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# The impacts of climate change on plankton as live food: A review

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**Abstract.** Climate change is expected to warm up the ocean surface where majority of life inhabits. Ocean warming influences vertical mixing and stratification patterns, which alter nutrient cycle, plankton production, and aquatic food web. Plankton serves as the first food source for all larval organisms and the base of aquatic ecosystem. Zooplankton community is a crucial component of the aquatic food web. They are critical components in an ecosystem of aquatic and worldwide biogeochemical cycles. Zooplankton contributes as food source to economically valuable fishes, primary-production grazers, and carbon and nutrient cycle drivers. Climate change contributes to dire consequences by altering the baseline of aquatic food web structure. However, the ocean biota itself can influence climate change, and the implications of this are evident from the increase and decrease of wild fisheries production. This review highlights the effect of climate change on phytoplankton and zooplankton production.

## 1. Introduction

Global warming has posed challenges to the marine and freshwater ecosystem and survival of species by altering physiological processes and food web structure [1]. The rate of temperature warming in the sea surface is forecasted to be higher in the 21st century compared to past centuries [2]. The effect of warming is higher on the marine ecosystem than the terrestrial ecosystem. Hence, global warming can jeopardize the marine food chain by altering phytoplankton and zooplankton production. Fluctuation of plankton production correlates with high temperatures at the bottom of marine food chain, resulting



in unstable vertical mixing and stratification [3]. Global warming is likely to shift zooplankton distribution and their life history pattern.

Phytoplankton serves as the basis of the aquatic food web and the functioning of ecosystems. Although phytoplankton accounts less than 1% of photosynthetic of earth's biomass, they are the main source of productivity in aquatic habitats accounting for almost 50% of the world's net main output [4]. [5] mentioned that the accumulation of uneaten plankton and other organic matters could cause the thriving presence of phytoplankton due to biological carbon pump. The biological carbon pump plays a crucial role in atmospheric CO<sub>2</sub> fluctuations and climate patterns. In addition, the production of phytoplankton and the growth of this primary producer community in the area of the euphotic zone are determined by the occurrence of organic substances [6]. Half of the primary production moves to the upper layer by metabolic activity and submerging in assimilated waste by the aquatic organisms and vertical migration of zooplankton [7].

Zooplankton is the source of life for most aquatic organisms, particularly fish and shellfish larvae, feed on phytoplankton, and move the food chain to the top predators [8]. The zooplankton community is a crucial component of the aquatic food web and plays a major role worldwide for the biogeochemical cycle. They contribute as prey to economically valuable fish, primary-production grazers and carbon and nutrient cycle drivers. These organisms are used as an intermediate species in the food web, transferring energy to the larger invertebrate predator and fish which feed on them from phytoplankton. At the same time, the changing environment has an impact on their dynamics.

The increased global demand for animal proteins has driven the growth of aquaculture industries worldwide [9]. As a result, aquaculture has grown rapidly worldwide and has played a significant role in the global fish supply, which has increased from 41 million tonnes to 90 million tonnes, with 6.7% annual increase in production [10]. However, unstable climate conditions have limited the production of fishery products and growth of aquaculture industries globally. Climate change has a direct and indirect impact on fish stocks. Direct effects alter physiology and behaviour, influencing growth, reproductive capability, mortality, and distribution. The productivity, structure, and composition of marine food-dependent ecosystems are all affected by indirect effects. This study looked at (i) the role of plankton in the aquatic food web, (ii) the impact of climate change on plankton production, (iii) the impact of climate change on tropical fisheries and food security, and (iv) the impact of current climate change events on fisheries production and aquaculture.

## **2. A brief overview of zooplankton life history/physiology and distribution**

Zooplankton has adapted numerous ways to float and defend themselves from predators in the surrounding water [11]. Some fish larvae have oil globules that assist buoyancy in the water [12]. Zooplankton are a vital component of the food chain and are preyed upon by all filter-feeding aquatic organisms [13, 14]. Zooplankton is a secondary producer in pelagic habitats and includes a wide variety of organisms. The zooplankton population of continental shelf seas may consist of larval stages of littoral and benthic invertebrates, in addition to creatures that spend their whole lives in planktonic stages [15]. In these nutrient-rich environments, zooplankton grazing activity is generally responsible for phytoplankton production regulation. In terms of biomass, abundance, and trophic role, copepods are the most important members of zooplankton [16]. To achieve maximum abundance, these populations follow various regional and seasonal patterns.

The ocean's hydrology and climate are affected by climatic oscillations, which can be compared to temperature fluctuations. Increases in the quantity of certain types of zooplankton can affect the distribution and abundance of other species [17]. At specific seasons, changes in temperature, wind, and the winter circulation pattern can provide unfavourable conditions for various types of plankton. On the other hand, natural events such as El-Nino can also create rapid changes in ocean heat content distribution. As a result, the abundance of zooplankton in the high temperature zone has typically decreased, while the abundance of zooplankton in the low temperature zone has expanded [18]. Interdecadal regime shifts in these two systems, driven by climatic variances in the atmosphere, are first reflected in changes in the ocean's physical structure, followed by large-scale biological reactions.

Because of changes in secondary production and community structure, these regime changes profoundly impact the temporal and spatial distribution of planktonic species. There are fewer zooplankton species as you move up the water column and to higher latitudes, yet they are abundant [19]. Zooplankton, particularly copepod species, play an important role in the pelagic food web since they are the primary food supply for fish larvae.

### 3. Interaction of zooplankton with nutrient-phytoplankton interface

#### 3.1. Role of zooplankton in the marine food web

Plankton forms the first link between abiotic and pelagic fish, playing a significant role in energy transfer in marine food webs. Climate changes and related variations in primary and secondary development impact the distribution area, stocking density and migration behaviour of various marine fish. A few pelagic fish species that consumes plankton are affected such as the pelagic fish herring (*Clupea harengus*), Indian mackerel (*Rastrelliger kanagurta*), Capelin (*Mallotus villosus*), Blue whiting (*Micromesistius poutassou*), Anchovy (*Engraulis ringens*) and Sardines (*Strangomera bentincki*). These small fish populations also form a large portion of the overall animal population, and their abundance variations have had bottom-up impacts [20].

Furthermore, the abundance and distribution of fishes is not clarified by temperatures and their feed habitat. Zooplankton is an important component of aquatic pelagic food webs because it serves as a resource for eaters at higher trophic levels. The abundance and diversity of zooplankton are also affected by salinity and available diets in the ecosystem. Therefore, water salinity shifts also can alter the original taxa composition and ecological processes, such as primary productivity, decomposition, nutrient cycles, and food web function [21]. The observed enhanced growth rate of small pelagic fish was attributed to the increased quantity of zooplankton and the projected rise in demand. Increased precipitation and river runoff to aquatic environments are thought to encourage a bacteria-based food web, lowering pelagic production at higher trophic levels [22]. Pelagic predation and the availability of resources by lateral and vertical nutrient inputs define the population structures of plankton [23]. Variations in trophic transfer efficiency, food chain length, the proportion of benthic and pelagic fishes, and changes in fish metabolic requirement in cold and warm habitats all contribute to the relevance of primary production-primary production connections [24].

Primary productivity will increase during *El-nino* in some parts of the world. In contrast, [25] stated that the highest landed catch for sardine fishing occurs during *El-nino*, relative to non-*El-Nino* conditions. *El-Nino* boosted the upwelling of pelagic plankton-alimentary ecosystems. Even though increased productivity gives a higher food supply than phytoplankton, this can also lead to blooms in some algal species [26]. Algal blooms influence shellfish and contribute to fish-killing due to the lack of oxygen. Plankton may change their vertical position in the water column to avoid oxygen in the waters. Oxygen solubility is also affected by salinity, but perhaps the temperature effect is almost three times that of adjusting one salinity unit [27].

#### 3.2. Role of zooplankton in the biogeochemical cycle

Larger creatures in the water eat the proportion produced by zooplankton grazing on phytoplankton, smaller zooplankton, or organic debris. Because most sinking organic matter is remineralized to the inorganic matter at depths where it becomes isolated from the atmosphere for decades to centuries, production by a fraction of primary producers that fall below the mixed layer impacts biogeochemical and climate processes [28]. Larger plankton activity, particularly the generation and sinking of faecal pellets by mesozooplankton and macrozooplankton and larger animals, as well as the aggregation of diatoms, are the primary drivers of export production. As a result, export production reduces inorganic carbon concentrations on the surface and keeps atmospheric CO<sub>2</sub> levels around 200 parts per million lower than they would be without biological activity [29]. Bacteria and small zooplankton, on the other hand, re-mineralize and recycle organic matter in the upper ocean, limiting the amount of organic matter exported. The status of the environment, such as temperature, light, available nutrients,

and vertical mixing, govern these ecosystem processes, which are modulated by the plankton community's ecosystem structure.

The predator-prey size ratio was used to attribute feeding preferences to zooplankton. Even though there are data sets on zooplankton physiology, few research has looked at the involvement of various zooplankton in global ocean biogeochemical processes. Grazing, repackaging of organic matter in faecal pellets, and vertical migrations in the mesopelagic realm are all activities that zooplankton might use to influence the fate of exported materials [30]. Furthermore, research-based on regional models have revealed significant connections between grazing, nutrient cycles, and environmental conditions [31]. As a result, a more detailed depiction of various zooplankton could reveal vital information about how marine biogeochemistry works. More observation-constrained mechanistic parameters of zooplankton dynamics have been shown to improve simulations of phytoplankton biomass, the choice of grazing formulation to influence phytoplankton diversity and the resulting food web dynamics.

#### 4. Effect of climate change on plankton production

##### 4.1. Temperature

According to [32], phytoplankton biomass depends on temperature and nutrients. Temperature can affect the supply of nutrients when high in ambient and low when warming. When nutrient availability is reduced, warming contributes to the decrease of plankton biomass. Biomass production could be high if the nutrient is abundant, but the insufficiency of nutrient supply may contribute to detrimental temperature effects. [33] stated that zooplankton productivity is higher when the temperature is increased. This indicates that temperature directly influenced the diversity of the zooplankton. Therefore, increased temperature caused by the earth's climate can affect the zooplankton abundance. In addition, temperature affects the physiology and metabolic levels of phytoplankton. The basic metabolic processes of phytoplankton cells, including photosynthesis, respiration, and increase in nutrient intake, rely on temperature but decline sternly above the optimum temperature [34]. Temperature also influences the viscosity and density, such that the sinking rate of small suspended particles such as plankton is closely affected. Changes in the sinking levels may be critical if phytoplankton survival remains suspended.

[35] demonstrated that warming and shallow stratification incorporated into the water column of a profound lake separately accelerate the occurrences of weather changes to the extent to where marine organisms are not exposed to their vulnerability to the increased ground temperature. The long-term average climate influences biota, not only in the physical structures but also in the marine environment and habitat. A temperature rise is assumed to lead to a higher plankton growth rate and biomass accumulation [36]. Due to climate change and eutrophication interactions, the possibility of damaging phytoplankton production in the ocean has increased. Competition of zooplankton with phytoplankton exploitation can lead to diminished in survival, growth, and reproduction of zooplankton. The coastal ecosystem changes the plankton species due to warmer temperatures and the emergence of temporary mismatch between predators and their prey. Therefore, zooplankton represents the largest secondary producer in the oceans, with primary and planktivorous production interface. Thus, it is critical to transfer nutrients to a higher trophic level.

A warmer aquatic environment is becoming could pose serious challenges to plankton physiology and production. [37] found that *Calanus finmarchicus* biomass was temperature-dependent, where a combination of mixed layer depth and shallow caused this plankton to seek food from the bottom-up until the pelagic area. The warmer temperature did not cause an increase in *C. finmarchicus* biomass. Instead, spring biomass is generally higher, but population growth from spring to summer is low. This has shown that temperature changes may shift towards organisms better suited for warmer waters and potentially disrupt the food web.

#### 4.2. Ocean Acidification

Acidification has a variety of effects on zooplankton. Lower calcification rates and acid-based physiological disturbances are examples of direct acidification reactions that might affect other biological functions. Changes in the abundance, composition, and quality of their food source, while more challenging to assess, can significantly impact organism function [38]. Adult non-calcifying zooplankton is thought to be more acidifying than calcifying zooplankton, while the detrimental effects are amplified in their early stages of life [39]. Lower survival, hatching success, and uneven larval growth have all been seen in diverse zooplankton species during early stages. Thus, acidification can, directly and indirectly, impact zooplankton development, growth, reproduction, and population number.

**Table 1.** Plankton species and effect on climate change.

Plankton	Impact to the species	CO <sub>2</sub> level (µatm)	Effect of climate change	Reference
Phytoplankton	<i>Chlorella vulgaris</i>	200 >	Boost their susceptibility to disease and infection and physiological impacts on growth and development.	[40]
Phytoplankton	<i>Chaetoceros muelleri</i>		Impact in changes of biochemical content and affected to growth.	[41]
Phytoplankton	<i>Isochrysis galbana</i>	800 >	Impact in changes in fatty acid content and may have a major impact on the food system.	[41]
Phytoplankton	<i>Vicicitus globosus</i>	600-800	Impact on the population of the plankton, inhibiting the development of mesozooplankton communities, rupturing the trophic migration of primary organic substance	[42]
Zooplankton	<i>Acartia</i> sp.		Parallel effects of warming will affect density and also could affect to the other species of zooplankton biomass	[43]
Zooplankton	<i>Moina macrocopa</i>		Impact to life table, fatty acid and population dynamics	[21]

## 5. Vulnerability of zooplankton community to global warming

### 5.1. Change in the life history pattern

Climate changes are likely to affect both individual organisms and species relationships, resulting in complex responses at the community and ecosystem levels, thus it's vital to grasp their effects. Due to their response toward temperature swings, they are highly susceptible to environmental changes in their physical surroundings. Adjustments in their abundance and phenology have been attributed to a variety of weather factors in a variety of aquatic settings, where copepods and rotifers regularly interact and constitute a typical mutualistic relationship [44]. Moreover, according to [45] state that, short-lived rotifers and long-lived copepods have vastly different life histories and body size, which could lead to a wide range of sexual responses to global warming. Studies by [46] demonstrate that increased temperatures can cause rotifers to multiply at a rapid rate and with a short generation duration. In comparison, the delayed reaction to rising temperatures can be seen in sexually reproducing copepods for a longer generation, including an embryonic stage, six naupliar phases of development, five juvenile phases and adult stage [47]. These divergent effects of climate fluctuation on predators and beasts could induce temporal mismatch between predators [46].

Rotifers and copepods have unique techniques for diapause. Resting eggs cause diapause and the life cycle normally starts when epiphia are hatching into amictic females that then replicate in the water column [48]. In contrast, copepods enter diapause during their adult or subadult stages, and there are no reports of copepods generating epiphia [49]. Due to the fact that warmer conditions can trigger diapause induction and termination [49], zooplankton with variable diapause mechanisms may exhibit distinct reactions to climate change and variation of temperature. In addition, various zooplankton species have an influence on the temperature at different levels. Creatures with shorter cycles of life frequently respond more quickly to changing temperature than organisms that having longer biological processes [45]. Large-scale perturbations caused by climate change may have a significant impact on the natural equilibrium of zooplankton communities and, as a result, may have ramifications for the entire aquatic environment.

## 6. Illustration of current earth's climate event on fisheries and aquaculture production

**Table 2.** Potential impacts of climate change on aquaculture systems

Drivers of change	Impacts on culture systems	Operational impacts	Reference
<b>Sea surface temperature changes</b>	<ul style="list-style-type: none"> <li>Rise in harmful algal blooms</li> <li>Increased disease and parasites for longer seasons and decreased dissolved of O<sub>2</sub></li> <li>Competition, parasitism and carnivorous from changing local and competing habitats and invasive species</li> </ul>	<ul style="list-style-type: none"> <li>Maintenance and running costs changes</li> <li>Increased predator, pets, fouling, and pests, nuisance species</li> <li>Production levels changes</li> </ul>	[50]
<b>Changes in other oceanographic variables</b>	<ul style="list-style-type: none"> <li>Reduce food availability to shellfish and flushing rates.</li> <li>the availability of food change and fish meal products</li> </ul>	<ul style="list-style-type: none"> <li>Accumulation of wastes at sediment</li> <li>Operating costs higher</li> </ul>	[51]
<b>(SLR) Sea level rise</b>	<ul style="list-style-type: none"> <li>Aquaculture area loss</li> <li>Providing physical protection area loss</li> <li>Flooding risks of salt intrusions into freshwater improve</li> </ul>	<ul style="list-style-type: none"> <li>Damage in infrastructure</li> <li>Aquaculture zoning changing</li> <li>Reduced availability of freshwater</li> </ul>	[52]
<b>Increased storm activity</b>	<ul style="list-style-type: none"> <li>Larger waves and higher surges</li> <li>Flooding from precipitation salinity changes</li> <li>Damaging structure</li> </ul>	<ul style="list-style-type: none"> <li>Stock loss</li> <li>Damage facility</li> <li>Rise in costs for new facilities</li> <li>Rise in insurance costs</li> </ul>	[50]
<b>Drought and water stress</b>	<ul style="list-style-type: none"> <li>Salinity changes</li> <li>Low water quality</li> <li>Higher diseases uncertain water supplies</li> </ul>	<ul style="list-style-type: none"> <li>Damage facility</li> <li>Outer water users' conflict</li> <li>Production capacity low</li> </ul>	

Climate change is a global issue and poses a significant threat to the aquaculture industries [53]. Environment-friendly variables, such as high survival rates, development, and reproduction of fish

species, determine aquaculture's sustainable growth (Table 2). However, due to the significant contributions of aquaculture industries to financial development, especially in fuelling the economics, concerns about environmental externalities and the implications associated with the sustainability of aquaculture production have increased. Besides, fewer seed supplies and institutional supports were restricted to expand their agricultural operations. Therefore, the absence of sustainability and responsible aquaculture practices have been identified as some of the main flaws in the aquaculture industries, resulting in losses and reflecting a lack of leadership [54].

Climate change is a natural climate phenomenon that indirectly affects ecosystems and aquaculture development (Table 2). There is no certainty that the indirect effects of climate change on aquaculture will be related to aquaculture's dependence on external food supply. Such external inputs are potentially influenced by climate change; thus, indirectly affecting the aquaculture industries. According to [52], climate change impacts the aquaculture sector through the fluctuation of fish populations in the fishery ecosystem.

The sustainable growth of aquaculture is affected by biophysical variables, such as climate change and extreme weather. The increase in temperature, a decrease of dissolved oxygen and pH, variation in water quality parameters and uncertainty, several crucial climatic events, regularity of disease outbreak, viruses and toxic outbreaks, rising of sea levels, and possibility of fish stock (fish meal) for aquaculture feed are drivers of climate change that threaten the aquaculture operations. The modifications in physiological, ecological, and operational elements of aquaculture operations include weather, such as the modifications in the temperature, annual rainfall, stratification, and change of rainy and dry seasons [50].

Furthermore, climate change also causes disease outbreaks in the fish and shrimp cultures in its development. Agricultural production of dry foods (that fish feeds today depend on) also can be reduced; therefore, fresh and viable resources to produce more natural food, such as algae should be explored. This pressing challenge requires the aquaculture industries to seek for innovative alternatives. [55] demonstrated that access to protein, minerals, and omega 3 with essential fatty acids poses the most significant challenge to aquaculture. In addition, aquaculture and plankton distribution are increasingly exposed to extreme weather conditions. The effects of fish and shellfish, which may further boost their susceptibility to disease and infection, are associated with various stresses and physiological impacts that influence their growth and development.

In aquaculture, plankton cultivation is essential as new fish and crustacean seeds should be made, and high-quality starter feed should be prepared. Besides, there are direct or indirect adverse impacts of climate change on the natural aquaculture assets, such as seeds, water, energy, and feeds, on aquaculture's productivity and profitability levels. The large percentage of fish farming continues to depend on fish and shellfish at the bottom of the food web. In addition, microalgae also developed and may possibly act as carbon sequestration; thereby, helping to sequester carbon. Eventually, while most of those uncertainties are the extent of the earth's climate on aquaculture and its adaptability, aquaculture is influenced. Therefore, precautions should be taken to continue this operation, especially with the increasing dependence of the global population on aquaculture.

## **7. Future research directions**

Despite the difficulties inherent in testing and understanding how climate change affects microbial food webs, future research efforts should account for natural variations above and below mean trends in environmental drivers, as these fluctuations may become more frequent and intense as a result of ongoing global warming. We emphasize the need for a more complete understanding of the scale and the effect of zooplankton on water quality (related to climate change) at different plankton levels (from producer to last consumer in ecosystems), different scales of temporal and salinity (short and long runs), the types of ecosystems (sea and freshwater) and the effect of zooplankton on water quality alterations.

## 8. Conclusion

The increasing concern about climate change effects in the last few decades provides a clear picture of the significant modification of the plankton ecosystem. However, the ocean biota itself can influence climate change, and the implications of this are clearly evident from the increase and decrease of wild fisheries production. In order to recognize future changes in marine ecosystems, continuous plankton surveillance programmes around the globe should serve as a sentinel. The maintenance of plankton time-series and financing projects with the ongoing mining of distinctive information sets provided by these time-series are crucial in determining future changes.

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