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Chapter- 18

Plankton act as a key indicator of the health and stability of aquatic ecosystems: A review

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Abstract:

Bio-indicators help keep track of how healthy our natural ecosystems are. Every living thing in a biological system gives clues about its environment. Plankton, which includes both phytoplankton and zooplankton, respond rapidly to environmental changes such as shifts in nutrient levels, temperature fluctuations, and pollution. It reacts quickly to changes in the environment. It is an important marker for checking water quality and indicates when water is polluted. Their sensitivity and central role in the aquatic food web make them invaluable for monitoring water quality and detecting ecological shifts. Researchers found a clear link between the ecosystem's living (biotic) and non-living (abiotic) parts. They also noted how helpful phytoplankton zooplankton are as bio-indicators for spotting how well aquatic areas are doing. Researchers gain insight into ecosystem conditions, potential stresses, and overall biodiversity by analyzing plankton diversity, abundance, and composition. Some plankton species can handle harsh conditions and even thrive in dirty water, showing a high tolerance. On the other hand, if sensitive species are missing, that area has low tolerance. So, using these organisms can improve our monitoring studies on water quality. This review highlights recent studies on plankton dynamics, explores their applications in environmental assessment, and discusses the implications for ecosystem management.

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Introduction:

In an aquatic ecosystem, life is closely related to water's Physical, Chemical, & Biological properties. All these factors play a significant role in controlling everything. So, to get a good grasp of aquatic life, we need to know both the organisms and their environment. Now, there is also a connection between different groups of organisms (*Patra and* Madhu, 2009; Dutta et al., 2014; Chakrabarti et al., 2024). For instance, producers like plants, and consumers like fish and other animals. The biodiversity here is truly unique. It ranges from tiny plankton—both phytoplankton & zooplankton—to larger creatures like fishes, amphibians, reptiles, & even some mammals (Polazzo et al., 2022; Roy et al., 2022; Biswas et al., 2023). Studying a variety of plankton and their roles helps us better understand the ecosystem's character and economy. There are these special species called bio-indicators. Their populations or functions can tell us a lot about the health of the environment (Pereira et al., 2022; Das et al., 2023). There are lots of different kinds of bio-indicators, like in Figure 1. Plankton, like microalgae, copepods and small water crustaceans, are a great example of these bio-indicator species. They can be monitored for biochemical, physiological, or behavioral changes in aquatic ecosystems. They also help us understand how pollutants build up in the aquatic ecosystem (Cuadro et al., 2022). Planktons are those little microbes floating along the water currents. Phytoplankton forms the base of the food chain since they act like energy converters in the water.

On the other hand, zooplankton plays a key role too. They link phytoplankton and fish together. These organisms are fantastic indicators of water quality and the ecosystem's overall health because they quickly respond to environmental changes (Stanley et al., 2016). In water bodies, plankton is responsible for much primary production. So, they are a group of organisms containing chlorophyll, including phytoplankton. These planktons form communities that cycle vital energy and then pass it up to higher trophic levels (Parmer et al., 2016). Studies have shown that the types of plankton and how often we see them can vary quite a bit across different water bodies. This depends on things like nutrient levels, shape of the area, age, and other factors. Because of this variation, we can use them to show how healthy lake ecosystems are (Negrete-García et al., 2022). Planktons respond fast to ecological changes in their surroundings. They are excellent indicators of water quality and trophic conditions because they reproduce quickly. When everything is natural and good for them, their presence within an ideal range is based on key abiotic factors like oxygen levels, temperature, and pH—and their relationships with other organisms. Plankton communities' shifts help determine the trophic state of water bodies (Rani et al., 2021). Bio-monitoring has become important lately for checking our water quality and studying pollution (Garg et al., 2021).

The following are some of the advantages of using Bioindicator:

1) Organic results can be decided.

2) Assists in monitoring the opposing and synergetic impacts of different contaminants on the environment.

3) Toxicology and the antagonistic impacts of poisons on plants and people can be observed early.

4) Due to their wealth, they can be effortlessly counted.

5) Compared to other specialized measuring frameworks, it is financially reasonable.

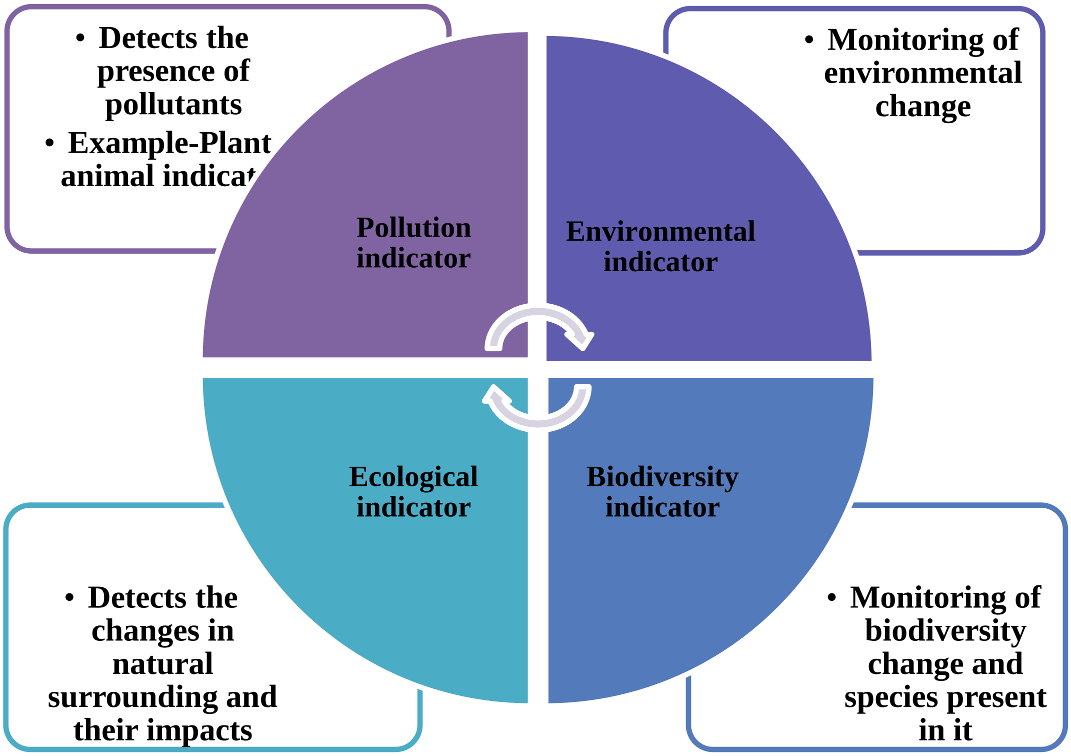

Figure 1. Types of Bio-indicator

Phytoplankton

Phytoplankton are pretty like other plants we see around us. They have chlorophyll and need sunlight to do photosynthesis. Most of them are active and can swim near the ocean's surface, where sunlight shines through the water (Verma et al., 2012; Singh and Ahluwalia, 2013). Photosynthesis helps them grow, and closely related to these two things are the use of food light plays a significant role. Though they comprise about 1% of all photosynthetic life on Earth, they produce around 50% of the global net primary production (Field et al., 1998). Phytoplankton, also called microalgae, are super sensitive to pollution. This sensitivity can show up in how many there are or how quickly they do photosynthesis. Some studies even suggest that algal assemblage could be used as an indicator of water quality. For instance, ten polluted tolerance algae species can handle pollution quite well. These include *Euglena viridis*, *Nitzschia palea*, *Scillatoria limosa*, *Scenedesmus quadricauda*, *Oscillatoria tenuis*, *Stigeoclonium tenue*, *Synedra ulna*, *Ankistrodesmus falcatus*, *Pandorina morum*, & *Oscillatoria chlorina* (Palmer, 1969). The life of these photosynthetic organisms depends on many factors—like how much stuff is available for them to eat, temperature changes, water mixing, and other environmental factors. Climate change may alter their types, seasonal patterns, and taxonomic composition. So, do we see changes in phytoplankton diversity? That could mean our waters might be getting polluted. Evidence applicable that plankton have been utilized for successful monitoring of water contamination has been summarized in Table 1 and Table 2, which show types of species and their habitat.

Table 1. Show water status and habitat of various phytoplankton species

Phytoplankton species	Habitat	Water status	References
Nitzschia palea	Flowing small stream (Nala)	Polluted	Bhatt et al. 2001
Synedra sp.			
Navicula cryptocephala			
Euglena acus	River	Eutrophic	Sampoorani et al. 2002
Euglena oxyuris			
Ulva lactuca	Bay	Sewage pollution	Wu et al.,2022
Oscillatoria sp.	Urban lakes	Eutrophic	Kumari et al. 2008
Ankistrodesmus sp.			
Frafellaria sp.			
Chlorococcum sp.			
Selenastrum sp.			
Lyngbya sp.			
Synedra sp.			
Merismopedia sp.			
Microcystis sp.			
Scenedesmus sp.			
Navicula sp.			
Phacus caudate	Water bodies	Polluted	Rai et al. 2008
Oedogonium capilliforme			
Euglena sp.			
Chlamydomonas globosa			
Scendesmus limorphus			
Ulothrix sp.			
Spirogyra sp.			
Nitzschia cuspidate			
Nitzschia palea			
Anabena sp.			
Microcystis sp.			
Aphanizamenon sp.			
Rivuloria sp.			

Coelastrum sp.	Reservoir	Polluted	Hulyal and Kaliwal, 2009
Oocystis sp.			
Scendesmus sp.			
Zygnema sp.			
Chlamydomonas sp.			
Chlorella sp.			
Spirogyra sp.			
Tribonema sp.			
Closterium sp.			
Ankistrodesmus falcatus	River	Polysaprobic	Jindal and Sharma 2011
Oscillatoriabrevis			
Nitzschia palea			
Chlorella vulgaris			
Chlamydomonas sp.			
Closterium acerosum			
Euglena viridis			
Navicula cryptocephala			
Spirulina sp.			
Stigeoclonium tenue			
Synedra ulna			
Microcystis aeruginosa,	Reservoir	Polluted	Katsiapi et al., 2011
Anabaena bergii			

Zooplankton

Zooplankton are tiny animals that live close to the surface of water. They're not very good at swimming though. These little creatures eat things like bacterioplankton, phytoplankton, and detritus. They are essential for fish and many other sea animals too since they provide a key food source. Now, it's interesting to note that zooplankton don't rely directly on nutrients to stay alive. However, their growth can change based on how much and what kind of algae, bacteria, & detritus there is in the water. They help the ecosystem by connecting primary producers (like plants) to higher trophic levels. The nano-phytoplankton is the dominant fraction in oligotrophic waters (those with low nutrient levels). This allows quick growth of zooplankton-like filter feeders such as calanoids & and large cladocerans, as shown in Table 1 (Xu et al. 2001). However, switching to eutrophic systems, where nutrients are plentiful, and small filter feeders like rotifers and tiny cladocerans (bosminids) have become very common (Table 1). These little creatures are more than just food; they also act as bio-indicators. This means they can help to monitor water pollution eutrophication and give hints about water quality in fresh bodies of water. To understand the health of a freshwater body, it's vital to look at seasonal changes in the zooplankton present. Different species and the variety of zooplankton biomass help determine the aquatic ecosystem's status. The potential for using zooplankton as bio-indicator species is high because their development relies on factors like abiotic ones (like saltiness, temperature layers, pollutants) and biotic factors (like availability of food or competition).

Table 2. Show water status and habitat of various Zooplankton species

Zooplankton species	Habitat	Water status	References
Moina sp.	Himalayan lake	Polluted	Jha and Barat, 2003
Daphnia sp.			
Bosmina sp.			
Cyclops sp.			
Phyllodiaptomus sp.			
Brachionus angularis	Lake	Eutrophic	Panikkar et al., 2022
Keratella cochlearis			
Brachionus quadridentatus			
Filinia longiseta			
Polyarthra vulgaris			
Trichocerca capucina			
Conochilus dossuarius			
Arcella vulgaris	Himalayan lakes	Eutrophic	Islam et al., 2022
Bosmina sp.			
Lecane luna			
Difflugia sp.			
Brachionus angularis			
Brachionus falcatus			
Brachionus terminalis			
Cephlodella gibba			
Keratella cochlearis			
Keratella tropica			
Chydorus sphaericus			
Daphnia pulex			
Diaphanosoma excisum			
Thermocyclops crassus			
Mesocyclops leuckarti			
Anuraeopsis fissa	Coastal lake	Eutrophic	Kruk et al., 2021
Diaphanosoma brachyurum			
Brachionus angularis			
Filinialongiseta			
Keratella cochlearis f. tecta			
Keratella quadrata			

Pompholyx sulcata			
Proales sp.			
Trichocerca pusilla			
Bosmina coregoni			
Bosmina longirostris			
Chydorus sphaericus			
Monostyla sp.	Parennial ponds	Eutrophic	Rajagopal et al. 2010b
Keratella sp.			
Lapadella sp.			
Leydigia sp.			
Moinodaphnia sp.			
Diaptomus sp.			
Diaphanosoma sp.			
Mesocyclopes sp.	Rain-fed lake	Eutrophic	Sharma et al. 2010
Brachionus forficula			
Brachionus calcyflorus			
Cyclidium glaucoma			
Cypris sp.			
Brachionus sp.			
Paramoecium caudatum			
Oxytricha ovalis			
Oxytricha oblongatus			
Holophyra simplex			
Keratella tropica			
Keratella procurva			
Neodiaptomus schmackari			
Mesocyclops leuckarti			
Mesocyclops hyalinus			
Aspidisca sp.	River	Polysaprobic	Jindal and Sharma 2011
Stylonychia sp.			
Bodo sp.			
Brachionus angularis			
Colpoda sp.			
Larvae of Chironomus sp.			
Eristalis tenax			
Daphnia pulex			
Mesocyclops sp.			
Tubifex tubifex			

Rotaria rotatoria			
Keratella sp.	Urban lakes	Eutrophic	Byeon et al., 2021
Brachionus sp.			
Moina sp.	River	Eutrophic	Ferdous and Muktadir, 2009
Ceriodaphnia sp.			

Impact of temperature change on plankton diversity

Temperature plays a significant role in how well organisms perform their tasks. It affects photosynthesis and respiration. In chilly polar seas, even low temperatures cannot prevent them from proliferating (Smith and Nelson, 1985). The most significant shifts in phytoplankton species usually come from changes in how warm or cool the water is (Diehl et al., 2002; Smol et al., 2005). When temperatures rise, phytoplankton grow faster and gather more biomass—especially when plenty of resources are available (Padilla-Gamino and Carpenter, 2007). However, temperature changes can have an even more significant effect on animals that rely on others for food, like herbivores. Warming could ramp up their eating habits more than the primary phytoplankton production. It might boost these animals' control over phytoplankton by making them graze more. Mixing events in the water mix up things like light and nutrients, essential for phytoplankton growth (Diehl et al., 2002; Salmaso, 2005). Meteorological factors are super important in how waters mix. Heat exchange and wind can make layers of water unstable and reduce mixing.

At the same time, turbulent energy input helps with mixing. So, a bit of a tug-of-war is going on (Wetzel, 2001). This battle leads to a yearly dance between summer stratification and winter mixing. Climate change can reduce the balance between stratification and mixing (Boyd and Doney, 2002). Turbulent diffusion and phytoplankton cells settling down are vital ways that non-motile cells move up and down in the water column. These processes can shift when there is a change in how long or strongly thermal stratification happens (Huisman et al., 2006). Smaller plankton are often advantageous if there is not much turbulence to stir everything up (Findlay et al., 2001; Huisman et al., 2004).

Impact of change in nutrients on plankton diversity

The nutrients that plankton need to grow depend significantly on how water mixes. When water layers become more stable, nutrients stop moving from deeper areas. This means nutrient-depleted conditions are becoming increasingly prevalent in the environment (Huisman et al., 2004). Different mixing patterns can influence which types of algae have the upper hand when competing for these nutrients. Some algae are good at holding their spot near the surface where light is best (Falkowski and Oliver, 2007). Mechanistic models show that if vertical mixing happens less, it could change the balance between buoyant cyanobacteria and those sinking phytoplankton in richer waters (Huisman et al., 2004). Greater hypolimnetic means more oxygen is used in the deeper parts of lakes and seas. This dramatically affects how nutrients cycle internally (Jankowski et al., 2006; Schaeffer et al., 2012). So, in simple terms, climate change might boost phosphorus levels while keeping certain areas without oxygen for more extended periods. Expanding runoff can alter the asset proportion in certain sorts of frameworks, depending on the geochemistry of the catchment, and consequently change phytoplankton species' competitive advantage. The export of nitrogen and dissolved organic carbon from the catchment through a Swedish subarctic lake was controlled by temperature, indicating that climate can affect the balance between phytoplankton and bacterial production (Jansson et al., 2010).

Impact of seasonal variation on planktons

Plankton blooms are common in seasonal aquatic habitats, powering the activities of various ecosystems and communities and providing an essential energy source for higher trophic levels (Winder and Cloern, 2010). Seasonal phytoplankton succession is a community phenomenon determined by the population dynamics of different primary producers and consumers. Individual species' life histories and physiological responses to the changing abiotic environment are drivers of blooms. Population feedbacks affect the timing and extent of blooms through resource dynamics and predator-prey interactions (Jager et al., 2008).

Fluctuations in water temperature and light availability typically drive spring plankton blooms. Spring phytoplankton blooms in deep systems coincide with the onset of the thermos-stratification, increasing the average light exposure of phytoplankton cells in the mixed surface layer. Species thrive under these conditions. Phytoplankton blooms are closely linked to external light conditions controlled by ice cover, cloud cover, or day length and can occur independently of temperature changes in shallow, well-mixed systems (Sommer and Lengfellner, 2008).

The timing and extent of seasonal plankton blooms are changing in response to climate change, as demonstrated in many studies (Straile, 2002; Edwards and Richardson, 2004), and are supported by dynamic models of pelagic producer-grazer systems (De Senerpont Domis et al., 2007). In many ecosystems, shifts in plankton spring phenology have been linked to climate, but later in the season, other factors, such as biotic interactions, often complicate the extraction of a strong climate signal. The timing of blooms has changed in the western Scheldt estuary, with an earlier bloom onset coinciding with increased temperatures over the past 30 years (Kromkamp and Van Engeland, 2009). In the Baltic Sea, a shift towards a warmer North Atlantic Oscillation (NAO) has caused stratification and an earlier onset of the spring bloom (Smayda et al., 2004; Alheit et al., 2005), as well as shifts in the timing of numerous phytoplankton taxa in the North Sea (Smayda et al., 2004; Alheit et al., 2005). Amid the warm NAO stage, a prior spring sprout was watched

over Central European lakes due to quickened early summer algal concealment due to quicker herbivore development in hotter water (Straile, 2002).

Table 3. Trophic status of Plankton

	Oligotrophic	Eutrophic
	Closterium pseudodianae	***Chlorella vulgaris***

Phytoplankton species	***Merismopedia elegans***	***Cyclotella* sp.**
	Peridinium inconspicuum	***Euglena oxyuris***
	Ceratium hirudinella	***Scenedesmus quadricauda***
	Dimorphococcus lunatus	***Ankistrodesmus falcatus***
	***Dinobryon* sp.**	***Closterium acerosum***
	***Euastrum* sp.**	***Cryptomonas erosa***
	***Gloeocapsa* sp.**	***Gomphonema gracile***
	Sorastrum spinulosum	***Melosira granulata***
	Strombomonas verrucosa	***Microcystis* sp.**
	Synura adamsii	***Navicula cryptocephala***
	Tetraedron minimum	***Synedra ulna***
Zooplankton species	***Euchlanis dialata***	***Alona pulchella***
	***Actinophrys* sp.**	***Aspidisca* sp.**
	Bosmina longirostris	***Asplanchana brightwelli***
	***Coleps* sp.**	***Brachionus angularis***
	Cyclops bicuspidatus	***Brachionus calyciflorus***
	***Daphnia* sp.**	***Chydorus* sp.**
	Keratella procurva	***Colpidium* sp.**
	***Notholca* sp.**	***Epistylis* sp.**
	Voritcella nebularia	***Eucyclops* sp.**
		***Glaucoma* sp.**
		***Stylonychia* sp.**
		Voritcella convallaria

Conclusion

All these studies revealed significant correlations between abiotic and biotic ecosystem components and the usefulness of phytoplankton and zooplankton as bio-indicators to detect the health and trophic status of aquatic environments. Some species can tolerate harsh abiotic conditions and thrive in polluted environments, indicating high tolerance, while sensitive species are absent, indicating low tolerance. The results may improve the use of these organisms in water quality monitoring studies.

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