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A Review on Seasonal Variations in Zooplankton Abundance and Diversity in Freshwater Ecosystem of Maharashtra, India

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Abstract

Zooplankton are essential for nutrient cycling and aquatic food webs, making them an essential component of freshwater ecosystems. This study focuses on the seasonal variation of zooplankton populations in Maharashtra, India, throughout the pre-monsoon, monsoon, and post-monsoon seasons. Anthropogenic influences like as pollution, eutrophication, and habitat modification exacerbate alterations in zooplankton diversity, while climate change further jeopardizes biodiversity by disrupting ecological balance. Alongside identifying research requirements and unique patterns in Maharashtra's aquatic ecosystems, comparative evaluations with other regions advocate for the utilization of advanced technologies such as GIS and molecular methods in forthcoming investigations. Understanding periodic variations was essential for the conservation of freshwater biodiversity and the sustainable management of aquatic resources under shifting climate circumstances.

Zooplankton play a pivotal role in maintaining ecological balance within freshwater ecosystems through their involvement in nutrient cycling, energy flow, and trophic interactions. This review highlights the seasonal dynamics of zooplankton abundance and diversity across pre-monsoon, monsoon, and post-monsoon periods in the freshwater bodies of Maharashtra, India. The study emphasizes the influence of physicochemical factors such as temperature, dissolved oxygen, turbidity, and nutrient availability, alongside anthropogenic stressors like pollution and eutrophication. Findings reveal that zooplankton populations exhibit significant temporal shifts, with peak diversity and density often observed post-monsoon. Certain taxa also serve as effective bioindicators of water quality. The review advocates for integrated ecosystem monitoring using advanced tools such as GIS, molecular techniques, and remote sensing to better understand zooplankton ecology under climate change scenarios. These insights are crucial for sustainable water resource management and the conservation of aquatic biodiversity in tropical regions.

Keywords: *Freshwater Ecosystem, Physicochemical Parameters, Seasonal Variations, Zooplankton Abundance, Zooplankton Diversity.*

Introduction

Zooplankton are tiny animals that are vital constituents of aquatic ecosystems, ranging in size from a few microns to several millimetres or beyond, including almost every taxon within the animal kingdom [1]. Within zooplankton, some organisms exist entirely as plankton (holoplankton), while others inhabit a portion of their life cycle as plankton (mesoplankton). Zooplankton refers to creatures inhabiting the water column, which are gathered using a plankton net, sometimes termed net zooplankton. The zooplankton population may include non-motile or weakly swimming creatures that are carried by water currents in aquatic settings and are linked to fluctuations in phytoplankton communities [2].

The zooplankton community is affected by both abiotic and biotic elements in an aquatic environment. The distribution, abundance, and seasonal fluctuation of zooplankton communities are influenced by biotic factors like as food quality and predation, as well as abiotic factors including pH, biological oxygen demand, temperature, conductivity, turbidity, and chemical oxygen demand. Other significant biological variables, such as dispersion by air wind and ocean currents, govern zooplankton distribution. Freshwater zooplankton is categorized into five groups: ostracoda, protozoa, cladocera, rotifera, and copepoda.

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Many of these groups rely on diverse bacterioplankton and phytoplankton as primary food sources while others ingest smaller zooplankton, functioning as secondary consumers in the food chain. Zooplankton communities are crucial to the equilibrium of aquatic ecosystems, significantly influencing various biological processes, such as the distribution of matter, energy, and pollutants across trophic levels in food webs.

Types of zooplankton

- **Rotifers** often referred to as wheel organisms, are soft-bodied metazoan protostomes that are found all over the world [3]. These diverse rotifer assemblages live in environments ranging from mildly acidic to mesotrophic. They adopt a filter-feeding system for sustenance, consuming multiple kinds of food of various sizes. The composition and density of rotifer communities significantly fluctuate according to eutrophication levels; hence they often serve as bioindicators of aquatic pollution [4]. The family Brachionidae of rotifers signifies water eutrophication, with the prevalence of Brachionus calyciflorus indicating organic contamination.
- **Copepods**: are the most common kind of zooplankton in freshwater habitats, appearing in benthic, planktonic, and groundwater forms [5]. Copepods contribute significantly to consumer biomass in aquatic habitats and play a significant role in food webs as primary and secondary consumers in the aquatic food chain. Copepods are a main food source for both invertebrates and vertebrates, including commercially important species like fish and prawns. Copepods live in both freshwater and marine habitats. Within freshwater, they are categorized into five orders: Gelyelloida, Siphonostomatoida, Cyclopoida, Harpacticoida, and Clanoid [6].
- **Cladocerans**: sometimes known as water fleas, reside in benthic zones, pelagic, and littoral, however there are few of them in oceans [7]. In freshwater lakes, plankton, particularly cladocerans of the genus Daphnia, serve as substantial herbivores that can be readily grown and have a short generation period, making them useful model organisms for ecological and evolutionary research.
- **Ostracods**: represent the most diversified assemblage of crustaceans inhabiting freshwater, marine, and brackish environments, serving as a model group for many ecological and evolutionary investigations. The primary ecosystem service provider in aquatic environments exhibits oscillations in ecological parameters such as temperature, pH, and salinity; hence, they might operate as bioindicators of climate change [8].

1. **Zooplankton in Food Webs**
   The trophic structure systematically arranges the biotic elements of an ecosystem to enable the transfer of substance (nutrients) and energy. The intensity of trophic interactions is significantly impacted by the ratio of prey production to predator production, which is essential for comprehending a number of ecological processes [9]. Trophic transfer efficiency influences several ecological attributes, such as food chain length, trophic structure evaluation, carbon transfer, and fishing productivity. Studies on historical aquatic food webs have shown that certain species are pivotal in influencing aquatic ecosystems and trophic interactions [10]. In planktonic food webs of aquatic environments, zooplankton serve as an essential connection between primary producers and higher trophic levels. Consequently, these herbivorous zooplankton species significantly affect phytoplankton biomass production and species composition, while also serving as a primary nutrient source for numerous invertebrate predators and fish.
2. **Zooplankton Diversity**
   The diversity of zooplankton in Maharashtra's aquatic environments serves as a critical indicator for assessing the health of these ecosystems [11]. Diversity indices such as the Simpson and Shannon-Wiener indices are commonly utilized to measure species richness and evenness. The Simpson index, ranging from 0 to 1, demonstrates distribution patterns, with values nearing 1 indicating a high level of evenness and optimal variety. This measure often diminishes as pollution levels rise [12]. The Shannon-Wiener index is frequently employed to assess water quality in Maharashtra's reservoirs and lakes, with values beyond 3 signifying unpolluted water and values below 3 indicating pollution. Seasonal fluctuations in zooplankton in Maharashtra closely mirror those of phytoplankton.
   This relationship shows that the dynamics of zooplankton populations are influenced by a variety of factors, including temperature variations, light availability, alkalinity, dissolved oxygen concentrations, pH levels, and grazing pressures [13]. Research in the Masooli Reservoir has revealed a number of zooplankton species, including copepods, rotifers, cladocerans, and ostracods. Throughout the summer, many species exhibit considerable population increases, presumably as a result of ideal meteorological circumstances marked by high temperatures and an abundance of food. In the Masooli Reservoir, the zooplankton exhibits regional variability. Increased abundance is found at sites A and B, which provide certain growth-promoting environmental conditions such reduced turbidity and nutrient enrichment [14].
3. **Zooplankton as Aquatic Ecosystem Bioindicators**
   Bioindicators are organisms, such as plants, animals, microbes, and plankton, utilized to evaluate the health and status of natural ecosystems and to detect biogeographical or environmental alterations resulting from contaminants or pollutants that may disrupt biodiversity and the species within the environment (Fig.1) [15]. Aquatic systems exhibit differences in factors such as nutrient availability, dissolved oxygen, and pH levels; on land, lichens and mosses serve as sensitive indicators of alterations in air quality and overall pollution, particularly sulfur dioxide. Biomarkers provide measurement of environmental factors and contaminant concentration levels. Changes in ecosystems may now be accurately quantified. Mussels and other bivalves serve as indicators for the quantity of heavy metals in aquatic environments, whereas fish reveal patterns of bioaccumulation within aquatic food webs.

Physiochemical characteristics of water

In addition to biological interactions, climatic and physicochemical variables also influence the makeup of zooplankton populations [16]. Certain species are therefore found in many environmental circumstances, whilst others are constrained by several physico-chemical variables [17]. The seasonality of species succession and population dynamics has been linked to a wide range of interconnected factors. These include food and predation, as well as physical and chemical elements. The next sections address several water quality indicators in relation to zooplankton occurrence.

a) **Temperature:** Maharashtra has a different climate, with hot summers that raise the temperature of the water in rivers and lakes. Seasonal temperature swings affect aquatic ecosystems, according to research performed on lakes such as Powai and Mulshi. Summer high temperatures have an impact on zooplankton growth and fish reproduction by increasing evaporation and lowering dissolved oxygen levels. Thermal stratification in reservoirs like Bhatsa demonstrates how temperature affects species composition.

b) **pH:** Water bodies in Maharashtra frequently have a pH range of 6.5 to 8.5, influenced by area geology and human activity [18]. Urban lakes, like Lonar Lake, exhibit a somewhat alkaline pH resulting from bicarbonate-rich inflows, whereas contaminated streams next to industrial districts typically exhibit acidic characteristics due to effluents. Zooplankton populations in regions with alkaline pH, such as Ujjani Dam, correspond with the carbonate-bicarbonate balance.

c) **Turbidity:** Turbidity levels of Maharashtra's rivers, such as the Godavari and Krishna, increase during the monsoon season owing to sediment runoff [19]. Elevated turbidity in reservoirs like Jayakwadi adversely impacts light penetration, hence restricting primary production. In contrast, aquatic basins with regulated sedimentation, such as Tansa Lake, have cleaner waters and increased zooplankton diversity.

d) **Secchi disk transparency:** Algal blooms and organic pollutants are linked to decreased Secchi disk transparency in eutrophic lakes like Powai. Transparency decreases during the monsoon and recovers after the monsoon due to silt settling, according to seasonal monitoring. In addition to maintaining greater transparency, Wilson Dam and other oligotrophic reservoirs are home to diverse zooplankton communities.

e) **Total dissolved solids:** The TDS levels in Maharashtra's water bodies exhibit significant variability, with urban reservoirs displaying increased TDS as a result of runoff and sewage discharge. Research demonstrates that TDS levels between 200 and 500 mg/L in rural reservoirs facilitate a variety of aquatic organisms. Elevated salinity in regions such as coastal estuaries adversely affects freshwater zooplankton while benefiting brackish water species.

f) **Dissolved oxygen:** Dissolved oxygen concentrations diminish in summer as a result of increased temperatures and organic load. For example, dissolved oxygen levels in the Mula-Mutha River drastically decrease in urban sections owing to sewage discharge. Reservoirs such as Koyna sustain elevated dissolved oxygen levels owing to minimal contamination and continuous aeration from hydroelectric activities.

g) **Low oxygen:** Hypoxic conditions are prevalent in severely polluted sections of rivers, including the Ulhas and Panchganga. These regions display restricted zooplankton diversity and a predominance of tolerant species. The coastal waters around Mumbai exhibit seasonal hypoxia attributed to organic loading and industrial effluent.

h) **Electrical conductivity:** The conductivity of water in Maharashtra's reservoirs varies from 150 to 700 µmhos/cm. Urban lakes, such as Powai, demonstrate elevated conductivity attributable to ionic contributions from residential and industrial origins. Variations in conductivity directly influence zooplankton assemblages, favoring species that are suited to elevated salt levels.

i) **Total hardness:** The hardness levels in Maharashtra's water bodies often fluctuate between 120 and 250 mg/L. Lakes in basaltic areas, like Lonar, have increased hardness owing to geological contributions. Calcium-rich waters facilitate the proliferation of crustaceans, which predominate in zooplankton groups within reservoirs such as Ujjani.

j) **Chloride concentration:** Chloride levels, often influenced by human activity, indicate pollution levels. Urban water bodies next to industrial centers, like Thane Creek, have increased chloride levels resulting from wastewater discharge. Elevated chloride concentrations are harmful to freshwater zooplankton while advantageous for brackish water organisms such as copepods. Shukla SC et al. [20] have noted that industrial and residential trash has negatively impacted the primary productivity of the River Ganga in Varanasi.

Environmental factors

1. **Light and Turbidity in Maharashtra's Water Bodies**
   Light penetration in the Maharashtra waters is heavily dependent on suspended particles, which consists mainly of organic and inorganic matter during the monsoon. For example. Water bodies like Ujjani have increased turbidity since heavy rains reduce light intensity hence limiting photosynthesis in phytoplankton [21,22]. Light penetration in lakes like Powai increases due to runoff from the city, which initially is conducive to the growth of phytoplankton, but later becomes unfavorable once light reduces.
2. **Temperature's Role in Plankton Dynamics**
   Seasonal temperature fluctuations profoundly influence plankton abundance in Maharashtra. Significant observations encompass. Elevated summer temperatures in lakes such as Koyna augment plankton metabolism and variety. Investigations in marine ecosystems, particularly in the coastal waters of Mumbai, underscore temperature as a catalyst for phytoplankton succession [23]. Increased temperatures during summer months negatively impact dissolved oxygen levels, significantly decreasing oxygen availability for aquatic life.
3. **Dissolved Oxygen (DO) and Nutrient Cycling**
   DO levels are critical to the survival of aquatic life and inversely proportional to temperature in water bodies in Maharashtra. Lower values for DO can be seen in urban rivers like Mula-Mutha of Pune due to inflow of organic wastes. Monsoon flushing

of nutrients in the reservoirs like Bhatsa, allow nutrient cycling and enrichment and boost plankton proliferation by nitrates and phosphates in the water column.

4. **Nutrients and Eutrophication**
Nutrient availability is the primary factor controlling plankton abundance in the Maharashtra region. High nitrate levels in Jayakwadi and other similar reservoirs have been associated with cyanophyta blooms that cause degradation of water quality. Nutrient loading from agricultural runoff into water bodies in rural areas causes eutrophication as seen in the water bodies of the Vidarbha region. It causes algal blooms, episodic fish kills, and reduction in aquatic biodiversity [24].

5. **Maharashtra's Aquatic Ecosystems**
The diversification and abundance of plankton in Maharashtra's aquatic ecosystems were elucidated through the interactions of light, temperature, dissolved oxygen, and nutrient cycling; however, threats such as turbidity, eutrophication, and urban pollution present significant risks, underscoring the necessity for sustainable management and conservation strategies.

Seasonal Patterns in Zooplankton Abundance and Diversity

Tropical monsoon climate over Maharashtra has enormous seasonal fluctuations in zooplankton richness and diversity in freshwater ecosystems that depend on pre-monsoon, monsoon, and post-monsoon periods [25].

1. **Pre-Monsoon (March-May):**
Zooplankton abundance is moderate in the pre-monsoon period, mostly attributed to reduced water levels and the subsequent concentration of nutrients owing to evaporation. The predominant taxa are resilient species such as Brachionus (Rotifera) and Moina (Cladocera), capable of withstanding elevated temperatures and diminished water levels [26,27]. Competition for resources and predation pressure intensify, hence impacting population stability.

2. **Monsoon (June-September):**
The monsoon induces substantial rainfall that diminishes nutrient concentration and elevates turbidity, leading to a decline in zooplankton population, reduced species richness, hydrological disruptions, and decreasing dissolved oxygen levels. Nevertheless, several eurythermal and opportunistic organisms possess the ability to adapt and flourish in such conditions.

3. **Post-Monsoon (October-February):**
The peak population of zooplankton occurs in the post-monsoon season mostly because to nitrogen enrichment from monsoonal runoff and subsequent phytoplankton blooms. Stabilized environmental conditions yield reduced temperatures, elevated dissolved oxygen levels, and enhanced water clarity, which promote greater species richness. Both generalist and specialized zooplankton species, including cladocerans and copepods, flourish.
Research documented 39 species of zooplankton, comprising 15 rotifers, 12 copepods, 10 cladocerans, and 2 ostracods. Positive connections were observed between zooplankton populations and factors including temperature, alkalinity, phosphate, hardness, and BOD, but negative correlations were linked to rainfall and salt [28].

4. **Future Perspectives**
That zooplankton ecology in freshwater lakes is highly impacted by physical and chemical parameters, as well as watershed features, land use, geochemical qualities, and sediment composition [29]. However, research gaps remain in understanding the impact of these additional factors on zooplankton dynamics, particularly in Indian freshwater lakes [30]. Current studies predominantly focus on aquatic conditions, overlooking the interconnected influences of surrounding terrestrial and geochemical environments. Advanced technologies, such as molecular techniques, GIS-based spatial analysis, and remote sensing, hold immense potential to enhance zooplankton research by improving species identification, tracking population dynamics, and monitoring environmental parameters more accurately [31]. To bridge these gaps, future research should focus on interdisciplinary approaches that combine aquatic and terrestrial ecosystem studies, adopt advanced technologies, and develop predictive models [32]. This expanded understanding of zooplankton ecology will be crucial for informing sustainable management practices and conservation policies for Indian freshwater lakes.

Conclusion

Seasonal variations in zooplankton population density and variety serve as essential indicators of the health of freshwater ecosystems in Maharashtra, reflecting the interaction between abiotic factors and biotic processes. Research indicates that zooplankton play crucial roles in nutrient cycle and energy transfer mechanisms, exhibiting substantial variation during the pre-monsoon, monsoon, and post-monsoon periods. Human-induced pressures like pollution and climate change intensify these processes, hence threatening biodiversity. This was accomplished by integrating zooplankton research into ecosystem management methods, utilizing modern technical tools, and enacting conservation measures for the sustainable management of aquatic resources.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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