Potential Impact of Climate Change on Marine Mammal Biodiversity of Southeast Asia: (A Review)

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Climate change is affecting the oceans, and various studies have shown potential impacts on marine mammals. Impacts could be direct via habitat loss; or indirect through changes in the availability of prey, thus changing distribution and migration patterns and decreasing reproductive success of marine mammals. Further, increased water temperature could increase susceptibility to diseases and enhance impacts of other stressors. Species that have limited distributions and have little chance of expanding their range will be most vulnerable.

Although most recent studies have focused on marine mammal species found in mid to high latitudes because of the relatively greater potential temperature changes in these areas, impacts on tropical species are also being recognized. Most vulnerable are those with limited distributions, particularly the tropical riverine, estuarine and coastal species. Many of these species are found in Southeast Asia, a region that houses 32 of the 109-plus species of marine mammals. Among those with limited distribution that are already threatened are the Irrawaddy dolphin (*Orcaella brevirostris*); finless porpoise (*Neophocaena phocaenoides*); Indo-Pacific humpback dolphin (*Sousa chinensis*); and the dugong (*Dugong dugon*). These species have been classified as Vulnerable by the IUCN in its Red List, except for *S. chinensis*, which is considered Near Threatened. Five sub-populations of the Irrawaddy dolphins, all found in Southeast Asia, are Critically Endangered. Adding to

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these threats are the high human population growth rates typical of the coastal areas in Southeast Asia, increased dependence on the ocean as a source of food as the intensifying El Niño brings drought into inland areas, and lack of regulation or enforcement of fishery and conservation laws.

KEYWORDS: climate change, Southeast Asia, marine mammals, dolphins, cetaceans, dugongs, sea water temperature, Irrawaddy, finless porpoise, Indo-Pacific humpback dolphin, shifting geographic range

INTRODUCTION

Scientific evidence has shown that the earth's climate is changing (IPCC, 2007a). Land and sea surface temperatures have been increasing over the last century in a large-scale and consistent manner. It is believed that at least in the last 50 years, human activities have contributed largely to the trend through combustion of fossil fuel (IPCC, 2007a) and this trend is likely to continue (Learmonth et al., 2006).

Over the 20th century, the global average surface temperature has increased by 0.6 ± 0.2 °C, with an increase of 0.4-0.7 °C in air temperature over the oceans and a 0.4-0.8 °C increase in sea-surface temperature (IPCC, 2001). The increase in global temperature from 1956 to 2005 is nearly twice that of the 100 years from 1906 to 2005 (IPCC, 2007a). Depending on the climate change model used, it is projected that globally, land and sea surface temperatures will increase by between 1.1–6.4 °C by 2100, with increases in higher north latitudes being more pronounced (IPCC, 2007a). It has also been observed that the ocean has been taking up over 80% of the heat being added to the climate system, and 69% of that heat is being absorbed in the upper 700 m of the oceans (IPCC, 2007b).

Climate change can impact the terrestrial and aquatic ecosystems by first altering their physical and geochemical characteristics (Learmonth et al. 2006), then impacting their biological components. Among the physical and geochemical impacts of climate change on the marine environment are increase in temperature, decreases in sea-ice cover, rise in sea level, increases in CO_2 concentrations, and changes in salinity, pH, oxygen solubility, rainfall patterns, storm frequency and intensity, wind speed, wave conditions and climate patterns (IPCC, 2007a).

These alterations in the physical and biochemical characteristics can, in turn, influence the biological components of the ecosystem, affecting the distribution and abundances of plants and animals, community structure, prey availability and abundance, composition and abundance of competitors and predators, habitat use, timing and range of migration, vulnerability to diseases and pollutants, timing of breeding, reproductive success and survival (Tynan & De Master, 1997; Würsig, 2002; Booth & Zeller, 2005; Learmonth et al., 2006). Climate change can also add more strain to species and populations that are already burdened by other anthropogenic pressures such as overharvesting, pollution, fragmentation and habitat destruction (Salvadeo et al. 2010). Such pressures could lead to local extirpations or even species extinctions and undermine the resilience of ecosystems to adapt to other changes.

Ecosystems and species have been affected by climate change in the past. For example during the Pleistocene (in the last 1.8 million years) temperature and precipitation also fluctuated, but in a much slower rate compared to this century, giving the global biota a chance to cope through evolutionary changes by employing natural adaptive strategies (IPCC, 2002). Past changes took place in a landscape where ecosystems were not severely stressed, habitats not alarmingly fragmented, and with the plant and animal populations not receiving added pressures from human activities as they do today. Habitat fragmentation has isolated many populations and most likely decreased genetic variability, affecting their ability to cope through natural evolutionary means (IPCC, 2002).

Whereas impacts of climate change are easily measured and predicted in some marine organisms (e.g. coral reefs, plankton, shellfish, fish), their likely effects on large animals and those that are found at the top of the food chain are not immediately evident (Moore 2009). Several recent reviews have dealt with potential effects of climate change on marine mammals (e.g. MacLeod et al., 2005; Booth & Zeller 2005; Simmonds and Isaac, 2007; Elliot & Simmonds, 2007; Learmonth et al., 2006; MacLeod, 2009; Alter, Simmonds, & Brandon, 2010; Gambaiani et al., 2009; Moore, 2009; Salvadeo et al., 2010). Many of these reviews deal with the effects on species found in mid and high latitudes where impacts can be more profound. Only a few authors have considered implications of climate change for marine mammal species in the tropics. This review will focus on potential effects of climate change on marine mammals as a whole but particularly on potential impacts on marine mammals in Southeast Asia.

Marine Mammal Distribution

The term marine mammals includes three higher taxa of mammals that are not phylogenetically related, the Cetacea (dolphins, whales and porpoises) in the Order Cetartiodactyla, the Order Sirenia (sea cows, manatees and dugongs) and members of the Order Carnivora (seals, sea lions, sea otters, walruses and polar bears). Although lacking in phylogenetic links, these mammals are often thought of as a group because they all rely in the aquatic, though not necessarily marine environment, in all, or part of their existence, and have evolved similar anatomical and physiological adaptations to aquatic life (Jefferson, Hung, & Würsing, 2008).

Although some marine mammal species like the killer whale, (*Orcinus orca*), and the humpback whale (*Megaptera novaeangliae*) occur throughout the world's oceans, the distribution of most species is influenced by physical, chemical, and biological characteristics of the environment (Forcada, 2009). Water temperature, water depth and the availability of prey (influenced in turn by bottom topography, salinity, ocean currents and primary productivity) tend to determine the ecological distribution of many marine mammals (Forcada, 2009; MacLeod, 2009).

In general, water temperature appears to be the main factor that influences the geographic ranges of most marine mammals, with the other factors primarily influencing the fine-scale distribution of the species within that geographic range (MacLeod, 2009; Learmonth et al., 2006). Latitudinal zones, i.e. tropical, sub-tropical, temperate, Antarctic or Arctic define the distribution of many marine mammals (Forcada, 2009). Some species are exclusive to a particular zone. For example the bowhead whale (*Balaena mysticetus*), the beluga (*Delphinapterus leucas*), the narwhal (*Monodon monocerus*) and the polar bear (*Ursus maritimus*), are restricted to the icy waters of the Arctic (Forcada, 2009). Others, like the long-finned pilot whale (*Globicephala melas*) and the Atlantic white-beaked dolphin (*Lagenorhynchus albirostris*) are temperate species with thermal limits in either directions, and some, like Fraser's dolphin (*Lagenodelphis hosei*), and spinner dolphin (*Stenella longirostris*) are restricted to only tropical waters (Forcada, 2009; MacLeod, 2009; Learmonth et al., 2006). Some species move between these latitudinal zones. For example the grey whale (*Eschrichtius robustus*) and humpback whale undergo long-distance seasonal migrations between warm-water tropical calving grounds in winter and high-latitude cold-water feeding grounds in summer.

MacLeod (2009) proposed three hypothesis to help explain the linkage between water temperature and the geographic ranges of marine mammals: [1] various species have thermal limits, although this would seem unlikely given the well insulated large bodies of marine mammals and their ability to thermo-regulate, [2] temperature affects the distribution of the marine mammals' preferred food and therefore indirectly also affects their distribution (Simmonds & Isaac 2007) and [3] water temperature determines the results of competitive interactions between species of similar ecological requirements (MacLeod et al., 2008). More research is recommended to ascertain which of these hypotheses is most likely to explain the linkage.

Impacts of the Changing Climate on Marine Mammals–Global Scenario

Predicting the impacts of climate change on marine mammals is difficult. Firstly because predicting future changes in global climate, which will be the result of various interactions between its components (i.e. atmosphere, ocean, land surface, ice areas and the biosphere), is a challenging task and secondly because very little is known about the specific habitat preferences of marine mammals and their abilities to adapt to rapid changes in their environment (Elliot & Simmonds 2007, Learmonth et al. 2006). To complicate matters, climate change is also predicted to modify human behavior and activities. For example decreased ice cover in the Arctic may increase shipping activities, oil and gas explorations and fishing, adding more pressure to the already stressed Arctic species (Alter et al., 2010).

Direct Effects

The impacts of climate change on marine mammals are expected to be varied in different areas. Some impacts may be direct, such as [1] increased water temperatures resulting in shifts in species' geographic range (MacLeod et al., 2005; Learmonth et al., 2006; Elliot & Simmonds, 2007; MacLeod, 2009) and, [2] reduced sea-ice and rising sea level affecting polar seals' haul-out sites (Learmonth et al., 2006).

It is expected that as the sea surface warms, the tropical zones will expand into higher latitudes, the temperate zones will shift toward the poles and the polar zones will contract (MacLeod, 2009). Alongside this change it is expected that mobile organisms will react by also shifting their distribution in order to remain within their preferred 'environmental envelope' (MacLeod, 2009; Simmonds & Elliot, 2009). This shift has already been observed in the white beaked dolphin in Scotland (MacLeod et al., 2005), northern bottlenose whale (*Hyperoodon ampullatus*) in the Bay of Biscay (MacLeod, 2009) and the Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) in the northeastern Pacific (Salvadeo et al., 2010).

Shifting geographic ranges, however, may be limited by the presence of barriers such as land masses. For example, the land mass of Asia may prevent the northward movement of some cetacean species in the Indian Ocean as the water warms. Another example is the endangered vaquita (*Phocaena sinus*) whose distribution is limited only to the northern Gulf of California. The 'closed embayment' of its habitat would prevent it from moving northwards to cooler waters if water temperature increases and prey availability changes (Simmonds & Elliot, 2009). In the same manner, bathymetric discontinuities can limit cetaceans from moving into their preferred habitat (MacLeod, 2009). The opposite may be true for other species. Because of changes in water temperature, barriers that have prevented them from colonizing other habitats in the past may be weakened or even may disappear, "releasing" them to have access to new resources. In the framework developed by MacLeod (2009) that incorporated 'barriers', 'releasers', temperature ranges, water depth preferences, climatic category and conservation status due to changes in species' range, he predicted that the geographic range of 88% of all cetacean species may be affected by changes in water temperature brought about by climate change. Of these, 47% of cetacean species are "anticipated to have unfavorable implications for their conservation" and for the 21%, the changes may "put at least one geographically isolated population of the species at risk of extinction".

The shift will have more serious implications for the distribution and survival of polar species such as the beluga, the bowhead whale, narwhal and polar bear, as there will be a limited amount of colder areas to move into (Elliot & Simmonds, 2007). Because climate change in the polar zones will be "among the most rapid of any regions on earth" (IPCC, 2007a), these species will have less time to cope with and accommodate to changes in their shrinking habitat. In the Arctic, sea ice cover during summer has been decreasing at a rate of about

9% per decade (IPCC, 2007a). Decrease in sea ice cover will directly affect species that rely on ice for breeding (e.g. ice seals) and those that require solid ground on which to hunt or haul out to rear their young (e.g. polar bears, walruses) (Moore, 2009; Learmonth et al., 2006). Most vulnerable are the pinniped species in inlands seas and lakes such as the Caspian Seal (*Pusa caspica*) and the Baikal seal (*Pusa Siberia*), (Learmonth et al., 2006). These animals are limited in their ability to track decreasing ice cover (Harwood, 2001).

Whereas geographic ranges of temperate and polar species are expected to decrease in total area, tropical species' range is expected to expand. As water in higher latitudes warms up, tropical species can move into new environments and colonize new habitats. With a few exceptions, these species will probably be the least affected negatively (MacLeod, 2009) in this direct way.

Indirect Effects

Climate change will have indirect impacts on marine mammals, such as [1] changes in the distribution and density of prey species, [2] changes in reproductive success and survival, [3] changes in migration patterns, [4] changes in community structure, and [5] increased susceptibility to diseases and pollutants.

Shifts in the geographic range of species could be an indirect effect of climate change. Like all organisms, marine mammal distribution is highly influenced by the availability of prey, and prey distribution is intricately linked to oceanographic conditions like water currents, upwelling, eddies and primary productivity, all of which can be affected by water temperature. Variation in plankton composition, distribution, and abundance as a result of regional changes in sea surface temperatures has been documented in many areas (Beaugrand & Reid 2003 in Learmonth et al., 2006; Gambaiani et al. 2009). Baleen whales feed mostly on large patches of plankton and therefore their distribution can be influenced by the same factors that influence plankton distribution. Toothed whales feed mainly on fish, squid and crustaceans. The distributions of these preys are influenced by oceanographic variables including temperature (Sims et al., 2001; Sissener & Bjørndal, 2005). The change in the distribution of the near shore population of the common bottlenose dolphin (*Tursiops truncatus*) in southern to central California has been indirectly linked to increases in temperature through the effects on prey during the El Niño year in 1982-83 (Wells & Scott, 2007).

Reproductive success and calf survival are also tied to prey abundance. For example, there appears to be a close relationship between food abundance, body fat and fecundity (Lockyer, 1986). Female fin whales (*Balaenoptera physalus*) may produce a calf in two consecutive years if food is abundant but only one in three years if prey supply is poor. Prey availability and reproductive success has also been found related in sperm whales (*Physeter macrocephalus*), humpback whales, pinnipeds and sirenians (Whitehead, 1997; Boyd, Lockyer, & Marsh, 1999; Learmonth et al., 2006).

Generally the reproductive cycle and migration patterns of whales are timed to coincide with maximum prey abundance in their feeding grounds in higher latitudes. This timing is important for the lactating mother and the calf being weaned. Observations gathered in the last 40 years on the migration pattern of grey whales show delay of one week (from January 8 to Jan 15) in migration timing in response to the El Niño event that occurred in 1998/1999 (Moore 2009).

Another indirect effect of climate change on marine mammals is change in their community structure. The expansion of the geographic range of some species in response to the warming of water temperatures would lead to changes in the species composition and abundance of marine mammals, as observed in the cetacean community in northwest Scotland, where abundance of cold water white-beaked dolphins declined, and abundance of short-beaked common dolphins, a warm-water species, has increased (MacLeod et al., 2008). Effects of changes in community structure have implications for competition and survival of member species (MacLeod, 2009).

Mixing of populations and species not previously associated with each other could also lead to introduction of novel pathogens and parasites into the 'naïve' population (MacLeod, 2009). The situation will be exacerbated by increased water temperature that could increase infection rates and growth of pathogens. Increased temperature can also increase susceptibility of marine mammals to pollutants that could further complicate the situation (Learmonth et al., 2006). For example Booth and Zeller (2005) predicted that increasing water temperature due to climate change will increase methylation rate of mercury in the water and therefore increase concentrations of methyl mercury in the food web. Top predators, like marine mammals, are more likely to accumulate this pollutant into their system.

Lastly, climate change is bound to modify human behavior, which indirectly can affect marine mammal distribution and even survival (Alter et al., 2010). For example, decrease in ice cover in the polar region will increase shipping, oil and gas exploration and fishing activities, which in turn can increase ship strikes, acoustic disturbance, by-catch and prey depletion. In the tropics, climate change may result in increased pressure to the marine environment as droughts in inland areas intensify as a result of climate variability - one of the impacts of climate change.

While most of the concern about the effects of climate change is focused on the temperate and polar areas, very little attention has been given to species found in tropical waters, which are considered by many to be at a lesser risk from the impacts of climate change. Alter et al. (2010), on the other hand, consider that many tropical species are vulnerable, especially to human-mediated actions induced by climate change. Marine mammal species and populations that are restricted to coastal, estuarine and riverine habitats are particularly at risk. Many of these populations are found in Southeast Asia.

Climate Change and the Marine Mammals of Southeast Asia

Southeast Asia is a sub-region of Asia, comprised of two geographic regions: the mainland and the island arcs and archipelagos. The mainland section consists of Burma (Myanmar), Cambodia, Laos, Vietnam, Thailand and Peninsular Malaysia, while the island arc section consists of Brunei, East Malaysia, Indonesia, Singapore, the Philippines, and East Timor (Timor Leste).

Occupying only approximately 3% of the earth's surface, Southeast Asia is home to 20% of all known species of plants and animals[1]. The mountains, jungles and seas of the countries found in it "form one of the biggest biodiversity pools in the world"[2]. Southeast Asia has the most extensive coastline in the world, the most diverse coral reefs and the richest marine biodiversity. And it is also the most ecologically threatened region of the world.

At least 32 species and one subspecies of marine mammals belonging to seven families have been reported to occur in Southeast Asian waters (Table 1). Twenty-seven percent of these have strictly tropical distribution, 46% extend their distribution to warm-temperate waters and 27% have a worldwide distribution. Impacts of climate change to the species found in the region are shown in Table 1, taken from the assessments of MacLeod (2009), Learmonth et al. (2006) and Alter et al. (2010).

Following MacLeod's (2009) framework, tropical species are expected to expand their distributional ranges as the seas warm up due to climate change, giving them the ability to colonize new areas. This scenario offers favorable implications to the conservation status of the species found in the Southeast Asian region, wherein most of the effects will be expansion of distributional ranges (Table 1). Assessments made by Learmonth et al. (2006), also based on water temperature increases in latitudinal zones, on the other hand, show that distributional ranges of 14 species (42%) of cetaceans found in Southeast Asia would expand and one (3%), the Irrawaddy dolphin, would have a decreasing range. The fate of 55% of the species cannot be predicted. Both of these assessments, however, did not include other climate change impacts (i.e. droughts and changes in precipitation, rise in sea level, and storm frequency and severity) that could potentially affect the abundance, distribution and even survival of tropical marine mammal species. Most importantly they did not include in their assessments impacts resulting from changes in human behavior in response to climate change that could greatly impact marine mammal conservation in tropical climates. These factors are particularly important in predicting impacts on species with restricted distributions and those that inhabit coastal, estuarine and/or riverine areas (Alter et al, 2010).

Six species and one subspecies of marine mammals that are found in Southeast Asia have coastal distributions. These include Omura's whale (*Balaenoptera omurai*), Indo-Pacific bottlenose dolphin (*Tursiops aduncus*), Indo-Pacific hump-backed dolphin; finless porpoise, Irrawaddy dolphin, a subspecies of the spinner dolphin, the dwarf spinner dolphin (*Stenella longirostris roseiventris*) and the dugong. Of these, three species (Irrawaddy dolphin, Indo-Pacific humpback dolphin and finless porpoise) are considered most vulnerable not only because they inhabit very shallow coastal, estuarine and sometimes riverine environments but also because they have very restricted geographical ranges, most of which are centered in areas that are densely populated by humans. These species are already under great extirpation pressures (considered Vulnerable-IUCN Red List, except for Indo-Pacific humpback dolphin which is considered Near Threatened), with some sub-populations declared as Critically Endangered (Reeves et al., 2008a; Reeves et al., 2008b; Reeves et al., 2008c; Reeves & Martin 2007).

Irrawaddy dolphin

Irrawaddy dolphins have a discontinuous distribution in the Indo-

Pacific region, with almost all populations exclusively tied to estuarine and freshwater systems (Stacey & Arnold, 1999). Distribution ranges from Borneo and the central islands of the Indonesian archipelago north to Palawan and the Visayas in the Philippines and west to the Bay of Bengal, including the Gulf of Thailand (Reeves et al., 2008c; Dolar et al., 2009). Freshwater populations occur in three large rivers: Ayeyarwaddy in Myanmar, Mahakam in Indonesia, and Mekong in Vietnam, Cambodia and Lao PDR, and two brackish water lakes in India and Thailand. Twenty-seven of the 32 locations (85%) where Irrawaddy dolphins have been recorded to occur are found in Southeast Asia (Kreb, 2004; Smith, 2009).

Many of the Irrawaddy dolphin sub-populations are at the brink of extirpation. For example IUCN has declared five sub-populations to be Critically Endangered: the Ayeyarwaddy River sub-population in Myanmar where there are only 58-72 individuals (Smith, Mya, & Tint, 2007), the Mahakam River subpopulation in Indonesia with 70 individuals (Krëb, Budiono, & Syachraini, 2007), Malampaya Sound with 77 animals (Smith et al., 2004), Mekong River with at least 125 individuals (Beasley et al. 2007), and Songkhla Lake, where it is estimated that probably fewer than 50 adult individuals exist (Smith & Beasley, 2004). The newly discovered Irrawaddy dolphin population in Guimaras and Iloilo Straits (Visayas, Philippines) with less than 40 individuals may also be critically endangered as well (Dolar et al., 2011).

Indo-Pacific humpback dolphin

Though currently considered a single species with two variable types, some biologists believe that the two types are distinct species: *Sousa chinensis* and *S. plumbea* (Reeves et al., 2008b). The distribution of the *plumbea* form includes the western Indian Ocean, from South Africa to at least the east coast of India. The *chinensis*-form ranges from the east and west coasts of northern Australia and from southern China in the east throughout the Indo-Malay Archipelago and westward around the Bay of Bengal (Reeves et al., 2008b). Recent phylogenetic studies, however, indicate that the humpback dolphins from Australia are significantly different and may represent a different species (Frere et al., 2008). The separation of the Australian group implies that most of the range of the *chinensis* form is within the Southeast Asian region. The population of this form is declining, with most of the estimates being in the low hundreds, except for the Pearl River Estuary in southern China (Reeves et al., 2008a).

Like the Irrawaddy dolphin, the humpback dolphin is a coastal obligate occurring on open coasts and in bays, lagoons, around rocky and/or coral reefs, mangrove swamps, and estuarine areas, preferring shelf waters less than 20 meters deep (Ross et al., 1994; Parra & Ross, 2007; Reeves et al., 2008b). The dolphins sometimes enter a few kilometers into rivers but remain within tidal range.

Indo-Pacific finless porpoise

Two species of finless porpoise are currently recognized: the Indo-Pacific finless porpoise (*N. phocaenoides*), which ranges from the Indian Ocean to the South China Sea and the East Asian or narrow-ridged finless porpoise (*N. asiaeorientalis*) (Wang et al., 2008). The distribution of the Indo-Pacific finless porpoise includes the northern rim of the Indian and western Pacific oceans from the Persian Gulf in the west to the Indo-Malay region in the east to Indonesia. Finless porpoises prefer shallow waters (<50m in depth) in mangrove zones of tropical waters. They also inhabit the estuaries and lower reaches of large river systems such as the Ganges and the Indus rivers. Populations of both species are declining (Reeves et al., 2008a).

Vulnerability of the tropical coastal marine mammal species to impacts of climate change

The affinity of coastal cetaceans to estuaries and freshwater sources has serious implications concerning the impact of climate change on these species (Fig. 1). Severe weather changes, the strengthening of El Niño and decreased precipitation could bring droughts into the region (IPCC, 2007a). This, coupled with an increasing trend of deforestation could diminish freshwater input into the estuaries. For cetacean populations living in rivers, that means decrease in their habitat size, and for those adapted to the estuarine environment, it means alteration in the salinity of their habitat. Further, sea level is predicted to rise as a consequence of melting ice in the Polar Regions and of thermal expansion (IPCC, 2007b). This will bring more seawater into estuaries and most likely, salt water will also encroach into river systems, exacerbating the effects of decreased freshwater inputs (Fig. 1). Sea level is predicted to rise about 0.5 m by the end of the century (IPCC, 2007b). The combined effect would be an increased salinity in estuarine areas and saltwater intrusion into rivers, resulting in a

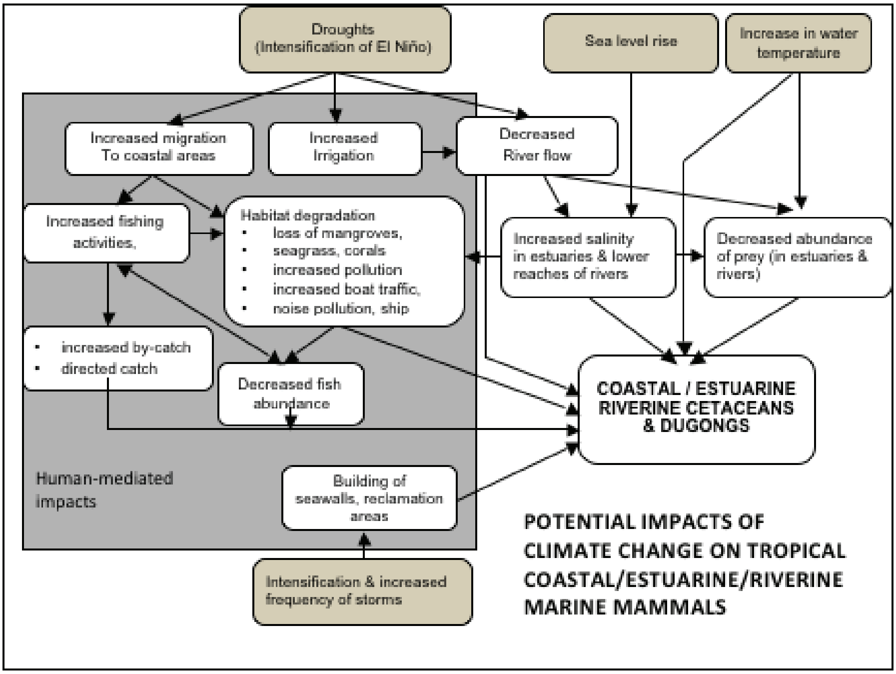

Figure 1. A model showing potential effects of climate change on tropical, coastal, estuarine and riverine species of marine mammals.

shrinking habitat for species that have become adapted to estuarine or riverine existence.

Although there is little information on the abilities of estuarine cetaceans to adapt to increasing salinities, it is speculated that these changes could affect their survival, either directly through physiological limitations to cope with high salinity, or indirectly through decreasing prey/food abundance. Estuaries are especially productive ecosystems with unique assemblage of organisms including fish and crustaceans that have developed adaptations to the brackish water environment. Decreased river flow means decreased nutrient inputs from land which can affect the overall productivity of estuaries. Mangroves which contribute greatly to the productivity in estuarine and coastal areas are also greatly vulnerable to climate-change-induced sea level rise (IPCC, 2001). Already, mangroves are under great anthropogenic pressures. They have been disappearing at an alarming rate. For example, 75% of mangrove forests in the Philippines have been lost in the last 70 years, and in Indonesia, an estimated 44,000km2 of mangroves have been destroyed in the past

35 years (IPCC, 2001).

Affinity of coastal species with shallow shelf waters may mean that they will be vulnerable indirectly to changes in water temperature. Shallow waters heat up faster than deep waters. Rise in environmental temperature increases the animal's metabolic rate and correspondingly increases demand for food. Meanwhile, general fishery productivity in tropical waters is expected to decline by about 40% as a consequence of warming seas (Cheung et al., 2009). Dolphins would then be faced with increasing demand for food but decreased food availability.

Other coastal marine mammal species found in Southeast Asia that are not tied to freshwater and estuarine habitats but are dependent on the productivity of shallow water ecosystems are the Indo-Pacific bottlenose dolphin, the dwarf spinner dolphin and the dugong (Perrin, Dolar, & Robineau, 1999; Wang & Yang, 2009). Productivity of coral reef systems is predicted to decrease as a result of impacts of climate change (IPCC, 2002). Warming ocean waters and ocean acidification observed in the last decades have resulted in increased coral bleachings and in some cases large-scale coral mortality (IPCC, 2002). Sea grass beds are also at risk. It is predicted that increased flooding brought about by intensification of storms will increase sedimentation rate, which in turn will put many of the sea grass beds at risk of extirpation, affecting species that rely on them for food. Dugongs are purely herbivorous, feeding mainly on seagrasses. Destruction of this habitat will have very serious effects on the survival of dugong populations in Southeast Asia, where they are already under tremendous extirpation pressures (Marsh 2009).

Human-mediated threats to tropical species induced by climate change

Alter et al. (2010) evaluated likely impacts on cetaceans caused by changes in human behavior and activities resulting from increasing temperatures, flooding, storm surges, aridity and decreasing ice cover and new focus on renewable energy. Their results suggest that not only are the species in polar areas at risk but also the tropical species, especially those with coastal estuarine and riverine habitats and with restricted distributions. For the species found in Southeast Asia, six (18%) have impact scores of 8, the second highest score, which implies high vulnerability, similar to that for belugas in the polar region (highest score of 11 was given to gray whales). The six species with impact scores of 8 are the Irrawaddy dolphin, Indo-Pacific humpback dolphin, finless porpoise (the two species combined), Indo-Pacific bottlenose dolphin, common bottlenose dolphin, and short-beaked common dolphin (*Delphinus delphis*). The humpback whale scored 7. Six (18%) have scores between 1 and 3, and 12 species (36%), most of which are pelagic and/or deep water species, do not appear likely to be affected at all (Table 1). Although there are no impact scores for the remaining three species and one subspecies, it is most likely that the dugong, because of its dependence on shallow waters and complete dependence on seagrasses for food, would have an impact score of 8 or greater. Factors that they predicted would have the greatest impacts on tropical species are drought, increase in storm severity, sea level rise, coral reef decline and possible increase in use of marine renewable energy.

Coastal species are particularly vulnerable because their habitats overlap with areas heavily used by humans. This is particularly significant in Southeast Asia where total human population is over 594 million, with a density of 750 people / km^2. This density is almost 10 times higher than the global average. The archipelagic nature of the region brings most of the human population near the coast, i.e. 65% of major cities with population of 2.5 million or more are located along the coasts (Hinrichsen, 1990). In addition, people in these islands are maritime in nature, using the seas extensively as a source of food and for travel between islands.

Droughts inland are expected to drive people to migrate to near the coast and increase reliance on marine ecosystems (Fig. 1). This will add pressure to the already overburdened fisheries in the area (Alter et al., 2010). Fishery effort is expected to increase while overall productivity of the oceans decreases in response to increasing sea water temperature. A recent study predicted that while climate change could increase fishery catch potential in the mid and high latitudes by 30-70%, there will be a decline of 40% in the tropics (Cheung et al., 2009). Increased fishing effort could result in increased marine mammal by-catch while depleting prey (Fig. 1). There is also a possibility that directed fisheries for marine mammals will increase, especially in areas where cetaceans are not protected or where there are few resources to enforce regulatory measures. The greatest threats that marine mammals face in Southeast Asia today are by-catch, and in some areas, directed catch (Perrin et al., 2005). It is expected that these threats will increase as fish yields decline. Increased human migration to the coast will also increase pollution. This, aided by increasing temperature will help promote algal blooms (Alter et al., 2010). Toxins released from algal blooms have caused mass dolphin mortality in several areas in the past (Gambaiani et al., 2009).

Because of declining precipitation and diminished freshwater flows, it is expected that more dams will be constructed to irrigate agricultural lands. Dams will fragment riverine dolphin populations.

Strong storm surges, flooding and sea level rise will drive people to construct protective structures such as seawalls, dikes, levees, floodwalls, breakwaters, flood gates, tidal barriers, beach replenishment and dune restoration and creation (Alter et al., 2010). The threat of flooding is predicted highest for South and Southeast Asia, Africa, southern Mediterranean coasts, the Caribbean and most islands in the Indian and Pacific Oceans (Nicholls, Hoozemans, & Marchand, 1999). Coastal construction will affect marine mammals through noise pollution produced by activities such as dredging and pile driving, habitat loss and degradation (Jefferson et al., 2008).

In summary, while the impacts of global warming have been predicted to be greatest for arctic and temperate marine mammal species, it is clear that impacts on tropical marine mammals will likely also be substantial and may lead to extirpation of some populations.

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ENDNOTES

[1] ASEAN Center for Biodiversity. http://www.aseanbiodiversity.org/index.php?option=com_content&view=article&id=79&Itemid=98

[2] ASEAN Center for Biodiversity. http://www.aseanbiodiversity.org/index.php?option=com_content&view=article&id=79&Itemid=98

Table 1.

Predicted impacts of climate change on marine mammal species in Southeast Asia. (**Habitat:** C = coastal, P = pelagic / **Distribution:** W = worldwide, WTE = warm temperate, CTE = cold temperate, TE = temperate, TR = tropical, STR = subtropical / **IUCN Conservation Status:** CR = critically endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened, DD = Data Deficient; LC = Least Concern / CC (Climate Change) Impacts: ML (MacLeod 2009): un = unchanged, f = favorable; L = Learmonth et al. 2006: ↑ = range increase, ↓ = range decrease, ? = not known; Alter et al. 2010, numbers represent impact scores. High score means more impact.

Species	Habitat	Distribution	IUCN	CC Impacts		
				ML	L	Alter
CETACEA (Whales, Dolphins and Porpoises)						
MYSTICETI / Baleen Whales						
Family Balaenopteridae—Rorquals						
Balaenoptera musculus (Blue whale)	P	W	EN	un	?	3
Balaenoptera physalus (Fin whale)	P	W	EN	un	?	3
Balaenoptera edeni (Bryde's whale)	P	WTE,TR	DD	f	?	1
Balaenoptera omurai (Omura's whale)	C	TR	DD	no info	?	no info
Balaenoptera acutorostrata (Minke whale)		W	VU	un	?	3
Balaenoptera borealis (Sei whale)	P	CTE,TR	EN	no info	?	2
Megaptera novaeangliae (Humpback whale)	P	W	LC	un	?	7
ODONTOCETI / Toothed Whales						
Family Delphinidae—Ocean Dolphins						
Delphinus capensis (Long-beaked common dolphin)	O	STR	DD	f	↑	no info
Delphinus delphis (Common dolphin)	O	TE,TR	LC	f	↑	8
Feresa attenuata (Pygmy killer whale)	O	TR,WTE	DD	f	↑	0
Globicephala macrorhychus (Short-finned pilot whale)	O	TR,STR	DD	f	↑	0
Grampus griseus (Risso's dolphin)	O	CTE,TR	LC	f	?	1
Lagenodelphis hosei (Fraser's dolphin)	O	WTE,TR	LC	f	↑	0
Orcaella brevirostris (Irrawaddy dolphin)	C,R,E	TR	VU, CR	f	↓	8
Orcinus orca (Killer whale)	O	W	DD	un	?	2
Peponocephala electra (Melon-headed whale)	O	TR	LC	f	↑	0
Pseudorca crassidens (False killer whale)	O	WTE,TR	DD	f	↑	0
Sousa chinensis (Indo-Pacific humpback dolphin)	C	TR	NT	f	?	8

Continued on the next page...

Table 1. (Continued...)

Predicted impacts of climate change on marine mammal species in Southeast Asia.

Species	Habitat	Distribution	IUCN	CC Impacts		
				ML	L	Alter
Stenella attenuata (Pantropical spotted dolphin)	O	W	LC	f	↑	0
Stenella coeruleoalba (Striped dolphin)	O	CTE,TR	LC	f	↑	1
Stenella longirostris longirostris (Gray's spinner dolphin)	O	TR	DD	f	↑	1
Stenella longirostris roseiventris (dwarf spinner dolphin)	C	TR	DD	no info	↑	no info
Steno bredanensis (Rough-toothed dolphin)	O	WTE,TR	LC	no info	?	0
Tursiops aduncus (Indo-Pacific bottlenose dolphin)	C	TR	DD	no info	?	8
Tursiops truncatus (Bottlenose dolphin)	O	W	DD	f	↑	8
Family Kogiidae—Pygmy and Dwarf Sperm Whales						
Kogia breviceps (Pygmy sperm whale)	O	WTE,TR	DD	f	↑	0
Kogia sima (Dwarf sperm whale)	O	WTE,TR	DD	f	↑	0
Family Physeteridae—Sperm Whale						
Physeter macrocephalus (Sperm whale)		W	VU	un	?	3
Family Ziphiidae—Beaked Whales						
Ziphius cavirostris (Cuvier's beaked whale)	O	W	LC	f	?	0
Mesoplodon densirostris (Blainville's beaked whale)	O	WTE,TR	DD	f	?	0
Indopacetus pacificus (Longman's beaked whale)	O	TR	DD	f	?	0
Family Phocaenidae						
Neophocaena phocaenoides (Indo-Pacific finless porpoise)	C	WTE,TR	VU	f	?	8
SIRENIA (Manatees and Dugongs)						
Family Dugongidae—Dugong						
Dugong dugon (Dugong)	C	TR	VU	no info	?	no info

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