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The Impacts of Global Warming on The Migration Routes of Whales and The Changes

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Abstract. This paper focuses on an in-depth study of the effects of global warming on the migration routes of whales and the changes it brings to marine ecosystems, mainly using humpback whales as an example. The paper discusses how the migration routes of whales, the largest marine mammals that travel long distances between feeding and breeding grounds, have been affected by global warming. The research indicates that while these whales demonstrate remarkable adaptability in adjusting their migration timing, ongoing climate changes may pose significant challenges, particularly in synchronizing their migration with prey availability. The significance of this research lies in the impacts on the entire marine ecosystem, where a decrease in humpback whale populations due to disrupted migration patterns can affect the entire marine food web. In order to mitigate these impacts, related conservation efforts such as protecting whale populations and the ecosystems they support are critical. It is evident that research on subsequent conservation efforts are critical to mitigate these impacts and protect whale populations and the ecosystems they support.

Keywords: Global warming, Humpback whales, Migration patterns, Phytoplankton, Primary productivity.

1. Introduction

Global warming is defined as the significant increase in the Earth's average surface temperature that primarily caused by human activities, such as fossil fuel combustion, deforestation, and industrial operations. All of these can contribute to exacerbating greenhouse gas emissions, particularly carbon dioxide, which have increased about 50% since the Industrial Revolution [1]. The Intergovernmental Panel on Climate Change (IPCC) reported that the global average temperature has risen about 1.07 °C since 1850 [2]. The impacts of global warming on oceans include rising temperatures, leading to increased sea levels, primarily due to the thermal expansion of seawater and the melting of ice sheets and glaciers. Research from NASA predicts that by 2100, sea levels might rise up to one meter by 2100 [3]. The warming oceans also absorb more carbon dioxide, leading to ocean acidification, which further threatens marine life. As a result, marine biodiversity is increasingly threatened by changes in habitats and food webs.

Over the last two decades, research reveal that the critical changes in patterns and behaviors of whale migration routes were primarily driven by rising ocean temperatures. Studies indicate that as ocean temperatures increase, humpback whales are migrating earlier and traveling farther. For example, research in the Gulf of St. Lawrence found that humpback whales have been arriving and departing over a day earlier each year due to the changes in their biological clocks and the declining availability of krill, their primary food source [4].

Melting polar ice is another significant factor affecting migration routes. To explain, as ice cover declines, essential habitats for whales are lost, leading to increased shipping traffic and noise pollution that disrupts their communication and navigation. This environmental change not only impacts migration patterns but also exposes whales to new diseases caused by parasites or pathogens [5].

Seasonal changes in primary productivity further complicate the situation by affecting the timing of phytoplankton blooms, which directly determine krill populations; it's shifting due to rising sea surface temperatures as mentioned above. Research indicates that primary productivity may decline

by 1–2% per year across most marine biomes, which directly affects prey availability for humpback whales [6]. Overall, current research underscores the urgent need for conservation efforts to mitigate the impacts of global warming on whale migration routes and the broader marine ecosystem.

Whales, particularly humpback whales, as one of the largest-sized mammals in the oceans, play vital roles in marine ecosystems ---- they are essential for nutrient cycling, as their feeding habits help regulate fish populations and promote the health of aquatic habitats. Humpbacks are known for their impressive migration patterns: they travel up to 5,000 miles between feeding grounds in colder waters and breeding areas in warmer regions. Studying the impacts of global warming on humpback migration routes is essential because the potential alterations in ocean temperatures and currents could affect their food sources, such as krill and small fish. These changes may disrupt their traditional migratory paths and breeding behaviors, which pose risks to their population stability and overall marine health. Furthermore, humpback whales, as indicators of oceanic health, their fluctuations in populations that can signal broader environmental changes, making them key subjects for climate research [7].

2. The Impacts of Global Warming on the Oceans

With the dramatic increase in human activities, the problem of global warming has become increasingly severe, also with a lot of negative impacts on the ocean in several ways——rising ocean temperature and sea level and seasonal changes in primary productivity. Firstly, global warming causes ocean temperature rise that can lead to thermal expansion of the ocean's surface layer, which is the density increases causing the water to expand in volume as the ocean warms, and melting of glaciers, directly causing sea level rise. This can be interpreted by Rahmstorf's proposed semiempirical model that links global sea-level variations on time scales of decades to centuries to global mean temperature, which explains 98% of the variance in observed sea-level data from 1880 to 2000, suggesting a strong correlation that is >0.99. Their findings also indicate that according to future temperature scenarios, sea levels could rise between 75 cm and 190 cm by 2100 emphasizing the urgent need to address global warming. It is noteworthy that ice melt could become a more dominant factor of sea-level rise as ocean temperatures increase more drastically in the future, which can also cause coastal erosion [8]. Secondly, global warming significantly influences seasonal changes in primary productivity, particularly the timing of spring phytoplankton blooms. Primary productivity is known as the rate at which energy is transformed into organic materials by photosynthetic producers [9]. According to the research, the seasonal amplitude of primary productivity is projected to decline by 1–2% per year by 2100 across most marine biomes, with the Arctic experiencing an increase of approximately 1% per year. The decline of primary productivity is also linked to rising sea surface temperatures, which are increasing more rapidly during peak temperature periods than during cooler periods. The research shows that the timing of peak primary productivity is expected to advance by about 0.5 to 1 month globally, with the most prominent changes occurring in Arctic regions. These shifts will transform areas that currently exhibit strong seasonal blooms (typically found at high latitudes) into regions with weak seasonal characteristics similar to those seen in subtropical waters [10].

3. The Impacts of Global Warming on the Migration Routes of Humpback Whales

An experiment conducted in the Gulf of St. Lawrence tracked the migration of humpback whales from 1984 to 2010 using photo recognition technology. The study found out that humpback whales from the Gulf of St. Lawrence had been arriving and departing earlier over 27 years, with over one day earlier per year, which is unprecedented. This change aligns with shifts in environmental conditions like earlier ice break-up and increased sea surface temperatures as the effects of global warming, that influence the timing of spring phytoplankton blooms and subsequent availability of prey, such as krill which feed on phytoplankton, as humpback whales are secondary consumers.

Significantly, the study also suggests that ongoing climate change could reshape humpback whales' migratory behaviors, they might face challenges of synchronizing migration with prey availability as ocean temperatures rise that are caused by global warming. Overall, while the whales have adapted to past climate fluctuations, continued rapid changes may lead to significant adjustments in their life cycles or distributions around the world. The impacts of these shifts, particularly for humpback whales with distant breeding grounds could be profound, by affecting their population dynamics and health [4].

After learning the case study which proves that humpback whale migration was altered due to climate change, this paper will then go on to introduce more details on how the negative impacts of global warming on the oceans affects the migratory routes and habits of the whales in more details through more studies from different perspectives. For example, whales, as the biggest mammals in the ocean, and especially, humpback whales as the case. The impacts on the migration routes of humpback whales will be discussed as two impacts as mentioned above, which are rising ocean temperature and sea level and seasonal changes in primary productivity.

To begin with, rising ocean temperatures and sea levels significantly affect the migration routes of whales, particularly species like humpback whales that travel for thousands of kilometers from Antarctica to breeding places around the equator. As the ocean temperatures increase, whales are migrating earlier and traveling farther. The case study in the Gulf of St. Lawrence also demonstrates that humpback whales have been arriving and departing earlier over 27 years, with over one day earlier per year [4,10]. This is because rising temperatures cause the whales' biological clocks to assume it is time to migrate; as well as the declining availability of their primary food source krill which feed on phytoplanktons [11] . Another aspect of the impact is that melting ice cover in polar regions also critically impacts whale migration routes by reducing essential habitats. As the ice sheets decline, many whales lose their habitat, leading to increased shipping that increases the risk of noise pollution, which will interfere with their communication and navigation. Plus, unpredictable ice patterns will affect their traditional migration paths; as well as make them vulnerable to new diseases, especially the ones caused by parasites or pathogens [5]. These changes force the whales to adapt to new environments, resulting in nutritional stress and reduced reproductive success.

Subsequently, the seasonal change in primary productivity can significantly impact humpback whales' feeding behaviors resulting in altering their migration patterns. Based on the humpback whales' food chain, as the case, the main primary productivity would be phytoplankton, also the foundation of the marine food web [12]. The key findings from the case study in the Gulf of St. Lawrence indicate that the change in humpback whales' arrival and departure time aligns with the timing of phytoplankton blooms as the primary productivity [4]. The study in the Magellan Strait also found that humpback whales require a significant portion of primary productivity to sustain their prey, estimating that between 6.8% and 41.5% of net primary productivity in the area is needed to support the prey required by these whales. This indicates that the fluctuations in primary productivity can directly affect prey availability, thereby influencing the whales' feeding and migration patterns [12]. Global warming affects phytoplankton blooms by rising ocean temperatures and light intensity that indicates their nutrient supply, which can lead to shifts in bloom timing and intensity. These changes can disrupt the food web, impacting krill populations that rely on phytoplankton for sustenance. As krill decline due to altered bloom dynamics, humpback whales, which primarily feed on krill as mentioned before, might face food shortages. There's also a risk of exacerbating harmful algal blooms (HABs), which will deplete oxygen and produce toxins that threaten krill populations [13]. These could all lead to decreased whale populations as they struggle to find their food sources, krill, ultimately affecting their migration patterns, as well as their health and reproductive success. The interconnectedness of these species highlights the broader impacts of global warming on marine ecosystems.

4. The Impacts of Changes in Humpback Whales' Migration Patterns on the Marine Ecosystems

The changes in humpback whale migration patterns significantly impact marine ecosystems. Recent studies indicate that shifts in their migratory routes due to global warming, thus altering prey availability, the whales may struggle to accumulate enough energy reserves for breeding, ultimately contributing to a decline in their populations and disrupting marine ecosystems that rely on their ecological roles [14]. In addition, increased temperatures, and reduced ice coverage in feeding areas have led to changes not only in the decline of humpback whales' populations but also the humpback whales' migrations behavior and distribution would potentially affect the distribution of krill as their prey, as well as the distribution of phytoplankton as the food sources for krill, thus the entire marine ecosystems.

As these whales migrate between polar feeding grounds and tropical breeding areas, they play a vital role in the entire marine food web. These alterations caused by global warming can impact both humpback whales' predators' populations, for instance, orcas that will decline due to food shortages, and their prey' populations, as the whales' feeding habits influence the populations of krill which feed on phytoplankton. To further explain, the decreased populations of humpback whales can lead to a proliferation of their food sources, including a rise in photosynthetic producers that leads to eutrophication, which results in the overgrowth of phytoplankton, as well as other primary productivity due to excessive nutrients in a water body, leading to exacerbating harmful algal blooms (HABs), depleted dissolved oxygen levels (hypoxia) cause other marine organisms death, and ultimately the creation of "dead zones" where marine life cannot survive anymore; or a rise in the populations of primary consumers leading to the productions of excessive concentration of carbon dioxide in the oceans, which will also ultimately lead to eutrophication [15]. Moreover, their excrement enriches are the nutrient sources for producers, boosting phytoplankton growth, which is crucial for oxygen production in the oceans. Thus, the decreasing populations of humpback whales can further contribute toeutrophication.

5. Suggestions for Alleviating the Impacts of Global Warming on Humpback Whales Migrations

The decline in whale populations due to threats like habitat degradation and fishing entanglements further exacerbates these issues, highlighting the need for conservation efforts to protect both whales and the ecosystems they support. To reduce the impacts of global warming on marine systems, especially by concerning the impacts on humpback whales' migrations, several measures can be implemented:

Firstly, expanding and strengthening MPAs helps protect important feeding and breeding habitat for humpback whales. By providing safe havens, MPAs can mitigate the effects of habitat loss caused by climate change and human activities, allowing whale populations to recover and maintain their ecological role. Conversely, without MPAs, whales would face increased threats from shipping, fishing, and habitat degradation, exacerbating population declines and damaging marine ecosystems. Secondly, implementing policies to reduce greenhouse gas emissions is critical to addressing the root causes of global warming. By transitioning to renewable energy sources and improving energy efficiency, we can slow the rise in ocean temperatures and protect the delicate balance of marine ecosystems. Conversely, failure to address emissions will lead to continued temperature increases, further altering whale migration patterns and prey availability, thereby destabilizing marine food webs. Last but not least, encouraging sustainable fishing helps maintain healthy populations of krill and other prey essential to humpback whales. Practices such as limiting bycatch and reducing overfishing ensure that prey supplies remain stable and thus support whale populations. Conversely, unsustainable fishing can lead to prey depletion, negatively impacting whale health and reproductive success and ultimately damaging the entire marine ecosystem. By implementing these measures, we

can work to alleviate the impacts of global warming on humpback whales and the wider marine environment and ensure the health of these important ecosystems.

6. Conclusion

The study on the impacts of global warming on humpback whale migration patterns reveals critical shifts in their behavior and the broader implications for marine ecosystems. Over a 27-year period, it was observed that humpback whales in the Gulf of St. Lawrence are arriving and departing earlier each year, with an average shift of more than one day sooner annually. This shift is closely related to rising ocean temperatures and altering seasonal patterns, which influence the timing of phytoplankton blooms—the key food supply for krill, which in turn nourishes humpback whales. The research indicates that while these whales demonstrate remarkable adaptability in adjusting their migration timing, ongoing climate changes may pose significant challenges, particularly in synchronizing their migration with prey availability. The significance of this research lies in its demonstration of how climate change can fundamentally alter the migratory behaviors of marine species, with potential cascading effects on entire marine ecosystems. As humpback whale populations decline due to disrupted migration patterns and prey availability, the stability of marine food webs is jeopardized, highlighting the urgent need for conservation efforts. However, the study has limitations, including its focus on a specific geographic area that may not fully represent both the behaviors of humpback whales in other regions and the status of migratory routes of other whales species. Additionally, the study does not account for potential migrations beyond the study area, which could further influence population dynamics. Future research should aim to expand the geographic scope of studies on humpback whale migration and include long-term monitoring of various populations across different regions. Investigating the impacts of climate change on prey availability and health will be also crucial to understanding the full implications for humpback whales and their ecosystems. Moreover, implementing conservation measures can be applied, such as establishing marine protected areas and promoting sustainable fishing practices will be essential in mitigating the impacts of global warming on these vital marine species. By addressing these challenges proactively, we can work towards preserving both humpback whale populations and the intricate marine ecosystems they inhabit.

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