`

APPROVAL OF HONORS PROGRAM SENIOR PROJECT

Candidate

Desiree Walker

Project Title

The Impact of Climate Change and Human Activities on Whale Populations

This Senior Project is approved as acceptable

Project Director

Dr. Daniel Elias

Committee Member

Dr. Paul Ewell

Committee Member

Dr. Lee Templeton

Honors Program Director

Dr. Bill Yankosky

Honors Program Assistant Director

Dr. Fred Sanborn

November 21, 2023

Title: The Impact of Climate Change and Human Activities on Whale Populations

Abstract

Global climate change has been the central topic over the past several decades with extensive research addressing its effects to humans and the environment. Marine environments have been greatly affected by these changes (e.g. increased water temperature, pH) that directly impact organismal fitness. Whales are significantly affected by climate change and anthropogenic activities through mass strandings and reproductive challenges. This review conducted a non-systematic search for English-written papers on climate change and whales from 2001 to 2023, resulting in 32 relevant articles to address and explore anthropogenic impacts on whale's population by naval activity, shipping noise, strikes, pollution, and human induced climate change. Increased water temperature and altered ocean parameters are likely causes of reduced reproduction success on whales. Sperm whale reproduction rates are adversely affected by increasing water temperatures, especially during El Niño events. Also, reduced prey availability worsens reproductive difficulties for various whale species (e.g. Beaked whale, North Atlantic Right whale). Warmer oceans reduce the population of krill. This decline directly affects the primary food source of many whale species. Specifically, baleen whale's gestation and corresponding energetic needs are affected by changes in krill population, thus affecting reproductive success. Naval activities, such as deployment of mid-frequency active sonar (MFAS) have emerged as threat to whales with a correlation between naval exercises and mass strandings. Beaked whales, exhibit strong avoidance behaviors in response to MFAS. Shipping noise, another whale stressor, disrupts whale communication, navigation, and feeding behaviors. Additionally, persistent pollutants such as PCBs and their increasing concentrations through the food web have harmful effects on whale populations. Overall, there is a pressing need for continuous research, regulations, and global collaboration to reduce the anthropogenic threats faced by whales. Conservation efforts have to be linked to successful policy to ensure the wellbeing of these marine mammals.

Introduction

Over the past several decades, there has been a lot of talk about global climate change and the effect it will have on the earth (Chami et al., n.d.; Karl and Trenberth, 2003)). It is now 2023 and we are seeing some of the effects of global change (Chami et al., n.d.; Karl and Trenberth, 2003), but also, we are starting to address them (Karl and Trenberth, 2003). In the National Oceanic and Atmospheric Administration's (NOAA) 2021 Annual Climate Report, the land and ocean temperature has increased at an average rate of 0.14 degrees Fahrenheit per decade since 1880 (Lindsey and Dahlman, 2023). However, the average rate of increase since 1981 has been more than twice as fast: 0.32 degrees Fahrenheit per decade (Lindsey and Dahlman, 2023). These temperature changes are affecting the ocean environment (Chami et al., n.d.; Karl and Trenberth, 2003).

Climate change is not only influencing the ocean temperature, but the processes that occur within the ocean. There are known effects on whale reproduction and strandings that are linked to climate change. There is known relation between strandings and anthropogenic changes. Overall, these changes can have a large effect on the whale population. Climate change is affecting timing and ranges of whale migration, distribution, and the ability to reproduce (us.whales.org, 2023; Chami et al., n.d.). It is expected that climate change will be the main cause of mass extinctions in the 21st century because whales are not able to adapt quickly enough to the rapid temperature changes (us.whales.org, 2023; Henson et al., 2016). This is crucial as some of these whales are currently endangered and the likelihood of the species recovering is becoming lower due to these changes. The extinction of whales can have a large impact on the ocean ecosystem.

Whales are an important component of the marine ecosystem (Chami et al., n.d.) which is why it is important that we understand how crucial mass strandings are to the ocean health. Whales belong to the Cetacea order since they live completely under water and are part of the Mysticeti suborder because they have baleen plates or big filters in their mouths instead of teeth (NOAA). Currently the most abundant whale is the Minke whale, which is part of the baleen or “great” whale family (NOAA). Most whales eat krill and typically live in temperate oceans and tropical waters around the equator, along with in the Artic and Antarctic oceans (IFAW.org; Chami et al., n.d.).

Whales are vital to marine ecosystems (Chami et al., n.d.). They have a symbiotic relationship with phytoplankton. When whales release waste rich in iron and nitrogen, they provide essential nutrients for phytoplankton to grow, as found in Chami et al.’s research (n.d.). This discovery shows that whales are significant in influencing carbon capture from the air by providing essential nutrients for phytoplankton’s carbon dioxide absorption from the atmosphere. Whales are major parts of the whale pump (nutrient movement caused by whales’ vertical movement; Chami et al., n.d.), phytoplankton population, and CO_2 absorption (Chami et al., n.d.). In this literature review, I will address anthropogenic changes such as the effects global climate change has on whales, specifically reproduction and strandings. I will also address the impact human activity is having on whale strandings.

Methods

A non-systematic search of peer-reviewed literature was conducted using Google Scholar and the university’s library search engine. The search focused mainly on climate change and whales. Keywords consisted of whales with a combination of environmental keywords such as “climate change”, “anthropogenic changes”, “ship strike” and “reproduction”. Papers looked at where from the years of 2001 to 2023 and were only English written papers.

Papers excluded from this review primarily centered on alternative marine species, such as fish and seals. Furthermore, some papers were omitted due to either their older publication date, predating the year 2000, or a deficiency in providing comprehensive and pertinent information for the purposes of this review. The decision to exclude older papers focused from the dynamic nature of scientific knowledge, with a preference for more recent research that aligns with current advancements in the field.

Additionally, certain papers did not meet the inclusion criteria because they lacked the necessary depth and clarity in whale dynamics and interactions with global climate change or the other variables included in this study. This category encompassed studies with ambiguous or inconclusive findings as well as studies recommending further investigations to establish a more conclusive perspective. After following our exclusion criteria, we gathered 32 peer reviewed articles (Table 1).

To categorize and synthesize the information contained within each selected article, I organized them into three distinct classifications: reproduction, climate change, and human-induced alterations in the marine environment. Reproduction included articles that had information on energetic needs for reproduction to how anthropogenic changes are affecting reproduction rates. Climate change included articles that had research on climate change as it affects the world all the way down to how it is affecting marine life, specifically whales. Human anthropogenic changes included articles that did studies on human activity affecting marine life. Some of these activities include naval, shipping and pollution.

Table 1: Peer reviewed research articles collected in this literature review from 2001 to 2023

Authors	**Year**	**Title**	**Category**
Chami et al.	N.D	Nature's Solution to Climate Change	Climate Change
Christiansen et al.	2022	Fetal Growth, birth size and energetic cost of gestation in southern right whales	Reproduction
Danovaro et al.	2011	Marine viruses and global climate change	Climate Change
Fortune et al.	2013	Energetic requirements of North Atlantic right whales and the implications for species recovery	Reproduction
Greene et al.	2004	Climate and the conservation biology of North Atlantic right whales: The right whale at the wrong time?	Climate Change
Henson et al.	2016	Observing climate change trends in ocean biogeochemistry: When and where	Climate change
Karl and Trenberth	2003	Modern global climate change	Climate change

Perryman et al.	2020	Environmental factors influencing eastern North Pacific Gray Whale calf production	Climate change and reproduction
Pirotta et al.	2019	Anthropogenic disturbance in a changing environment: Modeling lifetime reproductive success to predict the consequences of multiple stressors on a migratory population	Reproduction
Simmonds and Eliott	2008	Climate change and cetaceans: concerns and recent developments	Climate change
Simmonds and Isaac	2007	The impacts of climate change on marine mammals: Early sings of significant problems	Climate change
Tulloch et al.	2019	Future recovery of baleen whale sis imperiled by climate change	Climate change
IGI Global	n.d.	What is anthropogenic disturbance	Human Anthropogenic change
The marine mammal center	n.d.	Blue whale	
Zielinski	2016	Whales are full of toxic chemicals	Human Anthropogenic Changes
Jepson et al.	2016	PCB pollution continues to impact populations of orcas and other dolphins in European waters	Human Anthropogenic Changes
Amico et al.	2009	Beaked Whale Strandings and Naval Exercises	Human Anthropogenic Changes
Bossart and Duignan	2018	Emerging viruses in marine mammals	Climate change
Burge and Hershberger	2020	Marine Disease Ecology	Climate change
Us.whales.org	2019	Climate Change	Climate change
NOAA	2021	Marine Mammal Taxonomy	
NOAA	2022	Minke Whale	
Jensen and Silber	2004	Large Whale Ship Strike Database	Human Anthropogenic Changes
Lindsay and Dahlman	2023	Climate change: Global temperature	Climate change

Merriam-Webster	n.d.	Biomagnification definition and meaning	
Nowacek et al.	2007	Responses of cetaceans to anthropogenic noise	Human Anthropogenic Changes
National Geographic	n.d.	Pollution	Human Anthropogenic Changes
Simonis et al.	2019	Co-occurrence of beaked whale strandings and naval sonar in the Mariana	Human Anthropogenic Changes
Van der Hoop et al.	2014	Vessel strikes to large whales before and after the 2008 ship strike rule	Human Anthropogenic Changes
IFAW	n.d.	Whales: Threats, conservation and FAQs	Human Anthropogenic Changes
Oremus et al.,	2013	Genetic Evidence of Multiple Matrilines and Spatial Disruption of Kinship Bonds in Mass Strandings of Long-finned Pilot Whales, *Globicephala melas*	Human Anthropogenic Changes
Veirs, Veirs and Wood	2016	Ship noise extends to frequencies used for echolocation by endangered killer whales	Human Anthropogenic Changes

Global Climate Change and the Ocean

The effects of global climate change not only affect water parameters (e.g., temperature, pH) but also living organisms (Henson et al., 2016)). Whales, some of the world's biggest mammals, are being affected by these changes (Chami et al). The change in water temperature, pH and levels are having a large effect on the whales and their reproductive success (Simmonds et al., 2007 and Henson et al. 2016). Many studies have been done to show the effect of global climate change on whales, specifically when it comes to the reproductive success of these whales, as many are endangered (Simmonds and Isaac, 2007). Some studies that have researched effects of climate change on whale reproduction are Karl and Trenberth, 2003, Henson et al., 2016, Chami et al., Simmonds et al., 2007, and Simmonds and Isaac, 2007.

Global climate change is a prominent and critical issue, which will remain a central concern for the foreseeable future. The primary driver of global climate change is human activity (Karl and Trenberth, 2003; Henson et al., 2016). Human activities significantly influence the world, specifically through the modification of Earth's atmospheric conditions. This alteration in atmospheric dynamics is connected to the presence of greenhouse gases, including water vapor, carbon dioxide, ozone, methane, and nitrous oxide, which are naturally found in the atmosphere (Karl and Trenberth, 2003; Henson et al., 2016). Additionally, volcanic eruptions increase the presence of greenhouse gases as well as debris. All these factors contribute to the change in solar irradiance thus shifting global temperatures.

However, human activities influence on climate change has intensified over the last half-century and continues to expand. Humans shape global climate change by affecting energy flow within the ecosystem (Karl and Trenberth, 2003; Lindsey and Dahlman, 2023). Specifically, climate feedback through heat storage feedback affects heat distribution. Oceans cover 70% of Earth's surface and can store over 1000x the amount of heat relative to the atmosphere (Danovaro et al., 2001).

It is important to recognize that, while it is possible to mitigate the rate of climate change, it continues to be persistent ongoing challenge. These complex processes emphasize how urgent and important it is to tackle global climate change. Climate change is going to be seen for centuries, unless we can slow the process and save the species being affected. Henson et al. (2016) studied what effect climate change is going to have on the ocean by 2100. In their study they looked at the changes in sea surface temperature, surface pH, surface chlorophyll concentration and surface nitrate concentration. To test these parameters, eight Earth models were used to predict the levels from 2006 to 2100. The results found during the study were expected by the scientist: a decrease in pH and a rise in sea surface temperatures (Henson et al., 2016; Burge and Hershberger, n.d.). Perryman et al. (2020) found that the Artic waters are warming three times faster than the global average. There was also a decrease in surface nitrate along with chlorophyll (Henson et al., 2016). The study also showed a strong decrease in oxygen within the oceans.

These changes can have a huge impact on marine life (Simmonds and Eliott, 2008). Simmonds and Eliott (2008) looked at the direct and indirect effects of climate change on marine life. Direct effects included marine life not able to adapt to changes in water temperature and decreasing locations for migration (Simmonds and Eliott, 2008).

Ocean and Whales

The oceans act as a storage bank for large quantities of greenhouse gases (Danovaro et al., 2011). Oceans are estimated to have taken up roughly 50% of fossil fuel emissions and around 30% of all the anthropogenic emissions since the beginning of the 19^{th} century (Danovaro et al., 2011). Ocean life has an important role in greenhouse dynamics (Danovaro et al., 2011)

Whales play an important role capturing CO_2. Wherever whales are, it can be expected that there are millions of phytoplankton (Chami et al., n.d.). Phytoplankton can capture roughly 37 billion metric tons of CO_2, which is about 40%of all the CO_2 produced (Chami et al., n.d.). Recent studies (Chami et al., n.d.) have shown that whales have a multiplier effect in account to the phytoplankton (Chami et al., n.d.). This is because of the waste products of whales. Their waste has a high amount of iron and nitrogen which is what the phytoplankton need to grow (Chami et al., n.d.). Whales also bring up a large amount of minerals to the ocean’s surface by a phenomenon known as the “whale pump” (Chami et al., n.d.). A whale pump is the vertical movement that is made when a whale dives underwater to feed and then comes back to surface to breathe (Chami et al., n.d.). Once at the surface, they release their buoyant fecal plumes (Chami et al., n.d.)

Global Climate Change and Whale Reproduction

The effects of global climate change not only affect water parameters (e.g., temperature. pH) but also living organisms (Henson et al., 2016; Burge and Hershberger, n.d.). Whales, some of the world’s biggest mammals, are being affected by these changes (Chami et al., n.d.). The changes in water temperature and pH levels are having a large effect on the whales and their reproductive success (Simmonds et al., 2007; Henson et al., 2016). Many studies have been done to show the effect of global climate change on whales, specifically when it comes to reproductive success of these whales, as many are endangered (Simmonds and Isaac, 2007). Some studies that have researched effects of climate change on whale productions are Karl and Trenberth, 2003, Henson et al., 2016, Chami et al., n.d., Simmonds et al., 2007, and Simmonds and Isaac, 2007.

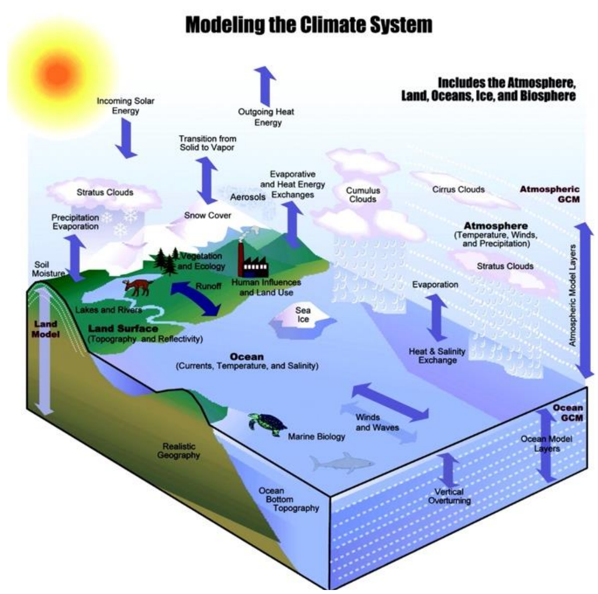

Figure 1: Above is a figure that shows how the climate system is affected and what majorly affects it (Karl and Trenberth, 2003).

For example, sperm whale reproduction rates have decreased with increasing water temperature (Simmonds and Issac, 2007). This lack of reproductive success has been related to periods of the warming sea surface temperatures caused by El Niño events (Simmonds and Isaac, 2007). Additionally, phenotypic mismatching or mismatch synchrony affects ocean life (Simmonds and Eliott, 2008). Phenotypic mismatching is when the levels of prey do not match the number of animals migrating. This mismatch of predator to prey affects numerous species of whales. Tulloch et al. (2018) researched the recovery of the baleen whales under climate change conditions. Baleen whales include blue, fin, humpback, Antarctic mink, and the southern right whale (Tulloch et al., 2018). These whales need large amounts of food during the earlier periods of gestation (Tulloch et al., 2018; Perryman et al., 2020). A normal blue whale can eat up to 6 tons of krill in one day (The Marine Mammal Center). Perryman et al. (2020) found that the amount of food a female whale eats in the early stages of gestation is extremely crucial to the reproductive success of the whale. Since the food levels are decreasing, models show possible extinctions by the year 2100 (Tulloch et al., 2018). In 1990-2000, the feeding conditions were that the reproduction rates dropped drastically (Greene and Pershing, 2004).

The impact of food on gestation

As stated earlier, food is important to the early stages of gestation because of the development of the whale. In the later stages if the female whales do not have the energy stored up from the earlier stages, they are struggling to migrate to breeding grounds, thus lowering reproductive success. The amount of energy needed in the North Atlantic right whale was compared by Fortune et al. (2013) and it was found that a lactating female whale need the most amount of energy per day. Since lactating females need the most amount of energy, they need the most amount of food. In Fortune et al. (2013), the amount of food needed to meet these energy requirements was found.

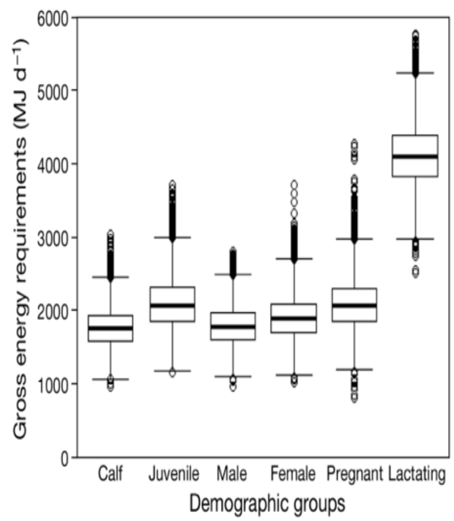

Figure 2: The mean daily gross requirement for the different demographic groups of the North Atlantic right whale (Fortune et al., 2013)

Perryman et al., (2020) found that there is a correlation between the environmental conditions of the year before and the calf production of the North Pacific gray whale of the next breeding season. Some of these results could be affected by the history of long-lived mammals.

Some whales must weigh the cost of energy lost in pregnancy and lactation compared to their own survival and their potential reproductive future (Perryman et al., 2020). Some female whales will not ovulate, avoid pregnancy, or not carry to full term if there is a natural fluctuation in prey (Perryman et al., 2020). Feeding conditions must be robust for a female whale to go through with a pregnancy (Perryman et al., 2020).

Kraus et al. (2001) studied reproductive parameters of the endangered North Atlantic right whale from the years of 1980 to 1998, at this time there were between 299 and 437 living whales and 70 of those whales were mature females, meaning they can reproduce. Throughout the study, Kraus et al. (2001) found that the calving intervals, the length of time between observed calves, increased. There is a hypothesis that believes the increase is a result of inbreeding, pollutant effects and food limitations (Kraus et al., 2001). Kraus et al. (2001) found that the number of mature females, who were actively reproducing, had slowly started to increase throughout the study. From 1987-1992, the population of reproductive females was sitting at a stable number in the low fifties (Kraus et al., 2001). By 1997, the total number of reproductive females had increased to 75, which then dropped back down to 70 in 1998 due to some mortalities. Kraus et al. (2001) also examined the calving rate to see if it was also increasing or decreasing with the number of the reproductive females. It was found that from 1980-1998, the number of claves born each year was from 6-22, with the mean rate for these years being 11.32 calves (Kraus et al., 2001). In 1998, the calving rate fell to an all-time low, the same year that there had been mortalities in reproductive mothers. It was also found that in those years of low calf production, the feeding grounds for these whales were anomalous (Kraus et al., 2001).

Pirotta et al. (2019) studied anthropogenic disturbances and climate change to see the effect on North Pacific blue whales and their reactions to these scenarios. The models and simulations showed that environmental changes that led to unfavorable years, led to a reduction in the reproductive success and repeated disturbance caused a stronger effect on reproductive success and survival (Pirotta et al., 2019). Overall, the results show that individually environmental and anthropogenic disturbances do not have as large of an impact on the whales as they do together, meaning that the combination of both stressors led to a change in female survival and reproductive success, suggesting that both stressors act in synergy (Pirotta et al., 2019).

Global Climate Change and Krill

Most whales feed off krill and copepods. Food decline will lead to species competition for food (Tulloch et al., 2018). Krill decline is associated with ocean warming (Perryman et al., 2020). Sea water warming is three times faster than the global average, this condition increases sea ice melting. Krill relies on sea ice to avoid predation. Thus, reduced hiding spots will decrease krill population and affect whales feeding and overall population (Perryman et al., 2020).

Tulloch et al., (2018) found that by 2100, krill density is expected to rapidly decrease, and whale population is expected to be affected by that. If the food conditions are not fit, female whales will not have the energy required to reproduce (Tulloch et al., 2018).

Christiansen et al. (2022) studied the energetic cost of gestation in the southern right whale, which is part of the baleen whale family. Baleen whales have some of the fastest fetal growth rates in the animal kingdom, which leads to high energetic needs during gestation (Christiansen et al., 2022). Southern right whales use between 95-98% of their energy during the pregnancy, meaning that if there is not enough krill to fulfill the energy requirements, the whales will struggle to reproduce (Christiansen et al., 2022; Tulloch et al., 2018). Most of the energy is needed during the fasting period due to migrating to breeding grounds (Christiansen et al., 2022). Fasting periods can lead to vulnerability to anthropogenic changes, which are the disturbances in ecological areas due to human-induced development activities (Christiansen et al., 2022; IGI Global, n.d.).

Global Climate Change and Whale Strandings

Anthropogenic changes affecting whales

Anthropogenic changes include, but are not limited to, climate change, coastal pollution, fishing, and habitat fragmentation (Burge and Hershberger, n.d.; Oremus et al., 2013). Another form of anthropogenic changes is human induced, such as naval activity and ship strikes. These actions could cause mass whale strandings. These mass whale stranding events have been happening for decades, but recently have become more common. Mass whale strandings can be described as complex phenomena with multiple environmental causes (Oremus et al., 2013). Aristotle said that “it is not known for what reason they run themselves aground on dry land; at all events it is said they do it at times and for no obvious reason” (Oremus et al., 2013). Oremus et al. (2013) looked at two different hypotheses for the cause of mass strandings. The first being that there is a maternal relationship between the whales or “extended matriline” (Oremus et al., 2013). The second hypothesis being there is a close relationship between the whales that strand themselves also known as “kinship cohesion” (Oremus et al., 2013). The study found that these mass strandings could be related to multiple matrilineal groups, not just one (Oremus et al., 2013). As Oremus et al. (2013) looked at the social factors, Amico et al. (2009) looks at the human factors, the navy.

Marine Viruses

Climate change and warming water contribute to various ecological challenges, including the impact of marine viruses on sea animals and their reproductive rates. Climate change affects host and pathogen dynamics. These changes in global climate patterns started to become evident in the mid-1990s (Burge and Hershberger, n.d.; Bossart and Duignan, 2018)

This became evident by a multitude of independent observations such as: decreasing sea ice coverage, receding glaciers, reduced snow cover, increases in sea level, ocean heat content, sea surface temperature, temperatures over the oceans, water vapor and troposphere temperatures (Burge and Hershberger, n.d.). The ongoing changes will potentially affect the balance between host, pathogen, and environment. Emerging infectious diseases (EIDs) have been on the rise over the past 20 years (Bossart and Duignan, 2018; Burge and Hershberger, n.d.).

EIDs can be associated with infectious agents (Bossart and Duignan, 2018). There are multiple factors that are contributing to the increase of EIDs, these include microbial adaptation, host immunologic dysfunction, expansion of the human population and consequent environmental degradation (Bossart and Duignan, 2018; Burge and Hershberger, n.d.). Climate change can affect water quality, which can disrupt host-pathogen interactions and could be creating the perfect conditions for pathogens to thrive and microbial and ecological dysbiosis (Burge and Hershberger, n.d.). The climatic changes have resulted in zoonotic vectors and negative synergies to shift causing an effect on infection and non-infectious diseases (Bossart and Duignan, 2018). Water quality is important when looking at host to pathogen relationships.

Changes in water quality can result in disease outbreaks. These changes include increase or decrease in temperature, hypoxia (low oxygen), CO2 accumulation, salinity changes, and storm frequencies (Burge and Hershberger, n.d.). These changes can also result in immediate impacts on the equilibrium of host and pathogen relationship (Burge and Hershberger, n.d.). Of all the changes, temperature is the most studied. Typically, temperature changes do not have a large effect on finfishes, but subtle temperature changes can affect physiological process and metrics of health and performance (Burge and Hershberger, n.d.). Subtle changes have an impact on the pathogen regeneration time, leading to shifts towards overt disease in marine life (Burge and Hershberger, n.d.). Some of these reproductive times include that of sea lice, resulting in an epizootic episode for marine life (Burge and Hershberger, n.d.). From a host perspective, temperatures do directly influence biological processes (Burge and Hershberger, n.d.). An example of this is when there is a lack of sunlight in the polar regions during overwinter periods, a natural dearth is created for food availability for planktivorous (Burge and Hershberger, n.d.). Overwinter starvation increases with warmer temperatures (Berger and Hershberger, n.d.). Starvation levels also increase with parasitic infections, such as the endemic parasite *Ichthyophonus* (Berger and Hershberger, n.d.). This parasite interrupts fat storage, which sends the fish into an overwinter fasting period with a lipid reserve that is 30% lower than the uninfected fish (Berger and Hershberger, n.d.). These outbreaks are likely to lead to bioenergetic balances in the marine systems in favor of host starvation (Berger and Hershberger, n.d.). Some of the marine viruses on the rise are ones that are not only seen in humans but are now being seen in marine life.

These viruses seen in humans that are currently being seen in whales are papillomaviruses, morbilliviruses, influenza, poxviruses, herpesviruses, and adenoviruses (Bossart and Duignan, 2018). Over the past ten years, there has been a rise in these viruses in marine life (Bossart and Duignan, 2018). In nature these relationships are normal, but the issue that is arising is how these relationships are being affected by climate change and/or anthropogenic changes (Burge and Hershberger, n.d.).

Naval Activity

Naval activities have been going on for decades. From the year of 1950 to 2004, there have been over 120 mass whale strandings, which was after the introduction of modern high power mid-frequency active sonar (MFAS) (Amico et al., 2009). Some of these strandings include 12 beaked whales (Simonis et al., 2019). The beaked whale family is reported to be more vulnerable to severe and fatal response to MFAS (Simonis et al., 2019). Simonis et al. (2019) studied seasonal acoustic presence of beaked whales near Saipan and Tinian using high-frequency acoustic recording packages (HARP). Using visual and acoustic monitoring helped improve the understanding of the impact military activities had on marine mammals (Simonis et al., 2019). Using this technology, it was found that from 2007 to 2019, there were eight beaked whale strandings with 50% of the strandings being related to naval activity (Simonis et al., 2019). The stranding that occurred on August 23, 2011, is predicted to be associated with naval activity (Simonis et al., 2019). The US navy confirmed the use of sonar during the training session which took place 80 nmi from the location of the stranding on August 23rd (Simonis et al., 2019). The US Navy also confirmed that the stranding events that happened in March of 2015 and 2016 were also associated with their training exercises (Simonis et al., 2019). Previous studies show that only 9% of the beaked whale mass stranding are correlated with US Naval training, but mass strandings include two or more animals (Simonis et al., 2019). From 2007 to 2019, there were six single animal strandings with two of strandings being involved with US Naval activity (Simonis et al., 2019). Beaked whales can adapt to these activities (Simonis et al., 2019).

After years of exposure to the naval activity, beaked whales have shown a strong avoidance to near and distance MFAS (Simonis et al., 2019). The whales are learning to abandon their preferred habitat during this time or adjust to it (Simonis et al., 2019). Avoiding these activities can lead to high energetic cost for the species (Simonis et al., 2019). In one of the areas that was studied (Mariana Archipelago), there is infrequent sonar activity and low noise levels (Simonis et al., 2019). The difference may lead the beaked whales to an increase in their behavioral response to sonar (Simonis et al., 2019). Sonar-associated strandings could be a high risk for areas with similar conditions to Mariana Archipelago (Simonis et al., 2019).

Nowacek et al. (2007) looked at the response whales have to anthropogenic noise. In the review, the most common response to anthropogenic noise is displacement (Nowacek et al., 2007). Further studies need to be conducted to find out where the whales relocate to and the duration of the displacement from their desired habitat (Nowacek et al., 2007). Displacement for short periods of time could not be a large concern, but long durations of displacement could be important to look at (Nowacek et al., 2007). Some of the endangered whale species cannot afford to have displacement from feeding or breeding grounds (Nowacek et al., 2007). Naval activity is not the only noise that whales must deal with, shipping noise is another common noise that whales are having to deal with (Veirs et al., 2016).

Shipping Noise and Strikes

Commercial ships have become more and more common as the years have gone on. These ships radiate noise underwater generated from propeller cavitation, propeller singing and propulsion (Veirs et al., 2016). Most noise is generated from propeller cavitation which has peak noise levels from 50 – 150 Hz, while ships can produce noise levels from 20 – 200 Hz (Veirs et al., 2016). Propeller cavitation can radiate broadband power at frequencies up to 100,000 Hz (Veirs et al., 2016). Larger vessels typically generate noise at lower frequencies (<1,000 Hz) because of the relatively high power, deep draft and slow turning engines and propellers (Veirs et al., 2016). Many marine animals rely on sound to find prey, moderate social interaction, and facilitate mating (Veirs et al., 2016), so shipping noise can have an impact on these animals, one being whales. In previous studies, it was found that North Atlantic right whales had decreased stress levels when ship noise was absent (Veirs et al., 2016). Veirs et al. (2016) looked at shipping traffic for 850 days in a selected area. It was found that the average daily ship traffic was 19.5 ships/day, with noise levels reaching 40,000 Hz (Veirs et al., 2019). The amount of ship noise produced can block out odontocete signals, especially if the shipping lanes are close to the shoreline (<10 km) and the high frequency sounds are not able to be absorbed (Veirs et al., 2016). Ship noise could also lead to interference with communication, foraging and navigation (Veirs et al., 2016).

Jensen and Silber (2004) looked at ship strikes for the years 1975 to 2002. In those years, there was a total of 292 confirmed or possible ship strikes to large whales (Jensen and Silber, 2004). That comes to roughly 11 ship strikes a year, almost one every month. Of the 292 reported strikes, 11 different species were confirmed (Jensen and Silber, 2004). Finback whales were the most reported species (75 reports), followed by humpback with 44 reports (Jensen and Silber, 2004). It was also found that of the 292 strikes, 68% were fatal, only 2.4% appeared to have no sign of injury (Jensen and Silber, 2004). From the database, vessel type can also be found. 134 of the 292 cases have information on the vessel type (Jensen and Silber, 2004). Of the 134 known vessel cases, 17% were due to naval ships, 15% were due to container/cargo ships, 14% were due to whale watching vessels and 12% were due to cruise ships (Jensen and Silber, 2004). It should be noted that the Navy and Coast Guard have standardized military and government reporting practices towards striking a whale, so the collision rates could seem higher compared to other vessels (Jensen and Silber, 2004). It should also be noted that a lot of ship strike fatalities go undetected or reported, the databased used could only represent a fraction of actual strikes (Jensen and Silber, 2004). Jensen and Silber (2004) also found that the threat of ship strikes to North Atlantic right whales is higher compared to other species. Van der Hoop et al. (2014) evaluates the ship strike rule which was put into place to help protect North Atlantic right whales.

The Ship Strike Rule was put into place in 2008 to help reduce vessel strike mortalities in US waters to North Atlantic right whales by mandating speed <10 knots for commercial vessels >65 ft long in 10 spatially and temporally defined Seasonal Management Areas (van der Hoop et al., 2014). The Ship Strike Rule also established Dynamic Management Areas (DMAs) which recognize interannual variability in whale distribution and habitat use (van der Hoop et al., 2014). Van der Hoop et al. (2014) evaluated the effectiveness of the rule with a series of indicators which are vessel strike mortalities and reduced likelihood of death to right whale from vessel collisions. It was found that from 1990 to 2012, 1,198 mortalities were observed, 975 of those cases were to one of the eight large whale species (van der Hoop et al., 2014). Entanglement in fishing gear was found to be the number one cause of mortality with nonhuman causes and vessel strikes behind it (van der Hoop et al., 2014). After the implementation of the Ship Strike Rule, entanglement was still the number one cause, but vessel strike is now second and nonhuman caused mortalities is third (van der Hoop et al., 2014). Van der Hoop et al. (2014) found that there was a significant reduction in right whale vessel strikes after the implantation of the Ship Strike Rule. With shipping traffic comes pollution from the ships and humans that are on the ships

Pollution

With human activity comes pollution. Pollution is the introduction of harmful materials into the environment (National Geographic, n.d). Pollution can affect everything from the air to oceans (National Geographic, n.d.). Pollutants in the water can be harmful to the organisms living in it and even the humans that eat the organisms living in it (National Geographic, n.d.). Human activities contribute to water pollution through runoff, mining and drilling, oil spills and improper storage of waste (National Geographic, n.d.). Some pollutants affecting whales are Polychlorinated Biphenyls (PCBs), chlordane, toxaphene, and Dichlorodiphenyltrichloroethane (DDT) (Zielinski, 2016). The most seen chemical in whales recently has been PCBs (Zielinski, 2016). All these chemicals have been banned in Europe and the United States in the 1970s-1980s (Jepson et al., 2016), but due to the process of biomagnification, the chemicals can still be seen in marine animals today (Zielinski, 2016). Biomagnification is the process by which a pollutant or pesticide increases its concentration in the tissues of organisms as it travels up the food chain (Merriam-Webster). Due to this process, certain whales have higher concentrations of PCBs in their body because of the level they are in the food web (Zielinski, 2016). Jepson et al. (2016) studied the levels of PCBs found in orcas in European waters over the past 15-20 years. Jepson et al. (2016) found that from 1990 to 1998, PCB lipid concentrations had decreased and from 1998 to 2012, the levels remained relatively stable. When Jepson et al. (2016) looked at blubber PCB concentrations, it was found that concentrations were exceeding all mammalian toxicity thresholds. These high levels of exposure could be causing reproduction issues in orcas, thus influencing their already small population (Jepson et al., 2016). There have only been six reported mature females that had calved from the years of 1999 to 2011 (Jepson et al., 2016).

Conclusions

Throughout this literature review, multiple peer reviewed sources determined and supported that whale's population face multiple threats including global climate change, naval activity, shipping noise and collisions, and pollution. Climate change and anthropogenic activities poses a great concern for whale's future. Global climate change affects oceanic parameters which in return affect whale's reproductive success. Declining krill population, a primary food source for many whale species, is associated with reduced gestational success in whales (i.e. North Atlantic Right whales), and negative health impacts on calves.

Naval activities including mid-frequency active sonar (MFAS) are a predominant threat to whales; beaked whales exhibit detrimental changes in behavior under MFAS. Shipping noise and strike along with pollution further compromises whale conservation efforts specially for whale's species designated as endangered under the Endangered Species Conservation Act (e.g., Humpback whales). Thus, stricter regulations and policy are essential to protect whales and their role in the ecosystem.

References

1. Amico, A., Gisiner, R., Ketten, D., Hammock , J., Johnson , C., Tyack , P., & Mead , J. (2009). *Beaked Whale Strandings and Naval Exercises* . Aquatic Mammals . https://apps.dtic.mil/sti/pdfs/ADA514660.pdf
2. Bossart, G., & Duignan, P. (2018). *Emerging viruses in marine mammals*. CAB reviews . https://www.marinemammalcenter.org/storage/app/media/Misc/PDF/Research%20Publications/2019/emerging-viruses-in-marine.pdf
3. Burge , C., & Hershberger , P. (2020). *Marine Disease Ecology*. Google Books. https://books.google.com/books?hl=en&lr=&id=BibTDwAAQBAJ&oi=fnd&pg=PA83&dq=climate%2Bchange%2Band%2Bmarine%2Bdisease&ots=0hxUr1HnzP&sig=AL-H7In6ZSXf7zZK7Aa2XL68Chs#v=onepage&q=climate%20change%20and%20marine%20disease&f=false
4. Chami, R., Cosimano, T., Fullenkamp, C., & Oztoson, S. (n.d.). *Nature's solution to climate change - actu-environnement*. Retrieved April 18, 2023, from https://www.actu-environnement.com/media/pdf/news-34050-article-finances-developpement.pdf
5. Christiansen, F., Uhart, M. M., Bejder, L., Clapham, P., Ivashchenko, Y., Tormosov, D., Lewin, N., & Sironi, M. (2022). Fetal growth, birth size and energetic cost of gestation in southern right whales. *The Journal of Physiology*, *600*(9), 2245–2266. https://doi.org/10.1113/jp282351
6. *Climate change*. Whale & Dolphin Conservation USA. (2019, May 14). https://us.whales.org/our-4-goals/create-healthy-seas/climate-change/#:~:text=It%20is%20affecting%20the%20timing,adapt%20quickly%20enough%20to%20survive
7. Danovaro, R., Corinaldesi, C., Dell'Anno, A., Fuhrman, J. A., Middelburg, J. J., Noble, R. T., & Suttle, C. A. (2011). Marine viruses and global climate change. *FEMS Microbiology Reviews*, *35*(6), 993–1034. https://doi.org/10.1111/j.1574-6976.2010.00258.x
8. Fisheries, N. (2021, August 20). *Marine Mammal Taxonomy*. https://www.fisheries.noaa.gov/national/outreach-and-education/marine-mammal-taxonomy
9. Fisheries, N. (2022, September 16). *Minke Whale*. https://www.fisheries.noaa.gov/species/minke-whale
10. Fortune, S. M. E., Trites, A. W., Mayo, C. A., Rosen, D. A. S., & Hamilton, P. K. (2013). Energetic requirements of North Atlantic right whales and the implications for species recovery. *Marine Ecology Progress Series*, *478*, 253–272. https://doi.org/10.3354/meps10000
11. Greene, C. H., & Pershing, A. J. (2004). Climate and the conservation biology of North Atlantic right whales: The right whale at the wrong time? *Frontiers in Ecology and the Environment*, *2*(1), 29–34. https://doi.org/10.1890/1540-9295(2004)002[0029:catcbo]2.0.co;2

12. Henson, S. A., Beaulieu, C., and Lampitt, R. (2016). Observing climate change trends in ocean biogeochemistry: When and where. *Global Change Biology*, *22*(4), 1561–1571. https://doi.org/10.1111/gcb.13152
13. Jensen, A., & Silber , G. (2004). *Large Whale Ship Strike Database*. U.S. Department of Commerce. file:///Users/desireewalker/Downloads/noaa_23127_DS1.pdf
14. Jepson, P. D., Deaville, R., Barber, J. L., Aguilar, À., Borrell, A., Murphy, S., Barry, J., Brownlow, A., Barnett, J., Berrow, S., Cunningham, A. A., Davison, N. J., ten Doeschate, M., Esteban, R., Ferreira, M., Foote, A. D., Genov, T., Giménez, J., Loveridge, J., … Law, R. J. (2016, January 14). *PCB pollution continues to impact populations of orcas and other dolphins in European waters*. Nature News. https://www.nature.com/articles/srep18573
15. Karl, T. R., & Trenberth, K. E. (2003). Modern global climate change. *Science*, *302*(5651), 1719–1723. https://doi.org/10.1126/science.1090228
16. Lindsey, R., & Dahlman, L. (2023). *Climate change: Global temperature*. NOAA Climate.gov. https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature#:~:text=According%20to%20NOAA%27s%202021%20Annual,0.18%20%C2%B0C
17. Merriam-Webster. (n.d.). *Biomagnification definition & meaning*. Merriam-Webster. https://www.merriam-webster.com/dictionary/biomagnification
18. Nowacek, D., Thorne, L., Johnston, D., & Tyack , P. (2007). *Nowacek - 2007 - Wiley Online Library*. Wiley Online Library. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2907.2007.00104.x
19. OctoberCMS. (n.d.). *Blue Whale*. The Marine Mammal Center. Retrieved April 17, 2023, from https://www.marinemammalcenter.org/animal-care/learn-about-marine-mammals/cetaceans/blue-whale
20. Oremus, M., Gales, R., Kettles, H., and Baker, C.S. (2013). Genetic Evidence of Multiple Matrilines and Spatial Disruption of Kinshi[Bonds in Mass Strandings of Long-finned Pilot Whales, Globicephala melas. Journal of Heredity, 104(3), 301-311. https://doi.org/10.1093/jhered/est007
21. Perryman, W. L., Joyce, T., Weller, D. W., & Durban, J. W. (2020). Environmental factors influencing eastern North Pacific Gray Whale Calf Production 1994–2016. *Marine Mammal Science*, *37*(2), 448–462. https://doi.org/10.1111/mms.12755
22. Pirotta, E., Mangel, M., Costa, D. P., Goldbogen, J., Harwood, J., Hin, V., Irvine, L. M., Mate, B. R., McHuron, E. A., Palacios, D. M., Schwarz, L. K., & New, L. (2019). Anthropogenic disturbance in a changing environment: Modelling lifetime reproductive success to predict the consequences of multiple stressors on a migratory population. *Oikos*, *128*(9), 1340–1357. https://doi.org/10.1111/oik.06146
23. *Pollution*. Education. (n.d.). https://education.nationalgeographic.org/resource/pollution/
24. Simmonds, M. P., and Eliott, W. J. (2008) Climate change and cetaceans: concerns and recent developments. *Journal of the Marne Biological Association of the United Kingdom*, 89 (1), 203-210. https://doc.rero.ch/record/297811/files/S0025315408003196.pdf

25. Simmonds, M. P., & Isaac, S. J. (2007). The impacts of climate change on marine mammals: Early signs of significant problems. *Oryx*, *41*(1), 19–26. https://doi.org/10.1017/s0030605307001524
26. Simonis, A., Brownell, R., Thayre, B., Trickey, J., Oleson, E., Huntington, R., & Baumann-Pickering , S. (2019). *Co-occurrence of beaked whale strandings and naval sonar in the Mariana ...* Royalsocietypublishing.org. https://royalsocietypublishing.org/doi/pdf/10.1098/rspb.2020.0070
27. Tulloch, V. J., Plagányi, É. E., Brown, C., Richardson, A. J., & Matear, R. (2019). Future recovery of baleen whales is imperiled by climate change. *Global Change Biology*, *25*(4), 1263–1281. https://doi.org/10.1111/gcb.14573
28. van der Hoop, J., Vanderlaan, A., Cole, T., Henry, A., Hall, L., Mase-Guthrie, B., Wimmer, T., & Moore, M. (2014). *Vessel strikes to large whales before and after the 2008 ship strike rule*. Conservation Letters . https://conbio.onlinelibrary.wiley.com/doi/pdfdirect/10.1111/conl.12105
29. Veirs, S., Veirs, V., & Wood, J. D. (2016). Ship noise extends to frequencies used for echolocation by endangered killer whales. *PeerJ*, https://doi.org/10.7717/peerj.1657
30. *Whales: Threats, conservation and faqs*. IFAW. (n.d.). https://www.ifaw.org/animals/whales#:~:text=Whales%20live%20in%20every%20ocean,North%20Sea%20and%20the%20Mediterranean
31. *What is anthropogenic disturbance*. IGI Global. (n.d.). Retrieved April 17, 2023, from https://www.igi-global.com/dictionary/ecological-areas-and-challenges-of-urbanization/103199
32. Zielinski, S. (2019, August 9). *Whales are full of Toxic Chemicals*. Science News. https://www.sciencenews.org/blog/wild-things/whales-are-full-toxic-chemicals