Climate Change Impacts on Zooplankton Phenology and Migration Patterns in Rajasthan: A Mechanistic Modeling Approach

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Abstract:

With changes in temperature, salinity, and hydrological cycles, among other environmental factors, climate change is dramatically affecting the phenology and migration patterns of zooplankton, which is an important organism in aquatic ecosystems. Rising global temperatures and changing precipitation regimes are having an adverse effect on zooplankton phenology, which controls the timing of vital life events like feeding and reproduction, as well as their vertical or horizontal migration patterns. In order to comprehend these effects, a mechanistic modeling approach is discussed in this review. It focuses on freshwater and marine ecosystems, with particular attention to freshwater zooplankton in areas such as Rajasthan. Mechanistic models use temperature-driven growth and metabolic models, hydrological models, and ecosystem models to predict changes in zooplankton dynamics. These models mimic the physiological reactions of zooplankton to environmental changes. The findings point to potential mismatches between zooplankton and their main food sources, such as phytoplankton, as well as earlier seasonal blooms and higher metabolic rates. These factors could have a domino effect on aquatic food webs. The effects of climate change are exacerbated in shallow freshwater systems, like those in Rajasthan, by increasing salinity, less water available, and unpredictable monsoons that change the habitat and dispersal patterns of zooplankton.

This study offers insights into how zooplankton communities will be impacted by climate-driven environmental changes through mechanistic modeling, with broad implications for ecosystem services, biodiversity, and fisheries management. Nonetheless, there are still unknowns, particularly in areas with limited data, which calls for more field research to improve models and forecasts of the long-term effects of climate change on zooplankton populations.

Keywords: Arid region, Climate change, Environmental variables, Zooplankton Phenology

1. Introduction:

The study of zooplankton in Rajasthan, an arid and landlocked region of India, requires a specialized approach because of its distinct freshwater ecosystems, which include lakes, reservoirs, and seasonal water bodies. Freshwater zooplankton, which is essential to these ecosystems, takes center stage from marine systems. The primary habitats of zooplankton in Rajasthan's freshwater ecosystems are lakes, rivers, reservoirs, and wetlands, including Pushkar Lake, Jawai Dam, and Sambhar Salt Lake. Daphnia, Bosmina, and rotifers are examples of freshwater zooplankton species that are essential for the cycling of nutrients and serve as fish and other aquatic organisms' main food sources. This review examined how zooplankton communities may respond to climate change in the future, both as it has been observed and as it may develop. The main focus is on how global warming affects stratification and nutrient enrichment processes by heating the ocean's upper layers. Copepod research predominates in the literature on zooplankton due to the organism's global reach, significance in marine foodwebs, resilience in the lab, and bias in sampling and preservation. The author of this review attempted to concentrate on research pertaining to the effects of climate change on the phenology and migration patterns of zooplankton in Rajasthan. The results of this review will be useful in measuring and forecasting the responses of zooplankton populations and behaviors to changes brought about by climate change.

2. Global importance of zooplankton:

Zooplankton is a diverse group of small microscopic organisms that leave in water. They play very important role in aquatic ecosystems and have global importance. Fish, whales, seabirds, and other marine animals depend on zooplankton as their primary food source. Zooplankton are tiny photosynthetic organisms that they consume. Fish populations around the world, which are vital to food security and global economies, would be negatively impacted by the collapse of the food chain that supports larger aquatic species in the absence of zooplankton. Zooplankton participate in the "biological pump," which is the process by which they transfer carbon to the Earth. Their bodies sink to the ocean floor when they die or excrete waste, and they feed on phytoplankton that absorbs atmospheric CO2 through photosynthesis. By lowering the amount of CO_2 in the atmosphere, this helps sequester carbon from the atmosphere and mitigate climate change.Zooplankton is an essential component of aquatic ecosystems because it recycles nutrients. By eating phytoplankton and detritus, they replenish the water with nutrients like phosphorus and nitrogen, encouraging more phytoplankton growth and maintaining the primary productivity of lakes and oceans.Aquatic ecosystems' biodiversity is enhanced by zooplankton. Population fluctuations in zooplankton can be used as early warning signs of changes in the environment, including declining water quality, acidification of the ocean, and the consequences of climate change. Scientists can evaluate the health of aquatic ecosystems by keeping an eye on zooplankton populations because they are sensitive to changes in their surroundings.

3. Zooplankton phenology and migration patterns observed globally:

Phenology and migration patterns are vital components of life cycle of zooplankton and have a big impact on marine environments. These patterns have profound effects on food webs and the cycling of nutrients. They are influenced by environmental cues like light, temperature, and the availability of food. Zooplankton species typically reproduce in tandem with the availability of phytoplankton, which is their main food source. Because of increased sunlight and nutrient availability, phytoplankton blooms happen in spring and summer in temperate and polar regions. This phenomenon causes a corresponding rise in zooplankton populations. Changes in the timing of phytoplankton blooms, often driven by climate change, can disrupt zooplankton phenology, potentially causing "trophic mismatches" where zooplankton populations peak when food availability is low. Seasonality is present in the developmental stages of zooplankton. In the winter months, many species go through diapause phases, or dormancy, especially in polar and temperate waters. One such species is the copepod. In the period of diapause, zooplankton retreats to deeper waters, where they cease growing until the water temperature rises or spring blooms appear. The impact of ocean warming on zooplankton phenology timing is substantial. Reproduction, growth, and migration patterns can all be affected by slight variations in water temperature. The entire marine food web is impacted by this, especially the species that depend on zooplankton for sustenance. Diel vertical migration, or DVM, is one of the largest mass migrations on Earth exhibited by zooplankton, as they migrate daily up and down the water column in response to environmental conditions. When it's sunny outside, zooplankton usually heads for deeper waters to avoid being eaten by predators like fish that hunt by sight. The distribution of predators and light levels frequently dictate the depth to which they descend. They move upward to surface waters at night in order to feed on phytoplankton and other food sources that are accessible. They limit their vulnerability to predators by engaging in this activity at night. DVM is essential for sequestering carbon and cycling nutrients. In essence, zooplankton transfers carbon to the deep ocean by moving organic matter from surface waters, where they feed, to deeper waters, where they decompose or die.

4. Environmental factors which effect the zooplankton migration and phenological patterns observed globally:

The main cause of DVM is light availability, especially the diel light cycle, since zooplankton use daylight to evade predators. Seasonal variations in temperature affect the depth of vertical migrations as well as phenological processes like diapause and reproduction. Zooplankton frequently synchronize their reproductive cycles and migrations with phytoplankton blooms to guarantee an abundance of food for their larvae and juveniles. Numerous zooplankton migrations are adaptive reactions to evading predators. Moving to darker, deeper waters during the day lessens the chance of being eaten. In aquatic ecosystems, the regulation of energy flow, nutrient cycling, and food web interactions is contingent upon the phenology and migration patterns of zooplankton. Environmental factors, especially climate change, can alter these patterns and have far-reaching ecological effects. Certain zooplankton species also migrate vertically during the seasons, especially in the polar and temperate regions, in addition to their diel migration. They migrate to deeper waters to overwinter, frequently going into a state of diapause, during the colder months. They migrate back to shallower waters in the spring and summer to feed and breed. Certain zooplankton species migrate horizontally in response to water currents, seasonal variations, or particular life cycle stages, despite the fact that vertical migration is more frequent. Because zooplankton can move between different habitats, it can affect the distribution of other marine species that rely on them for food.

5. Different Mechanistic Modeling Approaches to Examine How Rajasthan's Climate Affects Zooplankton Parameters:

5.1 Temperature-Driven physiological Models: These models forecast the effects of increasing water temperatures on the growth, reproduction, and metabolic rates of zooplankton. Q10 models, for instance, can be used to simulate how biological processes quicken with a temperature increase of 10°C. Higher temperatures have been linked to earlier peaks in zooplankton abundance, which may desynchronize with freshwater body food availability in Rajasthan, according to mechanistic models.

5.2 Food Web Models: Mechanistic models can also be created to forecast the potential cascade effects of changes in zooplankton phenology on populations of fish that depend on them for food and other higher trophic levels. Reductions in biodiversity may result from a shift toward species that are tolerant of heat and salinity, according to models that take temperature and salinity changes into account.

5.3 Salinity Models: To determine how the composition of zooplankton species will change (e.g., from freshwater species to more saline-tolerant species), salinity changes in areas such as Sambhar Lake caused by evaporation or decreased freshwater input could be modeled. Changes in the timing and abundance of zooplankton in reservoirs like Bisalpur may have an effect on fish populations that depend on them for food, which could have an effect on the productivity of the fishery.

5.4 Hydrological Models: This Models that mimic the impacts of rainfall patterns, evaporation rates and water retention are essential for comprehending how climate change will affect habitat availability, since Rajasthan's zooplankton depends on monsoon-fed lakes and reservoirs.

6. Impact of Climate Change

6.1 Climate Change impacts on freshwater bodies in Rajasthan.

The Earth's climate system's current modes of variability are probably responsible for a large portion of the effects of climate change on zooplankton. The expression for these climate modes is variations in the synoptic atmospheric pressure fields. Global warming is causing temperatures in Rajasthan to rise, which has an impact on freshwater bodies' thermal characteristics. Water levels and the hydrological regimes of lakes and reservoirs are altered by changes in monsoon patterns, which has an immediate effect on the habitats of zooplankton. Higher temperatures cause evaporation rates to rise, which shrinks water bodies and changes their depth and size. This can lower zooplankton populations and change their migration patterns (Ref….). Furthermore, higher evaporation in Sambhar Salt Lake can concentrate salts, changing the salinity and affecting the species composition of zooplankton (Ref..). It is anticipated that the hydrological cycle—which involves soil moisture, evapotranspiration, and precipitation-will be significantly impacted by climate change. A temperature shift or increase is the most obvious indicator of climate change. The most susceptible to temperature changes is crop water requirements or evapotranspiration. Therefore, any change in temperature will have a significant impact on the total amount of water required for crops, which will then have an impact on any area's water resources. The goal of the current study is to understand how Rajasthan's water resources are likely to be affected by climate change. The Penman-Monteith equation was used to calculate reference evapotranspiration (ETo), and Goyal and Gaur, (2022) investigated the sensitivity of ETo by raising the temperature from 1% to 3% while maintaining other parameters constant. An annual increase in temperature of 1% (≤0.42 °C, given Rajasthan's typical maximum temperature) will result in an increase in evapotranspiration demand of 11.7 mm.

6.2. How Rajasthan's climate affects phenological shifts

The timing of recurring seasonal events like migrations and reproduction is known as phenology, and it is extremely vulnerable to climate change. On land, springtime events like the emergence of butterflies in the US, the arrival of swallows in the UK, or the blossoming of cherry trees in Japan all occur earlier in the year as a result of rising temperatures. Despite the fact that zooplankton phenology has been studied far less than that of terrestrial plants, insects, or birds, an analysis of the data that is currently available indicates that zooplankton phenology changes are substantially larger than those of terrestrial groups.

The growth, development, and reproduction rates of zooplankton are accelerated by rising water temperatures, which may result in earlier seasonal blooms. A mismatch between the timing of phytoplankton blooms, which are caused by temperature and light availability, and zooplankton reproduction could result in food scarcity for the zooplankton, as many freshwater zooplankton feed on phytoplankton (ref..). Furthermore, irregular monsoon patterns may cause the usual cycles of the wet and dry seasons to change, which would affect the life cycles of zooplankton, which depend on particular temperatures and water levels to survive.

6.3. Climate's effects on patterns of migration and dispersal

While diel vertical migration is more noticeable in deep lakes, this behavior is constrained in Rajasthan by the shallow nature of many water bodies. Rather, horizontal migration—the movement of zooplankton within a body of water in search of ideal conditions—may be impacted by climate change (e.g., cooler, less saline zones). The dispersal of zooplankton, including diapause eggs, can occur between bodies of water due to rainfall or flooding. With unpredictable precipitation, the dispersal process might be impaired, impacting species' spread and colonialism.

7. Conservation and management implications on climate change in zooplankton phenology

There is several ways to stop or reduce impact of climate change in zooplankton phenology like we should focused towards the management of fishing. Moreover we should also focused and identified area for zooplankton refugia. knowledge of these information would be helpful to manage the adverse effect of climate change.

8. Conclusion

In Rajasthan, the distinct features of its freshwater ecosystems must be taken into consideration when utilizing a mechanistic modeling approach to investigate how climate change is affecting zooplankton. Zooplankton phenology and migration will probably change in response to changes in temperature, precipitation patterns, and water availability. This will have an impact on the health of the ecosystem and the services that these bodies of water offer, like fisheries. Climate change is expected to have a major impact on the phenology and migration patterns of zooplankton in Rajasthan's freshwater ecosystems. This will have far-reaching implications for the health of the ecosystem and related services like fisheries. The life cycles, distribution, and survival of zooplankton species are expected to be altered by temperature rises, changes in rainfall patterns, and fluctuations in the availability of water. This will likely disrupt their vital roles in the cycling of nutrients and the maintenance of food webs. Mechanistic modeling, which incorporates the distinct ecological and climatic features of the area, offers a useful tool for comprehending and forecasting these changes. These models can help develop adaptive strategies for sustainable resource management by providing insights into the adaptability of freshwater ecosystems under various climate scenarios. Taking into consideration the intricate relationships between zooplankton dynamics and environmental factors, this method is essential for predicting the cumulative impacts of climate change and guaranteeing the long-term well-being and efficiency of Rajasthan's aquatic ecosystems.

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