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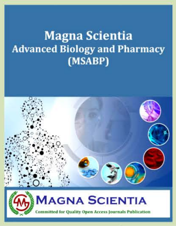

(REVIEW ARTICLE)

The impact of climate change on the ecology, reproduction and distribution of marine mammals and the possible legislation, conservation and management approaches to protect these marine mammal species: A systematic review

Lakhnarayan Kumar Bhagarathi [1, 2, *], Phillip N. B. DaSilva [2], Gyanpriya Maharaj [3], Rahaman Balkarran [4], Aarif Baksh [2], Sushmita Kalika-Singh [2], Ferial Pestano [2] and Chalasa Cossiah [2]

[1] *Faculty of Natural Sciences, University of Guyana, Turkeyen Campus, Greater Georgetown, Guyana.*
[2] *Faculty of Natural Sciences, University of Guyana, Berbice Campus, Tain, Corentyne, Guyana.*
[3] *Centre for the Study of Biodiversity, Faculty of Natural Sciences, University of Guyana, Turkeyen Campus, Turkeyen, East Coast Demerara, Guyana.*
[4] *Queensborough Community College, New York, United States of America.*

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Abstract

This paper aims to review and evaluate published literature on the impact of climate change on marine mammals. A systematic method was utilized to access research works of literature on "Impact of Climate Change on Marine Mammals". A total of eighty-two (82) research papers published between the years 1976 to 2024 were accumulated and used for this review. A subjective approach was used to select the topics: impact of climate change and marine mammals. In this paper, nine (9) direct and indirect effects of climate change and environmental factors affecting marine mammals were assessed in this paper. Further, six (6) detrimental impacts of climate change on marine mammals were evaluated and presented. In addition, an integrated checklist of one hundred twenty-seven (127) marine mammal species were presented along with their current IUCN Red List status categories. Subsequently, a total of eighty-three (83) cetaceans (whales, dolphins and porpoises), thirty-four (34) pinnipeds (seals, sea lions and walruses), six (6) sirenians (manatees and dugongs) and four (4) fissipeds (polar bears and sea otters) were presented on the integrated checklist. In addition, this paper assessed some marine mammal species that are endangered and threatened with extinction such as *Monachus monachus* and *Phocoena sinus*. Legislation, conservation and implications for the management and preservation to address marine mammals and combat the effect of climate change was also presented in this review. The published works of literature established that the global marine mammal population dynamics, ecology, reproduction, abundance and distribution are all affected by the threats of climate change. The availability of prey impacts the distribution, abundance and movement of marine mammals as well as their community structure, vulnerability to toxins and disease, success of their reproduction, and, ultimately, their survival. Additionally, marine mammals are particularly vulnerable to the possible effects and repercussions of changes in salinity, pH, and CO_2. This review highlights that more extensive studies on the impact of climate change on marine mammals should be done in neotropical countries since there are gaps of such information on research and published data in these biodiversity-rich regions.

Keywords: Climate change; Marine Mammals; Cetaceans; Pinnipeds; Fissipeds; Sirenian; Conservation; Management

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[*] Corresponding author: Lakhnarayan Kumar Bhagarathi

1. Introduction

1.1. Climate Change and Marine Mammals

The Earth's climate is changing [83]. Over the twentieth century, the worldwide average land and sea surface temperature increased, as did precipitation, notably in the mid- and high latitudes [31] [81] [114]. These modifications have resulted in secondary effects. For example, as temperatures have risen, ice cover has reduced while the global sea level has risen. Such changes are seen in the global network of climate instruments and, on a longer timescale, in using historical proxies such as tree rings or ice cores. The origins of such changes are debatable, but the majority of the observed warming over the previous 50 years was most certainly caused by rising CO_2 emissions, which are expected to continue [31] [81] [114].

The Intergovernmental Panel on Climate Change (IPCC)'s research studies have made it obvious that climate change will cause temperature variations as well as alterations in ocean circulation, ice coverage, and sea level [127] [165]. Changes in the frequency of extreme events are also projected, which will have an impact on the structure and function of marine ecosystems and negative feedback global biogeochemical cycles and the climate system [47] [48] [70] [81] [83] [85] [114] [127] [159] [165]. The IPCC reports that the world's oceans have warmed over the past 50 years, with regional differences and rising sea levels. Marine mammals and seabirds are sensitive indicators of ocean changes [127] [165].

Climate change known or predicted large-scale and regional impacts on the marine environment include increased temperature, rising sea levels, and changes in ocean circulation, sea-ice cover, salinity, CO2 concentrations, pH, rainfall patterns, storm frequency, wind speed, wave conditions, and climate patterns [47] [48] [70] [81] [83] [85] [114] [159]. Climate change is anticipated to pose a significant threat to the world's species, as well as have an impact on total biodiversity levels. Climate change has already had an impact on wildlife across a variety of taxa, and these consequences are expected to worsen unless appropriate mitigation measures are implemented [38] [133] [153] [189].

This review highlighted the relevant literature linking the changes in marine mammal populations to changes in global climate. However, predicting the specific effects of climate change on most wildlife is challenging, particularly for highly nomadic marine mammals. Due to aquatic environments, most marine mammal species are naturally difficult and expensive to research, and long-term data sets specifying range and habitat are uncommon [165]. The relationship between global climate change and predator responses is only now being investigated [51] [165], and patterns and trends in species diversity in the open oceans remain a mystery [165] [200].

The effects of climate change on higher trophic levels can be particularly challenging to study because they entail non-trivial, nonlinear connections that are influenced by temporal lags [116] [113] [165]. The limits of contemporary climate models severely limit the ability to anticipate the responses of specific species, while predictive capability is expected to improve [92] [165].

Sea surface temperature is an excellent predictor of marine animal distributions [100] [152] [165]. Some species can only be found in warm tropical waters, some in temperate zones, and yet others only in the poles. While certain species may migrate regularly between temperature zones on a regular basis regularly, they may also be suited to specific temperature regimes during different life cycles. Young marine mammals, for example, may demand warmer water [165] [167]. Marine mammals primarily exploit patchy prey species that they require in dense concentrations, therefore their distribution reflects those oceanic features, both static (such as depth and slope) and movement (such as fronts and upwellings), with high productivity [165].

2. Material and Methods

The topic of “impact of climate change on marine mammals” was the subject of a systematic review using “Google Scholar,” a web-based search engine which provides a quick and easy way to search and access published literature from articles, journals and books. Thematic search terms such as impact, climate change, marine mammals, cetaceans, pinnipeds, fissipeds, sirenian, conservation and management were used in the search.

The subjects evaluated in this research were chosen using an approach that involved assessing at the related works of literature. Publications between the years 1976 to 2024 were acquired for this review. However, not all of the articles that were reviewed, were used in this study because the major objective was to assemble data from recent research (past 10 to 20 years) on impact of climate change on marine mammals. However, papers that contained relevant literature from as far back as the 1900's and the 2000's were also utilized for this review. One hundred-seventeen (107) research articles were retrieved and included in this review and literature from eighty-two (82) papers published between the years 1976-2023 were presented in this paper.

The search yielded different results: Some articles had all the thematic keywords and some were obtained that were specific to conservation and legislation measures and management approaches to protect marine mammals, while others were specific on the incidence and occurrence of diseases on marine mammals, marine mammals threatened with endangerment and extinction and marine mammals' responses to environmental factors.

3. Results

When searching "Google Scholar" for information on the impact of climate change on marine mammals, a total of 77,400,000 was retrieved. Among the results obtained from the search, a total of 22,100 were published within the years 2000-2023, 27,400 were published between the years 2010-2023 and 24,200 were published within the years 2015-2023. 27,800 publications between 2010 and 2023 reviewed the impact of climate change on marine mammals.

However, not all the results retrieved for this research focused on the impact of climate change on marine mammals. Some focused solely on climate change on marine mammals, others examined the conservation and legislation measures and management approaches to protect marine mammals from the impact of climate change and some were specific on the impact of disease incidence and occurrence on marine mammals. Further, some papers focused on checklists of marine mammals threatened with endangerment and extinction and the IUCN Red list of marine mammal species.

4. Discussion

4.1. Predictions

4.1.1. Environmental threats

MacGarvin and Simmonds (1996) examined the potential effects of climate change on cetaceans and concluded that 'among the many environmental threats faced by cetacean populations, the most speculative, and yet perhaps potentially the most important, concern the implications for them of changes in atmosphere and climate'. They proposed that changes in their prey would adversely affect cetaceans in terms of productivity as well as alterations in prey species distribution and might have a negative impact on the base of marine food web changes due to increases in water temperature, turbulence, and surface salinity [165].

MacGarvin and Simmonds (1996) also highlighted five other related issues: (1) The rate of climatic change is beyond the evolutionary experience of current cetacean species [102]. (2) Many whale species have complex life cycles and appear to rely on finding specific resources in specific places at specific times (for instance, water with a specific temperature range or abundant prey; examples include whale species that migrate long distances between feeding and breeding grounds) [177]. (3) Water movement and temperature fluctuations may have an impact on whales' capacity to navigate across oceans [86]. (4) Many whale populations are already at critically low [91]. (5) Other factors are causing harmful effects on species and populations simultaneously [138]. Furthermore, MacGarvin and Simmonds (1996) predicted that rising sea levels might destroy coastal habitats such as estuaries, bays, and lagoons, exacerbating pollution by flooding coastal dump sites or agricultural land.

The International Whaling Commission (IWC) hosted a workshop on climate change in 1995. It noted difficulties in making projections but also stated that 'concerns about the ability of at least some cetacean populations to adjust to future conditions are legitimate' [92]. Burns (2002) reiterated the relevance of environmental changes in Antarctica, where 90% of the world's great whales graze, highlighting the link between krill *Euphausia* spp. and sea ice extent [24].

4.1.2. Food sources

Sea ice edges may protect krill from predators, and sea ice algae are an important food source for krill. When the sea ice melts, salps (tunicates of the species *Salpa thompsoni*) take over and may outcompete krill. Salps are more tolerant of warmer and lower nutrient water than krill, and there is evidence that their range is expanding, with far-reaching implications for the Southern Ocean food web, which includes penguins, albatrosses, seals, and whales, all of which have large foraging ranges but are vulnerable to krill shortages [7] [165]. At the same time there is a significant difference between land-based predators who rely on localized krill at vital moments during the raising of their young and whales which may be more mobile, the whales tend to respond to the same climate-driven signals as seals and penguins [113] [165].

In the Arctic, unlike in the Southern Ocean, no single species of plankton dominates, and phytoplankton levels are expected to decline, with knock-on effects across the Arctic food chain. Several critical prey species of cetaceans may be impacted, but some cetacean species in the region, such as fin whales *Balaenoptera physalus* and bowhead whales *Balaena mysticetus*, have shown adaptation in feeding behavior and may be able to move to other species [165] (Burns, 2002). Polynyas, or leads, are open water areas in the polar ice pack that are vital for some species of marine mammals, such as feeding, breeding, and overwintering habitats, and their extent may be influenced by climate change [26] [165].

4.1.3. Population

Simmonds and Mayer (1997) documented an apparent increase in large die-offs in marine mammal populations in recent years, and Burns (2002) added that global warming may promote hazardous algal blooms and contribute to epidemics. While viruses (particularly those from the highly deadly morbillivirus family) have been identified as the primary cause of some big mortality incidents, environmental variables may have worsened or even precipitated these epizootics [165] [166]. One example is the die-off of striped dolphins *Stenella coeruleoalba*, which swept throughout the Mediterranean in the 1990s and resulted in the deaths of thousands of animals. The dolphins' poor nutritional state, induced by insufficient food input to the eastern Mediterranean, first driven by deficient rainfall, could have been a precipitating factor [165] [166].

Wursig *et al*. (2002) projected that species that rely on small patches of specific types of habitats, such as land- or ice-breeding pinnipeds, coastal and freshwater cetaceans, and sirenians, will be especially vulnerable to climate change. They observed that changes in prey distribution or quantity can influence even more mobile ice-edge species, such as the bowhead *Balaena mysticetus* and beluga *Delphinapterus leucas*.

Table 1 Climate Change and its impact on marine mammals

Effects	**Description of impacts**	**Author(s)**
Impact on Predator-Prey Relationships and Food Webs	El Niño phases are essential as a proxy for climate change, while a shift in their frequency could be a hallmark of climate change itself. Recent El Niño occurrences have caused reproductive failure, particularly in seabird and seal colonies, as seen by increased juvenile mortality. For example, during the El Niño year of 1982, all female Galapagos fur seals (*Arctocephalus galapagoensis*) lost their pups, while other marine species had simultaneous distributional shifts. Near-bottom spawning market squid (*Loligo opalescens*) left southern California, accompanied by at least one of its predators, the short-finned pilot whale (*Globicephala macrorhynchus*). It is unclear whether the loss of prey and apparent climate-induced change resulted in mortality or health deterioration. Several years later, an influx of Risso's dolphins (*Grampus griseus*) arrived in the same vicinity, feeding on market squid that had returned. Dolphins may have taken advantage of the niche left by the pilot whales. During the El Niño event, common bottlenose dolphins (*Tursiops truncatus*) expanded from southern to central California and remained there when the event finished. Lusseau *et al.* (2004) established a climate-driven signal in the first study to establish a relationship between climate fluctuation and social behavior in a marine system. Using two unusually long-term and thorough data sets, they discovered that the group size of common bottlenose dolphins (*Tursiops truncatus*) in Scotland's Moray Firth and orcas (*Orcinus orca*) in Canada's Johnstone Strait fluctuated from year to year in response to large-scale ocean climate change. Local prey abundance indices fluctuated with climate, and cetaceans preferred to reside in smaller groups when there were fewer salmon, which arrived two years after a lower phase of the North Atlantic and Pacific Decadal Oscillations (these are regular patterns in sea surface temperatures; the North Pacific oscillates over 15-25 years and 50-70 years, whereas the North Atlantic Oscillation has a dominant period of 12 years). The change in group size demonstrates the adaptability of huge marine predators. Hundreds of grey whales (*Eschrichtius robustus*) were stranded along the east coast of the Americas in 1999-2000, possibly due to a drop in their prey in the Chirikov Basin in the Bering Sea, which resulted in hunger. The number and biomass of the grey whale's amphipod prey species have been declining in the northern Bering Sea since the 1980s, and the amphipod species composition in this region has shifted to favor species that are less lipid-rich and thus less nutritious. These changes have been hypothesized to be induced by changing oceanographic conditions and warming oceans, and apex predators such as grey whales (*Eschrichtius robustus*) and walruses (*Odobenus rosmarus*), that feed directly on benthic bivalves and amphipods, were presumably greatly affected by these changes to their prey base. In addition to contributing to climate change, increased atmospheric CO_2 concentrations cause seawater acidification. Squid, important prey species for many deep-diving marine mammal species, may be especially vulnerable to this change because their high-energy swimming and metabolism require a steady supply of oxygen. An increasing CO_2 concentration lowers blood pH and its ability to transport oxygen effectively. Acidification is also likely to harm calcifying organisms, such as coral and some phytoplankton and zooplankton species, potentially affecting marine predators. Several research suggest that possible effect on other marine taxa may also impact marine mammals via the food chain. Salinity decreases due to increased freshwater imports, increases in CO_2,	(Boyle, 1983); (Evans, 1990); (IWC, 1997); (Grebmeier & Dunton, 2000); (Rindorf *et al.*, 2000); (Arnott & Ruxton, 2002); (Bjørge, 2002); (Stenseth *et al.*, 2002); (Walther *et al.*, 2002); (Wursig *et al.*, 2002); (Moore *et al.*, 2003); (Edwards & Richardson, 2004); (Frederiksen *et al.*, 2004); (Greene & Pershing, 2004); (Lusseau *et al.*, 2004); (Pörtner *et al.*, 2004); (Santos *et al.*, 2004); (Stenseth *et al.*, 2004); (Frederiksen *et al.*, 2005); (Gulland *et al.*, 2005); (Royal Society, 2005); (TSC, 2005); (Wanless *et al.*, 2005); (Behrenfeld *et al.*, 2006); (Leaper *et al.*, 2006); (Learmonth *et al.*, 2006); (Mavor *et al.*, 2006); (Trites *et al.*, 2006); (Durant *et al.*, 2007); (IPCC, 2007); (Kenney, 2007); (Simmonds & Isaac, 2007); (Thompson *et al.*, 2007); (Evans *et al.*, 2008); (Huntington & Moore, 2008); (MacLeod *et al.*, 2007); (MacLeod *et al.*, 2007); (Pierce *et al.*, 2007); (Nicol *et al.*, 2008); (IWC, 2009); (Moore, 2009); (Van Deurs *et al.*, 2009); (Evans & Bjørge,

	and resultant acidification, which primarily affects cephalopods. Changes in CO_2 and pH levels are anticipated to have an impact on metabolic activity, as well as growth and reproduction. Ommartrephid squids, such as *Illex illecebrosus*, have the highest sensitivity due to their high metabolic rate and pH-sensitive blood oxygen transport. Several marine mammal species eat solely or primarily on cephalopods. Squid have increased in abundance in recent years in the Western Approaches, Channel, and North Sea, which may lead to an increased presence in these waters of squid predators such as Risso's dolphin (*Grampus griseus*), striped dolphin (*Stenella coeruleoalba*), sperm whale (*Physeter macrocephalus*), and species of beaked whales, in areas where suitable habitat exists.	2013); (Schumann *et al.*, 2013); (Albouy *et al.*, 2020); (Evans & Waggitt, 2020); (Grundlehner, 2020); (Roberts & Hendriks, 2022); (Chatzimentor *et al.*, 2023); (Jan *et al.*, 2023)
Impact on Distribution, Abundance, Migration and Range Shifts	The relevance of temperature on species distribution in the oceans appears to follow a general rule: diversity is positively correlated with thermal fronts and dissolved oxygen, but is a non-linear function of temperature, with an optimum of about 23˚C. Predator demography is assumed to be affected by prey, therefore changes in prey distribution or abundance may precede shifts or losses in predator populations. On a larger scale, colder water species are expected to move towards the poles, resulting in a restricted worldwide range. Perry *et al.* (2005) investigated long-term climate changes in demersal fish in the North Sea. They discovered that both exploited and non-exploited fish responded significantly to recent sea temperature rises, with approximately two-thirds of species moving their mean latitude or depth (or both) over a 25-year time frame. There is some evidence that predators are following a similar path. Data on cetacean strandings, sighting frequency, and relative abundance in north-west Scotland suggested a range expansion of common dolphins (*Delphinus delphis;* a warmer water species) and a decrease in range of white-beaked dolphins (*Lagenorhynchus albirostris*), which may be the first direct evidence that this pole-ward shift is occurring in a cetacean species. A recent large-scale survey of the European Atlantic continental shelf reveals that harbour porpoises (*Phocoena Phocoena*) in the North Sea have been redistributed over the previous ten years, with a considerable rise in numbers in the southern region. This is backed by some sighting and stranding data (though strandings are not always reliable markers of distribution). Similarly, based on stranding data, it has been proposed that the distribution of sperm whales (*Physeter macrocephalus*) in the north-east Atlantic is changing, and this has been linked to fluctuations in the North Atlantic Oscillation, which could alter squid prey species. While some cetaceans regularly move vast distances, with many completing extremely extensive annual migrations, others are restricted to certain maritime areas. One example is the vaquita (*Phocoena sinus*) population that lives entirely in the northern Gulf of Mexico and are rapidly depleting. Furthermore, even among species that are considered highly migratory, there are populations with restricted distributions. For example, humpback whales (*Megaptera novaeangliae*) in the northern Indian Ocean and fin whales (*Balaenoptera physalus*) in the Mediterranean appear to be restricted to particular sea areas. It can be argued that species like the vaquita (*P. sinus*) are especially vulnerable to climate change because they cannot simply move away from negative changes within their ranges (the vaquita, for example, cannot move north due to a land barrier), and the same may be true for other marine mammal populations with limited ranges. Whales that migrate frequently, on the other hand, are particularly sensitive since changes might harm them anywhere along their migration routes. A whale, for example, arrives to its polar feeding zone after depleting its energy reserves through breeding and migration. It may consequently be critical for its survival to find nourishment within a specific	(Boyle, 1983); (Wells *et al.*, 1990); (Southward *et al.*, 1995); (Kenney *et al.*, 1996); (MacGarvin & Simmonds, 1996); (Tynan & DeMaster, 1997); (IWC, 1997); (Planque & Taylor, 1998); (Shaughnessy & Green, 1998); (Ducrotoy, 1999); (Heath *et al.*, 1999); (Heath *et al.*, 1999); (Edwards *et al.*, 2001); (Sims *et al.*, 2001); (Beare *et al.*, 2002); (Bjørge, 2002); (Edwards *et al.*, 2002); (Stebbing *et al.*, 2002); (Wells & Scott, 2002); (Zheng *et al.*, 2002); (Beaugrand, 2003); (Beaugrand & Reid , 2003); (Pierce & Boyle, 2003); (Reid *et al.*, 2003); (Arkhipkin *et al.*, 2004); (Beare *et al.*, 2004); (Beare *et al.*, 2004); (Moline *et al.*, 2004); (Edwards & Richardson, 2004); (Simmonds, 2004); (Wilson *et al.*, 2004); (MacLeod *et al.*, 2005); (Perry *et al.*, 2005); (Robinson *et al.*, 2005); (Worms *et al.*, 2005); (Sissener & Bjørndal, 2005);

	timeframe. Baleen whales, as well as other marine mammals, need dense areas of prey, which include schooling fish, cephalopods (squid), copepods, euphausiids (krill), amphipods, and shrimp. Baleen whale migration, abundance, and distribution are thus a reflection of these dense prey patches' distribution, abundance, and movements, which have been connected to oceanographic phenomena including eddies, fronts, and primary productivity. Numerous factors, including temperature, might influence these traits and consequently the development of dense prey patches. Because surface temperature and bathymetric variables like depth and slope affect the distribution of prey, it is possible to forecast the distribution of feeding whales, like North Atlantic right whales, based on these variables. Temperature and other aspects of the ocean environment are correlated with changes in plankton distribution, quantity, and composition. For instance, there have been recent changes to all copepod assemblages in the northeastern North Atlantic Ocean and nearby seas. Warm-water species have expanded more than 10° northward in latitude, whereas the number of colder-water species has decreased. The regional rise in sea surface temperature is reflected in these changes. Thus, these changes in distribution may have an impact on marine mammals and their prey that depends on plankton species. Prey distribution has a significant impact on odontocetes' distribution, abundance, and migration. For instance, in northeastern America's Gulf of Maine/ Georges Bank, cetacean abundance and dispersion changes are linked to fish abundance patterns. Peaks in catch rates are associated with warmer temperatures and the presence of their primary prey, the pelagic squid (*Todarodes sagittatus*), in the Faroe Islands, where long-finned pilot whales (*Globicephala melas*) have been heavily harvested for almost 300 years. Temperature directly impacts the presence of pelagic squid or indirectly affect productivity or hydrography, which in turn affects the distribution and abundance of pilot whales. Most fish and cephalopod species are directly impacted by temperature in terms of their growth, survival, spawning time, age at sexual maturity, and embryonic development. Temperature also affects the distribution, abundance, and migratory of a number of fish and cephalopod species, such as Patagonian long-fin squid (*L. gahi*), veined squid (*Loligo forbesi*), herring (*Clupea harengus*), and whiting (*Merlangius merlangus*). In response to recent increases in sea temperature, the distributions of both exploited species—such as Atlantic cod (*Gadus morhua*) and common sole (*Solea solea*)—and nonexploited species in the North Sea have changed significantly. Over the past 25 years, the distributions of nearly two-thirds of the species have shifted in mean latitude and depth. Recent temperature rises are also correlated with an increase in some warm-water species, such as sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*) in the North Sea and North Atlantic. The distribution of marine mammal species will probably be impacted by these changes in prey species. For instance, through their impact on prey, shifts in a species' distribution have been indirectly linked to rising temperatures. Near-shore bottlenose dolphins migrated from southern to central California during the 1982–1983 El Niño event, and they remained in this new northern range long after the warming episode abated in the mid-1980s. The expansion of the range is thought to have been triggered by the movement of prey rather than the water's temperature. The northernmost point of the bottlenose dolphin's range lies off the northeastern coast of Scotland. There is evidence of a recent extension of the range; the reasons for this are unknown, although they might have to do with modifications in the distribution and/or abundance of prey. Fur seals' recent range expansion in the subantarctic Indian Ocean has been linked to changes in the weather and how these affect their prey. For instance, warmer temperatures, glacier retreat, and maybe better food supplies have all	(Learmonth *et al*., 2006); (Simmonds & Isaac, 2007); (Evans *et al*., 2008); (Huntington & Moore, 2008); (Whitehead *et al*., 2008); (MacLeod, 2009); (Simmonds & Elliott, 2009); (Hansen, 2010); (Fall, 2011); (Kaschner *et al*., 2011); (Lambert *et al*., 2011); (Evans & Bjørge, 2013); (Schumann *et al*., 2013); (Silber *et al*., 2017); (Albouy *et al*., 2020); (Evans & Waggitt, 2020); (Grundlehner, 2020); (Gulland *et al*., 2022); (Roberts & Hendriks, 2022); (Chatzimentor *et al*., 2023); (Jan *et al*., 2023)

	coincided with the resurgence of Antarctic fur seals (*Artocephalus gazelle*) on Heard Island during the last 50 years.	
Impact on Changes to Physical Habitats (Sea Ice Changes)	The amount of available ice heavily influences ice-breeding seals. For example, harp seal (*Pagophilus groenlandicus*) pup mortality in the Gulf of St. Lawrence, Canada, has been estimated to be as high as 75% in weak ice years, and ice conditions in this area have been related to the North Atlantic Oscillation. The polar bear (*Ursus maritimus*) lives across the Arctic's ice-covered waters, but especially on the near-shore yearly ice cover above the continental shelf, where production is maximum. Climate change models suggest that changes in sea ice will result in fewer seals for polar bears to hunt. Initially, polar bears may be favored by an increase in leads in the ice that make ideal seal habitat available; however, if the ice thins further, they will have to travel further, consuming energy to maintain contact with favored habitat. Given the Arctic's high rate of ecological change and polar bears' long generation period and specialized behaviors, it is improbable that they will survive as a species if the ice melts completely. Polar bears have been regarded as an ideal animal for monitoring human-caused impacts on the arctic ecosystem, particularly climate change. In the Hudson and James Bays of Canada, sea ice melts sooner in the spring and forms later in the autumn, reducing the amount of time bears may spend on the ice, saving energy for the summer and autumn when there is little food available. In Hudson Bay, the most common cause of death for cubs is a lack of food or a lack of fat on nursing mothers. Climate change can, and most likely already is, having varying consequences in different places. Winter sea ice concentrations in Baffin Bay and the nearby Davis Straight (between Canada and Greenland) showed notable increasing trends from 1979 to 1996. Baffin Bay also has the highest population of wintering narwhals (*Monodon monocerus*), who rely solely on leads and cracks in the ice to breathe. Major mortality events have been observed when narwhals become caught in ice, and given their excellent site fidelity and the decrease in open sea areas, these arctic experts appear to be highly susceptible to climate change. Rising sea levels may damage shallow water animals such as tucuxi (*Sotalia fluviatilis*), Atlantic humpback dolphins (*Sousa teuszii*), Indian Ocean humpback dolphins (*Sousa plumbea*), Indo-Pacific humpback dolphins (*Sousa chinensis*), Australian humpback dolphins (*Sousa sahulensis*) and narrow ridged-finless porpoises (*Neophocaena asiaeorientalis*), as well as species such as the gray whale (*Eschrichtius robustus*) that calve in shallow coastal bays.	(IWC, 1997), (Harwood, 2001); (Wursig *et al*., 2002); (WWF, 2002); (Hammill & Stenson, 2003); (Derocher *et al*., 2004); (Ferguson *et al*., 2005); (Johnston *et al*., 2005); (Heide-Jørgensen & Laidre, 2004); (Laidre & Heide-Jørgensen, 2005); (Simmonds & Isaac, 2007); (IWC, 2009); (Evans & Bjørge, 2013); (Schumann *et al*., 2013); (Albouy *et al*., 2020); (Evans & Waggitt, 2020); (Gulland *et al*., 2022); (Roberts & Hendriks, 2022); (Chatzimentor *et al*., 2023); (Deb & Bailey, 2023); (Jan *et al*., 2023)
Impact on breeding seasonality and reproductive success	Pinnipeds are often easier to monitor than cetaceans, and breeding ensembles of Antarctic fur seals (*Arctocephalus gazella*) in South Georgia have been tracked since the summer of 1984 and 1985. Positive sea surface temperature anomalies at South Georgia preceded and were cross-correlated with repeated El Niño-La Nina occurrences between 1987 and 1998, explaining significant declines in Antarctic fur seal pup production throughout a 20-year study period. These anomalies were most likely caused by a lack of available prey, primarily krill. Climate change has been linked to the reproductive success of the southern right whale (*Eubalaena australis*), the more numerous of the two right whale species. A comparison of Argentina's calving rate to sea surface temperatures in the south-west Atlantic and the El Niño 4 region (in the western Pacific) revealed a strong relationship between calving success and temperature anomalies at South Georgia in the previous autumn, as well as mean El Niño 4 temperature anomalies delayed by 6 years. Other cetacean cues indicate that breeding is or will be impaired. Commercial whaling has had a significant impact on sperm whale	(Hamilton & Blaxter, 1980); (Lockyer, 1986); (Read & Gaskin, 1990); (Wiley & Clapham, 1993); (Boyd, 1996); (Whitehead, 1997); (Boyd *et al*., 1999); (O'Brien *et al*., 2000); (Stenseth *et al*., 2002) (Wursig *et al*., 2002); (Beaugrand *et al*., 2003); (Beaugrand & Reid, 2003); (Edwards & Richardson,

	(*Physeter macrocephalus*) populations, and their recovery is gradual. Climate change may impede any recovery, and the reproductive success of this species in waters surrounding the Galapagos Islands has been linked to periods of high sea surface temperature, which are typically triggered by El Niño occurrences. Climate change may be the agent that keeps the North Atlantic right whale (*Eubalaena glacialis*), from recovering and driving it to extinction. Following the end of commercial whaling, this cetacean was expected to recover gradually. However, population growth slowed in the 1990s, with collisions with ships and fishing net entanglement recognized as the most serious risks. The relatively high abundance of the planktonic copepod *Calanus finmarchicus* (the primary food for North Atlantic right whales, *Eubalaena glacialis*) in the 1980s explained the stable calving rate at the time, and the collapse of this copepod in the early 1990s coincided with a drop in calving. However, in 1996, the North Atlantic Oscillation Index experienced its highest single annual decrease of the twentieth century, resulting in negative conditions that have far-reaching implications for the north Atlantic's physical and biological oceanography. Effects in the Gulf of Maine/ Scottish Shelf region was not noticed until 1997-1998, including a substantial decrease in the calving rates of the North Atlantic right whale (*E. glacialis*). Climate change's effects on whales are difficult to anticipate on a regional scale. The North Atlantic Ocean Index has been primarily positive over the last 25 years, which should provide favorable conditions for right whale eating and, consequently, reproducing. However, one of the IPCC's conclusions is that climate variability would rise, and Greene & Pershing (2004) questioned whether the 1996 situation was uncommon or indicative of future climate swings. The worst-case scenario is a lengthy period of negative North Atlantic Ocean conditions (marked by weaker or less consistent westerly winds and a colder and drier northern Europe, whereas southern Europe is warmer and wetter than usual). If right whale calving rates were significantly reduced for an extended period, the time to extinction would be considerably shorter than the 200 years currently forecast. Climate change and variability must clearly be included in the management of this population's recovery, but the principal dangers to the species, ship hits and entrapment in nets, must be addressed immediately. There is some evidence that variations in rainfall patterns may alter the breeding behavior of grey seals (*Halichoerus grypus*). Increased rainfall, for example, can increase the availability of pools in certain mating populations. Females congregate around pools, allowing a small number of males to have exclusive access to females as they reach oestrus. In contrast, in dry conditions, females scatter more widely, allowing more males to mate. Heavy rain and severe weather may also increase pup mortality at breeding sites. Seals, on the other hand, may adapt to many of these changes, resulting in the formation of new habitats. Temperature variations may have detrimental consequences on marine mammal reproductive success through their influence on prey availability. For instance, the impacts of climate variability on prey abundance have been linked to a decline in right whale calf survival in the North Atlantic. In years of high food supply at the summer feeding grounds, female fin whales may give birth to a calf in two consecutive years; in years of low food richness, the cycle may extend to three years. In female fin whales, fertility, body fat percentage, and food availability seem to be closely related. It is believed that if a particular threshold amount of body fat or weight is not reached, ovulation is suppressed. Identical strategies have also been noted in terrestrial species, such as *Cervus elaphus*, or red deer. Humpback whale calving intervals and sex ratios have been linked to maternal condition; females in 'superior' condition had calving intervals of three years or longer and sex ratios leaned toward males in their calves. The quantity of sperm whale calves and	2004); (Greene & Pershing, 2004); (Forcada *et al*., 2005); (Leaper *et al*., 2006); (Learmonth *et al*., 2006); (Simmonds & Isaac, 2007); (Twiss *et al*., 2007); (Evans & Bjørge, 2013); (Schumann *et al*., 2013); (Silber *et al*., 2017); (Albouy *et al*., 2020); (Evans & Waggitt, 2020); (Roberts & Hendriks, 2022); (Chatzimentor *et al*., 2023); (Jan *et al*., 2023)

	observations of the sea surface temperature close to the Galapagos Islands indicate that females have a decreased rate of conception following warm-sea-surface temperature spells, which are typically brought on by ENSO events. While the link between rising sea surface temperatures and calves' abundance is not conclusive, it is corroborated by the low foraging success of females and young sperm whales in warm weather, when primary productivity is reduced. Thus, any rise in temperature brought on by global warming and/or an increase in El Niño events' frequency and length may have detrimental effects on populations, including sperm whales in the Galápagos Islands. Variations in the availability of prey in pinnipeds, sirenians, and odontocetes have also been linked to variations in their reproductive success. For instance, variations in the growth and sexual maturity age of harbor porpoises from the Bay of Fundy have been connected to variations in the availability of prey. When there is less available prey, Antarctic fur seals give birth later in the year and undergo longer gestations. During the 1982 El Niño major, various seal colonies, including the Galápagos fur seals (*Artocephalus galapagoensis*), suffered from reproductive failure, particularly in the form of substantial juvenile mortality. Because malnutrition was associated to at least some deadly and sublethal effects, changes in prey distribution were blamed for this catastrophic recruitment failure. The life-history characteristics of sirenians seem to be highly malleable in response to food availability; food scarcity is likely to cause sirenians to spawn less frequently and later in life. Many species schedule their breeding to occur when there is the greatest abundance of suitable prey, either for the calf at weaning or for the nursing mother. This means that any changes in the environmental factors that affect the abundance of prey could throw off the synchronization between the predator and prey, either in terms of time or place. Long-distance migrants who move between their breeding and feeding grounds may be especially susceptible to mismatching. Phenological linkages' uncoupling affects trophic interactions, changing the patterns of food webs and the ecosystem as a whole. Higher marine trophic levels rely heavily on synchronization with plankton production for successful recruitment. There is evidence from observations that the marine pelagic community reacts to climate change with varying degrees of responsiveness across communities and seasonal cycles. A mismatch between subsequent trophic levels and a shift in the time synchronization between primary, secondary, and tertiary production have resulted from these response discrepancies. In the northeast Atlantic, the relationship between climate change and the cascade effects on trophic levels has been demonstrated in phytoplankton, zooplankton, and salmon (*Salmo salar*). It is anticipated that rising temperatures will lead to a decrease in the number of salmon migrating back to their native waters. Cod larvae (*Gadus morhua*) require synchronized production with their primary diet, the early stages of zooplankton, in order to grow and survive. Rising temperatures impact the plankton environment, which has been related to the drop in cod recruitment in the North Sea. Changes brought about by imbalances in the food chain and their consequences on prey species would probably have a negative impact on marine animals.	
Impact on the Susceptibility of Contaminants, Disease Occurrence and	Global warming has been linked to a worldwide increase in reports of diseases affecting marine creatures, particularly marine animals. Climate change has the ability to accelerate pathogen proliferation and survival, disease transmission, and host susceptibility, but higher temperatures may stress organisms, making them more susceptible to certain diseases. Subtle impacts of pollution, such as disturbance of the immunological, reproductive, or endocrine systems, may be worsened by dietary stress. The frequency and intensity of toxic	(Helle *et al*., 1976); (Fuller & Hobson, 1986); (Geraci *et al*., 1989); (Reijnders, 1986); (Kennedy *et al*., 1992); (Aguilar & Raga, 1993);

other causes of death	algal blooms (i.e., those producing domoic acid) are also expected to rise as a result of nutrient enrichment (more rainfall and freshwater runoff), as well as higher warmth and salinity, and there is some indication that this is already happening. Several marine animal species have had mass die-offs as a result of deadly poisonings, including Mediterranean monk seals (*Monachus monachus*), California sea lions (*Zalophus californianus*), bottlenose dolphins (*T. truncatus*), and Florida manatees (*Trichechus manatus*). They may also be responsible for increasing calf mortality among Patagonian right whales (*E. australis*) and contributing to documented decreases in harbour seals (*Phoca vitulina*) in the North Sea. The consequences of pollution as additional stresses on predators already suffering from habitat and prey availability are poorly known. Some argue that global warming, which causes changes in temperature, precipitation, and weather patterns, would affect the pathways (e.g. persistence) and quantities of pollutants that penetrate more pristine places via long-distance transport on air and ocean currents. Reductions in the availability of prey or changes in the type of prey have been linked to increased susceptibility to disease, hunger, and contaminated environments. For instance, significant interannual fluctuations in the diet, physical condition, and availability of food in harbor seals (*Phoca vitulina*) were linked to physiological responses, including variations in haematological markers. Variations in the quantities of contaminants or nutrients in the prey could have led to immunosuppression, which could explain observed variations in leukocyte counts. The consumption of blubber reserves and the consequent mobilization of any stored pollutants, including as organochlorines, organobromines, and polyaromatic hydrocarbons, are the outcomes of insufficient prey availability. Most harmful substances and persistent organic pollutants can interfere with immunological, reproductive, and endocrine functions. As temperatures rise and nutrients become more abundant due to increased rainfall and runoff, hazardous algal blooms are expected to occur more frequently and to a greater extent. There have been cases of fatal poisonings in manatees, pinnipeds, and cetaceans. Certain marine disease organisms and algae species are substantially influenced by one or more of these elements, which can also alter water quality in estuarine and marine waters. These factors include changes in precipitation, pH, water temperature, wind, dissolved CO_2, and salt. Increases in disease transmission, host susceptibility, and pathogen development and survival rates are all possible effects of climate change. In addition, organisms that are already at the maximum limit of their thermal tolerance may be more stressed by higher temperatures, which could make them more vulnerable to certain diseases. Many marine mammals are predicted to see changes in their migratory habits and range due to climate change, which may result in new infections and the spread of viruses. Although the exact causes are still unknown, there appears to have been a rise in large-scale mortality events in the last 20 years, including morbillivirus infections that led to massive die-offs of seals in Europe and striped dolphins (*Stenella coeruleoalba*) in the Mediterranean Sea.	(Aguilar & Borrell, 1994); (de Swart *et al*., 1994); (Kuiken *et al*., 1994); (Cebrian, 1995); (Kennedy, 1996); (Thompson *et al*., 1997); (Bossart *et al*., 1998); (Hernández *et al*., 1998); (Aguilar *et al*., 1999); (Geraci *et al*., 1999); (Harvell *et al*., 1999); (Jepson *et al*., 1999); (Kennedy, 1999); (Ross *et al*., 2000); (Scholin *et al*., 2000); (Hoffman *et al*., 2001); (Van Bressem *et al*., 2001); (Domingo *et al*., 2002); (Geraci & Lounsbury, 2002); (Harvell *et al*., 2002); (Reijinders & Aguilar, 2002); (Gilmartin & Forcada, 2002); (Wursig *et al*., 2002); (Peperzak, 2003); (Lafferty *et al*., 2004); (MacDonald *et al*., 2005); (Jepson *et al*., 2005); (Hall *et al*., 2006); (Learmonth *et al*., 2006); (Fire *et al*., 2007); (Van Dolah, 2007); (Burek *et al*., 2008); (Fire *et al*., 2008); (IWC, 2009); (Van Bressem *et al*., 2009); (SCOS, 2011); (Evans & Bjørge, 2013); (Gadamus, 2013); (Schumann *et al*., 2013); (Albouy *et al*., 2020); (Evans & Waggitt, 2020); (Roberts & Hendriks, 2022); (Sanderson & Alexander, 2020); (Barratclough *et al*., 2023); Chatzimentor *et al*., 2023); (Jan *et al*., 2023)

Impact on community structure	A species' changes in range may be a direct or indirect reaction to climate change due to variations in the availability or distribution of prey as well as interactions with other species. The current warming of the ocean has been linked to changes in the cetacean community in northwest Scotland. The proportion of white-beaked dolphin sightings and strandings (a colder water species) has decreased, while the proportion of sightings and strandings of common dolphins, a species found in warmer waters, has increased. These findings imply that the ranges of common and white-beaked dolphins may be expanding and contracting, respectively, possibly due to direct temperature changes or indirect impacts like competitive exclusion. The lack of suitable shelf waters further north may limit white-beaked dolphins' ability to respond to climate change by tracking suitable habitat, which could have serious consequences for the species. White-beaked dolphins are typically found in cold water less than 200 meters deep in northwest Europe. This might cause its range to become fragmented or cause its abundance to fall. El Niño episodes have also been linked to changes in the organization of cetacean communities caused by climate change. Short-finned pilot whales (*Globicephala macrorhynchus*), which typically feed on near-bottom spawning market squid (*Loligo opalescens*), and the squid itself were not present in the southern California region during the 1982–1983 El Niño. A few years after the pilot whales vanished, an influx of Risso's dolphins (*Grampus griseus*) eating the market squid that had been restored to the area occurred. The El Niño episode may have caused the pilot whales to temporarily vacate their niche, which the Risso's dolphins may have taken advantage of.	(Shane, 1994); (Shane, 1995); (Davis *et al*., 1998); (MacLeod *et al*., 2005); (Learmonth *et al*., 2006); (Albouy *et al*., 2020); (Evans & Waggitt, 2020); (Roberts & Hendriks, 2022); (Chatzimentor *et al*., 2023); (Deb & Bailey, 2023); (Jan *et al*., 2023)

Table 2. displays an integrated checklist of one hundred twenty-seven (127) marine mammal species addressed throughout this review, along with their IUCN Red List categories. A total of eighty-three (83) cetaceans (whales, dolphins and porpoises), thirty-four (34) pinnipeds (seals, sea lions and walruses), six (6) sirenians (manatees and dugongs) and four (4) fissipeds (polar bears and sea otters) were presented in the checklist below (Table 1). Many species are already threatened to varied degrees, even before climate change implications are considered in the assessments [165].

Table 2 Integrated Checklist of species of marine mammal and the International Union for Conservation of Nature (IUCN) Red List of threatened species.

Family	**Species**	**Common name**	**Red list category ***	**Author(s)**
Cetaceans (Whales, Dolphins & Porpoises)				
Balaenidae	*Balaena mysticetus*	Bowhead whale	LR/cd	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Balaenidae	*Eubalaena glacialis*	North Atlantic right whale	EN (D)	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Balaenidae	*Eubalaena australis*	Southern right whale	LR/cd	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)

Balaenopteridae	*Balaenoptera acutorostrata*	Common minke whale1	LR/nt	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Balaenopteridae	*Balaenoptera bonaerensis*	Antarctic minke whale1	LR/cd	(IUCN, 2004); (Learmonth et al., 2006)
Balaenopteridae	*Balaenoptera physalus*	Fin whale	EN (A)	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Balaenopteridae	*Balaenoptera musculus*	Blue whale	EN (A)	(IUCN, 2004); (Learmonth et al., 2006)
Balaenopteridae	*Megaptera novaeangliae*	Humpback whale	VU (A)	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Balaenopteridae	*Balaenoptera edeni/brydei*	Bryde's whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Balaenopteridae	*Balaenoptera borealis*	Sei whale	EN (A)	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Orcinus orca*	Orca/ Killer whale	LR/cd	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Delphinidae	*Globicephala macrorhynchus*	Short-finned pilot whale	LR/cd	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Delphinidae	*Grampus griseus*	Risso's dolphin	DD	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Delphinidae	*Lagenorhynchus albirostris*	White-beaked dolphin	LR/lc DD	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Delphinidae	*Stenella coeruleoalba*	Striped dolphin	LR/cd	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Delphinidae	*Tursiops truncatus*	Common bottlenose dolphin	DD	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Delphinidae	*Cephalorhynchus heavisidii*	Heaviside's dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Cephalorhynchus hectori*	Hector's dolphin	EN (AC)	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Steno bredanensis*	Rough-toothed dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Sousa teuszii*	Atlantic hump-backed dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Sousa plumbea*	Indian hump-backed dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)

Delphinidae	*Sousa chinensis*	Indo-pacific hump-backed dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Sotalia fluviatilis*	Tucuxi	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Tursiops aduncus*	Bottlenose dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Stenella attenuata*	Pantropical spotted dolphin	LR/cd	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Stenella frontalis*	Atlantic spotted dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Stenella longirostris*	Spinner dolphin	LR/cd	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Stenella clymene*	Clymene dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Delphinus delphis*	Short-beaked Common dolphin 2	LR/lc	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Delphinidae	*Delphinus capensis*	Long-beaked Common dolphin 2	LR/lc	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Delphinus tropicalis*	Arabian Common dolphin 2	LR/lc	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Lagenodelphis hosei*	Fraser's dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Lagenorhynchus acutus*	Atlantic white-sided dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Lagenorhynchus obscurus*	Dusky dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Lagenorhynchus australis*	Peale's dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Lagenorhynchus cruiger*	Hourglass dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Lissodelphis borealis*	North right whale dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Lissodelphis peronii*	South right whale dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Peponocephala electra*	Melon-headed whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Feresa attenuata*	Pygmy killer whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Pseudorca crassidens*	False killer whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Globicephala melas*	Long-finned pilot whale	LR/cd	(IUCN, 2004); (Learmonth et al., 2006)

Delphinidae	*Orcaella brevirostris*	Irrawaddy dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Cephalorhynchus eutropia*	Chilean dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Delphinidae	*Cephalorhynchus commersonii*	Commerson's dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)
Eschrichtiidae	*Eschrichtius robustus*	Grey whale	LR/cd	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Iniidae	*Inia geoffrensis*	Boto/ Amazon River dolphin	VU (A)	(IUCN, 2004); (Learmonth et al., 2006)
Kogiidae	*Kogia breviceps*	Pygmy sperm whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Kogiidae	*Kogia sima*	Dwarf sperm whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Lipotidae	*Lipotes vexillifer*	Baiji	CR (ACD)	(IUCN, 2004); (Learmonth et al., 2006)
Monodontidae	*Monodon monoceros*	Narwhal	DD	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Monodontidae	*Delphinapterus leucas*	Beluga or white whale	VU (A)	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Neobalaenidae	*Caperea marginata*	Pygmy right whale	Lc	(IUCN, 2004); (Learmonth et al., 2006)
Platanistidae	*Platanista gangetica*	Ganges river dolphin	EN (A)	(IUCN, 2004); (Learmonth et al., 2006)
Phocoenidae	*Phocoena phocoena*	Harbour porpoise	VU (A)	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Phocoenidae	*Phocoena sinus*	Vaquita	CR (C)	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Phocoenidae	*Neophocaena phocaenoides*	Finless porpoise	DD	(IUCN, 2004); (Learmonth et al., 2006)
Phocoenidae	*Phocoena spinipinnis*	Burmeister porpoise	DD	(IUCN, 2004); (Learmonth et al., 2006)
Phocoenidae	*Phocoena dioptrica*	Spectacled porpoise	DD	(IUCN, 2004); (Learmonth et al., 2006)
Phocoenidae	*Phocoenoides dalli*	Dall's porpoise	LR/cd	(IUCN, 2004); (Learmonth et al., 2006)
Physeteridae	*Physeter macrocephalus*	Sperm whale/ Cachalot	VU (A)	(IUCN, 1994); (IUCN, 2006); (Simmonds & Isaac, 2007)
Pontoporiidae	*Pontoporia blainvillei*	Franciscana/ La Plata dolphin	DD	(IUCN, 2004); (Learmonth et al., 2006)

Ziphiidae	*Ziphius cavirostris*	Cuvier’s beaked whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Berardius arnuxii*	Arnoux’s beaked whale	LR/cd	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Berardius bairdii*	Baird’s beaked whale	LR/cd	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Tasmacetus shepherdi*	Shepherd’s beaked whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Indopacetus pacificus*	Longman’s beaked whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Hyperoodon ampullatus*	Northern bottlenose whale	LR/cd	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Hyperoodon planiforms*	Southern bottlenose whale	LR/cd	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Mesoplodon hectori*	Hector’s beaked whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Mesoplodon mirus*	True’s beaked whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Mesoplodon europaeus*	Gervais’ beaked whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Mesoplodon bidens*	Sowerby’s beaked whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Mesoplodon grayi*	Gray’s beaked whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Mesoplodon peruvianus*	Pygmy beaked whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Mesoplodon bowdoini*	Andrew’s beaked whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Mesoplodon carlhubbsi*	Hubbs’ beaked whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Mesoplodon ginkgodens*	Ginko-toothed beaked whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Mesoplodon stejnegeri*	Stejneger’s beaked whale	DD	(IUCN, 2004); (Learmonth et al., 2006)

Ziphiidae	*Mesoplodon layardii*	Strap-toothed beaked whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Mesoplodon densirostris*	Blainville's beaked whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Mesoplodon traversii*	Spade-toothed whale	DD	(IUCN, 2004); (Learmonth et al., 2006)
Ziphiidae	*Mesoplodon perrini*	Perrin's beaked whale	EN	(IUCN, 2004); (Learmonth et al., 2006)
Pinnipeds (Seals, Sea Lions & Walruses)				
Odobenidae	*Odobenus rosmarus*	Walrus	LR/lc DD	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Otariidae	*Arctocephalus galapagoensis*	Galapagos fur seal	VU (A)	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); Simmonds & Isaac, 2007)
Otariidae	*Arctocephalus gazella*	Antarctic fur seal	LR/lc	(IUCN, 1994); (IUCN, 2004); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Otariidae	*Artocephalus pusillus*	Cape fur seal	LR/cd	(IUCN, 2004); (Learmonth et al., 2006)
Otariidae	*Artocephalus tropicalis*	Subantarctic fur seal	LR/cd	(IUCN, 2004); (Learmonth et al., 2006)
Otariidae	*Artocephalus townsendi*	Guadalupe fur seal	VU (D)	(IUCN, 2004); (Learmonth et al., 2006)
Otariidae	*Artocephalus philippii*	Juan Fernández fur seal	VU (D)	(IUCN, 2004); (Learmonth et al., 2006)
Otariidae	*Artocephalus forsteri*	New Zealand fur seal	VU (D)	(IUCN, 2004); (Learmonth et al., 2006)
Otariidae	*Artocephalus australis*	South American fur seal	VU (D)	(IUCN, 2004); (Learmonth et al., 2006)
Otariidae	*Callorhinus ursinus*	Northern fur seal	VU (A)	(IUCN, 2004); (Learmonth et al., 2006)
Otariidae	*Zalophus californianus*	California sea lion	VU (A)	(IUCN, 2004); (Learmonth et al., 2006)
Otariidae	*Zalophus wollebaeki*	Galapagos sea lion	VU (A)	(IUCN, 2004); (Learmonth et al., 2006)
Otariidae	*Eumetopias jubatus*	Steller sea lion	EN (A)	(IUCN, 2004); (Learmonth et al., 2006)
Otariidae	*Neophoca cinera*	Australian sea lion	EN (A)	(IUCN, 2004); (Learmonth et al., 2006)
Otariidae	*Phocarctos hookeri*	New Zealand sea lion	VU (D)	(IUCN, 2004); (Learmonth et al., 2006)
Otariidae	*Otaria flavescens*	South American sea lion	VU (D)	(IUCN, 2004); (Learmonth et al., 2006)

Phocidae	*Pagophilus groenlandicus*	Harp seal or Earless seal	LR/lc LR/nt	(IUCN, 1994); (IUCN, 2006); (IUCN, 2006); (Learmonth et al., 2006); (Simmonds & Isaac, 2007)
Phocidae	*Ergnathus barbatus*	Bearded seal	VU (D)	(IUCN, 2004); (Learmonth et al., 2006)
Phocidae	*Phoca vitulina*	Harbour seal	VU (D)	(IUCN, 2004); (Learmonth et al., 2006)
Phocidae	*Phoca largha*	Spotted seal	VU (D)	(IUCN, 2004); (Learmonth et al., 2006)
Phocidae	*Pusa hispida*	Ringed seal	VU (D)	(IUCN, 2004); (Learmonth et al., 2006)
Phocidae	*Pusa caspica*	Caspian seal	VU (B)	(IUCN, 2004); (Learmonth et al., 2006)
Phocidae	*Pusa sibirica*	Baikal seal	LR/nt	(IUCN, 2004); (Learmonth et al., 2006)
Phocidae	*Halichoerus grypus*	Grey seal	LR/nt	(IUCN, 2004); (Learmonth et al., 2006)
Phocidae	*Histriophoca fasciata*	Ribbon seal	LR/nt	(IUCN, 2004); (Learmonth et al., 2006)
Phocidae	*Cystophora cristata*	Hooded seal	LR/nt	(IUCN, 2004); (Learmonth et al., 2006)
Phocidae	*Monachus monachus*	Mediterranean monk seal	CR (C)	(IUCN, 2004); (Learmonth et al., 2006)
Phocidae	*Monachus schauinslandi*	Hawaiian monk seal	EN (C)	(IUCN, 2004); (Learmonth et al., 2006)
Phocidae	*Mirounga leonina*	Southern elephant seal	EN (C)	(IUCN, 2004); (Learmonth et al., 2006)
Phocidae	*Mirounga angustirostris*	Northern elephant seal	EN (C)	(IUCN, 2004); (Learmonth et al., 2006)
Phocidae	*Leptonychotes weddellii*	Weddell seal	EN (C)	(IUCN, 2004); (Learmonth et al., 2006)
Phocidae	*Ommatophoca rossii*	Ross seal	EN (C)	(IUCN, 2004); (Learmonth et al., 2006)
Phocidae	*Lobodon carcinophaga*	Crabeater seal	EN (C)	(IUCN, 2004); (Learmonth et al., 2006)
Phocidae	*Hydrurga leptonyx*	Leopard seal	EN (C)	(IUCN, 2004); (Learmonth et al., 2006)
Sirenians (Manatees & Dugongs)				
Trichechidae	*Trichechus manatus*	Caribbean manatee	VU (A)	(IUCN, 2004); (Learmonth et al., 2006)
Trichechidae	*Trichechus manatus latirostris*	Florida manatee	VU (A)	(IUCN, 2004); (Learmonth et al., 2006)
Trichechidae	*Trichechus manatus manatus*	Antillean manatee	VU (A)	(IUCN, 2004); (Learmonth et al., 2006)
Trichechidae	*Trichechus senegalensis*	African manatee	VU (A)	(IUCN, 2004); (Learmonth et al., 2006)

Trichechidae	*Trichechus inunguis*	Amazon manatee	VU (A)	(IUCN, 2004); (Learmonth et al., 2006)
Dugongidae	*Dugong dugon*	Dugong	VU (A)	(IUCN, 2004); (Learmonth et al., 2006)
Fissipeds (Polar Bears & Sea Otters)				
Ursidae	*Ursus maritimus*	Polar bear	VU	(IUCN, 2001); (IUCN, 2006); (Simmonds & Isaac, 2007)
Mustelidae	*Enhydra lutris*	Sea otter	EN (A)	(IUCN, 2004); (Learmonth et al., 2006)
Mustelidae	*Lontra felina*	Marine otter	EN (A)	(IUCN, 2004); (Learmonth et al., 2006)
Mustelidae	*Lutra lutra*	Common otter	(NT)	(IUCN, 2004); (Learmonth et al., 2006)

IUCN Status: *CR-Critically Endangered; EN-Endangered; VU-Vulnerable; A-Declining population; B-Small Distribution or Decline or Fluctuation; C-Small Population Size and Decline, D-Very Small or Restricted; DD-Data Deficient; LR-Lower Risk (Lc-Least Concern; Nt-Near Threatened; Cd-Conservation Dependent). LR:cd-Low Risk, Conservation Dependent; LR:nt-Low Risk, Near Threatened; LR/lc means that the species has been evaluated and is not on the Red List.

1. Minke whale: several authors refer to two species of minke whale — the Antarctic minke whale (*B. bonaerensis*) and the dwarf minke whale (*B. acutorostrata*) — however, in the context of this review both are sometimes referred to as minke whales.

2. Common dolphins: three species of common dolphins have been identified — the short-beaked common dolphin (*D. delphis*), the long-beaked common dolphin (*D. capensis*) and the Arabian common dolphin (*D. tropicalis*) — however, in the context of this review all are sometimes referred to as common dolphins due to the overlap in distribution of *D. capensis* and *D. delphis.*

Some categorizations above are based on v. 2.3 of the IUCN Red List [88] except that of the polar bear, which is based on v. 3.1 [89]. Other categorizations above are sourced and based on [90] [99] [123] [135] [143] [144] [148] [149]

Table 3 Direct and indirect effects of major climatic and environmental factors affecting marine mammals

Climatic Factor	**Direct Effect**	**Indirect Effect**	**Author(s)**
Temperature	The direct effects of changes in water temperature on marine mammals are shifts in species ranges as species adapt to preferred or needed temperature conditions. This change can be seen in the following organisms: Baleen whales are less likely to be directly influenced by temperature fluctuations than other marine mammals due to their mobility and thermoregulatory capacity, though calves may be more vulnerable than adults. The majority of baleen whales, including blue, grey,	Climate change's indirect effects on prey species can have various indirect consequences on marine mammals, such as changes in distribution, abundance, migration, community structure, vulnerability to illness and pollutants, and reproductive success. Climate change may also indirectly impact marine mammal species by increasing competition with other marine animals.	(IWC, 1996); (IWC 1997); (IPCC, 2001); (IPCC, 2007); (IWC, 2009); (Bannister 2002); (Reynolds & Powell, 2002), (Wursig *et al.* 2002); (Learmonth *et al.*, 2006); (Evans & Waggitt, 2020); (Roberts & Hendriks, 2022); (Chatzimentor *et al.*, 2023); (Jan *et al.*, 2023)

	humpback, and fin whales, travel long distances and face temperature differences between their polar feeding grounds and tropical breeding grounds. Several species, such as bowhead whales, have a more restricted distribution, as they are exclusively found in the Arctic's polar seas and may be uniquely heat intolerant. Toothed whales (odontocetes) are more likely to be directly affected by changes in water temperature than baleen whales because they are generally smaller, and certain species have a limited range of water temperatures in which they may live. Belugas (*Delphinapterus leucas*) are only found in polar and cold temperate waters in the Arctic. As water temperatures fluctuate, species that live in specified temperature ranges are predicted to move their geographic ranges to follow preferred or necessary temperature conditions. However, certain species may have physical limitations on their capacity to modify their geographic distribution. The endangered vaquita (*Phocoena sinus*), which lives only in the warm waters of the northern Gulf of California, and river dolphins such as baiji (*Lipotes vexillifer*), Ganges River dolphin (*Platanista gangetica*), Boto (*Inia geoffrensis*), and tucuxi (*Sotalia fluviatilis*), may be especially vulnerable. Some individuals within a group may be more sensitive than others, such as finless porpoise (*Neophocaena phocaenoides*) calves. Increased variance in sea temperature, particularly in coastal locations, may also be significant; for example, a mass mortality of bottlenose dolphins (*Tursiops truncatus*) in the Gulf of Mexico has been connected to an exceptional cold-water occurrence. Changes in water temperature will also have a direct impact on		

	pinnipeds and sirenians. Temperature affects manatee distribution, with colder waters (below 20˚C) increasing susceptibility to cold stress and mortality. An increase in sea temperature (extension of the 20˚C isotherm) may increase range, which is directly tied to temperature variations.		
Sea levels	Cetaceans, including baleen whales and odontocetes, are unlikely to be directly harmed by rising sea levels; however, crucial habitats for coastal species and species that rely on coastal bays and lagoons for breeding, such as grey and humpback whales, may be affected. Pinniped haul-out sites for breeding, nurseries, and resting are expected to be directly impacted. Rising sea levels, for example, could remove the already few haul-out sites of the Mediterranean monk seal (*Monachus monachus*), particularly by flooding caves that serve as the sole shelter for certain groups.	The development of sea-wall defenses and coastal habitat protection measures in response to rising sea levels may have an influence on coastal marine species and disrupt migration paths. Between 1974 and 1996, in Florida, approximately 4% of manatee deaths were caused by crushing and drowning in flood gates or canal locks. Dams and other infrastructure have also impeded manatees' typical migration paths along South America and West Africa rivers.	(IWC, 1996); (IWC 1997); (Harwood, 2001); (IPCC, 2001); (IPCC, 2007); (IWC, 2009); (Reynolds & Powell, 2002), (Wursig *et al*. 2002); (Learmonth *et al*., 2006); (Evans & Waggitt, 2020); (Roberts & Hendriks, 2022); (Chatzimentor *et al*., 2023); (Jan *et al*., 2023)
Ocean currents	Changes in ocean currents and frontal locations may directly impact on the range of marine animals connected with oceanic fronts, such as the Antarctic convergence in the Southern Ocean. The Antarctic convergence, an oceanic front that separates cold southern polar waters from northern temperate seas, is a significant physical feature in the Southern Ocean that defines the natural southern extent of the distributions of most tropical and temperate marine mammals. The ocean temperature can vary by up to 10˚C throughout the Antarctic convergence, which may just be a few miles wide. Male and female sperm whales are segregated due to Antarctic convergence, with only males seen in the Southern Ocean during the summer and females and immature	Changes in ocean mixing, deep water production, and coastal upwelling will have a significant impact on the coastal zone's sustainability, productivity, and biodiversity. Changes in ocean currents will directly impact the distribution, abundance, and migration of plankton, as well as many fish and cephalopod species, all of which will influence marine animals. For example, oscillations in the influx of Atlantic water in the Barents Sea affect the location of the polar front as well as water temperature. This changes the distribution and species composition of primary and secondary production, which in turn affects minke whale distribution and diet.	(IWC, 1996); (IWC 1997); (Planque & Taylor 1998); (IPCC, 2001); (Waluda *et al*., 2001); (Bjørge, 2002); (Boyd, 2002); (Walther *et al*., 2002); (IPCC, 2007); (IWC, 2009); (Learmonth *et al*., 2006); (Evans & Waggitt, 2020); (Roberts & Hendriks, 2022); (Chatzimentor *et al*., 2023); (Jan *et al*., 2023)

	males remaining north of the polar front throughout the year.		
Salinity	The salinity of surface waters in the open ocean ranges from 32 practical salinity units (psu) in the subarctic Pacific to 37 psu in subtropical gyres. At the ocean's coastal and polar borders and marginal seas, activities such as local precipitation and evaporation, river runoff, and ice formation can produce salinities ranging from less than 10 to more than 40 psu. Many marine mammals have evolved to survive fluctuations in salinity. However, bottlenose dolphin populations from places with low water temperature and salinity have been reported to have a higher prevalence and severity of skin lesions. Such conditions are thought to have an impact on epidermal integrity or cause more general physiological stress, potentially making animals more susceptible to natural diseases or anthropogenic stressors. This shows that environmental differences significantly impact disease in marine mammals.	Changes in salinity, such as those caused by changes in river inputs/runoff and melting ice, will influence the distribution and availability of prey through effects on stratification of the water column and circulation, as well as restricted salt tolerance. For example, most cephalopods are highly sensitive to salinity fluctuations. Changes in phytoplankton community structure, from diatoms to cryptophytes, in near-shore coastal waters along the Antarctic Peninsula have been connected to glacial melt-water flow and lower surface water salinity. This modification in phytoplankton community structure has a direct impact on zooplankton assemblages. Because of their small size, Antarctic krill cannot efficiently graze on cryptophytes, and an increase in the relative abundance of cryptophytes will cause a shift in krill spatial distribution. This will impact higher trophic levels in the food web, as krill is an important prey for several seabird and marine mammal species.	(Boyle, 1983); (IWC, 1996); (IWC 1997); (Wilson *et al*., 1999); (IPCC, 2001); (Fiedler, 2002); (Moline *et al*., 2004); (IPCC, 2007); (IWC, 2009); (Learmonth *et al*., 2006); (Evans & Waggitt, 2020); (Roberts & Hendriks, 2022); (Chatzimentor *et al*., 2023); (Jan *et al*., 2023)
CO_2 concentrations and pH	Carbon dioxide accumulates in the atmosphere and seeps into ocean surface layers, potentially affecting marine species. The immediate effects of rising CO_2 concentrations and the resulting drop in pH on marine mammals remain unknown.	Elevated CO_2 levels significantly impact large marine animals that do not breathe air (i.e., marine mammals' prey. As elevated CO_2 acidifies, bodily tissues and fluids (hypercapnia) are impaired and the blood's ability to transport oxygen effectively is hindered. Changes in CO_2 and pH levels are anticipated to have an impact on metabolic activity, as well as the growth and reproduction of water-breathing creatures. Ommastrephid squids, such as *Illex illecebrosus*, have the highest sensitivity due to their fast metabolic rate and particularly	(IWC, 1996); (IWC 1997); (IPCC, 2001); (Pörtner *et al*. 2004); (Royal Society; 2005); (Learmonth *et al*., 2006); (IPCC, 2007); (IWC, 2009); (Evans & Waggitt, 2020); (Roberts & Hendriks, 2022); (Chatzimentor *et al*., 2023); (Jan *et al*., 2023)

		pH-sensitive blood oxygen transport. Fish are better protected from CO_2 effects than squid because they have slower metabolic rates and greater ability to adjust for CO_2-induced pH changes. The number of species experiencing acute CO_2 poisoning will be restricted. Individuals in a population may be tolerant for a short period, but it is impossible to determine the long-term impact of CO2 levels and pH changes on individuals and populations.	
Rainfall patterns	More intense precipitation events and flash floods will cause more runoff. Thus, increased nutrient inputs into coastal waterways, combined with rising water temperatures, may result in harmful algal blooms and eutrophication which has an impact on marine mammals.	Eutrophication significantly impacts the seasonal and community dynamics of phytoplankton in the southern North Sea. Changes in rainfall patterns, such as a decrease in salinity in coastal waters, will influence prey species distribution and abundance. Greater runoff due to greater precipitation may also result in an increase in pollutant inputs, particularly sewage, which may have an impact on coastal marine animal and prey populations. Changes in rainfall patterns are projected to increase demand for fresh water in some places, necessitating water flow regulation by dams and dredging. These represent significant constraints to river dolphin migration. Such operations have already resulted in small, isolated populations making certain parts of the ideal habitat inaccessible. Flood control will result in the loss of shallow water habitats, which are frequently exploited during rainy seasons.	(IWC, 1996); (IWC 1997); (Edwards *et al*. 2001); (Harwood, 2001); (IPCC, 2001); (Learmonth *et al*., 2006); (IPCC, 2007); (IWC, 2009); (Evans & Waggitt, 2020); (Roberts & Hendriks, 2022); (Chatzimentor *et al*., 2023); (Jan *et al*., 2023)
Storm frequency, wind speed and wave conditions	Changes in prevailing ocean wave height and direction, as well as storm waves and surges, are projected to have a significant influence on coasts as sea levels rise. Pinniped haul-out locations and nurseries are likely to be vulnerable to variations in storm frequency	Coastal habitats such as coral reefs and atolls, salt marshes and mangrove forests, and submerged aquatic vegetation will all be directly affected by changes in storm frequency and intensity changes. These areas serve as vital nursery grounds for many fish	(IWC, 1996); (IWC 1997); (IPCC, 2001); (Harwood, 2001); (Wursig *et al*. 2002); (Learmonth *et al*., 2006); (IPCC, 2007); (IWC, 2009); (Evans & Waggitt, 2020); (Roberts & Hendriks, 2022); (Chatzimentor *et al*., 2023); (Jan *et al*., 2023)

	and wave conditions, such as the Mediterranean monk seal, which relies on a limited number of caves or narrow beaches for breeding.	and invertebrate species, which are then preyed upon by marine mammals.	
Climate patterns	El Niño occurrences have been associated to enormous die-offs and adjustments in the distribution of plankton, fish (including anchovy), seabirds, and marine mammals.	The predicted increase in the frequency of warm events associated with the ENSO would result in a decrease in plankton biomass and fish larvae abundance, negatively impacting fish recruitment patterns and spatial distribution of fish stocks, with downstream effects on marine mammals, seabirds, and ocean biodiversity. The indirect effects associated with El Niño events on marine mammal species are mostly related to changes in prey availability and include (i) changes in community structure, for example, after the 1982–83 El Niño short-finned pilot whales appeared to be replaced by Risso's dolphins, (ii) changes in species ranges, for example, the range expansion of bottlenose dolphins along the Californian coast during and after the 1982–83 El Niño event, and (iii) effects on reproduction, for example, reduced fecundity or calf survival in sperm whales of the eastern tropical Pacific during and after an El Niño event in the late 1980s, and high juvenile mortality in seal colonies, such as Galapagos fur seals during the El Niño year of 1982. The 1982-83 El Niño event off Peru may have had an impact on female dusky dolphins (*Lagenorhynchus obscurus*) reproduction. During El Niño, pregnant and lactating females experienced nutritional stress as evidenced by the deposition of weakly calcified dentinal growth layer groups in their teeth due to reduced prey availability. The NAO has direct and indirect effects on the recruitment, growth, distribution, abundance,	(Manzanilla, 1989); (Wells *et al*., 1990); (Shane, 1994); (Shane, 1995); (IWC, 1996); (IWC 1997); (Whitehead, 1997); (Planque & Taylor 1998); (Boyd *et al*., 1999); (IPCC, 2001); (Beare *et al*., 2002); (Stenseth *et al*., 2002); (Walther *et al*., 2002); (Wursig *et al*., 2002); (Beaugrand & Ibanez, 2004); (Learmonth *et al*., 2006); (IPCC, 2007); (IWC, 2009); (Evans & Waggitt, 2020); (Roberts & Hendriks, 2022); (Chatzimentor *et al*., 2023); (Jan *et al*., 2023)

		and survival of a variety of fish, cephalopod, and plankton species. For example, fluctuations in water temperatures caused by NAO variations have been connected to cod recruitment in Labrador and Newfoundland, as well as in the Barents water. The NAO has been associated with the temporal and spatial population dynamics of *Calanus finmarchicus* and *C. helgolandicus*. Calanus species' early stages serve as the primary diet for larvae and early juveniles of numerous fish species throughout the North Atlantic, influencing fish recruitment success and, as a result, population size. Changes in prey availability and distribution caused by the NAO are anticipated to have both direct and indirect effects on marine mammal species. In addition to ENSO and NAO variability, the persistence of multi-year climate-ocean regimes and shifts from one regime to another have been identified, as have changes in fish recruitment patterns associated with such flips. Similarly, the survival of marine mammals and seabirds is influenced by interannual and long-term variability in a variety of oceanographic and atmospheric features and processes, particularly at higher latitudes.	
Sea-ice cover	Seals that rely on ice for mating are projected to lose a significant amount of habitat if sea ice extent decreases. Species confined to inland seas and lakes, such as the Caspian seal (*Phoca caspica*), the Baikal seal (*Phoca siberica*), and ringed seal subspecies (*Phoca hispida lagodensis* and *P. h. saimensis*), may be especially vulnerable, as their ability to track the receding ice cover is limited. During the breeding season, the ice on which pinnipeds haul out must be thick enough and last long	Changes in sea ice extent and concentration may affect the seasonal distribution, geographic ranges, migration patterns, nutritional status, reproductive success, and, ultimately, the abundance and stock structure of species associated with the ice edge, including plankton, fish, crustaceans, and marine mammals. Melting ice sheets in the Arctic will diminish ocean salinities, potentially causing highly variable adjustments in the distribution and biomass	(IWC, 1996); (IWC 1997); (Tynan & DeMaster, 1997); (Stirling *et al*., 1999); (Harwood, 2001); (IPCC, 2001); (Burns, 2002); (Boyd, 2002); (Forcada, 2002); (Stern, 2002); (Fraser & Hofmann, 2003); (Heide-Jørgensen & Laidre, 2004); (Laidre *et al*., 2004); (Ferguson *et al*., 2005); (Laidre & Heide-Jørgensen, 2005); (Learmonth *et al*., 2006); (IPCC, 2007); (IWC, 2009); (Evans & Waggitt, 2020); (Roberts &

	enough to allow for the essential stages of birth, pup feeding, and, in many cases, annual moulting. Ice characteristics can influence pinniped distribution and activity patterns, with pack ice (large pieces of ice ranging in diameter from a few meters to several hundred meters that are not attached to land) providing a more consistent substratum than fast ice (ice that is attached to the land), which varies greatly with season. For pinnipeds that reproduce on rapid ice, the duration of breastfeeding and the upbringing of their young is heavily influenced by weather conditions. Ringed seals, bearded seals (*Ergnathus barbatus*), and walruses (*Odobenus rosmarus*) may be especially vulnerable to fluctuations in sea-ice extent. For example, earlier spring ice breakup and lower snow depths indicate that ringed seal pup survival remains low in western Hudson Bay. Polar bears require ice as a firm foundation on which to hunt and raise their young. Polar bear distribution is most likely determined by the distribution of ice conditions that allow them to hunt and travel efficiently, particularly on ice floes between foraging sites and locations where they give birth and rear their young. As a result, changes in ice cover extent and type are likely to have an impact on polar bear ranges, foraging, and reproductive success. Between 1981 and 1998, there was a significant decline in the condition of adult male and female polar bears in western Hudson Bay, as well as an overall decline in the proportion of independent yearling cubs, owing to earlier sea ice breakup, which caused the bears to come ashore in poorer condition. Open-water areas, such as annual recurring polynyas (areas within the pack ice that are	of critical Arctic food web components. These changes in the distribution and amount of prey will affect more migratory species such as bowhead whales, belugas, and narwhals, as well as resident or sedentary species like pinnipeds and polar bears. For example, declines in the production of ringed seals, and hence polar bears, have been connected to ice conditions, possibly as a result of a fall in regional productivity, resulting in poor nutritional conditions in seals. Large baleen whale species that migrate large distances from tropical breeding grounds to high-latitude feeding areas near the ice edge may be threatened when the polar ice caps melt. The lengthier migration patterns will increase travel expenses and shorten the feeding season. Species that rely on the Arctic for summer feeding grounds, such as the grey whale, are expected to see disturbances in the timing and distribution of their food sources. Migratory species in the Arctic will also be affected; for example, beluga and narwhal migration is linked to ice algae production in the spring and ice-edge productivity. Warming in the Arctic will alter species compositions, including poleward shifts in species assemblages and the extinction of some polar species. Climate change in the Southern Ocean is anticipated to result in long-term, maybe permanent physical oceanography and ecology changes. Reduced sea-ice extent is expected to change under-ice biota and the spring bloom in the sea-ice marginal zone, having far-reaching consequences for all levels of the food chain, from algae to krill to whales. Marine mammals with life histories tied to specific breeding sites, such as Weddell (*Leptotonychotes*	Hendriks, 2022); (Chatzimentor *et al.*, 2023); (Jan *et al.*, 2023)

	almost always clear of ice) caused by upwelling or wind, variable shore leads or cracks, or tidal- and wind-driven openings in the sea ice, are critical for several marine mammal species, including walrus, belugas, narwhals, and bowhead whales. Although global warming has reduced sea-ice formation in the Arctic, the trend is not consistent, and any changes in the timing and distribution of these critical open water areas would have immediate and serious consequences for the marine mammals that rely on them.	*weddellii*), Ross (*Ommatophoca rossii*), and crabeater seals (*Lobodon carcinophaga*), will be severely impacted by shifts in their foraging habitats and prey species migration caused by a decrease in sea ice extent. For example, krill quantity directly influences the growth and survival of seal pups. Warming could limit the area of Antarctic pack ice, affecting krill distribution and abundance. Krill abundance declined in the Antarctic Peninsula region throughout the 1990s, which was connected to reduced winter sea-ice extent.	

Climate change's potential effects on marine mammals can be (i) direct, such as the effects of reduced sea ice and rising sea levels on seal haul-out sites or a species tracking a specific range of water temperatures in which they can physically survive, and (ii) indirect, such as the potential impacts on reproductive success through effects on prey distribution and abundance or the structure of prey communities at specific locations. Figure 1 and Table 3. below compares the direct and indirect effects of some major climatic and environmental factors that are affecting marine mammals and their populations globally.

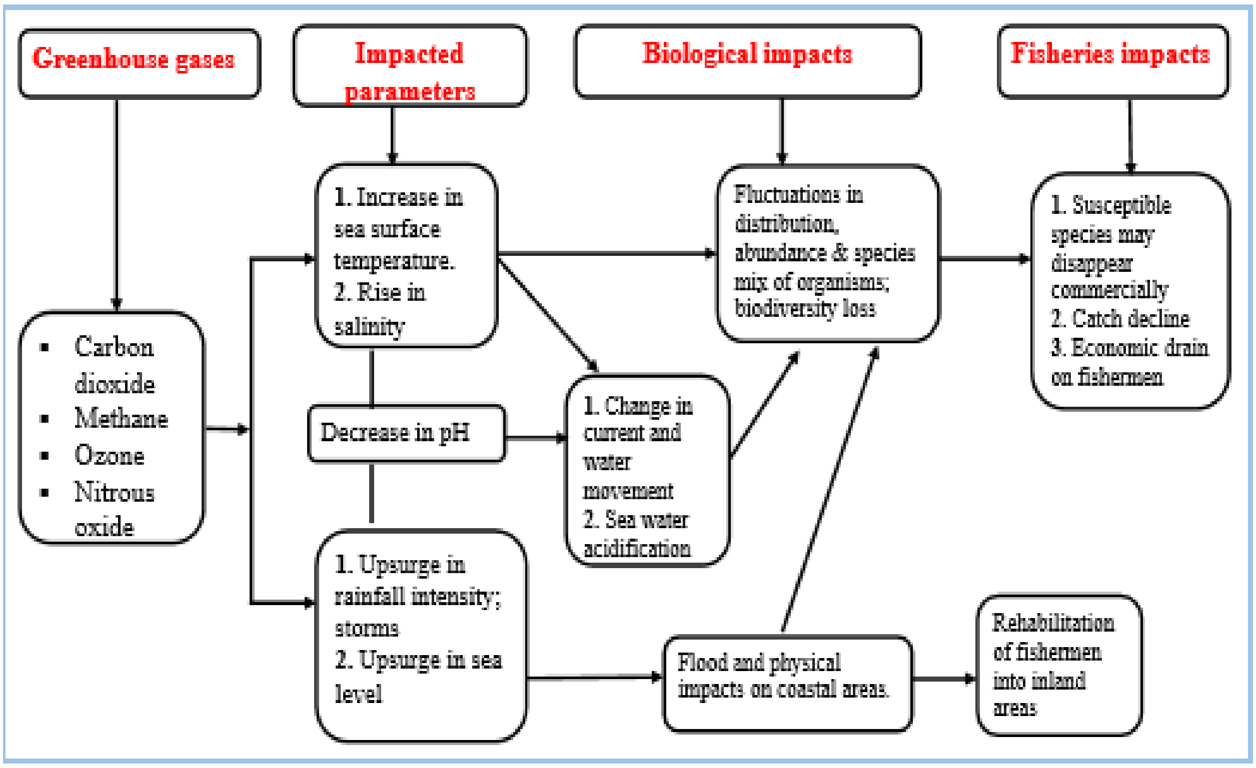

Figure 1 Direct and indirect effects of major climatic and environmental factors affecting marine mammals (Taken from Vivekanandan, 2006).

4.2. Climate change and its implication for the management and conservation of marine mammals

Marine mammals' possible range alterations and evolving needs must be considered in management and conservation strategies. If the remaining habitat can be found, protecting it could lessen the negative effects on breeding habitat [19] [114]. However, managing human influences on the resources needed by marine mammal species through ecosystem-based management will be the primary strategy for adapting to changes in the broader environment [19] [114]. Three key components are suggested for managing all human activities in the sea by the European Marine Strategy: an ecosystem approach, integrated management, and a regional focus for the organization and implementation of management initiatives [19] [114].

Determining marine protected areas, sometimes known as "no-take zones," for both marine mammal species and their prey is one method of safeguarding marine animals. But the best place for these places will probably change in the future, necessitating the adoption of new laws in place of the ones that are in place now [19] [114]. For instance, when creating Special Areas of Conservation (SAC), or protected areas for marine mammals, some leeway must be allowed for the possibility that the needs and range of these animals will change as a result of climate change [19] [114] [120] [198].

However, many of the issues that marine animals confront as a result of climate change cannot be resolved by conservation and protective measures; instead, the only viable option may be to mitigate greenhouse gas emissions in order to stop temperature increases and the resulting changes in climate [19] [114].

The World Conservation Union (IUCN), which keeps a red list of endangered species and advises agencies like the International Whaling Commission (IWC) and the Convention on International Trade in Endangered Species of Wild

Fauna and Flora (CITES), provides information on the conservation status of marine mammals [19] [114] [140]. Six of the twenty-eight (28) cetacean species for which there was sufficient data are listed as endangered, five as vulnerable, and two, the vaquita and baiji, as critically endangered in the most recent Red List [90] (see Table 1) [19] [114] [140]. Of the fifteen species listed as low risk, fourteen are dependent on conservation, and one is listed as near threatened. The IUCN red list contains sixty-seven (67) species of cetaceans, of which over 60% are classified as "data deficient" [19] [114] [140]. According to the IUCN red list, two pinniped species are classified as endangered, seven as vulnerable, and one, the Mediterranean monk seal, as critically endangered. The marine and sea otters are both threatened with extinction, all four Sirenian species are classified as fragile, and polar bears are dependent on conservation efforts [19] [114] [140].

All throughout their range, marine mammals face a variety of threats and pressures, such as accidental fisheries catch, boat strikes, prey depletion, pollution (heavy metals, organic compounds, oil, and sewage), habitat disturbance and degradation, algal blooms, noise pollution, the introduction of exotic species and pathogens, marine debris, and climate change [19] [40] [114] [135] [140].

The IWC was established in 1946 as a result of the International Convention for the Regulation of Whaling, and it is one of the international conservation conventions and organizations that deals with marine mammals. The IWC, formerly focused on controlling whaling, is becoming increasingly active in the conservation and recovery of cetacean populations. A workshop on climate change and cetaceans was sponsored by the IWC in 1996 [19] [93] [114] [140].

An international treaty called the Convention on the Conservation of Migratory Species of Wild Animals (also known as the Bonn Convention) offers a framework for regional conservation agreements. The resulting agreements are the Agreement on the Conservation of Small Cetaceans of the Black Sea, Mediterranean Sea, and Contiguous Atlantic Area (ASCOBAMS) and the Agreement on the Conservation of Small Cetaceans of the Baltic and North Sea (ASCOBANS) [19] [114] [140]. Further, in 1994 an international abundance assessment of cetaceans was conducted by ASCOBANS throughout the Baltic and North Sea [19] [69] [114] followed by a second survey that was conducted later in the year 2005 [19] [114] [140].

The Marine Mammal Protection Act in the United States and the Convention for the Conservation of European Wildlife and Natural Habitats (Bern Convention) both provide protection for marine mammals [19] [114] [140]. Numerous regions have been designated as protected or managed areas with the intention of benefiting marine animals, at least partially. Two such instances are the Hawaiian Island Humpback Whale Sanctuary and the Biosphere Reserve in the upper Gulf of Mexico, which was created to safeguard the vaquita [19] [114] [140] [142].

5. Conclusion

Although marine mammals help to maintain the health of ecosystems, they can also act as sentinel species—a kind of early warning system—when the health of an environment is declining. At the majority of trophic levels, marine mammals are consumers of production. They are believed to significantly impact the composition and functionality of some aquatic communities due to their size and abundance. Still, there isn't a lot of empirical data supporting these functions. Variations in temperature can have a direct impact on species distribution, causing certain species to grow while others constrict. Further research is required regarding the potential ramifications and direct physiological impacts of elevated temperatures on marine mammals. The availability of prey has an impact on the distribution, abundance, and movement of marine mammals as well as their community structure, vulnerability to toxins and disease, success of their reproduction, and, ultimately, their survival. Depending on the species and region, changes in the range and number of rivals and predators will also have various effects on marine animals. By designating protected areas for the surviving and anticipated habitat, management and conservation strategies must account for prospective changes in the range of the species.

Rising sea levels and an increase in storm frequency have the potential to demolish or render these places unsuitable. Protecting remaining breeding habitats is necessary, as is safeguarding potentially appropriate breeding sites in the event that conditions alter. Building barriers to shield coastal ecosystems from sea level rise may have a number of effects on coastal marine animals, including habitat degradation, effects on prey, direct death, and movement restriction. Comprehensive environmental impact evaluations that consider the effects on marine animals both now and in the future are necessary. The distribution of marine mammals may be directly impacted by changes in ocean currents, upwellings, and fronts, particularly if the boundaries between two water masses define the limits of their range. Alternatively, changes in the distribution and occurrence of prey linked to these currents, upwellings, and fronts may have an indirect impact. Instead of fixed regions, protective measures could incorporate adaptive no-take zones that adapt to variations in the distribution of prey.

The direct consequences of a decline in sea-ice cover are particularly dangerous for marine animals, especially those that depend on ice or the area near the ice edge. All species near the ice border will be impacted by changes in sea level and salinity, either directly or indirectly through shifts in the availability of prey across temporal and spatial changes. Although prey species, notably cephalopods, may be particularly vulnerable, the possible effects and repercussions of changes in salinity, pH, and CO_2 on marine animals are not fully understood and require further research. Toxic algal blooms may become more prevalent due to altered rainfall patterns, increased runoff, and variations in temperature, salinity, pH, and CO_2. Hazardous algal blooms have killed marine mammal species. The hazards of increased eutrophication and hazardous algal blooms may be raised by better water management and discharge control.

The main threat to marine mammals is most likely the way that climate change is altering their food supplies. The geographic distribution of these oceanographic conditions may vary due to climate change, which could have detrimental effects on marine mammal survival and reproduction. The effects (direct and/or indirect) of climate change may be more significant for populations that are already threatened.

Many of the published pieces of literature that were reviewed provided information on countries external to the neotropics. Therefore, there is a need for more research on climate change on marine mammals and possible strategies to mitigate its effect on these fauna and conservation strategies to ensure further protection since there is a limited and paucity of data in this biodiversity-rich region.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors hereby declare that this manuscript does not have any conflict of interest.

Statement of informed consent

All authors declare that informed consent was obtained from all individual participants included in the study.

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