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Influence of artificial light at night on pond plankton community with special reference to seasonal succession: A pilot study

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Abstract
Artificial Light at Night has been shown to have various effects on aquatic communities in various habitats. Planktonic organisms are an integral part of extensive and semi-intensive carp culture ponds and play the role of food organisms for many aquaculture species in the pond ecosystem. Therefore, a study has been conducted to understand how the practice of artificial illumination for security purposes after dark affects the plankton community of aquaculture ponds. The plankton diversity and density in illuminated and non-illuminated carp polyculture ponds at the Instructional Fish Farm of Govind Ballabh Pant University of Agriculture and Technology, in the Terai region of Uttarakhand, India, was studied from November 2019 to March 2020, to determine the influence of ALAN on the seasonal succession of the community. The study reveals that artificial illumination influences the plankton density, diversity as well as the stage of fall and spring seasonal succession in these ponds.

Keywords: Artificial illumination, phytoplankton, pond ecology, zooplankton

Introduction

Light Pollution is said to occur when artificial light causes alterations in the natural night environment [1]. Artificial Light at Night (ALAN) is a major component of Ecological Light Pollution and has been shown to have an influence on various organisms and ecosystems [2]. Like various other habitats, the aquatic habitats are also affected by this stressor, and it has been observed to affect aquatic primary producers [3], the behaviour of zooplankton [4, 5], aquatic insects [6], fish [7] and frogs [8]. It has also been observed to alter the structure of aquatic [9, 10] and riparian [11] communities.

The plankton community is an integral part of any aquatic ecosystem, be it a natural lake or a carp production pond. They play various roles in the pond environment, from that of fish food organisms for many species such as *Catla catla*, *Hypophthalmichthys molitrix* and *Aristichthys nobilis* [12, 13] to being the major primary producers and consumers in the system. Given how semi-intensive carp culture systems rely on the natural productivity of ponds for the nutrition of the cultured fish, it may be useful to study how our management practices such as the use of artificial lights on fish farms affects these fish food organisms in a pond ecosystem.

The density and composition of the plankton community in any aquatic system do not remain constant throughout the year, and there exist seasonal patterns of changes in the community [14, 15].

The PEG-Model explains the seasonal succession in planktonic communities, governed by various factors including temperature, nutrient and light availability. The phenomenon is governed by the vernal light increase and the autumnal light decrease [16]. It is observed every year that the fish ponds at the site of the study show a peak of zooplankton population in the autumn months from October to November, as has been recorded by students of various batches as well as the staff of the institute for the purpose of study and laboratory work that is part of the curriculum. This observation conforms to what is suggested by the PEG model, which suggests an autumn maximum of zooplankton populations. Another shift in the planktonic community is observed each year in the spring, in the months of February and March. This observation is also consistent with the model, which elucidates the importance of the phytoplankton community composition and abundance, as well as nutrient and light availability in determining the dynamics of the zooplankton community in an aquatic system.

This study investigates the role of ALAN in altering the seasonal succession of the plankton community in a pond ecosystem. Fish farms, for the purpose of safety and security, are often provided with artificial light sources. Considering the impact of ALAN on natural water bodies, it stands to reason that the ecology of production ponds would also be affected by the same stressor. Given the importance of both phytoplankton and zooplankton in aquaculture of various species, it is important to investigate what inadvertent effects some of our management practices may have on the community.

Material and Methods

The Experimental Site

The plankton community was studied in six production ponds of the Instructional Fish Farm at College of Fisheries, Govind Ballabh Pant University of Agriculture and Technology (29˚01'22.31"N, 79˚29'16.59"E, 231m above msl [17]. Three ponds were selected that had an artificial light source (a street light) close to them (designated L_1, L_2 and L_3), and three others were selected that did not have a light source near them (designated D_1, D_2 and D_3). The lights are switched on every night and illuminate the ponds throughout the night. The management practices for all the selected ponds, including those of lime and manure application follow the same dosage and frequency, and the ponds are all stocked with six major carp species *viz. Catla catla*, *Labeo rohita*, *Cirrhinus mrigala*, *Hypophthalmichthys molitrix*, *Ctenopharyngodon idella* and *Cyprinus carpio*.

Water Quality Analysis

The water temperature and Total Dissolved Solids (T.D.S.) were measured using a hand-held digital T.D.S. + Thermometer. The pH was also recorded using a digital pH-meter.

The Dissolved Oxygen (DO) content of the water was estimated using starch as indicator and titrating the fixed solution against sodium thiosulfate. The free CO_2 content of the water was estimated by titrating the sample against N/44 NaOH solution, using phenolphthalein as indicator. For estimating the Total Alkalinity of the water samples, they were titrated against 0.02 N H_2SO_4 solution with phenolphthalein and methyl orange as indicators [18].

Plankton Collection and Preservation

The plankton samples were collected monthly by filtering 50L pond water with the help of a beaker through a plankton net. The samples from L_1, L_2 and L_3 were collected from within a 5m radius of the base of the light source. The filtered plankton were preserved in 3-4% formaldehyde solution.

Observation, Identification and Enumeration

The plankters were observed under a compound microscope, and were identified to the level of the genus with the help of reference literature [19]. The quantitative assessments were made using a Sedgewick Rafter Cell for zooplankton and the Drop Count Method for phytoplankton [18].

Two diversity indices *viz.* Margalef's Index (D_{Mg}) [20] and Menhinick's Index (D_{Mn}) [21], 1964) were calculated for the phytoplankton and zooplankton, using the formulae:

Margalef's Index (D_{Mg}) = S-1/ln N,

Where S is the total number of species encountered, and
N is the total number of individuals counted in a sample

Menhinick's Index (D_{Mn}) = S/√N

Where S is the total number of species observed, and
N is the total number of individuals in a sample.

Statistical Analysis

The variations in the two treatments were analysed through t-Test for Equality of Means, using the software IBM SPSS Statistics 21. The charts were prepared using the same software.

Results

Water Quality

The water quality was compared for the two treatments and significant differences were observed in the values of Total Alkalinity and T. D. S. between them (Table 1).

Table 1: Comparison of water quality of the two treatments

Variables	Treatment	Mean ± s.d.	t-Value	Significance
Water Temperature	With Artificial Light Source	18.86 ± 2.24	-0.056	0.96
	Without Artificial Light Source	18.94 ± 2.30		
Dissolved Oxygen	With Artificial Light Source	6.36 ± 0.38	2.05	0.08
	Without Artificial Light Source	5.90 ± 0.33		
Free Carbon diOxide	With Artificial Light Source	2.92 ± 0.30	-1.25	0.25
	Without Artificial Light Source	3.20 ± 0.40		
Total Alkalinity	With Artificial Light Source	110.80 ± 3.90	-5.68	0.00
	Without Artificial Light Source	128.40 ± 5.73		
pH	With Artificial Light Source	7.80 ± 0.27	-1.90	0.09
	Without Artificial Light Source	8.10 ± 0.22		
Total Dissolved Solids	With Artificial Light Source	174.60 ± 4.83	-8.46	0.00
	Without Artificial Light Source	240.00 ± 16.60		

The values for mean temperature, dissolved oxygen, free carbon di oxide, total alkalinity, pH and total dissolved solids for the illuminated ponds were 18.86 ± 2.24, 6.36 ± 0.38, 2.92 ± 0.30, 110.80 ± 3.90, 7.80 ± 0.27 and 174.60 ± 4.83, respectively.

The values for the same parameters in the ponds without any artificial light source were 18.94 ± 2.30, 5.90 ± 0.33, 3.20 ± 0.40, 128.40 ± 5.73, 8.10 ± 0.22 and 240.00 ± 16.60, respectively.

Phytoplankton Density and Diversity

A comparison of the phytoplankton density and diversity in the two treatments is given in Table 2. Significant differences were found in the plankton density between the ponds exposed to ALAN and those without exposure, as well as their mean values for Margalef's Index of Species Richness.

Table 2: Comparison of Phytoplankton Density and Diversity between the two Treatments

Variables	Treatment	Mean ± s.d.	t-Value	Significance
Plankton Density (number x 10^7/l)	With Artificial Light Source	6.03 ± 5.96	2.39	0.02
	Without Artificial Light Source	2.26 ± 1.40		
Margalef's Index	With Artificial Light Source	0.88 ± 0.60	-2.29	0.03
	Without Artificial Light Source	1.43 ± 0.70		
Menhinick's Index	With Artificial Light Source	0.92 ± 0.51	-1.29	0.21
	Without Artificial Light Source	1.21 ± 0.45		

The mean values for phytoplankton density, Margalef's Index and Menhinick's Index were 6.03 ± 5.96, 0.88 ± 0.60 and 0.92 ± 0.51 respectively for the illuminated ponds. The same parameters had the values 2.26 ± 1.40, 1.43 ± 0.70 and 1.21 ± 0.45 respectively in the unilluminated ponds.

Zooplankton Density and Diversity

The zooplankton density and diversity of the two treatments have been compared in Table 3. No significant difference was observed in the zooplankton density or diversity of the two treatments. It was, however, observed that the illuminated ponds had a lower density as well as values for the selected diversity indices.

Table 3: Comparison of Zooplankton Density and Diversity between the two Treatments

Variables	Treatment	Mean ± s.d.	t-Value	Significance
Plankton Density (number x 10^4/l)	With Artificial Light Source	6.43 ± 9.20	-1.17	0.25
	Without Artificial Light Source	9.91 ± 6.98		
Margalef's Index	With Artificial Light Source	0.29 ± 0.33	-1.70	0.10
	Without Artificial Light Source	0.54 ± 0.47		
Menhinick's Index	With Artificial Light Source	0.52 ± 0.60	-1.40	0.17
	Without Artificial Light Source	0.78 ± 0.42		

The values for zooplankton density, Margalef's Index and Menhinick's Index were 6.43 ± 9.20, 0.29 ± 0.33 and 0.52 ± 0.60 for illuminated ponds, and 9.91 ± 6.98, 0.54 ± 0.47 and 0.78 ± 0.42 for the unilluminated ponds respectively.

Seasonal Succession

Differences were observed in the density and diversity of phytoplankton and zooplankton in both the treatments through the period of the study, as is shown in Table 4. The highest peaks for phytoplankton density were observed in November and February in both the treatments.

Table 4: Monthly variation in plankton density in the two treatments

Month	November	December	January	February	March
Phytoplankton Density with Artificial Illumination (number x 10^7/l)	9.54 ± 6.39	1.60 ± 0.62	1.30 ± 0.46	10.71 ± 4.75	7.01 ± 8.31
Phytoplankton Density without Artificial Illumination (number x 10^7/l)	3.40 ± 1.25	1.50 ± 0.30	1.10 ± 0.17	4.00 ± 0.96	1.30 ± 0.62
Zooplankton Density with Artificial Illumination (number x 10^4/l)	0.00	1.00 ± 1.73	6.53 ± 8.21	17.87 ± 13.46	6.73 ± 6.11
Zooplankton Density without Artificial Illumination (number x 10^4/l)	12.83 ± 8.25	15.00 ± 7.94	5.00 ± 1.91	9.33 ± 6.13	8.40 ± 8.56

The phytoplankton density in November and February was observed to be 9.54 ± 6.39 and 10.71 ± 4.75 in the illuminated ponds and 3.40 ± 1.25 and 4.00 ± 0.96 in the unilluminated ponds respectively. The minimum phytoplankton density was observed in the month of January in both the treatments, with the values 1.30 ± 0.46 and 1.10 ± 0.17 for the illuminated and unilluminated treatments respectively.

The zooplankton density showed two peaks in the unilluminated ponds in December and February, with values of 15.00 ± 7.94 x 10^3 l^{-1} and 9.33 ± 6.13 x 10^3 l^{-1} respectively. In the illuminated ponds, only a single peak was observed in February with the mean density of 17.87 ± 13.46 x 10^3 l^{-1}.

Discussion

Water Quality

Significant differences were observed in the values of Total Alkalinity and T. D. S. between the two treatments. Since the regular manure application supplies nitrates and phosphates to the pond ecosystem, it stands to reason that any differences in the plankton biomass would not be caused by a difference in the available nitrogen and phosphorus in the water. The low T. D. S content of the illuminated ponds may have been a result of higher uptake of dissolved nutrients by the denser phytoplankton population in these ponds, as it is known that the uptake rate is directly proportional to the number of cellular uptake sites, which are finite in a single cell [22]. Since manuring is a regular procedure in these ponds, it may be assumed that this difference in TDS is due to uptake of the pond's autochthonous dissolved solids. The difference in Total Alkalinity of the water may be due to higher bicarbonate uptake by the phytoplankton in the illuminated ponds [23].

Phytoplankton Density and Diversity

The major classes of phytoplankton observed in both the treatments were Chlorophyceae, Bacillariophyceae, Cyanophyceae and Euglenophyceae. In the illuminated ponds, Chlorophyceae was represented by *Spirogyra*, *Ulothrix* and *Closterium.* Bacillariophycae was represented by *Navicula*, *Synedra*, *Amphora*, *Diatoma* and *Nitzschia*. *Microcystis*

representing Cyanophyceae and *Euglena* were also present.
In the unilluminated ponds, Chlorophyceae was represented by *Spirogyra, Ulothrix* and *Closterium.* The Diatoms present were *Navicula, Frustulia, Nitzschia, Cymbella, Amphora, Tabellaria, Asterionella* and *Melosira*. *Microcystis* and *Euglena* were also present here.Fig.1-4 show some species of phytoplankton observed in the present study.

The increased phytoplankton density in the ponds receiving artificial light at night as well as the same management practices employed to maintain the fertility of all the ponds suggests that *increased* exposure to light, rather than nutrient availability, promotes greater primary production and hence results in a higher phytoplankton density under artificial illumination. The lower species richness of the illuminated ponds also suggests that ALAN facilitates the dominance of certain classes of algae in a pond ecosystem.

Zooplankton Density and Diversity
The zooplankton observed in the two treatments included copepods (*Cyclops, Diaptomus)*, cladocerans (*Daphnia, Moina*), ostracods (*Cypris*), rotifers (*Brachionus*) and hydrozoans (*Hydra*). It appears that whatever negative influence ALAN may have had on the pond zooplankton was negated by the larger crop of phytoplankton and the resultant food availability in the illuminated ponds. The zooplankton community seems to be governed more by the phytoplankton abundance rather than the light regime in the pond ecosystem. Fig. 5-8 show some species of zooplankton observed in the present study.


Fig. 1: *Cymbella* observed under the microscope

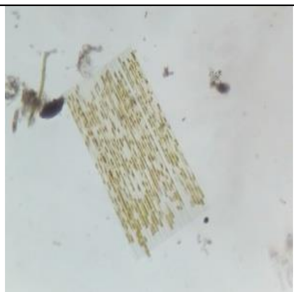
Fig. 2: *Tabellaria* observed under the microscope


Fig. 3: *Asterionella* observed under the microscope


Fig. 4: *Spirogyra* and zooplankton observed under the microscope

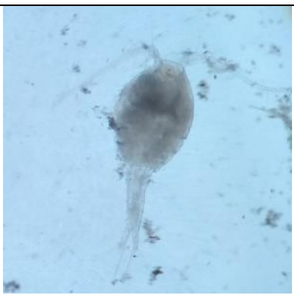
Fig. 5: *Cyclops* observed under the microscope

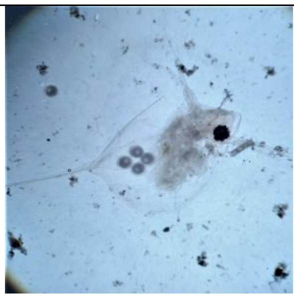
Fig. 6: *Daphnia* observed under the microscope

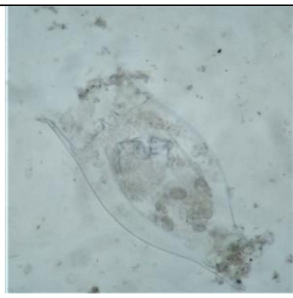
Fig. 7: *Brachionus* observed under the microscope


Fig. 8: *Hydra* observed under the microscope

Seasonal Succession
The phytoplankton density remained low in the ponds without an artificial light source as compared to the illuminated ponds throughout the period of the study. The monthly variations in phytoplankton density in both the systems have been shown in Fig. 9.
In both the cases, autumn and spring peaks of phytoplankton were observed in November and February respectively, although the fluctuation in phytoplankton density spanned greater amplitude in the illuminated ponds. The maximum phytoplankton density was observed in the spring in both the systems, which conforms to the results of a study on freshwater fish pond plankton by Michael (1969) [14].
The trends in zooplankton density differed for the treatments, as is shown in Fig. 10. The unilluminated ponds showed a higher and a lower peak in December and February respectively, but the illuminated ponds only showed a single peak in the spring. It is possible that the zooplankton in these ponds had reached their autumnal maximum density in the months before the study began, and declined to a winter minimum in November itself. It was also observed that although the zooplankton density remained higher in the unilluminated ponds through the winter months, it achieved a much higher spring peak in the illuminated ponds. This may be attributed to the greater phytoplankton abundance in the illuminated ponds in February.
It may also be noted that although the zooplankton density reached a higher peak in the illuminated ponds in the month of February, the density declined sharply in March in these ponds, whereas the decrease was gradual in the unilluminated ponds. This suggests that the clear-water phase may be achieved earlier in pond ecosystems under the influence of ALAN.

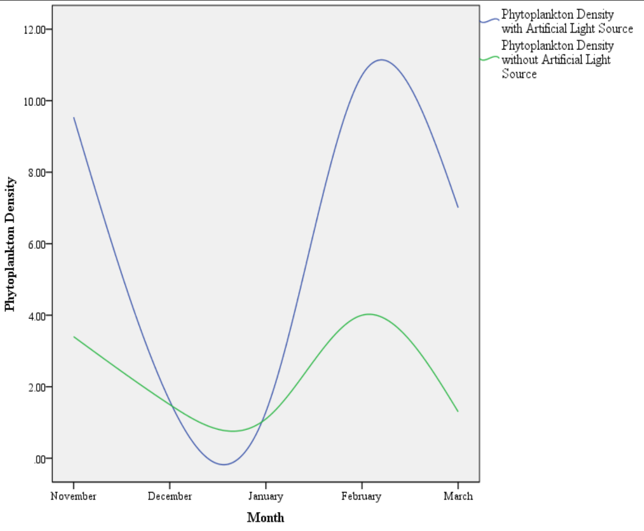

Fig. 9: Monthly variations in phytoplankton density (number x 10^7/l) in the two treatments

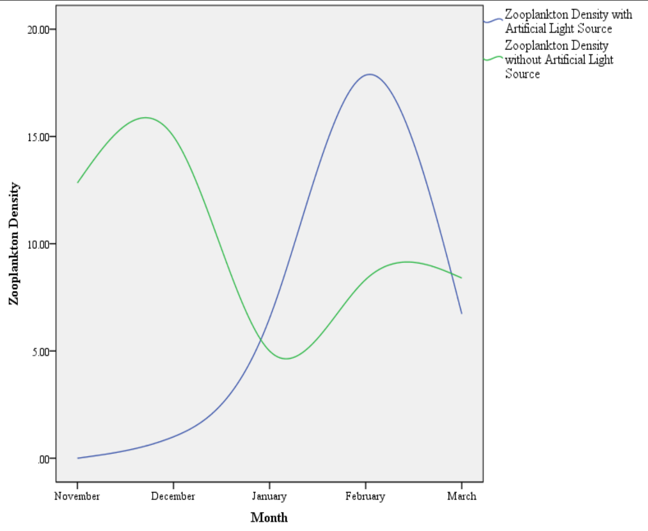

Fig. 10: Monthly variations in zooplankton density (number x 10^4/l) in the two treatments

The composition of the plankton community also gives important insight about the stage of seasonal succession. According to the PEG-model of Seasonal Succession of Plankton [16], the diatoms start to become more important during the autumn, which also sees an autumnal maximum of zooplankton that includes larger forms and species. As the light intensity decreases as winter progresses, there is a fall in algal biomass to a winter minimum. By the end of winter, a spring crop appears, consisting of cryptophyceae and diatoms. These phytoplankters are grazed upon by herbivorous zooplankton and ultimately a clear water stage is reached, when the zooplankton grazing depletes the phytoplankton biomass.

A shift in the phytoplankton community was observed in both the systems, with the minimum number of algal classes in the winter months of December and January in the illuminated and unilluminated ponds respectively. Both the maximum and minimum number of species for a month were observed in the unilluminated ponds in the months of February and January respectively.

The unilluminated ponds showed a larger representation of diatoms in the autumn, which is consistent with the PEG-Model.

In the illuminated ponds, the diatoms were only represented by *Navicula* in November, but the number of diatom species grew to include *Synedra*, *Amphora* and *Diatoma* in December. The number of diatom species decreased again in these ponds in January.

The spring crop of phytoplankton in both the treatments showed an increase in the number of diatom species, though it was delayed in the illuminated ponds by a month. Fig. 11 and Fig. 12 show the variations in the composition of the phytoplankton community of the non-illuminated and illuminated ponds, respectively.

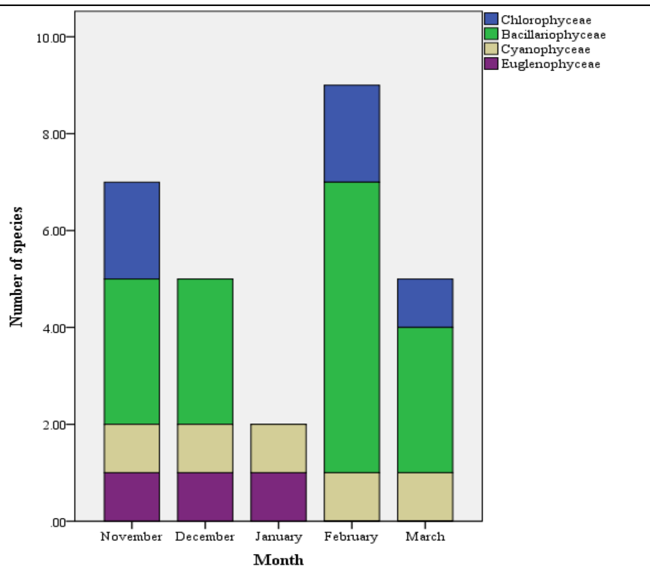

Fig. 11: Variations in the phytoplankton community in the ponds without artificial illumination

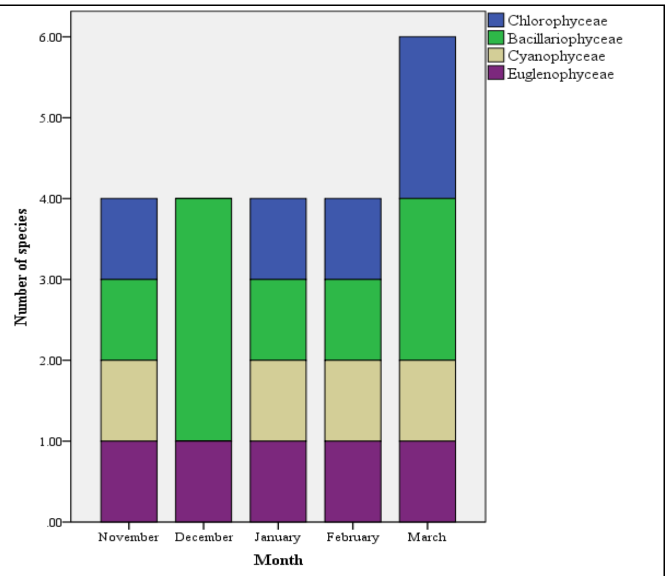

Fig. 12: Variations in the phytoplankton community of the ponds with artificial illumination

The zooplankton observed in the unilluminated ponds consisted of rotifers, copepods, cladocerans, ostracods and hydrozoans. In this respect too, the unilluminated ponds seemed to follow the PEG-model, which predicts an autumnal maximum of zooplankton that includes larger species. In December, the zooplankton in these ponds consisted only of the larger copepods and cladocerans, which was accompanied by an increase in the zooplankton density. As the zooplankton density reached a minimum in January, rotifers were once more observed in the samples. The zooplankton in February included species of copepods, ostracods and hydrozoans, but no rotifers. The rotifers once more appeared in March, now having replaced the hydrozoan species. These changes in the zooplankton community of the ponds without artificial illumination are depicted by Fig 13.

In the illuminated ponds, no zooplankton was observed in the month of November, despite the abundance of edible diatoms and green algae. In December, a single copepod species was observed in one of the ponds. The zooplankton diversity increased to include species of both copepods and cladocerans in the next month, and in February, rotifers were observed in the samples from the illuminated ponds. The rotifers disappeared in March, and the zooplankton community was now represented by species of copepods, cladocerans and ostracods. The changes in the zooplankton community of the illuminated ponds are depicted by Fig 14.

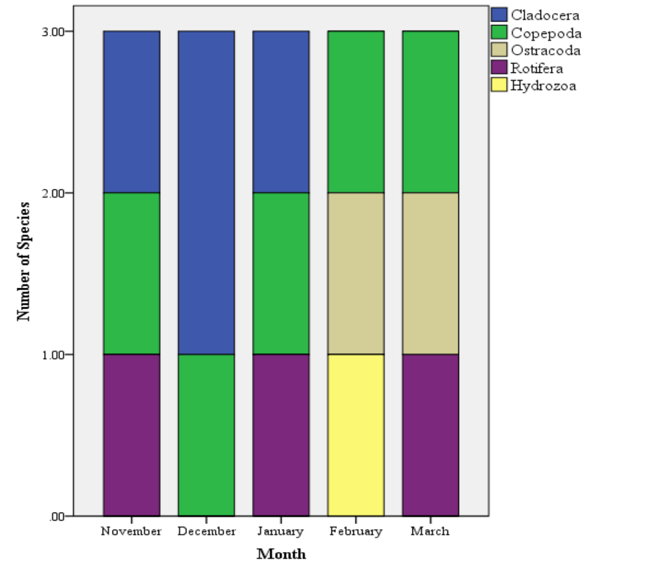

Fig. 13: Variations in the zooplankton community in the ponds without artificial illumination

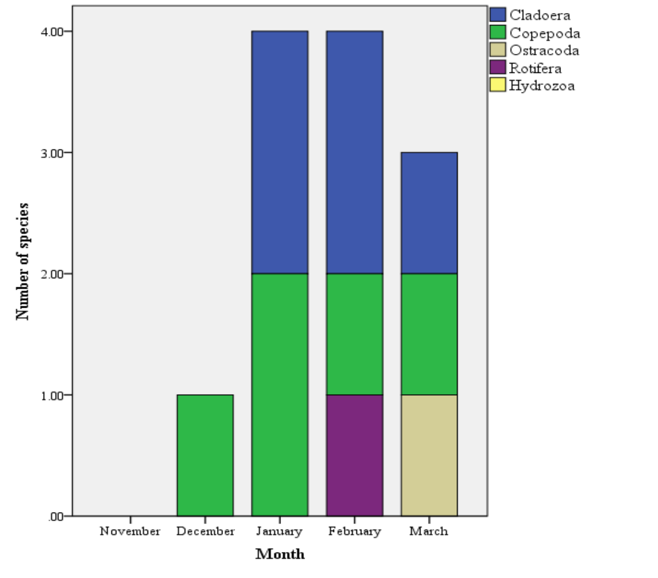

Fig. 14: Variations in the zooplankton community in the ponds with artificial illumination

It may be noted that the presence of diverse groups of zooplankton including copepods, cladocerans and rotifers, indicates the availability of edible phytoplankton [15] in the unilluminated ponds for most of the months. However, rotifers were observed only in the spring in the illuminated ponds and that too, only in February. This suggests that the influence of ALAN on the quality of phytoplankton is important in determining the quality of zooplankton in a pond ecosystem.

Conclusion

Both the systems show significant differences in some water quality parameters as well as the phytoplankton density and Margalef's index of species richness for phytoplankton. The study shows that ALAN also influences zooplankton diversity through its influence on phytoplankton diversity. Since both phytoplankton and zooplankton play important roles in aquaculture, especially during the early life stages of various farmed fish species, it may be of use to manage our use of artificial lighting in such a manner that does not negatively affect the plankton community in aquaculture ponds. It may be useful to consider aspects of location of the light source as well as light intensity and duration of illumination when making arrangements for lighting in a fish farm or near a fish pond.

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