Impacts of climate change on marine mammals, relevant to the coastal and marine environment around the UK

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EXECUTIVE SUMMARY

- The main observed effects of climate change on marine mammals globally have been geographical range shifts and loss of habitat through ice cover loss, changes to the food web, increased exposure to algal toxins and susceptibility to disease.
- Climate-change impacts on marine mammals are particularly evident in polar regions where there has been physical loss of sea-ice habitat. Species most affected include polar bear, walrus, bearded seal, ringed seal, and narwhal.
- Earlier and more-extensive phytoplankton blooms in subpolar and polar regions due to increased solar radiation leading to enhanced thermal stratification and hence higher productivity may have helped population increases in some baleen whale species, such as bowhead whale.
- In mid-latitudes in the Northern Hemisphere such as around the British Isles, geographical range shifts appear to be occurring, with northward extensions of the range of warmer water species, such as striped dolphin, short-beaked common dolphin, and Cuvier's beaked whale, and possible range contractions of cold-water species such as white-beaked dolphin.
- In low latitudes where sea temperatures are highest, some species (e.g. bottlenose dolphin, baleen whales, manatees) have experienced occasional mass die-offs linked to the presence of algal toxins. These may now also be affecting marine mammal species in mid-latitudes, such as Californian sea lions and harbour seals.
- Continued rises in sea temperature could result in a shift in the species composition for cetaceans around the British Isles, with increased biodiversity particularly of subtropical and warm temperate pelagic species.
- Marine mammal species that traditionally make long-distance seasonal migrations (e.g. most baleen whales) will likely arrive earlier or remain in high latitudes for longer, with increased breeding attempts.

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- Ecosystem regime shifts in UK waters may result in lower food availability for a number of marine mammal species, and lead to re-distribution of some regional populations.

1. INTRODUCTION

Over the last decade, there has been a proliferation of studies published suggesting a number of impacts of climate change on marine mammals. These include geographical range shifts (Kaschner *et al*., 2011; Lambert *et al*., 2011; Hazen *et al*., 2013; Ramp *et al*., 2015; Nøttestad *et al*., 2015; Vikingsson *et al*., 2015; Silber *et al*., 2017), loss of physical habitat such as ice (Haug and Øigård, 2012; Stirling and Derocher, 2012; Derocher *et al*., 2013; Laidre *et al*., 2015), changes to the food web (Ramp *et al.*, 2015; Nøttestad *et al*., 2015; Vikingsson *et al*., 2015), and increased susceptibility to disease and contaminants (Hall and Frame, 2010; Twiner *et al.*, 2011; Fire and Van Dolah, 2012; Jensen *et al*., 2015; Haüssermann *et al*., 2017; Mazzariol *et al*., 2018).

Impacts have been greatest in polar regions in particular, with loss of ice (estimated at 3.5–4.1% reduction per decade since 1979 in the Arctic – IPCC, 2014) affecting ice-breeding pinnipeds such as the ringed seal, harp seal and hooded seal (Huntington and Moore, 2008; Kovacs *et al*., 2010; Johnston *et al*., 2012; Haug and Øigård, 2012; Post *et al*., 2013; Haug *et al*., 2017; Moore, 2018); range shifts (Nøttestad *et al*., 2015; Vikingsson *et al*., 2015); and changes to the food web resulting in food shortages (Bogstad *et al*., 2015) most conspicuously being experienced currently by polar bears (Stirling and Derocher, 2012; Derocher *et al*., 2013; Post *et al*., 2013; Regehr *et al.*, 2016; Harvey *et al*., 2018). At low latitudes, impacts tend to be observed through algal blooms and other biotoxins causing mass die-offs such as those of bottlenose dolphins (Twiner *et al.*, 2011; Fire and Van Dolah, 2012) and even baleen whales (Haüssermann *et al*., 2017). In mid-latitude regions, such as around the British Isles, evidence for climate change impacts is manifested mainly in the form of apparent range shifts, with warmer water cetacean species occurring more frequently or in greater abundance, and cold water cetacean species becoming less common (as reported in the previous MCCIP reviews – see Evans and Bjørge, 2013).

2. WHAT IS ALREADY HAPPENING?

Climate-change impacts on marine mammals, leading to species range shifts, are most likely to occur indirectly through influences on their ectothermic prey – zooplankton, fish, cephalopods or crustaceans (Evans *et al.*, 2010a, b).

In the North Sea, a northward shift in the distribution of zooplankton has now been well established, with a general reduction in biomass, with total *Calanus* biomass estimated to have declined by 70% between the 1960s and 1990s (Beaugrand *et al*., 2002; Reid *et al*., 2003; Beaugrand *et al*., 2010; Edwards *et al*., 2016). This ecosystem regime shift in the North Sea in the late 1980s occurred ten years later in oceanic regions west of the British Isles, and has been associated with the movement of the 10°C thermal boundary as it moves northwards in the North Atlantic (Edwards *et al*., 2013). Other climate change impacts on plankton have included changes in the seasonal timing of plankton production with repercussions on the life cycles of fish predators (e.g. sandeel) timed to exploit seasonal peaks. This in turn may affect top predators, such as seabirds and marine mammals, particularly those that have timed reproductive activities to coincide with these peaks.

A number of fish and cephalopod species have also experienced a northward shift in their distribution (Beare *et al*., 2005; Perry *et al*., 2005; Cheung *et al*., 2009). These include sardine and anchovy into waters around the British Isles (Beare *et al*., 2004), the spread of mackerel into Faroese and Icelandic waters (Astthorsson *et al*., 2012; van der Kooij *et al*., 2016a), increases in European seabass populations in the early 2000s (Pawson *et al*., 2007), and a number of squid species in the North Sea over the last 35 years (van der Kooij *et al*., 2016b). All these can have implications for the status and distribution of marine mammal species that prey upon them.

In a study of regime changes across the North-West European continental shelf between 1965 and 2012, Montero-Serra *et al.* (2015) noted that the North and Baltic Seas have shifted away from cold-water assemblages typically characterised by Atlantic herring and sprat in the 1960s to 1980s, to warmer-water assemblages typified by mackerel, horse mackerel, sardine and anchovy from the 1990s onwards, with the primary driver of change in these species being sea-surface temperatures in all cases.

The Barents Sea ecosystem has also experienced major changes in species abundance over the last four decades (Wassmann *et al*., 2006; Johannesen *et al*., 2012; Bogstad *et al*., 2015; Haug *et al*., 2017), with climate change considered partly responsible for marked increases in abundance of cod, reaching an all-time high in the most recent decade (Kjesbu *et al*., 2014). In spite of this, the growth and condition of cod has remained relatively stable (Bogstad *et al*., 2015). During the same period, the abundance of harp seals has declined whereas the minke whale stock has been at a stable level, although their body condition (as measured by blubber thickness) has decreased, particularly for harp seals. Bogstad *et al.* (2015) suggest as a possible explanation that cod are outperforming the marine mammal stocks in the competition for food. The main advantages for cod are considered to be a larger availability of food (mainly capelin) during winter–spring than for marine mammals, as well as a wider range of prey species being available to cod than to marine mammals. Harp seals are more dependent than the other two predators on prey items found close to the ice edge, which could partly explain why the condition of harp seals is worse than that of cod or minke whales.

In the Norwegian Sea, Nøttestad *et al*. (2015) assessed possible shifts in the distributional patterns of cetaceans, and related these to their feeding ecology during three summer seasons (2009, 2010 and 2012). During the previous two decades, elevated average surface temperatures were observed along with a reduction in zooplankton biomass. Over the same period, large abundances of pelagic planktivorous fish, such as spring-spawning herring, Atlantic mackerel and blue whiting were reported feeding in the region during the summer, which the authors considered were linked to the higher densities of toothed whales, killer whales and long-finned pilot whale, than the previous norm for these waters. Baleen whales, such as minke whales and fin whales, which are often associated with macro-zooplankton, also displayed a distribution overlap with pelagic fish abundances, whereas humpback whales were observed in low numbers, indicating a shift in habitat preference, compared to sighting surveys from only a few years earlier. They concluded that the study provides new evidence on high ecological plasticity in response to changing predator-prey trophic relationships and elevated sea-surface temperatures.

During the last two decades, substantial increases in sea temperature and salinity have also been reported around Iceland (Hátún *et al*., 2005). Concurrently, pronounced changes have occurred in the distribution of several fish species and euphausiids (a northward shift in summer distribution of capelin, haddock, monkfish and mackerel, a crash in sandeel abundance, and decrease in euphausiid abundance – Astthorsson *et al*., 2007; Hátún *et al*., 2009; Solmundsson *et al*., 2010; Astthorsson *et al*., 2012). The distribution and abundance of cetaceans in the Central and Eastern North Atlantic have been monitored regularly since 1987 through a series of surveys (North Atlantic Sighting Surveys) (Vikingsson *et al*., 2015). Significant changes in the distribution and abundance of several cetacean species have occurred over this time period. The abundance of humpback and fin whales has increased from 1800 to 11,600 and 15,200 to 20,600, respectively, in the period 1987–2007 (Vikingsson *et al*., 2009, 2015). In contrast, the abundance of minke whales (known to feed on sandeel, herring and capelin) on the Icelandic continental shelf decreased from around 44,000 in 2001 to 20,000 in 2007, and 10,000 in 2009. The increase in fin whale abundance was accompanied by expansion of distribution into the deep waters of the Irminger Sea, where the abundance of euphausiids (their main prey) was believed to have increased. The distribution of blue whales (feeding exclusively on euphausiids) had also shifted northwards in this period. Following the modelling of relationships to environmental variables, Vikingsson *et al*. (2015) concluded that these changes in cetacean distribution and abundance could represent a functional feeding response of the various cetacean species to physical and biological changes in the marine environment. Such ecosystem regime shifts may become more widespread if climate-change impacts accelerate.

Farther south, monitoring of cetaceans since the 1980s has involved a mixture of large-scale synoptic surveys at decadal intervals (Hammond *et al*., 2002, 2013, 2016) and more-regular regional surveys (e.g. Gilles *et al*., 2011, 2016). On occasions, the different surveys have been integrated to examine overall patterns of distribution (Reid *et al*., 2003; Paxton *et al*., 2016). The latest attempt has been a collation of survey datasets from 40 research groups representing eleven countries around North-West Europe, as part of the NERC/Defra funded Marine Ecosystem Research Programme (2013–18). A total of 2.6 million kilometres of survey effort from 1986–2016 have been analysed, with modelled predictions of density distributions and abundance trends for an area covering the North-West European continental shelf from south-west Norway to Portugal. For details of the methods used and the main results, see Waggitt *et al*. (2019).

The first analysis provided estimates of population sizes between 1985 and 2017. These were obtained from extensions of existing Species Distribution Models (SDMs) estimating distributions across seasons. Seasonal models use broad-scale environmental gradients (depth and temperature) to identify biogeographical ranges, and fine-scale habitat descriptors (seabed roughness and tidal fronts) to identify aggregations within biogeographical ranges. Inter-annual models add prominent climatic indices to this suite of environmental characteristics and habitat descriptors. These include 5-, 10- or 20-year moving averages of Atlantic Multidecadal Oscillation (AMO) and North Atlantic Oscillation (NAO). Predictions are based on the combination of variables which produce the lowest Akaike Information Criteria, AIC.

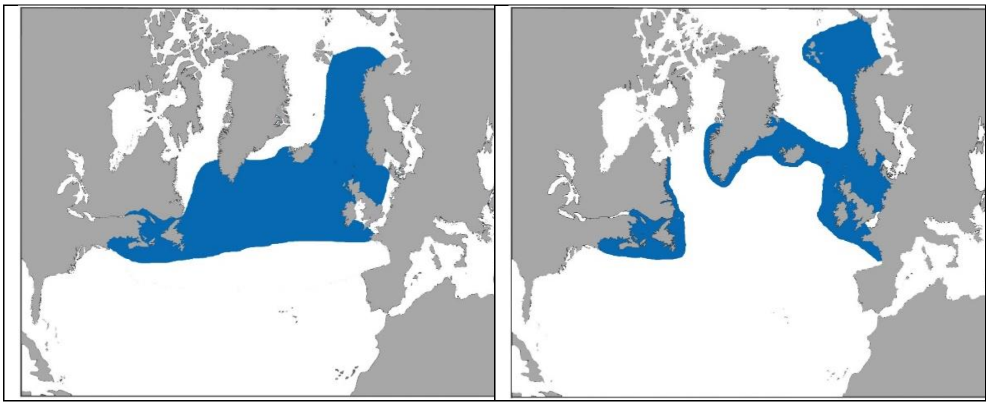


Figure 1: Main ranges of Atlantic white-sided dolphin (left) and white-beaked dolphin (right). (From Evans, 2020)

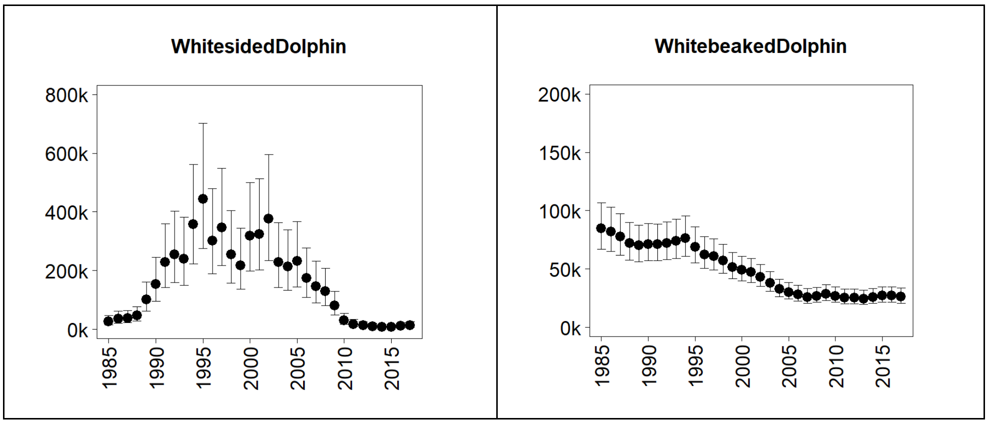


Figure 2: Abundance trends for Atlantic white-sided dolphin (left) and white-beaked dolphin (right). (MERP Project.)

Over the study area as a whole, two cetacean species (Atlantic white-sided dolphin, white-beaked dolphin) with known cold temperate to low-arctic ranges (Figure 1) have shown downward trends over the last three decades (Figure 2). At the same time, two cetacean species (short-beaked common dolphin, striped dolphin) with warm temperate ranges (Figure 3) have increased (Figure 4).

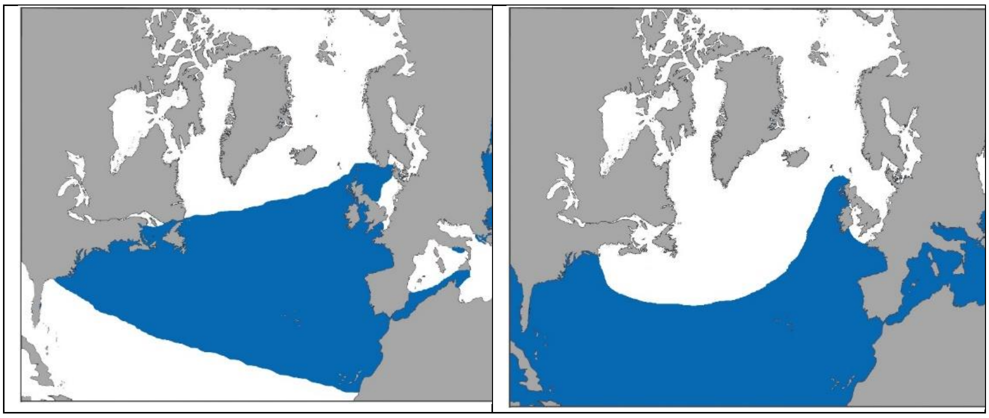


Figure 3: Main ranges of short-beaked common dolphin (left) and striped dolphin (right). (From Evans, 2020.)

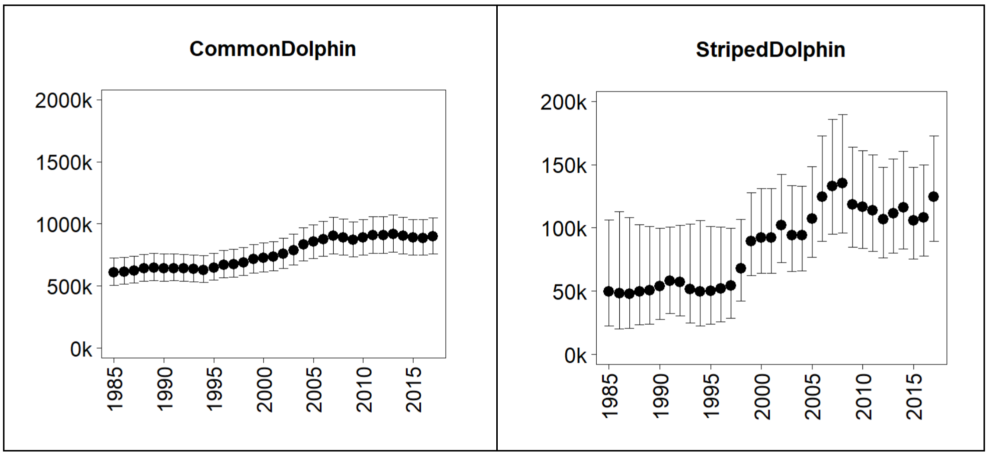


Figure 4: Abundance trends for short-beaked common dolphin (left) and striped dolphin (right). (MERP Project.)

The Atlantic white-sided dolphin favours the continental slope (mainly around 100–300m depth) and deeper waters, particularly areas of high bottom-relief and around deep submarine canyons (Evans and Smeenk, 2008a). White-beaked dolphin occurs over a large part of the North-West European continental shelf, mainly in waters of 50–100 m depth, and almost entirely within the 200 m isobath (Evans and Smeenk, 2008b). However, in west Greenland, it can be found in much deeper waters of 300–1000 m (Hansen and Heide-Jørgensen, 2013), and, in the Barents Sea, commonly at 150–200 m and 400 m depths (Fall and Skern-Mauritzen, 2014). The short-beaked common dolphin occupies both offshore habitats at depths of 400–1000 m and continental shelf seas at depths of 500–200 m, although favouring shelf-edge features (Murphy *et al*., 2008). The striped dolphin is a more offshore species, usually occurring well beyond the continental shelf in depths of >1000m, although it will occasionally come onto the shelf, where it can be recorded in waters of 60 m depth or less (Evans and Collet, 2008).

Three environmental parameters relevant to climate change have been examined: Mean Temperature within the upper 150 metres, the North Atlantic Oscillation (NAO), and the Atlantic Multi-decadal Oscillation (AMO) indices.

Sea temperature is a major driver of marine ecosystems and one of the key factors affecting the physiology and ecology of marine fish and shellfish (Pörtner and Farrell, 2008; Pörtner and Peck, 2010; Frost *et al.*, 2012; Hughes *et al*., 2017). Between 1984 and 2014, coastal water temperatures rose around the UK at an average rate of 0.28°C/decade (Hughes *et al.*, 2017). The rate has varied between regions, with the slowest warming being in the Celtic Sea at 0.17°C/decade and the maximum rate in the Southern North Sea at 0.45°C/decade.

The NAO is the dominant mode of climate variability across Europe, and has a significant impact on oceanic conditions (Visbeck *et al*., 2001; Hughes *et al*., 2017). It affects wind speed, precipitation, evaporation, and the exchange of heat between ocean and atmosphere, and its effects are most strongly felt in winter (Hughes *et al*., 2017). During winters with a strong NAO Index the ocean responds quickly and the effects can continue throughout the following year. All but one of the winters, 2012–16, have had a positive NAO index (Hughes *et al*., 2017).

The AMO index indicates the variability in sea-surface temperature in the North Atlantic (Hughes *et al*., 2017). Because of the strong links in the ocean-atmosphere system, the variability of this region has been shown to be strongly linked to decadal climate fluctuations across the Northern Hemisphere (McCarthy *et. al.*, 2015), driving variability in the UK and European climate. The AMO has remained in the positive phase since the mid-1990s, adding to the warming associated with long term global change (Hughes *et al*., 2017).

The second analysis investigated inter-annual changes in encounter rates, and correlations between encounter rates and several measurements of climate change between 1985 and 2017. Inter-annual changes were investigated using Generalized Additive Models (GAMs) (Zuur *et al*., 2009). The response variable was the number of animals encountered per 100 km of surveys per year, and the explanatory variable was year. The degrees of freedom in the explanatory variable were constrained to three. This would detect overall trends at decadal-scales and be less responsive to variation at small-scales; the later could be an artefact of heterogeneous survey effort. Correlations between encounter rates and measurements of climate change were investigated using Generalized Linear Models (GLMs) (Zuur *et al*., 2009). The response variable was again the number of animals encountered per 100 km of surveys per year, and the explanatory variable was either concurrent measurements of temperature, NAO or AMO indices. Temperature represented mean values in the North-East Atlantic, whereas NAO and AMO represented a 5-year moving average. The latter provided trends of NAO and AMO across the study period rather than sporadic variation between years. The statistical significance of inter-annual changes and correlations with measurements of climate change was assessed using F-tests and resultant p-values (Zuur et al 2009). A quasi-Poisson distribution was used throughout analyses to adjust the resultant p-values based on the over-dispersion in GAM/GLM residuals (Zuur et al 2009), providing a conservative estimate of statistical significance.

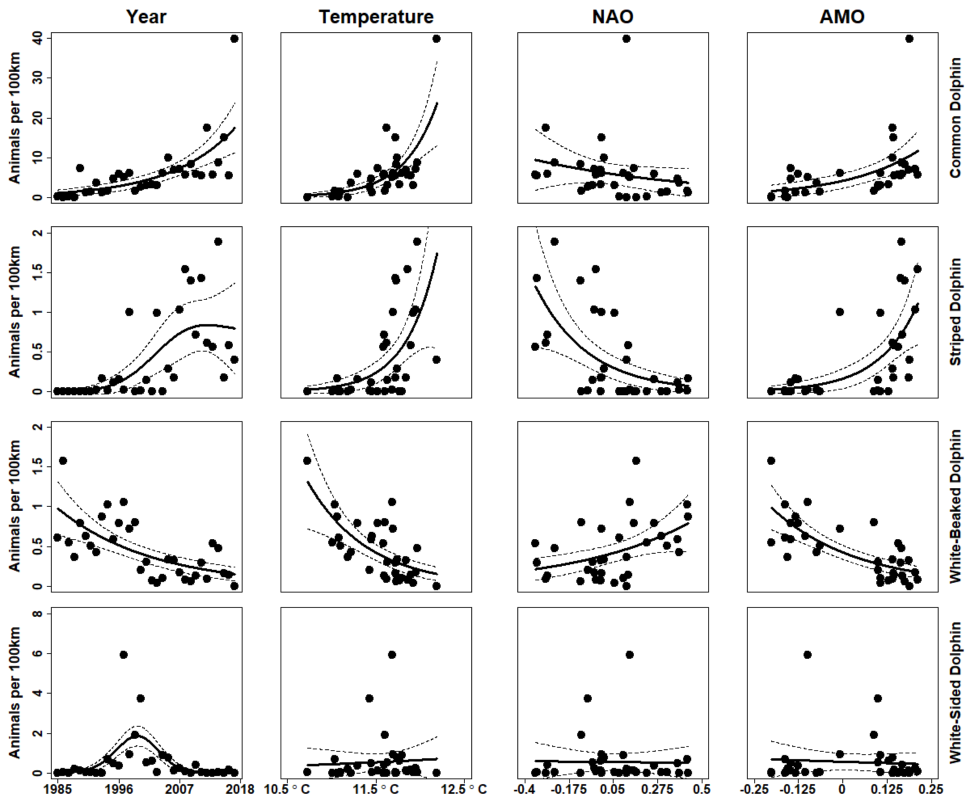


Figure 5: GAM/GLM results for common dolphin, striped dolphin, white-beaked dolphin and Atlantic white-sided dolphin shown against (a) Year, (b) Temperature, (c) NAO, and (d) AMO. (MERP Project.)

Figure 5 and Table 1 show the GLM results for four cetacean species in relation to year, temperature, NAO and the AMO index. Atlantic white-sided dolphin abundance showed no relationship to increasing temperature, whilst white-beaked dolphin, which has a more northerly distribution, showed a strong negative relationship to increasing temperature. Both short-beaked common dolphin and striped dolphin showed positive relationships, strongest in striped dolphin which is the species with the more southerly distribution. Atlantic white-sided dolphin abundance showed no relationship to NAO and AMO. White-beaked dolphin abundance showed a strong positive relationship to NAO, and negative relationship to AMO. Short-beaked common dolphin abundance showed no relationship to NAO, and positive relationship to AMO. Striped dolphin abundance showed a strong negative relationship to NAO, and positive relationship to AMO. These findings support the earlier evidence for range shifts of a cold-water dolphin species (white-beaked dolphin) northwards away from the British Isles, and of the two warmer water species (striped dolphin and short-beaked common dolphin) northwards farther into British waters.

Table 1: Statistical outputs (see Zuur et al 2009) from GAM/GLM testing for relationships between encounter rates and years/climatic variables.

Short-beaked Common Dolphin
- Year: $F_{1,32}$ = 31.31, p <0.01, deviance explained = 55% **
- Temperature: $F_{1,32}$ = 24.26, p <0.01, deviance explained = 51% **
- AMO: $F_{1,32}$ = 12.11, p <0.01, deviance explained = 36% **
- NAO: $F_{1,32}$ = 2.78, p = 0.11, deviance explained = 11%

Striped Dolphin
- Year: $F_{1,32}$ = 3.94, p = 0.03, deviance explained = 46% **
- Temperature: $F_{1,32}$ = 9.94, p <0.01, deviance explained = 29% *
- AMO: $F_{1,32}$ = 10.72, p <0.01, deviance explained = 40% **
- NAO: $F_{1,32}$ = 14.34, p <0.01, deviance explained = 37% **

White-beaked Dolphin
- Year: $F_{1,32}$ = 21.89, p <0.01, deviance explained = 44% **
- Temperature: $F_{1,32}$ = 21.98, p <0.01, deviance explained = 43% **
- AMO: $F_{1,32}$ = 34.15, p <0.01, deviance explained = 55% **
- NAO: $F_{1,32}$ = 7.24, p = 0.01, deviance explained = 20% **

Atlantic White-sided Dolphin
- Year: $F_{1,32}$ = 22.15, p <0.01, deviance explained = 57% **
- Temperature: $F_{1,32}$ = 0.11, p = 0.74, deviance explained = 1%
- AMO: $F_{1,32}$ = 0.15, p = 0.70, deviance explained = <1%
- NAO: $F_{1,32}$ = 0.01, p = 0.93, deviance explained = <1%

The results show strongest relationships with climatic variables (see Table 1) for those two species with most contrasting ranges: white-beaked dolphin which has its greatest abundance around Greenland, northern Iceland, and the Barents Sea (Galatius and Kinze, 2016) and striped dolphin which has its greatest abundance in the North Atlantic off the Iberian Peninsula and in the Bay of Biscay (Macleod *et al*., 2008).

Extra-limital records

The occurrence of rare species whose range is normally far to the north or south of the British Isles can be an indication of unusual environmental conditions favouring such an extra-limital movement. In fact, in the last twenty years, there have been unusual records both of warm-water and cold-water species. These are detailed below:

Warm-water species

Pygmy sperm whale: There have been sixteen strandings in the UK and ten in Ireland, most of which have been since 2000 (UK Cetacean Strandings Investigation Programme database).

Dwarf sperm whale: An individual was live-stranded at Penzance, Cornwall in October 2011, but was successfully re-floated. This is the first record from the UK, and the northernmost record in Europe (Evans, 2020).

Cuvier's beaked whale: Although rarely sighted in British waters, the number of strandings recorded in Britain (and Ireland) has increased markedly since the 1960s (Evans *et al*., 2008), and there have been two notable mass stranding events in north and west Scotland, one in early 2008 (Dolman *et al*., 2010) and a second between June and September in 2018 (A. Brownlow, *pers. comm.*). In the case of the latter, around eighty animals were recorded a stranded, mainly on the west coasts of Ireland and Scotland, but also as far north as Iceland. This species typically has a warm temperate to subtropical range, but recent aerial and ship-based surveys as well as acoustic monitoring have indicated that it regularly inhabits waters west of Ireland, such as within the Porcupine Sea Bight (Kowarski *et al*., 2018; Rogan *et al*., 2018). These offshore areas were not well surveyed in earlier years and so it is not possible to say whether this represents a recent northward shift in range. The steady increase in strandings in recent decades suggests it may do so although this could also reflect increased mortality linked to human activities (e.g. from naval sonar exercises which is well known to cause mass strandings in this species).

Cold-water species

Bowhead whale: A bowhead whale, possibly the same individual in all cases, was photographed in the Isles of Scilly in February 2015 and at Marazion, Cornwall in May 2016 (Evans, 2020). Later that month, a bowhead was seen and photographed in Co. Down, Northern Ireland) and in Brittany, France (Evans, 2020). During 2017, a bowhead whale was photographed at Ostende, Belgium during March–April, at Vlissingen in The Netherlands in April 2017, and in Co. Cork, Ireland in the same month (Evans, 2020).

Beluga: This species occasionally makes incursions into British waters, with 20 sightings since 1960, but no obvious trend (Evans *et al*., 2003; Sea Watch Foundation database). Most records are from Scotland and the northern North Sea, although a beluga spent several months in the Thames Estuary between September and December 2018 (Evans and Waggitt, 2019).

Narwhal: A narwhal was observed alive in the River Scheldt, Belgium, in March 2017, and later found dead in the same river the following month (Haelters *et al*., 2018a). The only sighting of a narwhal in UK waters was of two individuals off Orkney in June 1949 (Evans *et al*., 2003).

Vagrant seals: Most seal species in the North Atlantic have polar or cold temperate distributions, and therefore it is not surprising that records of vagrant seals in Britain originate from populations further north. In the last twenty years, there have been sightings of bearded seal (12), hooded seal (11), harp seal (9), walrus (4), and ringed seal (2). The majority of records come from northern Scotland, particularly from the isles of Orkney and Shetland (Sea Watch Foundation sighting database).

The sightings of cold-water species might seem anomalous in the face of patterns of general warming. However, occasional extra-limital records of Arctic species have long occurred and there is little evidence for any particular trend. The reasons for vagrancy of this nature are not well known. It may relate to poor environmental conditions within their normal range, extreme climate events, or a mixture of the two.

The opening up of the Arctic Ocean between the North Pacific and North Atlantic, may have led to the grey whale occurring again in the Atlantic after a gap of almost four hundred years, with confirmed sightings of the species in the Mediterranean Sea off Israel and Spain, in May-June 2010 (Scheinin *et al.*, 2011), and off Namibia in South-west Africa in May and June 2013 (Elwen and Gridley, 2013).

The loss of sea-ice in polar regions, however, does provide opportunities for migratory species such as baleen whales to forage in Arctic waters earlier and remain later in the feeding season (Moore, 2018). In the Pacific Arctic, belugas that migrate along the northeast Alaskan coast in summer have been shown to arrive two weeks earlier than in the 1980s, and to have extended their foraging season by at least two weeks (Hauser *et al.*, 2016).

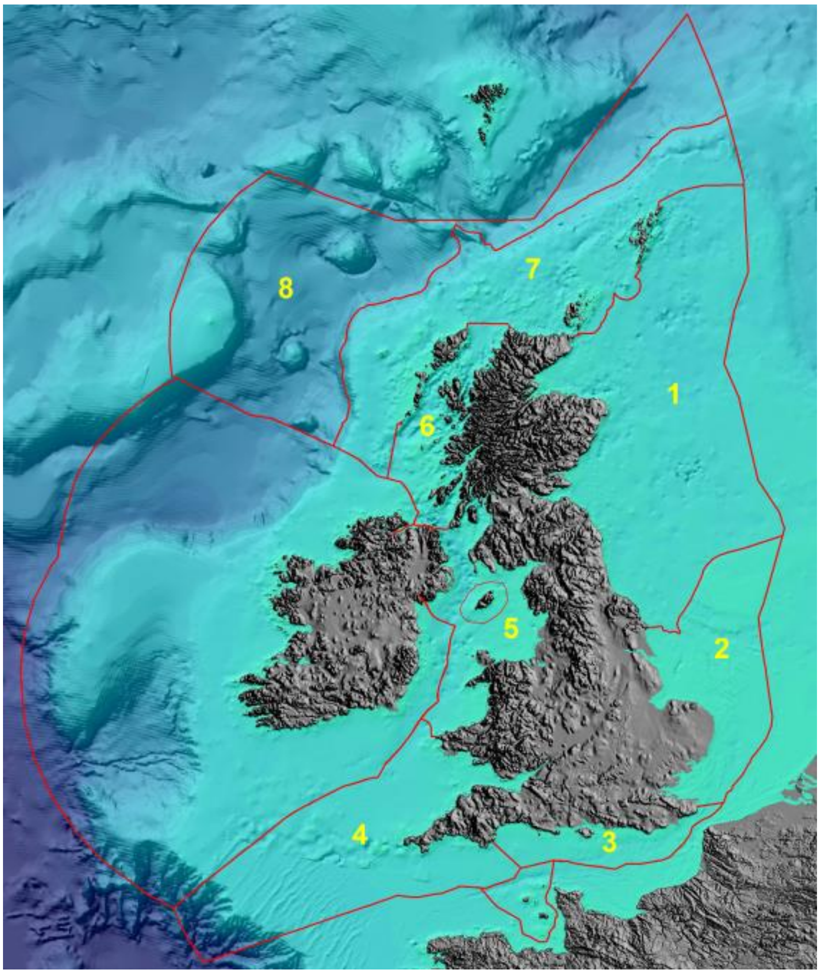


Figure 6: Map of Charting Progress (CP2) regional areas

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

Reviews of the status and trends of marine mammals in each region were given in Evans and Bjørge (2013). Much of what was written at that time still applies. Here, we focus upon any new information since 2013. For seals around the UK, we draw heavily upon the latest report of the Special Committee of Seals (SCOS, 2019), and two associated publications (Russell *et al*, 2019; Thomas *et al*., 2019). Harbour seals are surveyed at moulting haul-out sites in late summer, whereas grey seal populations are monitored by counting pups in autumn. Regions follow UK Charting Progress 2, and are depicted in Figure 6.

Northern North Sea (Region 1)

The main 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; Cheney *et al*., 2012; Evans and Waggitt, 2019). A number of species whose typical habitat is the shelf edge or beyond may also enter deeper waters of the northern North Sea. These include Atlantic white-sided dolphin, long-finned pilot whale, northern bottlenose whale, sperm whale, and fin whale (Evans *et al*., 2003; Reid *et al*., 2003; Evans and Waggitt, 2017).

Several of the trends reported by Evans and Bjørge (2013) have continued since then. Numbers of harbour porpoise appear to be stable but well below the levels of 25 years ago (Hammond *et al*., 2002, 2013, 2017). There are few records of Atlantic white-sided dolphin now in the central North Sea compared with earlier years but the species continues to occur around the Northern Isles (Evans *et al*., 2003; Reid *et al*., 2003; Hammond *et al*., 2013, 2017; Sea Watch Foundation, unpublished data). Short-beaked common dolphin and Risso's dolphin, on the other hand, have become regular visitors to the region, the latter occurring particularly off north-east Scotland, and around Orkney and Shetland (Sea Watch Foundation, unpublished data). These same coastal areas are visited particularly between May and August by pods of killer whales, where they may be observed hunting seals; some of these have been photo-identified as belonging to groups that range around Iceland where they feed on herring in the winter months (Samarra and Foote, 2015). Offshore, killer whales have been observed in large pods during autumn and winter, associated with herring and mackerel fisheries (Couperus, 1994; Luque *et al*., 2006). Changes in migration patterns and stock sizes of herring and mackerel almost certainly have determined the movements of killer whales between Norway, Iceland and northern Scotland. They may also be at least partly responsible for the steady increase in sightings of humpback whales in the north-western North Sea (Evans and Bjørge, 2013; Sea Watch Foundation, unpublished data). The coastal population of bottlenose dolphins that has long inhabited the Moray Firth is showing signs of increase and range extension, with recognisable individuals regularly occurring off east Scotland and eastern England (Cheney *et al*., 2013, 2014).

Seal populations in the region have also continued to experience trends established earlier. After a period of stability during the 1990s, harbour seals in the Firth of Tay declined by 95% over the next 15 years from *c*. 680 in 2002 to 29 in 2017 (SCOS, 2019). The bulk of the east Scotland harbour seal population now resides in the Firth of Forth. A separate population in the Moray Firth has also experienced an overall decline between counts in the 1990s and those in 2015–17, the decline being greatest between 2000 and 2003, but with no significant trend in counts since then (SCOS, 2019). The main cause for these harbour seal declines has not been established but two potential reasons currently being investigated are interactions with grey seals (both competition for food and direct predation) and exposure to toxins from harmful algae (domoic acid and saxitoxin continue to be detected in seals and their prey) (Jensen *et al*., 2015; SCOS, 2019).

Pup production at grey seal UK colonies in the North Sea overall have continued to increase rapidly up to 2016. These show an annual increase of 8% per year between 2014 and 2016, slightly less than the 10.8% per year. between 2012 and 2014, and the 12% per year rate of increase between 2010 and 2012. In the Firth of Forth, grey seal pup production increased by 5% per year between 2014 and 2016 with continued expansion of newer colonies on the mainland coast in Berwickshire. Pup production at the Farne Islands increased dramatically, by 18% per year between 2014 and 2016, after a period of little change since 2000 (SCOS, 2019).

Southern North Sea (Region 2)
The harbour porpoise is the main cetacean species in the southern North Sea. After a shift in porpoise abundance from the northern to the southern North Sea between the 1990s and 2000s resulting in an increase in abundance in this region (Hammond *et al*., 2002; Camphuysen, 2004; Camphuysen and Peet, 2006), numbers appear to have remained stable (Hammond *et al*., 2013, 2017). 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; Hammond *et al*., 2013, 2017). A recent analysis of white-beaked dolphin stranding trends along North Sea coasts between 1991 and 2017 indicates a recent decline in the south-western sector between 2009 and 2017, whereas numbers of strandings along northern North Sea coasts have generally increased over the last 10–20 years (Ijsseldijk *et al*., 2018; Kinze *et al*., 2018).

One cetacean species that has shown a marked increase in records is the humpback whale. Since the early 1990s, the species has changed its status in the region from vagrant to becoming a regular annual visitor (Leopold *et al*., 2018). The earliest records tended to be strandings, but now most records are of live sightings. Reasons for this increase are not known but the population generally in the North Atlantic has been increasing for a few decades since the cessation of whaling, whilst stocks of potential prey such as herring and sprat have been improving in the region in recent years.

The harbour seal population along the east coast of England (mainly in The Wash) declined by 52% following the 1988 Phocine Distemper Virus (PDV) epidemic. A second epidemic in 2002 resulted in a decline of 22% in The Wash, but had limited impact elsewhere in Britain (SCOS, 2019). Counts in the Wash and eastern England indicated a continued decline until 2006, then increased rapidly from 2006 to 2012, but have remained relatively constant since 2012 (SCOS, 2019). In contrast, the adjacent European colonies in the Wadden Sea experienced continuous rapid growth after the epidemic, but again, the counts over the last five years suggest that the rate of increase has slowed dramatically.

The main colonies of grey seals in the region are at Donna Nook in Lincolnshire and around East Anglia. Pup production has been increasing steadily in the region over the last two decades. The majority of the increase has been due to the continued rapid expansion of newer colonies on the mainland coasts in Lincolnshire, Norfolk and Suffolk (SCOS, 2019). Estimates are available for the ground counted colonies at Donna Nook, Blakeney and Horsey in 2015 and 2016. The 2015 counts suggest a much lower annual increase for the English mainland colonies than for colonies in the northern North Sea, with the largest colony at Blakeney showing a slight decrease after 12 years of extremely rapid (>30% per year) growth (SCOS, 2019). The same slowdown in the rate of increase has been observed at both Donna Nook and Horsey (SCOS, 2019).

Eastern Channel (Region 3)

Similar to the southern North Sea, the main cetacean species in the eastern Channel is the harbour porpoise. Since the 1990s, the species has become more common in this region (Kiszka *et al*., 2004), and is now regularly seen in good numbers (Laran *et al*., 2017; Haelters *et al*., 2018b). The other species occurring in this region include bottlenose dolphin and short-beaked common dolphin, and occasionally minke whale, whilst a small population of white-beaked dolphins continues to frequent Lyme Bay, Dorset, and adjacent waters (MarineLife, unpublished data; Sea Watch Foundation, unpublished data).

Both harbour seal and grey seal occur in the region but in low numbers. Harbour seals occur in the vicinity of Dover (Kent) and Chichester and Langstone harbours (Sussex), with some indication of an increase in recent decades, whilst grey seal records are thought to derive from colonies along the French coast or Channel Islands (Sea Watch Foundation, unpublished data; Chichester Harbour Conservancy, unpublished data). Similar increases of both species (but particularly grey seal) have been observed on the French Channel coasts, in the case of grey seal probably due to movement from the North Sea (Hassani *et al*., 2010; Vincent *et al*., 2017).

Western Channel and Celtic Sea (Region 4)
The most-common cetacean species in the region is the short-beaked common dolphin although numbers have varied over time (Hammond *et al*., 2002, 2013, 2017). Other regular species include harbour porpoise, bottlenose dolphin, Risso's dolphin, and minke whale (Sea Watch Foundation, unpublished data). There has been no obvious change in the status of those species, but most recent UK records of striped dolphin, whose range is primarily warm temperate and subtropical seas, come from this region and Irish waters (Hammond *et al*., 2017; Evans and Waggitt, 2019).

Small numbers (*c*. 350 pups in 2016) 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 (SCOS, 2019). Movements of grey seals between south-west Britain and Ireland and France have been revealed from radio-tagging studies (Vincent *et al*., 2017). Numbers of grey seals, and to a lesser extent, harbour seals have been increasing along the French coast in recent years (Vincent *et al*., 2017). In the aforementioned case, it appears to be due to immigration to the area from south-west Britain and Ireland rather than through increased local breeding production (Vincent *et al*., 2017).

Irish Sea (Region 5)
The 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). No obvious trends in status have been observed in those species since 2005 (Hammond *et al*., 2013, 2017), although there has been no annual monitoring for any of the species except for bottlenose dolphin (Lohrengel *et al*., 2017). Bottlenose dolphin numbers, monitored annually in Cardigan Bay since 2001, increased in abundance to a peak in 2007–08 but have generally declined since then, although numbers now are similar to those in 2001 (Lohrengel *et al*., 2017).

The grey seal is the only species of pinniped breeding in the English/Welsh sector of the Irish Sea. It is widely distributed in Wales, breeding in caves and on relatively inaccessible small beaches on offshore islands and in less populated parts of the mainland coast (Baines and Evans, 2012). The only sizeable breeding colony in Wales that is monitored annually is on Skomer Island, where following a period of little population growth (1993–2011), pup production has increased by an average of 10% per annum between 2011 and 2015 (Bull *et al*., 2017). The most recent data for pup production from the major breeding sites in Wales are estimates from 2016 (SCOS, 2019). Counts in 2017 were disrupted by a severe storm that reportedly killed 75% of the pups present at around the peak of the pupping season. The 2016 estimates from Ramsey and Skomer Islands have therefore been combined with earlier estimates for North Wales to derive an overall estimate for the Welsh pup production. The 2016 estimates were of 96 pups in North Wales, 465 pups in north Pembrokeshire in 2016, and 345 pups born on Skomer and adjacent mainland sites in 2016 (SCOS, 2019).

Small colonies of both grey seal and harbour seal occur in Northern Ireland, mainly in the vicinity of Strangford Lough, whilst colonies of harbour seals may also be found in Carlingford Lough, Dundrum, on the Ards Peninsula, Copeland Island and in Belfast Lough (Duck, 2003; Duck and Morris, 2012; Culloch *et al*., 2018; SCOS, 2019). Excluding years of low effort, for the whole of Northern Ireland there was a 0.1% and 0.9% annual increase in adult harbour seals and pups, respectively; and for grey seals, there was a 1.2% and a 4.9% annual increase in adults and pups, respectively, using survey data from 1995–2014 (Culloch *et al*., 2018).

Minches and western Scotland (Region 6)

Seven cetacean species occur regularly in the shelf seas of western Scotland including the Minches (Evans and Waggitt, 2019). Harbour porpoises are the commonest and most widely distributed, followed by short-beaked common dolphin, minke whale white-beaked dolphin, Risso's dolphin, bottlenose dolphin, and killer whale (Evans *et al*., 2003; Reid *et al*., 2003; Hammond, 2013, 2017; Evans and Waggitt, 2019). Less frequent visitors to the shelf waters include Atlantic white-sided dolphin, long-finned pilot whale, fin whale, and humpback whale (Evans and Waggitt, 2019). The evidence for range shifts in two species, Atlantic white-sided dolphin and short-beaked common dolphin since the 1990s has been maintained (Evans *et al*., 2003; MacLeod *et al*., 2005; Evans and Bjørge, 2013; Evans and Waggitt, 2019). Between the mid 1990s and middle of the first decade of the 21st century in particular, both Atlantic white-sided dolphin and white-beaked dolphin decreased in abundance over the region whereas short-beaked common dolphins increased, and were recorded more regularly in the north Minch (Evans and Bjørge, 2013; Evans and Waggitt, 2019). As noted previously, these apparent range shifts may reflect changing distributions of particular fish prey species in response to climate change. Minke whale numbers and distribution have also varied between years, thought to be 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. Grey seal annual pup production in both the Inner and Outer Hebrides remained relatively constant between 2012 and 2014, as has been broadly the case since the mid-1990s, but then increased between 2014 and 2016 at 6% per year in the Inner Hebrides and 5% per year in the Outer Hebrides (SCOS, 2019). However, the latest recorded increase should be treated with caution as the survey methodology changed after 2010 with greater efficiency introduced by use of improved camera technology and lower survey flight heights.

Harbour seal numbers in south-west Scotland and the Hebrides remained relatively stable between the mid-1990s and 2007–09, but since then have increased by 30%, whilst elsewhere along the west coast of Scotland numbers actually increased by 50% between 2009 and 2015–17 following a similar period of stability (SCOS, 2019).

Scottish Continental Shelf (Region 7)

This region encompasses the Northern Isles of Orkney and Shetland, the waters around the north coast of Scotland, and shelf seas west of the Outer Hebrides. Similar to the west of Scotland, the Scottish Continental Shelf 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. Along the shelf edge, the following are the main species occurring: Atlantic white-sided dolphin, bottlenose dolphin, long-finned pilot whale, and fin whale (Evans *et al*., 2003; Reid *et al*., 2003; MacLeod *et al*., 2008; Hammond *et al*., 2013, 2017; Evans and Waggitt, 2019).

For most species, long-term trends have not been established, but there has been a marked increase in reports of both killer whale and humpback whale in the region over the last decade or more, although with the rise in use of social media, this has almost certainly raised their profile amongst public observers (Evans and Waggitt, 2019). Winter associations with vessels fishing locally for mackerel and herring (Luque *et al*., 2006), and summer availability of breeding populations of harbour seals and grey seals in the Northern Isles (Deecke *et al*., 2011), may be at least partly responsible. Photo-ID matches have confirmed seasonal movements of individuals between Iceland and northern Scotland, related to changes in feeding ecology (Samarra and Foote, 2015). Harbour porpoise and white-beaked dolphin, on the other hand, have become less common in northern Scotland (Hammond *et al*. 2002, 2013, 2017; Evans and Waggitt, 2019).

Harbour seal and Atlantic grey seal both breed in the region. Harbour seals are common and widespread in Orkney and Shetland (SCOS, 2018). In Scotland, grey seals have their main breeding concentrations in Orkney and along the north coast of Scotland, but with colonies also in Shetland (SCOS, 2018).

As with northern North Sea colonies, major declines have occurred in harbour seal populations in the region, with declines of 85% in Orkney/north coast and 44% in Shetland between 1996–97 and 2015–17 (SCOS, 2019). However, whereas harbour seals in Shetland declined by 50% between 2000 and 2009, they then increased by 10% between 2009 and 2015–17 (SCOS, 2019).

Overall, there has been a continual increase in pup production of grey seals since regular surveys began in the 1960s (SCOS, 2019). In Orkney, the estimated 2016 pup production was the same as the 2014 estimate and again similar to the 2012 estimate. Pup production in Orkney increased by <1% per year between 2012 and 2016. As in the Hebrides, the rate of increase in Orkney has been low since 2000, with pup production increasing at around 1.4% per year between 2000 and 2010 (SCOS, 2019).

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

Survey effort in this offshore region has always been low, reliant largely upon occasional wide-scale northern North Atlantic surveys (referred to NASS – North Atlantic Sighting Survey) which focus primarily on waters to the north of this region. As a result, knowledge of the status of cetaceans in this particular region remains poor and insufficient to robustly assess status changes. Deepwater species typical of the main habitats in this region are the cetaceans mainly recorded: 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; Macleod *et al*., 2009; Evans and Waggitt, 2019).

In this offshore region, hooded seals, breeding and moulting further north on drifting ice in the Greenland Sea, make long-distance winter movements south from Jan Mayen as far as the continental shelf edge around the Faroe Islands and north and west of Shetland, as revealed from tracking studies (Vacquie-Garcia *et al*., 2017).

Irish Waters

In the Irish sector of the Irish Sea, the main species are harbour porpoise, short-beaked common dolphin, Risso's dolphin, and minke whale, with small numbers of bottlenose dolphin (Berrow *et al*., 2010; Baines and Evans, 2012; Wall *et al*., 2012; Rogan *et al*., 2018). Fin and humpback whale also occur in small numbers in the western Irish Sea and northern Celtic Sea (Berrow *et al*., 2010; Baines and Evans, 2012; Wall *et al*., 2012; Evans and Waggitt, 2019).

In Atlantic waters off Ireland, the species composition varies between shelf seas and more pelagic waters. Over the continental shelf, the most common and widely distributed species are harbour porpoise, short-beaked common dolphin and bottlenose dolphin (Berrow *et al*., 2010; Wall *et al*., 2012; Rogan *et al*., 2015, 2018). During aerial surveys in 2015 and 2016 (as part of the Irish ObSERVE Project), bottlenose dolphin abundance was greatest in winter (Rogan *et al*., 2018). Other typical species include minke whale and Risso's dolphin, whilst small numbers of fin whale, humpback whale, killer whale and white-beaked dolphin are regularly recorded (Wall *et al*., 2012; Ryan *et al*., 2016; Rogan *et al*., 2018; Evans and Waggitt, 2019). A small, apparently genetically isolated, resident population of bottlenose dolphin inhabits the Shannon Estuary, with numbers remaining relatively stable (Mirimin *et al*., 2011; Berrow *et al*., 2012; Nykanen *et al*., 2015; Rogan *et al*., 2015).

Beyond the shelf, the most abundant species are long-finned pilot whale, short-beaked common dolphin, and bottlenose dolphin, with smaller numbers of striped dolphin, Atlantic white-sided dolphin, sperm whale, killer whale, and various beaked whale species (mainly identified as Cuvier's beaked whale, Sowerby's beaked whale, and northern bottlenose whale) (Berrow *et al*., 2010; Wall *et al*., 2012; Rogan *et* al., 2018; Evans and Waggitt, 2019). Acoustic monitoring in deep waters beyond the shelf west of Ireland has highlighted the regular occurrence of Cuvier's beaked whale and Sowerby's beaked whale (Kowarski *et al*., 2018). It is not known whether the regular presence of Cuvier's beaked whale at these latitudes has been the case historically or is a recent trend, although strandings of this species have increased markedly in recent years (Berrow and Rogan, 1997; O'Brien *et al*., 2009; Berrow *et al*., 2010).

Both grey seals and harbour seals breed in Ireland. Harbour seals are distributed mainly on the west coast, with concentrations in Northwest 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 (such as Dundalk Bay, Lambay Island, and Wexford Harbour, as well as on the border with Northern Ireland, in Carlingford Lough) (Cronin *et al*., 2004, 2007; Duck and Morris, 2013a, b). A comparison of count from aerial surveys in 2003 and 2011–12 (Duck and Morris, 2013a, b) showed a small increase for the Republic of Ireland as a whole, but with regional differences. In Co. Galway, harbour seal numbers had increased by as much as 75%. In Counties Donegal, Mayo and Wexford there were small increases, while in Counties Sligo, Cork and Louth, they were slightly lower than in 2003. There was very little difference in numbers in Counties Clare, Kerry and Dublin (Duck and Morris, 2013a, b).

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 South-west Donegal (O'Cadhla *et al*., 2008), but with 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, 2013). There is limited information on population trends for grey seals in Ireland, but the combined estimate from counts of pup production undertaken between 2009–12 exceeded those in 2005, and were higher at all of the main breeding areas with the exception of the Saltee Islands, where a slightly lower figure was recorded in 2009 (Ó Cadhla *et al*., 2008, 2013).

Isle of Man

The waters around the Isle of Man is relatively rich in cetacean species, including the more pelagic cetacean species such as short-beaked common dolphin, Risso's dolphin and minke whale, and typical shelf species, harbour porpoise and bottlenose dolphin (Baines and Evans, 2012; Felce, 2012). The first three species are 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, although systematic annual surveys are lacking in the region (Baines and Evans, 2012; Felce, 2012).

The grey seal is the only seal species breeding in Manx waters. Although widely distributed, numbers are greatest in the south in an area encompassing the Calf of Man, Kitterland and Chicken Rock (Travers, 2005; Stone *et al*., 2012). There is no annual monitoring programme, although numbers of adults counted increased ten-fold between the 1960s and the middle of the first decade of the 21st century (Sharpe, 2007).

Channel Islands

A sizeable resident population of bottlenose dolphins inhabits the waters around the Channel Isles, particularly between Jersey and the Normandy coast (Louis *et al*, 2015). Other regular species include harbour porpoise, short-beaked common dolphin, Risso's dolphin, long-finned pilot whale and minke whale (Evans *et al*., 2003; Evans and Waggitt, 2019). Although there is no regular systematic monitoring of abundance of cetacean species in the region, none show any obvious recent change in status.

Small numbers of grey seals occur in Jersey particularly at Les Ecrehous, Les Minquiers and Iles Chausey reefs, and around La Rocque, in Guernsey (e.g. shingle bank at L'Eree), Burhou and other islets off the west coast of Alderney, at Herm (The Humps) and Sark (B. Bree and N. Jouault, pers. comm.). These sites along with others on the adjacent Normandy coast of France extending westwards to Brittany, represent the southernmost parts of the range of the grey seal, where the species has been showing a significant increase in numbers at 'haul out' sites in recent years (Harkonen *et al*., 2010; Hassani *et al*., 2010; Vincent *et al*., 2017; SCOS, 2018). Harbour seals have occasionally been recorded visiting the Channel Islands.

3. WHAT COULD HAPPEN IN THE FUTURE?

As noted in the previous relevant MCCIP review (Evans and Bjørge, 2013), responses to climate change for marine mammal species generally remain poorly understood so that predicting future impacts becomes very difficult.

At this stage, it is unrealistic to assess impacts for specific time horizons beyond anticipating that range shifts will likely continue, resulting in cold temperate to polar species potentially disappearing from UK waters whereas warm temperate and tropical species could become more regular inhabitants of British seas. Given that species diversity is greatest in tropical regions, the prediction is that a general northward shift will result in species diversity becoming higher in mid-latitudes, particularly above 40° (Whitehead *et al*., 2008; Kaschner *et al*., 2011). Inevitably, colder water species inhabiting their preferred thermal habitats will face greater pressure from global warming as they have reduced areas into which to move. In the North Atlantic, this applies to Arctic cetaceans such as the bowhead whale, narwhal and beluga, to pinnipeds such as walrus, ringed seal, bearded seal, hooded seal, and harp seal, and the polar bear.

On the other hand, the bowhead whale, the only baleen whale endemic to the Arctic, appears to be thriving during a period of rapid sea ice loss, at least in the Pacific Arctic region. There, population size has grown, calf counts have increased, and body condition of individual whales has improved over the last 25 years (George *et al*., 2015; Drukemiller *et al*., 2017). These positive outcomes have been attributed to overall expansion of primary production and an augmented food supply for bowheads due to increased zooplankton advection into the Pacific Arctic, accompanied by upwelling of prey during the extended open-water season (Moore, 2016; Moore and Reeves, 2018). While still recovering from over-harvest during the commercial whaling era, bowhead whales in the Davis Strait–Baffin Bay region also appear to be increasing (Laidre *et al*, 2015).

Using seal telemetry data and environmental grids, the Sea Mammal Research Unit has explored potential habitat shifts of both harbour and grey seals in two scenarios of climate change (from IPCC, 2014) in the North Atlantic. The low warming scenario predicted an overall compression of core habitat, with slight loss of habitat in the northern and extensive habitat loss in the southern edges of distribution in the North Atlantic. In the high warming scenario, there was a general northward shift in predicted core habitat in the North Atlantic for both species. In geographical terms the northern expansion of habitat exceeds the southern contraction so that both species would be predicted to have larger habitat extents in the future. However, specific loss of the habitat on the Scotian shelf means that areas currently holding the majority of the grey seals in the western Atlantic will likely be lost (SCOS, 2018).

Seals that breed or haul-out in low lying coastal areas will also be vulnerable to sea level rise and increased storm surges. This could become an issue in particular for seals in the southern North Sea (Evans and Bjørge, 2013; Zicos *et al*., 2018).

There is also concern that warming seas may lead to the spread of infectious diseases into new areas, novel pathogens able to survive in a different warmer climate, and greater susceptibility for marine life including marine mammals (Geraci and Lounsbury, 2002; Lafferty *et* al., 2004; Gulland and Hall, 2007; Burek *et al*., 2008; Van Bressem *et al*., 2009; Simeone *et al*., 2015; Cohen *et al*., 2018). 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).

Cohen *et al*. (2018) identify four fundamental modes through which climate change is likely to affect host-pathogen dynamics: increased heat stress, increased pathogen incidence, pathogen range expansion, and host range changes. Range expansions of pathogens into new areas where hosts may be unaccustomed to infection may result in unusually high mortality events.

Because seals must haul out on land or ice for breeding and pupping, they are at risk of exposure to both marine and terrestrial pathogens. One such example is bacteria of the genus *Brucella*, the causative agent of brucellosis. High *Brucella* seroprevalence rates have been observed among several seal species, such as hooded seals in the North Atlantic and Barents Sea (Nymo *et al*., 2011), and both grey and harbour seals along the coast of Scotland, in the North Sea, and the Baltic (Foster *et* al., 2002; Hirvelä-Koski *et al*., 2017; Kroese *et al*., 2018). It is predicted that with climate warming, *Brucella* will spread into new areas and infect new species (Cohen *et al*., 2018). However, for the time being *Brucella* is not considered to be a cause of declines in harbour seals in parts of Scotland (Kershaw *et al*., 2017).

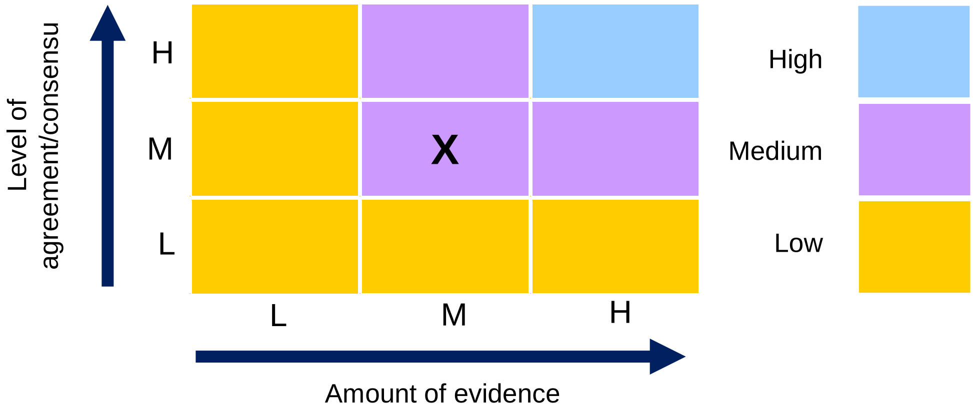
Subtle effects of pollutants (e.g. disruption of the immune, reproductive or endocrine systems) could also be exacerbated by nutritional stress brought on by reduced food availability where this is a consequence of climate change (Jepson *et al*., 2005; Hall *et al*., 2006).

The frequency and severity of toxic algal blooms (e.g. those producing domoic acid) are also predicted to increase as a result of nutrient enrichment through increased rainfall and freshwater runoff, and increased temperature and salinity (Van Dolah, 2000; Peperzak, 2003; Lafferty *et al*., 2004; Broadwater *et al*., 2018). Mass die-offs due to fatal poisonings have been reported in several marine mammal species (Geraci *et al*., 1999; Geraci and Lounsbury, 2002; Domingo *et al*., 2002; McCabe *et al*, 2016), for example Mediterranean monk seals (Hernández *et al*., 1998), California sea lions (Scholin *et al*., 2000; McCabe *et al*., 2016), bottlenose dolphins (Fire *et al*., 2007, 2008), and Florida manatees (Bossart *et al*., 1998; Hanea *et al*., 2017; Runge *et al*., 2017). They may also be responsible for increased calf mortality amongst Patagonian right whales (IWC, 2009; Wilson *et al*., 2015), and may be contributing to the observed declines in harbour seals in the North Sea (SCOS, 2018).

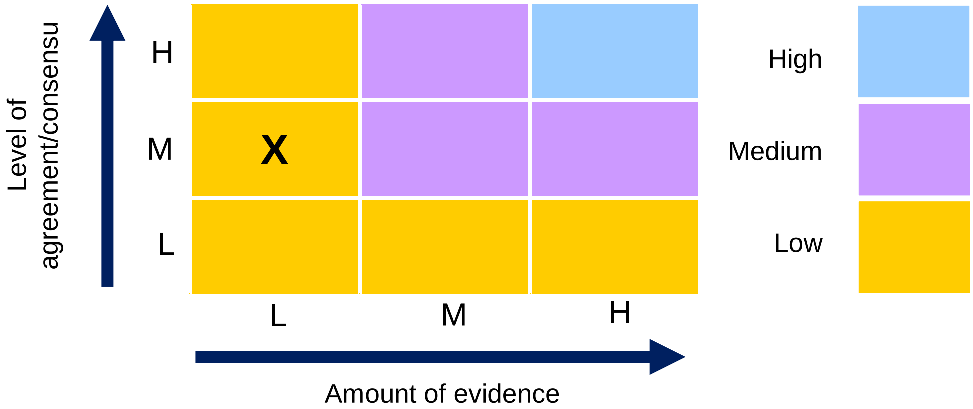
The effects of pollutants as added stressors to predators already suffering from changes in habitat and prey availability remain poorly understood (IWC, 2009). There are some suggestions that climatic warming causing changes in temperature, precipitation, and weather patterns, will alter the pathways (e.g. persistence), and concentrations of pollutants entering more pristine regions via long-range transport on air and ocean currents (MacDonald *et al*., 2005; Mazzariol *et al*., 2018).

4. CONFIDENCE ASSESSMENT

What is already happening



What could happen in the future?



Over the last two decades, the evidence for range shifts in a number of cetacean species (e.g. short-beaked common dolphin, striped dolphin, Atlantic white-sided dolphin, white-beaked dolphin), reported earlier in several publications (Evans *et al*., 2003; Macleod *et al*., 2005; Evans *et al*., 2010; Evans and Bjørge, 2013) has strengthened. Further north in polar regions, there is now substantial evidence for impacts upon polar species of marine mammals (seals, polar bear, narwhal, baleen whales) through melting of ice and ecosystem changes to plankton and fish communities (for example, IWC, 1997; Würsig *et al*., 2002; Derocher *et al*., 2004; Kovacs and Lyderson, 2008; IWC, 2009; Kovacs *et al*., 2010; Kaschner *et al*., 2011; Laidre *et al*., 2015; Frederiksen and Haug, 2016). As a result, our confidence in what is already happening to at least some species of marine mammal, and level of agreement, may now be regarded as medium rather than low. Regarding predictions for the future, there is general consensus that the effects currently observed will continue although how those effects are mediated for different species remains poorly understood.

5. KEY CHALLENGES AND EMERGING ISSUES

Some of the same key challenges apply as were highlighted in the previous MCCIP review (Evans and Bjørge, 2013). This remains the case for **monitoring changes in distribution and abundance** of most cetacean species. Up to now, insufficient resources have been available for wide-scale abundance surveys at more frequent than decadal intervals. The patchiness in space and time of regional surveys presents challenges in tracking longer term trends whereas the large-scale surveys are unable to identify inter-annual variation. The NERC-Defra funded Marine Ecosystem Research Programme has attempted to address this by collating data from as large a range of regional surveys as possible, and then using modelling approaches to help fill gaps in coverage where they apply (Waggitt *et al*., 2019). Unless greater resources are made available, uneven coverage in space and time will continue to be a constraint when attempting to interpret trends in these highly mobile animals.

Marine mammals, particularly cetaceans, are difficult to study because of their relative inaccessibility. Although new technologies are constantly evolving to aid research, this continues to limit the study species, so that in NW European seas our knowledge is better for the commoner and more accessible species such as harbour porpoise, bottlenose dolphin, and short-beaked common dolphin, than for offshore deep water species such as blue whale, Cuvier’s beaked whale, and pygmy sperm whale. These limitations need to be considered when drawing general conclusions over climate change effects across taxa.

The main consequence of climate change that we predict for cetaceans around the British Isles is that of range shifts. This may actually lead to increased diversity of species at those mid-latitudes, and perhaps increased abundance for some of those species for which Britain currently forms the northern limit of their range. On the other hand, species of low latitudes in the North Atlantic often experience different human pressures. If they increasingly occupy north-west European seas, particularly those within the coastal zone, they will be exposed to a more industrialised environment with a greater variety of human pressures. Thus, it is important that attention be paid to the investigation of potential **cumulative effects**. This area of study is still in its infancy, and providing a quantitative description of synergistic effects of multiple stressors presents many challenges.

We are still far from understanding effects upon top predators resulting from the impacts at lower trophic levels that may occur more directly. Those linkages need to be explored further. In this context, **ecosystem models** need further development, particularly incorporating the upper trophic levels. This requires more information on regional and seasonal variation in marine mammal diets, potential prey preferences, the effects of prey availability and quality upon marine mammal energetics, and how this may influence population processes.

Most species of seal and cetacean are believed to have varied diets, and are capable of switching from one prey to another in response to their availability. However, it is poorly understood whether shortages of particular prey species affect fecundity or survival in seals or cetaceans, or simply lead to movements to new areas. In the UK, pup production in Atlantic grey seal populations has been steadily increasing in the North Sea including Orkney over the last 15 years but has been stable in the Hebrides (SCOS, 2018). Harbour seal numbers, on the other hand, have fluctuated, with declines in Scottish waters following phocine distemper virus epidemics in 1988 and 2002 (SCOS, 2018). Populations in south-west Scotland, east Scotland, and the Moray Firth have shown little change over the last 25 years whereas over the last ten years or so they have declined in Orkney and along the north coast of Scotland and increased in west Scotland (SCOS, 2018). Causes for these variations in population demography have been investigated but remain unclear. Detailed information on fecundity and survival rates are lacking, particularly at the regional level. A wide range of potential causes have been considered and causal mechanisms identified, several of which have now been ruled out as primary causes (SCOS, 2018). Research efforts currently focus upon interactions between grey seals and harbour seals, and exposure to toxins from harmful algae, both of which may relate to secondary effects of climate change. However, the factors driving population change in seals (and other top predators) are likely to be many and varied, and interdependent, some of which might be linked to climate change. It will always be challenging to disentangle these and identify ones linked largely to climate change.

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