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Climate Change and it's Impact on Marine Species.

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A B S T R A C T

Marine ecosystems are centrally important to the biology of the planet, yet a comprehensive understanding of how anthropogenic climate change is affecting them has been poorly developed. Recent studies indicate that rapidly rising greenhouse gas concentrations are driving ocean systems toward conditions not seen for millions of years, with an associated risk of fundamental and irreversible ecological transformation. The impacts of anthropogenic climate change so far include decreased ocean productivity, altered food web dynamics, reduced abundance of habitat-forming species, shifting species distributions, and a greater incidence of disease. Although there is considerable uncertainty about the spatial and temporal details, climate change is clearly and fundamentally altering ocean ecosystems. The non exploited North Sea species have responded markedly to recent increases in sea temperature, with nearly two-thirds of species shifting in mean latitude or depth or both over 25 years. For species with northerly or southerly range margins in the North Sea, half have shown boundary shifts with warming, and all but one shifted northward. Species with shifting distributions have faster life cycles and smaller body sizes than non shifting species. Further change will continue to create enormous challenges and costs for societies worldwide, particularly those in developing countries. Even though 243,000 marine species will have been identified by 2022, there is still much we don't know about the richness of the ocean. This information gap could have detrimental and far-reaching effects on the preservation of marine ecosystems, especially in light of the ongoing changes to our biosphere caused by humans, the rapid advancement of climate change, and other worldwide environmental upheavals.

Keywords: Trophic structure, Diversity, Food Webs, Climate changes & Ocean

Background

The physical and chemical characteristics of the ocean are changing due to climate change, which has an impact on marine ecosystems. Here, we examine data regarding how marine life has responded to the recent changes in climate in various oceanic regions, ranging from tropical seas to polar oceans. We take into account observed shifts in the phenology, abundance, distribution, demography, and calcification rates of marine organisms. We utilize data from the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, which is complemented by a database of observed effects of climate change on marine species. We talk about elements including fishing pressure, prey availability, habitat, light, and other resources, as well as dispersal by ocean. We discover that overall patterns in species' responses-such as distribution changes to deeper and higher latitudes, improvements in spring phenology, decreases in calcification, and rises in the number of warm-water species—are in line with predictions made by climate change. Different ocean locations and taxonomic groups have different amounts and types of information related to species responses to climate change; the majority of this evidence comes from the extensively researched north Atlantic Ocean. Few observations have been made about the effects of altering oxygen levels, wave climates, precipitation (coastal waters), or ocean acidification. The majority of studies on the effects of climate change have focused on the effects of temperature changes.

Rising atmospheric CO_2 levels and climate change in marine ecosystems are linked to simultaneous changes in temperature, circulation, stratification, nutrient input, oxygen content, and ocean acidification. These changes may have a broad range of biological effects. Physiological resistance to novel settings, modified dispersion patterns, and modifications to species interactions are causing population-level transformations. In addition to the invasion and extinction caused by local climate change, these processes change the variety and organization of communities and may even lead to the formation of new ecosystems. Because polar ecosystems are more vulnerable to sea-ice retreat, poleward species migration, and small temperature increases that affect coral-algal symbiosis, the effects are most noticeable in the tropics and the poles. Upwelling systems in the midlatitudes, such as the California current, exhibit strong linkages between climate and species distributions, phenology, and demography. Aggregated effects may modify energy and material flows as well as biogeochemical cycles, eventually impacting the overall ecosystem functioning and services upon which people and societies depend.

We identify regions with few records that do not represent current species richness, as well as regions adequately represented in terms of available records and so having more reliable data, using standard ecological and spatial analysis methodologies. To comprehend the impact of human activity on marine ichthyofauna, we combine these findings with the locations of fishing exploitation zones and marine protected areas. We also assess conjectures concerning the taxonomic, regional, and temporal distribution of information biases in order to enhance our present comprehension of global public records of species occurrences. Taking into account the analysis of almost 40 years of data, the findings demonstrated that, globally speaking, the primary data on marine fish available on the GBIF (Global Biodiversity Information Facility) and OBIS (Ocean Biodiversity Information System) platforms are still far from being representative and complete. For our studies, just 1.14% of the records were relevant. Furthermore, we discovered that the data appears to be skewed toward coastal locations, places next to wealthy nations, and regions with a high level of fishing activity. Lastly, species and families with small bodies that inhabit shallow habitats and are typically valued for their cultural or commercial worth.

Literature study

70% of the earth's surface is made up of rivers, lakes, and seas, home to a wide variety of aquatic animals that are ecologically significant consumers in aquatic ecosystems. These animals respond uniquely to changes in the environment at different temporal and spatial scales and have evolved highly effective survival strategies.

These species contribute to the flow of energy between trophic levels in the ecosystem and exhibit a variety of reactions based on how well they can adjust to changes in their surrounding. As a survival strategy, they may alter their habitat, control population density, and adjust to the shifting food web, or they may use genetic variety to promote local adaptability. Thus, biodiversity shifts as a result of how organisms react to changes in their environment. Marine ecosystems range from coastal to deep seas, tropical to polar seas, and pelagic to benthic zones. Both local and global climate change have an impact on these environments. Sedentary and migratory species react differently to environmental changes during their life cycles. Examples of this include squid (Todarodes pacificus) migrating from subtropical to subarctic waters, salmon (Oncorhynchus keta) changing their migration patterns between rivers and seas, and sedentary clams' physiological reactions to temperature increases in temperate coastal zones. Additionally, alterations in the marine environment result in the extinction of species, invasions, and modifications to dominant species, which can create new biological competitions like shifts in the food chain.

Additionally, modifications to the marine environment can result in the loss of species, invasions by new species, and shifts in the dominant species. These events can also give rise to novel biological competitions, such as adjustments to the food web, for which predators and prey need to have adaptable survival strategies. Effective analysis methods are also required to comprehend how ecosystems react to changes in their surroundings.

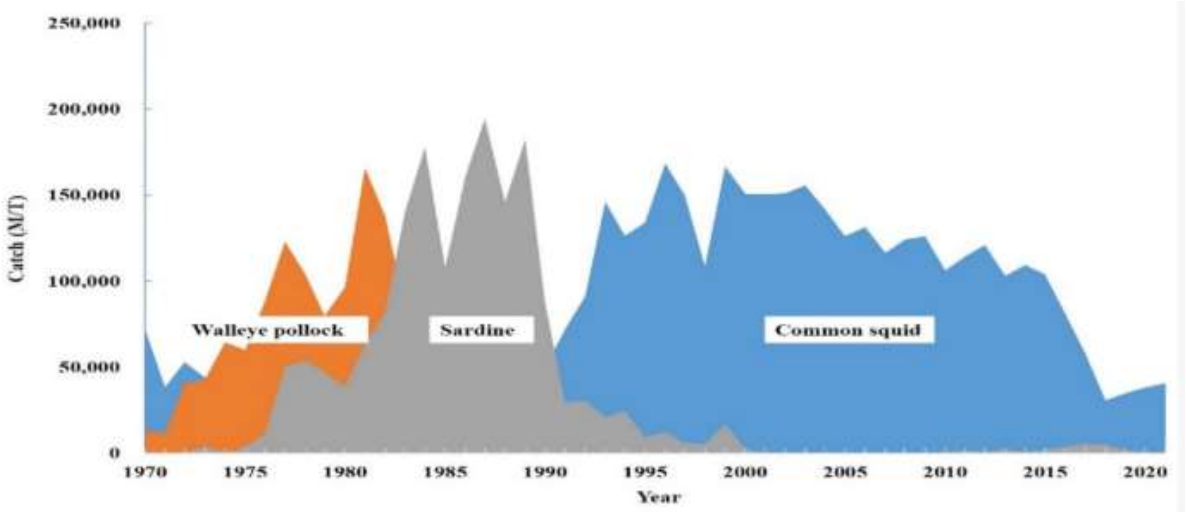


Figure 1- Changes in dominant species of fishery resources caught in the Pacific Northwest marginal seas.

Fish and invertebrates are crucial biological consumers in aquatic environments, and knowledge of their food supplies and trophic relationships is crucial to forecasting the top-down effects of prospective anthropogenic stressors and climate change. Understanding the functioning of aquatic ecosystems requires a thorough assessment of the trophic pathways and nutritional sources used by consuming species. Numerous researchers have shown how shifts in community structure and the migration, replacement, and depletion of particular aquatic animals in response to shifting environmental conditions can result in modifications to the topologies of aquatic food webs . In particular, prey-predator relationships, the abundance and composition of aquatic creatures, and their feeding habits can all be impacted by climate change, particularly through ocean warming.

Stomach content analysis has long been a standard approach for assessing changes in dietary sources and the structure of the food web. The trophic structure of aquatic creatures and the trophic transfer of organic matter based on the actual, longer-term assimilation diets of consumer species have been extensively studied recently using the stable isotope technique. More recently, it has become possible to apply metabarcoding with both quantitative and qualitative studies of prey species. With those technologies, we could gain a deeper understanding of how the changing climate is affecting the food web.

Variations in the temperature, salinity, currents, or carbon dioxide would undoubtedly cause different physiological reactions in different creatures, such as those related to growth, reproduction, or the metabolic pathway.

The earth's ecology has generally been greatly impacted by human activity over the past 100 years, and this is also true of the water environment. Aquatic animal habitats are being negatively impacted by human activity due to things like industrial pollution, recreational activities, agricultural pollutants, and climate change. Aquatic animals continue to exist by adjusting to and coping with the stressors brought on by these influences. This Special Issue will share scientific evidence for potential future changes and offer crucial information for understanding the physiological and ecological response characteristics of aquatic animals to changes in the marine environment at different temporal and spatial scales that arise during the process of climate change. The main effects of climate change on Europe's oceans include growing atmospheric carbon dioxide concentrations, rising world temperatures, and decreasing water oxygen concentrations. Approximately 30% of carbon emissions and 91% of the heat produced by rising greenhouse gas emissions to the atmosphere have already been absorbed by the ocean globally (IPCC, 2021; UNFCC 2021).

The "deadly trio" of climate change for marine biodiversity—ocean acidification, sea warming, and deoxygenation—are largely caused by carbon dioxide and rising temperatures .

Climate change and biodiversity loss are linked by the 'deadly trio'

Multiple, high-intensity stressors are a common feature of past mass extinction events. These stressors include increased global warming, ocean acidification and increased deoxygenation – together commonly referred to as climate change's 'deadly trio'. When these occur at the same time, the synergetic effects damage marine life and ecosystem structure and functions (Erwin, 2008; Veron, 2008; Barnosky et al., 2011).

Ocean Acidification

The availability of calcium carbonate for organisms is decreased due to ocean acidification, which is mostly brought about by carbon dioxide emissions. Due to this, it becomes more challenging for certain plankton, mollusks, and corals to develop and preserve their skeletons and shells. Since the pre-industrial era, ocean acidification has been quickly growing, with a 30% decrease in Ph . Due to acidification and carbonate skeleton loss, there could be serious effects on cold water corals in the North Atlantic Ocean. When organisms are affected by ocean acidification, the impacts spread across the food chain and have an influence on ecosystem services like fisheries.

Warmer Waters

Since the 1970s, the oceans have warmed steadily as a result of the absorption of extra heat brought on by global warming. The average temperature is predicted to rise by 0.88°C between 2011 and 2020 compared to 1850–1900, continuing this trend (IPCC, 2023). In April 2023, the global average sea surface temperature set a new record of 21.1°C (NOAA, 2023).

The metabolisms of organisms change in warmer water. For instance, the need for oxygen may rise in warmer water. As observed with many fish species, it can force mobile species to relocate and alter their range of distribution, changing food webs and ecosystem dynamics. Extreme weather conditions known as marine heat waves have the potential to completely wipe out local species, particularly when they occur in the summer. In 2003, something similar occurred in the Western Mediterranean Sea.

Heatwaves not only kill native species but also expose ecosystems to outside pressures such as non-native species. The "ecological space" that the extinction of native species leaves vacant can be quickly occupied by these. Thus, non-indigenous species have the potential to become invasive through ecological niche overtake.

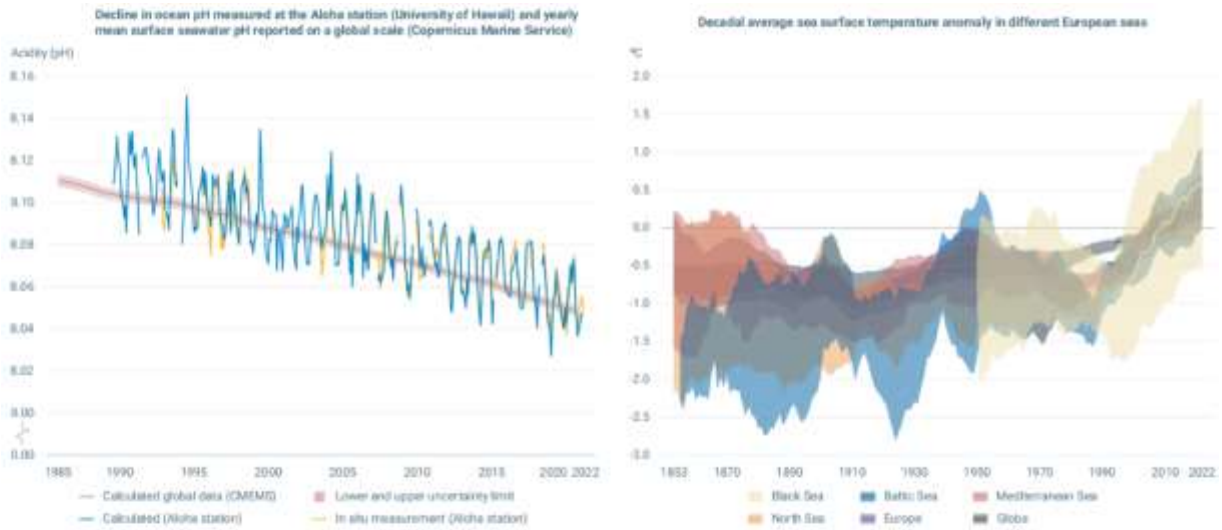
Deoxygenation of the ocean

Ocean warming causes deoxygenation, or the loss of oxygen in seawater. It happens because there is less dissolved oxygen in warmer seas. Along with greater stratification, altered ventilation, and increased oxygen consumption by diverse organisms, this also takes place (IPCC, 2019).

Deoxygenation can contribute to the spread of hypoxic or anoxic conditions, especially when combined with an increase in nutrient content brought on by increased precipitation or runoff from intensive farming. Many species, especially sessile (non-mobile) marine animals, will perish under these conditions.

Since the 1950s, the number of coastal areas affected by hypoxia has quadrupled (Breitburg et al., 2018). There are only a few regions in Europe where data on oxygen loss is readily available. Of the stations keeping an eye on the marine zones of the EU, 3% indicated an improving trend and 9% a deteriorating trend. However, no pattern could be seen for the remaining 88% (EEA, 2022c). By 2100, the world's oceans are expected to lose 3-4% of their oxygen content.

Figure2 The increasing trajectories of ocean acidification and sea warming are putting more stress on marine organisms



As the environment undergoes transformations due to climate change, the intricate processes and interactions shaping communities are also affected . Game theory, rooted in the principle of natural selection driving organisms toward optimizing reproductive success, has become instrumental in analyzing the evolution of phenotypes amidst environmental changes . While game theory traditionally addresses pairwise competition based on behavioral, size, age, and sex differences, climate stressors such as warming, acidification, and hypoxia disrupt these processes [88]. This disruption extends to alterations in food availability, predator-prey interactions, habitat competition, and selection, leading to destabilization in food webs and community dynamics . Environmental warming, particularly in damselfishes and estuarine fishes, impacts intra- and interspecific competition, shifts competitive dominance, and influences growth rates, ultimately modifying community structures and interactions. These findings highlight the nuanced and multifaceted impacts of climate change on marine ecosystems, suggesting that indirect effects may reshape interconnected species interactions.

Potential solutions

Climate change poses significant threats to marine species, necessitating urgent and comprehensive solutions. Mitigating the impacts on marine life requires a multi-faceted approach that addresses the root causes of climate change, promotes ecosystem resilience, and implements adaptive management strategies.

Reducing Greenhouse Gas Emissions:

At the core of combating climate change and its detrimental effects on marine species is the reduction of greenhouse gas emissions. Implementing stringent policies and international agreements to limit carbon dioxide, methane, and nitrous oxide emissions is crucial. Transitioning to renewable energy sources, enhancing energy efficiency, and adopting sustainable practices across various industries are essential steps in mitigating climate change impacts on marine ecosystems.

Conservation and Restoration of Coastal Habitats:

Protecting and restoring coastal habitats can act as a natural buffer against the impacts of climate change on marine species. Mangroves, seagrasses, and salt marshes not only sequester carbon but also provide critical breeding and feeding grounds for numerous marine organisms. Establishing and maintaining marine protected areas, along with habitat restoration initiatives, contribute to the overall resilience of marine ecosystems.

Sustainable Fisheries Management:

Implementing sustainable fisheries management practices is imperative for preserving marine biodiversity. Overfishing exacerbates the vulnerability of marine species to climate change. Adopting science-based quotas, promoting selective fishing methods, and reducing bycatch help maintain healthy fish populations and enhance their ability to cope with changing environmental conditions.

Promoting Climate-Resilient Marine Species:

Research and development efforts should focus on identifying and promoting climate-resilient marine species. This involves breeding programs and genetic studies to enhance the adaptive capacity of species facing increased temperatures, ocean acidification, and altered habitats. Additionally, supporting the migration patterns of species in response to changing conditions can aid in maintaining their populations.

Community Engagement and Education:

Engaging local communities in climate change mitigation and adaptation efforts is crucial. Empowering coastal communities with knowledge about sustainable practices, climate-resilient livelihoods, and the importance of marine conservation fosters a sense of stewardship. Community-based initiatives can lead to more effective and locally tailored solutions that align with the needs of the people who depend on marine resources.

International Collaboration and Policy Advocacy:

Addressing climate change impacts on marine species requires coordinated efforts on a global scale. Collaborative research, information sharing, and the development of transboundary policies are essential. Advocacy for international agreements that prioritize marine conservation and climate action, such as the Paris Agreement, plays a pivotal role in fostering a united front against climate change.

Conclusion

In conclusion, the complex web of interactions and processes that forms marine communities makes clear the significant effects of climate change on marine species. When one looks at the evolutionary dynamics fueled by natural selection through the prism of game theory, one may see the weaknesses and disruptions brought about by climate stressors like warming, acidification, and hypoxia. The destabilization of marine food webs and community structures is partly caused by these stresses, which have a complex impact on habitat selection, predator-prey relationships, food availability, and competition for habitats.

Changes in competitive dominance, growth rates, and niche space modifications are found in intra- and interspecific competition as a result of ongoing climatic warming. The reversal of competitive dominance is best illustrated by damselfishes that live in degraded coral ecosystems and have higher CO_2 levels. Estuarine fishes also exhibit variations in growth rates brought on by small temperature increases. The dynamic nature of marine ecosystems under strain from climate change is highlighted by the existence of range-extending coral reef fishes that modify their niches in response to temperate species.

Furthermore, the density-dependent effects on fish fitness traits highlight the complex ways in which population dynamics might be impacted by climate change. Crucially, the complexity of the effects of climate change on marine species is highlighted by the simultaneous occurrence of both positive and negative changes to community structures. The complexity of species interactions highlights the need for comprehensive conservation and adaptation methods since it raises the possibility that unintended consequences could upset the delicate balance of marine ecosystems.

It is critical to keep improving our knowledge of these intricate relationships, put sustainable fisheries management practices into place, and promote global cooperation to address the underlying causes of climate change in order to protect marine biodiversity and ecosystem resilience. To maintain the health and longevity of our oceans and the creatures that call them home, we must work together, find creative solutions, and make a worldwide commitment to addressing the challenges brought about by climate change.

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