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A REVIEW ON THE EFFECT OF SEASONS AND POLLUTION ON PLANKTON DIVERSITY IN INDIAN FRESHWATERS

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This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

ABSTRACT

Plankton diversity serve as a good bio indicator of the overall health status of the water body. In most of the studies, the plankton diversity was found to be higher during pre monsoon and post monsoon seasons with comparison to monsoon season. These fluctuations are dependent on various environmental factors like pH, light, temperature, turbidity, salinity, dissolved oxygen content etc. Plenty of sunlight, temperature and clear water in pre monsoon and post monsoon seasons are significant reasons for plankton abundance. Monsoon season is characterized by inflow of water, nutrients, silt, and the resultant turbid waters will in turn prevent light penetration and affect the productivity of the aquatic ecosystem. During monsoon season, nutrients were washed off to the water bodies resulting in the diversity of planktons. In the review, it was noted that some planktons are sensitive whereas others are tolerant to environmental stress. Phytoplankton belonging to Cyanophyceae, Euglenophyceae, Chlorophyceae, Bacillariophyceae and Myxophyceae are predominantly seen on polluted waters indicating organic load and eutrophication, whereas zooplanktons like rotifers, copepods and calanoids are abundantly seen in most studies. This review deals with the studies done on plankton diversity with respect to degradation of water quality in freshwater bodies of India.

Keywords: Bio indicator; eutrophication; phytoplankton; zooplankton.

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1. INTRODUCTION

Water is a precious natural resource and less than 1% of freshwater resources are available for all living organisms. The water quality is deteriorating due to human activities like dumping of domestic, sewage and industrial wastes, agricultural runoff, waste water from thermal plants etc. Degradation of water quality is a serious threat to all aquatic organisms as well as human beings. Organic load in water causes eutrophication, and is mainly due to manmade activities rather than natural phenomena [1].

Safe drinking water is a human right. According to [2] reports, billions of acute gastrointestinal disease cases are reported annually, major reason being unsafe water and improper sanitation facilities.

The various parameters determining water quality are colour, turbidity, temperature, pH, DO, BOD, COD, nitrates, phosphates, salinity, alkalinity, conductivity, total hardness, heavy metals, primary productivity etc. In addition to these, planktons are also important ecological indicators of water quality. They serve as warning signals to assess the present health status of an aquatic ecosystem [3].

Studies showed that the dominance of planktons rely on various biotic and abiotic factors of the aquatic ecosystem. Seasonal variations have a profound effect on the abundance of planktons. Many studies showed that plankton quantity, diversity and primary productivity are influenced by seasons [4].

Studies on lentic freshwater ecosystem marked planktons are indicators of the trophic status of lakes. The plankton dominance and seasonal variation depends on climatic factors, age, nutrient status and morphometry [5].

Seasonal variations in the different water quality parameters in lakes markedly influence the abundance of planktons, affecting the overall productivity of the aquatic ecosystem [6-9].

It will be beneficial to have a thorough knowledge about the species composition and seasonal variations of planktons in successful fishery management and aquaculture practices, as phytoplankton form the base of the food chain in any aquatic ecosystem. Different phytoplankton species are habitat specific, hence their distribution will give us an idea about the features of the water body in which it grows and develops. Hence phytoplankton can be considered as a tool to assess the pollution and health status of the water bodies [10]. Extensive studies on plankton diversity in marine environment have revealed that phytoplankton are consumed by primary consumers like zooplankton, shell fish and finfish, hence considered as an integral part of marine food chain [11-14].

The photosynthetic activity of phytoplankton is dependent on the individual species composition and diversity [15]. Extensive studies have been done in different regions of Indian coastal waters that helped in gaining knowledge about the species composition and seasonal variations in plankton abundance [16].

Zooplanktons are the secondary producers, and their richness depends on the presence of primary producers, the phytoplankton. Among all the freshwater aquatic organisms, the zooplankton population will give an idea about the nature and potential of any aquatic ecosystem [17]. Zooplanktons are food for planktivorous fishes, many vertebrates and invertebrates, thus controls the trophic status of the water body. Their presence is maintaining balance in the different trophic levels of the food chain, otherwise it would have collapsed [18].

Zooplankton communities are highly sensitive to environmental fluctuations. Being sensitive to anthropogenic impacts, studies on them may be useful in the prediction of long-term changes in lake ecosystems [19-22].

Natural water bodies without much pollution effected are defined by high diversity in planktons without showing much dominance of one species over another. But when water is polluted, it causes stress, resulting in the elimination of sensitive species together with the dominance of tolerant species [3].

There are various bio indices of species diversity which is mainly categorised as Margalef index, for assessing species richness, Simpson index, for assessing species dominance and Shannon - Wiener index, for assessing both the richness and dominance of species. These diversity indices help the researchers to get a clear picture about the species abundance and diversity in any ecosystem [23].

Diversity indices have been developed considering the number and abundance of species. Higher values of diversity indices point out the trophic status of the water bodies. In Simpson index, the values range between 0-1, where values near to 0, will be the least distributed and values near to 1 will be the most evenly distributed, showing maximum diversity. Margalef index points out the relation of number of species to the total individuals. Decline in this index value points out the rise in the pollution level. In Shannon-Wiener index, if the value is greater than 3, indicates unpolluted water whereas values less than 3, indicates pollution [24].

2. ENVIRONMENTAL FACTORS

Light is an important factor determining the quantity of planktons, as light is essential for photosynthesis. The presence of suspended matter such as clay, silt, organic as well as inorganic matter or many microscopic organisms are considered as general causes for turbidity of water. High turbidity and nutrient loading will increase the growth of phytoplankton [25]. The studies of [26] agreed with the idea that water flushing helps in nutrient cycling and nutrient enrichment and positively influence the abundance of planktons. Negative impacts of turbidity were seen in studies related to plankton abundance. The investigators have found that high turbidity will result in more concentration of suspended solids which will decrease light intensity, thereby affecting the growth of phytoplankton [27,28].

Temperature has a profound effect on plankton abundance. Extensive studies have shown that temperature is a key driver in phytoplankton richness in freshwater as well as marine ecosystem. Dissolved oxygen is essential for the normal functioning of different life forms in an aquatic ecosystem. The studies of [29] found that there is a negative correlation between DO and temperature. Studies have shown that DO and free carbon dioxide also exhibit negative correlation [30].

Studies of [31] have showed that nutrient availability plays an integral part in the regulation of plankton density. Nutrients are key factors controlling plankton abundance. Nitrates are one of the key factors helping in the growth and distribution of blue green algae or Cyanophyta in freshwater. Findings of [32] strongly supported this view. Excessive leaching of phosphorous and nitrogen compounds to the water body may cause eutrophication and turns the water dirty and release of toxins may lead to the death of fishes and affect biodiversity of the aquatic ecosystem.

pH is another important factor determining plankton diversity. Some species are found to have high pH tolerance but most of the scientists are of the view that optimum development occurs only in a narrow range of pH, [33] have reported that diatoms are abundantly found in alkaline water.

Biological oxygen demand (BOD) is a measure of microbial respiration and it is considered as an important indicator of pollution. The more organic pollutants in the water body, the more will be the usage of dissolved oxygen (DO) for its decomposition [34]. The overall decrease in DO is an indicator of enhanced eutrophic conditions [35].

According to [36-38] water quality parameters like total alkalinity, salinity and high concentration of chloride, can cause eutrophication and is usually considered as an index of pollution.
REVIEWS

Shukla SC et al. [39] have observed that industrial and domestic wastes have adversely affected the primary productivity of River Ganga at Varanasi. Studies have marked that planktonic biomass is affected by biotic and abiotic factors of the water body, irrespective of the nature of the water body (lentic or lotic). In rivers, river discharge and water residence time also determines plankton diversity. The limited residence time adversely affect their growth and development. Studies of [40,41] showed a negative correlation between phytoplankton biomass and river discharge.

Studies on phytoplankton population of Nanmangalam Lake exhibited a bimodal pattern in summer and winter. Light, temperature, pH, total alkalinity were the key factors determining the relative abundance of planktons in those seasons. The study supported the findings of [42,43]. Phytoplankton of species Cyanophyceae, Chlorophyceae and Bacillariophyceae were found abundantly in summer and winter seasons, which indicated the pollution load of the water body, which was confirmed by the presence of pollution indicator species like *Anabaena* and *Microcystis* of Cyanophyceae, *Spirogyra, Clostridium* and *Scenedesmus* of Chlorophyceae and diatoms, *Navicula, Nitzchia, Pinnularia* of Bacillariophyceae. The profuse growth of species *Microcystis aeroginosa* indicated the degraded water quality of the lake. The studies revealed that it may be due to the heavy load of domestic wastes dumped into the lake [9].

The studies showed that plankton abundance was found to be decreasing in the order Bacillariophycea, Cyanophyceae, Chlorophyceae and Euglenophyceae. The study supported the results of [44] with plankton abundance in the decreasing order summer, winter and monsoon. Higher concentrations of nutrients resulted in the abundance of the planktons of the species Chlorophyceae maximum in summer and moderate in monsoon seasons. Euglenophyceae were found predominantly in monsoon and post monsoon seasons [45].

The presence of zooplanktons cyclopoids, copepods, cladocerans, *Daphnia sp. Diaphanosonia sp.,* *Ceriodaphnia sp.* and *Brachionus sp*. were noted during eutrophication [46].

The studies of [44] reported phytoplankton density in different seasons decreasing in the order of summer, winter and monsoon, that supported the studies on seasonal variation in plankton density in Talsande Tank, Maharashtra. Planktons of Class Chlorophyceae followed by Class Cyanophyceae were found abundant in summer and minimum during monsoon. pH, temperature and light are the favourable factors for their abundance. The findings in the study supported the view that blue green algae grow abundantly in alkaline and nutrient rich waters. *Microcystis aeroginosa*, a pollution indicator species was found abundant throughout the year. Bacillariophyceae was found dominant in winter and minimum in summer [47]. The study supported the findings of [10] that diatoms such as *Melosira* and *Fragilaria* grow well in polluted waters. The abundance of *Melosira granulata* and *Fragilaria capucina* in the water body was supporting the view.

Studies of [48] observed that euglenoides were abundantly seen during rainy season. [49] studies also reported higher density of Euglenophyceae during monsoon and post monsoon seasons. Studies of [47] witnessed the same, and suggested that the abundance of euglenoids may be due to the high carbondioxide content and low dissolved oxygen content of the water.

Studies of [50] revealed that the plankton density was higher during pre monsoon and low during monsoon season. Studies in Pamba River (Thottapally) have showed the same findings in the abundance of plankton. The plankton biomass was found to be higher during pre and post monsoon season and low during monsoon season. The relatively high turbidity and lower concentration of nutrients have adversely affected the productivity of planktons in the monsoon season. The stagnant nature of water, is considered as a characteristic feature of our water bodies in the post monsoon seasons, helped in the growth of planktons to a great extent, in turn increasing their biomass [51].

Studies of [52,53] in Cochin backwater and Vembanad Lake, Kerala, found that there were two peak periods for plankton, one during pre monsoon season and the other during post monsoon. Rainfall, turbidity and water currents characteristic of monsoon seasons adversely affect the planktonic biomass. Studies showed dominance of phytoplankton of the species Chlorophyceae during the monsoon season. The probable reasons suggested were the reduction in salinity and increased nutrient supplies favouring the predominance of Chlorophyceae over diatoms and dinoflagellates. On the contrary, the abundance of diatoms and dinoflagellates were found increased in summer seasons. The reasons may be the increase in salinity and decrease in turbidity of waters [51].

Studies done in Thottappally estuarine canal, showed the abundance of pollution tolerant genera like *Melosira, Closterium, Navicula, Anacystis and Scenedesmus* which is an indication of presence of organic wastes in the water. The abundance of *Oscillatoria,* a pollution indicator species of the genus Myxophyceae, predominantly in the post monsoon seasons indicated the presence of heavy load of organic pollution in the water body [51]. The study observed the dominance of phytoplankton of the species Chlorophyceae followed by Myxophyceae, their presence are considered as reasons for eutrophication and organic pollution of the concerned aquatic ecosystem. Planktons belonging to Chlorophyceae such as *Pediastrum tetras*, *Pediastrum duplex, Ankistrodesmus falcatus, Ankistrodesmus convolutes*, *Scenedesmus bijugatus, Scenedesmus quadricauda,, Cosmarium tenue, Cosmarium distichum,, Closterium actum, Chlorella vulgaris, Coelastrum, Ulothrix, Spirulina sp, Oedogonium, Oocystis crassa, Zygnema sp. Chlorococcum sp., Characaeum sp., Volvox aureus, Kirchineriella microscopica and Clamydomonas epiphyta* were observed abundantly [51].

The studies of [55,56] observed *Pandorina sp.* and *Scenedesmus sp.* profusely grew in sewage-polluted water bodies. In the study, *Pandorina morum* and *Scenedesmus bijugatus* were having high abundance. Chlorococcales like *Chlorella vulgaris* and *Ankistrodesmus falcatus* are indicators of the paper industry and sewage waste [57]. The presence of higher population of chlorococcalean population in organic rich water bodies is considered as a method of self-purification as well as has an important role in degrading surfactants. The abundance of chlorococcales species benefits its biomass production more effectively [58].

The studies of [3] on three freshwater lakes in India observed the presence of planktons such as *Microcystis aeruginosa, Stigeoclonium tennae, Chlamydomonas reinhardii, Oscillatoria limosa, Oscillatoria princeps, Oscillatoria stigonema, Fragilaria capucina, Navicula cryptocephala, Chlorella vulgaris, Euglena acus, Euglena oxyuris, Closterium tumidium, Closterium aerosum, Ankistrodesmus falcatus., Anabaena sp., Gomphonema gracile, Gomphonema parvulum, , Nitzschia palea, Nitzschia frustulum, Synedra ulna., Pandorina morum*, *Phacus pleuronectes* and *Phacus longicauda* among phytoplanktons and zooplanktons forms of *Brachionus sp*.[46] like *Brachionus caudatus, Brachionus calyciflorus, Brachionus plicatilis, Brachionus forficula Brachionus quadridentatus, Keratella cochlearis, Moina brachiata, Daphnia sp.,* such as *Daphnia magna, Daphnia pulex, Daphnia smilis, Bosmina longirostris, Cyclops sp., Cyclops leucarti, Cyclops viridis, Cyclops bicuspidatus, Mesocyclopes leuckarti* , larvae of *Chironomus sp., Oxytricha sp., Eristalis tenax.,* and *Epistylis sp.* were tolerant to water pollution [59,60].

Studies on the trophic status of Mamasin Dam Lake (Aksaray-Turkey), observed that *Chlorella sp*., and *Scenedesmus sp.*, are the pollution indicator species of planktons [61].

Jha P, [59] observed the abundance of zooplanktons *Cladocera, Moina and Daphnia sp*. in Mirik Lake in Darjeeling, Eastern Himalayas, indicated the organic pollution of water. Among zooplanktons, copepods are considered as sensitive taxa for water pollution, as they are not seen in contaminated waters [62]. The copepod population is affected by seasonal variations, this idea was supported by investigators from different regions in India [63,64,65,66].

Studies of [67] on waters in Sahastradhara stream in the Garhwal region of lesser Himalayas reported that plankton diversity is influenced by seasonal variations and physico chemical characteristics of the waters. Studies were done comparing the plankton diversity of the water stream during summer, winter and monsoon season and it revealed that plankton density was found to be maximum in the winter season, major reason being environmental factors like low temperature and velocity, higher levels of dissolved oxygen in the water. The minimum density was observed in the monsoon season, probably due to high turbidity and water velocity of the water stream. Studies by [68,69] on River Ganga and Jamuna observed maximum density of planktons in the winter season. Phytoplanktons belonging to classes Chlorophyceae, Bacillariophyceae, Cyanophyceae and Euglenophyceae and zooplanktons belonging to protozoa, rotifera, copepoda, cladocera were observed in the study. In Bacillariophyceae, the dominant species during winter were observed during winter were *Diatoms*, *Nitzschia, Navicula, Cyclotella, Cocconeis* , *Cymbella affinis, Achnanthes devei, Fragilaria pinnata, Synedra rumpens* and *Gomphonema longiceps. In Chlorophyceae Zygnema* and *Volvox* were seen abundantly in winter season compared to other species of the class such as *Spirogyra, Ulothrix, Tetraspora, Oedogonium, Chlorella, Cladophora* and *Closterium*. Except *Chlorella, Closterium* and *Hydrodictyon*, all the other species were not observed in the monsoon season. In Cyanophyceae, *Aphanimenon and Spirulina* found dominantly in all seasons. *Anabaena, Oscillatoria, Rivulria, Nostoc* and *Nadularia* were the species commonly found during summer season. In Euglenophyceae, *Peridis* showed dominance in all seasons whereas *Euglena* was found predominantly in winter. Among zooplanktons, protozoans such as *Arcella, Paramecium, Bursaria, Vorticella* were seen more abundantly in summer season. Rotifers like *Brachionus*, *Trichocerca*, cladophores such as *Daphnia*, *Bosmina* and copepods such as *Cyclops* were found during summer and winter, but absent in monsoon season.

Investigations on Cauvery river in Pallipalayam, Tamilnadu observed that the water body was polluted by the nearby industries, textile effluents etc, which greatly influenced the phytoplankton diversity. The study observed the dominance of planktons of Class Chlorophyceae, followed by Bacillariophyceae, Cyanophyceae and Euglenophyceae. *Microcystis aeruginosa*, *Microcystis delicatissima, Askenasyella clamydopus, Chara longifolia, Cladophora glomerata, Characium gracilipes, Closterium dianae, Closterium depressum, Nitella opacum, Anabaena, Diatoma vulgare, Fragilaria oceanic, Pinnularia viridis, Synedra capitata, Nitzschia biobata, Spirulina gomontii, Euglena gracilis, Phacus longicauda, Phacus pleuronectes* were the most abundant species found in the study. Abundance of pollution tolerant phytoplankton species like *Microcystis, Nitzschia, Closterium, Fragilaria, Pinnularia, Synedra, Phacus* marked that the water is highly polluted. The study suggested measures for decreasing the pollution of Cauveri River [70].

Investigations of [71] on planktons as bioindicators of water pollution reported that pennate diatoms like *Cymbella sp., Cymbella ventricosa, Nitzschia sp*., *Nitzschia palea, Nitzschia frustulum* and the centric *Cyclotella sp*., *Cyclotella meneghiniana* were tolerant to environmental factors. Similar studies by [56,72,73] reported that planktonic forms like *Synedra ulna, Navicula cryptocephala* and *Nitzschia palea* were pollution-tolerant and indicate high pollution load.

Komala HP et al. [74] selected a polluted and non-polluted site in Akravati River, Karnataka to study the plankton diversity, which revealed that nutrient enrichment from nearby silk industries have polluted the waters and affected the plankton diversity. Zooplanktons like Rotifers and crustaceans were found dominantly in both polluted sites of the river. Planktons of Myxophyceae and zooplanktons were seen dominated in the polluted waters compared to Euglenophyceae which were found less abundant. The most commonly seen zooplankton species in both sites of Akravati River were *Asplachna*, *Cyclops*, *Daphnia*, *Mesocyclops*, *Nauplius*, *Siphlonurus* whereas species like *Arcella*, *Lacane*, *Macrocyclops*, *Tipula*, *Anopheles* larvae and *Chironomus* larvae were only seen in polluted site. *Carchesium polypium*, *Paramaecium aurelia*, *Brachionus caudatus*, *Epiphanes macrourus*, *Diurella sp*., *Gastro pushyptopus*, *Keratella quadrata*, *Diaphanosoma sp*., and *Chaoborus sp*. were seen in non-polluted site, indicating that they may be the sensitive ones.

Atici T et al. [75] during their study (Ankara stream), observed that Anabaena, Spirulina and *Oscillatoria sp*. were adapted to pollution. Cyanophyceae showed a significant positive correlation with water temperature, conductivity, calcium ions, chloride, total hardness, phosphate, and sulphate. In the study, *Microcystis aeroginosa* were found profusely growing in the waters, which supported the study, that *Microcystis sp.* are most commonly found in eutrophic waters of India [76].

Studies of [3] on three different lakes of Mandi, Himachal Pradesh, observed that *Navicula cryptocephala, Nitzchia palea, Melosira granulate,Chlorella vulgaris, Oscillatoria limosa, Microcystis aeroginosa* and *Ankistrodesmus falcatus* were some of the major pollution indicator species found during the study. *Pandorina sp*. and *Scenedesmus sp*. mostly grew abundant in sewage-polluted water bodies [55,56].In the study, *Scenedesmus bijugatus* and *Pandorina morum* was having the highest abundance.

The study recorded five *Euglena sp*, three *Lepocinclis sp*. and *Phacus pleuronectes* at the Kuntbhyog and Rewalsar sites of the lake. [48] reported the presence of euglenoids during the rainy season. On the contrary, they were present mostly throughout the year and were found in low numbers during winter. Their presence throughout the year is considered as an indication of higher organic pollution. The comparatively higher dominance of *Euglena acus* and *Euglena oxyuris* in Rewalsar Lake, confirmed its higher eutrophic status [77].

In the studies of [3] *Epistylis*, *Coleps*, and *Vorticella* were found in Rewalsar or Kuntbhyog Lakes. In eutrophic lakes, *Epistylis* sp. are more commonly observed in abundance [78,79]. The species of *Coleps* and *Vorticella* were found to have omnivorous feeding habits, their preferences being bacteria and algae. The omnivorous feeding habits enable them to survive even in hard and polluted waters [80]. In the study, among the *Vorticella* genus, *Vorticella convallaria* and *Vorticella nebularia* were found in both lakes.

Studies reported the presence of many species of rotifers such as *Keratella cochlearis*, *Brachionus angularis*, *Brachionus quadridentatus*, *Polyarthra vulgaris Conochilus dossuarius*, *Filinia longiseta* and *Trichocerca capucina*. They are considered as bioindicators of eutrophication [46,81].

Studies of [82] found that the plankton diversity was higher during the pre monsoon and summer seasons, main reason being the stable hydrographic conditions. Environmental factors showed a profound effect in the zooplankton diversity, their diversity showed a distinct seasonal pattern in the pre monsoon and summer seasons. Of the 92 species of zooplanktons identified, copepods were dominant. The abundance of phytoplankton was lowest during monsoon months. The possible reasons for this decline were observed to be heavy rainfall followed by high turbidity mainly from runoff, decrease in salinity, temperature, pH etc. In contrast, freshwater algal species such as *Nostoc, Anabaena*, *Oscillatoria*, *Volvox*, *Chlorella*, *Spirogyra*, *Lynbya*, *Microcystis* and *Spirulina major* were found abundantly in monsoon season.

3. CONCLUSION

This review gives an idea that planktons are the bio indicators that play an integral part in assessing the health status of any aquatic ecosystem. The species composition and abundance of planktons are dependent on various environmental conditions and exhibit variations in different seasons. The plankton abundance in pre monsoon and post monsoon season are due to the availability of abiotic factors like pH, light, temperature, salinity, alkalinity, dissolved oxygen etc. Monsoon season is characterized by increased inflow of water and turbid waters that will prevent light penetration and in turn affect the productivity. Some species are sensitive while others are tolerant to environmental stress resulting in the elimination of some species, thereby affecting the ecological balance of the aquatic ecosystem. Some plankton communities are even replaced, major reason being the pollution of waters which causes environmental stress. Planktons are good indicators to assess the health status of any water body and should take utmost care in not polluting our precious freshwater resources.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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