The tertiary threat: Human-mediated impacts of climate change on cetaceans

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ABSTRACT

Climate change is likely to affect the health and survival of cetaceans at multiple levels, including individual-level (primary) effects, and population-level (secondary) effects. Tertiary effects have been defined as impacts at the population or community level resulting from changes in human actions due to climate change. For example, climate change may result in increased hunting pressure on near-shore dolphins and whales off Asia, Latin America, Africa, and elsewhere as the availability of other marine resources diminishes. Potential tertiary effects have also recently been highlighted in the Arctic context following the loss of sea ice and could include increases in ship strikes, industrial activity, fisheries activities (potentially causing increased bycatch and prey depletion) and acoustic injury and exposure to sound pollution.

Tertiary effects may be highly significant for some cetacean populations but could not be considered by the recent IWC workshop on climate change due to time constraints, so we provide here a review of potential impacts intended to augment the report from the workshop.

While concern about impacts of climate change on cetaceans has been largely focused on polar species, the evidence presented here suggests that tropical coastal cetaceans may also be particularly vulnerable to those aspects of climate change that are mediated by changes in human behavior. We recommend that 1) knowledge about cetacean populations should be incorporated into national, regional and international climate adaptation decisions wherever possible (for example, via GEF-sponsored adaptation initiatives); and 2) tertiary impacts of climate change should be included in cetacean management plans (including the management procedures of the IWC) where possible. Because tertiary and other impacts of climate change are likely to evolve rapidly over the coming years and decades, it is important that cetacean conservation and management plans include regular reviews to allow them to adapt to new information.

KEY WORDS Climate change, cetaceans, whales, dolphins, Arctic

Introduction

Climate change is expected to affect cetaceans primarily via loss of habitat (given the distinct thermal ranges of most species), changes in prey availability, quality and distribution, and potentially increased competition from range expansions of other species (Learmonth *et al.* 2006; Simmonds and Isaac 2007; Simmonds and Elliot, 2009). However, changes in human behavior or activities resulting from increasing temperatures, flooding, storm surges, aridity, decreasing ice cover and other environmental shifts may also impact cetacean populations. For example, reduced ice cover in the Arctic is projected to lead to increased shipping, oil and gas exploration, and fishing (Huntington 2009), which will result in additional noise and chemical pollution in marine ecosystems. Wursig *et al.* (2002) classify these impacts as ñtertiary effectsò based on a framework that defines primary effects of climate change as impacts at the individual level, and secondary effects as impacts at the population level mediated by changes in prey or habitat. The IWC recently held a workshop on the potential effects of climate change on cetaceans and whilst this workshop acknowledged the likely significance of tertiary effects, its focus was on primary and secondary impacts (IWC 2009). Though the importance of these human-mediated or tertiary effects remains unknown, it is likely that for particular populations and regions they could equal or even outweigh the primary and secondary effects of climate change on cetaceans (Wursig *et al.* 2002, Simmonds and Isaac, 2007).

Furthermore, while designing management initiatives to mitigate the direct effects of climate change on cetaceans is difficult, given the current state of knowledge, devising precautionary policies to address tertiary effects (as well as attempting to reduce non-climate related stressors) may be a more practical approach. Currently, numerous governments including the UK, Finland, Germany, the U.S. and Canada, are developing climate adaptation plans and the UNDPõs Global Environmental Facility is coordinating a response plan among nations at a larger scale. It is important and timely, therefore, to ensure that effects on cetacean populations are considered in policy decisions regarding adaptation to climate change.

Here possible human-mediated or tertiary effects of climate change on cetaceans are outlined and classified, along with the physical and biological changes underlying them. In addition, factors that may make particular cetacean species especially sensitive to human-mediated climate impacts are discussed. Finally, the international and country-specific regulatory frameworks that may be useful in managing human-mediated impacts to cetaceans are reviewed. We focus our review on threats deriving from climate-induced changes in human behavior, rather than the more general topic of direct impacts of climate on cetaceans which have been covered in depth in other studies (e.g., Learmonth *et al.* 2006, Simmonds and Isaac 2007, Gambiaini *et al.* 2008, Simmonds and Elliot 2009).

Effects of climate change on human behavior

Despite broad uncertainties in how the earthõs climate will change in the future and human responses to those changes, emerging trends can be used to build predictions about the human-mediated impacts of climate change. Numerous physical and biological changes have already been observed and attributed to climate change, including diminishing sea ice, changes in terrestrial and marine surface temperature, sea level rise, changes in ocean circulation, rainfall, and storm severity. According to the most recent IPCC report, eleven of the last twelve years (1995-2006) rank in the twelve warmest years since instrumental record keeping began (1850) (IPCC 2007). Human societies and economies are attempting to adapt to all of these changes, with many implications for cetacean populations.

The effects of climate change on human societies are unlikely to be uniform around the world, as particular areas will experience more severe impacts on physical and biological systems, and some societies have less economic or cultural capacity to adapt. Therefore, human-mediated impacts of climate on cetaceans are also likely to be concentrated in certain regions and therefore may have disproportionate effects on certain species or communities. IPCC (2007) lists four regions that are ìlikely to be especially affected by climate changeî:

Åthe Arctic (due to high rates of warming and impacts on natural systems and human communities)
ÅAfrica (because of low adaptive capacity in the face of projected climate change impacts)
ÅSmall islands (due to high exposure to climate change impacts)
ÅAsian and African megadeltas (because of large population concentrations and high exposure to sea level rise, storm surges and flooding).

A summary of human-mediated impacts of climate change on cetaceans

Below, we describe the physical and biological changes expected to result from climate change, and how these changes may impact human behavior with cascading effects on cetacean populations. Results are summarized in Table 1.

Decline in sea-ice extent

Since 1978, annual average Arctic sea extent has diminished by 2.7% per decade (with a decrease in summer ice of 7.4% per decade) (IPCC 2007). Under some IPCC scenarios, Arctic late-summer sea ice is projected to disappear altogether by the last half of this century (Overpeck *et al*. 2005). The annual temperature in the Arctic has increased at nearly twice the rate of the rest of the globe over the past several decades (ACIA 2004).

While reductions in sea ice are likely to have numerous direct effects on Arctic cetacean populations, indirect effects from increasing human activities in newly ice-free areas may also have large impacts. It is highly likely that sea ice reduction will result in increased shipping as the navigational season is extended and seasonal passage through the Northwest Passage (NWP) and the Northern Sea route becomes more consistent (Brigham and Ellis 2004, ACIA 2004). Increasing ice movement may make particular channels of the NWP more difficult to navigate initially (ACIA 2004). Oil and gas exploration and extraction are also increasing in the Arctic, and development of unconventional mineral resources such as large offshore deposits of heavy oil, coalbed methane and methane hydrate deposits may occur as existing reserves are depleted. Likewise, future fishing pressure may increase in the Arctic as fish stocks there become more available or productive in newly ice-free areas (ACIA 2004).

Impacts to Arctic areas from reduced sea ice are likely to differ by region. In the North Atlantic sector (East Greenland, Iceland, Scandinavia, Northwest Russia and adjacent seas including the Barents and Kara Seas), oil, gas and mineral extraction and fisheries are likely to increase. Development of oil resources in this region is likely to include additional marine terminals and Arctic tanker traffic (AMAP 2007). Shipping increases could have a large effect in the Siberian region as navigational opportunities through the Northern Sea route improve. In the western Arctic Seas (Chukchi and Beaufort Seas, Mackenzie Delta), increases in oil and gas exploration are ongoing and may be stimulated by the completion of the Mackenzie Valley gas pipeline. The central and eastern Canadian Arctic and West Greenland are likely to experience increases in shipping through the Northwest Passage, and possibly increases in fisheries as new species such as haddock, herring and tuna shift their ranges northward (ACIA 2004).

Increasing human activities in the Arctic may have both acute and chronic effects on cetacean populations. Increased ship traffic is likely to result in a higher incidence of mortality or serious injury due to ship strikes. In addition, low-frequency (<1000 Hz) shipping noise can mask sounds that baleen whales use for communication, potentially affecting critical behaviors such as mating, foraging and migrating, and can cause other behavioral disruptions. Shipping is thought to be the primary source of overall anthropogenic noise in the oceans (NRC 2003). While concern over auditory masking or behavioral disruption has focused on baleen whales, due to the fact that their use of sound overlaps with the main frequency band of shipping noise, broadband cavitation noise from fast-moving vessels may also transmit higher frequencies with potential effects on toothed whales (Aguilar Soto *et al.* 2006) such as beluga (*Delphinapterus leucas*) or narwhal (*Monodon monoceros*).

Like shipping, fisheries and oil and gas development also present both acute and chronic risks to cetacean populations. An increase in fishing activity presents direct risks of mortality or serious injury from bycatch (Read 2005), and indirect threats from prey depletion (NRC 1996; Vilhjalmsson and Hoel 2005; Plagany and Butterworth 2005). A catastrophic oil spill could be extremely harmful to bowhead (*Balaena mysticetus*), beluga, and narwhal populations, particularly if a spill were to occur during overwintering or migration when animals are more constrained by pack ice. While cetaceans are less vulnerable to oiling than many other marine species such as otters and seabirds, oil can harm eyes and baleen and surface vapors may be dangerous if inhaled, and oil spills may have long-term impacts on prey populations including fishes and benthic invertebrates (AMAP 2008). Spills in the Arctic Seas are more difficult to contain and respond to because of the difficulties of operating in sea ice. Populations of cetaceans may also be at risk from cumulative effects of chronic oil pollution from small tanker spills, pipeline leaks and other accidents. Further, petroleum hydrocarbons persist longer at low temperatures, increasing the susceptibility of Arctic wildlife to long-term cumulative impacts from these substances (AMAP 2008).

In addition, the exploration of the sea floor for oil and gas resources involves seismic testing. The loud, broadband sounds produced by seismic airguns have been shown to cause avoidance and other behavioral responses in gray (*Eschrichtius robustus*), bowhead, and beluga whales (in addition to other species) (Malme *et al.* 1984; McCauley *et al*. 1998; Miller *et al.* 2005). Seismic impulses can travel for long distances, and in some cases have been detected over 3000 km from the source (Nieukirk *et al.* 2004). Of particular concern for migratory species such as bowhead whales is the possibility of multiple seismic operations at the same time that could effectively create a wall of sound through which whales would be unwilling to travel. Seismic airguns may also affect cetacean prey including fish and squid (McCauley *et al.*, 2003; MacKenzie 2004).

Other changes in human behavior from loss of sea ice include a potential increase in military activity as ice-free zones are claimed by various nations, and increased hunting effort targeting cetaceans for food resources as ice-dependent seals and walruses become less available. While the harvest of Arctic cetaceans has generally been closely managed (e.g., IWC 2003), unsustainable harvest has been cited as a primary cause of decline in Cook Inlet beluga whales (Mahoney and Shelden 2000) and West Greenland beluga whales (Butterworth *et al.* 2001). Nielsen (in press) presents evidence that changing ice conditions are increasing the take of narwhals in Siorapaluk, Greenland. Effort has not increased and the hunters attribute the significantly increased take since 2002 to changed sea ice conditions that allow access by boat to Smith Sound as early as June or July. Nielsen suggests that this indicates that climate change will have a considerable impact on narwhal hunting in northern Greenland.

However, it is important to recognize that marine mammal harvests may also become more unpredictable as spring pack ice and wind conditions change. Hovelsrud *et al.* (2008) conclude that many of the consequences of climate change are likely to be negative for marine mammal hunters as well as marine mammals. They postulate that hunting will be affected by changing ice conditions; shifting species abundance and distribution; introduction of new species; increased ocean temperature; and changes in marine mammal health and reproduction. This could cause a shift in hunting pressure to other species and/or increased pressure on other stocks. Hovelsrud *et al*. (2008) comment that sea ice conditions may become more hazardous to the point at which traditional knowledge would have be ósupplemented with modern technologyôand they note that already many hunters carry small boats on their sledges to avoid becoming stranded.

The potential for increases in takes by subsistence hunters has been recognized by certain management organizations, like the IWC (IWC 2003). For example, simulation testing of the Strike Limit Algorithms (*SLA*s) used to set quotas under the Aboriginal Whaling Management Procedure (AWMP) of the IWC is based on a range of plausible parameter space designed to evaluate (among other factors) the performance of the *SLA*s to a doubling and even tripling of need over a 100 year time frame. While the plausibility of these increases in future need is not attributed to specific mechanisms, regular Implementation Reviews are scheduled to ensure that the current state of nature is not outside the realm of plausibility envisioned during the testing of the *SLA*s. Like the RMP, the AWMP is reviewed every five years to ensure that new information is incorporated (Donovan and Bjorge 2009). Further, substantial events (e.g., a spike in need, evidence of mass mortality, *etc.*) can trigger an Implementation Review during the interim between scheduled reviews. It is important that the IWC and other management organizations regularly review the state of their management strategies to ensure that management advice is precautionary in nature and does not lag behind the potentially rapid evolution of tertiary and other threats.

Increase in ocean temperatures and ocean acidification

Coral reef systems are highly vulnerable to warming ocean waters and ocean acidification, resulting in projected increases in bleaching events and large-scale mortality. The widespread loss of entire reef ecosystems, particularly in densely populated coastal areas where corals face additional stressors such as run-off, may cause the marine tourism sector to switch or place increased effort on whale and dolphin-watching rather than snorkeling or diving excursions. A growing body of work on the population-level effects of whale and dolphin-watching suggests that these activities can produce significant levels of disturbance (e.g., Bejder and Samuels 2003) and require careful management and enforcement. Such displacement is likely to impact all coastal cetaceans in tropical areas where coral reef-based tourism is high (Lawler *et al.* 2007), and may be a particular problem for species like spinner dolphins (*Stenella longirostris*) in Hawaii, which rest during the day in coastal lagoons that are easily accessible to tour operators.

The movement of important fisheries such as tuna or herring to higher latitudes or further offshore may increase interactions with fisheries and habitat disturbance for cetacean populations in mid- and high latitude areas (Vilhjalmsson and Hoel 2005). In addition, as northern water temperatures become more suitable for temperate fish and shellfish species, the aquaculture sector may expand. Deleterious effects of aquaculture operations on small toothed cetaceans can include nearshore eutrophication, loss of coastal habitat, entanglement, and shooting or other harassment (Wursig and Gailey 2002). As fisheries contract in other regions of the world such as the Mediterranean, cetaceans and fisherman may increasingly compete for fish leading to a greater incidence of harassment (Gambaiani *et al.* 2008). Species such as the Mediterranean common dolphin (*Delphinus delphis*) may thus be affected both by a climate-induced decline in prey such as European anchovy (*Engraulis encrasicolus*), European pilchard (*Sardina pilchardus*), round sardinella (*Sardinella aurita*) and sprat (*Sprattus sprattus*) and by the negative effects of competition (or even perceived competition) with fisheries over these species.

Increases in terrestrial surface temperature

Over the past 100 years, the Earth's global surface temperature has risen by an estimated 0.74 [0.56-0.92]ºC (IPCC 2007). Continued warming for the next two decades at a rate of roughly 0.2ºC per decade is predicted under a range of emission scenarios, but future warming rates depend greatly on the particular emission scenario. Regardless of the rate, warming is projected to be greatest at high northern latitudes. Warmer surface temperatures will likely result in an increase in human density and agricultural practices at higher latitudes. Resulting urban and agricultural runoff, and potential increases in hunting and tourism, may affect mid- to high latitude coastal cetaceans such as harbour porpoises (*Phocoena phocoena*).

In Arctic communities, warmer terrestrial surface temperatures may lead to more hunting difficulty inland or a decline in terrestrial food resources such as caribou and reindeer (*Rangifer tarandus*) (Griffith *et al.* 2001) or birds, which may result in additional pressure on marine food resources including harvests of marine mammals. For example, hunters in Barrow, Alaska, typically conduct spring goose hunting inland after the spring bowhead whale hunt. Inland travel depends on a sufficient amount of snow, which has been melting earlier in recent years in Barrow (Hinzman *et al.* 2005). Likewise, fall snow cover necessary for inland caribou hunting has been developing later than in the past. As these terrestrial resources become less reliably available, it is possible that hunters will increasingly utilize marine food sources. However, as noted above, marine mammal hunting may also become more unpredictable with changing spring ice conditions (Hovelsrud *et al.* 2008).

Decrease in precipitation in many terrestrial ecosystems

Since 1900, precipitation has declined significantly in the Sahel, Mediterranean, southern Africa and parts of southern Asia. This trend is very likely to continue for most subtropical land regions as well as other semi-arid areas including the western U.S., southern Africa and north-eastern Brazil. Water availability is projected to decrease overall by 10-30% in some mid-latitude dry regions and in the dry tropics (IPCC 2007).

Conflicts over food and water resources in areas with increasing aridity and drought may result in greater reliance on marine ecosystems for food, as well as diminished concern/resources for conservation. In some African nations, agricultural yields could diminish by up to 50% due to decreases in precipitation, and food production could be severely compromised (IPCC 2007). Compounding this problem is continued population growth that is projected to increase global demand for food threefold over the next 50 years (McMichael 2007). Crop productivity and livestock production may also decrease in parts of Latin America. As increasing aridity affects agricultural practices at lower latitudes, the need for food security may lead to other ecosystem effects including water diversion and higher use of fertilizer with a resulting increase in anoxic ocean zones and potentially harmful algal blooms in coastal zones (Geraci *et al.* 1989, 1999; Domingo *et al.* 2002).

Drought and aridity may cause additional human migration to coastlines in some parts of the world, leading to increases in coastal development and pollution. Approximately 37% of the global population in 1994 lived within 100 km of a coastline (Cohen *et al.* 1997) and this number is likely much higher today. Conflicts over water resources exacerbated by drought may also lead to reduced habitat for freshwater cetaceans, and may disrupt life cycles of anadromous prey species such as salmon. For example in the western U.S. and Canada, warming is projected to result in decreased snowpack, increase in winter flooding and reduction in summer river flows, leading to conflict over allocation of water resources (IPCC 2007). Habitat destruction in the form of water diversion for agriculture as well as dams has been implicated in the decline in chinook salmon (*Oncorhynchus tshawytscha*) populations in the Pacific Northwest and the failure of Southern Resident killer whales (*Orcinus orca*) to recover (CBD 2001).

Increase in sea level rise and storm frequency/severity

Global sea level has risen at a rate of 3.1 mm/yr on average since 1993, and will continue to rise by 0.18-0.59 m by the end of the century (IPCC 2007), although these estimates may be conservative. Sea level rise in low-lying coastal areas will result in inundation, increasing flooding by storm surges, and intrusion of sea water (Meehl *et al.* 2005). For example, Nicholls *et al.* (1999) estimate that given a 0.5 m rise in sea level, the number of people experiencing flooding by storm surges in a typical year would increase six-fold. Additionally, the intensity of tropical cyclones is likely to increase (IPCC 2007), resulting in further coastal erosion and damage to coastal infrastructure. The effects of sea-level rise may be exacerbated by drainage and excessive groundwater withdrawal in coastal urban areas. Coastal communities will adapt to these threats through flood management and protection, including the construction of both ñhardò protective structures (e.g. seawalls, dikes, levees, floodwalls, revetments, bulkheads, breakwaters, floodgates and tidal barriers) and ñsoftò protection (e.g. wetland restoration and creation, beach replenishment, dune restoration and creation) (Richard *et al.* 2001). Small island regions, deltaic areas and coastal wetlands are the most vulnerable to increased flooding (Nicholls 2000). From a regional point of view, the threat of flooding is highest for South and Southeast Asia, Africa, southern Mediterranean coasts, the Caribbean, and most islands in the Indian and Pacific Oceans (Nicholls *et al.* 1999).

Richard *et al.* (2001) note that despite evidence that ñsoftò protection may be more practical and less ecologically destructive in many areas, hard protection such as seawalls and jetties are often politically preferred perhaps due to their greater visibility and tangibility. Soft protections may have impacts on cetacean populations through potential loss of habitat (wetlands construction) or the introduction of foreign pathogens or contaminants (beach replenishment). However, these effects are likely to be less harmful than impacts of large-scale hard protection, which could include habitat destruction or fragmentation and an increase in noise propagation. For example, coastal construction projects to manage flooding may fragment populations of freshwater dolphins, further disrupting habitat that may already be directly threatened by sea level rise and/or diminished freshwater flows (Smith *et al.* 2009). Off the western coast of Taiwan, seawall construction has been listed as a possible threat to the Eastern Taiwan Strait population of Indo-Pacific humpback dolphins (*Sousa chinensis*) (Wang *et al.* 2004).

Increase in offshore renewable energy sources

As governments strive to decrease fossil fuel consumption while meeting global energy needs, the construction of offshore renewable energy platforms is expected to increase. These platforms include offshore wind turbines, tidal and wave-powered generators (Wright *et al*. 2009). Offshore wind farms are the most prevalent of these and are currently concentrated off the coast of Europe (including Denmark, Germany, the Netherlands and the UK) (Brown and Simmonds, 2009). Two of the worldõs largest wind farms are off the coast of Denmark in shallow water <20 m, but future construction is planned for a variety of depths up to 100 m (Madsen *et al.* 2006). Studies suggest that the pile-driving during construction of wind turbines is potentially the greatest threat to cetaceans from such activities but it is difficult to judge the potential consequences of an emerging industry deploying rapidly evolving new technologies (Simmonds and Dolman, 2008, Wright *et al*. 2009). Pile-driving is known to create acoustic disturbances for at least some species. Carstensen *et al.* (2006) found that construction affected habitat use by harbour porpoise in the Atlantic. Further studies show that operational turbine noise can be detected by harbour porpoises, but it is unclear what effect this may have on behavior (Koschinski *et al.* 2003). The cetacean species most likely to live in habitats suitable for wind farms include temperate and subarctic coastal cetaceans including (but not limited to) harbour porpoises, white-beaked dolphins (*Lagenorhynchus albirostris*), bottlenose dolphins (*Tursiops truncatus*), minke whales (*Balaenoptera acutorostrata*) and the northern right whale (*Eubalaena glacialis*).

The impacts of tidal and wave-powered energy on cetaceans are much more poorly known but will involve construction, potentially including pile-driving (Wright *et al*., 2009). Tidal generators may pose a risk of collision with blades, and cables carrying power to the mainland may produce strong electromagnetic currents that could affect navigation or fish populations. Tidal and wave platforms have greatest potential in temperate latitudes with strong winds and swiftly flowing water, which also tend to be highly productive areas that attract cetaceans. For example, sites identified as suitable for tidal power include the Bay of Fundy (Pelc and Fujita 2002) as well as the western sounds of Scotland (Bahaj and Myers 2003), both of which are well-known as areas of high cetacean density.

Discussion: vulnerable taxa and policy priorities

Vulnerability of particular cetacean taxa

While concern about impacts of climate change on cetaceans has largely focused on polar species, the evidence presented here suggests that tropical coastal cetaceans may also be particularly vulnerable to those aspects of climate change that are mediated by changes in human behavior. Overall, some of the largest impacts to human societies and economies are predicted to occur in densely populated, low-lying coastal areas such as megadeltas in Africa and Asia. Recent studies indicate that Africa is one of the most vulnerable continents to climate variability due to low adaptive ability and multiple climate stressors (IPCC 2007). Growing populations along coastlines will place additional demands on marine ecosystems including cetaceans, and conservation concern for cetaceans and other marine megafauna may decline in the face of very real human emergencies. Coastal species, and in particular those that depend on riverine or estuarine habitat, may be affected by coastal construction to prevent flooding and storm damage. This category includes many species that are already threatened or endangered, such as the South Asian river dolphin (*Plantanista gangetica*), Irrawaddy dolphin (*Orcaella brevirostris*), and finless porpoise (*Neophocaena phocaenoides*). Small resident island-associated populations, such as bottlenose dolphins (including both *T. truncatus* and *T. aduncus*) and Indo-Pacific humpback dolphins in the Indian and Pacific Oceans, may also be vulnerable to construction of coastal infrastructure as human communities attempt to adapt to rising sea levels and changes in precipitation and surface temperature.

Human-mediated impacts of climate change are also likely to disproportionately affect Arctic cetaceans. As sea ice declines and high-latitude temperatures become more habitable for humans and commercial fisheries, human activities will inevitably encroach on an increasing amount of cetacean habitat in the Arctic (Huntington *et al*. 2007; Huntington 2009). Shipping and oil and gas development, in particular, are likely to have wide-spread impacts on the acoustic environment of the Arctic and may cause avoidance and/or disruption of critical behaviors by bowhead and gray whales, as well as possible impacts on beluga and narwhal populations. Laidre *et al*. (2008) found that narwhal and bowhead whales were among the most vulnerable of Arctic marine mammal species to climate change based on nine biological indicators of vulnerability. Future work to evaluate relative vulnerability of populations should account for tertiary impacts in analyses where possible ï for example, an indicator for susceptibility to disturbance from noise could be added.

Particular attention should be given to cetacean populations in areas that are likely to experience significant cumulative effects of climate change and other anthropogenic activities. One way to identify such areas would be to determine overlap between marine and coastal regions experiencing high anthropogenic impact and areas expected to be most impacted by climate change. Data collected through the National Center for Ecological Analysis and Synthesis (NCEAS) could easily be utilized for such a comparison. Halpern *et al.* (2008) synthesized data from a broad variety of threats (including climate change as well as other threats) and produced a global map of cumulative impacts on the marine environment. They found that particularly impacted areas include the North Sea, South and East China Sea, Bering Sea, and portions of the coasts of Europe, North America, the Caribbean, China and Southeast Asia. Climate change (using Sea Surface Temperature as a proxy) was found to be a particular threat in the North Sea, Bering Sea, Mediterranean, mid-Atlantic and the coast of China among other areas. While a cetacean-specific analysis is needed to improve the relevance and spatial resolution of conclusions, the study by Halpern *et al.* (2008) suggests that conservation and adaptation efforts to mitigate the effects of climate change on cetaceans might initially focus on the North Sea, Bering Sea, the South China Sea and the western coast of Japan. Several of these areas, particularly the South China Sea and the coast of Japan, also correspond to regions of high cetacean diversity (Kaschner *et al.* unpublished data, Weilgart 2006) and thus may warrant special attention.

Policy priorities and mechanisms

Ultimately, improving the resilience of cetacean populations in the face of both direct and human-mediated threats from climate change will necessitate two approaches: 1) integrating knowledge about cetacean populations into climate adaptation decisions and 2) including projections about how climate change may influence human behaviors into cetacean-specific adaptation plans.

Policy-makers and resource managers are increasingly considering how human communities should adapt to climate change threats, but few of these discussions or plans have included explicit consideration of cetaceans and other marine megafauna. One approach to improving this situation would be to ensure that marine mammal specialists are represented as part of marine expert panels in assessing potential effects of adaptation activities on ocean life. For example, the North Pacific Fisheries Management Council in the U.S. is considering a proposal that would limit commercial fisheries in the U.S. Arctic until enough data are available to determine how fishing might affect Arctic ecosystems (Wilson 2007; NPFMC 2008). The calculation of catch limits for this region should include consideration of cetacean populations, their conservation status, and any other human activities that may have cumulative impacts upon populations such as acoustic disturbance.

Another approach is to ensure that management plans for cetacean populations have incorporated into them expected changes in human behavior due to climate change. For example, protection areas for cetaceans could be developed to limit shipping, oil and gas development, and shipping pressure. Hunting quotas could be adjusted for populations that are expected to sustain direct, indirect or human-mediated losses from climate change such as range contraction following coastal construction. As new information becomes available and tertiary threats manifest in the future, management strategies will need to be based on adaptable and precautionary frameworks which have been developed to account for likely scenarios of human-mediated threats of climate change. As a first step toward the goal of incorporating the potential effects of climate change into management plans, the IWCõs CC2 Workshop recommended that scenarios used in the Implementation Simulation Trials (RMP) and Evaluation Trials (AWMP) be re-evaluated in light of additional climate change impacts (IWC 2009). The results presented here suggest that any such re-evaluations of the trials should include consideration of human-mediated as well as direct effects of climate change.

To achieve these goals of integrating cetacean concerns and climate adaptation plans, policy and management actions will be needed at national, regional and international levels. Some examples of policy mechanisms at each of these levels are provided in Table 2. At the level of individual nations, natural resource agencies should ensure that cetaceans are included in climate adaptation discussions, such as the ongoing National Academies study, ñAmericaõs Climate Choicesò in the U.S. Both direct and human-mediated potential impacts of climate change should be explicitly included in cetacean stock assessments and management reports. Regional efforts could occur under the auspices of bodies such as ACCOBAMS, ASCOBANS, and the Arctic Council (until a stronger regional framework for this area exists).

At the international level, there are several routes for integrating cetaceans into climate adaptation discussions. First, the UNDP's Global Environmental Facility (GEF) administers adaptation funding under the UN Framework Convention on Climate Change (UNFCC), and recently approved initial allocations for adaptation projects under a $50 million Strategic Priority on Adaptation (SPA) initiative. GEF has also developed the Adaptation Policy Framework to develop and implement adaptation strategies. Bangladesh and island states in the Caribbean and the Pacific are assessing adaptation options with assistance provided under UNFCC. The IWC should make a request to the UNDP-GEF that cetacean populations (in addition to other marine environmental concerns) be considered in the formulation of GEF-sponsored adaptation plans. Second, marine conservation should be integrated into development aid programs through bilateral aid, the World Bank and other organizations. Bilateral aid programs have already committed $110 million to more than 50 adaptation projects in 29 countries. Ensuring that cetaceans are considered as such projects are planned will be an important step toward mitigating the human-mediated impacts of climate change on populations of whales and dolphins worldwide.

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Table 1. Summary of potential human-mediated impacts of climate change on cetaceans.

Change in physical or biological environment	Potential change in human behavior	Predicted primary Impact on cetaceans	Species that may be affected
Diminishing sea ice	Increased shipping	Acoustic disturbance	Arctic and subarctic cetaceans
	Increased fishing pressure	Depletion of prey base	Toothed whales (particularly beluga); humpback whales
	As ice-dependent marine resources decline, Arctic communities may shift hunting effort to cetaceans	Direct hunt	Harvested Arctic cetaceans (beluga, bowhead, narwhal, gray whale)
	Increase in military presence	Acoustic disturbance	Baleen whales; beluga whales; beaked whales
Decline of coral reef health	Displacement of tourism to whale and dolphin-watching	Harrassment, acoustic disturbance	Coastal tropical cetaceans
Warming of high latitude waters	Increase in aquaculture	Coastal eutrophication; cetacean interactions with aquaculture operations may lead to harrassment/culling	Coastal high latitude species, particularly small toothed cetaceans
	Increase in fisheries as target species move north	Increase in bycatch	Primarily small toothed cetaceans
Drought and decreasing precipitation	Decline in food security may result in greater reliance on marine ecosystems for food	Prey depletion; direct catch of cetaceans for food	Tropical coastal cetaceans at mid and low latitudes
	Increase in human migration to coastal areas	Increase in urban and agricultural runoff, potential increases in tourism	All coastal cetaceans
	Increased water conflict may lead to reduced freshwater habitat for anadromous fish prey	Reduction in prey base	Toothed whales that eat anadromous fish (killer whales, beluga, porpoises)
	Increase in desalination	Localized disturbance	Coastal cetaceans, particularly those that use shallow lagoon or bay habitat
	Increase in fertilizer use	Increase in anoxic zones and potentially HABs	All coastal cetaceans, particularly those near river mouths

Table 1 (cont.). Summary of potential human-mediated impacts of climate change on cetaceans.

Change in physical or biological environment	Potential change in human behavior	Predicted primary Impact on cetaceans	Species that may be affected
Warming of high latitude terrestrial ecosystems	Increase in human densities and terrestrial activities (e.g. agriculture)	Increase in urban and agricultural runoff, potential increases in tourism	Coastal cetaceans
Increase in storm severity	Construction of seawalls, jetties, etc may increase coastal noise propagation	Acoustic disturbance	Coastal cetaceans
	Erosion prevention measures such as beach renewal	Coastal habitat destruction or fragmentation; introduction of foreign contaminants and disease	Coastal cetaceans
Sea level rise	Coastal construction projects to manage flooding	Habitat fragmentation	Coastal cetaceans (particularly estuarine and riverine)
	Land acquisition and creation of marsh and wetlands	Habitat loss; potential impacts on prey species	Coastal cetaceans (particularly estuarine and riverine)
New focus on renewable energy sources	Construction of offshore wind farms	Acoustic disturbance	Acoustically sensitive species such as harbour porpoise
	Construction of tidal and wave-powered energy sources	Little known; potential for habitat disruption or displacement	Cetaceans in continental shelf habitat
	Increase in hydroelectric power sources	Destruction of freshwater habitat for cetaceans and prey	Riverine and estuarine cetaceans; species that depend on freshwater fish prey

Table 2. Examples of policy mechanisms at national, regional and international levels

Potential change in human behavior	**National (e.g., U.S.)**	**Regional**	**International**
Increased shipping	NOAA (US)	ACCOBAMS, ASCOBANS, NAMMCO	International Maritime Organization
Increased fishing pressure	NOAA (US)	ACCOBAMS, ASCOBANS, NAMMCO	FAO, UNCLOS
Increased hunting of cetaceans	NOAA (US), First Nation governments (Canada)	NAMMCO, Arctic Council	IWC
Increase in military presence in Arctic	Department of the Navy (US)	NATO	UN General Council
Displacement of tourism to whale and dolphin-watching	NOAA (US)	ACCOBAMS	IWC
Increase in aquaculture	NOAA (US)	-	FAO
Increase in fisheries as target species move north	NOAA (US)	ICES European Union	FAO
Increase in human migration to coastal areas	State governments	African Union	UNDP, UNHCR
Increased water conflict	State governments	European Union	UNDP, World Bank
Increase in desalination	-	-	UNDP, World Bank
Increase in fertilizer use	EPA, Dept of Agriculture (US)	-	FAO
Increase in human densities and terrestrial activities (e.g. agriculture)	EPA, Dept of Agriculture (US)	-	UNDP
Coastal construction projects (breakwaters, beach renewal, etc)	Army Corps of Engineers (US)	-	UNDP, World Bank
Construction of offshore wind farms	NOAA/MMS/ FERC (US)	-	-
Construction of tidal and wave-powered energy sources	NOAA/MMS/ FERC (US)	-	-
Increase in hydroelectric power sources	FERC (US)	-	UNDP, World Bank