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REVIEW ARTICLE

Seasonal Dynamics of Zooplankton in Relation to Water Quality of Fresh water Lentic Ecosystem: A Review

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ABSTRACT

Lentic freshwater ecosystems are intricate and dynamic habitats where zooplankton plays a pivotal role in maintaining ecological integrity through nutrient cycling and energy transfer. They act assensitive bioindicators and are susceptible to even small changes in key physico-chemical variables such as temperature, pH, dissolved oxygen, and nutrient levels. Zooplankton communities exhibit conspicuous temporal and spatial variations in diversity, abundance, and distribution, mirroring the shifts in their habitat. This review synthesizes insights from studies on different lentic habitats to explore the complex relationship between zooplankton populations and water quality. Seasonal patterns reveal that temperature and nutrient availability significantly influence zooplankton with rotifers frequently emerging as the dominant group. Presence of pollution-tolerant species such as *Brachionus* and *Keratella* in eutrophic and comparatively less polluted waters proves them as critical indicators of deteriorating water quality. Different diversity indices, such as the Shannon-Wiener, Simpson, and Margalef indices, are commonly used to assess the trophic status and ecological health of lentic ecosystems. Zooplankton, not only serve as reliable indicators of the changes in their habitats, but also play a crucial role in energy transfer from producers to higher trophic levels. Long-term monitoring of zooplankton communities helps to attribute the impacts of anthropogenic activities such as pollution load and eutrophication on lentic ecosystems. This review focuses the importance of regular assessments of zooplankton diversity, as a pre-requisite for detecting the magnitude of the temporal and spatial ecological shifts; followed by policy design and planning for conservation of lentic water resources for sustaining aquatic biodiversity and ensuring ecosystem resilience in response to environmental changes. By understanding the interplay between zooplankton populations and physico-chemical parameters, researchers and policy makers can better foresight and predict ecosystem responses to natural and human-induced disturbances, thereby contributing to the effective planning for mitigation and management of freshwater resources.

KEY WORDS: Bioindicators, Freshwater Lentic Ecosystems, Zooplankton Dynamics, Seasonal Variations, Water Quality Assessment

INTRODUCTION

Lentic aquatic ecosystems are dynamic and complex environment that support a wide range of life forms. Among the most significant contributors to these ecosystems are zooplankton, that make a link between the primary producers and higher trophic levels (Sharma *et al.,* 2013) exhibiting their vital roles in nutrient cycling and energy transfer for maintaining the sustainability of food webs and biodiversity in a tropical floodplain lake (Sharma *et al.,* 2000) and in a reservoir (Rajashekhar *et al*., 2010).

Zooplankton communities in lentic systems are highly diverse, comprising several major groups such as Rotifera, Cladocera, Copepoda, and Ostracoda, each with distinct ecological roles (Joshi, 2011; Dorlikar, 2016). Rotifers are known for their adaptability and fast reproduction rates; and often dominant in lentic freshwater ecosystems. Cladocerans, commonly referred to as water fleas, are potent grazers controlling the algal populations. While

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copepods maintain the nutrient cycling by grazing over phytoplankton andpredating smaller zooplankton; ostracods or seed shrimps are known for their role in detritus processing and energy dynamics. The functional diversity of these groups underscores their importance in maintaining ecosystem integrity and resilience.

Freshwater zooplanktons are highly sensitive to changes in aquatic parameters, making them reliable indicators of water quality and ecosystem health (Ahmad *et al.,* 2011; Ayaz *et al*., 2012). Factors such as temperature, pH, dissolved oxygen levels, and nutrient availability significantly influence the survival, diversity and abundance of zooplankton (Sitre, 2014; Bari *et al*., 2021). For instance, higher temperatures can accelerate metabolic rates and production in some zooplankton species; whereas, fluctuations in dissolved oxygen directly impacts their survival and distribution patterns.

Eutrophication caused by different point and non-point polluting sources has emerged as a critical problem negatively affecting the zooplankton communities and aquatic biodiversity by depleting oxygen level in lentic freshwater systems. Zooplankton populations respond to such change, with pollution-tolerant species becoming more prevalent in such eutrophic habitat. Different species of *Brachionus* and *Keratella* are often witnessed in such nutrient-rich environments, proving them as bioindicators of deteriorating water quality (Dede & Deshmukh, 2015; Rao, 2017). This adaptability and sensitivity make zooplankton valuable tools for assessing the trophic status of water bodies and detecting early signs of ecological stress.

Their grazing activity can help to regulate the algal blooms, thereby maintaining the quality of water. However, anthropogenic changes and habitat degradation have disrupted these natural processes, emphasizing the need for regular surveillance of zooplankton populations to ensure timely alert for sustainable water management and conservation of biodiversity (Bari *et al.*, 2021; Bashar *et al*., 2015). Seasonal patterns in zooplankton populations provide valuable insights into the ecological health of aquatic ecosystems. For example, certain species may dominate during specific seasons, reflecting favourable environmental conditions, while others may decline substantiating their indicator value.

This review consolidates findings from various studies that examine the influence of physico-chemical parameters on zooplankton diversity and their utility as bioindicators in assessing water quality (Dede & Deshmukh, 2015; Rao, 2017). Emphasis is placed on comparing the outcomes of different studies to conclude the trends, patterns, and gaps in existing literature. The review aims to provide a comprehensive understanding of the complex interactions between zooplankton populations and environmental variables, offering insights that are crucial for developing effective conservation strategies and ensuring the sustainability of freshwater ecosystems (Dorak *et al*., 2013; Dorlikar, 2016; Fule *et al.,* 2009; Gadhikar & Sawale, 2016; Gazulha *et al.,* 2011). Further, authors do not claim to have gone through the entire literature published so far on the concerned topic; but have referred only those which were thought to be the most appropriate, supportive and conclusive for this review.

Zooplankton Diversity and Distribution

Several studies highlight the diversity of zooplankton in freshwater ecosystems. Rotifers, cladocerans, and copepods dominate in most lentic environments, with rotifers often being the most abundant (Dorlikar, 2016; Rohankar & Dahegaonkar, 2016). Dorlikar (2016) observed 26 species across Rotifera, Cladocera, Copepoda, and Ostracoda in Ghodazari Lake, Maharashtra. Similarly, studies in Kailash Lake and Pampoo Pond reported high copepod and cladoceran populations, reflecting favourable ecological conditions (Ayaz *et al.,* 2012; Singh *et al.*, 2021). Vagh *et al.*(2019) reported the diversity of zooplankton is affected by the water quality in a reservoir in Saurashtra, Gujarat.

Zooplankton diversity is a critical parameter for understanding the ecological health of freshwater ecosystems. Various studies have documented the richness and distribution of zooplankton species across different water bodies (Jose & Sanal Kumar, 2012; Joshi, 2011; Khan *et al.,* 2016). Ahmad *et al.* (2011) identified that the composition of zooplankton in a sewage-fed pond was influenced by the water's physico-chemical characteristics, with rotifers being dominant. Similarly, Akindele & Adeniyi (2013) found that zooplankton diversity in Lake Tiga, Nigeria, was affected by seasonal changes in habitat caused by anthropogenic activities.

Anand *et al*. (2016) noted that water quality directly impacted the zooplankton community in Lapkaman Pond, India; while Ayaz *et al*. (2012) observed that temperature and nutrient levels influenced zooplankton species richness in a high-altitude lake. Dagne *et al.* (2008) observed a balanced distribution of zooplankton groups, including rotifers, cladocerans, and copepods Lake Ziway in Ethiopia. Dorlikar (2016) reported that pollution-tolerant species like *Brachionus* and *Keratella* were prevalent in Ghodazari Lake, indicating water quality degradation.

Seasonal Variations in Zooplankton Populations

Seasonal changes in water quality play a significant role in shaping the population dynamics and community structure of zooplankton in freshwater ecosystems. Various environmental factors, including temperature, nutrient availability, and water turbidity, fluctuate with the seasons, directly affect the zooplankton diversity and abundance. Higher temperatures during the summer season enhance primary productivity by promoting the growth of phytoplankton, which serves as the primary food source for zooplankton. This increase in food availability leads to a rise in zooplankton density during the summer months (Gadhikar & Sawale, 2016; Rao, 2017). However, during the monsoon season, rainfall-induced dilution and increased turbidity reduce the availability of food, causing a decline in zooplankton populations (Rajashekhar *et al.*, 2010; Sharma *et al.,* 2010).

Several studies have demonstrated the impact of seasonal variations in habitat parameters on zooplankton communities in different freshwater bodies. For instance, Joshi (2011) & Sitre (2013) reported that zooplankton populations peaked during the summer and winter seasonsin Dhanora Lake, while their abundance significantly decreased during the monsoon. This trend highlights the importance of temperature and food availability in regulating zooplankton dynamics.

Rajashekhar *et al.* (2010) observed distinct seasonal patterns in a freshwater reservoir, noting that rotifer populations peaked during the summer months when environmental conditions were favourable. Similarly, Manickam *et al.* (2018) found that seasonal changes in zooplankton diversity were primarily influenced by fluctuations in temperature and nutrient availability, with different groups of zooplankton responding to these variations in unique ways.

Joshi (2011) revealed that zooplankton density was highest in the summer season due to optimal environmental conditions such as higher temperatures and increased nutrient input in a lake; he further noted that copepods were more abundant during the summer months, whereas rotifers dominated in winter. This seasonal shift in dominance between different zooplankton groups highlights the plasticity in adaptability of these organisms to changing environmental conditions.

Fule *et al.* (2009) investigated the seasonal zooplankton diversity in Nal Damayanti Dam and concluded that species richness varied in response to rainfall and water temperature. Their study emphasized that rainfall during the monsoon season caused dilution of nutrients and increased water turbidity, leading to a decline in zooplankton abundance. On the other hand, the dry season provided more stable conditions that supported higher zooplankton diversity.

Gazulha *et al.* (2011) studied the influence of natural floating plant banks in a subtropical lake on the seasonal distribution of zooplankton. They found that these plant banks provided a unique microhabitat that helped sustain certain zooplankton species throughout the year, despite seasonal fluctuations in the broader aquatic environment. Similarly, Gadhikar & Sawale (2016) reported that rotifer diversity was highest during the summer season in Shahanoor Dam, correlating with increased nutrient input and favourable conditions for zooplankton growth.

Overall, the seasonal variations in zooplankton populations reflect the complex interplay between environmental factors and biological responses in freshwater ecosystems. The timing and magnitude of these seasonal changes are influenced by local climatic conditions, hydrological regimes, and anthropogenic activities. Understanding these patterns is crucial for assessing the health of aquatic ecosystems and implementing effective conservation strategies. By monitoring seasonal dynamics, researchers can identify periods of ecological stress and take timely measures to mitigate the impacts of environmental changes on zooplankton communities.

Physico-Chemical Parameters and Zooplankton

Physico-chemical characteristics like temperature, dissolved oxygen, pH, and nutrient levels in lentic systems directly influence zooplankton diversity and abundance (Dhanasekaran *et al.,* 2017; Prashanthakumara & Venkateshwarlu, 2016; Patra*et al*., 2011). Rotifers thrive in eutrophic waters, with *Brachionus* and *Keratella* as the dominant species serving as pollution indicators (Sharma *et al.,* 2013; Vairagade, 2024). Cladocerans are sensitive to oxygen depletion, while copepods show resilience to environmental fluctuations (Sawane *et al.,* 2012; Manickam *et al.,* 2018). While Dhanasekaran *et al.* (2017) concluded that nutrient levels and water transparency were the key determinants of zooplankton abundance in Dharmapuri Lake; Pereira *et al.* (2002) made the similar observations in Linhos Lake. Extending the studies on other lake, Shukla *et al.* (2012) reported that pH, dissolved oxygen, and nutrient levels significantly influenced zooplankton populations in Chando Lake. Mohammad *et al.* (2015) observed in Wyra Reservoir that temperature and dissolved oxygen were critical factors affecting zooplankton diversity. Further, Patra *et al.* (2011) concluded that nitrate and phosphate concentrations influenced zooplankton populations in Santragachi Jheel. Dorak *et al.* (2014) studied the effects of physico-chemical factors on zooplankton distribution in Tahtalý Reservoir through primary production by affecting the *chlorophyll-a* level in phytoplankton population.

Zooplankton as Bioindicators

Zooplankton plays a pivotal role in freshwater lentic ecosystems, not only as primary consumers in food webs but also as reliable and sensitive bioindicators of water quality and ecological health. Their sensitivity towards changes in various physico-chemical variables makes them valuable tools for detecting and monitoring the ecological health of the lentic system (Bari *et al.,* 2021; Sharma *et al.,* 2010). Further, Pereira *et al*. (2021) emphasized that zooplankton diversity can reflect the trophic status of water bodies. Their study demonstrated that the presence or absence of certain species can indicate varying levels of deterioration, ranging from oligotrophic (nutrient-poor) to eutrophic (nutrient-rich) conditions. This ability to gauge water quality through zooplankton diversity is critical for early identification of ecological stress and implementation of effective conservation measures.

Among the various zooplankton groups, rotifers have been recognized as effective bioindicators due to their quick and timely response to environmental changes. Presence of pollution-tolerant species such as *Brachionus* are commonly observed in eutrophic lentic water bodies, where nutrient enrichment promotes accumulation of organic mattersresulting in algal blooms indicatingdecline in water quality; whereas, their absence suggests improved water conditions (Bari *et al.,* 2021; Sharma *et al*., 2010). Verma *et al.* (2011) observed similar findings in Phutala Lake. Ahmad *et al.* (2011) documented that pollution-tolerant species like *Asplanchna* and *Keratella* dominated in a sewage-fed pond, highlighting their significance as indicator of high levels of organic pollution. Similarly, Gadhikar & Sawale (2016) observed that rotifers were particularly prevalent during periods of high organic matter decomposition, indicating elevated nutrient levels and potential eutrophication.These findings underscore the adaptability of certain zooplankton species to adverse environmental conditions, making them reliable indicators of anthropogenic impacts on freshwater ecosystems. Further, the use of rotifers like *Brachionus*, *Asplanchna*, and *Keratella* as indicators provides an efficient and cost-effective approach to water quality assessment, which can be the basis for the sustainable management and conservation of aquatic habitats (Tijare & Shastrakar, 2018).

Overall, the established indicator value of zooplankton facilitates the policymakers to keep surveillance for its early detection for effective monitoring and management of the lentic freshwater bodies.

Zooplankton and Food Web

Zooplanktons play a pivotal role by becoming an essential link for transferring energy from primary producers to higher trophic levels in lentic food web. Rao *et al.* (2017) highlighted the importance of zooplankton as a food source for fish in Quaid-e-Azam Park Lake. Goswami (2018) emphasized that zooplankton diversity directly impacts fish populations. Sitre (2013) & Sharma *et al.* (2013) noted that the abundance of copepods and cladocerans is essential for fish larval development. Sawane *et al.* (2012) reported that zooplankton grazing on phytoplankton exhibits regulatory effect over primary production and maintain ecosystem integrity.

Diversity Indices: A Mirror to Trophic Status of Lentic Water Bodies

Diversity indices such as Shannon-Wiener, Simpson, Margalef, and Menhinick indices are essential tools for assessing the trophic status of water bodies. Dorlikar (2016) reported that Shannon-Wiener index values in Ghodazari Lake indicated a mesotrophic status. The Wetland Zooplankton Index (WZI) has been widely employed to assess the trophic status of lentic habitats by analysing the composition and abundance of zooplankton communities (Bari *et al.,* 2021; Dorlikar, 2016). This index provides the efficient practical method for evaluation of water quality based on the prevalence of specific bioindicator species. Dhanasekaran *et al.* (2017) found similar diversity index values in Dharmapuri Lake. Picapedra *et al.* (2020) conducted a long-term study on Brazilian reservoirs and found that diversity indices reflected changes in water quality over the time. Sharma *et al.* (2000) noted that diversity indices could help detect trends in pollution and eutrophication.

The existing review reveals that zooplankton diversity in lentic water bodies is heavily influenced by the complex interplay and dynamics of water quality variables. Temperature, nutrient availability, dissolved oxygen levels, and water pH were recorded to be among the key factors shaping zooplankton communities across lentic freshwater ecosystems. Higher temperatures during summer months promote primary productivity, which in turn causes zooplankton proliferation; while monsoonal rains lead to decline in population by dilution and increased turbidity which results in reduced food availability and altered water chemistry (Rajashekhar *et al.,* 2010; Dhanasekaran *et al.*, 2017).

Different zooplankton groups' exhibit varied responses to these physico-chemical changes, indicating their ecological preferences and adaptive strategies. Rotifers, for instance, are dominant in eutrophic waters and are known to thrive in polluted environments, making them reliable indicators of water quality degradation (Sitre, 2014; Rohankar & Dahegaonkar, 2016). Cladocerans, on the other hand, show a preference for cooler temperatures and nutrient-rich environments, suggesting that their abundance may serve as an indicator of favourable to nutrient richness. Copepods demonstrate remarkable resilience and stability under varying environmental conditions, establishing their wide range of adaptability in maintaining balance within aquatic ecosystems (Ayaz *et al.,* 2012; Singh *et al.,* 2021).

Zooplankton play a critical role in nutrient cycling and energy transfer within aquatic ecosystems, linking primary producers to higher trophic levels, including fish and other invertebrates. This is considered as a mean of assessing ecosystem health and identifying the impacts of various stresses, and climate change (Bari *et al.,* 2021; Manickam *et al*., 2018).

The reviewed studies collectively highlight the essential role of zooplankton in maintaining the ecological integrity of lentic freshwater ecosystems. The dominance of rotifers in various water bodies underscores their adaptability to diverse environmental conditions and their ability to survive in varying levels of pollution (Sharma *et al.,* 2000; Zakaria *et al.,* 2007). Seasonal variations in zooplankton populations, as observed by Patra *et al.* (2011) and Manickam *et al.* (2018), reflect the continuous changes occurring in aquatic ecosystems and the adaptability of zooplankton to these fluctuations.

The relationship between physico-chemical parameters and zooplankton abundance further highlights their importance for water quality monitoring. Studies by Shukla *et al.* (2012) & Mohammad *et al.* (2015) demonstrate that zooplankton population changes can serve as an early warning system for surveillance and detecting alterations in water quality. Zooplankton's role as bioindicators is well established, with several studies showing that the presence of pollution-tolerant species such as *Brachionus* and *Keratella* indicates deteriorating water quality (Ahmad *et al.,* 2011; Verma *et al*., 2011) and is critical for identifying eutrophic and semi-polluted conditions in aquatic systems.

Moreover, zooplankton diversity indices provide valuable insights into the trophic status of water bodies. Various indices, such as the Shannon-Wiener Index, Simpson's Index, and Margalef Index, have been employed to assess temporal changes in water quality (Dorlikar, 2016; Dorak *et al*., 2013). These indices offer a quantitative approach to evaluate the ecological health of freshwater ecosystems and identifying the areas that require immediate intervention to prevent further degradation.

Overall, the reviewed literature emphasizes the importance of regular monitoring of zooplankton communities to ensure the sustainable management and conservation of freshwater ecosystems. Given their sensitivity to environmental changes and their crucial role in ecosystem functioning, zooplankton serve as reliable indicators of negative impacts caused to water qualityby both natural and anthropogenicsources. Continued research and monitoring efforts are essential to develop effective strategies for maintaining aquatic biodiversity and mitigating the adverse effects of pollution and climate change on freshwater habitats.

CONCLUSION

Zooplankton plays a critical role in maintaining the ecological balance of freshwater ecosystems by linking primary producers to higher trophic levels and facilitating nutrient cycling. Their diversity and dynamics in numerical abundance are highly sensitive to environmental parameters such as temperature, dissolved oxygen, and nutrient availability; hence, provide valuable insights into water quality and the overall health of aquatic habitats.

Seasonal variations in water quality greatly influence zooplankton population. Warmer temperatures and increased nutrient availability during the summer months promote zooplankton proliferation, while monsoonal dilution and turbidity result in population declines. The presence or absence of specific zooplankton species can signal changes in water quality, with pollution-tolerant species indicating eutrophic conditions. Understanding these patterns is crucial for assessing the trophic status of water bodies and identifying early signs of ecological stress. Long-term monitoring of zooplankton communities is essential for the sustainable management of lentic freshwater ecosystems. By analysing their relationship with physico-chemical parameters, deterioration in water bodies can be detected over the time facilitating to develop effective conservation strategies; and hence the biodiversity of higher trophic levels of lentic water bodies.

Effective conservation measures should focus on minimizing anthropogenic impacts, such as pollution and nutrient runofffrom point and non-point sources in lentic system. Regular assessments of zooplankton diversity using established diversity indices can help to track ecosystem health and guide towards the effective decision making for well-directed management and mitigation.In conclusion, zooplankton are indispensable indicators of freshwater ecosystem health. Their study provides critical information for maintaining aquatic biodiversity, mitigating the impacts of pollution, and ensuring the long-term resilience of freshwater habitats. Continued research and monitoring are essential for safeguarding these ecosystems against the increasing pressures of human activities and climate change.

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