ADVANCE SOCIAL SCIENCE ARCHIVE JOURNAL
Available Online: https://assajournal.com
Vol. 02 No. 04. Oct-Dec 2024.Page#.1551-1566
Print ISSN: 3006-2497 Online ISSN: 3006-2500
Platform & Workflow by: Open Journal Systems
https://doi.org/10.5281/zenodo.17271012

IMPACT OF CLIMATE CHANGE ON MARINE LIFE: A CASE STUDY OF ARCTIC OCEAN REGION

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ABSTRACT
This study focuses on exploring the impact of climate change on marine environment of Arctic Ocean region. The Artic, also called as Earth's climate barometer, has faced significant changes due to rising global temperature, resulting in increasing melting of ice and ocean acidification. The study analyzes changes in temperature of sea surface distribution of key marine species highlighting the vulnerability of Arctic environment. Changes in temperature of water have disrupted food chains, migration of fish and threatened the habitat of species. The research also focuses on how melting ice is affecting the world by increasing sea levels and changing oceanic flow. This study also focuses to understand the impact of climate change on biodiversity and explored the broader biological, geopolitical, and environmental effects of climate change in the Arctic Ocean by considering both short term and long-term changes. Using Ecological Systems Theory as a framework and employing a qualitative, explanatory research design, the study explores how various components of the Arctic ecosystem are interlinked and how climate-induced changes affect these connections. This study emphasizes the urgent need for strengthened global governance and targeted conservation strategies to protect the fragile Arctic marine environment.
***Keywords**: Climate Change impacts, marine ecosystem, Ocean acidification, biodiversity loss, Migration*

Introduction

Climate change is a serious problem affecting the entire planet. One of the most affected areas is the Arctic Ocean that is warming four times faster than rest of the world[1]. The Arctic Ocean is ecologically important in regulating the Earth's global temperature. Climate change in the Arctic has raised global concerns. It is rich in biodiversity, facing severe changes due to increased global warming and melting of ice. Arctic, once known for its thick layers of ice and freezing temperatures, is now experiencing rising temperatures, melting ice caps, ocean acidification, and

1 IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. IPCC. (2021)

significant disruptions to marine ecosystems[2]. Climate change has also led to ocean acidification, particularly in the Arctic, where cold water absorbs higher concentrations of CO_2. The Arctic Ocean has increased in acidity by 30% since the 1990s, which is destructive to aquatic organisms such as plankton, shellfish, and fish that serve as the foundation of the food web[3]. These changes have direct and serious consequences for marine life in the Arctic. These transformations in climate have caused disruptions in marine ecosystems, affecting regional biodiversity and food chains[4]. It is considered as an important body in regulating Earth's climate pattern, now standing at the frontiers of climate-driven environmental shifts. This change has deeply impacted the marine life that depends on cold, icy waters for survival. This research also focused on how climate change is harming fish, seals, polar bears, and other marine animals in the Arctic Ocean.

Additionally, the study emphasized the importance of understanding the impact of climate change on biodiversity and explored the broader biological, geopolitical, and environmental effects of climate change in the Arctic Ocean by considering both short term and long-term changes. It is grounded in ecological system theory and employs qualitative research methods with explanatory research design. By using Ecosystem Theory as a framework, the study examines how various elements of the Arctic ecosystem are interconnected and how changes in one part of the system can affect the other. The study highlighted which species are most at risk, how their behavior and migration patterns are changing, and what this means for the future of the Arctic Ocean. These alterations have resulted in the migration of species and changes in their behavior. The loss of sea ice has affected habitat of species that depend on ice for survival and has allowed boreal species to migrate into Arctic zone.

Despite growing global awareness, significant disparity remains due to dynamic nature of the climate system. Strengthening environmental governance and international climate policy frameworks is necessary to protect the marine environment and climate change mitigation. Many international efforts that include United Nations Framework Conventions on Climate Change (UNFCCC) and Arctic Council have had an impact on the preservation of Arctic marine life. However, there are hurdles like lack of enforcement, limited international collaboration, and scientific uncertainty that cause hindrance to achieving long-term success. This research aims to address these complexities by using the Arctic Ocean as a case study to obtain a better understanding of the impacts of climate change on the marine environment. There exists a large knowledge gap in the literature that considers comprehensively how climate-driven environmental changes influence species behavior, migration, existence, and food chain dynamics in the Arctic. In order to bridge this gap, the research employed Ecological Systems Theory as the theoretical framework to help explain the interdependence of Arctic marine animals and the cascading impact of climate change in the ecosystem. The study adopted a qualitative approach with an explanatory research design to examine short-term and long-term effects of environmental change. It also focused on identifying the most vulnerable specie, their behavioral and migratory patterns, and the implications for the conservation of marine biodiversity. It

2 Thomas, D. N., et al. (2019). A changing Arctic Ocean. *Nature Climate Change*, 9(9), 740–741.

3 National Oceanic and Atmospheric Administration (NOAA), "Ocean Acidification in the Arctic," 2015 [4] Fossheim, M., et al. (2015). Recent warming leads to a rapid borealization of fish communities in the Arctic. *Nature Climate Change*, 5(7), 673–677.

examined these issues in depth, using the Arctic Ocean as a case study to explore the broader relationship between climate change and marine life. This study argues that climate change is inducing unprecedented ecological disturbance in the Arctic Ocean, putting marine biodiversity at risk and necessitating increased international governance measures. Furthermore, this study serves as an important resource of teachers, students as well as policy makers to address climate related challenges and identify appropriate solutions. It also examines the chemical, physical and biological processes and how these are interrelated.

Statement of the problem:

Due to the climate change and global warming, the Arctic Ocean

Region's temperature has risen almost four times higher than the rest of the globe, causing severe problems within the marine organisms and endangering numerous species[4]. This rapid warming has led to extensive sea ice loss, and satellite observations indicate that the extent of the Arctic Sea ice has shrunk by approximately 13% each decade since 1979[5]. The environmental fluctuations pose a threat to many species, disturbed energy flow, and changed migration trends. If these challenges persist, biodiversity loss and ecosystem distraction could occur which could disturb the food supply chain and change the earth's climate. Despite many international efforts such as UNFCCC and Arctic Council are being made to tackle this issue, climate change continues to threaten marine life, resulting in ecosystem disturbance, biodiversity loss, and limitations on species adjustment in the Arctic Ocean.

Objectives of research:

- To explore the impacts of climate change on marine life worldwide, focusing on changes in ocean temperature, acidity, and ice coverage.
- To analyze how melting sea ice and rising temperatures specifically affect marine species in the Arctic Ocean region.
- To examine the changes in behavior and population of Arctic marine animals due to climate change.

4 M. Rantanen et al., "The Arctic Has Warmed Nearly Four Times Faster than the Globe since 1979," *Communications Earth & Environment* 3, no. 1 (2022): 1–105

5 NASA, "Arctic Sea Ice Minimum," NASA Global Climate Change, 2020

Literature Review:

Climate change is one of the major issues in current era that that cause sea ice to melt earlier which affect the marine ecosystem and threatening of many species in Arctic Ocean. Solan, Martin, Philippe Archambault, Paul E. Renaud, and Christian März article "The Changing
Arctic Ocean: Consequences for Biological Communities, Biogeochemical Processes and Ecosystem Functioning" in 2020 discusses mainly how climate change is drastically reshaping Arctic marine ecosystems and calls for urgency in interdisciplinary and long-term studies. The authors emphasize that even when global warming is stabilized, the Arctic will keep experiencing profound ecological changes from sustained changes in ice cover, temperature, acidification, and freshwater inflow. However, the article does leave some crucial points unexplored. Geographically, the study is focused in certain areas such as the Barents Sea and Baffin Bay, with minimal mention of other major Arctic regions such as the Canadian Arctic Archipelago or the Siberian shelf seas. There is also a deficiency of in-depth analysis of how the scientific results might guide specific policy choices or be translated into action by governing institutions such as the Arctic Council and UNFCCC[6].

Heath, Michael R., Deborah Benkort, Andrew S. Brierley, Ute Daewel, Richard Hofmeister, Jack H. Laverick, Roland Proud, and Douglas C. Speirs article “How Is Climate Change Affecting Marine Life in the Arctic? "In August 2020 emphasizes the significant effect of climate change on Arctic ecosystems, specifically the effects of melting sea ice and how it affects the food web in the Arctic. The article also discusses how this change may influence species throughout the food web. The article omits a few important points while discussing climate change and melting in the Arctic. It fails to completely discuss long-term evolutionary consequences on Arctic wildlife or the detailed consequences on a particular species such as polar bear or fish. There is also not enough mention of international policy or regulation on how to handle the environmental change in the Arctic[7].

Geir Ottersen, Andrew J. Constable, Anne B. Hollowed, Kirstin K. Holsman, Jess MelbourneThomas, Mônica M. C. Muelbert, and Mette Skern-Mauritzen article “Climate Change Impacts on Polar Marine Ecosystems: Toward Robust Approaches for Managing Risks and Uncertainties" in 2022 provides a discussion on several challenges in future forecasting and managing the impacts of climate change in polar marine ecosystems, including prospects for future adaptation and resilience strategies. One important approach mentioned is the "management strategy evaluation" (MSE), which is useful in comparing adaptation strategies considering multiple climate scenarios and models. Yet the application of the method in polar regions is still limited, and additional studies are necessary to help resolve major uncertainties, including those for ecosystem processes and structural model errors in climate models[8].

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6 Martin Solan, Philippe Archambault, Paul E. Renaud, and Christian März, "The Changing Arctic Ocean: Consequences for Biological Communities, Biogeochemical Processes and Ecosystem Functioning," *Frontiers in Marine Science* 7 (2020)

7 Michael R. Heath, Deborah Benkort, Andrew S. Brierley, Ute Daewel, Richard Hofmeister, Jack H. Laverick, Roland Proud, and Douglas C. Speirs, “How Is Climate Change Affecting Marine Life in the Arctic?,” *Frontiers in Marine Science*, August 2020.

8 Geir Ottersen, Andrew J. Constable, Anne B. Hollowed, Kirstin K. Holsman, Jess Melbourne-Thomas, Mônica

Scott C. Doney article "Climate Change Impacts on Marine Ecosystems" in 2012 emphasizes the deep impacts of climate change on marine ecosystems, especially in polar areas. It explores how increased temperatures, the decline of sea ice, and ocean acidification are transforming marine biodiversity, productivity, and food webs. The article speaks of the disruptions in major ecosystems like the Arctic and Antarctic, citing changes in species composition, habitat loss, and alterations in primary production. It also examines the cascading impacts on marine life, such as seabirds, mammals, and fish, and the implications at larger scales for global ocean systems and biogeochemical cycling. The research highlights the complexity of such changes, with both anticipated and unanticipated effects for marine ecosystems and their interactions with climate. Yet it does not consider socioeconomic consequences or long-term adaptive measures and does not investigate how changes in one area would impact global marine systems and food webs in coupled ways[9].

Katherine J. Kuletz, Steven H. Ferguson, Morten Frederiksen, Colin P. Gallagher, Donna D. W. Hauser, Haakon Hop, Kit M. Kovacs, Christian Lydersen, Anders Mosbech, and Andrew C. Seitz article "A review of climate change impacts on migration patterns of marine vertebrates in Arctic and Subarctic ecosystems" in 2024 focuses on how Climate change is impacting severely the polar oceans, but we still don't have sufficient data, particularly on marine organisms. Technological innovations and global collaboration are assisting, but there's much more to be done.it identifies significant uncertainties in climate models for polar marine ecosystems, particularly because of coarse global models that overlook regional changes. The paper is missing uniform data from the real-world validation such as observed fisheries collapses. It is based largely on coarse global models that fail to capture regional ecological shifts[10].

P. Wassmann, C.M. Duarte, S. Agustí, and M.K. Sejr article "Biodiversity of Arctic marine ecosystems and responses to climate change" in 2012 focus on emphasizes the increasing susceptibility of the Arctic to introductions of nonindigenous species (NIS), fueled by climate change as well as human activities such as shipping, aquaculture, and fisheries. With increasing temperatures and melting sea ice in the Arctic, human activities are increasingly enabling the transport of species to the region, many of which can potentially become established, leading to ecological, economic, and health issues. The research identifies taxonomic patterns in NIS introductions, calling for observation and control of the species to avoid negative effects on Arctic ecosystems. The article does not address how to avoid NIS introductions, long-term ecological

M. C. Muelbert, and Mette Skern-Mauritzen, "Climate Change Impacts on Polar Marine Ecosystems: Toward

Robust Approaches for Managing Risks and Uncertainties," *Frontiers in Marine Science* 9 (2022)

9 Scott C. Doney, "Climate Change Impacts on Marine Ecosystems," *Annual Review of Marine Science* 4, no. 1 (2012)

10 Katherine J. Kuletz, Steven H. Ferguson, Morten Frederiksen, Colin P. Gallagher, Donna D. W. Hauser, Haakon Hop, Kit M. Kovacs, Christian Lydersen, Anders Mosbech, and Andrew C. Seitz, "A Review of Climate Change Impacts on Migration Patterns of Marine Vertebrates in Arctic and Subarctic Ecosystems," *Frontiers in Marine Science* 11 (2024).

effects, or international policies' role. It also ignores the economic advantages or disadvantages of NIS in the Arctic[11].

David N. Thomas, Fabian Grobe, Damian L. Arévalo-Martínez, Julia Grosse, and Allyson Tessin article "A Changing Arctic Ocean" in 2019 emphasizes on quick environmental changes in the Arctic region because of climate change, including the melting of sea ice, disturbed ecosystems, and global effects like sea-level rise and greenhouse gas emissions. It emphasizes the importance of scientific research, inclusive governance, and immediate global action to respond to such changes. Not much attention is provided to the role of corporations, resource extraction activities (such as oil, gas, and mining), and shipping industries that heavily affect the Arctic ecosystem. The article highlights cooperation and governance but is short on legal enforcement, on monitoring systems, or on how such agreements are enforced or broken[12].

Maria Fossheim, Raul Primicerio, Edda Johannesen, Randi B. Ingvaldsen, Michaela M. Aschan, and Andrey V. Dolgov article "Recent warming leads to a rapid borealization of fish communities in the Arctic" in 2015 focuses that Arctic is warming at a rate twice the global average, and it results in dramatic changes in fish populations. Boreal (warmer water) fish species such as cod and haddock have migrated northward in the Barents Sea as sea temperatures have increased, and ice levels have decreased. Native Arctic fish species are being pushed into deeper and more northerly waters, where there is limited space. As more boreal species take over, Arctic fish is threatened with local extinction. This broad-scale transformation, or borealization, captures the way climate warming is reorganizing marine life in the high north. This article does not address long-term ecological implications of boreal species displacing Arctic species, including possible disruption to food webs or loss of biodiversity. It also ignores socioeconomic effects on Indigenous peoples and fisheries. It also does not include policy suggestions or measures to counteract these changes[13].

Jean-Pierre Pommereau, Florence Goutail, and Andrea Pazmino article "Recent Arctic ozone depletion: Is there an impact of climate change?" in 2018 focus on Arctic ozone loss, with emphasis on the winters of 2015–2017, during which major ozone loss was experienced because of stratospheric cooling and activation of chlorine. It emphasizes the third-largest ozone loss in 2015–2016 and the long-term trends in Arctic ozone loss since 1990. The research also foresees continued stratospheric cooling and the possibility of extreme ozone loss events, despite the reduction of ozone-depleting substances. Arctic sea ice loss is also mentioned as affecting stratospheric temperatures and ozone concentration. The article is centered on Arctic ozone depletion but neglects several points, including the contribution of other greenhouse gases, wider human and environmental implications, regional differences, long-term fore casting, interactions with global climate change, and socio-economic implications in the Arctic region[14].

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11 P. Wassmann, C.M. Duarte, S. Agustí, and M.K. Sejr, "Biodiversity of Arctic Marine Ecosystems and Responses to Climate Change," *AMBIO* 41, no. 1 (2012).

12 David N. Thomas, Fabian Grobe, Damian L. Arévalo-Martínez, Julia Grosse, and Allyson Tessin, "A Changing Arctic Ocean," *Science Advances* 5, no. 12 (2019).

13 Maria Fossheim, Raul Primicerio, Edda Johannesen, Randi B. Ingvaldsen, Michaela M. Aschan, and Andrey V. Dolgov, "Recent Warming Leads to a Rapid Borealization of Fish Communities in the Arctic," *Nature Climate Change* 5, no. 7 (2015)

14 Jean-Pierre Pommereau, Florence Goutail, and Andrea Pazmino, "Recent Arctic Ozone Depletion: Is There an

Paul Wassmann, Carlos M. Duarte, Susana Agustí, and Mikael K. Sejr article "Footprints of Climate Change in the Arctic Marine Ecosystem" was published in October 2010 focuses on the effects of climate change on Arctic marine ecosystems in terms of changes in species, growth, and shifts at the community level but is short of quantitative information on endemic species and under-studies areas such as the Siberian shelf. It is mostly concerned with marine mammals and fish and does not consider general ecosystem and socioeconomic effects. The research contribution is still small and prevents full comprehension of climate change effects in the Arctic[15].

Hugh W. Jacoby, David R. A. Thompson, and Erik L. D. F. Van Der Wal book "The Arctic Climate System" published in 2005 provides a holistic approach to the Arctic as a system of interconnected components including the atmosphere, ocean, sea ice, and hydrology. It is a history of change in the exploration of the Arctic, a description of the physical and climatic characteristics of the region, and an examination of the current environmental change stemming from climate change. The book makes the point that knowledge of the Arctic must have both historical basis and scientific foundation and points out how change is now instantaneous and a determining factor in the Arctic climate. it provides an integrated overview of the physical climate of the Arctic, stressing interconnection between atmospheric, oceanic, and land processes. Although the second edition incorporates new scientific developments and reorganizes material to emphasize current Arctic change, some shortcomings remain. the book concentrates mainly on physical climate dynamics and offers little treatment of ecological effects, traditional knowledge, and socioeconomic impacts. It also does not substantively confront data limitations of Arctic climate modeling. Addressing these areas would offer a fuller representation of the climate dynamics in the region[16].

Franz J. Mueter and colleagues Book "Responses of Arctic Marine Ecosystems to Climate Change" (2013) reports and predicts probable changes in environmental processes and species responses, with emphasis on the management of living marine resources and human responses to a changing Arctic. The Arctic Ocean and its bordering seas are experiencing accelerated environmental modification, primarily in the area and seasonality of sea ice coverage. The book also examines the place of science in policymaking for the Arctic Ocean and includes observations from indigenous peoples, giving a holistic view of the effects of climate change on marine ecosystems in the Arctic. Indigenous knowledge, governance, and long-term monitoring is also not featured, underrepresenting significant human and ecological dimensions[17].

Research gap:

Most research examines broad climate trends or individual species but does not investigate the complete effect on the entire Arctic marine ecosystem. There are also too few current, long-term records of how rising temperatures, ice melting, and ocean chemistry are affecting biodiversity

Impact of Climate Change?," *Atmospheric Chemistry and Physics* 18, no. 19 (2018)

15 Paul Wassmann, Carlos M. Duarte, Susana Agustí, and Mikael K. Sejr, "Footprints of Climate Change in the Arctic Marine Ecosystem," *Global Change Biology* 17, no. 2 (2010):

16 Hugh W. Jacoby, David R. A. Thompson, and Erik L. D. F. Van Der Wal, *The Arctic Climate System* (Cambridge: Cambridge University Press, 2005).

17 Franz J. Mueter et al., *Responses of Arctic Marine Ecosystems to Climate Change* (Dordrecht: Springer, 2013).

and food webs in the region. This research aims to bridge this gap by concentrating on the alterations in sea life due to climate change within the Arctic Ocean region. Additionally, there is lack of interdisciplinary attempts that combine marine biology, climate modeling, and economic forecasting to predict future dangers. Accordingly, this research addresses an important gap by providing a comprehensive evaluation of how Arctic marine conditions vary because of climate impact and affect ecological stability, economic development, and regional sustainability.

Research questions:

- How is climate change and global warming impacting marine life?
- What are the effects of melting of sea ice on marine life in the Arctic Ocean?
- How has climate change influenced the behavior and migration of marine species in the Arctic Ocean?

Core argument:

Climate change, led by rising world temperature and growing greenhouse gas emissions, is causing significant environmental changes in the Arctic Ocean region such as rapid loss of sea ice, ocean warming, and acidification. These changes have a significant impact on marine life by changing habitats, destabilizing food webs, and compelling changes in species distribution and behavior. Sea ice loss diminishes ice-dependent species' habitat, and increased warmth in the water allows boreal species to encroach on historically Arctic environments, causing changes in biodiversity as well as local extinctions. Climate change is therefore an inciting cause that initiates ecological effects, restructuring marine biodiversity and ecosystem processes in the Arctic Ocean.

Theoretical framework:

The impact of climate change on marine life is a complex issue that need comprehensive theoretical approach to understand interconnected ecological, physical, and socio-political processes involved in its manifestation. This research is grounded in Ecological System Theory which provides an extensive systemic process for analyzing how different environmental layers interact and influence Arctic marine ecosystem. This theory was originally formulated by Urie Bronfenbrenner that understand how species interact and respond to changing environments[18]. In the case of the Arctic Ocean, the theory is useful for understanding climate-change drivers such as rising sea temperature, melting sea ice, ocean acidification, and species shift impact the marine ecosystem at different levels.

This theory operates in different levels of influence: At the microsystem level, reduced sea ice, increased water temperature, and changes in marine species distribution are direct impacts that disturb pre-existing biological communities. The mesosystem approach enables us to delve into the ways these modifications modify predator-prey interactions, nutrient cycling, and general ecosystem stability[19]. For example, the invasion of temperate species into the Arctic Ocean influences native biodiversity and food web structure, which can have a cascading influence across the marine system.

18 Bronfenbrenner, U. (1979). *The Ecology of Human Development: Experiments by Nature and Design*. Harvard University Press.

19 Post, E., Bhatt, U. S., Bitz, C. M., Brodie, J. F., Fulton, T. L., Hebblewhite, M., ... & Walker, D. A. (2013). Ecological consequences of sea-ice decline. *Science*, 341(6145), 519–524. https://doi.org/10.1126/science.1235225

The exosystemic level expands the perspective to include atmospheric warming patterns, ocean acidification, and rising freshwater input from glacier melting, all of which impact marine ecosystem functioning indirectly but with great significance. These drivers interact to transform the chemical and physical properties of Arctic waters, producing novel environmental conditions that test the resilience of marine organisms[20]. Applying Ecological Systems Theory, the study also provides a strong framework for studying the effects of climate change on the Arctic marine ecosystem through the highlighting of interdependence among ecological layers and dynamic interactions at multiple scales. The theory not only enables a diagnosis of multi-dimensional consequences of environmental change but also supports the development of sustainable solutions necessary to preserve the fragile ecosystems of the Arctic Ocean in the face of global climate challenges.

Research Methodology:

This research employs a qualitative research methodology, as it helps to understand evolving nature of climate and its impact on marine life in Arctic Ocean. The main objective is to examine how rising ocean temperature is contribute to increased salinity, ocean acidification and migration patterns. The study also follows explanatory research design to investigate the causes, impacts and patterns of climate change in Arctic Ocean and investigate relation between climate change and vulnerability of marine life.

This study uses secondary data, including official reports, scientific journals and environmental studies produced by reports of international organizations, such as UNFCCC, books and online database which focused on climate science and marine biology. This research goes with document analysis, interpret the key themes and identify common impacts (habitat loss and migration of species) and relate them to climate indicators like rising sea surface temperature etc. It is based on responsible and ethical manner. Although it uses publicly available secondary data, proper citations and acknowledgement of all sources are ensured to maintain academic integrity.

Delimitations:

This research focuses exclusively on the Arctic Ocean and does not cover other marine environments such as polar and subpolar regions. It concentrates on marine animals and organisms and does not examine the impact on terrestrial organisms. The study highlights ecological changes over the past three decades, as this period has shown major transformations in the Arctic Ocean. While it does not provide a detailed analysis of geopolitics and governance mechanisms, a brief mention is included for contextual understanding.

Significance:

It emphasizes the impact of climate change on marine life in the Arctic Ocean, and the results focus on increasing awareness of the environmental effects on ocean ecosystems and the vulnerability of marine animals in the region. It also encourages scientific research that supports biodiversity conservation and emphasizes the need for enforcing environmental policies. The study can serve as a valuable resource for both students and teachers, helping them gain insights into future threats to marine life in other regions as well. Additionally, it can be a reliable source for policymakers to address climate-related challenges and identify effective solutions.

20 Steinacher, M., Joos, F., Frölicher, T. L., Plattner, G. K., & Doney, S. C. (2009). Imminent ocean acidification in the Arctic projected with the NCAR global coupled carbon cycle–climate model. *Biogeosciences*, 6(4), 515– 533. https://doi.org/10.5194/bg-6-515-2009

Global Climate Change and Its Impact on Oceanic Life Systems

Climate change is large and persistent shifts in the world's climate, induced mainly through human activities that include the combustion of fossil fuels, deforestation, and industrial processes. These activities raise the level of greenhouse gasses (GHGs) in the environment, causing global warming. It is one of the major issues of 21st century. Climate change is a significant threat to life in our ocean, including coral reefs and fishery, with effects on marine ecosystems, economies and society, particularly those most reliant on natural resources. By reducing global warming to no more than 1.5°C, the risk of climate change can be minimized. Human influence climate through emissions from fossil fuels and industrial activities which ultimately increase global warming. Human activity has non-climatic impacts everywhere too, such as over-fishing and pollution. Ocean absorbs 91% of heat because of greenhouse gas emissions[21]. Greenhouse gases like CO2 contribute to global warming and global surface temperature rise between 1.8- and 4.0-degree centigrade by the end of 21st century[22]. With ongoing ocean warming, the ocean expands, generating sea-level rise, which has direct consequences on glacier melting and the Arctic and Antarctic Sea ice and favoring conditions for extreme weather events. Due to climate change sea level is rising, causing damage to costal and pelagic habitat, which affects migration pattern and reproduction process. Both the Arctic Ocean and Southern Ocean have a rich diversity of life, from small plankton to fish, krill and seafloor invertebrates to whales, seals, polar bears or penguins organisms that live on or under sea ice are threatened directly by climate change through loss of habitat. Over the past decade, rapid industrial growth in developing nation has contributed to an increase in the global average sea surface temperature by approximately 0.13°C per decade. As a result, significant changes have occurred in world's oceans, and these warming patterns change by region due to ocean [24]. This widespread change cause damage to coral reefs and mangroves that is responsible to support life in oceans. Majority of heatwaves took place from 2004 to 2015 that caused severe degradation of reefs and coral bleaching[23].

Ocean Acidification:

Another major impact of climate change is ocean acidification. It is the absorption of CO2 from atmosphere that changes the PH of the ocean and result in sea water more acidic. Ocean acidification deteriorates the calcium carbonate structure of any marine species. This acidification can weaken skeleton and shells of marine organisms and plankton that is harder for them to survive, and it affect species that need calcium carbonate to make their bones and shells. If phytoplankton growth is disturbed, it affects the whole food web. Since preindustrial area, ocean PH has dropped by 0.1 units which is about 26% rise in acidity. This threatens entire marine

21 Intergovernmental Panel on Climate Change (IPCC). (2021). *Sixth Assessment Report: Climate Change 2021 – The Physical Science Basis*.

22 Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2021: The Physical Science Basis*, Contribution of Working Group I to the Sixth Assessment Report (Cambridge University Press, 2021), p. 10. [24] Serreze, M. C., & Stroeve, J. (2015). "Arctic Sea Ice Trends, Variability and Implications for Seasonal Ice Forecasting." *Philosophical Transactions of the Royal Society A*, 373(2045), p. 20140159.

23 United Nations, *Ocean Impacts of Climate Change*, https://www.un.org/en/climatechange/science/climatehttps://www.un.org/en/climatechange/science/climate-issues/ocean-impactsissues/ocean-impacts

ecosystem and affect biodiversity in sensitive regions like polar seas[24]. This also affects entire marine ecosystem and food chain that result in shift of marine species, disrupt reproduction pattern [25] and also weakens the reproductive system of fish and other invertebrates[26]. It affects population dynamics, community composition and overall function of ecosystem. Climate change also results in distribution of cold-blooded animals due to rise in temperature which disrupts habitat and physiological processes. Even minor temperature changes significantly influence the behavior of marine animals[27]. These changes result in impair feeding habits, distribution and migration and alters the natural timing of seasonal events which affect fisheries and other marine mammals. Major increase in global temperature from 2 to 3% in few decades above pre-industrial level could put around 30% of plants and animals' species at high risk of extinction. Projections also indicate that global average temperature rise of 0.2°C per decade over the next two decades, with a total increase between 1.8°C to 4°C by 2100[28].Using Ecological System Theory, it becomes clear that marine ecosystem is highly interconnected. A change in one element such as melting ice due to climate change and global warming cause affect across other components such as migration of species. Global warming also causes low oxygen level and ultimately results in death of many species which demand high oxygen. Due to severe heat wave in 2023, clownfish in Papa New Guinea shrank in size[29].

Marine Life in Peril: Climate-Induced Changes in the Arctic Ocean Ecosystem

Global warming result in climate change in Artic Ocean that undergoes significant changes such as dramatic loss of sea ice. Arctic is approximately 67% marine region and since 1979 Arctic Ocean faced 40% loss of se ice [30]. This decrease of sea ice is not same at all areas, but it varies across different areas such as the Beaufort Sea, Chukchi Sea, Barents Sea, and the
Greenland Sea. By 2100, winters and summers temperature in Arctic could increase by 16 to 28°C[31]. This loss of ice caused serious consequences for marine species also that depends on ice for their reproduction and breeding. This also result in declining and phenological changes of marine animals. Species like cod, shrimp, jellyfish, snake pipefish are moving northward are

24 Fabry, V. J., et al. (2008). "Impacts of Ocean Acidification on Marine Fauna and Ecosystem Processes." *ICES*
Journal of Marine Science, 65(3), pp. 414–432

25 Hallegraeff, G. M. (2010). "Ocean Climate Change, Phytoplankton Community Responses, and Harmful Algal Blooms: A Formidable Predictive Challenge." *Journal of Phycology*, 46(2), pp. 220–235

26 Smith, C. (2016). Ocean acidification impacts on reproduction and survival of marine invertebrates.
Marine Pollution Bulletin, 103(1–2), 1–6

27 Bonachea, L. A. (2019). Climate change and its physiological impact on marine ectotherms. *Environmental*
Biology Reports, *24*(3), 199–214.

28 Bonachea, L. A. (2019). Climate change and its physiological impact on marine ectotherms.
Environmental Biology Reports, *24*(3), 199–214.

29 *The Washington Post*, "Clownfish Are Shrinking to Survive Climate Change," May 21, 2023,

30 National Snow and Ice Data Center (NSIDC). (2023). Arctic Sea Ice News & Analysis.
https://nsidc.org/arcticseaicenews/

31 IPCC (2021). *Sixth Assessment Report: The Physical Science Basis*. Intergovernmental Panel on Climate Change

moving to cooler water. One of the most prominent examples of Pacific diatom (tiny plankton) was found in the Atlantic is moving northward due to changes in ocean current. Some Arctic species like seals are facing problems in breeding due to ice reduction[32]. SubArctic species are moving northward and increasing its production, affecting predator-prey relationship that is ultimately reducing reproduction growth, Native predators face problems and struggle to find their prey, forcing them to change diets or migrate. Sea ice also provides safe shelter to sea algae that is foundation of Arctic food web, because sea algae is eaten by small animals (zooplankton), which are then eaten by fish, marine animals. Due to ocean acidification, it affects pteropods and shellfish which are important food for fish and whales that result in shrinking of many species in number or disappear from some areas. Arctic seas such as Greenland Sea, Beaufort Sea, Bering Sea, Chukchi sea are facing severe climate change that is impacting marine life there.

Case studies:

Barent Sea: The Barents Sea is among the most productive marine ecosystems globally, and it supports a rich variety of species such as more than 200 fish species, thousands of benthic invertebrates, and diverse communities of plankton, seabirds, and marine mammals[33]. This ecosystem not only maintains a wide variety of marine life but also hosts some of the world's largest fisheries, with major commercial species such as capelin (Mallotus villosus), polar cod (Boreogadus saida), Atlantic cod (Gadus morhua), haddock (Melanogrammus aeglefinus), redfish (Sebastes spp.), Greenland halibut (Reinhardtius hippoglossoides), and shrimp (Pandalus borealis) contributing to catches of close to 2.9 million tonnes in 2010 [34] .

Yet this extremely productive environment is facing radical transformation by climate change, most strongly by warming temperatures and a reduction in sea ice cover. Ever since the early 2000s, the Barents Sea has experienced one of the most rapid regional warming events ever documented with the record high temperatures since the beginning of the 20th century in 20042007. This warming has directly caused a massive decline in sea ice extent, exposing areas once covered in ice to greater human exposure in the form of shipping, tourism, mining, and oil and gas exploration, thus placing further pressures on the ecosystem. The melting of sea ice and warming of ocean temperatures have resulted in significant changes in species abundance and distribution. Cold-water, ice-associated species like polar cod experience habitat loss, while temperate species like Atlantic cod shift their ranges north into the Barents Sea. This realignment changes predator-prey balance and ecosystem structure, with ripple effects on food webs and fisheries.

It is located in Norway and Russia and one of the fastest warming regions in the world with declining of ice by 60% since last 5 decades[35]. Polar bears face reduces sea ice that force them to

32 Wassmann, P., Duarte, C. M., Agustí, S., & Sejr, M. K. (2011). Footprints of climate change in the Arctic marine ecosystem. *Global Change Biology*, 17(2), 1235–1249. https://doi.org/10.1111/j.13652486.2010.02311.x

33 ICES. 2010. Report of the Arctic Fisheries Working Group. ICES CM 2010/ACOM:07. International Council for the Exploration of the Sea, Copenhagen.

34 ICES. 2010. *Report of the Arctic Fisheries Working Group*. ICES CM 2010/ACOM:07. International Council for the Exploration of the Sea, Copenhagen

35 AMAP (Arctic Monitoring and Assessment Programme). (2017). Arctic Climate Change Update.

swim long distance between separated ice. This leads to reduce their body conditions[36]. Reduced sea ice has decreased the magnitude of phytoplankton booms which is very important for Arctic food web. It has also reduced zooplankton food availability and affecting fish population (Arctic cod) which is important source for seals and seabirds[37]. With increase in temperature, temperature species increasing in number while Arctic species decline, affecting predator-prey relation relationship[38].

Chukchi Sea: It lies between Alaska and Russia and important marine ecosystem for many species. It has faced 15% ice reduction per decade since 1980s, due to increase temperature of Arctic Ocean which is creating more drastic problem for many marine species that rely on ice for reproduction and survival[39]. Walruses also depend on sea ice, and they are forced to use land haul-outs that increase energy need and vulnerability to predators. In 2015, about 35000walruses hauled out in Alaska and hundreds of Calf deaths[40]. Ringed seals are also declining due to increasing warming in Arctic Ocean. Seals are primary source of food for polar bears and their reduction in population affect the multiple level of food web.

The melting of the Arctic oceans, such as the Chukchi, is not only endangering regional biodiversity but has worldwide implications. The decline of sea ice contributes to worldwide sea levels and affects climate patterns far beyond the Arctic region. If trends remain consistent, the Chukchi Sea's distinct and delicate ecosystem could suffer irreversible changes.

Shifting Species and Disrupted Balance: Behavioral and Ecological Responses in the Arctic Ocean

Climate change is still changing the migration process and behavior of Arctic species. As Arctic is warming nearly four times than global average temperature leading to changes in reproduction, migration patterns and timings of marine species. Many species such as polar bears, seals, narwhals which are dependent on ice for their survival, breeding and hunting are facing disruptions in their habitats[41]. Borealization of subarctic species in Arctic waters is introducing new form of competition for indigenous species. As a result, food chain has become disrupted and marine animals are shifting farther north due to ice melting and ultimately resulting in disruption of Arctic marine ecosystem[42].

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36 Laidre, K. L., et al. (2015). Arctic marine mammal population status and sea ice loss. *Conservation Biology*, 29(3), 724-737.

37 Wassmann, P., et al. (2011). Footprints of climate change in the Arctic marine ecosystem. *Global Change Biology*, 17(2), 1235-1249.

38 Hop, H., et al. (2015). Arctic marine food web shifts in the Barents Sea. *Polar Biology*, 38(8), 1171-1185.

39 Perovich, D. K., Meier, W. N., Tschudi, M. A., Farrell, S. L., Hendricks, S., & Gerland, S. (2019). *Sea Ice*. Arctic Report Card.

40 Jay, C. V., et al. (2012). Climate change and walrus habitat use. *Ecological Applications*, 22(8), 1965-1982.

41 Kristin L. Laidre et al., "Arctic Marine Mammal Population Status, Sea Ice Habitat Loss, and Conservation
Recommendations for the 21st Century," *Conservation Biology* 29, no. 3 (2015): 724–737,

42 Yang, C. (n.d.). *The impact of climate change on animal behavior: The Arctic marine and Monterey Bay ecosystems*.

Climate change impacts ecosystems globally and the entire biosphere. The behavior of predators in Arctic Ocean has changed. Ocean warming and acidification are altering reproductive behavior and timing. These interruptions pose threats to the sensitive ecological dynamics of the Arctic. Seabird species, like the ivory gull (Pagophila eburnea), are declining as a result of the destruction of ice-associated feeding habitats and extinction of ice-bound fish species. Furthermore, numerous fish species are moving northwards. For instance, Atlantic cod (Gadus morhua), capelin (Mallotus villosus), and other economically valuable fish inhabit Arctic waters where they previously did not[4]. This invasion brings new predators and competitors for indigenous Arctic species such as the Arctic cod (Boreogadus saida), which compromises established food chains. Migration patterns of whales like the bowhead whale (Balaena mysticetus) have also altered, with earlier onset of migrations and changes in routes because of warmer water and shifting prey abundance These changes profoundly affect Arctic Indigenous people, whose subsistence economies rely on reliable animal behavior and seasonal migration patterns for hunting and fishing[43]. These disruptions are not merely environmental but also cultural, since Indigenous Arctic communities, whose subsistence hunting relies on the predictability of wildlife behavior, experience mounting uncertainty and food insecurity[44]. The interdependence of species behavior, climate, and human existence highlights the farreaching impacts of Arctic climate change. Therefore, the changes in behavior of Arctic marine animals as a consequence of the increasing temperature, the breakdown of sea ice, and the modification of food supply demonstrate a rapidly evolving ecosystem under duress, with impacts reverberating throughout the biosphere.

Habitat Alteration: Global warming changes the habitat of northern species. These species rely on thick and icecovered area for resting and hunting. Melting ice don't only affect physical space of these species but also the whole ecosystem. Warmer water forces species to migrate to cooler areas leading to ecosystem instability. These factors not only affect the individual species but also threaten whole ecosystem in northern region. Global warming, due to climate change disrupts the reproductive cycle of Arctic marine species. Food availability is reduced by global warming. Less access to essential nutrients and they do not have energy resources enough for effective breeding.

Conclusion: Arctic Ocean is considered as one of the most rapidly changing ecosystems on this earth that is facing severe climate change. The sudden decline in the extent of sea ice, warming oceans, and shifted salinity regimes have triggered a cascade of ecological alterations that compromise biodiversity, destabilize food webs, and test the sustainability of natural resources vital to wildlife and human communities alike.

The Arctic Ocean is warming four times faster than global average, or the Arctic amplification. Our results affirm that the decrease in summer sea ice extent has achieved record low levels over the past few decades, with projections for further decline. This loss of sea ice significantly decreases habitat for ice-dependent species, including polar bears (Ursus maritimus), seals (Phocidae family), and walruses (Odobenus rosmarus). These animals depend on ice platforms for resting, breeding, and hunting. The loss of ice thus not only compromises their survival but also results in higher human-wildlife conflicts as animals venture closer to coastal populations in search of food.

43 Huntington, H. P. et al. (2007). The impacts of climate change on Indigenous marine subsistence hunting in the Arctic. *Arctic*, 60(2), 135–143.

44 Ford, J. D., Smit, B., & Wandel, J. (2006). Vulnerability to climate change in Canada's Arctic: A case study from Arctic Bay, Nunavut. *Global Environmental Change*, 16(2), 145–160.

In addition, the productivity and timing of phytoplankton blooms basis species of the marine food chain are being altered by modifications of water temperature and light penetration. The earlier onset of sea ice melting results in more rapid phytoplankton blooms that can become desynchronized from the lifecycle events in zooplankton and fish larvae that rely on this resource. Such a disparity is expected to lower the survival rates of juvenile fish species like Arctic cod (Boreogadus saida), which are of key importance as prey for higher trophic levels such as seabirds, marine mammals, and commercially valuable fish species. Our results also provide evidence of a northward shift of sub-Arctic and boreal species like capelin (Mallotus villosus) and Atlantic cod (Gadus morhua).

Although this might seem advantageous by adding diversity in species, it has the potential to upset established prey-predator dynamics and add competition for food sources. Invasive species imported through warming waters can also bring with them new parasites and diseases, which further strain native populations. This reorganization of ecosystems is a notable challenge for the stability and resilience of marine ecosystems in the Arctic. From a socioeconomic viewpoint, local communities and indigenous peoples that rely on the natural resources of the Arctic for food security, cultural identity, and livelihood are the most vulnerable. The traditional subsistence hunting and fishing lifestyles are threatened by declining numbers and changing animal behavior. In addition, the likely opening up of new shipping lanes and enhanced commercial fisheries because of decreased ice coverage can cause habitat destruction and pollution, posing threats both to wildlife and community livelihoods.

Findings:

- Arctic marine species are migrating earlier and moving farther north due to warming waters, threatening native marine life.
- Climate governance in the Arctic suffers from weak enforcement, limited Arctic-specific policies, and poor global coordination under bodies like the UNFCCC and Arctic Council.
- Limiting global warming through international agreements is essential for preserving Arctic marine biodiversity, reducing habitat loss for key species such as polar bears, seals, and Arctic cod, and ensuring the continued delivery of ecosystem services. Melting sea ice not only threatens top predators like polar bears but also reshapes the entire Arctic marine food web, influencing the abundance and distribution of phytoplankton, zooplankton, fish, and marine mammals.
- The Arctic Council emphasizes the importance of including Indigenous communities in environmental policymaking, recognizing their deep connection to the land and their long-standing observations of ecological changes.

Recommendations:

- Strengthen Climate Pledges and Arctic-Region-Specific Financing under UNFCCC Architectures. Boost climate finance for Arctic adaptation and mitigation under the Green Climate Fund (GCF) with a priority on protection of marine biodiversity and resilience of coastal communities.
- Promote transparency and accountability in reporting on emissions, particularly for nations that have high carbon footprints and affect polar areas disproportionately.
- Increase the Power of the Arctic Council to Enforce Binding Marine Conservation Protocols

- Legally enforce marine protected areas (MPAs) and conservation zones restricting industrial fishing and commercial shipping in ecologically sensitive zones.
- Invest in long-term research programs on Arctic marine ecosystems, including ocean acidification, ice cover dynamics, and species migration patterns.

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