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Climate Change and Cetaceans – an update.

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Abstract
A brief update on the latest literature is provided in the context of predicted and observed reactions from cetaceans to climate change. Increases in sea surface temperature (SST) and other climate-related alterations to ocean conditions in many regions are already influencing cetacean habitat use and prey availability. Some species in some localities seem to be exhibiting an ability to adapt, at least to some extent in the short-term, whilst others, such as the bowhead whale, may have only a limited ability to find alternative habitat. Climate-driven changes act synergistically with other stressors and threats putting further pressure on individual cetacean welfare and the conservation status of populations. Threats may increase in some regions as humans change their behaviour in response to climate change, for example through increased shipping in areas that were previously inaccessible due to sea ice cover. It is time for climate change to be treated as an urgent issue affecting cetacean welfare and conservation.

Introduction

The marine environment is experiencing climate-related changes including increased sea surface temperature (SST), decreasing ice cover, rising sea levels and changes in ocean circulation, salinity, rainfall patterns, storm frequency, wind speed, wave conditions and climate patterns, all of which are affecting cetaceans and their prey (Learmonth et al., 2006; Silber et al., 2017). Alongside these factors, an increase in the amount of CO_2 being absorbed by the ocean is also lowering the pH of the seawater, leading to ocean acidification, which amplifies the adverse effects of global warming (Pace, Tizzi and Mussic, 2015; IPCC, 2018). Deoxygenation is another associated stressor and, globally, the world's oceans have lost about 2% of their oxygen, although in some areas oxygen levels have reduced by as much as 33% since the 1960s (Laffoley and Baxter, 2018).

Understanding the mechanisms through which climate change will impact any given species is now a significant challenge facing those working to conserve and manage wildlife (Frederiksen and Haug, 2015). Scientists are striving to use their increasing understanding to predict future consequences for marine mammals (Simmonds, 2016). The International Whaling Commission (IWC), for example, has held a series of workshops about climate change and has highlighted, among other things, the need to understand the relationship between cetacean distribution and measurable climatic indices such as SST (IWC, 2010).

The impacts of climate change on cetaceans can be direct, such as changes in water temperature causing physiological stress, or indirect, such as changes in prey availability (Learmonth et al., 2006). Subsequent results can include changes in distribution, abundance and migration patterns, presence of competitors and/or predators, community structure, timing of breeding, reproductive success and survival (Learmonth et al., 2006). Other potential outcomes of climate change could be more dramatic such as the appearance of epizootics leading, initially, to population crashes (Simmonds, 2016) and followed by longer term problems (Verborgh et al., 2019).

It is estimated that human activities have caused approximately 1.0°C of global warming above pre-industrial levels to date (IPCC, 2018). At the current rate of increase, global warming will reach 1.5°C between 2030 and 2052. This increase is predicted to shift the ranges of many marine species and to damage ecosystems. According to the IPCC (Intergovernmental Panel on Climate Change), if global warming is limited to 1.5°C (compared to 2°C) increases in ocean temperature and acidity will be constrained, as will decreases in ocean oxygen levels (IPCC, 2018). The IPCC is currently preparing a special report on how climate change is affecting the oceans and the cryosphere (IPCC, 2019).

Methods

This short review is based on literature searches using the Web of Science/Biosis database and Google Scholar with a particular focus on publications in the last few years. It is intended to provide a brief update to earlier reviews such as Simmonds (2016).

Ocean Warming and Sea Surface Temperature (SST)

Global sea surface temperatures (SSTs) have been increasing steadily since the 1970s, with more rapid increases in some areas, such as Europe, compared to the global average (Reid, 2016). In northerly European waters, there have been elevated sub-surface temperatures in the Norwegian Sea (Nøttestad et al., 2015), whilst waters around Svalbard have been warming which has contributed to a decline in sea ice (Descamps et al., 2017). Sea temperature and salinity have also increased in Icelandic waters (Víkingsson et al., 2015). Monitoring of seawater temperature in the Balearic Islands in the Western Mediterranean found that the average annual maximum temperature for 2002-2006 was 1°C above the mean maximum temperature (MMT) of 26.6°C that was recorded in the period 1988-1999 (Marbà and Duarte, 2010).

Modelling by Tulloch et al. (2019) found that in the southern hemisphere, ocean warming is predicted across all latitudes with the greatest warming between 40°S and 60°S by the end of the 21st century. Changes in SST will be highest in the Atlantic/Indian region with an average 2.5°C warming in 40-50° and 2.2°C warming in 50-60°, although in some areas SSTs may increase by 5°C by 2100.

The distribution of marine mammals is controlled by a combination of demographic, ecological, evolutionary, habitat-related and man-made factors

(Learmonth et al., 2006) and the strong associations between cetacean distributions and those of water bodies, boundaries and temperature regimes have long been recognized (Gaskin, 1982). For example, some cetacean species are only found in Arctic waters. Chambault et al. (2018) recently reported that bowhead whale (*Balaena mysticetus*) movements in West Greenland were closely associated with SST and that this species typically only experienced very limited temperature variations (means: -1.6 ^{o}C to 2.7^{o}C). Interestingly, bowheads leave the highly productive waters in Baffin Bay before the peak zooplankton bloom, suggesting that their movements are not related to prey availability but, rather, to remaining in cooler waters. High temperatures, such as summer temperatures in Disko Bay which reach 9^{o}C, could cause hyperthermia for bowheads which have limited ability for heat exchange (Chambault et al., 2018).

In Oceania, breeding grounds used by humpback whales (*Megaptera novaeangliae*) are likely to be impacted by rising SSTs making some currently used areas unsuitable (Derville et al., 2019). However, as humpbacks seem more flexible in terms of their habitat usage and their thermal tolerance, there is perhaps potential for them to move to new breeding areas.

When selecting habitat in the Ligurian Sea, fin whales (*Balaenoptera physalus*), striped dolphins (*Stenella coeruleoalba*) and sperm whales (*Physeter macrocephalus*) are all also influenced by SST and, therefore, distribution of cetaceans in this area may alter in response to climate change (Azzellino et al., 2008). Likewise, a rise in SST in the Alboran Sea (the most western part of the Mediterranean) is predicted to reduce the suitable habitat available for common dolphins (*Delphinus delphis*) (Cañadas and Vázquez, 2017). As this subpopulation has already been listed as endangered in the IUCN Red List due to declines in numbers over recent decades, this could have serious implications.

Extreme weather, such as the heatwave that affected Shark Bay in Western Australia in 2011 and caused coastal water temperatures to rise 2-4^{o}C above average for over two months, can have immediate repercussions for cetaceans (Wild et al., 2019). After the Shark Bay heatwave, female reproductive rates in Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) declined significantly and survival remained lower in the seven years following the heat wave compared to before. The marine heatwave damaged 36% of seagrass meadows which, in turn, had an impact on fish stocks. This lower prey availability may have meant that female dolphins had to spend more time foraging and, therefore, calves were more at risk of shark predation. Reductions in prey availability can also lead to increased abortion rates and neonate mortality if the mother and calf's nutritional requirements are not met. Reduced fertility is another potential consequence when prey is lacking.

Abundance and distribution

Changes in abundance and distribution of some species have been recorded and linked to climate change in recent years. Since 1987, the abundance of Central North Atlantic humpback and fin whales in Icelandic waters has increased and the abundance of common minke whales (*Balaenoptera acutorostrata*) on the Icelandic continental shelf has decreased (Víkingsson et al., 2015). Blue whale

(*Balaenoptera musculus*) distribution has also altered with a shift northwards (Víkingsson et al., 2015). In the North Atlantic, models have predicted that species that favour warmer waters (e.g. striped dolphin) will expand northwards and that cooler water species (white-beaked dolphin (*Lagenorhynchus albirostris*), northern bottlenose whale (*Hyperoodon ampullatus*) and minke whale) will contract their range northwards (Lambert et al., 2014).

The apparent upward trend in Antarctic minke whale (*Balaenoptera bonaerensis*) numbers seen over the last century in the southern hemisphere is predicted to slow in the Atlantic/Indian region and to reverse in the Pacific over the next 100 years (Tulloch et al., 2019).

Aerial surveys in the Chukchi Sea did not record any sub-Arctic cetaceans in the period 1982-1991, whereas there were 159 sightings of 250 individuals in 2008-2016 including 123 humpbacks, 84 fin whales and 43 minke whales (Brower et al., 2018). These increased sightings may be affected by increased survey effort but other factors may be moving these species into new areas including increases in primary production and the effects of climate change such as summer sea ice melting earlier and in greater quantities.

Ocean productivity and prey availability

Large-scale changes in prey can impact cetaceans but small-scale oceanographic features associated with krill abundance can be important for some species such as blue whales (Silber et al., 2017). In the southern hemisphere, climate change is predicted to lead to reductions in krill biomass which will subsequently have an impact on many baleen whale species causing population declines (Tulloch et al., 2019). Models indicate that fin whale populations in the southern hemisphere will only be at 5% of pre-commercial whaling numbers by 2100 because of projected changes in temperature, chlorophyll and primary productivity (Tulloch et al., 2019). In the Pacific, populations of fin whales and southern right whales (*Eubalaena australis)* are predicted to go extinct before 2100 and blue whale numbers are expected to be <1% of pre-commercial whaling numbers. In the Atlantic and Indian Oceans, population declines are not expected to be as extreme.

Anthropogenic CO_2 concentration in the Mediterranean is higher than in other marginal seas and in the Atlantic and the Pacific at the same latitude, and acidification has been detected in Mediterranean waters (Pace, Tizzi and Mussic, 2015; Lacoue-Labarthe et al., 2016). Combined with rising temperatures, acidification may impact cetaceans for example by affecting the availability of their prey (Pace, Tizzi and Mussic, 2015; Lacoue-Labarthe et al., 2016). Long-finned pilot whale (*Globicephala melas*) distribution and population structure in the Mediterranean may be affected by climate change and ocean acidification as some of their prey, e.g. squid, is sensitive to temperature and ocean acidification (Verborgh et al., 2016). Lacoue-Labarthe et al. (2016) identified a number of ways in which ocean acidification in the Mediterranean will affect the trophic web, such as a reduction in productivity of seagrass (*Posidonia oceanica*), and impacts on productivity and biodiversity of phytoplankton and zooplankton.

These changes will, in turn, affect higher levels of the food web. Deoxygenation of the ocean due to warming is another threat to ocean productivity and marine species and could be a particular problem in enclosed areas such as the Black and Baltic Seas (Reid, 2016).

Biological Timing Issues

Many cetaceans are migratory, ranging from bigger species that regularly oscillate between polar feeding grounds and warm breeding grounds to smaller species that regularly move between inshore and offshore areas. The animals need to find certain conditions for their survival and the timing of migrations allows exploitation of resources such as the spring bloom of prey in the Arctic. However, climate change may affect the timing of key phenomena causing whales to arrive out of sync with the resources that they seek (Simmonds and Elliott, 2009). In the Norwegian Sea, some shifts in the distribution and abundance patterns of cetaceans have recently been linked to changing levels of abundance in their prey and elevated sea surface temperatures (Nøttestad et al., 2015). Similar plasticity in behaviour has been suggested for fin whales in the Mediterranean (Notarbartolo di Sciara et al., 2016). However, the extent that populations will be able to respond to changing conditions is unknown.

Ability to adapt

Some species of cetaceans, for example dolphin species which range across large areas and work together to find prey, may be able to adapt to the changes in their environment caused by climate change (Simmonds, 2017a). In the Norwegian Sea both large and small cetaceans have demonstrated adaptive search behaviour in reaction to changes in levels of prey abundance (Nøttestad et al., 2015). As macro-zooplankton becomes less available because of higher temperatures there, fin whales and minke whales have adapted their feeding to focus more on pelagic fish such as Norwegian spring-spawning herring (*Clupea harengus*) (Nøttestad et al., 2015).

Belugas (*Delphinapterus leucas*) in Svalbard continue to use glacier fronts as foraging areas but, following recent declines in sea ice, have started to spend more time in the fjords of west Spitsbergen during summer and autumn (Vacquié-Garcia et al., 2018). This suggests a change in diet, or at least a broadening of their diet, as they start to feed more on Atlantic fish species which are arriving in the fjords with warmer Atlantic water (Vacquié-Garcia et al., 2018). This behavioural flexibility may help belugas adapt to changing conditions in Svalbard. Something similar is happening in Icelandic waters where the changes to sea temperature and salinity have been accompanied by a change in the distribution of a number of fish and krill species and the distribution and abundance of several species of cetaceans (Víkingsson et al., 2015).

The Mediterranean fin whale, because of their nomadic and opportunistic lifestyle, may also have some ability to adapt as climate change and ocean acidification affect marine productivity patterns and fin whale prey (Notarbartolo di Sciara et al., 2016). Humpback whales have also shown themselves, to some extent, to be adaptable feeders when climactic conditions have changed (Fleming et al., 2016).

It is predicted that baleen whales feeding in mid-latitude areas in the southern hemisphere will be more affected by changes in prey availability due to climate change than those whales further south (Tulloch et al., 2019).

Inability to adapt and loss of habitat

Some cetaceans, such as those which inhabit continental shelf areas, may find that continued changes in temperature, and/or prey availability, make their home area inhospitable (Simmonds, 2017a). For example, McLeod et al. (2008) predicted that white-beaked dolphins living in shelf waters off the United Kingdom and Ireland might experience increased sea temperatures leading to a contraction in their range. Modelling conducted by Lambert et al. (2014) predicted that suitable habitat for this species will see an 80% reduction by 2060 in UK and Irish waters (in medium or high emission scenarios). They also predicted that the southern part of the North Atlantic minke whale's range will see a reduction in suitable habitat and feeding opportunities by the 2080s (in medium and high emission scenarios) (Lambert et al., 2014).

Species with restricted habitats where there is little opportunity to disperse to new similar habitat areas may be especially affected. For example, it has been suggested that beaked whales which rely on deep sea trenches might be unable to adapt to changes in conditions such as temperature increases or reduction of prey (Simmonds, 2016). Similarly, cetaceans that live in enclosed areas - such as the three delphinid species resident in the Black Sea (short-beaked common dolphin, Black Sea bottlenose dolphin (*Tursiops truncatus ponticus*) and harbour porpoise (*Phocoena phocoena*)) - may be unable to adapt (Simmonds, 2017a).

Sousa et al. (2019) assessed seven cetacean species in the waters around Madeira to rate their vulnerability to climate change and determined the sperm whale to be most vulnerable, followed by the fin whale, bottlenose dolphin (*Tursiops truncatus*) and Bryde's whale (*Balaenoptera brydei*). Sperm whales were found to be particularly vulnerable because of their low genetic variability and diet diversity, their IUCN Red List status (vulnerable) and their migratory behaviour (Sousa et al., 2019).

Human Behaviour, Cetacean Welfare and Synergies

Climate change will cause humans to alter some of their behaviours, potentially adversely impacting cetaceans (Simmonds, 2017a). For example, if humans become more reliant on marine species as food, cetaceans may face increased prey depletion and bycatch or even being taken directly (Alter et al., 2010). If the availability of prey is reduced to a point where individuals are unable to find enough food, they will suffer from poor nutrition leading to health problems and, potentially, starvation (Simmonds, 2017b).

Potential increases in aquaculture could lead to local eutrophication and conflict with marine mammals (Alter et al., 2010). Other human-mediated effects might include: more coastal construction work, increased exposure to pollution and pathogens and an increase in disasters such as oil spills as vessels move into new areas (Alter et al., 2010).

Increased shipping in some areas is also likely under a changing climate (Alter et al., 2010). For example in the Bering Strait, changes in seasonal ice conditions and improvements to vessels have lead to increased shipping which puts species such as the fin, humpback, minke and grey whale at increased risk of ship strike (Morse, 2016). Human activities and how they affect species' vulnerability to climate change need to be researched further (Sousa et al., 2019).

The welfare of individual animals should also be taken into account. Welfare will be impaired, for example, if individual cetaceans find their ability to feed and reproduce is impacted or their health otherwise compromised or if the temperature of the water increases to an uncomfortable level. Climate-driven changes will act synergistically with other stressors, including ocean acidification, pollution, including from PCBs (persistent polychlorinated biphenyls), and other threats (Simmonds, 2017b; Jepson et al., 2016).

Indeed, how cetaceans are impacted by climate change needs to be considered alongside other threats to their health and wellbeing. For example, Jepson et al. (2016) reported that certain European cetaceans are particularly at risk from PCBs contamination. The resulting immunosuppression and reproductive failure which this contamination can produce, when combined with changes in the marine environment due to climate change, may make some cetaceans more susceptible to disease (Jepson et al. 2016; Simmonds, 2016; Simmonds, 2017b).

Conclusions

Ten years ago, Simmonds and Eliott (2009) wrote:

"There is widespread acceptance that climate change generally poses a threat to cetaceans, although the potential for perhaps short-term gain for some more adaptable populations has also been mooted. The need for multinational large scale and long-term work to better understand risks is clear and leadership is coming from appropriate international bodies. However, such bodies will need to give appropriate priority to these endeavours and allocate adequate funding. This may require international bodies and supporting governments to rise above institutional constraints or attitudes that would otherwise slow or fail to prioritize climate change-related research and implementation of remediation measures."

They also called for a 'new paradigm' in conservation with swifter and more precautionary actions being taken to manage emerging developments and changes as they arise.

In 2019, as this review helps to illustrate, we have improved predictive power, some disturbing predictions and more direct evidence about the reactions of cetaceans to a changing climate. However, any new conservation paradigm is yet to be realised and, similarly, we see little sign of new major international effort to look at this issue.

More positively, increased knowledge about how cetaceans might respond to changes in their habitats due to climate change, should allow better conservation decisions to be taken.

Until climate change and loss of biodiversity are universally recognized as major threats, there remains an impediment to the expeditious action that is urgently needed. There are both significant scientific and communications challenges ahead which include recognising the full importance of marine biodiversity, including the cetaceans, to the future health of our planet and the stepping up of protective actions.

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