salmon farms.

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 based on the ranges within which certain acoustic effects can be expected. They recognised four zones, three of which are generally thought of as occur at increasing sound level: the zone of audibility; zone of responsiveness; and the zone of hearing loss, discomfort or injury. The extent of a fourth zone, the zone of masking, depends on the characteristics of sounds that might be masked as well as that of the noise itself. If the detection of very faint sounds is considered then the zone of masking could be almost as great as the zone of audibility. Recent research that hints at the possibility that disruption of normal diving behaviour, which may be noise induced, could lead cetaceans to develop decompression sickness (e.g. Jepson *et al*., 2003; Fernandez *et al*., 2005) suggests that in some cases severe physical effects could be caused within the zone of responsiveness by sound at levels lower than those required for direct physical effects.

3.1.1.1 Zone of audibility

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

Both conditioned behavioural responses to sound playback and electrophysiological measurements have been used to measure hearing sensitivities for a number of marine mammal species (see Richardson *et al.*, 1995). Such research has been confined to pinnipeds and small odontocetes that can be maintained in captivity. The resulting audiograms are typically U shaped with sensitivities declining rapidly at high and low frequencies. Absolute sensitivity and hearing range varies markedly between marine mammal groups and also between individuals.
Information on the hearing sensitivity of those species likely to be encountered in the SEA-7 area is summarised below and an extensive review of available information on marine mammal audiograms has recently been collated by Nedwell, Edwards, Turnpenny and Gordon (2004).

3.1.1.1.1 Hearing sensitivity of pinnipeds

Underwater audiograms have been measured 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 1). No behavioural audiograms are available for the grey seal, 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 2). 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 and 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 3). Pinnipeds appear to be considerably less sensitive than humans to airborne sounds below 10 kHz.

Table 1. 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 2. Characteristic frequencies of vocalisations produced by grey seals.

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

Table 3. 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 with vocalisations of some species being largely 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-7 area are shown in Table 4. The high upper frequencies quoted here often represent outliers that may not be representative. Most baleen whale sounds are concentrated at frequencies less than 1 kHz, but sounds up to 8 kHz are not uncommon. The dominant call from fin whales is an infrasonic 20Hz pulse and in many oceans their calls are a prominent feature of ambient noise at these frequencies in certain times of the year.

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

Table 4. Characteristic frequencies of vocalisations produced by baleen whales (Richardson *et al*., 1995; Matthews *et al.*, 1999).

Species	Frequency range of tonal vocalisations (kHz) (mean minimum – mean maximum)
Minke whale *Balaenoptera acutorostrata*	0.06 – 0.14
Humpback whale *Megaptera novaeangliae*	0.25-4
Fin whale *Balaneoptera physalus*	0.015 – 0.043
Blue Whale *Balaenoptera musculus*	0.017 – 0.019

3.1.1.1.3 Hearing sensitivity of toothed whales

Behavioural audiograms have been reported for some odontocete species mainly the smaller toothed whales (dolphins and porpoises) (Table 5). These are most sensitive to sounds above about 10 kHz and below this sensitivity deteriorates. High frequency hearing is good; upper limits of sensitive hearing range from about 65 kHz to well above 100 kHz. This reflects the use by these species of high frequency sound pulses for echolocation and moderately high frequency calls for communication.

Frequencies at which the species in Table 5 had best sensitivity ranged from about 8 to 90 kHz and here their hearing is acute with the lowest underwater thresholds of any marine animals. Below the frequency range of optimum sensitivity, thresholds increase gradually with decreasing frequency.

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

Table 5. Hearing sensitivity of toothed whales from underwater audiograms

Species	Lowest Frequency tested (kHz)	Threshold (dB re 1 µPa)	Most sensitive Frequency kHz)	Threshold (dB re 1 µPa)	Upper Frequency (kHz)	Threshold (dB re 1 µPa)
Killer whale	1	105	20	34	100	75
Bottlenose dolphin	0.075	130	60	47	150	135
Risso's dolphin	1.6	124	8.0	63.7	110	123
Harbour porpoise	0.25	115	100	32	180	106

For those species occurring in the SEA-7 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 6.

Table 6. Characteristic frequencies of vocalisations produced by other toothed whales found in the SEA-7 area (Tonal data taken from Matthews (1999) click data from Rasmussen (2002), Hooker (2002) and Johnson (2004). NA = not applicable – tonal vocalisations not known; * data from Pacific white-sided dolphin *L obliquidens)*.

Species	Frequency range (mean minimum to mean maximum) for whistles (kHz)	Peak Frequency Clicks
Long-finned pilot whale	–3-6	No data
Globicephala macrorhynchus		
Sperm whale	na	10-20
Physeter macrocephalus		
Northern bottlenose whale	–na	24
Hyperodon ampulatus		
Cuvier's beaked whale	na	30-50
Ziphius cavirostris		
Bottlenose Dolphin	5-16	52
Tursiops truncatus		
Whitesided Dolphin	8-12	59*
Lagenorhynchus acutus		
White-beaked dolphin	9-12	120
Lagenorhynchus albirostris		
Common dolphin	6-12	
Harbour Porpoise	na	120

Small odontocetes have lower hearing thresholds at high frequencies than are phocid seals. At their best frequencies, odontocetes are around 20-30 dB re 1µPa more sensitive than are phocids. However, below about 2 kHz phocids become more sensitive than small odontocetes, eg. At 2kHz harbour porpoises and juvenile bottlenose dolphins have hearing thresholds of 50-70 dB re 1µPa, similar to measures 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 band.

3.1.1.2 Zone of responsiveness

This is defined as the region around a source within which a marine mammal shows an observable response (Richardson *et al*., 1995). Behavioural responses are always inherently variable. While the physical process of detecting or being damaged by a sound can be predicted reasonably reliably 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 of course by conditioning from 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.

One of the best known examples of noise inducing an acute and serious effect on marine mammals is the mortalities resulting when beaked whale strand in response to military sonar (see below). While the causal association between the use of mid-frequency sonar and these dramatic incidents is now accepted, the mechanisms that lead to these mortalities have yet to be established. Recent observations suggest that these animals may have developed decompression sickness (Jepson *et al.*, 2000; Fernandez *et al*., 2005) and that this may be induced when the diving behaviour of animals is altered in response to sonar signals. For example, animals disturbed by sonar may surface too quickly and/or remain too long at the surface. While, in the absence of direct observations during exposure to sonar signals, this mechanism remains hypothetical, the example does serve to emphasise that behavioural changes in response to acoustic signals can have acute and serious consequences.

Available information on behavioural and physiological responses of seals and cetaceans, to potential noise sources in the SEA-7 area are described below.

3.1.1.3 Zone of masking

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

Critical ratios, i.e. the ratio of sound level to background noise 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, environmental noise useful for orientation and navigation, and, for echo-locating species, 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

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

echolocation for example, the proportional decrease in effective range will be the most appropriate metric. For other acoustic tasks the decrease in effective sensory area or volume should be considered. Mohl (1981) modelled masking effects in such a framework. He found that proportional decrease in detection range was independent of the signal to noise ratio necessary for a particular task and that it was inversely related to the amount of background noise already in the environment. Even low levels of anthropogenic noise can significantly decrease the efficiency with which acoustic tasks can be performed, especially in regions that have low levels of "natural" background noise.

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

3.1.1.4 Zones of hearing loss and injury

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

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 uncontrolled study location, San Diego Bay, an environment with significant and variable ambient noise levels, masking noise was broadcast as a background during experiments. Hence "masked thresholds", not absolute thresholds were measured and it should be noted that shifts in masked thresholds are generally smaller than the non-masked TTS that would be induced by the same level of fatiguing noise. One second tones centred at 0.4, 3, 10, 20, and 75 kHz were used as fatiguing noises in this experiment. At 10 and 20kHz received levels of 192dB were required to cause a 6dB mTTS.

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

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

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

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

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

One example of noise induced damage highlights the problem of our lack of knowledge. Mass strandings of Cuviers's beaked whales linked to the use of powerful sonars had suggested that this species, and perhaps beaked whales generally are particularly vulnerable to being damaged by such sound sources (Frantzis *et al.,* 1997). Whales killed in recent well documented, standing events in the Bahamas and the Canaries exhibited physical damage to a variety of structures associated with hearing and/or adjacent to air spaces and symptoms consistent with decompression sickness (Balcomb, 2001; Evans and England, 2001; Jepson *et al.,* 2003; Fernandez *et al*., 2005). 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 of their apparent vulnerability to noise;
2. Other species may be equally vulnerable, and this group may be vulnerable to other intense noise sources;
3. The mechanism that led to the injury and damage in these animals still remains unknown.
4. Although, with hindsight mass strandings can be seen to hve been linked in time and space with sonar deployments, it has taken 40 years for the association to be recognised and 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 the 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, the range for injury is predicted to reduce to 500m. "Safe" distances for larger animals are expected to be shorter than for smaller ones (Richardson *et al*. 1995). Young (1991) estimated safe ranges for marine mammals of three different sizes and for human divers. However, the "safe" distances for humans are substantially greater than those for an equivalent sized marine mammal. Richardson *et al*. (1995) have suggested that a precautionary approach would involve applying the human value for all marine mammals. This would give a safe distance of 600m for a 1kg explosion, 900m for a 10kg explosion and 2km for a 100kg explosion.

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

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.

Other 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; Houser, Howard and Ridgway, 2001)

Crum and Mao (1996) modelled the process of bubble growth in sound fields and concluded that a few minutes of exposure to 190 dB re 1µPa in the frequency range of 250-1000 Hz, could induce bubble formation which might lead to occlusion of capillaries. Thus, exposure to intense sound could be the critical factor triggering the bends in human divers or marine mammals with super-saturated tissues.

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

3.1.2 Responses of marine mammals to different types of noise

Many offshore activities are noisy. Two that are of particular concern offshore in the SEA-7 area are offshore oil and gas exploration and production and the construction and operation of wind farms. These activities involve a number of distinct phases and different loud and potentially disturbing and or even damaging sounds are produced in each. Wind farm development is a relatively new activity and knowledge of noise production and marine mammal responses associated with offshore oil and gas are much better known. Inshore in this area aquaculture facilities routinely use Acoustic Deterrent Devices designed to deter seals from approaching fish farms.

3.1.2.1 Oil and Gas

Three phases in the life of an oil and gas field can be identified

- **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.

3.1.2.1.1 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 currently the commonest high-energy source used for seismic survey; by 1985 more than 97% of marine seismic surveys used airguns (Turnpenny and 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 and Nedwell, 1994; Barger and 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 several 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 pret. Their ability to cause hearing damage will of course also 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 levels directed vertical, 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 and Hamblen (1980) reported a bandwidth of 40Hz centred about 120 Hz. The peak spectral level (the SPL in 1Hz steps) occurred between 35 and 50 Hz, and decreased monotonically with increasing frequency; spectral level at 200Hz was 48dB down on the peak at 40Hz.

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

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

The reactions of some baleen whales (bowhead, grey, blue, fin, minke and humpback) to airgun noise have been studied in the field (summarised in Gordon *et al.* (2004) table 2). Clear behavioural responses, in terms of changes in surfacing patterns and movement away from the source when it was within 5 km of the whales, have been observed on a number of occasions (Malme *et al.,* 1983, 1984, 1988; Richardson *et al.,* 1995). Reactions have been most pronounced when the whales were to the side of the arrays long axis. McCauley *et al.* (1998) showed consistent avoidance of airguns by humpback whales during a series of careful observations made in Australia. They found that mothers and calves were more vulnerable to disturbance than single animals. Fin and blue whales continued to call in presence of airgun noise (McDonald *et al.,* 1993). But McDonald also showed apparent avoidance by fin or blue whale. In UK waters, minke whales were sighted significantly further away from seismic vessels during periods of seismic array activity, suggesting active avoidance (Stone 1997, 1998).

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

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

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

4D or time lapse seismic is rapidly becoming an accepted tool for reservoir management (Bouska *et al.*, 2000; Koster *et al.*, 2000). Data from sequential seismic surveys are compared, and differences between these "time lapse" datasets can be interpreted in terms of changes in the reservoir due to extraction activity. 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.

3.1.2.1.2 Vessel noise

There is substantial medium sized commercial and military shipping activity in this area.. Noise from shipping is roughly related to vessel size; larger ships have larger, slower rotating propellers, which produce louder, lower frequency sounds. Various models for predicting shipping noise on the basis of speed and hull length have been developed and are summarised and compared in a review by Heitmeyer *et al.* (2004). Broadband source levels of ships between 55 and 85m are around 170-180 dB re 1 µPa@1m (Richardson *et al*., 1995), with most energy below 1 kHz. Use of bow thrusters increases broadband sound levels, in one case by 11 dB and includes higher frequency tonal components up to 1 kHz (Richardson *et al*., 1995).

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

3.1.2.1.3 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). However, many different process are involved in drilling oil wells and the noise emissions associated with each of these have been poorly classified and characterised. There may also be substantial differences related to the water depth, and whether the drill platform is floating or jacked up above water.

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

There is no clear evidence of avoidance behaviour by small odontocetes to drilling noise. Bottlenose, Risso's and common dolphins were seen close to oil platforms in the North West

Atlantic, and sightings rates were similar in areas with and without rigs (Sorensen *et al.*, 1984).

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

Construction activities associated with establishing new platforms and pipelines will also generate noise. The loudest sounds are likely to be impulsive hammering sounds, associated with pile driving and pipe installation. Source levels can be high, levels of 131-135 dB re 1 μPa. were measured 1km from a hammer used for pipe installation on an artificial island (Richardson *et al.*, 1995) and much higher levels have been reported recently during the construction of wind farms, see later. . 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.

<u>3.1.2.1.4 Decommissioning</u>

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, tissue damage, or death 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, unpublished data).

Mitigation procedures dependent on real time detection are even less appropriate for seals. Even in good sightings conditions seals are rarely seen at the surface and seals are rarely vocal. 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.

3.1.2.2 Wind farms

Somewhat similar phases can be identified in the operational life of a wind farm.

- **Site Survey** (Seismic Survey, sidescan sonar),
- **Construction** (vessel traffic, pile driving in many cases, dredging)
- **Operations** (Turbine noise)
- **Decommissioning** (Possible Explosive removals)

Nedwell and Howell (2004) review likely noise sources at windfarms during these different phases. Geophysical site survey work would probably involve boomers and sparkers. These are less powerful than the seismic arrays used during oil and gas exploration but there is little information on their source levels or other acoustic characteristics.

The construction phase will often involve pile driving of monopiles and dredging activity. Pulses produced during pile driving of the large pylons used to support wind turbines can be very intense. Nedwell *et al*. (2005) extrapolated a source level of 272 dB re 1µPa @ 1m (p-p) level based on recordings made during the driving of a 4.4 m diameter wind farm pylon. According to their models, higher levels of 290 dB re 1µPa @ 1m (p-p) should be expected for a larger 6.3m , diameter pile planned for larger offshore installations. Suction and hopper dredgers have shown levels of up to 177 dB re 1 µPa in the range 80-200Hz.

Harbour porpoises showed equivocal responses to construction activity at two sites in the Danish North Sea. At Horn's Reef, encounter rates increased whereas at Nysted they decreased by a factor of 8 indicating almost complete avoidance of the area during construction (Henriksen *et al.*, 2004; Tougaard *et al.*, 2004). Porpoise density from sightings was not significantly different between the year before and after construction work at Horn's Reef. There is little information on the responses of seals to such construction activity although a small sample of satellite tracked harbour seals continued to transit across Horn's Reef during construction work (Tougaard *et al*., 2003).

Both harbour seals and harbour porpoises showed behavioural responses to playback of underwater noise from a simulated 2MW wind turbine (Koschinski *et al.*, 2003). Porpoises did not approach as close and vocalised more when the source was on, although the behavioural responses were less dramatic than those seen in response to net pingers. Harbour seals also appeared to move away from the source, although the increase in median closest approach distance was small, 120m to 180m.

3.1.2.3 Acoustic Deterrent Devices at Aquaculture Sites

The inshore waters of SEA-7 contain the majority of the UK's aquaculture facilities, most of which, salmon farms. This is also the natural habitat of many predators of salmon and depredation by predators has been a problem for the industry since its inception. Seals can be particular destructive and one technique for deterring them is the deployment of powerful underwater sound producers termed acoustic deterrent devices (ADDs). Several different makes of ADDs are used at UK Aquaculture facilities and each has a different sound signature. Some are active continuously; others are triggered by cues thought to be indicative of a seal attack. Manufacturers are not required to measure or report the output levels and spectra of their devices. However, Lepper *et al.* (2004) measured source levels and spectra for three ADDs used at aquaculture sites in this area and reported source levels of 192, 193 and 179 dB re 1µPa @ 1m for different models. Peak frequencies for these devices were between 10 and 20kHz but there was also significant sound energy produced outside this range. These very high source levels at frequencies to which marine mammals are particularly sensitive, have led to concerns about the effects of these devices on other marine life. Gordon and Northridge (2003) reviewed the potential for effects of ADDS on wildlife with a particular emphasis on the situation in Scotland. No experimental work has been done to explore whether ADDs could damage the hearing of marine mammals but Gordon and Northridge could not exclude this as a possibility, especially for seals that might be highly motivated to approach salmon farms to feed. Ironically, while there are no published papers that show the efficacy of the ADDs used commercially in reducing seal predation at salmon farms, there are several well documented cases of ADDs excluding, or severely reducing the densities of, cetaceans. For example, during a well controlled experiment, Olesiuk *et al.* (2002) showed that porpoise were completely excluded from within 400m of an ADD and levels were reduced to less than 10% of control levels at ranges between 2.5 and 3.5 km (the maximum range observed). Johnston (2002) obtained similar results from detailed theodolite tracking of individual porpoise. Morton and Symonds (2002) reported that sightings of identified killer whales pods fell by a factor of three in the Broughton Archipelago after ADDs were introduced and remained low for the six years that the devices were used there. Whale encounter levels returned to pre-exposure levels once the devices were removed. This example is remarkable not just for the substantial area of apparently important habitat affected but also for the apparent lack of habituation over a six year time period.

3.1.3 Research Requirements

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

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

Addressing these knowledge gaps will require a substantial research program. Partnerships amongst noise producers (e.g. industry, renewables, shipping, military) should be established.

While this may seem a daunting scientific task, it is, in reality, trivial compared to the engineering challenges that offshore engineers face and overcome 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 their prey 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), the butyl tins and most recently the perfluorinated chemicals.

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 differentially accumulate 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.
- animals are exposed to complex mixtures of compounds that may have additive or synergistic effects on various target organs and systems.

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 lipid store 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 also means that females can offload a large proportion of their contaminant burdens to their offspring (Debier *et al.*, 2003). Other POPs may behave slightly differently and recent studies have shown the PBDEs to be at high concentrations in the adrenal glands as well as the fat stores (Klasson Wehler *et al.*, 2001). These compounds, particularly the tetra and penta group, are now found in the blubber of seals and cetaceans from UK waters (Allchin *et al.*, 1999) and in studies on juvenile grey seals, larga and ribbon seals are associated with thyroid hormone disruption (Hall, *et al.*, 2003; Chiba *et al.*, 2001).

Many factors can affect the occurrence and distribution of POPs in marine mammals. These include diet, foraging strategy, age, species, sex, 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. However, there is currently concern over the impact of the polybrominated compounds (largely PBDEs which are used as flame retardants). The deca-product mixture is still in use, whilst the penta and octa- mixtures containing the lower brominated compounds (the congeners that have been found in birds, seabirds and marine mammals, De Wit, 2002) have been banned in Europe. In the US the penta and deca-mixtures are both still legally used in many industries.

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^{++}. Metallothioneins have a high affinity for binding such cations, and they sequester the metals to form biochemical complexities with reduced toxicities. In addition mercury forms complexes with selenium, producing insoluble tiemannite granules (Nigro *et al.,* 2002). This is an important mechanism, complementary to excretion, and enables many species to cope with a relatively high dietary exposure to mercury (Dietz *et al.,* 1996). High levels of liver cadmium have been reported in a number of cetacean species and this probably also 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 the biomagnification of PAHs is low, because fish (the main food of marine mammals) are good metabolisers of PAHs compared with molluscs and other invertebrates. Bioaccumulation or exposure to these compounds will be lower in fish-eating marine mammals than those that feed on cephalopods or small crustaceans and plankton (such as the mysticete whales). 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 into 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 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; Miller *et al.,* 2005; Tilley *et al.,* 2002).

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

These groups of compounds were identified in liver samples of marine mammals, following knowledge about their toxicity and endocrine disrupting effects in invertebrates and fish (Iwata *et al.* 1994). Results of analysis in liver samples from stranded animals have indicated a widespread contamination around the coasts of England and Wales; indeed TBT and DBT have been found in open ocean cetacean species, which indicates a wider contamination of the sea by these compounds (Law *et al.,* 1999). However, recent data on temporal trends of DBT, TBT and MBT in harbour porpoises from Norwegian waters (Berge *et al.*, 2004) have found a decrease in tissue concentrations following the restrictions on the use of TBT on small boats in the late 1980s. Nakata *et al.* (2002) found that TBT and its metabolites caused suppression of immune function (as measured by the proliferation of T lymphocytes) in blood samples collected from Dall's porpoises, bottlenose dolphins, a California sea lion, a largha seal and humans at levels of around 90 ng/ml for TBT and DBT. When cells were exposed to a mixture of TBTs and PCB congeners the proliferative responses were suppressed even further, suggesting possible synergistic effects between these compounds.

3.2.1.5 Perfluorinated organochemicals

Perfluorinated organic compounds are widely used in the manufacture of plastics, electronics, textile and construction material in the garment, leather and upholstery industries. Recent studies have also found perfluorinated organochemicals (FOCs) in the tissues of marine mammals. Van de Vijver *et al.* (2003) measured the presence of FOCs in marine mammals, indicating a potential biomagnification of these compounds and their widespread occurrence. Liver, kidney and spleen appear to be the major target organs (Van de Vijver *et al.*, 2005). Among all the measured FOC compounds, PFOS (perfluorooctane sulfonate) was predominant in terms of concentration. The highest PFOS concentrations were found in the liver of harbour seal compared to white-beaked dolphin, harbour porpoise, grey seal, sperm whale, white-sided dolphin, striped dolphin, fin whale, and hooded seal. Harbour and grey seals and white-beaked dolphin, which displayed the highest trophic position, contained the highest PFOS levels, while offshore feeders such as sperm whales, fin whales, striped dolphin, and white-sided dolphin showed lower PFOS concentrations (Van de Vijver *et al.*, 2005)

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) issued a bibliography containing over 1,200 references and many more have been published in the last 6 years. However, there are many good reviews on the levels of contaminants found, the patterns of different compound groups in various species and the temporal changes in concentrations. The most comprehensive are: Aguilar and Borrell (1997), Geraci and St. Aubin (1990), Hall (2001), Law (1996), O'Shea (1999), Reijnders, Aguilar and Donovan (1999).

3.2.3 Knowledge

Although our knowledge of the effects of contaminants on marine mammals remains limited, largely due to the difficulties involved in investigating the responses in wild animals, it has increased considerably in recent years. It has been relatively straightforward to determine the tissue concentrations of various compounds in dead and live-captured animals, but the significance of these concentrations for the health and ultimate survival of the individuals has been more difficult to assess. Some studies have investigated the responses to exposure on animals in captivity, comparing responses between exposed and control groups and associations between dysfunction and contaminant exposure have been reported in free-living individuals and populations. These studies are increasing whereas those merely reporting levels in tissues are declining. Thus the body of information on correlations among toxic endpoints and contaminant exposure measures continues to increase and is now being supplemented with data from *in vitro* studies using cellular and molecular methods (De Guise *et al.*, 1998; Hammond, *et al.*, 2005a; Levin *et al.*, 2005; Mori *et al.*, 2006).

3.2.3.1 Persistent organic pollutants

Two observations on wild populations in the 1980s 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 females 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 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). 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) and in the 1987-88 bottlenose dolphin morbillivirus outbreak in the US (Kuehl *et al.*, 1991). Furthermore similar results were obtained in live and dead harbour seals following the 2002 European PDV epidemic (Hall and Thomas, 2005). Studies by Ross *et al.* (1995) and DeSwart *et al.* (1994) found evidence for the mechanism of the effect. They reported 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. More recently Hammond *et al.* (2005a) found that harbour seal immune function assays carried out *in vitro* were impaired when exposed to a commercial mixture of PCBs whereas grey seal (*Halichoerus grypus*) immunity was not affected.

The PBDEs (flame retardants) are being reported as potential endocrine disrupting compounds. Although the production and use of the lower brominated compounds has been controlled in Europe, the oil industry continues to use BDE209 and the penta-mixtures (commercial formulations with lower brominated compounds) are still used in North America. Hall *et al.*, (2003) found a correlation between PBDEs and thyroid hormone levels in grey seals during their first year of life and in adult harbour seals (Hall and Thomas, 2005) but it is still unclear whether this relationship is causal.

In 2003 SMRU studied various harbour seal populations around the UK following the 2002 phocine distemper virus outbreak. Samples collected included blubber biopsies for contaminant analyses (funded by DEFRA's Endocrine Disrupters in the Aquatic Environment programme, Hall and Thomas, 2005). Harbour seals hauling out on Islay and Jura in the Western Isles were included and concentrations of PCBs (total of 45 congeners - PCBs 18, 22, 28, 31, 41/64, 44, 49, 52, 54, 60/56, 70, 74, 87, 90/101, 95, 99, 104, 105, 110, 114, 118, 123, 138, 141, 149, 151, 153, 155, 156, 157, 158, 167, 170, 174, 180, 183, 187, 188, 189, 194, 199 and 203), organochlorine pesticides (α-chlordane, γ-chlordane, α-HCH, β-HCH, γ-HCH HCB, o,p'-DDD, p,p'-DDD, o,p'-DDE, p,p'-DDE, o,p'-DDT and p,p'-DDT,) and PBDEs (total of 21 congeners 17, 28, 32, 35, 37, 47, 49, 71, 75, 77, 85, 99, 100, 119, 138, 153, 154, 166, 181, 183 and 190) were measured. Five adult males and five adult females were sampled at four of the haulout sites (Islay and Jura, Orkney, Moray Firth and Abertay) and three adult males and 14 adult females were sample in the Wash on the east coast of England.

The results are shown in Figure 22 (geometric mean blubber concentrations, error bars=1 geometric s.e. *Note:* the difference in the scales of the y axis between the graphs of the different groups of compounds). The animals from Islay and Jura had the highest PCB concentrations, particularly in the males but the PBDE concentrations were highest in the seals from the Wash. In addition the blubber concentrations were positively correlated with thyroid hormone levels in the blood (after controlling for differences among sites, sex and body condition, Hall and Thomas, 2005), a finding also reported in laboratory animal studies (Wade *et al.*, 2002).

Bergman and Olsson (1985) also reported the occurrence of adrenocortical hyperplasia, hyperkeratosis and other lesions in grey 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 the highest exposures 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 studies by Jepson *et al.* (1999, 2005) and Hall *et al*. (in press) indicated that the risk of mortality from infectious disease in harbour porpoises (*Phocoena phocoena*) that stranded around the coast of England and Wales increased with high exposure to PCBs (50% increase in relative risk at concentrations total PCBs >25mg/kg lipid in the blubber). In addition, stranded harbour porpoises from the German, North and Baltic seas were more severely diseased than by-caught animals and thymic atrophy and splenic depletion were significantly correlated to increased PCB and PBDE levels (Beineke *et al.*, 2005). Various immune function endpoints measured *in vitro* in cetaceans (bottlenose dolphins Lahvis *et al*., 1995; beluga whales De Guise *et al.*, 1998) and in wild polar bears (Lie *et al*., 2005) following PCB exposure further suggest that these compounds are also immunsuppressive to small cetaceans and bears.

3.2.3.2 Heavy metals

Of the toxic elements studied those of most importance are cadmium, lead, zinc 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 in 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).

Pillet *et al.* (2000) found that zinc exposure affected the phagocytic response of seal white cells *in vitro* and that this response differed between the sexes and Kakuschke *et al.* (2005) reported that a small number of harbour seals appeared to be hypersensitised to a number of heavy metals. Whilst there are few studies that show major impacts of heavy metals, it's possible that they may have combined effects as they often co-occur with the persistent organic contaminants.

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. In addition Neale *et al.* (2002) assessed the effects of the prototypic polycyclic aromatic hydrocarbon (PAH), benzo[a]pyrene (B[a]P), and two polychlorinated biphenyls (PCBs), CB-156 and CB-80, on the T-cell proliferative response to mitogen in harbor seal peripheral lymphocytes. They found a suppressive effect of B[a]P (10 uM) exposure on T cell mitogenesis. Exposures to 10 uM CB-156 and CB-80, and 1.0 and 0.1 uM B[a]P, did not produce significant depression in lymphocyte proliferation. Exposure to the model PAH at 10 uM resulted in a 61% (range 34-97%) average reduction in lymphocyte proliferation and they hypothesize that extensive exposure of PAHs by some marine mammals affects their cell-mediated immunity against viral pathogens.

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

In 1993 the *Braer* oil tanker ran aground in Shetland. Observational studies on exposed animals indicated that grey seals hauled out in the area of the spill had increased respiratory symptoms compared to control animals (Hall *et al.*, 1996). However, it was not possible to determine if this link was only correlational.

Following the *Braer* spill, the risk of oil spills in the Minch were a subject of much debate and although tankers are encouraged to use the Deep Water Route west of the Western Isles, there is still traffic in the Minch. Thus marine mammals between the Inner and Outer Hebrides and on the west coast of the outer Hebrides, including those using the major grey seal breeding colonies of the Monach Isles and North Rona and cetaceans which inhabit waters up to the continental shelf edge, remain at risk following accidental exposure.

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 when 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 *et al.*, 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, their aromatic content (i.e. oil based dispersants), the functional group(s) and molecular structure of the surfactants, their chemical stability, and 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 long-term 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 still 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).

Information on the uptake and effect of polybrominated diphenyl ethers (the brominated flame retardants) on marine mammals is accruing, for a variety of invertebrates and fish as well as marine mammals, since higher levels were found in the UK than elsewhere in Europe (Zegers *et al*., 2001). Congener BDE209 is still used by the oil industry in the deca-mixture and it was found to be accumulated by grey seal pups from their prey in an experimental study (Thomas *et al.*, 2005). However, this congener has not been found in marine biota to any great degree. However, there is concern that this fully brominated compound (containing 10 bromine atoms) can be degraded to form lower brominated compounds that are potentially toxic to marine mammals. Further research into the nature of the relationship between PBDE levels and thyroid hormones in seals is needed.

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. Most recently Hall *et al*. (in press) developed an individual based model framework, using the impact of PCBs on bottlenose dolphins as an example of how to assess the effect of such compounds on population dynamics. This study (and that of Schwacke *et al.* (2002)) illustrate the need for reliable dose-response data for these and other species of marine mammal.

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 and bacterial 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 occurred in harbour and grey seals (PDV) in 1988 and again in 2002 and morbillivirus (DMV) occurred in Mediterranean striped dolphins in 1990 and US bottlenose dolphins in 1987 (Dietz *et al.*, 1989; Jensen *et al.*, 2002; Aguilar and Raga 1993; Lipscomb *et al.*, 1994). This led to a number of studies into the epidemiology of morbilliviruses; for example investigations into the grey seals which is not susceptible to the disease as potential immune carriers that could account for the spread of the virus (Hammond *et al.*, 2005b). These outbreaks were followed by other mass mortalities in the late 1990s, such as among Mediterranean monk seals, whose cause was disputed and although some evidence pointed to

PDV as a cause (Osterhaus *et al.,* 1997; Harwood, 1998; Hernandez *et al.,* 1998) it seems more likely that this outbreak was due to algal toxin exposure.

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

3.3.2 Sources of data

A number of reviews of infectious diseases in marine mammals have been published and the major sources are given below: Dierauf and Gulland (2001); Van Bressem, Van Waerebeek and Raga. (1999); Harwood and Hall (1990); Visser, Teppema and Osterhaus (1991). Gulland and Hall (2005) recently reviewed the literature on diseases in marine mammals detailing how they have been investigated over time. This work resulted in a database of over 600 references which is available at the Sea Mammal Research Unit website (http://www.smub.st-and.ac.uk)

3.3.3 Knowledge

3.3.3.1 Viruses

Table 7 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* isolations 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 potentially 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 still not known how these two isolates are related or if they are indeed the same organism. This bacteria does appear to be quite widespread worldwide (Maratea *et al.*, 2003)

Leptospira pomona has also been found in some marine mammals but has not been reported in those from UK waters. However recent preliminary research has found the occurrence of a different serotype in UK seals but it is not clear yet if this is a novel serotype (SMRU and Institute of Zoology, unpublished data). Leptospires can be highly pathogenic and have been associated with episodic outbreaks among California sea lions in which it causes abortion (Buck and Spotte, 1986; Colegrove, *et al*., 2005; Gulland *et al.*, 1996).

Tuberculosis (*Mycobacterium tuberculosis*) has been diagnosed in various fur seal and sea lion species, (Cousins *et al.,* 1990; Forshaw and Phelps, 1991; Bastida, 1999). Cousins *et al.* (2003) compared isolates from seals (pinnipeds) in Australia, Argentina, Uruguay, Great Britain and New Zealand to determine their relationships to each other. The seal isolates could be distinguished from other members of the M. tuberculosis complex on the basis of host preference and phenotypic and genetic tests. Pinnipeds appear to be the natural host for this 'seal bacillus', although the organism is also pathogenic in guinea pigs, rabbits, humans and possibly cattle. Cases of disseminated disease have been found. As with other members of the M. tuberculosis complex, aerosols are the most likely route of transmission. The name *Mycobacterium pinnipedii* sp. nov. has been proposed for this novel member of the M. tuberculosis complex.

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 on the west coast of Africa, where toxins produced by algae have been associated with mortalities of marine mammals. Indeed such blooms appear to be regular and repeating events, causing mass mortalities of dolphins, sea lions and manatees (Hallegraeff, 1993; Flewelling *et al*., 2005). Unusual mortality events include dinoflagellate toxins in Florida manatees and Humpback whales (Geraci *et al.* 1989; O'Shea *et al.,* 1991), brevetoxins in Bottlenose dolphins (Geraci, 1989; Flewelling *et al*., 2005), saxitoxin in sea otters (DeGange and Vacca, 1989), and ciguatoxin in Hawaiian monk seals (Gilmartin *et al.,* 1987). Mass mortalites among California sea lions, linked to *Pseudo-nitzschia australis* that produces domoic acid, a neurotxin found in fish and in the body fluids of the sea lions that died (Scholin *et al.,* 2000) are also now a more regular occurrence.

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 and the 2002 PDV outbreak, we know surprising little about the occurrence and impact of other infections in European seal populations. Stranding schemes designed to determine mortality rates and the causes of death of marine mammals around the UK have been forced by limited funding to concentrate their efforts on cetaceans rather than seals. Serological surveys could provide invaluable data on the exposure and immunity of populations to various diseases and this approach was proved useful in estimating the size of the susceptible harbour seal population in the UK before the recent outbreak of PDV in Europe (Thompson *et al.,* 2002).

A small-scale survey of anthropogenic bacteria such as *Salmonella* has been conducted in seals but we have no information on the occurrence of anthropogenic viruses such as enteroviruses. Indeed some pilot work suggested that other sewage related organisms such as *Campylobacter* may be a risk for marine mammal health but this study has not been followed up. Recent pilot studies have found UK seals to have been widely exposed to leptospirosis and toxoplasmosis (SMRU, unpublished) therefore this type of baseline surveillance needs to be expanded.

4. BYCATCH AND OTHER NON-OIL MANAGEMENT ISSUES

4.1 Bycatch

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

The SEA-7 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. However, compared with some other areas around the UK, the levels of fishing effort by gear types that are generally considered dangerous to marine mammals (pelagic trawls and gillnets) are low. The SMRU has monitored gill and tangle net fisheries in the Hebrides in the late 1990s and concluded that only a few tens of porpoises are likely to become bycatch per year, mainly due to the low levels of fishing activity (Northridge and Hammond, 1999). Pelagic trawls operate in much of this area, and a fairly high level of sampling of these fisheries (for herring, blue whiting, sprats, mackerel) has not yet recorded a single cetacean bycatch. There have been a few records of minke whales becoming ensnared in mooring lines, possibly those from lobster pot fisheries, in this region, but no systematic study or estimates of this interaction have been made.

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 in 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, one in the Moray Firth, Scotland and two in Cardigan Bay, Wales. 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 nine European countries including the UK are now Parties to the Agreement. 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 are revised regularly. Member 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-7 area is an important area for marine mammals. The waters of the Minch and Hebridean Sea and shelf waters west of the Outer Hebrides are very important foraging habitat for the large populations of grey and harbour seals in this area. Sperm whales and long-finned pilot whales are abundant throughout the deep waters west of the shelf edge. Bottlenose dolphins, white-beaked, and Atlantic white-sided dolphins are found both in the Hebrides and in shelf waters to the west of the Outer Hebrides. Harbour porpoises are abundant in the Hebrides year round, rarely found in deep waters, killer whales are also less frequent year round visitors to the area. Common dolphins are found throughout the area during the summer months though concentrated in the southern part. Minke whales and Risso's dolphins are also summer visitors to the Hebrides, though they, and harbour porpoises are also found in smaller numbers offshore.
- Marine mammals are important predators in this region. Because of the link between the abundance and availability of fish prey and the reproductive success 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 of seals and large whales in the SEA-7 area. Current mitigation methods are probably effective in preventing physical damage.
- There are no reliable data to suggest that vessel noise or drilling noise adversely affect seals or small cetaceans. Large whales may avoid areas of concentrated activity in the SEA-7 area.
- 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-7 area, but the fact that gillnet fisheries play a relatively small role in overall fishing activity in this area means that bycatches are likely lower than in many other areas around Britain.

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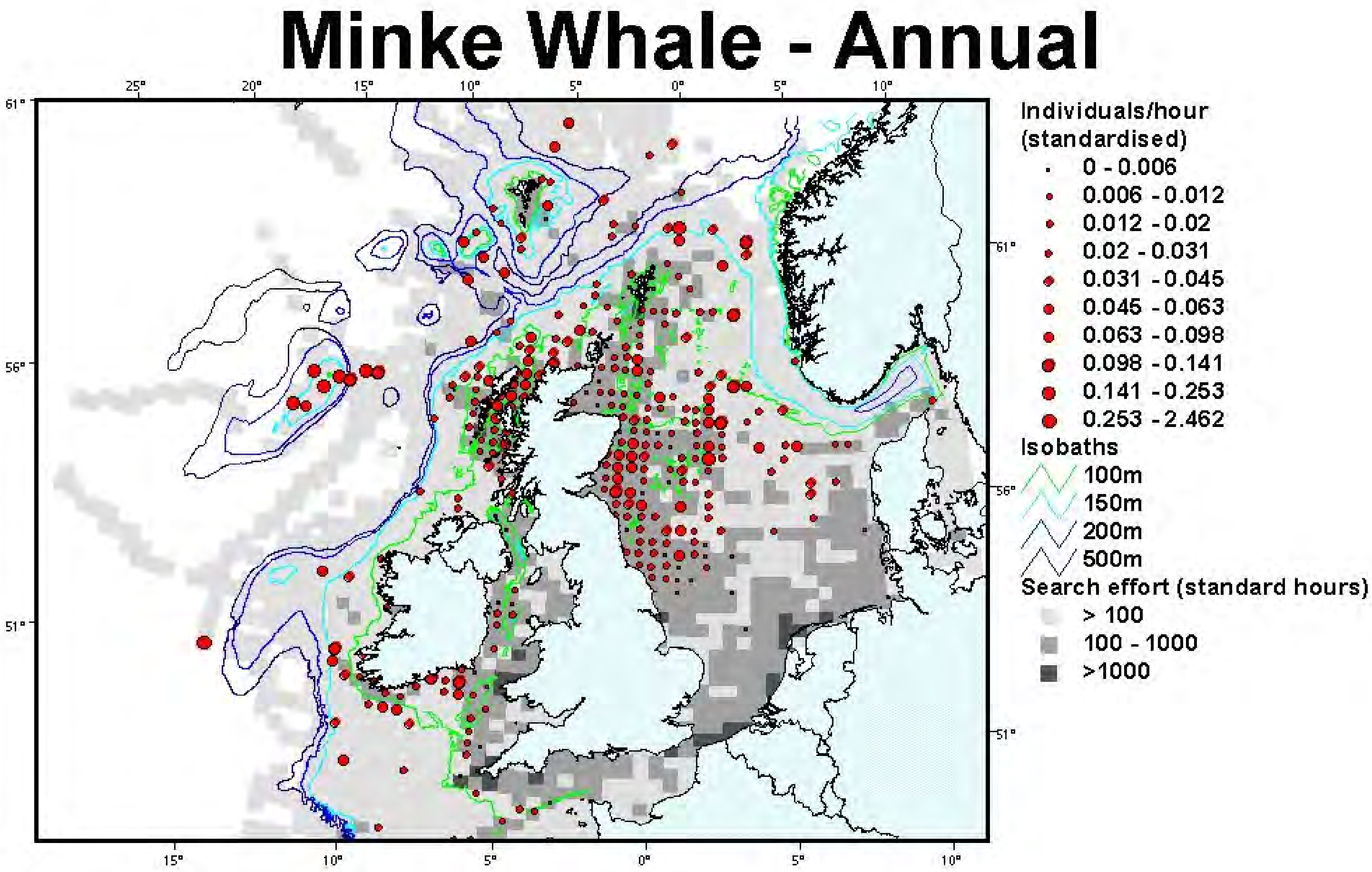

Figure 1: Sightings rates of minke whales around the UK (adapted from Reid *et al.*, 2001)

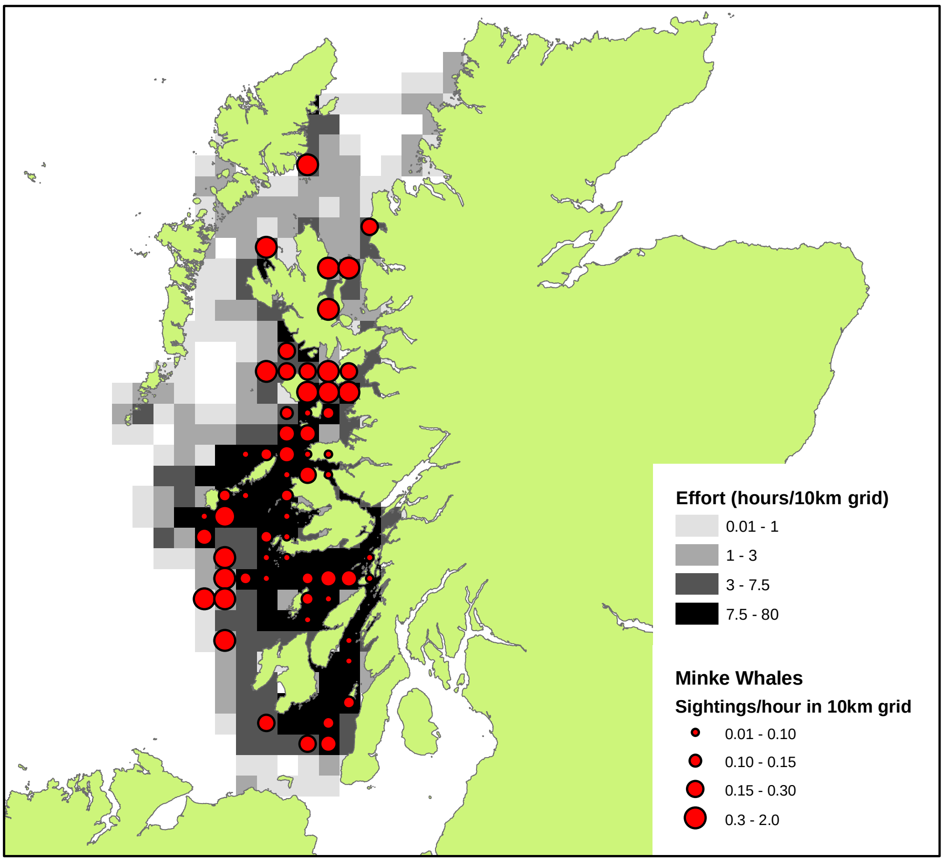

Figure 2: Distribution of sightings effort and minke whale sightings in the Inner Hebrides from April-September 2003-2005 from the HWDT motor-sailor, *Silurian*

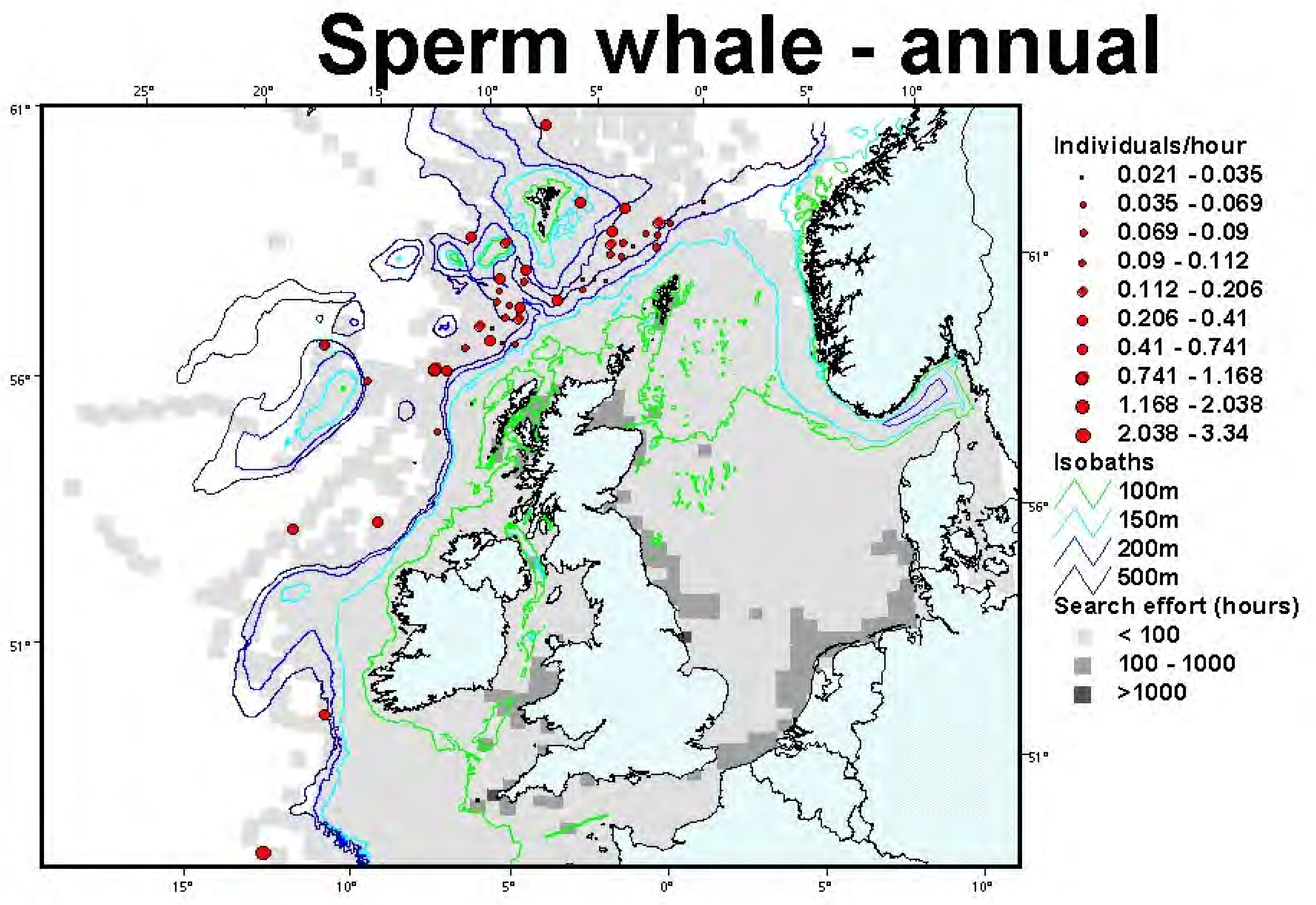

Figure 3: Sightings rates of sperm whales around the UK (adapted from Reid *et al.*, 2001)

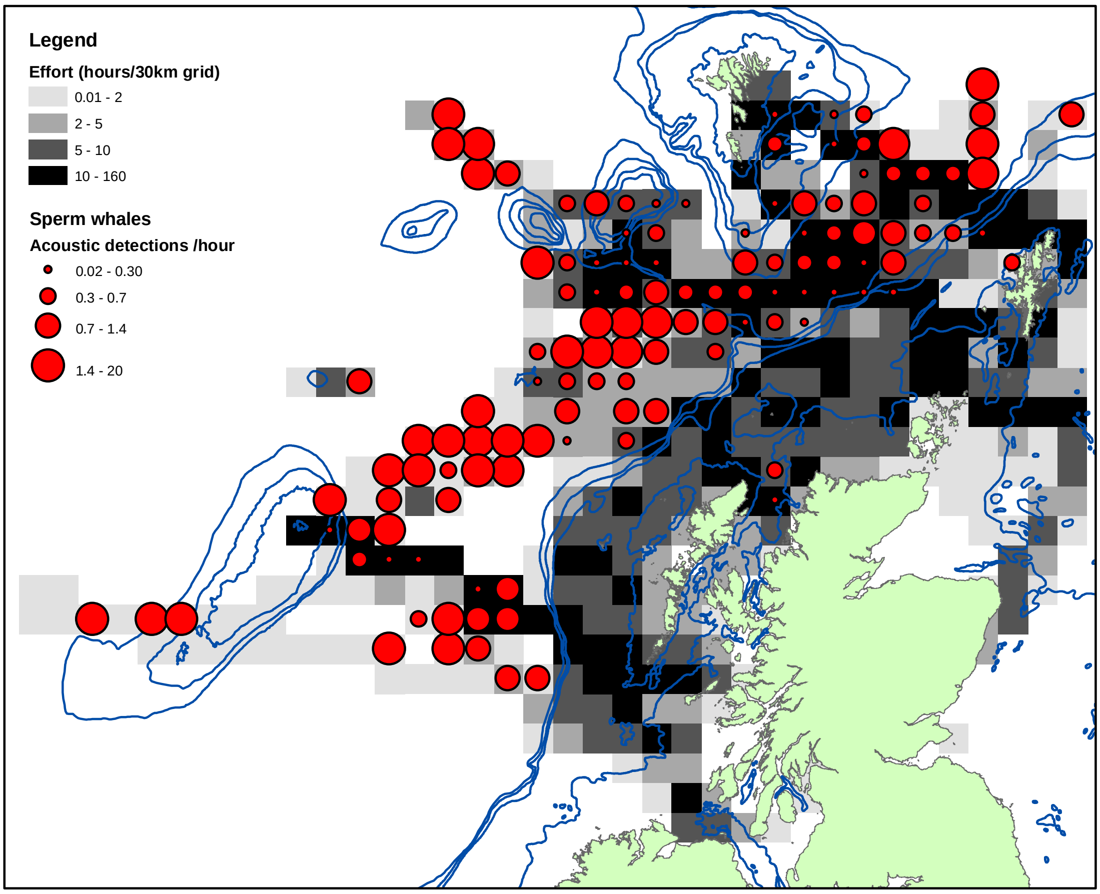

Figure 4: Distribution of passive acoustic survey effort and sperm whale acoustic detections off the west coast of Scotland from platforms of opportunity 2000-2005.

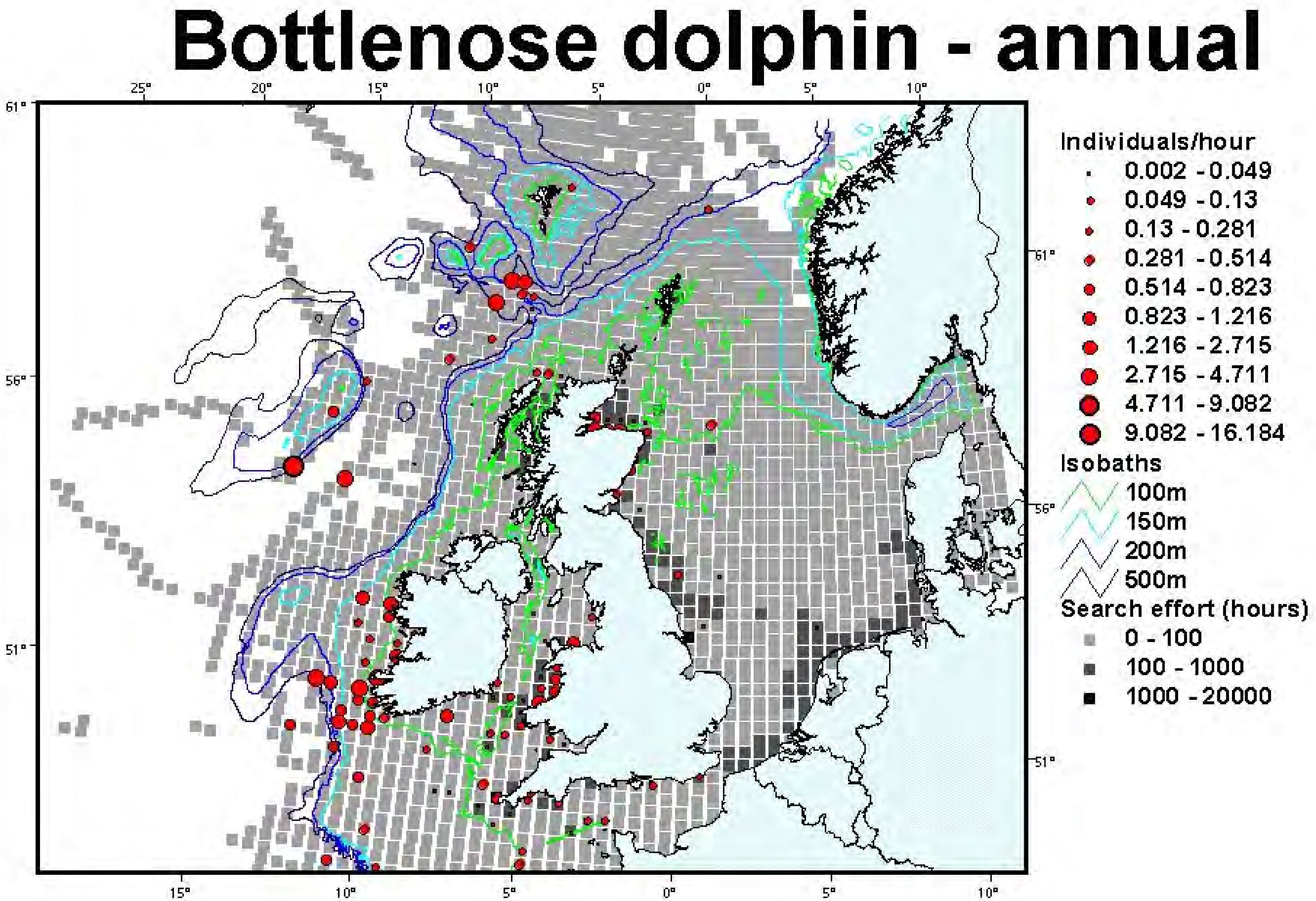

Figure 5: Sightings rates of bottlenose dolphins around the UK (adapted from Reid *et al.*, 2001)

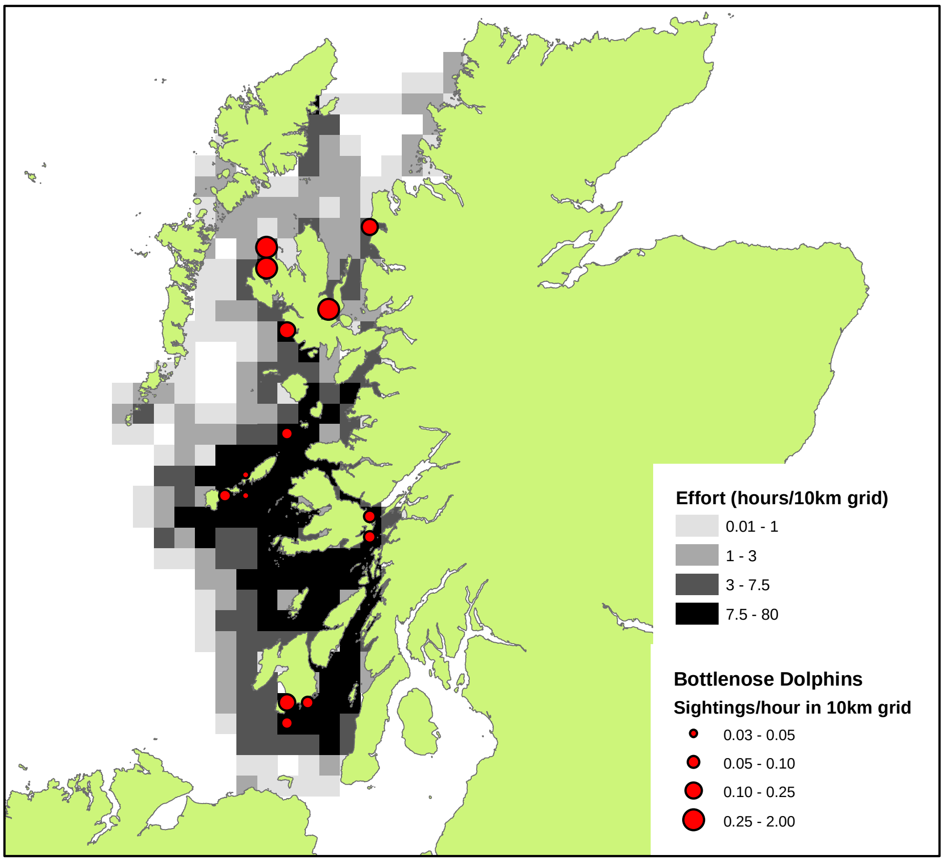

Figure 6: Distribution of sightings effort and bottlenose dolphin sightings in the Inner Hebrides from April-September 2003-2005 from the HWDT motor-sailor, *Silurian*

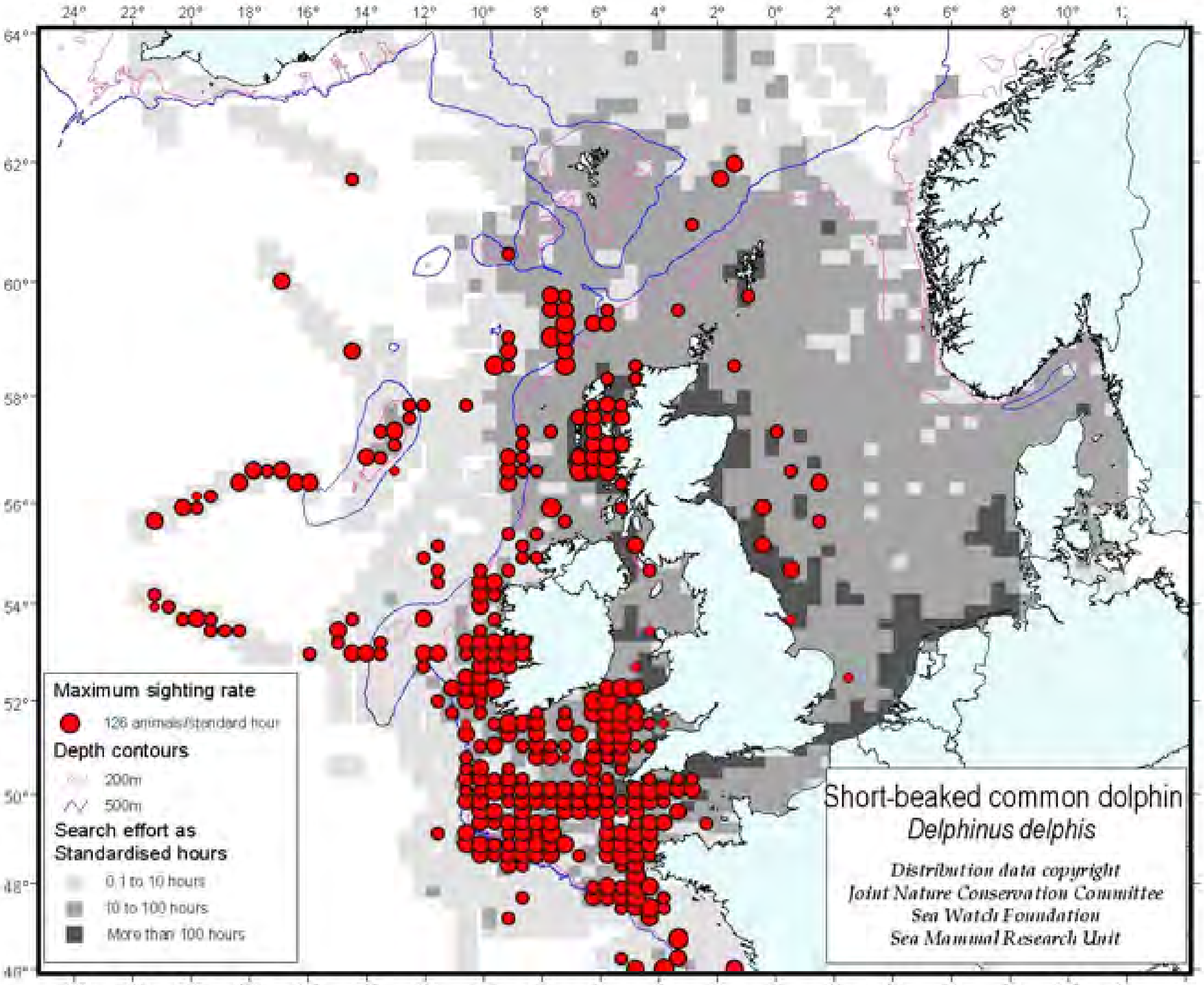

Figure 7: Sightings rates of common dolphins around the UK (adapted from Reid *et al.*, 2001)

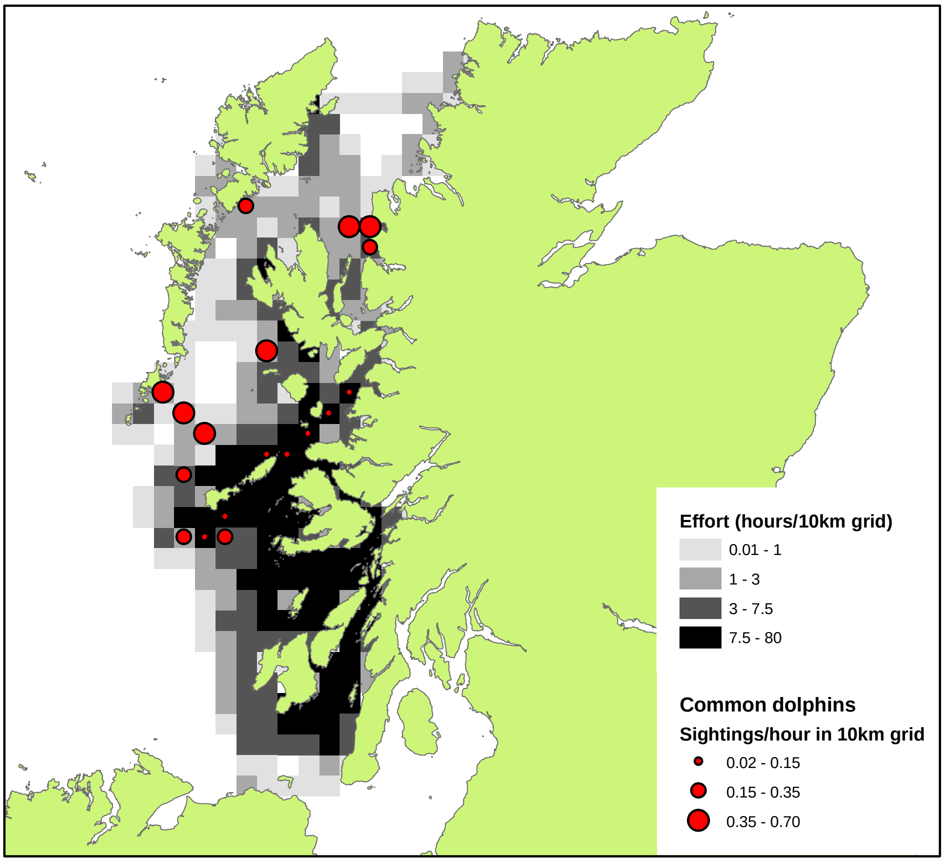

Figure 8: Distribution of sightings effort and common dolphin sightings in the Inner Hebrides from April-September 2003-2005 from the HWDT motor-sailor, *Silurian*

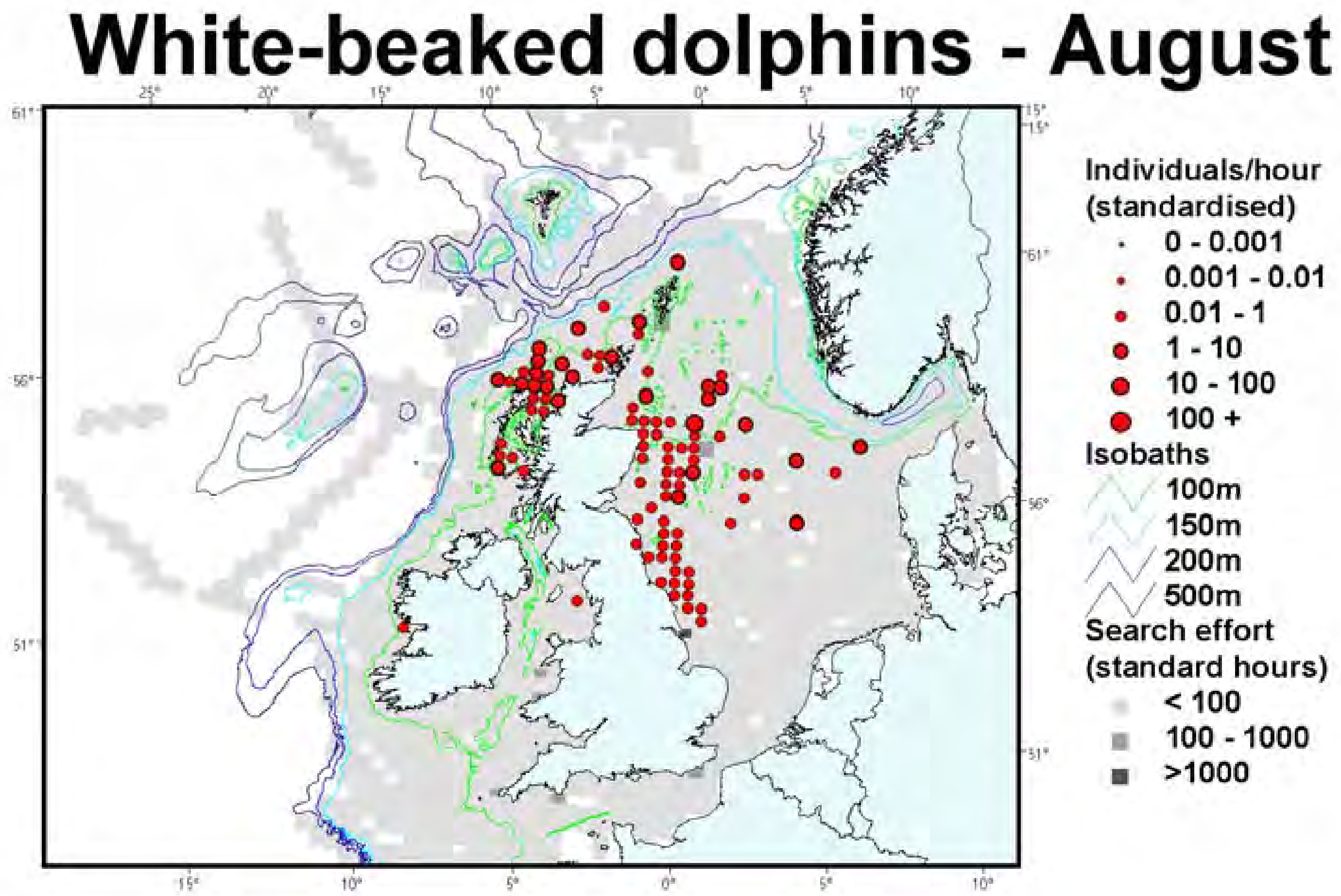

Figure 9: Sightings rates of white-beaked dolphins around the UK (adapted from Reid *et al.*, 2001)

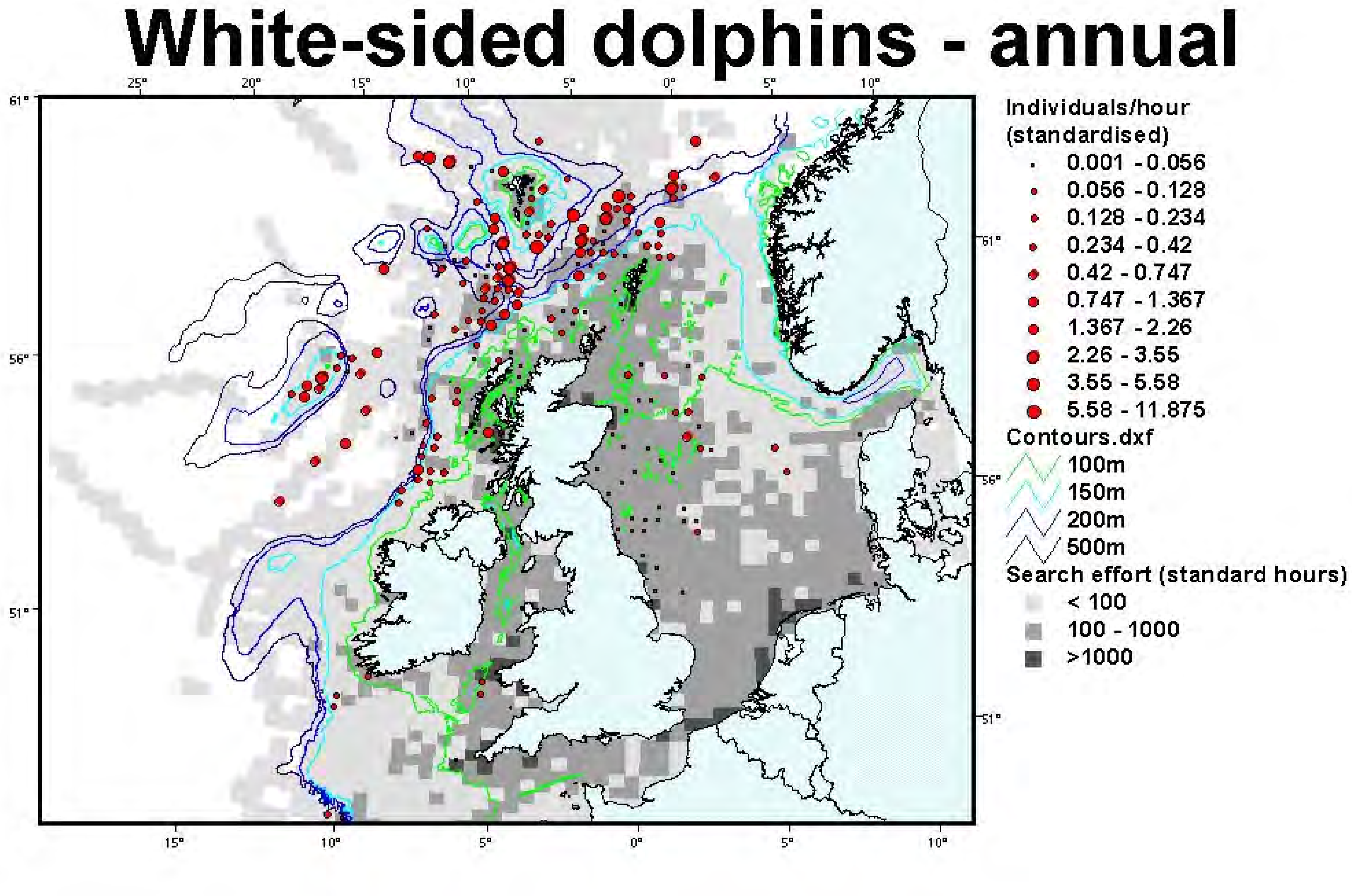

Figure 10: Sightings rates of Atlantic white-sided dolphins around the UK (adapted from Reid *et al.*, 2001)

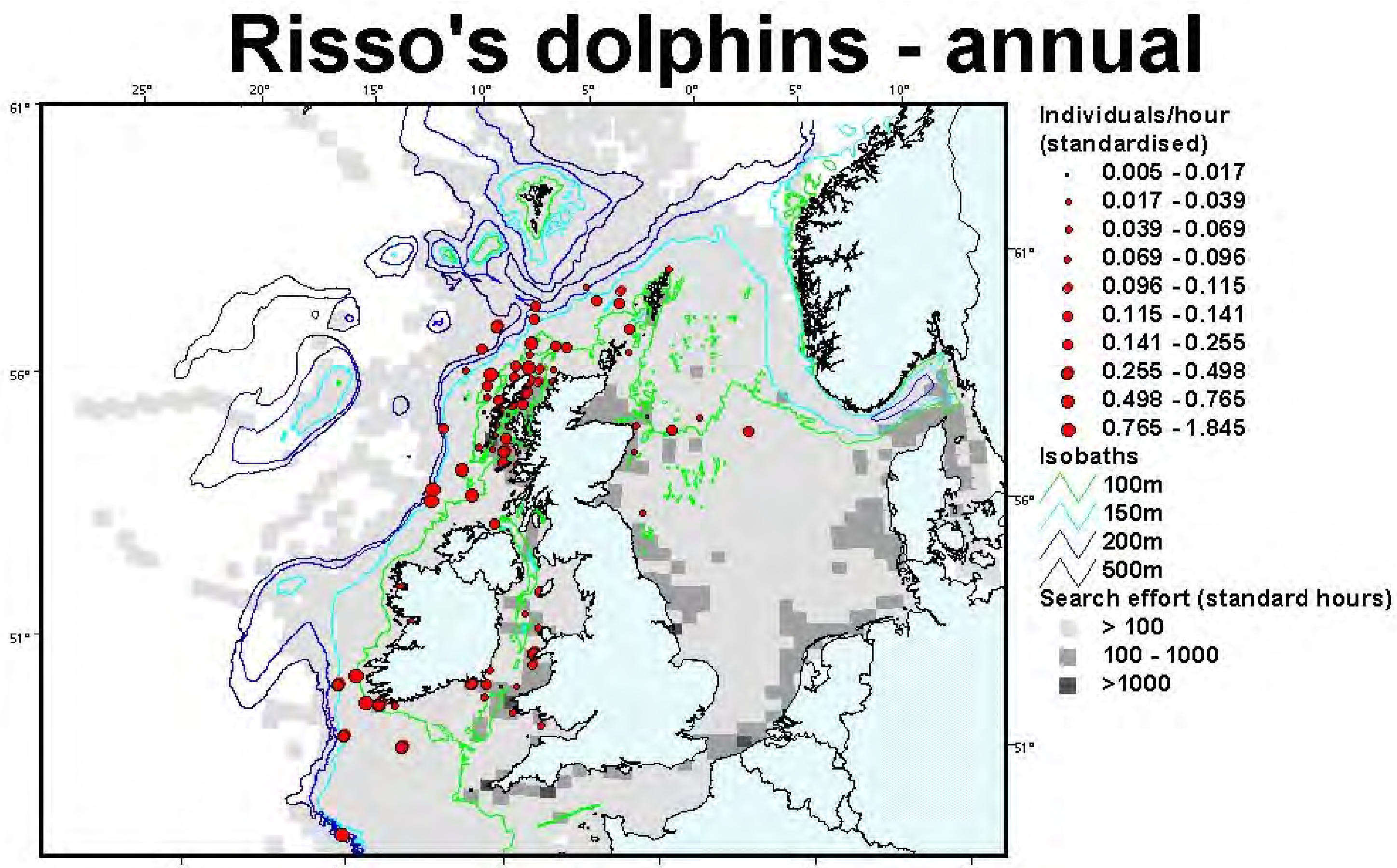

Figure 11: Sightings rates of Risso's dolphins around the UK (adapted from Reid *et al.*, 2001)

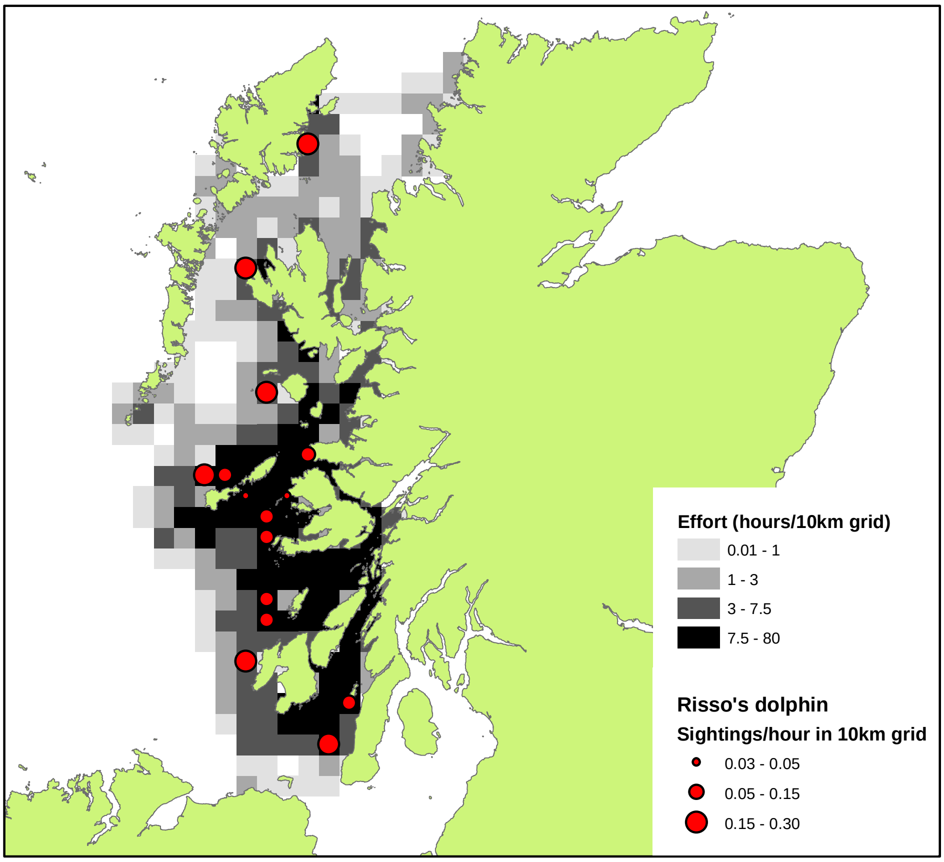

Figure 12: Distribution of sightings effort and Risso's dolphin sightings in the Inner Hebrides from April-September 2003-2005 from the HWDT motor-sailor, *Silurian*

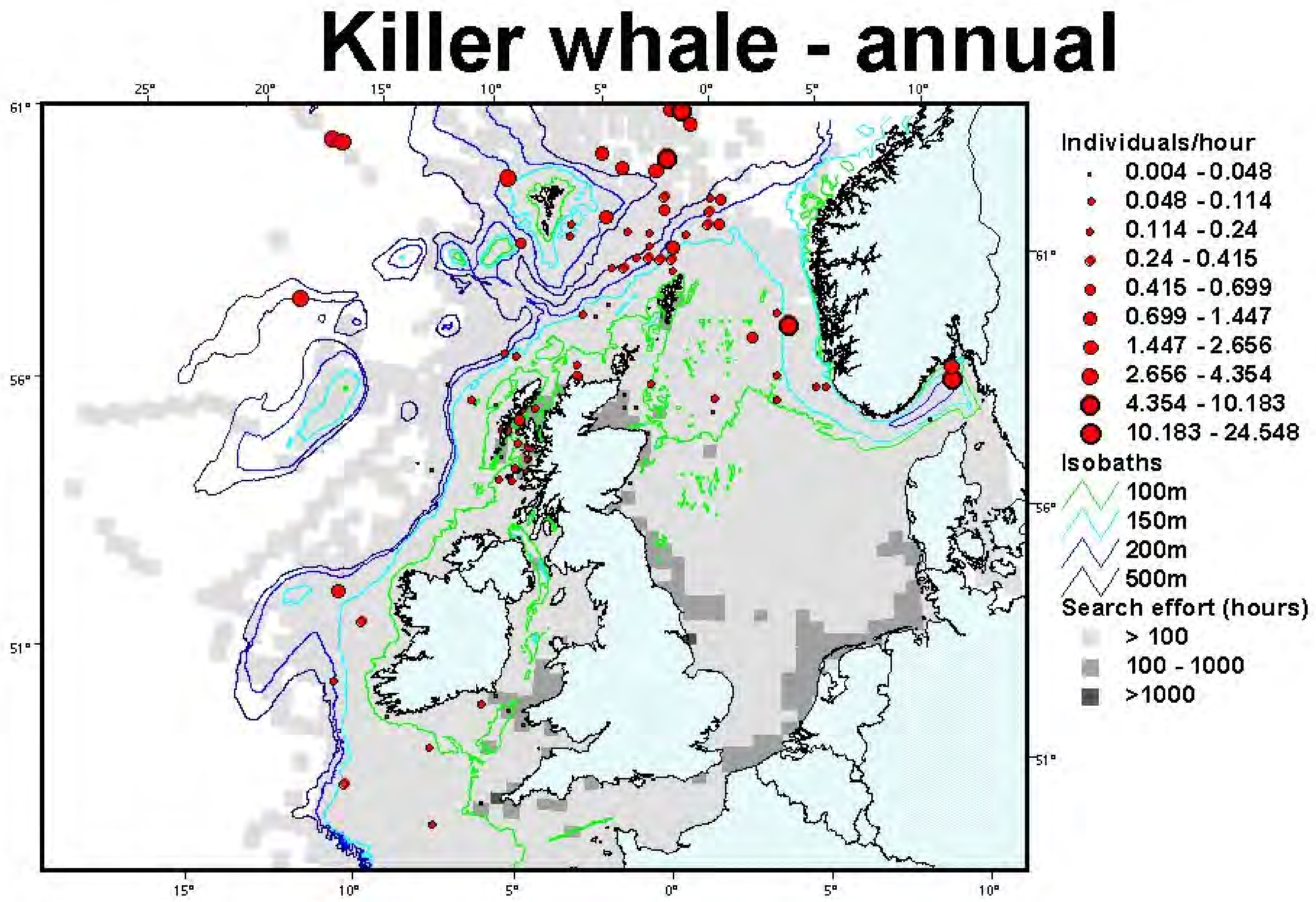

Figure 13: Sightings rates of killer whales around the UK (adapted from Reid *et al.*, 2001)

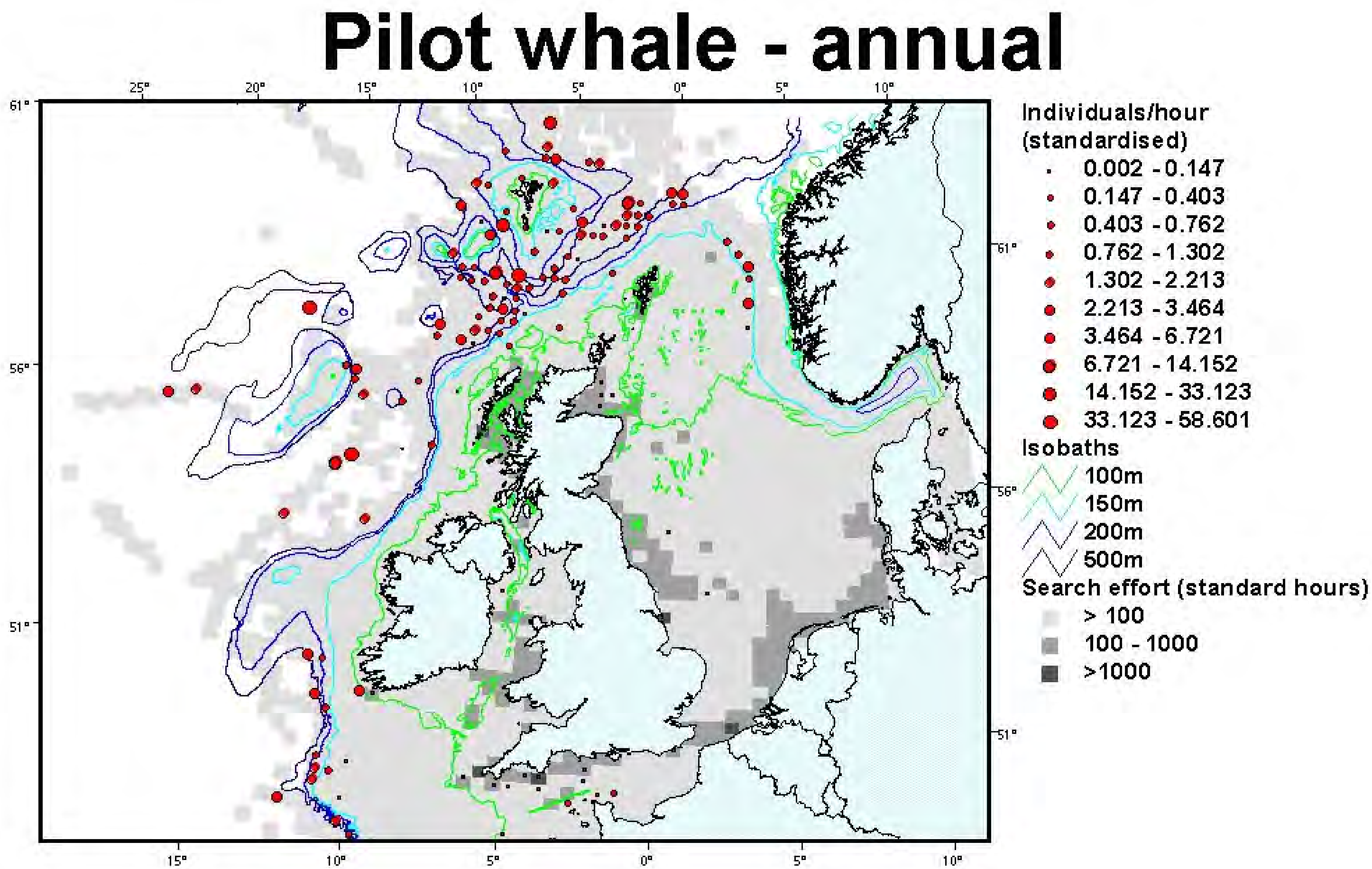

Figure 14: Sightings rates of long-finned pilot whales around the UK (adapted from Reid *et al.*, 2001)

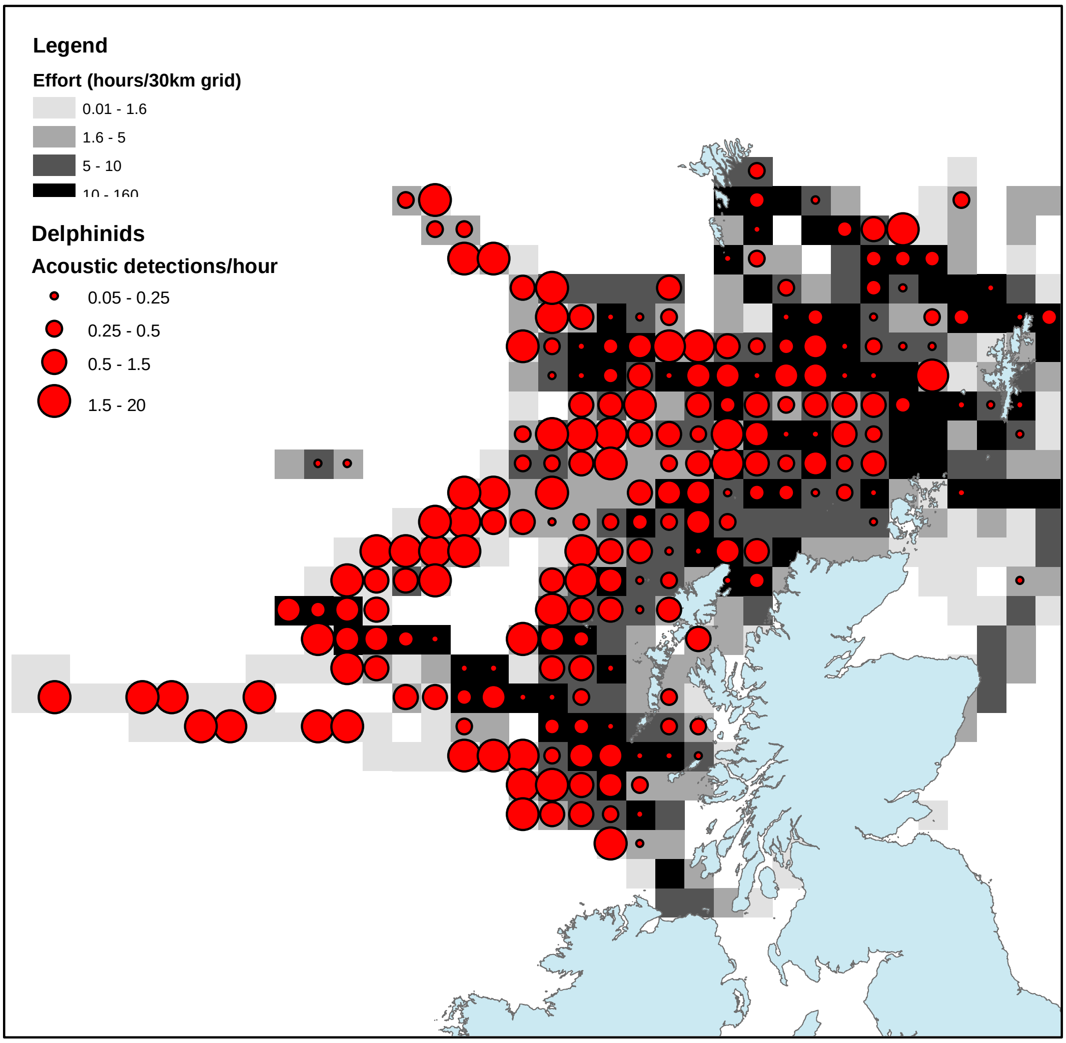

Figure 15: Distribution of passive acoustic survey effort and delphinid acoustic detections off the west coast of Scotland from platforms of opportunity 2000-2005.

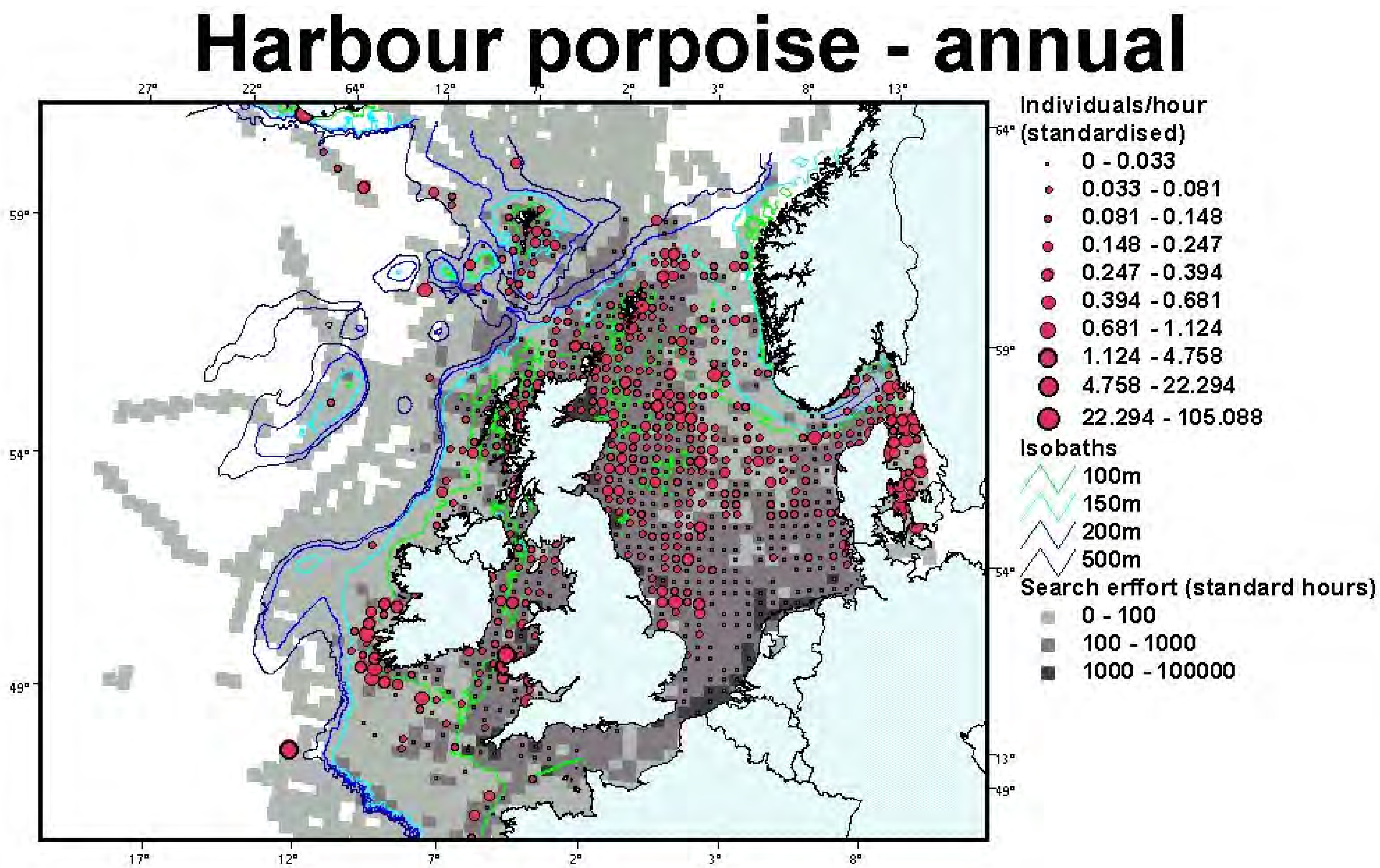

Figure 16: Sightings rates of harbour porpoises around the UK (adapted from Reid *et al.*, 2001)

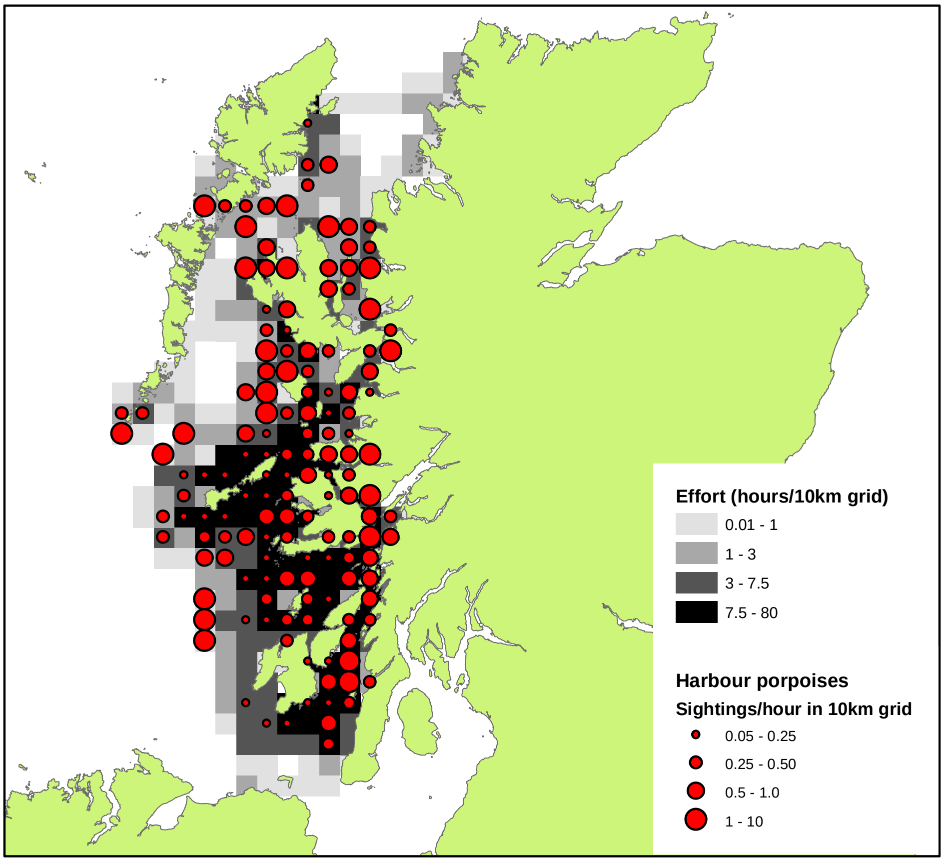

Figure 17: Distribution of sightings effort and harbour porpoise sightings in the Inner Hebrides from April-September 2003-2005 from the HWDT motor-sailor, *Silurian*

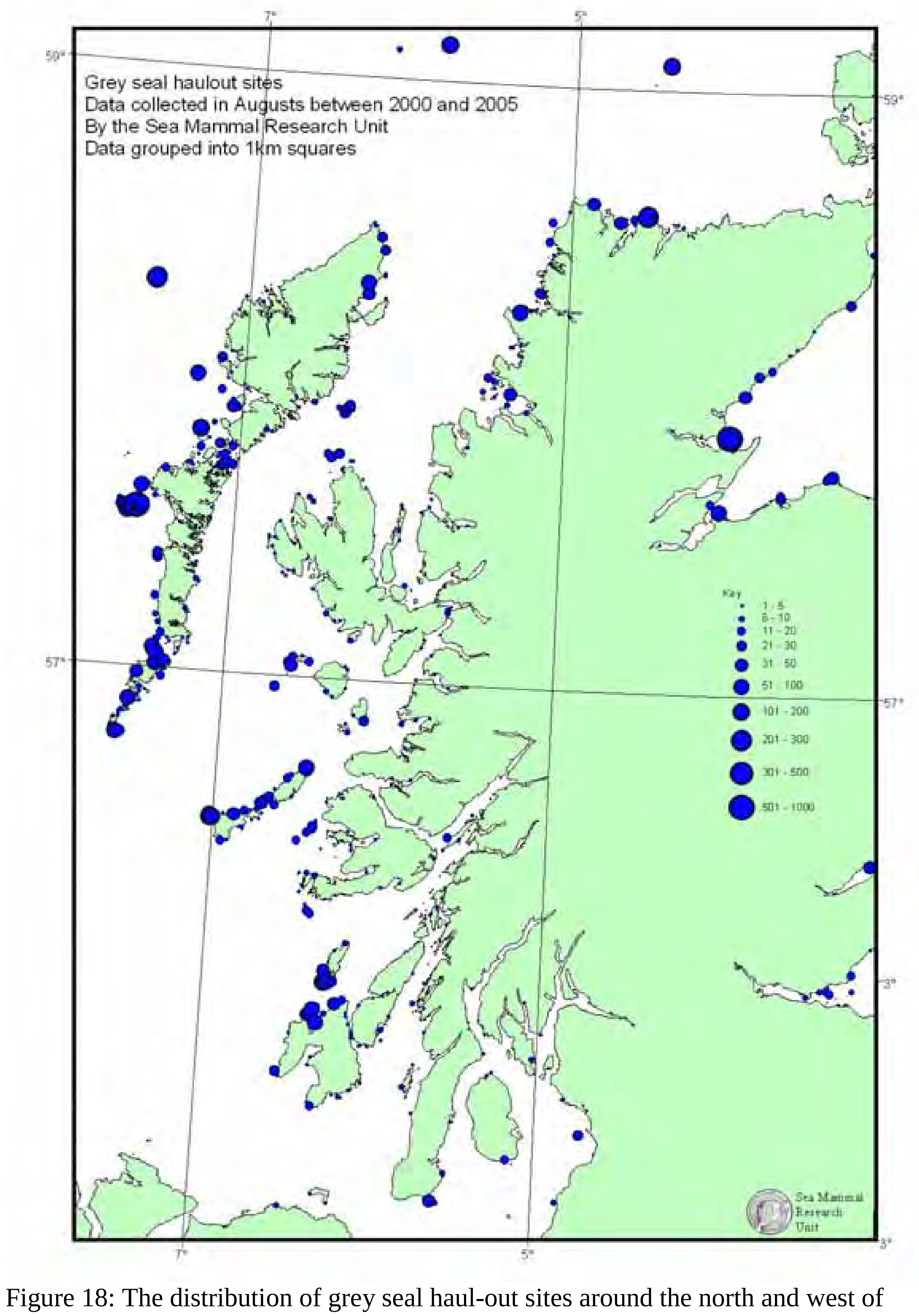

Figure 18: The distribution of grey seal haul-out sites around the north and west of Scotland.

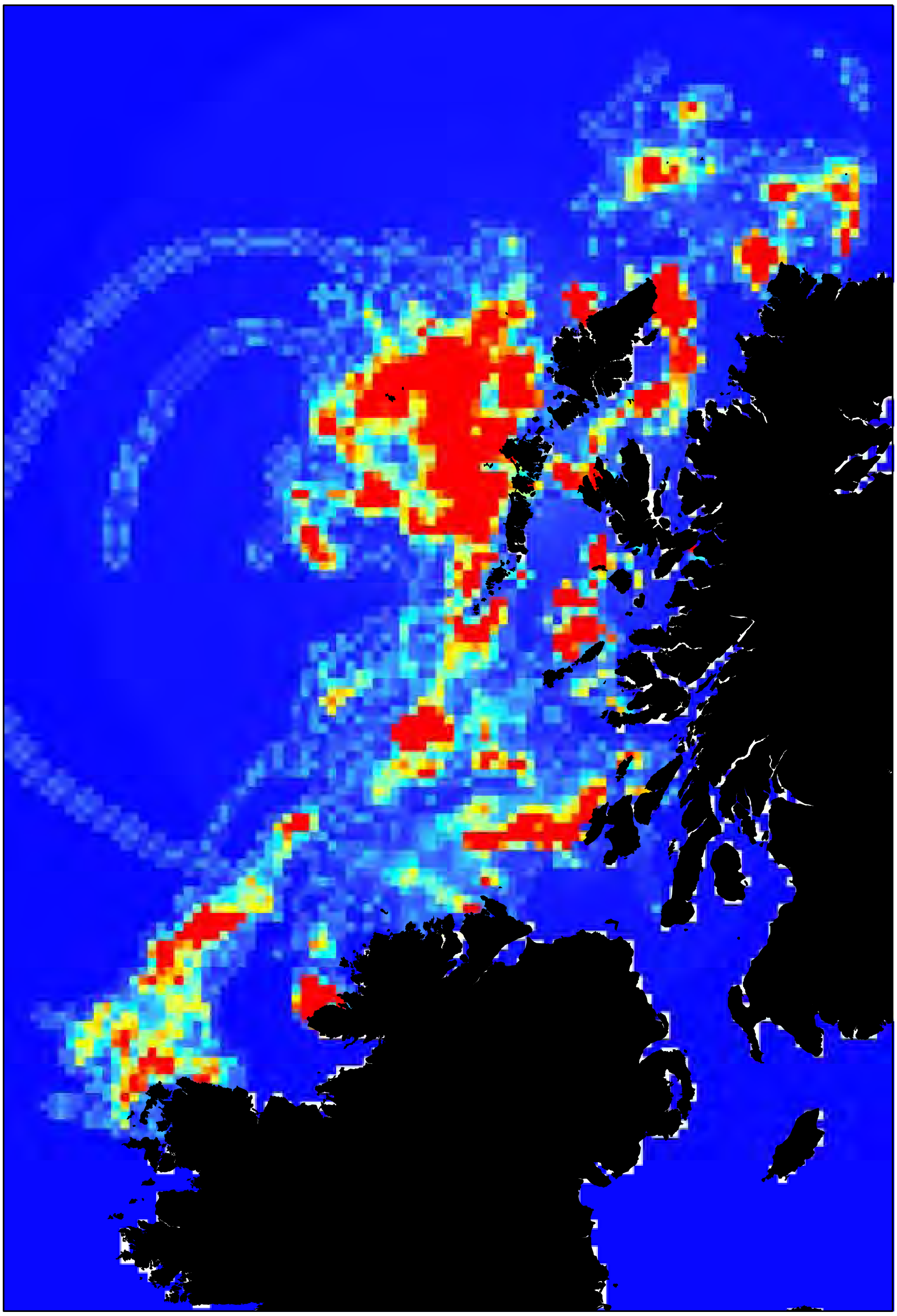

Figure 19: Spatial distribution of usage based on telemetry data from ~75 individual grey seals, haulout counts and accessibility of points in space relative to the haulout sites. Red indicating high usage and blue low usage.

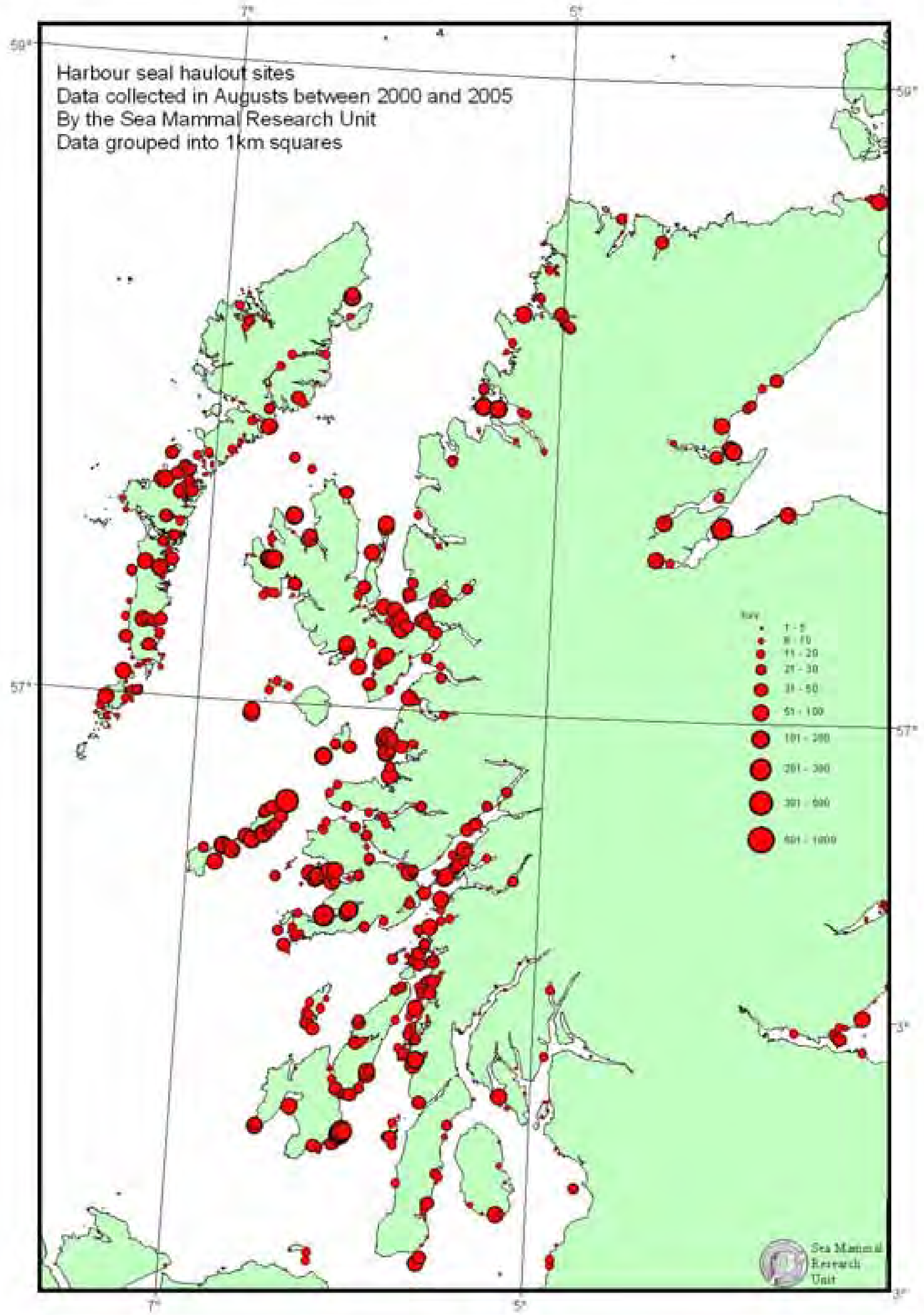

Figure 20: The distribution of harbour seal haul-out sites around the north and west of Scotland.

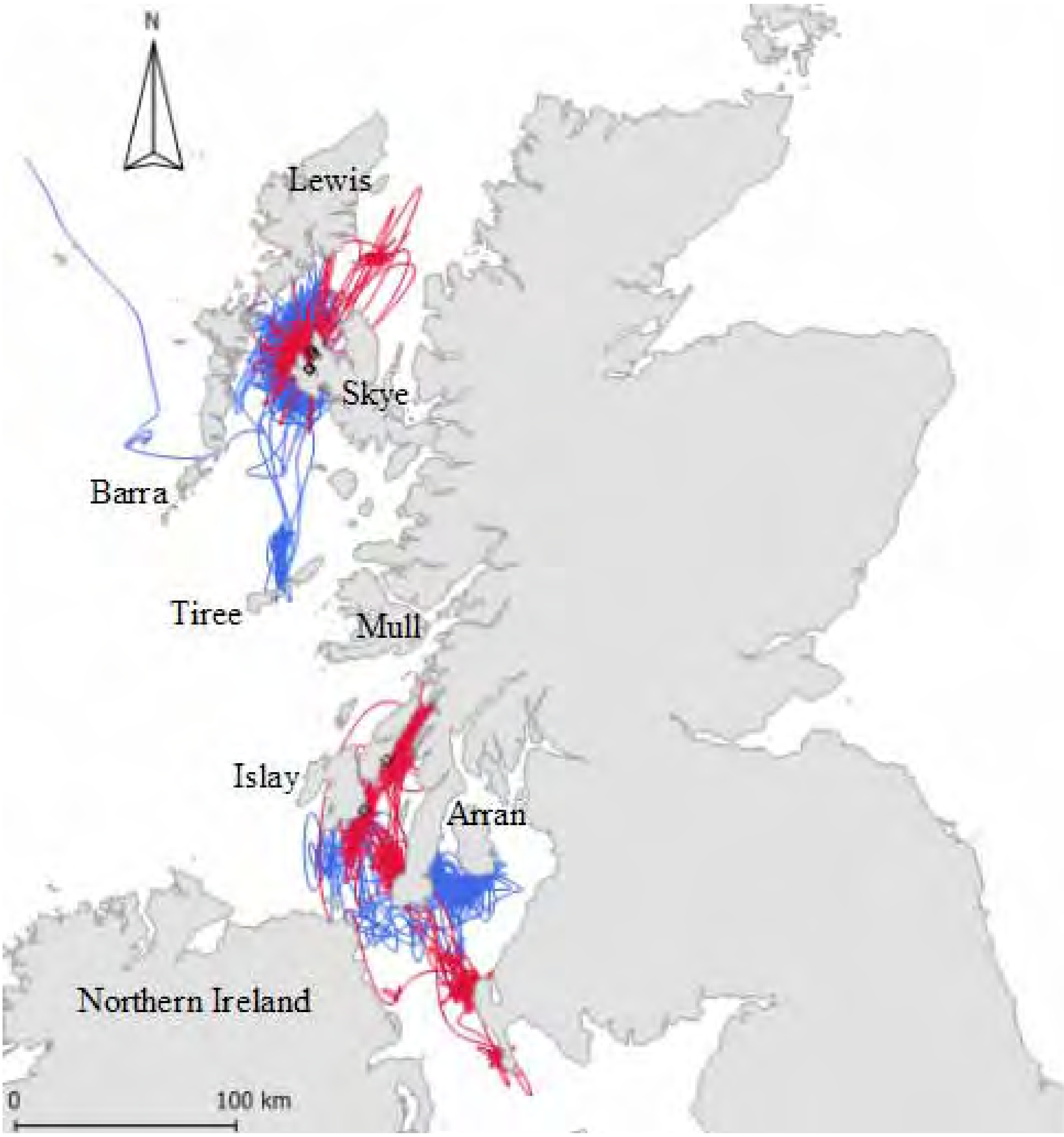

Figure 21: Individual tracks of male (blue) and female (red) harbour seals tagged off the Isles of Skye, Islay and Jura. Satellite Relay Data Logger deployment locations are illustrated in black.

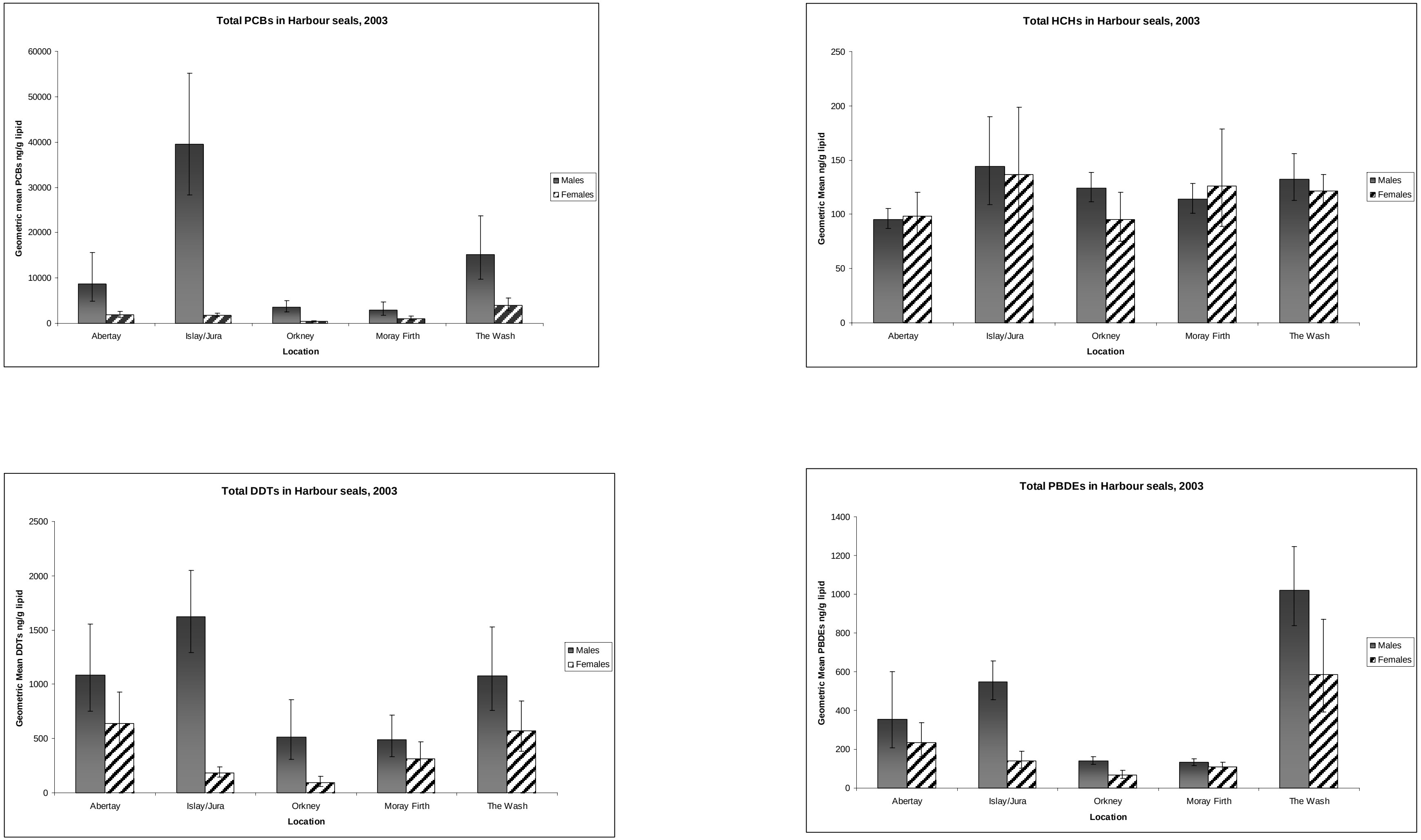

Figure 22: Contaminants (PCBs, DDTs and Pesticides) in harbour seal blubber samples (From Hall and Thomas, 2005)