

Review Article

Studies on Phosphate in Reference to Zooplankton: a Short Review

Bhoopendra Kumar, Vipul Sharma, Kuldeep Singh Gaur and Sharma M.S.

Department of Zoology, University College of Science,
Mohan Lal Sukhadia University Udaipur (Rajasthan) India.

Email: - bhoopendraverma@yahoo.com, ,madhu_limnology@yahoo.co in

ABSTRACT

In fresh water bodies variation is found in quality as well as quantity of plankton in time to time and space. Phosphate is one of the major cellular components of an organism. The compound of phosphate is necessary elements in composition of cell. They are found in DNA, RNA and enzymes in cell. Phosphorus in lake water occurs in both organic and inorganic forms. Major part of the inorganic phosphate is present in the form of orthophosphate (po₄-3). Intense ecological interest in phosphorus stems from its major role in metabolism in the biosphere. Zooplankton density shows seasonal fluctuation in different water bodies in different way, what are the key factors behind these fluctuations? So nutrient like phosphate and nitrate play a key role controlling these fluctuations and the important factor controlling production, growth and distribution of zooplankton in fresh water ecosystem.

INTRODUCTION

The secrets of aquatic life have enticed aquatic biologist since time immemorial. To understand the complex interaction of the aquatic ecosystem, various workers have investigated the physical, chemical and biological properties of water bodies time to time. The studies of Welch [1], Hutchinson [2], Needam and Needam [3] and Murphy and Riley [5] provided a deeper insight to the physico-chemical and biological properties of freshwater. In India, Ganpati, [5] was among the pioneer workers of limnology. Since then, the physico-chemical parameters of various freshwater bodies have been investigated from time to time by workers such as Arvind and Chatergee [6], Arvind and Pawar [7] and Alam [8]. Many workers have explored the physico-chemical characteristics and zooplankton of different water bodies of Rajasthan. These include Bohra [9], Mishra *et al.* [10], Dey [11], Sumitra *et al.* [12], Sharma *et al.* [13] and Sharma *et al.* [14].

Freshwater zooplankton consist mainly four major groups i.e. Protozoa, Rotifera, and two orders of Crustacea viz., Cladocera, and Copepoda. Cladocera. Zooplankton play a vital role in aquatic food webs because they are important food for fishes and invertebrate predators, they graze heavily on algae, bacteria, protozoan and other invertebrates. Zooplankton communities often respond quickly to environmental change because most species have short generation time (usually days to weeks in length). Zooplankton communities respond to wide variety of disturbances including input of nutrient load.

Some nutrient play limiting effect on diversity and dominance of Zooplankton, phosphate is one of the limiting factors. There are two main sources of phosphate in water bodies viz. Natural and through anthropogenic activities. Natural source includes leaching of phosphate from rock deposits and anthropogenic activities include use of detergent, decomposition of organic waste, agricultural run off and industrial effluents. Phosphate is a limiting factor in water ecosystem has limiting effect on Zooplankton. Various researchers worked on phosphate. In comparison to the relatively rich supply of other major nutritional and structural components of the biota (C, N, O, S), phosphorus is least abundant and it commonly limits biological productivity in aquatic ecosystem [15]. Along with phosphates other physico-chemical factor are also necessary to be considered so as to find out the effects of phosphate on zooplankton vis-à-vis other physico-chemical characteristics. The cladoceran species differed in sensitivity to P deficiency at both low and high food levels, The P content of the Daphnia species changed substantially along the C: P ratio gradient, contradicting the notion of strict homeostasis, whereas the other cladoceran species showed tight P homeostasis [16].

Study of Zooplankton

Zooplankton are small organisms that float freely on surface water of water bodies and whose distribution is primarily determined by water waves and current. These communities are typically diverse and occur in almost all lakes and ponds. These communities are highly sensitive to environmental variations; as a result change in their abundance, species diversity or community composition is an important indicator of environmental changes or disturbance. Davies, and Onome Augustina, [17], studied on Woji-Okpoka Creek which situated at a strategic location in Port Harcourt, Rivers State, Nigeria and it receives domestic and industrial wastes from the Trans-amadi industrial Layout, main Port Harcourt abattoir and riverine communities.

There was little information on the zooplankton of this creek. The study investigated species composition, diversity, abundance and distribution of zooplankton as well as some physico-chemical parameters that affect these organisms. Zooplankton demonstrated significant temporal variation ($P < 0.05$). A total of 85 species dominated by copepods (43.4%) were identified. Diversity indices for copepods were: 1.0 ± 0.03 (Margalef) and 0.5 ± 0.02 (Shannon). Phosphate and ammonia exceeded FEPA and USEPA acceptable levels for natural aquatic bodies. Phosphate demonstrated significant spatial variation ($P < 0.05$). The presence of dominant copepods indicates an environment is under stress. Many works on physico-chemical and bacteriological parameters, microbial, phytoplankton, zooplankton and pollution studies have been carried out on other creeks of the estuary [18, 19, 20, 21]. Zooplankton biomass, abundance and species diversity are used to determine the conditions of the aquatic environment. Generally, copepods dominate the zooplankton community in most aquatic ecosystems [22, 19, 23, 24].

Magdy T. Khalil and Nasser S. Abd E. Rahman, [25], studied surface zooplanktons at Egyptian coastal waters of the Gulf of Aqaba. Species diversity, numerical abundance and dynamics were analysed for each taxon, at six sites, inside three Protectorates. A total of 62 taxa and species were identified. At all sites, copepods were predominant in the standing crop with an average of 1945 ind. m^{-3} and formed -75.5%, numerically, of the total zooplankton community. The meroplanktonic larvae occupied the second rank and they constituted 19.7% of the total zooplankton.

Armengol and Miracle, [26], studied, the zooplankton communities from several lakes and pools in three zones of a karstic area in central Spain in spring and early autumn, in relation to morphometric, physical and chemical characteristics of the lakes. Zooplankton diversity was higher in autumn than in spring and it was positively correlated with lake size (area and depth) in spring, but not in early autumn. This effect was partially explained by the sharp zooplankton stratification in deep lakes, in early autumn. Some morphometric characteristics of lake basins were also correlated with the structure of zooplankton communities. Principal component analyses (PCA) and Two-Way Indicator Species Analysis (TWINSPAN) performed on zooplankton data and a posterior correlation analysis with the extracted factors and main limnological parameters showed that trophic state in the first place, and mineralization in the second place, were the main sources of variance to explain the data. However, the results of these analyses also shows that important sources explaining the variance of zooplankton data include some factors not quantified in the standard limnological analysis, but evidently related to Lake Topology, such as shallowness and type of water feeding and flux.

Devies, O.A., and Otene, B.B., [27], studied zooplankton Community of Minichinda Stream, Port Harcourt, Rivers State, Nigeria. Total of 3,350 zooplankton from 4 families, 48 genera and 51 species, dominated by Protozoa were identified. Species diversity indices for Protozoa were 0.07 ± 0.02 (Simpson's Dominance), 0.97 ± 0.01 (Evenness), 5.85 ± 0.16 (Margalef) and 1.32 ± 0.02 (Shannon). Protozoa and Rotifera abundances showed significant spatial variations ($P < 0.05$). Phosphate (P_04) (0.10 ± 0.02 mg/l) were similar in all the study stations ($P > 0.05$). Zooplankton Community of Minichinda Stream, Port Harcourt, Rivers State, Nigeria 491 counterparts and include the various Protozoa, Rotifera, Crustacea, Cladocera, Copepoda, Ostracoda and Meroplankton organisms including insect larvae [28]. Zooplankton study is a necessity in fisheries, aquaculture and paleolimnological research [29]. Zooplanktons are globally recognized as pollution indicator organisms in the aquatic environment [30]. According to Guy [29], phytoplankton abundance fluctuates with changes in environmental factors and grazing by zooplankton. Trivedi et al. [31] disclosed that places of low zooplankton population usually have rapidly multiplied phytoplankton population.

Mageed, [32], studied on holozooplankton. In the study maximum values of the nitrogen compounds and phosphate were measured in front of the drains. A total of 27 holozooplankton species were recorded in the lake, represented by three groups; Protozoa, Rotifera and Copepoda. Zooplankton of Lake Qarun was studied by Wimpenny and Titterton [33], they observed that most of the species were freshwater organisms. Girgis [34] recorded the marine copepod as abundant form. Abdel-Malek and Ishak [35], noticed that the lake harbored the marine forms only, as many of the species were transported to the lake through the transplantation of the Mullet fry from the Mediterranean Sea.

Chiba *et al.* [36], studied spatio-temporal variability of zooplankton community structure. Pinto-coelho *et al.* [37], studied effects of eutrophication on size and Biomass of crustacean zooplankton in a tropical reservoir. They studied a long-term study (1993-1998) on the effects of increasing eutrophication on the crustacean zooplankton structure in a eutrophic reservoir. The study first demonstrates that the eutrophication increase verified is a phenomenon well described by a single abiotic variable: total phosphorus. During the study period, zooplankton suffered extensive qualitative and quantitative changes. Significant size and biomass responses of certain zooplankton groups to the temporal variations of total phosphorus were found. These findings suggest that the variables size and biomass of major zooplankton groups should always be considered simultaneously in order to assess impacts caused by eutrophication on the structure of zooplankton. Modifications induced by eutrophication are often not limited to just one trophic level, and zooplankton responses to eutrophication have been studied in some cases [38, 39]. Lawal *et al.* [40] studied the water chemistry, crustacean zooplankton and some associated faunal species of a tropical tidal creek in Lagos, Nigeria. They studied the water chemistry characteristics, crustacean zooplankton and associated species spectrum of the Abule-Agege creek. The water chemistry and zooplankton characteristics showed variations in response to tidal (brackish water) incursion from the adjoining Lagos lagoon and inflow of fresh water conditions from land. The adult zooplankton spectrums were from four main phyla namely: the crustaceans (Arthropoda) being the most prominent. Other associated species were from the phyla Chaetognatha, Chordata and Cnidaria. The Arthropoda made up 59.31% (excluding juveniles), the Chaetognathas comprised 0.81%, the Chordates 0.20% and the Cnidarians recorded 2.83% of the total zooplankton crop. Similarly, the total recorded juvenile stages were dominated by crustacean forms. They were the zoea, megalopa, nauplius, fish larvae and fish eggs. Higher numbers of individuals were encountered in February and portend suitable hydro-climatic conditions at the period in terms of nutrients and water chemistry characteristics.

Ian Perry *et al.* [41], were identifying global synchronies in marine zooplankton populations. They studied analyses of the influences of climate variability on local zooplankton populations and those within ocean basins relatively recent (past 5e10 years). Lacking comparisons of zooplankton population variability among the world's oceans, in contrast to such global comparisons of fish populations. Comparisons of size structure, fecundity, and reproductive strategies of zooplankters can indicate the nature and extent of pollutant loads [42] made a detailed account of the systematic and ecology of freshwater rotifers of West Bengal, but investigations on rotifers inhabiting industrial or municipal wastewater of India are scant [43, 44].

In ecosystem, zooplankton was one of the most important biotic components influencing all the functional aspects of an aquatic ecosystem, such as food chains, food webs, energy flow and cycling of matter [45]. The distribution of zooplankton community depends on a complex of factors such as, change of climatic conditions, physical and chemical parameters and vegetation cover [46]. According to Murugan *et al.* [47] and Dadhich and Sexena [48] the zooplankton plays an integral role and serves bio-indicators and it was a well-suited tool for understanding water pollution status [49]. Information on Journal of Environmental Biology (May 2010), planktonic fauna was very limited [50].

According to Gaikwad *et al.* [51] the dilution of solid substance in turn reduces the EC value alkalinity and zooplankton production. Singh *et al.* [52] reported that higher rotifer populations occurs during summer and winter might be dominant due to hypertrophical conditions of the pond at high temperature and low level of water. Species composition and seasonal variation in phyto and zooplankton abundance has been studied in other regions of Indian coastal waters [53, 54]. The rate of zooplankton production can be used as a tool to estimate the exploitable fish stock of an area [55].

Arora & Mehra, [56], studied that the relative importance of various physical and chemical factors in determining rotifer community structure and seasonal succession is evaluated and Pearson-product moment correlations between physical chemical variates and rotifer densities are analyzed and discussed.

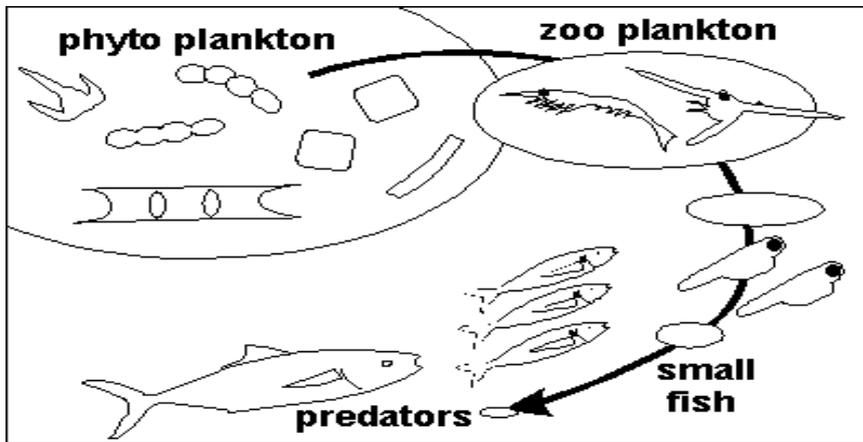


Figure: 1 - Figure showing zooplankton play an important role in water food chain

Studies on Phosphate as an important factor

Phosphate increase may be due to increase in concentration of phytoplankton and zooplankton excreta [57]. Phosphate is also one of the major macronutrients responsible for biological productivity and eutrophication of the water body. During the period under study higher values of phosphate were observed in rainy season. This may be attributed to surface runoff during rainy season receiving huge quantity of domestic sewage, cattle dung, detergents, and agricultural fertilizers from surrounding catchments area. Catchments area activities are enriching $\text{Po}_4\text{-3}$ in the lake. The lower values of phosphate in summer months may be due to more uptake of phosphate for luxuriant growth of macrophytes.

Phosphate contents are low during winter months and high during summer or post monsoon months. This could be due to low decomposition of organic matters during summer seasons [58]. According to Sharma [59] and Sharma *et al.* [60], phosphorus could be considered as an important index for the evolution and comparison of trophic level of water bodies spatially for the short duration limnological surveys. Murphy and Riley (61) standardized the methods for quantification of phosphorus showed a direct relation with plankton and it was observed that the plankton flourish well during the period of high concentration of phosphate. The reduction in phosphate immediately after the phytoplankton peak showed its utilization by the algal community [62]. Welch *et al.* [63] observed that phosphate plays an important role in phytoplankton growth. Phytoplankton growth was directly related to zooplankton. Phytoplankton exhibited a direct relationship emerged between phosphate and Bacillariophyceae and Chlorophyceae demonstrating how higher phosphate concentration favored their growth [64].

A high positive correlation of nitrogen and phosphorus was observed in hot periods than in the colder ones [65]. But strikingly in contrast to this, negative correlations of temperature were observed with phosphate by Verma and Mohanty [62]. Correlation of phosphate was observed with Cyanophyceae, Volvocales, Desmids and Xanthophyceae. Negative correlation of phosphate was observed with Chlorococcales, Bacillariophyceae and Euglenophyceae by Verma and Mohanty [62]. Andrew J. Pratt, [65], studied that phosphate was a bio-limiting macronutrient. The limitation in phosphate availability was related to the insolubility of important phosphate salts. Indeed, the relative solubilities of iron (II) and iron (III) phosphates have been widely considered as a key determinant in the phosphate cycle. The importance of understanding phosphate availability for addressing contemporary environmental issues, such as lake eutrophication (nutrient pollution), has led to more sophisticated analyses of phosphate sedimentation. The dynamics of iron phosphate solubility carry implications beyond contemporary environmental issues. Over long time-scales, bio-availability of dissolved phosphorus P controlled primary production [67], while for the modern

ocean some authors suggested that production might become increasingly P limited as a consequence of both anthropogenic and naturally induced climate changes [68].

In the open middle Adriatic area orthophosphate concentrations in the entire water column was extremely low, and P is also a limiting nutrient [69, 70]. As marine sediment presents the ultimate sink for particulate organic P from the water column [67,71]. Tamot and Sharma, [72] studied physico-chemical status of upper lake (Bhopal, India) water quality with Special reference to phosphate and nitrate concentration and their impact on lake Ecosystem. The phosphate and nitrate was two important nutrients in the lake loading through point and non-point pollution sources such as washing, bathing, agricultural activities in fringe area, joining of domestic raw sewage, and cultivation of trapa and huge growth of aquatic macrophytes.

Orthophosphate was the soluble reactive phosphorous which is also termed as inorganic phosphate. It plays a dynamic role in aquatic ecosystem which is taken up widely by phytoplankton [73]. The raw sewage was the source of nitrates and phosphates in the water [74].

Studies on Inter-relationship between Phosphate and Zooplankton

Maarten Boersma, and Karen H. Wiltshire, [75], studied nutrient-limited algae known to be a food source of inferior quality for zooplankter. Three factors were thought to determine this poor quality: direct elemental limitations of the algae, biochemical limitations and an increased resistance to digestion because of an increase in cell wall thickness. Thus far, most studies have concentrated on the effect of the algae on the daphnia. As a result, they could not find any evidence for nutrient uptake of these algae when they pass through the daphnids. They did find that animals adapted to low-P environments have higher incorporation efficiency for P, and conclude that digestion resistance in nutrient stressed algae was of very limited ecological relevance.

Recent evidence suggests that, when comparing algae cultured under different conditions, mineral limitation plays the primary role in the determination of food quality [76,77]. Indeed, many experiments with algae of different nutrient status as food for zooplankters have shown that when fed with nutrient limited algae, zooplankters show reduced growth [78]. Aloysio da et. al. [79], studied stoichiometry and growth rate variations and related aspects of the ecology and evolution of consumer-resource interactions. In zooplankton, these concepts have been explored primarily in a few species of Daphnia. Several studies have shown that the C: N: P ratio of primary producers varies markedly in terrestrial, marine, and freshwater ecosystems, whereas herbivores show much less variation in elemental composition [80].

According to the dominant paradigm, P was the main limiting element in freshwater systems, and seston C: P ratios suggestive of P limitation of herbivores [81] are commonly found in lakes. Although several studies have examined the consequences of dietary P deficiency at moderate to high food levels, few studies have examined P limitation in cladocerans at low food levels [82, 83].

David Poister and David E. Armstrong, [84], were to quantify the extent to which biomass and phosphorus in particular was removed from aquatic system via sedimentation as well as to identify factors that influence sedimentation of nutrient elements. The proportion of water column phosphorus reaching sediment traps showed a seasonal component with a minimum during late summer. Estimates of the impact of nutrient removal through diatom sedimentation indicate that this process can reduce primary production by decreasing the amount of nutrient re-mineralization in the water column during the stratified period. Spencer et al. [85], studied lower trophic levels compared in embayment, near shore, and offshore habitats of Lake Ontario in the context of oligotrophication and invasion of dreissenid mussels. Total phosphorus (TP), chlorophyll a (chl a), Secchi disk depth, temperature, and zooplankton were measured to spatially and temporally contrast these habitats and to test for recently hypothesized “decoupling” of chl a from TP (lower than predicted chl a per unit TP, consistent with dreissenid mussel grazing).

The embayment habitat had higher concentrations of TP and chl a, greater volumetric zooplankton density and biomass, and higher springtime water temperatures than both near shore and offshore habitats, while overall areal zooplankton biomass was highest in the offshore. Furthermore, concentrations of TP and volumetric zooplankton density in near shore habitats were more similar to the offshore pelagia than they were three decades ago. Offshore zooplankton production has declined with decreased phosphorus loadings [86]. Traditionally, most studies of nutrients, phytoplankton, and zooplankton in Lake Ontario have focused on offshore sites [87, 88]. Some studies, however, have identified major spatial gradients of temperature, nutrients, phytoplankton,

and zooplankton among different Lake Ontario habitats [89]. William et al. [16], studied patterns and sources of variation in *Daphnia* phosphorus content in nature. It has recently been shown that *Daphnia* can vary in the phosphorus P-content of their body tissues, but the relative importance of genetic versus environmental causes for this variation is unexplored. They measured variation in P-content as % body mass of *Daphnia* from eight lakes and conducted experiments to contrast three sources of variation: interspecific variation, clonal variation and phenotypic plasticity. *Daphnia* P-content decreased with increasing seston C: P ratio across lakes.

Daphnia parvula and *D. dubia* exhibited high P-content and were found in shallow lakes with low C:P seston, whereas *D. pulicaria* had low P-content and was found in deep, stratified lakes having high C:P seston. Populations of *D. dentifera* spanned this lake gradient and exhibited P-content that was negatively related to seston C: P. Evidence for phenotypic plasticity came from experiments with *D. pulicaria* and *D. dentifera* collected from a lake with P-deficient seston and fed a P-sufficient diet in the laboratory. The broad range in P-content exhibited by individual clones, acclimated for generations, suggests that variation in *Daphnia* P-content from laboratory experiments needs to be interpreted with caution. These results also show that phenotypic variation in response to environment can be a larger source of variation in P-content than genetic differences within or among species.

James et al. [90], studied limitation of algal growth by nitrogen and phosphorus, assessed in three north-temperate lakes with physiological bioassays and nutrient enrichment experiments. In addition, mesocosm experiments were performed in the three lakes to examine the effects of nutrient enrichment and zooplankton biomass and size on algal nutrient status. In situ indicators of N and P availability were inversely related in magnitude and transitions between N and P limitation were abrupt. Physiological bioassay results did not indicate simultaneous limitation by N and P. However, limited responses to single-nutrient enrichment and pronounced responses to simultaneous N and P addition in enrichment experiments suggested that potential limitation by the secondary nutrient was usually in close proximity to limitation by the primary nutrient. Transitions between N and P limitation closely accompanied major shifts in the zooplankton community. The importance of the zooplankton community in regulating the relative degree of N or P limitation was confirmed by the mesocosm experiments, which demonstrated that transitions between algal N or P limitation could be induced by manipulations of zooplankton biomass or size. This result supports a hierarchical view of the function of planktonic systems, in which biotic interactions structure the response of the algal community to a given nutrient load.

During the stratified season in many lakes, nutrient recycling by zooplankton can satisfy the nutrient requirements of a rapidly growing algal assemblage [91] and can significantly alter its nutritional status [92, 76].

According to stoichiometric theory, nutrient cycling, zooplankton growth, and competition among grazer species was all tightly coupled with resource nutrient ratios [93]. A laboratory study of *Daphnia magna* found that neither the food concentration nor the resource C: P ratio (molar range 64 to 165) influenced *Daphnia*'s P- to dry weight ratio. Subsequent studies found little or no seasonal or between lake variations in the specific P content of *Daphnia* and other zooplankton in lakes spanning oligotrophic to eutrophic conditions [94]. Across lakes and seasons, *Daphnia cucullata* and *Daphnia longispina* exhibited mean P to dry weight ratios of 1.58 and 1.55%, respectively. In contrast, the cladoceran *Bosmina longirostris* had a mean of 0.68%, and the mean for the copepod *Eudiaptomus gracilis* was only 0.38% [95]. Models of zooplankton growth and nutrient cycling have generally assumed a constant, high P gross growth efficiency at limiting P levels [96, 97].

William et al. [98], studied population dynamics, phosphorus balance, and individual growth to evaluate limitation of *Daphnia cucullata* by dietary phosphorus (P) in three interconnected, hyper-eutrophic Dutch lakes. Consistent with the P- limitation hypothesis, declines in egg production and population density coincided with seasonal increases in the seston C: P ratio from 300 to 400-500 (molar) in all three lakes. Laboratory experiments tested the growth of juvenile *D. cucullata* in controls with natural seston and in seston supplemented with phosphate or the P-rich cyanobacterium, *Synechococcus*. In each of 10 experiments, *D. cucullata* exhibited improved growth in response to the phosphate and *Synechococcus* supplements. In agreement with predictions, *Daphnia* exhibited the lowest control growth rate and the strongest response to P addition in seston from the lake with the highest seston C: P ratio. Our results confirm dietary P limitation but show

that energy limitation and residual factors also contributed to between lake differences in *Daphnia* growth.

Bosminids was predicted to be less sensitive than *Daphnia* to P limitation [99], and this prediction has been confirmed in laboratory growth experiments [100]. Estimates of C: P resource thresholds for *Daphnia* usually range from 200 to 300 molar units (101). DeMott, et al. (102) found that *Daphnia magna* suffered a loss in specific P content along a gradient of increasing dietary P deficiency. Because daphnids have higher P concentrations in their tissues than do other freshwater zooplankton [103]. Contrary to the digestion resistance hypothesis, isotope experiments have shown high P assimilation efficiency by *Daphnia* feeding on P-deficient green algae [104].

Overall these results tend to support the mineral P limitation hypothesis for daphnids, but they also suggest other factors will be the primary determinants of algal food quality for most zooplankters in most lakes. It is believed that algal mineral P content limits the production of certain herbivorous zooplankton [103, 104]. Several researchers have suggested the most likely critical seston C: P ratio above which daphnid production will be limited by seston P content is 300 [105, 104]. Jakob Walve and Ulf Larsson, [106], studied carbon (C), nitrogen (N) and phosphorus (P) contents (% of dry weight) of some crustacean zooplankton in the Baltic Sea. The copepod *Acartia* sp. had a stable C and N content ($48.3 \pm 0.8\%$ C, $12.4 \pm 0.2\%$ N, C: N ratio 4.5 ± 0.1). The P content was variable (1–2%), probably depending on developmental stage and season. Copepods accumulating fat, like *Pseudocalanus minutus elongatus*, had higher and more variable C content (50–60%), and lower N and P content (7–12% N, 0.6–1.5% P). The highest C and lowest N and P contents were found in adult *Limnocalanus macrurus*.

However, the N: P ratio was apparently independent of fat content and between 14 and 27 for all copepods. The cladocerans *Bosmina longispina maritima* and *Evadne nordmanni* had lower N content (9.3–10.8%) and higher C: N ratio (5.1–5.7) than *Acartia* sp. The P content (1.2–1.4%) was similar to *Acartia* sp. and the N: P ratios (16–19) were in the lower range of that found for the copepods. The N: P ratio was generally somewhat higher in the copepods than in seston, which most of the year had nearly Redfield C: N: P ratios. Potentially, nutrient recycling from crustacean zooplankton could enhance N limitation of phytoplankton, but small stoichiometric differences suggest that this effect was probably weak. The extent was dependent on the structure of the zooplankton community and the gross growth efficiencies. *Acartia* copepodites, which had nearly Redfield N: P ratios would have the opposite effect and enhance P limitation in late summer when seston N: P ratios increase.

Erik et al. [107], describe how species richness, biodiversity and trophic structure change along a total phosphorus (TP) gradient divided into five TP classes (class 1–5: B0.05, 0.05–0.1, 0.1–0.2, 0.2–0.4, >0.4 mg P L⁻¹). With increasing TP, a significant decline was observed in the species richness of zooplankton and submerged macrophytes, while for fish, phytoplankton and floatingleaved macrophytes, species richness was unimodally related to TP, all peaking at 0.1–0.4 mg P L⁻¹. The Shannon–Wiener and the Hurlbert probability of inter-specific encounter (PIE) diversity indices showed significant unimodal relationships to TP for zooplankton, phytoplankton and fish. Mean depth also contributed positively to the relationship for rotifers, phytoplankton and fish. At low nutrient concentrations, piscivorous fish (particularly perch, *Perca fluviatilis*) were abundant and the biomass ratio of piscivores to plankti-benthivorous cyprinids was high and the density of cyprinids low. Concurrently, the zooplankton was dominated by large bodied forms and the biomass ratio of zooplankton to phytoplankton and the calculated grazing pressure on phytoplankton were high.

Phytoplankton biomass was low and submerged macrophyte abundance high. With increasing TP, a major shift occurred in trophic structure. Catches of cyprinids in multiple mesh size gill nets increased 10-fold from class 1 to class 5 and the weight ratio of piscivores to planktivores decreased from 0.6 in class 1 to 0.10–0.15 in classes 3–5. In addition, the mean body weight of dominant cyprinids (roach, *Rutilus rutilus*, and bream, *Abramis brama*) decreased two threefold. Simultaneously, small cladocerans gradually became more important, and among copepods, a shift occurred from calanoid to cyclopoids. Mean body weight of cladocerans decreased from 5.1 mg in class 1 to 1.5 mg in class 5, and the biomass ratio of zooplankton to phytoplankton from 0.46 in class 1 to 0.08–0.15 in classes 3–5. Conversely, phytoplankton biomass and chlorophyll a increased 15-fold from class 1 to 5 and submerged macrophytes disappeared from most lakes. The suggestion that

fish had a significant structuring role in eutrophic lakes is supported by data from three lakes in which major changes in the abundance of planktivorous fish occurred following fish kill or fish manipulation. In these lakes, studied for 8 years, a reduction in planktivores resulted in a major increase in cladoceran mean size and in the biomass ratio of zooplankton to phytoplankton, while chlorophyll-a declined substantially. In comparison, no significant changes were observed in 33 'control' lakes studied during the same period.

CONCLUSION

The study is important from the aquaculture point of view as it reveals a clear scenario of the presence of zooplankton in presence of phosphate. On the basis of above review there is no clear work done on correlation between diversity, distribution and biomass of zooplankton. The production of most zooplankton taxa would not be expected to be limited by mineral P in a large proportion of lakes. According to study of above review phosphorus showed a direct relation with plankton and plankton flourish well during the high concentration of phosphate.

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