Journal of Research High School

Vol. 2023 (2) 178 – 188
ISSN 2688-3651 [online]

The Impact of Climate Change on Animal Behavior: The Arctic Marine and Northeast Pacific Ecosystems

Cecilia Yang[1] *

[1]The Harker School, San Jose, CA, USA
*Corresponding Author: cecilia.m.yang@gmail.com

Advisor: Carly Scott, cbscott@utexas.edu

Received February 11, 2023; Revised August 1, 2023; Accepted, September 19, 2023

Abstract

Climate change affects ecosystems worldwide and the entire biosphere. Although the effects of climate change have been extensively studied, comparisons of its effects on animal behavior across ecosystems are lacking. To narrow this gap, this review compared the changing behavior of marine mammals in the Northeast Pacific ecosystem to that in the Arctic marine ecosystem. This review highlighted the similarities and differences in the migration, predation, distribution, and reproductive behavior of selected animals in response to climate change. This review focused on marine mammal species central to each ecosystem: sea otters, seals, dolphins, orcas, and whales in the Northeastern Pacific Ocean and polar bears, seals, whales, orcas, and walruses in the Arctic. By comparing the Northeastern Pacific ecosystem and the Arctic marine ecosystem, researchers can gain an in-depth understanding of the changes in animal behavior due to climate change across wide geographies and suggest a new method of observing the impact of climate change globally to enable more accurate ecosystem predictions.

Keywords: Climate change; Behavioral ecology; Animal behavior; Arctic marine ecosystem; Northeast pacific ecosystem

1. Introduction

The effects of climate change on various environments and changes in animal behavior have been extensively investigated. Findings show that climate change has destroyed animal habitats, removed food sources, and resulted in many other serious ecological consequences, as demonstrated by melting ice caps and intensifying storms (Hardy, 2003). Changing environments cause some animals to become unfit for their habitat, forcing them to either adapt or migrate elsewhere. Many species acclimate to their new environment in situ, behaving differently to survive in unfamiliar habitats. These behavioral changes in various species also affect how they interact with each other (Harmon and Barton, 2013). The chain effects caused by climate change ultimately lead to major shifts in flora and fauna populations and significant alterations to ecosystems.

Climate change has caused major alterations in biomes and ecosystems worldwide (e.g., Hardy, 2003; Moore and Huntington, 2008; Wassman et al., 2011). When climate change affects animal behavior, it causes chain effects that also impact humans. Furthermore, the study of animal behavior reveals the reasons behind species interactions and animal responses to the environment. As climate change and other challenges prove to be a threat to animal survival, their behavior may change so that they can survive. Behaviors previously beneficial in an environment can become maladaptive, leading to a population die-off if they are not adjusted. Behavioral changes drastically transform interspecies relationships and ecosystems, as any shift in the behavior of a species can lead to a larger chain of reactions (Harmon and Barton, 2013). Additionally, changes in animal behavior mediate climate change and the environment. When a species alters its behavior, the species can in turn cause drastic environmental changes, and as a result, the

Vol. 2023 (2) 178 – 188
ISSN 2688-3651 [online]

combined impact of these changes can potentially lead to an ecological catastrophe in their ecosystem. In particular, these chain reactions often form a large-scale impact on community ecology and the trophic food chain, notably in consideration of keystone species (Harmon and Barton, 2013). Generally, patterns among species responding to climate variability arise through greater human-animal interactions, organisms migrating or dispersing as a consequence of habitat loss, and often, increased aggression or sociability towards humans (Beever et al., 2017).

This article reviews the literature on climate change and animal behavior and their close relationship in the Northeast Pacific and the Arctic ecosystems. The two ecosystems have been selected for their comprehensive similarities and differences; though both are sensitive to changes in the global climate and environment, the Arctic is exceptionally vulnerable due to global warming and ice melt as the rising sea level impacts the habitats of thousands of species. By contrast, the Northeast Pacific shares similarities in that it is also a marine ecosystem with overlapping organisms and similar human impacts on its environment. However, since it is less responsive to climate change, it may serve as a comparison to the extreme reactions within the Arctic marine ecosystem. Both ecosystems face the threat of rising sea levels, warming of the sea surface, and habitat destruction. Melting ice in the northern Pacific Ocean and the Arctic Ocean threatens the habitat of species such as seals and polar bears. Seals in the Arctic marine region and Northeast Pacific require ice to reproduce; therefore, the declining ice in the two areas reduces the population of seals (Gifford-Gonzalez, 2011; Moore and Huntington, 2008). The diminishing amount of sea ice also affects polar bears' distribution and predation behavior in the Arctic marine ecosystem (Atwood, 2016).

This research emphasizes the importance of observing the connection between climate change and changes in animal behavior and the major similarities in animal reactions to a changing environment in these ecosystems. Moreover, the differences between the responses of organisms in the two ecosystems allow for further understanding of the mechanism behind changes in animal behavior and pave the way for potential predictions of changes in animal behavior in other ecosystems.

2. Literature Review

2.1 Northeast Pacific Ecosystem

Northeast Pacific ecosystem is along the Pacific coastline of North America, serving as a habitat for thousands of species, including sea otters, seals, dolphins, orcas, and whales. Human fishing, boating, surfing, and increased pollution impact the region and threaten organisms in the area. According to statistics from the IPCC, the Intergovernmental Panel on Climate Change, marine heatwaves in the past forty years have doubled in frequency and become longer-lasting, more intense, and more extensive. Due to climate change, the sea surface temperature in the Northeast Pacific is rising rapidly (Chavez et al., 2017). Storm winds, particularly during the winter storm period, are intensifying, the sea level is rising, and seawater is becoming more acidic (Reiter, 2015). These factors all contribute to shifting animal behavior throughout the ecosystem, as many species are forced to adapt to their new environment.

The density of marine mammals along the North American Pacific coastline increases as the water temperature rises (Burrows et al., 2012). Throughout the Pacific Ocean, marine mammals, particularly those with limited thermal tolerances, have declined in population. Since most marine mammals cannot adapt quickly to a changing environment, those who survived the effects of the change to their habitats due to climate change had to adapt by changing their living and migratory habits. Table 1 provides a summary of animal behavioral changes in the Northeast Pacific ecosystem.

2.2 Species in Northeast Pacific

In the Northeast Pacific ecosystem, sea otters (*Enhydra lutris*), seals (*Pinnipedia* spp), dolphins (*Lagenorhynchus obliquidens*), orcas (*Orcinus orca*), and whales (*Cetaceae* spp.), the species examined in this article, are the major mammal species in this ecosystem, with otters being the keystone species. These five mammals adapt their behavior in different ways to changing environments caused by climate change. Specifically, these species primarily altered their migration, predation, distributive, reproductive, and social behavioral patterns.

Sea otters in the Northeast Pacific ecosystem have increased diet and prey selection variations due to climate change. As a result of the fluctuation of a consistent food source, specifically, sea urchin populations, otters in the Northeast Pacific show increasing individual variability in diet choices. Many otters have sought alternative food sources, and some have demonstrated extreme inter-individual variation in their diets (Estes et al., 2003). Furthermore, their presence near the Pacific coastline sharply increased as water closer to land became warmer after 2002. Because otters prefer warmer climates, as the Pacific coastline's surface temperatures increase, the populations of sea otters also increase in such regions (Burrows et al., 2012). As a result of climate change, sea otters in the Northeast Pacific ecosystem must alter their diets and living patterns to survive, and their behavior has changed in response to the warming seas. Thus, sea otters must spread more sparsely in the northern Pacific Ocean, causing them to have an increased and more diverse habitat range.

In the Northeast Pacific region, seals, similar to sea otters, have an increased habitat range due to the warming of the northern Pacific Ocean. Similar to sea otters, elephant seals (*Mirounga angustirostris*) and harbor seals (*Phoca vitulina*) demonstrated a notable increase in their populations along the North American Pacific coastline. However, the fur seal (*Arctocephalinae* spp.) population in the Pacific Ocean decreased (Burrows et al., 2012; Hazen et al., 2013). Fur seal pups are born later and are significantly smaller due to chain effects from rising sea levels. The rising sea level leads to displaced storm and weather patterns, thereby altering the foraging trips of female fur seals and changing their breeding grounds into an environment that is much more hostile to birthing seal pups (Gifford-Gonzalez, 2011). Harbor seals have also adapted to melting ice in northern latitudes by dispersing broadly while breeding to access resources more easily (Nicholson, 2000). All three species of seals have been affected by climate change, and their behavioral patterns have changed, whether in migration, location, or birthing.

Pacific dolphin (*Lagenorhynchus obliquidens*) populations in the Northeast Pacific coastline have declined. Initially, many dolphin species populations along the coastline increased drastically around 1999; however, their regional densities began to decline after 2002. Large groups of dolphins moved toward land in search of prey, such as squid, and left when the population density of such prey declined due to mass predation (Burrows et al., 2012). The densities of Pacific white-sided dolphins in the Northeast Pacific ecosystems are directly related to the temperature of the water, causing their populations to increase with the warming of bay water (Black, 1994). Dolphins have been forced to shift their living and predatory habits to adjust to changing environments. As more dolphins migrate into coastal regions, they affect the species in the same environment, particularly those they prey on, often disrupting these species' behaviors as they reduce their populations and force new migratory patterns.

Killer whales, otherwise known as orcas, (*Orcinus orca*) have experienced population decline throughout the Pacific Ocean, much of which is due to unnatural causes such as malnutrition or reasons related to human interaction. This population decline is significantly, and negatively, impacting the population health of this species. Although killer whales are traditionally a largely migratory species, due to human interference in their environment, their natural patterns of migration and distribution have been disrupted, often dying out of their regular habitat as a result of unfamiliar tides or becoming stranded on land. In a study where 53 killer whales from various coastal regions in the Pacific North American coastline were examined, 42% demonstrated significant impacts on population health as a result of human interaction and climate change. (Raverty et al., 2020). Furthermore, as an aftermath of human contaminants spilling over into the Pacific, killer whales face an increased risk of disease and fatality from chemical pollution in their habitats (Buckman et al., 2011). As a whole, killer whales have needed to alter their migratory and distributive patterns, and consequently, their predation habits, as human interactions negatively impact killer whales themselves, as well as the habitat in which they reside.

Many whale species migrate between the Arctic marine ecosystem and the Northeast Pacific ecosystem. However, these very migration patterns have been disrupted as a result of the increasing temperatures. Although species like the North Pacific gray whale (*Eschrichtius robustus*) and the blue whale (*Balaenoptera musculus*) have always migrated to the Arctic during the summer in search of cooler environments, these species have changed their migration patterns as a result of global climate change. Most whale species that move between the Arctic and Pacific Oceans have shifted their behavior to remain in the northern ocean for much longer, rather than returning to the Pacific when the summer ends (Moore and Huntington, 2008). Furthermore, since whale species in both oceans have unnaturally modified their distributive behavior, their typical prey in warmer oceans and the Pacific have been affected, causing chain reactions

Vol. 2023 (2) 178 – 188
ISSN 2688-3651 [online]

throughout the trophic cascade and impacts throughout the food chain. In a study where baleen whales in the Northeast Pacific movements were tagged to study their migratory movement, only 29% of the whales spent their time in one familiar region, instead often opting to travel further north (Bailey et al., 2009). Since whales are a tertiary consumer, they tend to keep their prey's species' population in check; however, with their changed distributive behaviors, they instead excessively decrease their prey population in the Arctic marine ecosystem, and allow similar populations in the Northeast Pacific ecosystem to grow out of control. Thus, the changing whale species' migratory, distributive, and predation patterns affect species in both ecosystems, linking the impact climate change has on tertiary consumers to two different environments.

Table 1. Summary of animal behavioral changes in the Northeast Pacific ecosystem

	Migration	Predation	Distributive	Reproductive	Social
Sea Otters	Increased presence along Pacific coastlines	Increased diet and prey variation	Sparser spread and increased habitat range	n/a	More human-animal interactions and new interspecies interactions
Seals	Increased presence along Pacific coastlines	n/a	Increased habitat range, broader dispersal	Disrupted and hostile birthing conditions, weaker pups	More human-animal interactions and new interspecies interactions
Dolphins	Increased presence along Pacific coastlines	Increased diet and prey variation	n/a	n/a	More human-animal interactions and new interspecies interactions
Orcas	Migration outside of their natural habitats	Increased diet and prey variation	Increased habitat range, presence near humans	n/a	More human-animal interactions and new interspecies interactions
Whales	Migration outside of their natural habitats (Arctic)	Increased diet and prey variation	Increased presence in Arctic, increased habitat range	Disrupted reproduction times and patterns	More human-animal interactions and new interspecies interactions

2.3 Arctic Marine Ecosystem

The Arctic Ocean provides a home for thousands of species, including polar bears, seals, whales, orcas, and walruses, the species this article will focus on. This ecosystem is in the northernmost body of water in the world and is covered with glaciers while receiving precipitation as snow (Walsh 2008). As time passes, more and more humans enter the region for residency, tourism, and fishing. Consequently, pollution in the area increases, and marine traffic in this ecosystem affects the migration and behavior of animals. However, as a consequence of climate change, ice in the Arctic marine ecosystem melts, and the temperature of seawater is rising rapidly. Since 1980, more than 50% of permanent ice in the Arctic ecosystem has been lost and is decreasing by 13% per decade (Townhill et al., 2022). From statistics from the IPCC, ice sheets and glaciers lost mass at an average rate of 218 gigatonnes per year from 2006 to 2015. As a result, the zooplankton population has declined, altering their consumers' behavior and the rest of the marine food chain (Wassman et al., 2011).

Northward distribution shifts are forcing the positions of food sources to change and introduce new predators into the Arctic region. With the changing prey distribution, predators have to adjust their migration timing and destinations to improve their chances of survival (Davidson and Ruhs, 2021). Because so many marine mammals are migrating

Vol. 2023 (2) 178 – 188
ISSN 2688-3651 [online]

north, their new behavior will alter species interactions within the ecosystem and cause chain effects in all species in the Arctic marine ecosystem. Additionally, the melting sea ice in the region is shifting migration patterns as the literal shape of the ecosystem is changing. Table 2 provides a summary of animal behavioral changes in the Arctic Marine ecosystem.

2.4 Species in the Arctic

Polar bears (*Ursus maritimus*), seals (*Pinnipedia* spp.), whales (*Cetaceae* spp.), orcas (*Orcinus orca*), and walruses (*Odobenus rosmarus*) are the major mammal species in Arctic marine ecosystems. These five mammals are tertiary consumers, which are usually keystone species and help control the population of other species and maintain a balance in the food chains of ecosystems. Many Arctic marine mammals are ill-equipped to adapt quickly to climate change. By analyzing these species, we hope to understand how major predatory species adapt to the effects of climate change.

Polar bears have gradually adjusted their land use behaviors in response to their melting habitat in the sea. More of the polar bear population in the Arctic Ocean's southern Beaufort Sea has begun to stay onshore for longer because of melting sea ice. From 1986 to 2013, the average distribution of polar bears on the shore increased from 5.8% to 37% (Atwood et al., 2016). Polar bears spend much of their time on sea ice; however, with the diminishing amount of sea ice due to global warming, polar bears in the southern Beaufort Sea have become more dependent on their terrestrial habitat. These polar bears risk interacting with humans to access more food on land, as climate change has destroyed much of their water habitat (Atwood et al., 2016).

Similarly, various species of seals in the Arctic area are poised to migrate further north as the Arctic climate continues to warm. Harp (*Pagophilus groenlandicus*), hooded (*Cystophora cristata*), ribbon (*Histriophoca fasciata*), and spotted seals (*Phoca largha*), among others, rely on sea ice to give birth to young; without sea ice, their populations are likely to decline (Moore and Huntington, 2008). The dependence of seals on ice masses for parturition is changing and as the amount of ice on the seas is waning, seals must migrate further north or face the threat of declining reproduction rates (Laidre et al., 2008). Seal populations have slowly decreased over the past century with the shift to a warmer climate. Seals do not typically migrate or move long distances; however, they have to make this behavioral change to survive the rapidly warming climate of the Arctic marine ecosystem.

The North Pacific gray whale (*Eschrichtius robustus*) population has altered its migration timing and reproduction rates in response to major shifts in its environment due to climate change. While the amount of sea ice is reduced by global warming, whales in the Arctic marine ecosystem, including gray whales, are likely to travel further north and stay longer. In places such as the Bering Sea, many whales remain in the northern areas of the sea all year instead of migrating back south once summer is over (Moore and Huntington, 2008). Due to this change in distribution and shifted migration schedule, whales will also have to adjust their reproduction timing accordingly. These location changes may delay or even prevent whales from reproducing as usual. As a repercussion of the dramatic influence of climate change throughout this ecosystem, whales have had to completely shift their migration and living behaviors to combat habitat destruction in the ocean. Yet as whale species are forced to remain in northern areas for longer periods of time as global temperatures consistently rise, they more commonly begin to adapt in situ, finding ways to adapt to climate change in the Arctic rather than in southern oceans like the Pacific.

In the Arctic, killer whales (*Orcinus orca*) have experienced extreme changes in their distributive and migratory behaviors as ice melt, habitat destruction, warmer temperatures, and the rising sea level affect their environment. Sightings of killer whales have become more frequent closer to human residency overall; however, such sightings decline drastically during winter, suggesting that these populations opt to move even further north than they have typically gone in search of colder climates suited to their biology (Higdon et al., 2011). As a whole, killer whales, like whales, have an emerging pattern of moving more and more north as temperatures globally steadily rise, and these populations seek the temperatures that they are accustomed to. However, as killer whales leave familiar habitats for survival, they may find that such unfamiliar environments may threaten them instead. Formerly, sea ice had inhibited killer whale movement, preventing entrance into potentially dangerous areas, or regions with large amounts of human activity. As such 'choke points' open when sea ice continues to melt, killer whales may endanger themselves with

Vol. 2023 (2) 178 – 188
ISSN 2688-3651 [online]

increased human interaction with sighting reports increasing substantially since 1850 (Higdon and Ferguson, 2009). Though killer whales migrate in hopes of finding the colder environments that they are accustomed to and surviving despite climate change's extreme impacts on their habitats, these changing behaviors may prove to be fatal instead.

Walruses (*Odobenus rosmarus*) in the Arctic marine ecosystem face several threats to their predation and distributive patterns as a consequence of the sea ice melting. The recession of spring sea ice past the Arctic shelves into deeper basins causes the typically icy waters to be less of a resting reproduction environment with easy access to the walruses' benthic prey. Thus, while the reproductive chances of the Pacific walrus is reduced, its survival rate also decreases, unable to fully utilize the Arctic basins to their advantage in deeper waters (Bluhm and Gradinger, 2008). Furthermore, in some cases, as walruses overwinter in the marine Arctic, their distribution changes as their habitat shifts around them. Often, these animals are forced out of comfortable resting areas, instead having to stay in areas with restricted access to sea water, becoming an easy target for animals like polar bears. Isolated walruses outside their natural zones are extremely vulnerable to predators, and their traditionally distributive overwintering behaviors become a risk rather than a solace to these organisms (Kiliaan and Sterling, 1978). Altogether, the melting sea ice poses great threat to marine mammals like the walruses, who depend on patches of ice within the water for their typical reproductive, predation, and distributive behaviors. However, with the decreasing amounts of sea ice and habitat destruction due to climate change, these behaviors instead consistently put walruses at risk and threaten the species' survival as a whole.

Table 2. Summary of animal behavioral changes in the Arctic Marine ecosystem

	Migration	Predation	Distributive	Reproductive	Social
Polar Bears	n/a	n/a	Increased presence onshore, less presence on sea ice	n/a	More human-animal interactions and new interspecies interactions
Seals	Migration outside of their natural habitats and increasingly northern	n/a	n/a	Declining reproduction rates	More human-animal interactions and new interspecies interactions
Whales	Migration outside of their natural habitats and increasingly northern	Increased diet and prey variation	Increased presence in Arctic, increased habitat range	Disrupted reproduction times and patterns	More human-animal interactions and new interspecies interactions
Orcas	Migration outside of their natural habitats and increasingly northern	Increased diet and prey variation	Increased habitat range, presence near humans	n/a	More human-animal interactions and new interspecies interactions
Walruses	n/a	Increased diet and prey variation	Increased habitat range, presence near predators	n/a	More human-animal interactions and new interspecies interactions

3. Comparative Analysis

3.1 Similarities between the Arctic marine ecosystem and the Northeast Pacific Ecosystem

Vol. 2023 (2) 178 – 188
ISSN 2688-3651 [online]

In response to rapid climate change, marine mammals in both ecosystems have changed their behavior to survive in these new environments. To illustrate, the species examined have adjusted their migration, distribution, and predation habits, among others, to face the new challenges that climate change presents to them in their environment.

The changing climate in both ecosystems has altered many interspecific relationships and species interactions in the food chains. Many species have all encountered changes in their food sources and have adapted their diets to their new environment. Due to climate change, sea urchin populations along the Northeast Pacific coastline have fluctuated, and sea otters have shifted their predation behaviors accordingly to compensate for their unreliable food sources (Estes et al., 2003). Dolphins have adjusted their distribution patterns to search for more prey, and their densities in the Northeast Pacific have increased (Burrows et al., 2012). Similarly, polar bears have changed their distribution patterns on land and in the sea in the Arctic marine ecosystem to access more prey.

Species in both ecosystems are declining because of the effects of climate change on their environments. All the species are noticeably decreasing in population. The chain effects of their behavioral changes can be seen throughout the trophic structure of each ecosystem. Because of the rising seawater temperature and sea level, many species have altered their migration patterns. Marine mammals in the Northeast Pacific have shifted their distribution patterns in response to an increase in warmer waters of the Pacific Ocean. Predation, reproduction, and dietary behaviors are also shifting.

3.2 Differences between the Arctic marine ecosystem and the Northeast Pacific Ecosystem

Although the two ecosystems share many similarities in their topographical features and species, changes in species behavior are not always parallel because of climate differences between the two ecosystems. In the Arctic marine ecosystem, ice is a major part of many animal habitats, and the melting affects their migration, reproduction, and other patterns. In contrast, the Northeast Pacific ecosystem does not face this issue because its location is more southern. Because of this difference in habitat, animals in the Arctic marine ecosystem contend with habitat loss and alter their distribution, migratory habits, and reproductive patterns. In the two ecosystems, seals have changed their reproductive behavior in different ways. In the Northeast Pacific, seals spread over icy areas in the northern Pacific Ocean, and seals in the Arctic Ocean migrate further northward to access more ice (Nicholson, 2000; Laidre et al., 2008). Since the Pacific Ocean is much farther away from the northern sea ice and seals cannot migrate large distances, they compensate for their lack of ice by spreading sparsely across the available ice. In comparison, the seals in the Arctic marine ecosystem are significantly closer to the northern sea ice; therefore, they can migrate to access more ice.

Although climate change manifests itself in similar ways in the two ecosystems, the types of behaviors the animals alter in response vary. Specifically, while the living and eating patterns of the five species have changed in the Northeast Pacific, the five species in the Arctic marine ecosystem have mainly changed their migration patterns. In the Northeast Pacific ecosystem, sea otters have mainly changed their predation behaviors, seals have changed their reproductive behaviors, dolphins have changed their predation behavior (see Table 3 and Figure 1). By comparison, in the Arctic marine ecosystem, seals have changed their migration and reproductive habits, polar bears have changed their distribution patterns, and walruses have altered their distributive and predation behaviors. Within both ecosystems, the overlapping species of whales and orcas demonstrate that these two species both face changes in their migratory and distributive patterns, consequently causing major changes in their predation and reproductive behaviors. Whales and orcas move between the two ecosystems throughout the year, spending the warmer part of the year further north in the Arctic marine, and they return to the more southern Northeast Pacific ecosystem when temperatures cool.

Due to this overlapping migration pattern, the two ecosystems experience different perspectives on the effect of climate change on whale behavior. As whale species spend more and more time in Arctic regions as global temperatures steadily rise, they also in turn have a greater impact on the ecosystem itself. Though the Arctic's ecosystem reacts from the added presence of whales when they are typically in the Pacific, the Northeast Pacific reacts from the loss of the whale species that are usually present. In the Arctic marine ecosystem, this migratory change has led to shifting reproductive timings as well as other Arctic species having to contend with a new predator. Within the Northeast Pacific ecosystem, the ecosystem reels from the partial loss of one of its major tertiary consumers, causing

Vol. 2023 (2) 178 – 188
ISSN 2688-3651 [online]

secondary consumer populations to grow unchecked and disrupting the entire food web of the ecosystem. Altogether, both ecosystems must face the consequences of the whale species in both choosing to spend more time in the Arctic, though the resulting changes manifest in two drastically different manners in these ecosystems.

Table 3. The effect of climate change on types of behavioral change relative to species

	Migration	Predation	Distributive	Reproductive	Social
Arctic Only	n/a	*Walruses*	*Polar bears, walruses*	n/a	*Polar bears, walruses*
NE Pacific Only	*Sea otters, dolphins*	*Sea otters, dolphins*	*Seals*	n/a	*Sea otters, dolphins*
Both	*Whales, orcas, seals*	*Whales, orcas*	*Whales, orcas*	*Whales, seals*	*Whales, orcas, seals*

The two ecosystems also show differences in species density in response to climate change. The Northeast Pacific is witnessing an increase in the densities of its species, while the Arctic sees a decrease in its densities (Whitt et al., 2015; Laidre et al., 2008; Moore and Huntington, 2008). The Arctic's melting ice causes many species to migrate further north in search of more ice. The diminishing habitat of species living on ice causes the population of these species to decline. Furthermore, seals in the Arctic, which require ice to give birth, also decrease in population as their necessary surroundings for parturition decrease. By contrast, due to increasing temperatures in the Northeast Pacific, sea otter and dolphin population densities increase in this ecosystem as more sea otters and dolphins move into the bay for warmer waters and more prey.

Although the species in the Northeast Pacific ecosystem have more variety in their behavioral changes, that is because they have the freedom to seek alternative means of survival. The behavioral changes as a result of climate change in the Northeast Pacific demonstrate greater complexity, as a result, it is more difficult to predict its subsequent outcomes on the overall ecosystem. The behavioral changes in the Arctic marine ecosystem are significantly more extreme, albeit less complex. The Arctic species' changing behaviors highlight the sensitivity and high vulnerability of the Arctic marine to the globally rising temperatures. More importantly, the discrepancy in the degree of complexity of behavioral changes reflects the striking variation in how different ecosystems respond to climate change. Based on the preceding analysis, it does not seem that the changes in the Northeast Pacific ecosystem will necessarily follow those changes observed in the Arctic marine ecosystem over time simply because one is more extreme than the other. The behavioral changes exhibit a variety of patterns, including increases or declines in population densities, and are driven by different underlying reasons, such as melting ice caps, water temperature, or availability of food sources, highlighting the importance of comparative analyses.

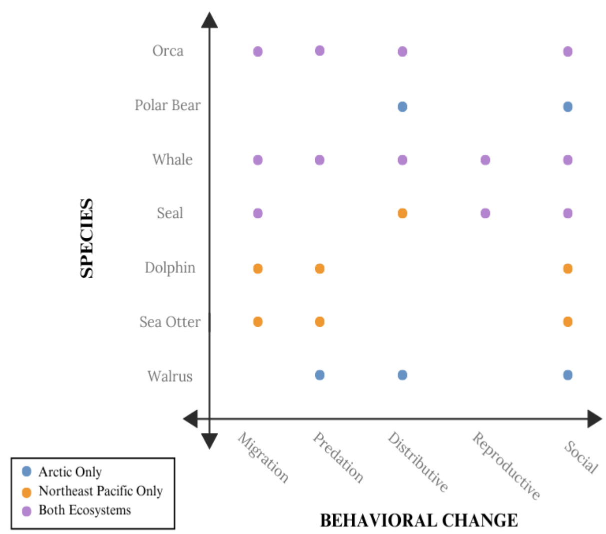

Figure 1. The effect of climate change on animal behavioral change across species. Here I show the five categories of behavior I identified from the literature and how the species analyzed may show behavioral changes for each category in each ecosystem. Some taxa have overlapping behavioral changes in both the Arctic and Northeast Pacific ecosystem. However, for many species, the effects of climate change impact them differently in the two regions, likely because the Northeast Pacific has a greater diversity of behavioral changes while the Arctic is experiencing more severe changes.

4. Discussion

In the years to come, climate change will likely continue to affect animal behavior. Within the Northeast Pacific region, many species may move in greater numbers into regions along the coastline, potentially overpopulating these areas and eventually causing the population of these species to decline. This may lead to negative consequences for the Pacific fishing industry. Other species might seek habitats further north. Overall, climate change will greatly affect the distribution patterns of the species in the Northeast Pacific ecosystem. The Arctic marine ecosystem is also likely to show an overall decline in species density. Due to habitat destruction, animals in the Arctic marine area will continue to shift their migration patterns to adapt to their changing climate, potentially leading to altered predation habits and reproduction rates. Different species distributions, migration patterns, and predation behaviors will lead to new species interactions. It is important for researchers to be cognizant of the differences in how climate change transforms specific animal behaviors in each unique ecosystem to identify effective tailored short-term and long-term solutions to these negative impacts. In summary, this review has demonstrated that climate change has drastically altered the lifestyles of many species, and ultimately the lifestyles of humans, and it will continue to do so unless prevented.

The scope of the review was limited as only five marine species were chosen for each ecosystem. The species were selected to highlight the main ecological crises caused by climate change in these two marine ecosystems; however, many more comparisons can be made at the ecosystem level, particularly in regards to species that are not marine mammals. Additionally, it is important to be mindful of the discrepancy between the size and species count of the two ecosystems while drawing a direct comparison between them. This review was also limited by a lack of empirical data and up-to-date research on animal behavioral changes in response to climate change. Future research that tracks observational data on key behavioral change variables will be essential in performing additional comparative analyses and making reliable predictions for behavioral changes in each ecosystem.

Future review studies on a similar topic may select a larger variety of species beyond marine mammals and predators and potentially include microorganisms or plants in marine ecosystems. A larger scope would provide additional evidence and insights into the effects of climate change. Future research may examine food chains as a whole rather than individual species or select the most at-risk species in ecosystems. Field experiments along the North American Pacific coastline or behavioral experiments along the Pacific coast will also be promising areas of future exploration. In addition, as global temperatures continue to rise and shatter previous records in written history and considering the record-breaking temperatures of the summer of 2023, future research could study the impact of accelerated temperature increases on various animals globally and the relationship between the vulnerability of an ecosystem and its animals' behaviors.

5. Conclusion

This review examines the impact of climate change on ecosystems worldwide while focusing on its impact on animal behavior, particularly in marine mammals. Furthermore, this review illustrates overarching behavioral signatures of climate change. By comparing two unique marine ecosystems, this review highlights similar behavioral adjustments that demonstrate the consequences of climate change. The effects of climate change are evident in the behavioral adaptations that have appeared in species throughout the Arctic marine and Northeast Pacific ecosystems. Research has shown that species in both ecosystems have altered their migration, distribution, predation, and reproductive patterns to adapt to their rapidly changing environment. While there are key differences between the two ecosystems, similarities in species' behaviors show the effect climate change has on marine mammals. As the impact of climate change worsens, more and more species' populations in the world continue to decline and struggle to respond to climate change. Ideally, this initial analysis will inform future research and underline the importance of considering animal behavior in changing ecosystems.

Acknowledgment

I would like to acknowledge my mentor, Carly Scott for her guidance on this project.

References

Atwood, T. C. et al. (2016). Rapid environmental change drives increased land use by an Arctic marine predator. *PLoS One*, 11 (6), e0155932. DOI: 10.1371/journal.pone.0155932

Bailey, H et al. (2009). Behavioural estimation of blue whale movements in the Northeast Pacific from state-space model analysis of satellite tracks. *Endangered Species Research*, *10*, 93-106. DOI: 10.3354/esr00239

Beever, E. A. et al. (2017). Behavioral flexibility as a mechanism for coping with climate change. *Frontiers in Ecology and the Environment*, *15*(6), 299-308. DOI: 10.1002/fee.1502

Bluhm, B. A., & Gradinger, R. (2008). Regional variability in food availability for Arctic marine mammals. *Ecological Applications*, *18*(sp2), S77-S96. DOI: 10.1890/06-0562.1

Breaker, L. C. (2006). "Nonlinear aspects of sea surface temperature in Monterey Bay. Prog. *Oceanography*, 69 (1), 61–89. DOI: 10.1016/j.pocean.2006.02.015

Buckman, A. H. et al. (2011). PCB-associated changes in mRNA expression in killer whales (Orcinus orca) from the NE Pacific Ocean. *Environmental Science & Technology*, *45*(23), 10194-10202. DOI: 10.1021/es201541j

Burrows, J. A. et al. (2012). Marine mammal response to interannual variability in Monterey Bay, California. *Marine Ecology Progress Series*, 461, 257–271. DOI: 10.3354/meps09712

Chavez, F. P. et al. (2017). Climate variability and change: response of a coastal ocean ecosystem. *Oceanography*, 30 (4), 128–145. DOI: 10.5670/oceanog.2017.429

Davidson, S. C., & Ruhs, E. C. (2021). Understanding the dynamics of Arctic animal migrations in a changing world. *Animal Migration*, 8 (1), 56–64. DOI: 10.1515/ami-2020-0114

Estes, J. A. et al. (2003). Individual variation in prey selection by sea otters: patterns, causes and implications. *Journal of Animal Ecology*, 72 (1), 144–155. DOI: 10.1046/j.1365-2656.2003.00690.x

Gifford-Gonzalez, D. (2011). Holocene Monterey Bay fur seals. Human impacts on seals, sea lions, and sea otters: Integrating archaeology and ecology in the Northeast Pacific: 221–242.

Higdon, J. W., Hauser, D. D., & Ferguson, S. H. (2012). Killer whales (Orcinus orca) in the Canadian Arctic: distribution, prey items, group sizes, and seasonality. *Marine Mammal Science*, *28*(2), E93-E109. DOI: 10.1111/j.1748-7692.2011.00489.x

Higdon, J. W., & Ferguson, S. H. (2009). Loss of Arctic sea ice causing punctuated change in sightings of killer whales (Orcinus orca) over the past century. *Ecological Applications*, *19*(5), 1365-1375. DOI: 10.1890/07-1941.1

Hardy, J. T. (2003). *Climate Change: Causes, Effects, and Solutions*. John Wiley & Sons.

Harmon, J. P., & Barton, B. T. (2013). On their best behavior: how animal behavior can help determine the combined effects of species interactions and climate change. *Annals of the New York Academy of Sciences*, 1297 (1), 139–147, DOI: 10.1111/nyas.12192

Hazen, E. L. et al. (2013). Predicted habitat shifts of Pacific top predators in a changing climate. *Nature Climate Change*, 3 (3), 234–238. DOI: 10.1038/nclimate1686

Kiliaan, H. P. L., & Stirling, I. (1978). Observations on overwintering walruses in the eastern Canadian High Arctic. *Journal of Mammalogy*, *59*(1), 197-200. DOI: 10.2307/1379895

Laidre, K. L. et al. (2008). Quantifying the sensitivity of Arctic marine mammals to climate-induced habitat change. *Ecological Applications*, 18 (sp2), S97–S125. DOI: 10.1890/06-0546.1

Moore, S. E., & Huntington, H. P. (2008). Arctic marine mammals and climate change: impacts and resilience. *Ecological Applications*, 18 (2 Suppl.), S157–S165. DOI: 10.1890/06-0571.1

Nicholson, T. E. (2000). *Social structure and underwater behavior of harbor seals in southern Monterey Bay, California*. Diss; San Francisco State University.

Raverty, S. et al. (2020). Pathology findings and correlation with body condition index in stranded killer whales (Orcinus orca) in the northeastern Pacific and Hawaii from 2004 to 2013. *PloS one*, *15*(12), e0242505. DOI: journal.pone.0242505

Reiter, S. M. et al. (2015). Climate adaptation planning in the Monterey Bay region: an iterative spatial framework for engagement at the local level. *Natural Resources*, 06 (5), 375–379. DOI: 10.4236/nr.2015.65035

Townhill, B. L. et al. (2022). Pollution in the Arctic Ocean: An overview of multiple pressures and implications for ecosystem services. *Ambio*, 51 (2), 471–483. DOI: 10.1007/s13280-021-01657-0

Walsh, J. E. (2008). Climate of the Arctic marine environment. *Ecological Applications*, 18 (sp2), S3–S22. DOI: 10.1890/06-0503.1

Wassmann, P. et al. (2011). Footprints of climate change in the Arctic marine ecosystem. *Global Change Biology*, 17 (2), 1235–1249. DOI: 10.1111/j.1365-2486.2010.02311.x

Whitt, A. D. et al. (2015). Abundance and distribution of Marine mammals in nearshore waters off New Jersey, USA. *J. Cetacean Res. Manag*., 15, 45–59.