Climate change and cetaceans: an update

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Abstract

Climate change and related threats to cetaceans have been on the agenda at the IWC since 1995. We consider here how, in the intervening 18 years, the goals for this work have developed and consider its current status. In addition, we summarise some of the most recent relevant literature.

1. Introduction

The first climate change workshop took place in 1995 following a call from the IWC Scientific Committee in 1993 for a workshop entirely devoted to reviewing and considering potential threats to cetaceans posed by a changing climate. At this stage, the Second Assessment Report (SAR) of the IPCC had been commissioned, and was published the following year predicting future global mean temperature change and sea level rise, with human activity cited as the likely driver of 'irreversible and unprecedented' changes to the global climate. (Houghton *et al*. 1996)

The first workshop (CC1) agreed that cetaceans would be adversely affected by increasing water temperature (IWC 1997) and that the most important impact was expected to be mediated via changes in prey distribution. It also noted that current climate change models had limitations in their predictive capabilities. Because of this, coupled with insufficient data on cetacean responses to climate change, it was concluded that considerable further research would be required to accurately predict the impacts of climate change on cetaceans. A key recommendation of CC1 was that the Scientific Committee and Commission consider ways in which to facilitate such research.

Over the following years, further emerging threats to cetaceans were identified and, in 1998, the effects of habitat degradation were identified as a priority area for research leading to a workshop on the subject in 2005 (IWC 2006). A Resolution passed in 1999 by the IWC requested that the Committee 'give high priority to proposed research on environmental factors...to identify and evaluate effects of environmental change on cetaceans in all priority areas.'

In 2007, the 2nd Climate Change workshop was proposed and in the following year it was agreed that it should provide:

- Expert statement on current understanding of the impacts of climate change on cetaceans
- Advice related to cetacean conservation and the aims of the IWC
- Advice for future research

In addition, the American Cetacean Society held a climate change focussed meeting entitled 'Whales in a Changing World' in 2008, and a further climate change workshop was held in Costa Rica, focussed on adaptation in the Eastern Pacific. It was recognised at this 2009 Workshop that adaptation for cetaceans may be more problematic than for other species, as migration and relocation into suitable habitat could not be expected to simply track polewards (Hoffman et al. 2009).

In 2007, the fourth IPCC Assessment on Climate Change (IPPC, 2007) was published, predicting a global increase in surface air temperature of between 1.8 and 4 °C over the next 100 years, and a sea level rise of between 18 and 59cm. AR4 notably reported that "*observations since 1961 show that the ocean has been absorbing more than 80% of the heat added to the climate system, and that ocean temperatures have increased to depths of at least 3000 m (9800 ft). Losses from the land-based ice sheets of Greenland and Antarctica have very likely (>90%) contributed to sea level rise between 1993 and 2003. Ocean warming causes seawater to expand, which contributes to sea level rising*."

The 2nd Climate Change Workshop (CC2) was convened to a backdrop of growing concern regarding the rate of global environmental change, and the potential extent of its impacts. Interest and research effort was focussing on disruptive impacts on ecosystems and difficulties in accurately predicting climate change response at a species level in order to mitigate effectively.

From this workshop came recommendations focused on developing more accurate models and quantifying levels of uncertainty; and further research to better understand the link between climate and cetacean distribution. CC2 also recommended that work continue on three themes:

1. Single species, regional contrast
2. Trophic comparison of 3 levels within the same region
3. Distribution shift – where data is sufficient to detect a change in distribution related to ecosystem parameters, to investigate whether this is attributable to climate change

In 2010, the Scientific Committee reviewed progress from CC2 (IWC 2010). A third climate change workshop had been proposed during CC2 with a focus on small cetacean species, which had not been adequately considered during CC2, and the relevance of ‘restricted habitats’ in the context of climate change driven range changes.

From this third workshop (CC3), held in Vienna in 2010, came particular concerns for the smaller non pelagic cetacean species with habitats restricted through the presence of physical barriers, e.g. riverine species, or populations residing in bays or coves (IWC 2012). Such species and populations were identified as particularly vulnerable because of their limited ability to migrate away from adverse changes.

Again, this workshop recognised that an improved understanding of how cetaceans interact with their environment is required, in order to accurately predict any expected response to change. Long term datasets were referenced for their validity in investigating these relationships. The workshop encouraged both further research, building on this ‘library’ of databases, and also that existing datasets of relevance should be identified and analysed.

Among the key outcomes of CC3 were the call for a global review on restricted habitats, and the recommendation that a list of priority species be drafted in context of the IUCN Red List, assessing the relative vulnerability and resilience of species to climate change.

An intersessional correspondence group was next established, with the goal of developing a global review of restricted habitats for small cetaceans. Following the 2012 Scientific Committee review of climate change, the working definition of restricted habitats was adapted and extended to conditions where: (1) the species/population has narrow habitat requirements; (2) the habitat is bounded by physiographic or oceanographic barriers; and (3) other suitable habitat which the population might be able to access is unavailable because it is occupied by competitors’ - the relevance being that the terminology could now be applied to larger cetacean species in addition to those restricted in the literal sense, via physical barriers.

At last year’s Scientific Committee review of climate change, no updates were given on previous climate change workshops, and no papers were submitted for review. The Committee agreed that while progress on the topic had slowed compared to previous years, unanimous opinion was that climate change should remain on the agenda as an issue of increasing importance.

This decision resulted in the continuation of the intersessional correspondence group, with the purpose of:

- Collating recommendations of past climate change workshops
- Identifying key research gaps and priorities
- Evaluating progress in understanding the impacts and implications of climate change for cetaceans
- Identifying climate change priorities
- Continuing to look at the issue of critical habitat in the context of climate change.

2. How has our understanding of the relevance of climate change to cetaceans developed: key studies and findings

The concept of a restricted habitat has been the topic of intense discussion within the IWC SC over the past four years. It is generally agreed that considering the physical boundaries of a species is an appropriate starting point when attempting to predict both immediate responses to, and the long term impacts of climate change. Thomas *et al.* (2004) proposed that extinction risk from climate change could be determined by range size; species with a more restricted range would be at greater risk of displacement, and less likely to find suitable habitat when climate driven migration polewards took place.

In 2006 Hijmans *et al.* discussed the use of 'bioclimatic envelope modelling' to predict the future range of a species under a changing physical environmental. This method required a thorough understanding of a species' current distribution as well as their physiology, in order to model changes. Cheung *et al.* (2009) then applied this methodology to assessing the impacts of climate change on marine biodiversity, resulting in predictions of 'numerous local extinctions in the sub-polar regions, the tropics and semi-enclosed seas', supporting the theory that smaller range size, more specific habitat requirements, and presence of barriers to migration can all

Heikkinen *et al.* (2002) raised the point that bioclimatic envelope models can only be as accurate in predicting species responses to climate change as the niche models they are generated from. These niche models are developed based on observations, and also assumptions as to how the environment shapes and influences a species' current range. Heikkinen *et al.* stressed the need for model limitations to be quantified if they are to be applied usefully.

Parmesan and Yohe (2002) successfully displayed the effects of climate change on species distribution in action, by analysing over 1,700 species and identifying an average polewards range shift of 6.1km per decade. These results were replicated in Perry *et al.*'s (2005) study focussing on range shifts in North Sea fish, where nearly two-thirds of species shifted in mean latitude, or depth, or both over 25 years.

This additional dimension present within the marine environment complicates the task of modelling and predicting responses to climate warming. Depth has a profound effect on the environmental conditions experienced at a specific latitudinal point. Barnett *et al.* identified a global warming signal in the world's oceans with a vertical structure which varied between oceans, and proposed that 'changes in advection combined with surface forcing to give this overall warming pattern" (Barnett *et al.* 2005).

Marine habitats do not blend into the next biozone gradually as in terrestrial environments; rather they are very distinct, isolated peaks in productivity determined by a combination of physical (upwellings, canyons, shelves, current) and environmental (temperature, sunlight, primary productivity plankton/nitrogen) conditions (Costello 2009).

Water itself as a medium is more volatile and less predictable than the atmosphere; 80% of the heat added to the earth system has been absorbed by the oceans without an incremental increase in water temperatures (IPCC 2007). The oceans do not respond to input predictably; there are complex feedback loops, and thresholds to the capacity of water to absorb excess heat energy which once exceeded are expected to cause a rapid increase in observed rate of warming (Cox *et al.* 2000).

Many marine species can migrate to compensate for temperature increase both latitudinally (polewards) but also vertically (Perry *et al.* 2005), and this introduces an added level of uncertainty into any models. Cetaceans have, of course, to regularly return to the surface to breath and their distribution has long been known to be very temperature dependent (Gaskin, 1982).

Doney *et al.* (2012) discussed the impacts of climate change on marine ecosystems, and considered both how individual species might adapt to climate change (shifts in ranges as species align their distributions to match their physiological tolerances under changing environmental conditions), and also the impact on ecosystem structure and dynamics. Closely interacting species within an ecosystem may respond to climate change at a different rate, or direction. This asynchrony in adaptive response is expected to disrupt trophic balance and lead to competitive exclusion, placing added pressures on species already experiencing range contraction (Parmesan 2006).

MacLeod identified this displacement and competitive exclusion in practice in cetaceans as early as 2005 (MacLeod *et al.* 2005). As the range of the common dolphin has expanded north around the Moray Firth region of Scotland, occurrence of the white-beaked dolphin – a species sharing a similar niche but at colder temperatures - has reduced (as established through stranding records and sightings data). MacLeod revisited this cetacean community in a 2009 review (MacLeod 2009), and in an opinion shared by other reviews (Simmonds and Isaac 2007, Simmonds and Elliot 2009) voiced concern regarding the absence of suitable habitat extending further north of the current range boundaries of the white-beaked dolphin. The white-beaked dolphin has a strong association with and habitat preference for the continental shelf area (MacLeod *et al.* 2007); the bottom topography beyond this zone does not support high marine productivity, and is the marine equivalent of a desert. There is no supporting habitat for the white-beaked dolphins to migrate north into. Since the original paper was published in 2005, occurrence of white-beaked dolphins has continued to decrease, and SST in this region continues to rise in concurrence (Tetley and Dolman 2013).

Identifying such trends does necessarily prove a direct relationship between two variables. Data is accumulating from a range of species exhibiting migration and range changes as a direct response to global climate change (Stewart *et al.* 2014, Pinsky *et al.* 2013, Sorte and Carlton 2010). However evidence to date showing cetacean responses to climate change remain speculative, It is in our interests to ensure that trends such as those identified by MacLeod *et al.* are formally recognised whilst there is still time - and opportunity - to mitigate the outcome.

McClellan *et al.* 2014 investigated environmental features influencing cetacean distribution with the English Channel, and acknowledge the risks in inferring a correlation between measurable environmental stimuli, and observed behavioural output. The authors stress the need for collaborative research to "capture and conserve the underlying biological and physical processes that form this biodiversity at the appropriate scales". Predictive models require an understanding of: (i) the variables proposed to drive behaviour; (ii) the mechanisms underlying this interaction; and (ii) the current responses exhibited. Applying this methodology to cetaceans is problematic on many levels.

Lambert *et al.* (2014) recognised the limitations of current scientific understanding of cetaceans, when attempting to model future distribution under climate change scenarios. Addressing each of the three key requirements for a successful model:

i) The mechanisms driving current cetacean distribution are poorly understood. Lambert *et al.* (2014) propose that SST is the primary determinant, and can be modelled directly against current species range boundaries. MacLeod (2009) proposed three processes through which temperature may determines species range: (i) physiological – considered unlikely because of cetaceans' large body size and ample insulation; (ii) changes in prey distribution and (iii) via competitive interactions with ecologically similar species within their temperature regime. Simmonds and Isaac (2007) suggest changes in prey distribution will be the key driver of future range changes, and Ainley *et al.* (2010) highlight the importance of considering the role of cetaceans within a marine ecosystem, and the complex food webs with feedback loops existing between predator and prey. What is agreed is that our current understanding of how cetaceans perceive and interact with the physical environment is limited, and further research is vital to identify the most important factors influencing cetacean distribution.

ii) Cetaceans exhibit a high degree of phenotypic plasticity, and may have a relatively wide thermal tolerance compared to other marine species, and their mobility is expected to confer greater adaptive ability (Simmonds and Elliot 2009). Polczanska *et al.* (2013) proposed that where the observed response to environmental change was not in the direction of predictions, this may be because of stronger, unidentified forces acting in opposing directions. For example, cetaceans may have a physiological limitation in their ability to thermoregulate, forcing migration polewards to compensate for increased water temperatures. But greater than this drive to move polewards could be a movement away from water of lower salinity at the poles, as ice caps melt releasing freshwater. Meager and Limpus (2014) analsysed a 17 year dataset to 'demonstrate a clear relationship between environmental forcing and natural mortality of inshore marine mammals'. Key observations were that peak mortality of inshore dolphins and dugongs followed sustained periods of elevated freshwater discharge (9 months) and low air temperature (3 months), highlighting the importance of considering how the chemical composition of marine environments (minerals, nutrients, pollutants) is expected to change in addition to temperature. Whilst cetacean distribution remains in a state of relative equilibrium, it is difficult to determine which of the proposed stimuli could override others.

iii) There is insufficient data on the distribution of the majority of cetacean species to accurately infer where current range boundaries may lie. Cetacean distribution data is difficult, costly and time consuming to collect. The most informative data comes from long-range datasets collected over many years (Simmonds and Smith 2009). Fundamental gaps in our knowledge of cetacean distribution have been recognised yet limited capacity and funding restrict how quickly we are able to resolve these. Acting on climate change requires fast and appropriate action, whereas traditional methods of data collection for cetaceans require a time investment of many decades.

The risks to cetaceans from climate change, both direct and emerging (through e.g increased human activity and habitat loss as a result of climate change impacts on human societies), are considered in detail in previously references reviews (e.g. Simmonds and Isaac 2007, Simmonds and Elliot 2009). To briefly summarise the main mechanisms through which cetaceans are expected to be impacted:

- range changes, driven by:
  - thermal tolerance
  - changes in prey distribution
  - competitive exclusion
- increased incidence of disease; reduced immunity, chronic stress through thermoregulation at higher water temperatures
- loss of habitat in arctic species associated with ice floes
- loss of habitat in species associated with features specific to a fixed location, e.g. continental shelves, enclosed bays
- more frequent interaction and competition with humans, increased bycatch or unauthorised hunting by the fishing industry

3. Recent Key Publications

Key publications from the past 18 months provide evidence of the above predicted responses, and reinforce the need for climate change impacts on cetaceans to remain on the agenda and be prioritised for urgent action. A summary of publications follows:

3.1 Species level responses to climate warming – range changes and disruption of the trophic balance

- Poloczanska *et al.* (2013) examined the impact of climate change on marine life compiling a database of 1,735 marine biological changes from the literature. Range shifts were found to track changes in oceanic sea surface temperature, with a key observation that while rate of SST warming is three times slower than on land, advances in phenology were advancing at a faster rate in the marine environment compared to terrestrial – average 4 days earlier, versus 2. The authors also highlighted the risk of mismatch within ecosystems. Phytoplankton exhibits a very rapid response to temperature change (facilitated through high dispersal rates and short generation times), whereas the rate of adaptation through migration and microevolution is expected to be limited with increasing trophic level position.
- Sorte *et al*. (2010) reviewed range shifts in marine species and noted that species spread occurs an order of magnitude faster in marine, than terrestrial environments, with 75% of range shifts occurring poleward as expected. Range shifts which were not followed by establishment were excluded from the study, and the authors propose that it is characteristics of the community being invaded, rather than the species in question, determine success rate of establishment in invasive species. Sorte *et al.* (2010) also highlighted the potential for ocean warming to open up new 'migration corridors', facilitating migration in directions and at rates not previously observed.
- Lescroel *et al.* (2014) warn that extreme climatic events can disrupt the phenotypic plasticity in a marine avian species, the Adelie penguin. This finding urges caution in expecting cetaceans to maintain a high level of adaptability and resilience to environmental variability, as the climate becomes more volatile.
- Arcangeli *et al.* (2014) use sightings data to examine the hypothesis that the fin whale *Balaenoptera physalus* has exploited a newly available niche as rising water temperatures and chlorophyll a concentration in the Tyrennian Sea have created a new summer feeding ground.
- Arcangeli *et al.* (2013) conducted a 20 year study in the same location (the Tyrennian Sea) but reported that, despite the time span of this study, no dramatic changes were observed for any species, bar the fin whale, in terms of distribution, relative abundance, group size or habitat preference. The authors note the limitations of their findings given how few studies are available for comparison.
- Albouy *et al.* (2014) examine the impacts of climate change on ecosystem structure, stability and functioning. Their results predict that: "connectance of the overall fish web would increase on average, from 0.26 to 0.29, mainly due to a differential loss rate of feeding links and species richness...this result masks a systematic decrease in predator generality, estimated here as the number of prey species" – highlighting the importance of considering both species level responses, but also impact on the ecosystem of a target cetacean species, in order to accurately predict responses to climate change.

- Beaugrand *et al.* (2014) apply ecological niche modelling to connect phenological, biogeographic and long-term community shifts in key zooplankton species between 1958 – 2009. Their method is able to account for 70% of the phenological and biogeographic shifts observed in *Calanus finmarchicus* in the North Atlantic, and 56% of long term shifts in all copepod species within the North Sea during this period. This study is of particular relevance considering previous findings on the relationship between *C.finmarchicus* abundance, and mortality rates in the endangered North Atlantic Right Whale (Greene and Pershing 2004).

In addition, the IPCC 5th assessment report is due in 2014, (AR5) and in the September 2013 summary for policy makers (IPCC 2013) the IPCC predicted that:

- "The oceans will continue to warm, with heat extending to the deep ocean, affecting circulation patterns Decreases are *very likely* in Arctic sea ice cover, Northern Hemisphere spring snow cover, and global glacier volume
- Global mean sea level will continue to rise at a rate *very likely* to exceed the rate of the past four decades
- Changes in climate will cause an increase in the rate of CO_2 production. Increased uptake by the oceans will increase the acidification of the oceans"

3.2 Application of MPAs to mitigate climate change and the continued relevance of 'restricted habitats'

- Selig *et al.* (2014) discuss methods for identifying areas of importance to endemic species. They incorporate a measure of range rarity, and identify places which contain species with restricted ranges independent of the number of species present by dividing range rarity values by species richness to give a proportional range rarity. By coupling data on areas where these two measures of endemism peak, with a model of estimated cumulative human impacts Selig *et al.* (2014) are able to generate a spatially explicit map for prioritising areas for conservation. This method also highlighted areas of high biodiversity and low human impact, which present opportunities for proactive conservation. Alter *et al.* (2010) reviewed potential climate driven shifts in human behaviour likely to impact cetaceans, which could be coupled with the methodology presented by Selig to further develop research in this area.
- Simmonds and Smith in 2009 applied a method of sensitivity scoring developed by Laidre et al. (2008), to predict relative vulnerabilities of cetacean species to climate change. The recent work of Davidson *et al.* (2012) could be useful in further developing this methodology; life history traits were found to be the strongest predictors of extinction risks, and species with a longer intergenerational span in addition to restricted geographic range area (criteria applying to many cetacean species) were at greatest risk.
- Hazen *et al.* (2013) used data from the Tagging of Pacific Predators (TOPP) project which employs over 4,300 tags across 23 species to model species distribution data as a fuction of SST, chlorophyll a concentration and bathymetry. Their analysis showed an increased migration distance between habitats in migratory species, and identified pelagic predator hotspots in the NE pacific. Tagging studies may become more common in cetacean surveys than sightings data, as the urgency with which data is required increases. The success of projects such as TOPP lend support to this approach of data collection.
- Borja (2014) recommends the application of Marine Spatial Planning as a management tool, a multidisciplinary approach which attempts to balance conservation efforts with increasing demands on marine resources
- In Australia, Schumann *et al.* (2013) identified a link between climatic variables and the distribution and reproductive success of Australian marine mammals. Schumann *et al.* (2013) also recommend the conservation of habitats and areas used by marine mammal species for key life history events (breeding or feeding grounds) and recognise that to date, our progress is limited by:

i) the limited <u>evidence</u> of temperature driven shifts in distribution
ii) poor understanding of the range and habitat preferences of marine mammal species, including which factors influence distribution

- In Helmuth *et al.*'s 2013 review of the impacts of climate change on marine organisms, it was noted that climate change impacts will exacerbate existing risks to species, and key to reducing the impact of climate change is minimising other threats which can be controlled. Designation of MPAs to remove human activity impacts in key areas will help to buffer species against the threats introduced with a changing climate.

- In a 2009 UNEP publication on the links between biodiversity and climate change it was noted that current protected areas are designed with the aim of conserving species under a stable climate, and advised that additional features need to be considered in designing protected areas which will support biodiversity adaptation under climate change. Key considerations suggested which could be applied to discussion on restricted habitats in cetaceans are that: (i) reserves contain a large enough area of a specific ecosystem, expected to remain unaffected by climate change, to act as a refugia (ii) that reserves include both stationary and displaced refugia of species of concern and (iii) that habitat heterogeneity is favoured.
- Bernhardt and Leslie (2012) examined coastal ecosystems for features which could increase resilience to climate change, and identified three key categories of ecological properties: (i) diversity, supporting a greater variety of responses to climate change and increasing likelihood that species can compensate for one another, i.e. alternative prey species for top level predator to shift diet towards; (ii) connectivity – to other suitable habitats, enhancing the capacity of an ecosystem for recovery; and (iii) adaptive capacity, measured through the phenotypic plasticity of constituent species, their potential to migrate and undergo range shifts, and the microevolutionary rate (determined by reproductive rate, therefore in cetaceans expected to be low). The authors note that ecosystem resilience is increased by the number of ‘links’ present and a greater number of interactions will stabilise a community under changing environmental conditions. These ecological observations should all be taken into account when designating protected areas with the intention of buffering cetacean species against climate change.
- Magris *et al.* (2014) commented on the limitations of species targeted conservation programmes which do not effectively incorporate biological processes or dynamic threats, a view shared by (52) who goes further to suggest the designation of MPAs based not only on ecological guidelines, but also taking into consideration any relevant social constraints or influences, and Levy and Ban in their 2013 review of marine conservation planning and application urge the incorporation of climate change predictions and models into future MPA design.
- Bond and Laver (2014) found that in spite of direct targeted conservation efforts, numbers of an apex marine predator (the Flesh footed shearwater (*Puffinus carneipes*) were still declining. The authors propose that climate change driven changes in the niche of this species have led to increased competition with sympatric species previously confined to distinct ranges, but with increasing range overlap as the habitat of the flesh footed shearwater undergoes ‘oceanic tropicalisation’. This theory is proposed to account for the observed reduced efficacy of conservation measures focussed only on minimising bycatch, highlighting the importance of remaining aware of evolving threats to species as the climate changes in order to continue focussing conservation efforts in the most efficient and cost effective manner.

4.Climate change and the IWC: where we are now?

The targets of the intersessional group following last year’s meeting of the Scientific Committee are noted above and recommendations from reviews referenced within this paper call for similar action: more long term studies providing the data needed to better predict cetacean responses to climate change; conservation of habitats of importance to buffer species against the impacts of climate change, and minimizing other human impacts (bycatch, pollution, introduction of disease and invasive species).

The limitations recognised when approaching this task will not be easy to overcome. The data required on cetacean distribution and habitat use will require collaborative effort over many years to collect.

Many sources referenced above highlight the importance of integrating future climate change scenarios into MPA planning, to avoid establishing reserves and sanctuaries in areas which will soon cease to be of use to the species they aim to conserve.

We have a difficult task in trying to predict the response of cetaceans to an uncertain future. A short term goal might be to target and educate those communities with influence over areas of importance to these species (i.e. breeding and feeding grounds, areas of high biodiversity, and specialist habitats) to increase and encourage the perception of cetaceans as a valuable resource to be protected during a time of rapidly changing climate. The successful application of social media platforms to raise awareness is a resource which should not be overlooked; in a changing climate as the marine environment shifts and adapts, there are new opportunities to be exploited in the age of digital media, and the virus-like spread of ideas and knowledge to target influential groups is a potential means to achieve change.

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