# Solutions for Mitigating the Effects of Ocean Acidification on Cetaceans

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Climate change has affected our whole planet for many decades, disturbing the migrations, breeding seasons, and feeding habits of many species. Cetaceans are certainly no exception due to their profound place on the trophic web as apex predators. One of the biggest threats to cetaceans is ocean acidification. Although there is a lack of substantial data on the direct effects of ocean acidification on cetaceans, such information is crucial to figuring out solutions for how to save them. This paper will explore how humans can mitigate the effects of ocean acidification on three species of cetaceans, the sperm whale (Physeter macrocephalus), the fin whale (Balaenoptera physalus), and the common bottlenose dolphin (Tursiops truncatus). This paper aims to outline what we currently know about the general effects of ocean acidification on cetaceans and describes recent proposed solutions for these problems. Several previous studies on the general effects of climate change and ocean acidification on cetaceans were compiled and reviewed so possible solutions to this problem could be found and analyzed. Through the analysis of the studies, it was found that ocean acidification affects the prey availability, habitats, and health of cetacean populations, in turn affecting their ranges. The main ways in which humans can mitigate ocean acidification and further protect cetaceans is discussed. This research will help create a framework for solutions to the effects of ocean acidification on cetaceans, build upon previous research, acknowledge knowledge gaps, and can be used in Congress to persuade legislators to create specific legislation meant to protect cetaceans.

**Keywords:** *Cetaceans, ocean acidification, ocean acidification mitigation, climate change, sperm whale, fin whale, bottlenose dolphin, common bottlenose dolphin*

## Introduction

Climate change is a major issue that has been affecting our planet over the past few decades[1]. Overwhelming evidence suggests it has been caused by human activities, particularly through the release of carbon dioxide and other greenhouse gases into the atmosphere[1]. Greenhouse gases keep the planet warm by absorbing and re-radiating heat from Earth's surfaces that would otherwise be radiated into space back to the ground[2]. However, these excessive greenhouse gases retain too much heat in the atmosphere, causing global temperatures to rise[2]. The shift in temperatures disrupts the meteorological seasons, which many organisms have relied on for millenia for the timing of important events such as migrations and breeding seasons[3]. For the past few decades, climate change as well as other human activities such as shipping and logging have been disrupting entire ecosystems, impacting food chains and food webs, and shifting organisms' ranges due to temperature changes[1]. The marine biome, Earth's largest ecosystem, is certainly no exception. But aside from rising temperatures, the world's oceans face another problem that affects its organisms–lowering pH levels, better known as ocean acidification. As part of the carbon cycle, carbon dioxide is dissolved in the oceans and released back into the atmosphere[4], but the amount of carbon dioxide being released by human activities is exorbitant, and this large amount is getting dissolved into the oceans, causing their pH to lower.

### Acidification Impact on Marine Life and Ecosystems

Ocean acidification can have detrimental effects on both individual organisms and the entire ocean food web[4]. Calcifying microorganisms are losing their habitat[4] and being severely affected by a reduced CaCO3 saturation state[5]. For organisms other than calcifiers, ocean acidification can decrease their reproductive potential, slow their growth, and increase their susceptibility to disease, which could have destructive effects on entire food webs and ecosystem structures[4]. Whales, porpoises and dolphins, which belong to the group known as cetaceans, are especially important predators that are capable of altering "food chain and habitat connectivity" and "prey abundance and diversity"[6] in a food web. Calcifiers are a major food source for some cetaceans[4], and since the calcifiers are losing their habitat, their populations could decline. This would lead to there being two groups of cetaceans–those that are able to adapt and those that are not. Those that would

adapt would do so by changing their food sources, and those that would not adapt would most likely go extinct if nothing drastic is done to save them. Cephalopods such as squids are another major food source for cetaceans[4], but they are especially sensitive to rising temperatures and acidification[7], so there is a predicted negative impact on cetaceans[4].

Although more discoveries need to be made about the direct impacts of ocean acidification on cetaceans, cetaceans that are dependent on cephalopods and certain planctivores are predicted to be affected the most severely[4]. It has been estimated that high-latitude areas will be the first to be severely and measurably impacted by ocean acidification[4]. Changes in high-latitude seawater chemistry by the end of the century are said to be inevitable and are predicted to alter the entire structures of high-latitude ecosystems and biodiversity[4]. This can have large-scale consequences for the Southern Ocean ecosystems, which many cetaceans depend on[4]. The impacts of climate change are population- or species-specific due to some species being better able to adapt than others, but climate change generally impacts cetaceans' foraging by lowering the availability of their prey, their habitats by facing them with habitat loss, and ranges by forcing them to move to different feeding grounds[8]. Overall, ocean acidification is projected to profoundly affect marine ecosystems[5].

**Indirect Impacts of Acidification on Cetaceans**

We know that ocean acidification can alter the quality of cetaceans' food[8] because some of the cetaceans' key prey species are very sensitive to temperature and pH changes[7]. As the acid levels in the ocean rise, available carbonate ions (CO32-) which would typically form calcium carbonate (CaCO3) bond with hydrogen and thus result in less available carbonate ions for calcifying organisms to use as part of their shells[9]. Carbonate structures, including skeletons, start to weaken and can even begin to dissolve[9]. This could lower the populations of these species and consequently the cetaceans. Ocean acidification also affects natural soundscapes by altering the sound production of a major feature of these soundscapes, the snaps of the snapping shrimp[10].

Natural soundscapes are used by many organisms such as fish larvae and cetaceans to navigate their environment, and future CO2 levels in oceans could be detrimental for population replenishment by dispersing larvae that rely on sound[10]. Such changes could affect the populations of cetaceans who mainly eat fish since fish larvae may be dispersed and thus groups of cetaceans may be smaller and more sparse. More cetaceans might try to hunt alone to catch more separated populations of fish. It is projected that biological sound cues may become less important for navigation if the levels of natural sound are being reduced by anthropogenic noise pollution[10]. While ocean acidification does affect the snapping shrimp, an important feature of biological soundscapes, any interruption of the soundscape, especially anthropogenic noise pollution, has an impact on organisms such as cetaceans who rely on sound to navigate, communicate, and find prey. Orientation towards a suitable habitat is important for many organisms, so there are important implications of the effects of acidification on the snapping shrimp and biological soundscapes for population replenishment[10].

It is currently unknown to what extent marine organisms can adapt to ocean acidification or which organisms can and cannot, but recent research shows a lack of trans-generational acclimation in fish[10]. If some fish species are unable to adapt to ocean acidification, cetaceans could be put in danger if the populations of their key prey species decline. Because sound is also a major component in the lives of cetaceans, not only could ocean acidification lower the populations of their key prey species and leave certain species and populations with a scarce amount of food, it could also alter the navigation systems and methods of cetaceans, meaning that they would possibly be unable to find food due to confusion in altered soundscapes unless they are able to adapt. Ocean acidification can also impact the physiology of individual organisms[5]. This means that the physiology of populations can be affected if ocean acidification impacts enough individual organisms.

**Future Effects on Cetacean Population**

Currently, we have many future projections for the possible effects of ocean acidification on cetaceans. For example, we know that ocean acidification could affect squid stocks, a major food source for deep-diving odontocetes (toothed whales) such as sperm whales[11]. It is also projected to impact fish stocks because fish larvae will not do well in future pH levels if drastic action is not taken[12], lowering the populations of cetaceans who have fish as one of their major food sources. Coral and some types of phytoplankton could also be affected, which could eventually affect top marine predators[11]. And while we do not know for sure, there is indication that ocean acidification may affect cetaceans' metabolism[8]. Data collected from studies of other species suggests that in order to compensate for the rise in ocean acidity, adjustments must be made to their metabolic processes[8]. Higher acidity caused by CO2 increase may force cetaceans to require more oxygen when they are at rest[8]. This shift in their bodily processes would use extra stored energy, and depletion of this stored energy will likely lead to weaker body conditions, reduced reproductive success, and an increased likelihood of succumbing to disease[8]. However, it is projected that some cetaceans may be able to adapt to the effects of ocean acidification and climate change in general. For example, fin whales in the Norwegian Sea have adapted to eating more pelagic fish in response to a decline in their main prey, macro-

zooplankton[7]. Other species of cetaceans may also be able to adapt and change their food sources and ranges, and over hundreds of years, assuming emissions and acidification continue at a steady or lower rate, these shifted ranges and food sources could eventually become their new main ones and a balance would be restored. However, some cetaceans, such as those who live in continental shelf areas, may not be able to adapt because continued temperature and prey availability changes may force them to move from their homes[7]. While the general impacts of climate change are the same for most cetaceans, a cetacean's ability to adapt to climate change is determined by its population's or species's circumstances[8]. Some cetaceans live in such areas that they can expand their habitat to adapt while others must shrink their ranges[8]. The populations of those who must shrink their ranges might decline due to a shift in the ranges of their prey across the food chain[8]. The cetaceans living in restricted geographical zones who are unable to shift their range or switch their prey may be among those who are unable to adapt[5] and, if nothing is done, may possibly go extinct. The impacts of climate change may also differ depending on the type of habitat, but we still do not know about how climate change affects populations in oceanic or remote areas[8]. Shifts in prey availability, one of the major effects on cetaceans of climate change in general, is one of the most detrimental effects on a population of cetaceans because it can cause cetaceans to alter their habits[5]. For example, bottlenose dolphins in the northern Adriatic Sea have been recorded spending the majority of their time and effort on feeding-related activities in response to environmental changes and shifts in their prey[5]. In fact, so much time had been spent on finding food that they had far less time to socialize and breed, which takes a toll on their reproductive success[5]. The health, physical strength, and abundance of bottlenose dolphins in the eastern Ionian Sea has also been observed to be affected by reactions to reduced prey availability[5]. Some species such as sperm whales can be vulnerable to climate change because of other factors, such as low genetic variability, low diet diversity, low populations in general (vulnerable status), and their migratory behavior[7]. Overall, we know that cetaceans are highly vulnerable to changes in the environment and temperature changes[5] and it is projected that they will be profoundly affected by ocean acidification. This paper will focus on three specific species of cetaceans, the sperm whale (Physeter macrocephalus), the fin whale (Balaenoptera physalus), and the common bottlenose dolphin (Tursiops truncatus), which will be hereafter referred to as simply the bottlenose dolphin.

## Species Included in This Paper

### Sperm Whale

The sperm whale is a type of toothed whale (odontocete) with the largest brain in the animal kingdom[13]. Males can reach a maximum length of 18m and a maximum weight of 57,000 kg, while females can reach a maximum length of 11m and a maximum weight of 15,000 kg[13]. They mainly eat squid, especially the giant squid, as well as octopus, fish, crustaceans, and sometimes deep-dwelling sharks[13]. The sperm whale can be found throughout the world's oceans, but they prefer to live in deep water and are seldom found close to land[13]. They are a migratory species, and females and young males seem to be restricted to warmer waters (north of approximately 45 degrees S in the Southern Hemisphere), but adult males travel to and from the waters of Antarctica[14]. They generally move to the south in summer and to the north in winter, particularly for males[14]. Their population is over 100,000[13], and their IUCN conservation status is vulnerable. They are especially vulnerable to climate change because of their low genetic variability, low diet diversity, vulnerable status, and migratory behavior[7].

### Fin Whale

The fin whale is a type of baleen whale (mysticete) and is one of the largest whale species, second only to the blue whale[15]. The average adult male fin whale is 70 ft long and weighs 45 tons[15]. The average adult female is 73 ft long and weighs 45 tons[15]. Being baleen whales, they feed on many different types of small schooling fish and invertebrates[15]. They can be found in polar, temperate, and subtropical waters worldwide, and they can be found as far north as the western Chukchi Sea, the Bering Sea, and throughout the Gulf of Alaska[15]. Fin whales spend their spring and early summer in high-latitude waters where they feed, and in the fall they tend to return to lower latitudes for their winter breeding season, though they may stay in their high-latitude ranges if food continues to remain plentiful[15]. There are approximately 75,000 fin whales in the world[15]. Their IUCN conservation status is Vulnerable.

### Bottlenose Dolphin

The bottlenose dolphin is a type of odontocete. They can grow up to 13 ft long and weigh 1,300 pounds and their diet consists of fish, squid, and shrimp[16]. They can live anywhere from alongside coasts to the open ocean[16] and they migrate up and down the Atlantic coast, north in spring and south in autumn[17]. Their population is about 600,000[18]. Their IUCN conservation status is Least Concern on a global level, but many populations are declining, such as in the Mediterranean and the Black Sea[19]. These three species were chosen because according to a study in which a new index for determining

cetacean vulnerability to climate change was developed and tested, it was determined that these three species are some of the most vulnerable to climate change[20]. Differences in vulnerability between the species were based on diet diversity, migrations, IUCN status, and exposure to climate change[20]. This paper will not only explore the effects of ocean acidification on cetaceans, but also ways that humans can mitigate these effects. Cetaceans play a major role in ocean food webs and losing them, whether it be populations in an area or an entire species, could be detrimental to the rest of the ecosystem2. Humans need these large predators as much as any other organism for cultural services, including aesthetics, cultural identity, bequest, and spiritual enrichment, meaning that cetaceans do not only influence ecological productivity but can also benefit humans[6]. Because they can alter food chains, prey abundance and diversity, and the availability of goods and services, cetaceans are needed by both humans and the rest of the Earth2. In order to be able to properly create conservation and management strategies, data relating to ocean acidification and its impact on the health of cetaceans is imperative2. This paper will review what is currently known about the impact of climate change and ocean acidification on cetaceans, discuss the results of previous findings, and explore possible strategies for the mitigation of ocean acidification and its effects on cetaceans.

## Methods

The research method is mixed method research design based on data collected from a literature review[21], including:

- Qualitative research, for example, cetacean behavior assessment
- Quantitative research, for example, % of population affected

The strength of the mixed method approach is that it leverages both the qualitative and quantitative data available from the literature. Both types of data were collected at the same time, which means that it was a convergent parallel design, where both types of data inform each other[22].

The literature review takes advantage of all studies that are relevant to climate change, specifically ocean acidification, and its impact on the cetacean population.

The literature review in this paper was a scoping review. A scoping review is a type of research method that determines the coverage of a body of literature on a given topic and clearly indicates the volume of research available as well as an overview of its focus[23]. Scoping reviews are typically used to identify the available evidence in a given field, clarify key concepts in the literature, examine the research methods on a certain topic or field, identify key characteristics or factors about a concept, as a precursor to a more specific systematic review, and to identify and analyze knowledge gaps[23]. Scoping reviews can examine evidence on a fairly new topic and report on the types of evidence that inform practice in the field and the research methods used to find the evidence[23].

We chose the scoping review design because there are many knowledge gaps to be investigated and very new data on the topic of the effects of ocean acidification on cetaceans. The scoping review was used to examine the available data on the subject and analyze these knowledge gaps.

The search terms used were the name of one of the three species (sperm whale, fin whale, or bottlenose dolphin) AND "ocean acidification" and "cetaceans" AND "ocean acidification".

We have identified 9017 potential articles through the boolean search. We reviewed 200 articles that were selected by relevance through the google scholar algorithm (top 50 most relevant articles per search terms). We included 33 articles in the review (Fig. 1).

In each article, I specifically looked for data on the effects of climate change or ocean acidification on cetaceans and tried to leave out anything that wasn't relevant to that. I also looked for data that I thought could have been relevant about projections for long-term effects of ocean acidification on cetaceans and marine life in general, current effects of climate change on marine life and oceans in general, and, of course, ways to mitigate these effects. One of the main factors that caused me to reject articles were if they were not about any of the particular species I studied. Another main factor was if the articles were not entirely relevant in another way, such as being mainly about another aspect of climate change or another type of human disturbance such as pollution affecting cetaceans instead of ocean acidification, or the effects of ocean acidification on other types of marine animals only.

## Results

Extensive data exists which demonstrates trends in how acidification could severely impact cetaceans' lifestyles, habitats, food sources, and ultimately their ability to thrive.

Generally, arctic species such as fin whales have been discovered to be especially vulnerable to climate change, but the effects on all cetaceans are global[8]. Future changes in seawater chemistry may also alter the biodiversity of high-latitude ecosystems and food webs, and the Southern Ocean ecosystems, on which many cetaceans depend, will especially be affected, also affecting those cetaceans[4]. Climate change also lowers cetaceans' prey availability, destroys the habitats of cetaceans, and in response to the lower prey availability changes cetaceans' ranges, forcing cetaceans to move to find more food as their prey responds to the effects of climate

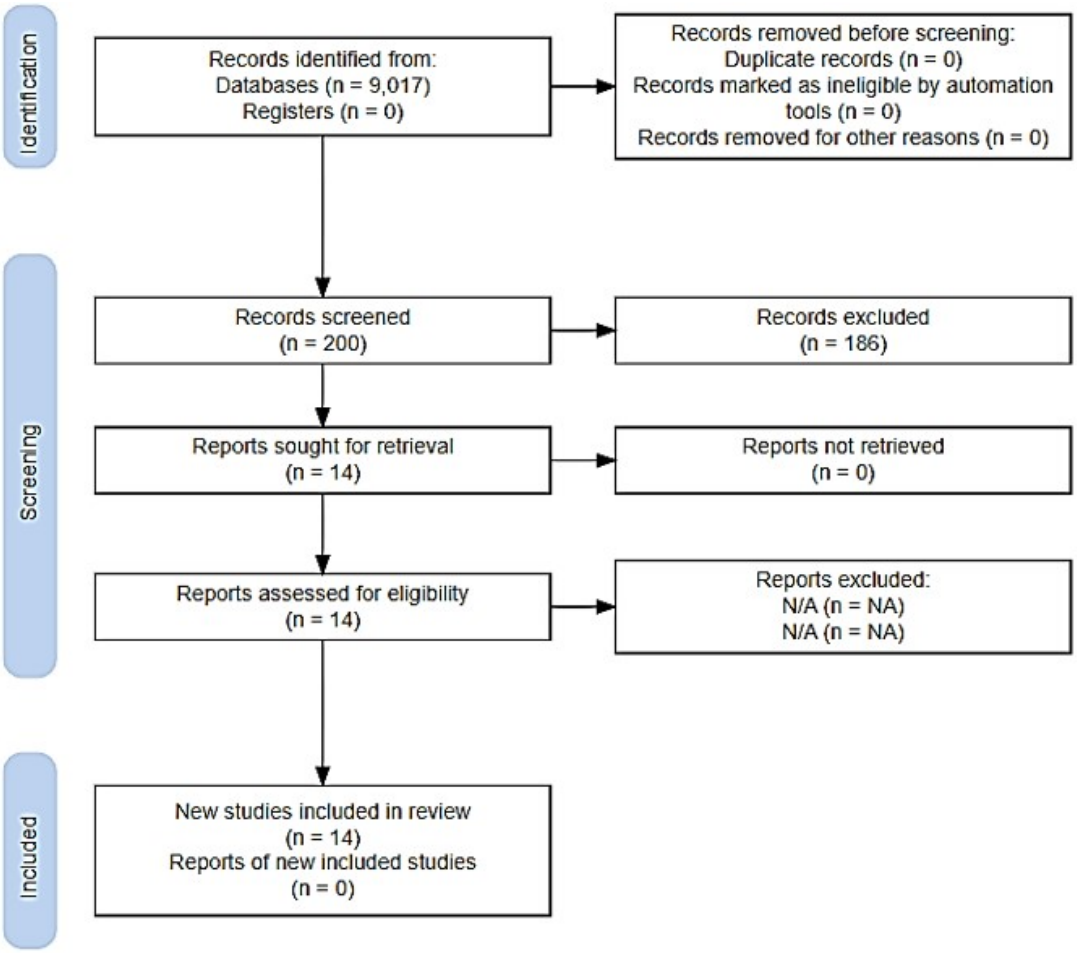


**Fig. 1** This diagram shows the research process. 9017 potential articles were identified, 200 were selected by relevance and reviewed, and 33 articles were included in the review.

change[8]. However, some cetaceans are unable to move out of their ranges, causing them to become more vulnerable[7].

Aside from cetaceans, calcifying organisms are also losing their habitat due to a rising saturation state, leading to cascading effects on food webs, especially considering that these calcifiers are a major food source for some cetaceans[4]. Cetaceans who are dependent on other types of food such as squid and planctivores, especially sperm whales, fin whales, and even bottlenose dolphins, are especially at risk[4].

It was also found that climate change affects cetaceans and other non-calcifying organisms by lowering their reproductive success and growth rates and increasing their susceptibility to diseases, which can also have detrimental effects on food webs and eventually the entire ecosystem[4] as these organisms will reproduce successfully less often, making already-decreasing populations smaller and in the worst-case scenario eventually leading to extinction. Further analysis into how ocean acidification specifically impacts sperm whales, fin whales and bottlenose dolphins reveals a decline in health, population and habitat quality (Fig. 2).

While some species will be able to adapt and some won't, sperm whales may be among the species that won't be able to adapt. One paper claims that the sperm whale's migratory behavior is one of the reasons that it will not be able to adapt to the effects of a changing climate[7], but another states that it may help the sperm whale adapt[24], presumably by allowing it to move from place to place if conditions become too harsh in one area. Some fin whales seem to be able to adapt to the changing climate by changing their ranges and prey[7], but Mediterranean fin whales may be in much more trouble, as their only known prey, northern krill, is at the limit of its range and if anything happens may not be able to move elsewhere[5]. Bottlenose dolphins have also had their prey species shifted[5], and ocean acidification and other climate change-

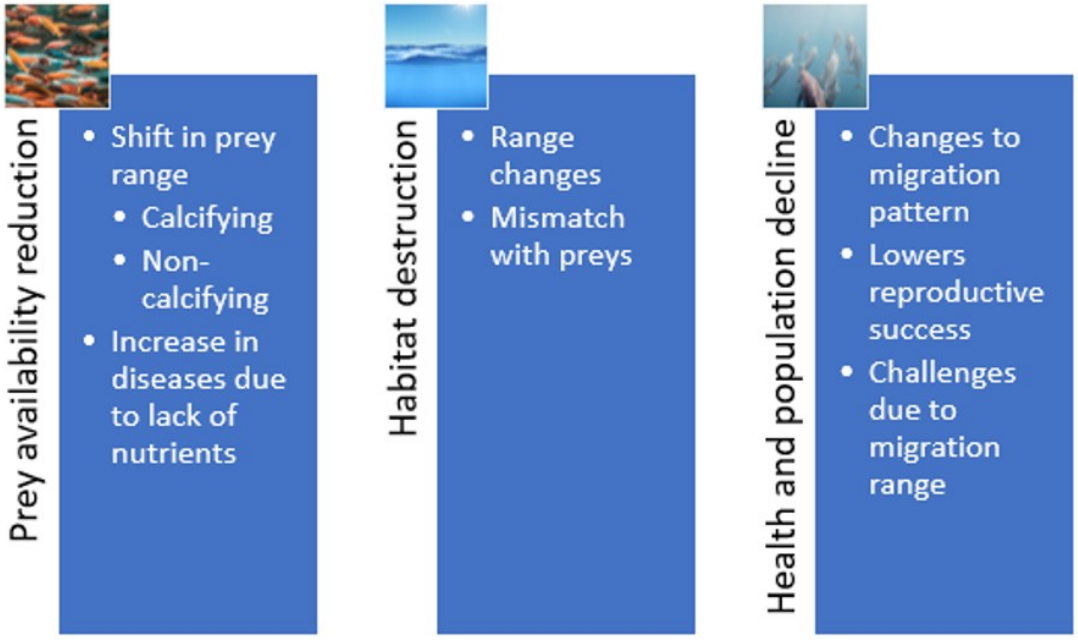


**Fig. 2** This graphic splits the indirect effects of ocean acidification on cetaceans into three distinct categories, prey availability reduction, habitat destruction, and health and population decline, and more specifically demonstrates the effects of each (Nunny & Simmonds, 2021).

related threats are among the biggest threats to bottlenose dolphins[25]. Ocean acidification can lower the populations of their prey, leading to food limitations, poor health, and increased susceptibility to diseases3. It is shown that the decline in the cetaceans' prey, habitats, health, and population all lead to a change in range (Fig. 3).

Humans have also been interfering in the lives and survival of cetaceans. For example, on top of all the pressure from the effects of climate change, bottlenose dolphins are competing with fishermen for prey species[5]. This affects them further because the ranges and behavior of cetaceans are largely influenced by the distribution and abundance of their prey, and the prey is already being affected by global warming[5]. The decreasing amount of fish stocks leads to less resources for both dolphins and fishermen and thus makes the competition worse, increasing the risk of fishermen harming and harassing dolphins[5]. If climate change continues to get worse, then cetaceans will need to adjust their lifestyles in order to survive[24]. This can make conservation planning more difficult by making it harder to anticipate those changes[24]. And on top of it all, the problems caused by non-climate stressors can also be made more complicated by climate change causing shifts in human behavior and needs[24]. For example, the reduction in sea ice increases shipping in the Arctic, which will likely lead to more cetaceans getting struck by ships[24]. We urgently need to mitigate the effects of ocean acidification on cetaceans. Cetaceans are an integral part of ocean food webs and ecosystems in general[6]. If cetaceans diminish or become extinct, entire food webs may be thrown out of balance, and we would lose all of the benefits that come with cetaceans. Both the climate and anthropogenic sources are huge threats to cetaceans, and we need to take urgent action in order to limit them[7]. Cetaceans such as those in the cold temperate waters around Europe who are limited to enclosed waters and thus cannot move away from threats may need more immediate attention[7]. Cetaceans also provide important cultural services for humans[7]. For example, sperm whales are important for Norway's tourism, but their projected decline could lead to a decline in tourism[12]. This would warrant an assessment of the conditions of the area[12] but could eventually lead to little to no tourism at all, hurting Norway's business and economy. To mitigate the effects of ocean acidification on cetaceans, we must use MPA's (Marine Protected Areas) and other types of protected areas[11], address non-climate threats to cetaceans to take the pressure off of them[7], educate the public about impacts of climate change on cetaceans[7], engage in activities that reduce CO2 emissions[7], monitor cetaceans and conduct health studies on them[7], and predict the long-term impacts on different species and populations in different locations to inform conservation efforts[7]. In addition, we can study the use of sound technology for habitat restoration[26] to replenish cetaceans' homes, counteracting the deterioration of soundscapes caused by ocean acidification. Further analysis provides solutions to mitigate ocean acidification and its effects

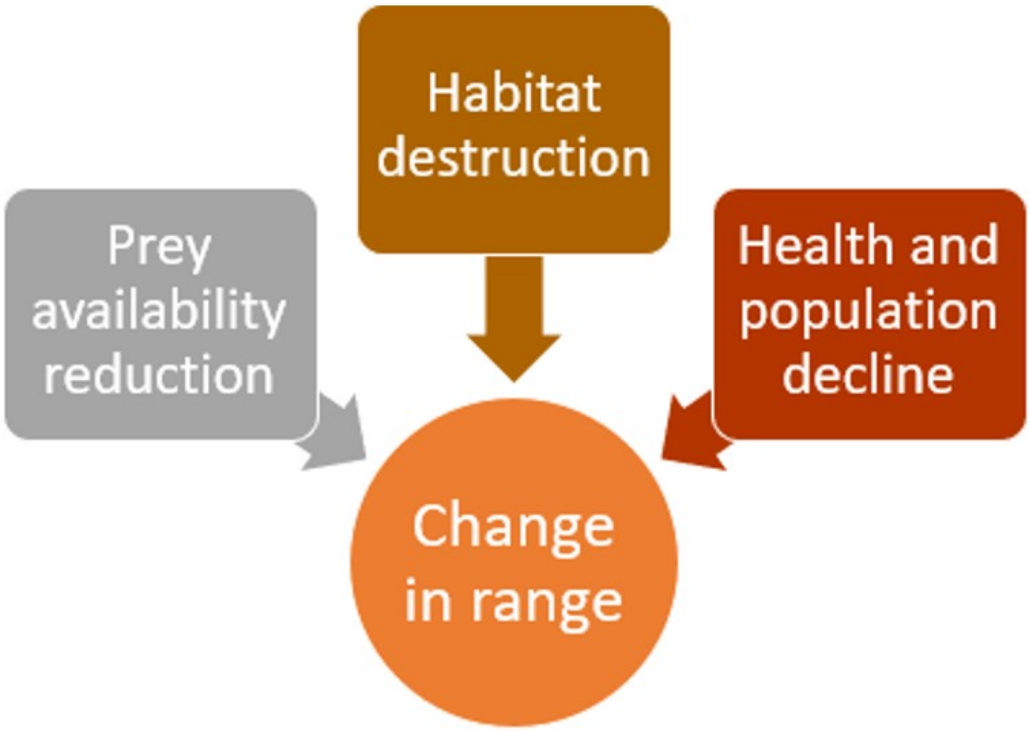


**Fig. 3** This graphic demonstrates how the indirect effects of ocean acidification on cetaceans, prey availability reduction, habitat destruction, and health and population decline, all lead to a change in range (Nunny & Simmonds, 2021).

on cetaceans (Fig. 4).

## Discussion

### Rationale for Cetacean Protection

Protecting cetaceans, especially odontocetes, is important because cetaceans are critical for maintaining the health and functioning of food webs, and losing such crucial predators affects other environmental processes such as disease dynamics, carbon sequestration, invasive species, and biogeochemical exchanges between sediments, water, and the atmosphere[6]. Not only are cetaceans important predators, they also benefit even the bottom of the food chain by providing nutrients to phytoplankton via their nitrogen-rich feces, nurturing organisms that feed the rest of the ecosystem and keep the food chain functioning[6]. Although more research must be done into both the effects of climate change on populations of cetaceans and how best to mitigate them[6], here we propose ideas based on our current data as to what we can do. There are many ways that the effects of ocean acidification and climate change in general can be mitigated if communities, regions, countries, and humanity as a whole will properly implement them.

### Marine Protected Areas

One way to ensure the safety and wellbeing of cetaceans is to create MPA's (Marine Protected Areas) like those in South Africa, which can protect species against the physical harms of anthropogenic threats such as fishing and shipping, therefore increasing the resilience of ecosystems[11]. There is some controversy as to whether MPA's actually allow ecosystems to recover faster or just cause resource extraction activities to move somewhere else, but if appropriately managed, they can provide havens for species in need of protection[11]. The boundaries of MPA's can also be made more flexible to account for the possibility of cetaceans needing to move outside of the protected areas in response to climate change[11]. Climate change trends are becoming increasingly harder to mitigate, as well as anthropogenic activities that further destroy the environment such as land-based pollution, for they require changes in consumer behavior[11]. But while MPA's offer many benefits to marine species, an ecosystems-based approach is more applicable for protecting cetaceans[11]. The best current use for MPA's is to keep species from further declining due


**Fig. 4** This graphic describes the main categories of solutions for mitigating the indirect effects of ocean acidification on cetaceans and the more specific benefits/ways to carry out the solutions (Nunny & Simmonds, 2021).

to anthropogenic threats while policymakers, researchers, and conservationists work on other tactics including litigation to reverse and prevent ocean acidification.

## Non-Climate Threats

Addressing non-climate threats to cetaceans, such as shipping, pollution, and overfishing, is also needed to take the pressure off of them[7]. The effects of global warming on the Earth will take many decades longer to lessen and change than direct anthropogenic threats to cetaceans[27]. If these anthropogenic threats were to be reversed now, the Earth would gradually cool over many decades, eventually shifting environmental cycles back to normal or near normal[27]. This would allow cetaceans to continue with their current, though adapting, lifestyles so that conservationists can direct their focus to directly reducing or reversing anthropogenic threats to the climate. However, this would require many companies to greatly lessen if not eradicate their reliance on fossil fuels over a short period of time, which is highly unlikely to happen. If these companies could invest in green energy and change their methods within a reasonable timeframe, say, over the span of about a decade or so, conservationists could focus more on solving the remaining climate issues and coming up with better ways for society to work sustainably. They could also focus more on finding better ways to protect cetaceans.

## Education

Educating the public is another great solution[7] that can gather more potential conservationists, get more people to care, and raise awareness of the threats to these important species. Social media may be a powerful tool that can be used to inform the public, especially about pollution. It could get more people to be more mindful of what products they use are made of and change their minds about those products so that less pollution

ends up in the oceans. Many people don't realize that common household products, such as cleaning products, plasticizers in paints, and even hydraulic equipment can contain toxic chemicals that bioaccumulate, or stay in the tissues of an organism that consumes them, and are very hard to remove from the environment, such as polychlorinated biphenyls (PCB) and Per- and polyfluoroalkyl substances (PFAS)[28]. Many products are also made of plastic, which is indestructible but at a cost for the environment, as it takes 20-500 years for plastic to biodegrade[29]. Educating the public not only increases awareness of environmental problems that affect cetaceans, it could also inspire them to promote environmental legislation and conduct local pollution control[30]. If truthfully greener alternatives are invented and used by a growing community of educated customers, then less pollution will affect the oceans and cetaceans will be a little bit more protected.

**CO2 Emission Reduction**

Communities and societies can also work to perform CO2-reducing activities such as meeting targets to reduce CO2 and other emissions, reducing consumption of fossil fuels, investing in renewable energy sources, reducing consumption of meat and other animal products, and buying local produce[7]. Meeting targets to reduce CO2 and other emissions and reducing consumption of fossil fuels would reduce ocean acidification, which if done quickly enough could preserve calcifying organisms and cephalopods that are the key prey species of sperm whales, fin whales, bottlenose dolphins, and many other cetaceans. It can be done within a reasonable timeframe of at least a decade, but it would require companies to significantly reduce their reliance on fossil fuels, and there is such a dependence on fossil fuels that society may not want to adapt to such a change when using fossil fuels that create CO2 emissions for energy would be much cheaper. However, with 62% of Americans acknowledging climate change as a great threat to their community[31], more members of the public may want to contribute to lowering CO2 emissions. Investing in renewable energy sources is an efficient, though usually more expensive, replacement, and, if the technology is implemented properly (such as wind turbines that do not create noise pollution and disturb cetaceans) or adjusted (such as solar panels that do not require minerals that need deep-sea mining to be obtained), it can become the future of society. Renewable energy sources may become so common that they become cheap, and these new cheaper costs will become the new baseline costs rather than becoming more expensive, or the costs may become reduced as more and more renewable energy sources are used. More research needs to go into creating the best renewable energy sources possible that not only provide energy to keep human civilization working, but also are safe for cetaceans and other important organisms (e.g. not causing any kind of pollution, especially noise pollution, or have little to no risk of causing collisions or other human-environment interference). Reducing consumption of meat and buying local produce can also reduce CO2 and methane emissions[7], which are released from transportation of coal, natural gas, and oil, municipal solid waste landfills, and livestock[32]. Reducing these emissions can keep climate change and ocean acidification from worsening and reduce their effects on cetaceans and their prey species. Individuals or families reducing their meat consumption and buying local produce can lead to less people buying imported food or meat, especially if the word is spread using social media, therefore giving those companies less business and encouraging them to switch to other, more environmentally-friendly focuses. Although convincing them to switch may be difficult at first, perhaps reframing the meat industry to be more selective and not mass-breeding farm animals may reduce methane and CO2 emissions and improve the market. Cow feed could also be changed so that cows will produce less methane as a result of their digestion. If environmentally-friendly products and food become a bigger trend, the meat industry may want to follow the market and become greener. The way they could do this is by reducing the amount of meat they produce and making it higher-quality so that they can improve their profits. Engaging in CO2-reducing activities can not only encourage society to improve, but also reduces ocean acidification and protects cetaceans.

**Cetacean Studies**

In addition, monitoring cetaceans and conducting health studies on them is another important mitigation strategy[7] which can provide valuable information to conservation efforts and let scientists know the conditions cetaceans are enduring. The impacts of climate change on cetaceans need to be considered alongside other threats to their health for conservation, for example certain European cetaceans are at risk from PCBs contamination[7]. This contamination can cause immunosuppression and reproductive failure in the cetaceans, and this can make some cetaceans more susceptible to diseases, making the problem worse[7]. Regularly, properly, and ethically checking cetaceans for such pollution, ailments, or diseases will give researchers an idea of the conditions that a cetacean population is enduring to determine whether or not their habitat needs to be assessed. Understanding cetaceans' habitat preferences is also important[25]. Surveying large areas that have not yet been examined is critical to understanding the habitat preferences of bottlenose dolphins and other cetaceans and identifying areas where many cetaceans live, which is needed to inform conservation management3. If we can understand what types of habitats cetaceans prefer, we can try harder to protect those habitats. And according to a study on bottlenose dolphins in central South Australia, due to the number of potential threats

these bottlenose dolphins face, estimates of population size are also important for informing conservation efforts[26]. If we know how big a population of cetaceans is, we can better get an idea of what their environment and lives are like and can better assess the risks of the threats they now face. Predicting the long-term impacts of climate change on different species in different locations can also help inform conservation projects[7]. These impacts can be predicted based on existing data and creating virtual simulations to demonstrate different scenarios, such as the three climate change scenarios that many scientists have today: higher emissions, same emissions, or lower emissions. Different species in different locations are affected by different anthropogenic factors and aspects of climate change, for example some cetaceans such as the fin whale live near less-populated areas such as Alaska[15], so they may be impacted less by anthropogenic threats than other species who live near more-populated areas, such as bottlenose dolphins impacted by shipping in central South Australia3. Therefore, predicting the long-term impacts of climate change on different species in different locations by using existing data and creating simulations specifically pertaining to certain species, conditions, and locations can help researchers and conservationists understand the conditions each specific species may endure if no drastic action is taken. It is harder to predict the long-term impacts of ocean acidification on cetaceans than other threats since not much is currently known about the direct impacts of ocean acidification on cetaceans, but based on the known impacts on their prey species, if no drastic action is taken to reduce ocean acidification and CO2 emissions, the populations of many cetacean species could lower, which can even cause them to become extinct in a worst-case scenario. We do know that if ocean acidification is reduced, there will be low morbidity and mortality and cetaceans' habitats will be improved[6], which is part of why we must reduce the effects of ocean acidification on cetaceans. In order to fully understand the direct effects of ocean acidification on cetaceans, we must conduct more direct studies on how sperm whales, fin whales, and bottlenose dolphins, three of the most vulnerable species to climate change, are being affected by ocean acidification over a short period of time.

### Soundscapes

One way to replenish the habitats of cetaceans is the use of sound technology to accelerate habitat restoration. Several studies have been completed using this method, including Kress's experiment, which involved amplifying arctic tern calls to attract them to a nesting site, eventually restoring their breeding grounds within three years, and Gordon's study, which involved playing healthy reef sounds in degraded coral reefs, which eventually doubled fish settlement and retention[26]. In another study, three distinct marine environments were recorded[26]. Based on sound pressure level and snapping shrimp snap counts, it was found that acoustic characteristics increased from degraded to healthier habitats, with the sedimentary habitat being the quietest, the rocky restoration site being louder, and the natural rocky reef being the loudest and containing the most snapping shrimp snaps[26]. The restored reef site had intermediate snap counts and volume, indicating that enough natural healthy sound early on in a habitat's decline can at least partially restore soundscapes, but sound technology may be required to speed up a habitat's restoration[26]. If soundscape playback can increase the abundance of the habitat-building species targeted for restoration, it may prove to be a useful tool for accelerating habitat restoration in the future[26]. However, there are currently knowledge gaps about the technical or biological aspects of using sound technology to restore habitats, so more large-scale research is needed to build confidence that we can use this solution[26]. Studies like these, if tested over a long period of time, may also be able to help restore cetacean habitats in the future. However, we do not know about some technical and biological aspects of sound technology habitat restoration and we do not know about how well it will work over a long period of time nor what constitutes a healthy soundscape[26]. As for now, it has been found that some animals, even cetaceans such as killer whales, can adapt to soundscape changes, but others cannot[26]. We may need to do more research on those that cannot so that we can find ways to conserve their habitats and help them adapt.

## Conclusion

The impact of climate change on cetaceans is very important to tackle because cetaceans benefit the lives of many cultures in many ways[6]. This paper reflects on the current information we have about the detrimental effects of ocean acidification on ocean ecosystems and cetaceans' prey species, but more research must be done. In order to protect the sperm whale, the fin whale, and the bottlenose dolphin from the effects of ocean acidification, we must establish larger and more flexible MPA's, address non-climate threats, educate the public on the effects of ocean acidification on cetaceans, engage in activities to reduce CO2 emissions, monitor cetaceans and conduct health studies on them, predict the long-term impacts of ocean acidification on cetaceans to inform conservation efforts, and further research the use of sound technology to restore the habitats of cetaceans. This research is useful in determining immediate solutions for climate-related problems currently affecting cetaceans that the public can also partake in. Additionally, it can be used in Congress to persuade legislators of the need to pass specific legislation to protect these wonderful creatures, including legislation that will allow larger, more flexible, and more MPA's and laws to ban fishing and ship-

ping in certain areas where cetaceans are most prevalent, for example during a migration. This research will build upon existing research and inspire ideas for new research to fill in our knowledge gaps.

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