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Impacts of climate change on marine mammals

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EXECUTIVE SUMMARY

Information since 2010, when the last report card was published, indicate little change to the overall conclusions.

Globally, the impact of climate change on marine mammals remains poorly understood, due largely to the difficulty of obtaining substantive evidence. Most obvious impacts are loss of available habitat such as ice cover to ice-breeding pinnipeds. This already is thought to affect ringed seals and their main predator, the polar bear, but also the breeding success of harp and hooded seals in arctic regions.

In more temperate regions, environmental changes will likely be reflected mainly in responses to changes in prey abundance and distribution as a result of warmer sea temperatures, and enhanced stratification forcing earlier occurrence of the spring phytoplankton bloom and potential cascading effects through the food chain. There may also be effects through changes in the locations of fronts and water masses, and overall reduced primary and secondary plankton production.

Range shifts can be observed in a number of odontocete cetacean species, and these have been linked to increasing sea temperatures. However, the mechanisms causing those changes remain uncertain, and for some species, it is difficult to differentiate between short-term responses to regional resource variability and longer-term ones driven by climate change.

NW European species likely to be most affected in the future will be those that have relatively narrow habitat requirements – shelf sea species like the harbour porpoise, white-beaked dolphin and minke whale may come under increased pressure with reduced available habitat if they experience range shifts northwards. If overall secondary production is reduced, this could directly affect some baleen whale species that feed upon zooplankton, as well as have indirect effects on fish and cephalopod feeders. Although the main cause of widespread declines in the UK harbour seal population is not known, the prevalence in the population of domoic acid derived from toxic algae may be a contributory factor, and could be exacerbated by increased sea temperatures.

1. WHAT IS ALREADY HAPPENING?

Recent warming of the seas around the British Isles has coincided with a northward shift in the distribution of zooplankton (Beaugrand *et al*., 2002, 2010; Reid *et al*., 2003) and fish species (Beare *et al*., 2004; Perry *et al*., 2005; Cheung *et al*., 2009). Those changes are most evident near the northern or southern boundaries of the species range (Rose, 2005). The same appears to be the case for certain cetacean species, with the typical warmer water dolphins – short-beaked common dolphin (Plate 1) and striped dolphin, apparently recently extending their shelf sea range further north off western Britain and around into the northern North Sea (Evans *et al*., 2003; MacLeod *et al*., 2005). Common dolphins are now seen quite regularly in the North Sea even in winter (Sea Watch Foundation, unpublished data), and this may reflect the expanding range of typically warmer water fish species like anchovy and sardine (ICES, 2008). Other warm water species recorded for the first time in the UK in recent years include Blainville's beaked whale (1993), Fraser's dolphin (1996), and dwarf sperm whale (2011), whilst ten out of eleven strandings of pygmy sperm whale in Britain and Ireland have occurred since 1980 (Evans *et al*., 2003; Deaville and Jepson, 2011), and between January and April 2008, there were 18 strandings of another typically warm water species, the Cuvier's beaked whale in Wales, Scotland, and Ireland (Dolman *et al*., 2010). Although these strandings may not be directly related to climate change, they occurred much further north than would be expected for this species, and generally at times of year when sea temperatures are at their highest. At this stage, however, it is unwise to draw too many conclusions from records of vagrants. By contrast, species with ranges north of the British Isles have not been recorded with increased frequency: bowhead whale has not been recorded for more than 100 years; narwhal (Plate 2) has not been recorded since 1949; and records of beluga have been 0 in the 1970s, 3 in the 1980s, 3 in the 1990s and 0 in the 2000s (Evans *et al*., 2003; Evans, 2008a).

The ability to detect long-term trends in cetaceans around the UK is limited by the paucity of effort-based sightings data before 1980. The recent multiple presence of short-beaked common dolphin schools in the northern North Sea is not new, for example. There have been both strandings and sightings in that region during the 1980s (Sheldrick, 1989; Baines *et al*., 2006), and a marked peak in UK North Sea strandings was reported during the 1930s (Fraser, 1946), and along the Dutch coast in the 1940s (Bakker and Smeenk, 1987; Camphuysen and Peet, 2006). These patterns in strandings may reflect decadal climatic cycles such as caused by the North Atlantic Oscillation (which was in a positive phase during those periods, characterised by stronger westerly winds, higher sea temperatures, and milder winters with wetter and stormier conditions - Hulme *et al*., 2002).

Another species reported to have recently exhibited range shifts is the white-beaked dolphin (Plate 1), a species of largely cold temperate to arctic waters (Evans *et al*., 2003; MacLeod *et al*., 2005, 2007c; Baines *et al*., 2006; Evans and Smeenk, 2008). Although these may not necessarily be directly related to sea temperature changes but simply reflect changes in the status of particular fish stocks that are favoured prey of the species, there have been shifts in regional distribution for this and other species. Stranding records have shown a significant increase of the white-beaked dolphin in the southern North Sea since the 1960s, and the species now regularly occurs in the Southern Bight (Bakker and Smeenk, 1987; Kinze *et al*., 1997; Camphuysen and Peet, 2006). This emphasises the difficulties in interpreting regional changes in status, not only because there are many potential confounding effects (not least being human over-exploitation of fish or squid stocks) but also because those marine mammal species may simply be responding to regional variability in resource availability independent of climate change.

Amongst marine mammals, information on population trends, breeding success and feeding ecology is much better for seals than for cetaceans. Nevertheless, the evidence for climate change effects upon both taxa in UK waters remains equivocal. There is no clear evidence that climate change has directly affected either of the two UK breeding species (grey and harbour seal), although elsewhere in the world, several authors have attempted to link changes in seal population dynamics and life history parameters to climate change (see, for example, Sun *et al*., 2004, McMahon and Burton, 2005; Forcada *et al*., 2005). It is possible that recent demographic changes (increases in most grey seal populations and declines in some harbour seal populations; Plate 1) are linked in some way to climate-mediated changes in food supply, although other factors (depletion of food resources from fishing, recovery from epizootics, interspecific competition, density dependent effects) may be more important (SCOS, 2008). Indeed, the recent finding of the prevalence of domoic acid (a neurotoxin derived from harmful diatomaceous algae) in faecal samples from East Scottish harbour seals (SCOS, 2011) could be induced by warming sea temperatures in the North Sea.

In the Northeast Atlantic, there are four species of ice breeding seals: harp seals, hooded seals, ringed seals and bearded seals (Plate 2). These species will be influenced by the changes in extent and quality of sea ice during the breeding season, which for all four species is in late winter/early spring. Harp and hooded seals are monitored on a regular basis and recent large-scale population changes have been observed. The Barents Sea stock had an estimated annual pup production of about 360,000 pups in the period 1998-2003 (Haug and Øigård, 2012a). Estimated annual pup production based on new monitoring in 2009 and 2010 was 160,000 (Haug and Øigård, 2012a). The reason for this reduction in pup production is not known, but the ice conditions in the breeding lairs in the White Sea after 2003 is anticipated to have played a role (Haug and Øigård, 2012a).

The hooded seal breeds in East Greenland Sea north of Jan Mayen. Ice conditions have changed dramatically in this area over the past few decades. The population declined from the late 1940s to 1980 (Haug and Øigård, 2012b). After 1980, the population was on a level of 10-15% of the population size 60 years ago (Haug and Øigård, 2012b). The decline between 1946 and 1980 was possibly driven by too heavy a harvest. From 1980, the catches have been at low levels and from 2007 all harvest was prohibited. The population continued to decline between counting in 1997 and 2007 (Haug and Øigård, 2012b). Harvest is possibly not the main reason for this continued decline, however, and a reduction in suitable ice for breeding is a more likely explanation.

2. WHAT COULD HAPPEN?

Responses both at the individual and population level of marine mammal species to climate change are poorly understood. Making predictions about future impacts becomes even more speculative. In the last 15 years, a number of marine mammal scientists have attempted to do this (Tynan and DeMaster, 1997; IWC, 1997; Würsig *et al*., 2002; Learmonth *et al*., 2006; Simmonds and Isaac, 2007; Huntington and Moore, 2008; Kovacs and Lyderson, 2008; Laidre *et al*., 2008; IWC, 2009; MacLeod, 2009; Evans *et al*., 2010; Kaschner *et al*., 2011). The main potential impacts are summarised under the following headings:

Range shifts: As a result of increased sea temperatures, it is thought that species will shift their ranges to remain within their preferred thermal habitats (Simmonds and Elliott, 2009; MacLeod, 2009; Lambert *et al*., 2011). This may not necessarily result in a negative response, although species with restricted distributions such as the vaquita, river dolphins, bowhead whale, narwhal, and polar seals, may be unable to change their geographic range (Tynan and DeMaster, 1997; IWC, 1997; Huntington and Moore, 2008). It has been suggested that a major impact of climate change will be a redistribution of cetacean species diversity from tropical regions to mid latitudes, particularly above 40° latitude (Whitehead *et al*., 2008; Kaschner *et al*., 2011).

Plate 1: Potential winners (left) and losers (right). Top left: short-beaked common dolphin [Credit: P. Anderwald]; Top right: white-beaked dolphin [Credit: K. Hepworth]. Bottom left: Atlantic grey seal [Credit: P. Anderwauld]; and, Bottom right: harbour seal [Credit: P.G.H. Evans].

In the UK, one might expect species like the short-beaked common and striped dolphin to occur more regularly off northern Britain and within the North Sea, displacing the white-beaked and Atlantic white–sided dolphin. The white-beaked dolphin favours shelf habitats and so may be placed under increased pressure if it loses the Northwest European continental shelf within its range, although off Greenland and in the Barents Sea, the species occurs in much deeper waters (preference for depths of c. 900m in West Greenland - Hansen (2010); abundance increases with depth at least to 300m in the western Barents Sea - Fall (2011)). Other shelf species, the harbour porpoise and minke whale, may also move northwards. On the other hand, Cuvier's beaked whale may become more regular in offshore Atlantic canyons such as the Porcupine Bight west of Ireland and the Rockall Trough west of Scotland, both potentially suitable habitat for the species (Evans *et al*., 2008). There could also be more records of warm-water vagrants to North-west Europe (e.g. Bryde's whale, pygmy sperm whale, dwarf sperm whale, rough-toothed dolphin, and Atlantic spotted dolphin). Baleen whales (e.g. humpback and fin whale), that move southwards to warmer waters to winter where they breed, may increasingly do so within UK waters. Interestingly, with the opening up of the Arctic Ocean between the North Pacific and North Atlantic, species like the gray whale may colonise the North Atlantic (where once it occurred), and there have already been confirmed sightings of this species off Israel and Spain, in May-June 2010. Overall, we may therefore actually experience an increase in species diversity.

Changes to physical habitat: The melting of sea ice clearly poses a threat to those marine mammals (such as seals) that use it for hauling out or breeding, as well as to their predators (Harwood, 2001; Derocher *et al*., 2004; Ferguson *et al*., 2005). Changes to open water refugia in the ice may affect species like beluga and narwhal (Heide-Jørgensen and Laidre, 2004; Laidre and Heide-Jørgensen, 2005). Rising sea levels may affect shallow water species such as tucuxi, humpback dolphin, and finless porpoise, as well as those species such as the gray whale, calving in shallow coastal bays (IWC, 1997, 2009; Würsig *et al*., 2002). In the UK, however, it is unlikely that changes to the physical habitat will affect cetaceans, although some seal haul-out / breeding locations in caves or on low lying coasts (e.g. in particular, parts of The Wash for harbour seals, but possibly also the Monach Isles on the Scottish continental shelf for grey seals, and the Dornoch Firth for both species) may be lost or modified. Increases in storm frequency and associated wave surges could exacerbate effects.

There is some evidence that changes in rainfall patterns might affect the breeding behaviour of grey seals. Increased rainfall, for example, can increase the availability of pools in some breeding colonies. Females aggregate around pools, thus enabling a small number of males to monopolise access to females as they enter oestrus. (Twiss *et al*., 2007). Conversely, in dry conditions, females disperse more widely, providing additional males with the opportunity to mate. Increased rainfall and severe weather may also increase pup mortality at breeding sites. On the other hand, seals may adapt to a number of these changes, and new habitats may be created.

Changes to the food web: Effects of changes to community structure are probably the most difficult to predict. Changes

a) b) c) d)

Plate 2: Species likely to be particularly affected by climate change: a) Harp seal [Credit: Institute of Marine Research, Norway (IMR)]; b) Bearded seal [Credit: IMR]; c) Hooded seal [Credit: IMR]; and d) Narwhal [Credit: M.P. Heide-Jørgensen].

in ocean currents and the positions of associated fronts as well as in ocean mixing, deep water production and coastal upwellings could have profound effects on biological productivity (Stenseth *et al.*, 2002, 2004; Walther *et al.*, 2002), which in turn is likely to affect top predators such as marine mammals (IWC, 1997, 2009; Bjørge, 2002; Würsig *et al.*, 2002; Huntington and Moore, 2008; Nicol *et al.*, 2008). A reduction in ocean productivity over the past decade has been driven largely by the warming and stratification of lower latitude waters blocking the nutrients necessary for phytoplankton growth (Behrenfeld *et al.*, 2006). Enhanced stratification also forces earlier occurrence of the spring phytoplankton bloom and potential cascading effects through the food chain. Reduced zooplankton abundance is likely to affect baleen whales, particularly those with restricted diets such as right whales, which feed largely upon copepod aggregations (Greene and Pershing, 2004; Leaper *et al.*, 2006; Kenney, 2007), thus inhibiting possible recovery of the species in the eastern North Atlantic. On the other hand, increasing storm events could deepen the mixed layer and thereby increase nutrient availability in the upper ocean and ultimately enhance production of marine mammal prey. In most cases it is difficult to determine how exactly these changes will impact particular marine mammal species (Trites *et al.*, 2006; Moore, 2009).

More complicated scenarios include mismatches in synchrony between predator and prey, either in time or location (Edwards and Richardson, 2004; Durant *et al.*, 2007). This uncoupling of phenological relationships at different trophic levels is thought to have been responsible for recent failures in sand eel recruitment in the North Sea with high winter temperatures negatively affecting early larval survival (Arnott and Ruxton, 2002; Van Deurs *et al.*, 2009) and consequent breeding failures amongst several UK seabird species largely dependent on sand eels (Rindorf *et al.*, 2000; Frederiksen *et al.*, 2004, 2005; Wanless *et al.*, 2005; Mavor *et al.*, 2006). There has been some speculation that the recent shift in abundance of harbour porpoises from the northern to southern North Sea may be due to a shortage of sand eels, a known prey item, Low abundance of sand eels may or may not be related to poor body condition amongst stranded porpoises in the Scottish North Sea (MacLeod *et al.*, 2007a, b; Thompson *et al.*, 2007). On the other hand, if these observations do indeed reflect a real change, it may also be due to other prey-related changes such as the recovery of some herring stocks in the southern North Sea (Evans, 1990). At present, we have little idea to what extent species like the harbour porpoise have particular dietary preferences although high-energy shoaling fish such as herring, sprat and sand eel often form important components of porpoise diet (Santos *et al.*, 2004; Pierce *et al.*, 2007; Evans *et al.*, 2008).

A number of findings indicating potential effects on other marine taxa could also impact upon marine mammals through the food chain. Examples include reductions in salinity due to increased freshwater inputs, increases in CO_2 and consequent increased acidification (IPCC, 2007) particularly affecting cephalopods (Boyle, 1983; Pörtner *et al.*, 2004; Royal Society, 2005). Changes in CO_2 levels and pH are likely to affect metabolic function and thus growth and reproduction (Pörtner *et al*., 2004; Royal Society, 2005). Sensitivity is highest in ommastrephid squids, such as *Illex illecebrosus*, which are characterised by a high metabolic rate and extremely pH-sensitive blood oxygen transportation (Boyle, 1983). Several marine mammal species feed either exclusively or to a large extent upon cephalopods.

Squid have increased in abundance in recent years in the Western Approaches, Channel, and North Sea (J. Van Der Kooij, pers. comm.) which in turn may lead to increased presence in these waters of squid predators such as Risso's dolphin, striped dolphin, sperm whale and species of beaked whales, in those areas where suitable habitat exists.

Susceptibility to disease and contaminants: Global warming has been implicated in the worldwide increase in reports of diseases affecting marine organisms, including marine mammals (Geraci and Lounsbury, 2002; Harvell *et al*., 2002; Lafferty *et al*., 2004; Burek *et al*., 2008; Van Bressem *et al*., 2009). Climate change has the potential to increase pathogen development and survival rates, disease transmission, and host susceptibility (Harvell *et al*., 2002), whilst higher temperatures may stress organisms, increasing their susceptibility to some diseases (Lafferty *et al*., 2004). Subtle effects of pollutants (e.g. disruption of the immune, reproductive or endocrine systems) could also be exacerbated by nutritional stress (Jepson *et al*., 2005; Hall *et al*., 2006).

The frequency and severity of toxic algal blooms (i.e. those producing domoic acid) are also predicted to increase as a result of nutrient enrichment (increased rainfall and freshwater runoff), increased temperature and salinity (Peperzak, 2003; Lafferty *et al*., 2004), and indeed there is some evidence that they already have (Van Dolah, 2007). Mass die-offs due to fatal poisonings have been reported in several marine mammal species (Geraci *et al*., 1999; Domingo *et al*., 2002; Geraci and Lounsbury, 2002), for example Mediterranean monk seals (Hernández *et al*., 1998), California sea lions (Scholin *et al*., 2000), bottlenose dolphins (Fire *et al*., 2007, 2008), and Florida manatees (Bossart *et al*., 1998). They may also be responsible for increased calf mortality amongst Patagonian right whales (IWC, 2009), and to be contributing to the observed declines in harbour seals in the North Sea (SCOS, 2011).

The effects of pollutants as added stressors to predators already suffering from changes in habitat and prey availability remain poorly understood (IWC, 2009). There are some suggestions that climatic warming causing changes in temperature, precipitation, and weather patterns, will alter the pathways (e.g. persistence), and concentrations of pollutants entering more pristine regions via long-range transport on air and ocean currents (MacDonald *et al*., 2005).

Thermal Intolerance: There are few direct data about thermal tolerances in marine mammals. Those species or populations that inhabit polar seas tend to have thicker blubber layers. Good examples are the bowhead whale, and other baleen whales when on summer feeding grounds at high latitudes. It has been suggested that except perhaps for the smallest species like the harbour porpoise, hypothermia is not so much an issue as the possibility of heat stress (hyperthermia) in warmer waters (Hokkanen, 1990). However, this has rarely been directly explored, and it is unclear how widely the generalisation holds. In their present calving grounds off the coasts of Georgia and northern Florida, northern right whales appear to select cooler water (Kraus *et al*., 1993; Ward, 1999), and it has been postulated that warming sea temperatures may subject the species to thermal stress and associated negative impacts forcing the species to shift its winter calving grounds northwards, reoccupying historical calving grounds that are no longer used (Kenney, 2007). The possibility of a negative effect will then likely depend on whether in those areas there is increased risk of ship strikes or fishing gear entanglement, both of which are currently important causes of mortality for the species (Kraus and Rolland, 2007). Nevertheless, at this stage, the extent to which marine mammals are constrained thermally, if at all, is poorly known, as are any possible consequences.

As yet, most of the above predictions are still somewhat speculative and often unsubstantiated by unequivocal evidence. This reflects the difficulties in studying marine mammals, using experimental approaches to test hypotheses, and in disentangling various potential confounding variables.

Summary of CP2 regional areas, Irish waters, and waters around the Isle of Man and Channel Islands

Northern North Sea (Region 1)

The characteristic cetacean species of this region include harbour porpoise, minke whale, killer whale, white-beaked dolphin, and in coastal waters of East Scotland, the bottlenose dolphin (Evans *et al*., 2003; Reid *et al*., 2003; Wilson *et al*., 2004). A number of species whose typical habitat is the shelf edge or beyond may also range into the northern North Sea where water depths generally exceed 50 metres. Included amongst these are Atlantic white-sided dolphin, long-finned pilot whale, northern bottlenose whale, sperm whale, and fin whale (Evans *et al*., 2003; Reid *et al*., 2003).

In the last ten years, the status of several species has changed somewhat. Harbour porpoises, though still regular, have become scarcer in the Northern Isles and across the northern North Sea towards Norway (SCANS II, 2008; Øien, 2010); white-beaked dolphins have become relatively uncommon in the same area, and Atlantic white-sided dolphins are now rarely reported from the North Sea (SCANS II, 2008; Evans and Baines, 2010). On the other hand, short-beaked common dolphin and Risso's dolphin have become regular visitors to the region, the former sometimes in large numbers (Sea Watch, unpublished data). Reasons for these changes may be related to changes in the distribution of prey species: declines in sand eel possibly affecting the harbour porpoise, increases in anchovy and sardines potentially affecting common dolphin, and various cephalopod species affecting Risso's dolphin distribution. Local increases in herring and mackerel stocks may account for the increased presence of humpback whale in the region (Anderwald *et al*., 2010). The Moray Firth bottlenose dolphin population size has remained relatively stable but since the 1990s has extended its range eastwards and then southwards to the Firth of Forth and beyond (Wilson *et al*., 2004; Anderwald *et al*., 2010; Cheney *et al*., 2012).

Two seal species breed in the region: harbour seal and Atlantic grey seal. Harbour seals are common and widespread in the inner Moray Firth and Tay Estuary (SCOS, 2011). Grey seals in the region have their main breeding concentrations in the Inner Moray Firth, north-east Grampian coast, Firth of Tay, Firth of Forth (Isle of May and Fast Castle), and the Farne Islands (SCOS, 2011).

Major declines have been documented in harbour seal populations around Scotland, with declines since 2000 of 46% in the Moray Firth, and 84% in the Firth of Tay (SCOS, 2011). The cause of these declines is not fully understood and possible factors include reduced food availability, increased competition with grey seals, or an increase in direct mortality. Some seal carcasses (both of harbour seal and grey seal), particularly in East Scotland, have been found to have "corkscrew" injuries, consistent with the seals being drawn through a ducted propeller commonly used in a wide range of vessels including tugs, self propelled barges and rigs, various types of offshore support vessels and research boats (SCOS, 2011). Biotoxins produced by various species of harmful algae have also been found in seals. Exposure to domoic acid is widespread among harbour seals around Scotland, and may therefore be a contributory factor to the decline, although the spatial pattern of declines does not entirely match that of the prevalence of domoic acid in faecal samples analysed. Domoic acid was most likely to have been ingested by seals that were preying upon demersal benthivores such as flatfish and squid than on other fish species sampled (SCOS, 2011). Grey seals appear to be less exposed.

The number of grey seal pups throughout UK has grown steadily since the 1960s when records began, but may now be levelling off (SCOS, 2011). Overall pup production at colonies in the North Sea continues to increase exponentially, although the increase has apparently slowed at the Isle of May and Farne Islands, and the increase is mainly due to expansion of newer colonies on the mainland coasts in Berwickshire (and around East Anglia) (SCOS, 2011).

Southern North Sea (Region 2)

The relatively shallow nature of the southern North Sea determines the cetacean fauna of this region. It is dominated by one species, the harbour porpoise, which appears to have increased in the region since the early 1990s (Hammond *et al*., 2002; Camphuysen, 2004; Camphuysen and Peet, 2006; SCANS II, 2008). Reasons for this change in status are not known. Stomach contents analyses of stranded and by-caught animals have contained mainly gobies, whiting and sand eels (Santos and Pierce, 2003; Santos *et al*., 2004). However, it has been suggested that changes in status of local herring stocks may also influence porpoise distribution patterns (Evans, 1990; Sveegaard *et al*., 2011a, b; 2012). The other two cetacean species occurring regularly are white-beaked dolphin and minke whale (Evans *et al*., 2003; Reid *et al*., 2003; Camphuysen and Peet, 2006). Occasional visitors to the region (mainly the northernmost sector) include bottlenose dolphin, humpback whale and fin whale, records of the latter two having increased in the last two decades (Evans *et al*., 2003; Sea Watch, unpublished data). Other cetacean species are only recorded as accidentals.

The main colonies of grey seals in the region are at Donna Nook (Lincolnshire) and around the Wash, with smaller colonies along the Norfolk and Suffolk coasts. Pup production in this region has been increasing by more than 15% per annum over the last ten years (SCOS, 2011). Harbour seal numbers are also concentrated around the Wash, with small numbers at Blakeney Point, Scroby Sands and Donna Nook, and a few other east coast sites (SCOS, 2011). The population in the Wash was affected badly by the phocine distemper virus outbreak in 1988, with a 52% decline in numbers, and to a much lesser extent by the subsequent PDV outbreak in 2002, when the decline was 22% (SCOS, 2011). Since then, numbers have increased (though not as sharply as in the nearest European population in the Wadden See in the Netherlands) (SCOS, 2011).

Eastern Channel (Region 3)

Only three species appear to be regular members of the cetacean fauna of this region: harbour porpoise, bottlenose dolphin, and short-beaked common dolphin; minke whales occur occasionally, although more common to the west and south (Evans *et al*., 2003; Reid *et al*., 2003). In the 1970s, long-finned pilot whales also regularly entered the region on a seasonal basis (Evans, 1980). A small population of white-beaked dolphins frequent the area of Lyme Bay (and have done so for at least 30 years) (Evans, 1980; Evans *et al*., 2003). Since the 1990s, harbour porpoises have become more common in the Eastern Channel (Kiszka *et al*., 2004).

Very small numbers of harbour seals inhabit this region (for example in Pegwell Bay near Dover in Kent, and Chichester Harbour in West Sussex), and grey seals are not regular east of Devon, small numbers occurring at the Mew Stone off the River Dart and at Peartree Point, south of Start Point (Hammond *et al*., 2008; SCOS, 2011).

Western Channel and Celtic Sea (Region 4)

The deeper waters of the Western Channel and Celtic Sea favour the presence of short-beaked common dolphin, which is abundant in the region (Evans *et al*., 2003; Reid *et al*., 2003). Other regular species include harbour porpoise, bottlenose dolphin, Risso's dolphin and minke whale, whilst along the shelf edge, long-finned pilot whales commonly occur (Evans *et al*., 2003; Reid *et al*., 2003). Small numbers of fin whale and humpback whale are recorded annually, and striped dolphins (a species predominantly of warmer waters) occasionally move northwards into the region, sometimes forming mixed schools with common dolphins (Evans *et al*., 2003; Evans and Collet, 2008). The number of strandings of striped dolphin recorded in southern UK and Ireland has increased steadily since the 1990s (Berrow and Rogan, 1997; Evans *et al*., 2003; Jepson, 2005; Deaville and Jepson, 2011).

Small numbers of grey seals breed around the coast of Cornwall, North Devon and Somerset, with colonies on the Isles of Scilly, and at Lundy Island in the Bristol Channel (Hammond *et al*., 2008; SCOS, 2011). Harbour seals are only occasional visitors (Thompson, 2008).

Irish Sea (Region 5)

The five main species of cetaceans occurring in the Irish Sea are harbour porpoise, bottlenose dolphin, short-beaked common dolphin, Risso's dolphin and minke whale (Baines and Evans, 2012). Other rarer species, which nevertheless occur annually, include fin whale, humpback whale, long-finned pilot whale and killer whale (Baines and Evans, 2012). Harbour porpoise is the commonest and most widespread, occurring year-round. Bottlenose dolphin is the next most commonly recorded species, with a predominantly coastal distribution centred upon Cardigan Bay, although in winter it is more widely dispersed, including much of the northern Irish Sea (Baines and Evans, 2012). The short-beaked common dolphin and minke whale have largely offshore distributions centred upon the Celtic Deep in water depths of 50-150 m (Baines and Evans, 2012). Risso's dolphin has a relatively localised distribution forming a wide band running SW-NE that encompasses west Pembrokeshire, the western end of the Llyn Peninsula and Anglesey in Wales, the southeast coast of Ireland in the west, and waters around the Isle of Man in the north (Baines and Evans, 2012). No obvious trends in status have been observed for any of these species in the last ten years (Baines and Evans, 2012), although since the 1980s, there may have been increases in harbour porpoise and minke whale relative abundance (Evans *et al.*, 2003; Paxton and Thomas, 2010).

The grey seal is the only seal species breeding in the English/Welsh sector of the Irish Sea. It is widely distributed in Wales, breeding in caves and small coves on offshore islands and less populated parts of the mainland coast (Baines and Evans, 2012). Pup production is greatest in north-west Pembrokeshire, particularly on Ramsey Island, but extending southwards to Skomer Island and northwards to southern Ceredigion (Baines *et al.*, 1995). Smaller concentrations occur around the Llyn Peninsula and the coast of Anglesey (Westcott and Stringell, 2003, 2004). These same areas are used as haul-out sites during the non-breeding season. In North-west England, some of the more important non-breeding haul-out sites include the West Hoyle sand bank near Hilbre island (Cheshire), Liverpool Bay, South Walney Island in Morecambe Bay, and sand banks in the Solway Firth.

Small colonies of both grey seal and harbour seal exist in Northern Ireland, mainly in the vicinity of Strangford Lough, whilst colonies of harbour seals also occur in Carlingford Lough, Dundrum, the Ards Peninsula, Copeland Island and Belfast Lough (Duck, 2003). There is no good information on trends in the Irish Sea region (SCOS, 2011; Baines and Evans, 2012).

Minches and western Scotland (Region 6)

This region, being adjacent to the Atlantic and with the shelf edge relatively close, has one of the more diverse cetacean faunas in the UK. Harbour porpoises are common and widely distributed; the second most commonly recorded (though not second most abundant) species is minke whale (Evans *et al.*, 2003; Reid *et al.*, 2003). Other regular species include short-beaked common dolphin, white-beaked dolphin, Risso's dolphin, bottlenose dolphin, and killer whale, whilst less frequent visitors include Atlantic white-sided dolphin, long-finned pilot whale, fin whale and humpback whale (Evans *et al.*, 2003). There is some evidence of range shifts in two species since the 1990s: Atlantic white-sided dolphins have become generally scarcer whereas short-beaked common dolphins are more regularly recorded north of the Isle of Skye (Sea Watch, unpublished data). During the 1970s-80s, white-beaked dolphins were seasonally abundant in the north Minch but in the last ten years may have shifted slightly northwards (Evans, 1980; Evans *et al.*, 2003; MacLeod *et al.*, 2005). These apparent range shifts may reflect changing distributions of particular fish prey species in response to climate change but their diets in the region are poorly known. Seasonal and annual variations in the distribution and abundance of minke whale have been related to changes in the availability of sand eel in early summer and sprat in late summer (Anderwald *et al.*, 2012).

The region has important breeding populations of both grey seal and harbour seal. Between 2005-10, grey seal annual pup production in the inner and Outer Hebrides has remained almost constant, with a possible small decrease in the Outer Hebrides since the mid 1980s (SCOS, 2011). Compared with the mid 1990s, harbour seal populations have declined by 35% in the Outer Hebrides, the west coast of Highland region appears to be stable, and in Strathclyde, the trend is unclear, having declined slightly after an apparent increase around 2000 (SCOS, 2011).

Scottish Continental Shelf (Region 7)

The Scottish Continental Shelf region has a very diverse cetacean fauna. Typical shelf species include harbour porpoise, white-beaked dolphin and minke whale, with more pelagic species – Risso's dolphin and killer whale being regular visitors; shelf edge species recorded annually include Atlantic white-sided dolphin, long-finned pilot whale, and fin whale (Evans *et al.*, 2003; Reid *et al.*, 2003; Evans and Baines, 2010). Other rarer species occurring in the region include sperm whale, northern bottlenose whale, humpback whale and sei whale (Evans *et al.*, 2003; Reid *et al.*, 2003; Evans and Baines, 2010). Offshore groups of bottlenose dolphins range along the shelf edge but are uncommon near-shore. Since the 1980s, sperm whales and humpback whales have been increasingly recorded, and minke whale abundance has apparently increased (Evans *et al.*, 2003). Since the 1990s, harbour porpoise and white-beaked dolphin have become less common in the area around Shetland (Hammond *et al.* 2002; SCANS-II, 2008; Sea Watch, unpublished data). Killer whales, on the other hand, have been recorded with increasing frequency in the Northern Isles, although this may be confounded by increased attention to the species over the last ten years (Bolt *et al.*, 2009). Nevertheless, winter associations with vessels fishing locally for mackerel and herring (Couperus, 1994; Luque *et al.*, 2006), and summer availability of breeding populations of harbour seals and grey seals in the Northern Isles (Deecke *et al.*, 2010), may be at least partly responsible.

Harbour seal and Atlantic grey seal both breed in the region. Harbour seals are common and widespread in Orkney and

Shetland (SCOS, 2011). In Scotland, grey seals have their main breeding concentrations in Orkney, but with colonies also in Shetland (SCOS, 2011).

As with northern North Sea colonies, major declines have occurred in harbour seal populations in the region, with declines since 2000 of 66% in Orkney and 50% in Shetland (SCOS, 2011). The cause of these declines is not fully understood and possible factors include reduced food availability, increased competition with grey seals, or an increase in direct mortality (SCOS, 2011). Overall, there has been a continual increase in pup production of grey seals since regular surveys began in the 1960s (SCOS, 2011). However, the rate of increase of grey seals in Orkney has declined since 2000, whilst pup production has been relatively constant since 2004 (SCOS, 2011).

Atlantic North-west Approaches, Rockall Bank and Trough and Faroe-Shetland Channel (Region 8)

Survey effort in this offshore region has been low so that knowledge of the status of cetaceans here remains poor. Deepwater species typical of the main habitats in this region are the cetaceans recorded mainly from surveys in the region: Atlantic white-sided dolphin, long-finned pilot whale, killer whale, northern bottlenose whale, Sowerby's beaked whale, sperm whale, fin, sei and humpback whale (Weir *et al*., 2001; Evans *et al*., 2003; Reid *et al*., 2003; CODA, 2009). There is insufficient information to reveal status changes in the region for any of these species, although the CODA survey in July 2007 recorded very few Atlantic white-sided dolphins (CODA, 2009) by contrast to earlier observation effort here from the previous decade (Weir *et al*., 2001; Macleod, 2004).

Telemetry studies show that hooded seals (breeding further north on drifting ice in the Greenland Sea) seasonally make long-distance movements south into this region in winter, moving from Jan Mayen to the continental shelf edge around the Faroe Islands and north and west of Shetland (Folkow and Blix, 1995; Folkow *et al*., 1996). It was suggested that blue whiting might be the potential prey (Folkow and Blix, 1995).

Irish Waters

The status and distribution of cetacean species in Irish waters vary between Irish Sea and Atlantic. In the Irish Sea, as noted earlier for the UK sector, the main species are harbour porpoise, short-beaked common dolphin, bottlenose dolphin, Risso's dolphin, and minke whale, although bottlenose dolphin is less common than across in Welsh waters (Berrow *et al*., 2010a; Baines and Evans, 2012; Wall *et al*., 2012). On the other hand, minke whale appears to be more common, probably due to the waters being deeper in the Irish sector, and rare species like fin and humpback whale are also more frequently recorded in the western Irish Sea and northern Celtic Sea (Berrow *et al*., 2010a; Baines and Evans, 2012; Wall *et al*., 2012).

To the south and south-west of Ireland, harbour porpoise and short-beaked common dolphin are the most common and widely distributed species, but others that are regularly observed include bottlenose dolphin, Risso's dolphin, minke whale, fin whale and humpback whale (Berrow *et al*., 2010a; Wall *et al*., 2012). The last two species occur annually in small numbers off the south coast, particularly between September and February. Occasional visitors include striped dolphin, killer whale, and long-finned pilot whale (Berrow *et al*., 2010a).

West of Ireland, harbour porpoises have historically appeared to be more abundant in the southwest than further north, although they occur over the shelf throughout this sub-region (Berrow *et al*., 2010a; Wall *et al*., 2012) and recent inshore line transect surveys do not indicate a clear regional pattern in summer abundance (for example, Ryan *et al*., 2010). Short-beaked common dolphin, bottlenose dolphin, Risso's dolphin and minke whale are also widely distributed here, whilst offshore along the shelf edge, other species regularly occurring include long-finned pilot whale (Berrow *et al*., 2010a; Wall *et al*., 2012). Atlantic white-sided dolphin was formerly commonly recorded but recently has apparently become scarcer in sighting records (O'Cadhla *et al*., 2004; CODA, 2009; Wall *et al*., 2012). There is a small, apparently genetically isolated, resident population of bottlenose dolphin inhabiting the Shannon Estuary (Berrow *et al*., 2010b; Mirimin *et al*., 2011). White-beaked dolphins are occasionally recorded in the west of Ireland, their range possibly contracting northwards since the 1980s (Berrow *et al*., 2010a), although there had been relatively little survey effort in earlier years (O'Brien *et al*., 2009). Strandings of striped dolphin have increased and become regular since the 1980s (Berrow and Rogan, 1997; O'Brien *et al*., 2009; Berrow *et al*., 2010a).

Both grey seals and harbour seals breed in the Republic of Ireland. Harbour seals are distributed mainly on the west coast, with concentrations in NW Donegal, Donegal Bay, Ballysadare Bay, Blacksod Bay, Clew Bay, Connemara, Galway Bay, Kenmare River, Bantry Bay and Roaringwater Bay, whilst on the east coast they occur at a few isolated sites (e.g. Dundalk Bay, Lambay Island, Wexford Harbour) (Cronin *et al*., 2004, 2007). There is some indication that numbers of harbour seals at particular haul-out sites in the south-west have increased (by 8-13%) between the periods 1985-99 and 2000-06 (Heardman *et al*., 2006) but recent surveys have been more rigorous in methodology, and trends are currently under more detailed investigation. Grey seals are widely distributed around Ireland, with the main breeding colonies situated off the west coast (particularly at the Blasket Islands, Co. Kerry, Inishshark and Inishgort, Co. Galway, the Inishkea Island group, Co. Mayo, and in SW Donegal (O'Cadhla *et al*., 2008), although there are nationally significant colonies also off the south coast in Roaringwater Bay, Co. Cork, and Great Saltee Island, Co. Wexford, and off the east coast at Lambay Island, Co. Dublin (O'Cadhla and Strong, 2007; O'Cadhla *et al*., 2008). There is little information on population trends for grey seals in Ireland (O'Cadhla *et al*., 2008; SCOS, 2011), but regular monitoring of key regional colonies and their population size is continuing.

Isle of Man

Situated in the centre of the northern Irish Sea, Manx waters host a range of the more pelagic cetacean species including short-beaked common dolphin, Risso's dolphin and minke whale, along with typical shelf species – harbour porpoise and bottlenose dolphin (Baines and Evans, 2012; Felce, 2012). The first three species tend to be mainly summer visitors whereas the latter two species are recorded in Manx waters year-round, although bottlenose dolphins occur more regularly between October and March (Baines and Evans, 2012; Felce, 2012). Other rare seasonal visitors include fin whale, humpback whale, long-finned pilot whale, and killer whale (Evans *et al*., 2003; Baines and Evans, 2012; Felce, 2012). No obvious status changes have been observed in the last ten years; before that, survey effort in this area was much reduced (Baines and Evans, 2012; Felce, 2012).

The grey seal is the only seal species breeding in Manx waters and can be found at many sites around the island, although numbers are concentrated in the south in an area encompassed by the Calf of Man, Kitterland and Chicken Rock (Travers, 2005; Stone *et al*., 2012). The grey seal population on the Isle of Man has increased substantially over the last five decades from a mean count of 20 individuals in the 1960s to a monthly mean of 220 individuals in 2007 (Sharpe, 2007).

Channel Islands

The most commonly recorded cetacean species from the waters around the Channel Isles is the bottlenose dolphin (Evans *et al*., 2003), which forms a resident community thought to number more than 400 individuals that ranges particularly between Jersey and the Normandy coast (M. Louis, pers. comm.). Other regular species include harbour porpoise, short-beaked common dolphin, Risso's dolphin, long-finned pilot whale and minke whale (Evans *et al*., 2003). All these species occur in the adjacent regions of the Eastern and Western Channel (Evans *et al*., 2003; Reid *et al*., 2003). There is no information suggesting major status changes over the last two decades although long-finned pilot whales were more frequently reported during the 1970s and 1980s, whereas harbour porpoise and minke whale were relatively scarce (Evans, 1980; Evans *et al*., 2003).

Small numbers of grey seals occur in Jersey (e.g. Les Ecrehous, Les Minquiers and Iles Chausey reefs, and around La Rocque), Guernsey (e.g. shingle bank at L'Eree), Burhou and other islets off the west coast of Alderney, Herm (The Humps) and Sark, representing with Brittany in France, some of the southernmost parts of the range of the species (SCOS, 2011; B. Bree and N. Jouault, pers. comm.). Harbour seals have occasionally been recorded visiting the Channel Islands.

3. KNOWLEDGE GAPS

a. A pre-requisite to assessing impacts of climate change on marine mammals at a population level is a long-term, wide-ranging, monitoring programme that can discriminate between regional population responses and those occurring on a wider geographical scale. This is presently lacking for all UK cetacean species whilst for seals there remain regions (e.g. Irish Sea) with only patchy coverage. Similarly, our knowledge of trends in basic life history parameters (growth rates, age at sexual maturity, reproductive rates, and mortality) for all cetacean species with the possible exception of harbour porpoise is woefully inadequate, based upon small sample sizes from a restricted number of areas, and without long-term continuity of data. For the majority of species, we are unlikely to obtain adequate information in the foreseeable future given how difficult they are to study and the resources available to do so. However, certain species could be targeted for more intensive study with some likelihood of success. In UK waters, these include (in addition to harbour porpoise) bottlenose dolphin, short-beaked common dolphin, white-beaked dolphin, Risso's dolphin, and minke whale. In particular, two long-term studies exist on coastal populations of bottlenose dolphins – Moray Firth (>20 years) and Cardigan Bay (>10 years), which could serve to provide a better understanding of the interaction between climate-mediated changes in the environment and changes in distribution, habitat use and demography.

b. Functional responses to environmental change through physiological and behavioural mechanisms are also poorly understood for most marine mammal species. For this, seals are rather better suited to experimental studies where variables can be controlled. However, it is unclear whether data from seals can be generalised to cetaceans due to ecological differences between the two groups. Once individual responses are better understood, it may be possible to make predictions at the population level, but it will be necessary to conduct these studies across both seals and cetaceans. Too little is known about how changes in fish, cephalopod and plankton dispersion, distribution and abundance may affect the foraging ecology of particular marine mammal species. Often, one of the major gaps in information lies in the lack of data for non-commercial fish and cephalopod species, although even for some commercial species, such information is lacking.

c. There is a need for better understanding of how predictions from climate models relate to changes most likely to impact upon marine mammals. Overall rises in sea temperatures, for example, need to be separated from changes in the timing and location of fronts, and in turn how these may affect prey resources (abundance, distribution, and availability) and the energetics of different marine mammal predators. Models have routinely been used on marine mammal populations to better understand population dynamics and to forecast the implications of anthropogenic impacts. However, they generally face the limitations of inadequate real data, a poor understanding of mechanisms, and an inability to model those mechanisms adequately. On the other hand, they can be useful to compare alternative scenarios and hence to identify specific data gaps that if filled are most likely to allow discrimination between scenarios. Priority should be given to developing models that can integrate the demographic and spatial consequences of climate change, as well as developing full ecosystem models using top-down as well as bottom-up approaches.

4. SOCIO-ECONOMIC IMPACTS

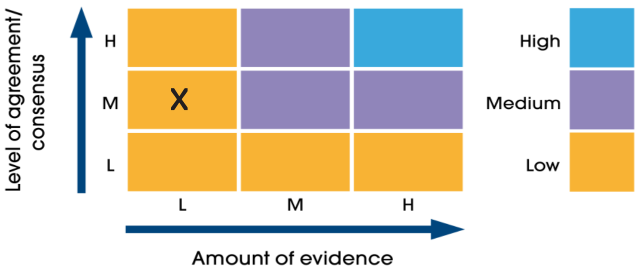
No marine mammal species in UK is exploited directly. However, changes in the status and distribution of marine mammals could potentially have commercial effects if species (e.g. minke whale, bottlenose dolphin) targeted by the ecotourism industry become scarce (Lambert *et al.*, 2010), or there are changes in competitive relations (e.g. an increase in seal predation upon commercially important fish).

If climate change affects human behaviour, for example by increased pressure on already depleted fish stocks or shifts to squid fisheries, those in turn could affect marine mammal species through their food supply. If there is increased usage of the coastal zone for particular human activities (e.g. recreation), these could impose pressures through disturbance and pollution.

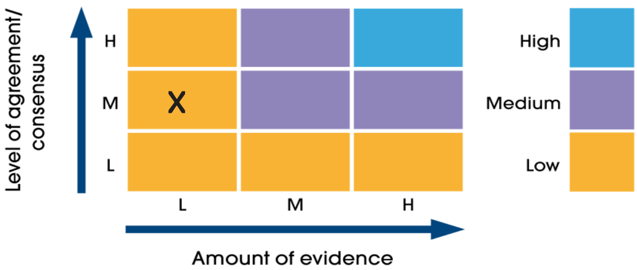
A greater emphasis upon offshore renewable energy sources such as wind, wave and tide may result in greater conflicts with marine mammal species like the harbour porpoise, bottlenose dolphin, minke whale, and harbour seal, that often forage in coastal areas and within high energy sites around headlands and island archipelagos. Negative effects include sound disturbance particularly during pile driving construction activities in the case of wind farms or physical damage in the case of tidal turbines (Carstensen *et al.*, 2006; Wilson *et al.*, 2007; Evans, 2008b; Teilmann and Carstensen, 2012). On the other hand, once wind farms are under production, it is possible they could have positive effects if they form safe havens for fish (Evans, 2008b; Scheidat *et al.*, 2011).

5. CONFIDENCE ASSESSMENT

What is already happening?



What could happen?



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