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Full Length Research Paper

Zooplankton-based assessment of the trophic state of a tropical forest river

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In this study, we explored the usefulness of zooplankton as a tool for assessing the trophic status of a Nigerian forest river. The river was sampled monthly and investigated for water physico-chemistry and zooplankton community structure using basic statistical measurement of diversity indices to characterize the zooplankton fauna. The trophic status of the river evaluated from the physico-chemical parameters indicates that the river is oligotrophic. The zooplankton composition was typical of a tropical freshwater river, with a total of 40 species made up of 16 rotifers, 12 cladocerans and 12 copepods and their developing stages in the following order of dominance; Rotifera > Cladocera > Cylopoida > Calanoida. The zooplankton community was dominated by numerous species of rotifers and crustaceans, which are typical of oligotrophic to mesotrophic systems, amongst these includes *Conochilus dossuarius* and *Synchaeta longipes*. However, the most dominant zooplankton species in West Africa freshwater ecosystems namely, *Keratella tropica, Keratella quadrata, Brachionus angularis*, *Trichocerca pusilla*, *Filinia longiseta*, *Pompholyx sulcata*, and *Proales* sp. amongst others which are indicator species of high trophic levels were not recorded in the river. We therefore, conclude based on these facts that the river is clear, oligotrophic and it can be used for all manner of recreational activities.

Key words: Trophic status, zooplankton, forest river.

INTRODUCTION

The zooplankton community is a dynamic system that responds promptly to environmental changes, therefore to understand such changes or to draw comparisons between natural systems and those that suffer disturbances, some knowledge of the structure of the community and of the main processes involved in nutrient cycling and production is required (Rocha et al., 1997). Zooplankton species succession and spatial distribution result from differences in ecological tolerance to abiotic and biotic environmental factors (Marneffe et al., 1998), yet, bio-indicator approaches, using the responses of organisms to evaluate trophic state, have often been neglected in favour of chemical and physical techniques.

In particular, despite the considerable potential of zooplankton as effective indicators of environmental change and their fundamental importance in the transfer of energy and nutrient cycling in aquatic ecosystems, the zooplanktonic communities have not been widely used as ecosystem indicators (Stemberger and Lazorchak, 1994).

The use of zooplankton community structure as an indicator of the wellbeing of lakes dates back to as early as Birge-Juday era, 1879 - 1910 (Frey, 1963). Around the world several researches have been carried out using zooplankton to investigate pollution (Gannon and Stemberger, 1978; Bays and Crisman, 1983; Pace, 1986; Beaver and Crisman, 1990; Canfield and Jones, 1996; Pedrozo and Rocha, 2005; Zorka et al., 2006) because, they are relatively easy to identify, particularly when community sensitivity can be detected based on zooplankton body sizes or gross taxonomic classifications (Whitman et al., 2002).

In Nigeria, investigation of the response of zooplankton to pollution is rare. Ovia River in particular is an important source of water for drinking and domestic use, washing, bathing and fishing and therefore vulnerable to anthropogenic impacts, yet there is very limited water quality data (Ogbeibu et al., 2001; Omoigberale and Ogbeibu,

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2005; Ogbeibu and Omoigberale, 2005).

Typically, the inference of water quality characteristics relies on monthly sampling of a variety of indicators. In this report, we investigated the environmental variables that appear to be most influential in shaping the zooplankton community and we explored the usefulness of zooplankton as a monitoring tool for this forest river. The community composition of zooplankton was documented and the resulting species datasets was used to infer the water quality of the river. The hypothesis in the present study was that the zooplankton species would show, by analysis of qualitative and quantitative sample data, that the trophic state of the environment is oligotrophic. The species with constant frequency of occurrence in the system, showing low numerical abundance in response to the nutrient level of the water would be classified as bio-indicators.

MATERIALS AND METHODS

Study site

The study was carried out in a stretch of Ovia River, about 20.5 km from Benin City, along the Lagos - Benin Express Road (6.54°N, 5.52°E), within the tropical rainforest belt of southern Nigeria. The river takes its source from the Akpata Hills in Ekiti State and flows in a South - westerly direction and transforms into the Osse River downstream which flow through the Gwato creeks into the Benin River, which empties into the Atlantic Ocean.

The study area is composed mostly of secondary rainforest vegetation that has suffered extensive deforestation. Palm trees (*Elaeis guinensis),* shrub, floating *Salvinia* sp., *Lemna* sp. and water hyacinth (*Eichorrnia crassipes*) amongst others are also common sight in the area. The climate in the study area is typically tropical with a pronounced seasonality of rainy and dry periods. The rainy season is from April to October with peak rainfall occurring during the months of June to August, while the dry season spans from November to March. The onset of the season, however, fluctuates from year to year, though it is relatively stable. The mean annual rainfall usually exceeds 60 cm, while mean annual temperature fluctuates, between 31.8 and 34.2°C.

Three sampling stations were selected: an upstream, a mid stream and a downstream section. The downstream section (Station 1) was located about 150 m away from the bridge across the Lagos - Benin express way. This sampling station has de-vegetated bank exposing the running water to direct effects of sunlight. There were few aquatic macrophytes like *Salvinia* sp, *Lemna* sp and water hyacinth (*E. crassipes)*. The most conspicuous human activities noticed at the station were fishing and excavation of laterite by payloaders.

The mid stream section (Station 2) was located about 150 m upstream of the bridge across the Lagos - Benin express way. The river bank here had luxuriant vegetation with tree canopies that shaded the station from direct effects of sunlight rays. The station was almost covered with water hyacinth at the peak of the rainy season. Water lettuce was also found but very scanty. Bamboo (*Bambusa bambusa*), palm trees (*E. guinensis*) and some other trees characteristic of tropical rainforest were present at this station. There was a local palm oil processing mill near the station, water for drinking and domestic use was sourced by the villagers at this point; other human activities here included washing, bathing and fishing.

The upstream (Station 3) was located about 300 m away from the bridge. The station was open to direct rays of the sun. There are few aquatic macrophytes like *Salvinia sp, Lemna sp* and *E. crassipes.*

Sampling and analysis

Monthly sampling of a section of Ovia River was carried out between April, 2005 and June, 2006. Sampling was carried out between 0800 and 1100 h starting from station 1, 2 and 3 in that order each sampling day.

Subsurface water samples were collected at the three stations using a 3.5 litre capacity Van Dorn water sampler in triplicates and homogenized before being sub-sampled for physico-chemical analyses. Air and water temperatures were taken *in- situ* during the survey. Conductivity, dissolved oxygen and pH were also recorded *in-situ* using a WTW water sampler probe. Other physico-chemical variables were measured based on the procedures suggested in APHA (1998).

Qualitative plankton samples were collected by towing a 55 µm mesh hydrobios plankton net tied to a 25 HP engine-powered boat driven at low speed just below the water surface for 5 min at each sampling station. Quantitative samples on the other hand were collected by filtering 100 litres of water fetched with a bucket through a 55 µm mesh hydrobios net. Both samples were preserved separately in 4% buffered formalin solution.

In the laboratory, specimens were sorted and dissected where necessary under a binocular dissecting microscope (American Optical Corporation, Model 570), while counting and identifications were done with an Olympus Vanox Research Microscope (mag X60) Model 230485. Identification of specimens was carried out at the University of Benin, Zooplankton laboratory using relevant literatures (Smirnov, 1974; Van de Velde, 1984; Gabriel, 1986; Jeje and Fernando, 1986; Jeje, 1988; Boxshall and Braide, 1991; Imoobe, 1997; Korinek, 1999).

The percentage relative abundance of the specimens was estimated by direct count. Each quantitative sample was concentrated to 10 ml and from this; 1 ml of sample was taken and all individual taxa present were counted. Relative abundance was calculated as the number of individuals per litre of water filtered through the net.

Species diversity indices were used to analyse the zooplankton community structure. Species richness was computed using Margalef's index (D) expressed as,

$$D = \frac{S-1}{InN}$$

Where; S = Number of species
N = Total Number of all individuals.
In= Natural logarithm.

This measure relies only on zooplankton abundance and the number of taxa. Richness increases when abundance is spread over a greater number of categories, but it does not take into account the evenness of that distribution. Also, between two samples with the same S, richness will be higher in the one with the lower abundance.

General species diversity using Shannon-Wiener (H') index was computed as,

$$H = \frac{N \log N - \sum_{i=1}^{k} niLogni}{N}$$

Where; N = total number of individuals,

ni = number of individuals in species
i k = total number of species.

This index takes into account the total number of species present, as well as their respective abundance, thus providing a more convenient means of comparing differences within ecological communities. Since changes in the environment are reflected in the types and number of organisms present, diversity indices provide a tool for monitoring changes. Evenness index, which expresses the degree of uniformity in the distribution of individuals among the taxa in the collections (Magurran, 1988), was also calculated as,

$$E = \frac{H'}{H_{max}}$$

Where; H' = Shannon-Wiener index, H_{max} = maximum expected diversity expressed as Log s.

Besides the application of diversity indices, inter-station comparisons were carried out to test for significant differences in faunal abundance using one – way analysis of variance (ANOVA) (Zar, 1984). Analysis of the definition of the frequency of occurrence of species in the samples was based on the percentages suggested by Dajoz (1973); 0 to 25% - occasional species; > 25 to 50% - accessory species and > 50% - constant species. From the abundance data of species with a constant frequency in the system, it was possible to test the hypothesis that zooplankton would exhibit quantitative differences among sampling stations.

RESULTS AND DISCUSSION

Environmental conditions

A summary of the physical and chemical conditions of the study stations is presented in Table 1. The water temperature ranged between 25.0 and 29°C throughout the study with the highest mean temperature value (27.22 ± 1.11°C) recorded in the downstream Station 1. Turbidity which is a function of the dissolved and suspended particulates in the water, had values which ranged from a minimum of 0 NTU (station 3) to a maximum of 1.2 NTU recorded in station 1. Generally, the lake water was relatively clear at all the stations sampled and there was no significant difference (p > 0.05).

The water was generally fresh with conductivity values ranging from 0.008 – 0.03 μScm^{-1}. The buffering capacity measured as alkalinity was low, a weak acidic to weak alkaline pH range of 5.98 - 7.18 was observed across the stations. The concentration of calcium and magnesium salts combined with various anions (usually carbonates) that constitutes the total hardness of water was also generally low indicating that the river was Soft Water River.

Mean dissolved oxygen concentration (5.82 to 6.93 mgl^{-1}), was high, while the mean BOD_5 (1.97 to 3.46 mgl^{-1}), was low. The essential primary productivity nutrients, nitrate (0. 0 to 2.0 mgl^{-1}), sulphate (0. 0 to 2.4 mgl^{-1}) and phosphate (0. 004 to 0.12 mgl^{-1}) were low. Forest ecosystems readily immobilize phosphorus, thus limiting its input to the river (Downing and McCauley, 1992). The river's watershed, combined with the lack of residential housing or farms surrounding the river, probably limits nutrient input. Generally, the spatial and temporal variations observed in all the environmental factors investigated were not significantly different (p > 0.05). The trophic status of the river as evaluated using Carlson's Trophic State Index (Carlson, 1977) and the trophic state designations assigned by Kratzer and Brezonik (1981) indicates that the river is oligotrophic. The low levels of nutrients are fundamental to the river's oligotrophic status. Evidence for low production is also seen in the river's oxygen profile, which does not go below 4.4 mg l^{-1} (Table 1), a condition which also contributes to the lake's phosphorus limitation through the binding of phosphorus to oxidized iron (Fe^{3+}) in the sediments.

Zooplankton species composition

Forty species of zooplankton were recorded during the 15-month sampling period of the study (Table 2). The greatest diversity was observed among Rotifera, with 16 species in ten families, this pattern is common in tropical freshwaters, whether in lakes, ponds, reservoirs, rivers, or streams (Neves et al., 2003). Cladocera and Copepoda were represented by twelve taxa each. Nauplii and copepodids, the developmental stages of Copepoda, were quite common. Most of the species identified indicated a typical tropical assemblage, however, predominantly temperate genera like *Synchaeta* and *Collotheca sp were* recorded. As in most tropical freshwaters, the cladoceran fauna included *Bosmina longirostris*, *Diaphanosoma excisum*, *Ceriodaphnia cornuta* and *Moina micrura*. The genus *Daphnia* was absent and this is typical for most tropical waters. Species richness at each of the three stations was 40 with a range of between 12 - 31 (Station 1), 17 - 29 (Station 2) and 15 - 28 (Station 3) per sample. In general, species richness, evenness and diversity of the zooplankton in the study area were high (Table 3). The high values of Margalef's index, Evenness index and Shannon-Wiener index indicates high diversity.

Small organisms like nauplii and rotifers predominated, even among the cladocerans, small forms, like B. longirostris and C. cornuta occurred frequently in high densities. An important consideration when there is a predominance of smaller species in rivers is the possible relation to suspended material in the water column due to the constant influence of the wind or due to predation pressure from planktivorous fishes (Carpenter et al., 1985; Stemberger and Lazorchak, 1994).

Numerous species of rotifers and crustaceans considered good indicators of the trophic state of rivers and lakes were found in the zooplankton community. Rotifer species recorded that are typical of oligotrophic to mesotrophic systems included Conochilus dossuarius and Synchaeta longipes. However, the regularly most dominant species in West Africa freshwater ecosystems namely, *Keratella tropica, Keratella quadrata, Brachionus*

Table 1. Mean (± SD) values of some physical and chemical conditions of the study stations, on Ovia River, April, 2005 – June, 2006 (minimum and maximum in parenthesis). N = Number of samples/sampling station.

Sampling stations	N	1	2	3
Temperature °C (Air)	15	27.27 ± 1.37 (24.8 - 28.7)	26.77 ± 1.28 (24.8 - 28.0)	26.97 ± 1.33 (24.8 - 28.5)
Temperature °C (Water)	15	27.22 ± 1.11 (26.1 - 29.0)	26.47 ± 0.89 (25.3 - 27.5)	26.72 ± 1.70 (25.0 - 29.0)
Turbidity (NTU)	15	0.47 ± 0.64 (0.02 - 1.2)	0.54 ± 0.45 (0.02 - 0.8)	0.57 ± 0.55 (0.0 - 1.1)
Conductivity (lScm^{-1})	15	0.022 ± 0.009 (0.01 - 0.03)	0.022 ± 0.009 (0.008 - 0.03)	0.022 ± 0.008 (0.01 - 0.03)
TDS (mgl^{-1})	15	20.01 ± 6.09 (14.2 - 29)	18.27 ± 6.99 (11 - 28.8)	19.81 ± 5.68 (14.5 - 28.6)
TS (mgl^{-1})	15	26.63 ± 4.77 (23.25 – 30)	26.45 ± 5.02 (22.9 - 30)	27 ± 5.66 (23. - 31)
pH	15	6.59 ± 0.4 (6.59 - 7.04)	6.58 ± 05 (5.98 - 7.18)	6.60 ± 0.41 (6.1 - 7.12)
Alkalinity (mgl^{-1} $CaCo_3$)	15	56.12 ± 27.1 (24.4 - 91.5)	51.24 ± 21.39 (24.4 - 73.2)	51.24 ± 14.04 (36.6 - 67.1)
Calcium (mgl^{-1})	15	4.89 ± 3.95 (0.8 - 9.22)	4.81 ± 5.42 (0.4 - 12.83)	5.61 ± 4.42 (0.8 - 10.82)
Magnesium (mgl^{-1})	15	2.33 ± 2.18 (024 - 5.35)	1.60 ± 1.5 (0.24 - 3.89)	1.65 ± 1.5 (0.24 - 3.65)
Dissolved Oxygen (mgl^{-1})	15	5.82 ± 0.83 (4.4 - 6.55)	6.93 ± 1.67 (5.15 - 9.0)	6.59 ± 1.41 (5.1 - 8.25)
BOD (mgl^{-1})	15	1.97 ± 0.81 (1.3 - 3.35)	3.46 ± 1.91 (1.5 - 5.8)	3.27 ± 2.1293 (0.3 - 6.05)
Sulphate (mgl^{-1})	15	0.77 ± 0.67 (0.0 - 1.2)	1.4 ± 1.22 (0.0 - 2.2)	1.4 ± 1.25 (0.0 - 2.4)
Phosphate (mgl^{-1})	15	0.032 ± 0.05 (0.004 - 0.12)	0.023 ± 0.032 (0.006 - 0.08)	0.023 ± 0.032 (0.004 - 0.08)
Nitrate (mgl^{-1})	15	0.66 ± 0.65 (0.0 - 1.5)	0.76 ± 0.79 (0.0 - 2.0)	0.69 ± 0.75 (0.0 - 1.8)
Chloride (mgl^{-1})	15	23.71 ± 5.3 (16.33 - 31.24)	19.6 ± 3.61 (13.49 - 22.01)	24.28 ± 4.85 (19.17 - 31.95)

angularis, *Trichocerca pusilla*, *Filinia longiseta*, *Pompholyx sulcata* and *Proales* sp. which are indicator species of high trophic levels were not recorded in the river.

The crustacean zooplankton community was made up of copepods and cladocerans. Copepod abundance was driven mostly by increases in nauplii and cyclopoid copepodids, although they were surpassed by rotifers. The observed reproductive increment in copepoda, represented by the high relative abundances of larval stages and the most frequent copepods namely, *Ectocyclops phaleratus, Eucyclops agiloides, Halicyclops korodiensis, Mesocyclops leukarti, Microcyclops varicans, Thermocyclops neglectus, Diaptomus minutes* and *Thermodiaptomus galebi* indicates water of high quality, signified by the oligotrophic status of the river.

The dominant cladocera was generally *B. longirostris*. *Bosminopsis deitersi, Moina micrura, Alona rectangula, C. cornuta* and *Simocephalus vetulus* were also represented in most samples. The occurrence and dominance of B. deitersi in oligotrophic and mesotrophic conditions is well recorded. Sendacz et al. (1985) recorded *B. deitersi* in great abundance in the oligotrophic reservoirs of São Paulo, while Spohr-Bacchin (1994) observed the dominance of this species in the mesooligotrophic Emboaba Lake, throughout the year, except in the winter.

Average zooplankton abundance in the river was very low throughout the period of study; the densities of zooplankton ranged from 18 to 55 individuals/l a trend that did not show a significant ($p > 0.05$) seasonal variation, though the zooplankton community usually experiences

Table 2. Species composition, percentage relative abundance and frequency of occurrence of zooplankton in the area of study. Number of samples (n) = 45.

Species composition	STN 1	STN 2	STN 3	Total	Freq. of Occurrence %	Relative abundance %
Cladocera						
Alona rectangula	14	12	14	40	62	2.6
Bomina longirostris	15	10	9	34	53	2.2
Bosminopsis deitersi	13	9	9	31	49	2
Ceriodaphnia cornuta	16	12	7	35	58	2.3
Chydorus sphaericus	9	10	14	33	53	2.1
Diaphanosoma excisum	10	10	13	33	47	2.1
Echinisca triseralis	13	12	6	31	44	2
Ilyocryptus spinifer	12	13	12	37	58	2.4
Kurzia longirostris	9	9	11	29	49	1.9
Macrothrix spinosa	12	5	13	30	42	1.9
Moina micrura	13	18	9	40	58	2.6
Simocephalus vetulus	13	11	11	35	49	2.3
Copepoda						
Afrocyclop curticornis	9	13	10	32	49	2.1
Diacyclops thomasi	12	12	10	34	47	2.2
Ectocyclops phaleratus	14	11	11	36	56	2.3
Eucyclops agiloides	8	11	11	30	53	1.9
Halicyclops korodiensis	12	13	14	39	58	2.5
Mesocyclops leukarti	18	4	13	35	51	2.3
Metacyclops minutus	10	8	13	31	49	2
Microcyclops varicans	10	14	15	39	60	2.5
Thermocyclops neglectus	15	10	16	41	62	2.7
Copepodids	13	8	11	32	42	2.1
Nauplii	14	14	14	42	64	2.7
Calanoida						
Diaptomus minutus	19	11	12	42	58	2.7
Thermodiaptomus galebi	18	13	14	45	60	2.9
Tropodiaptomus incognitus	6	12	14	32	49	2.1
copepodids	14	15	13	42	60	2.7
Rotifera						
Ascomorpha ovalis	9	17	9	35	49	2.3
Asplanchna priodonta	7	13	11	31	44	2
Brachionus diversicornis	14	11	11	36	49	2.3
Collotheca sp	12	16	10	38	58	2.45
Conochilus dossuarius	13	13	12	38	56	2.45
Conochilus unicornis	17	15	12	44	64	2.8
Euchlanis dilatata	16	8	6	30	40	1.9
Kellicottia longispina	8	13	13	34	51	2.2
Keratella cochlearis cochlearis	17	12	13	42	62	2.7
Keratella longispina	11	17	10	38	49	2.45
Lecane bulla	11	12	15	38	53	2.45
Polyarthra remata	12	13	7	32	49	2.1
Proales decipiens	14	6	14	34	53	2.2
Synchaeta longipes	14	17	15	46	62	3
Trichocerca cylindrica chattoni	18	15	11	44	58	2.8
Trichocerca similis	8	9	11	28	42	1.8

Table 3. Species diversity indices at the study area.

	Sampling stations		
	STN 1	**STN 2**	**STN 3**
Number of samples collected	45	45	45
Diversity			
Taxa Number (S)	40	40	40
Range of taxa number/sample	12-31	17-29	15-28
Taxa Richness Index (D)	6.274	6.339	6.359
Shannon Wiener's Index (H')	3.65	3.65	3.664
Evenness Index (E)	0.99	0.99	0.993

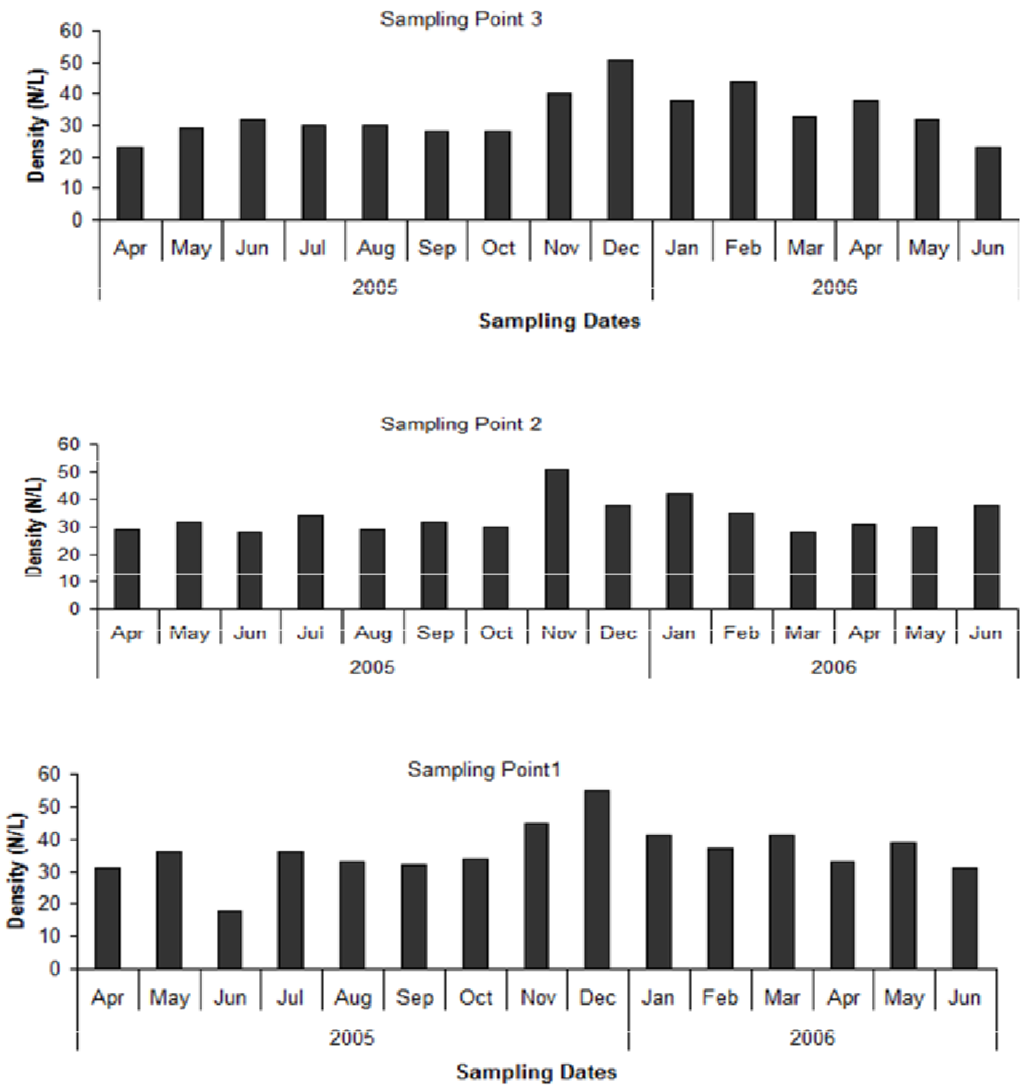

Figure 1. Temporal variation in the density of zooplankton in the Ovia River.

experiences slight decrease in the total density and taxa richness during the wet season months of April to October (Figure 1). Similarly, there was no significant difference (p > 0.05) in the abundance and spatial distribution of zooplankton among the three sampling stations, as all three stations had closely equal number of total zooplankton and taxa richness. Temperature and the availability of food are about the most important factors controlling abundance of zooplankton in lakes. In this study, with similar temperature regime pervading the entire study area throughout the period of study, the low level of food in the water as a result of the low primary productivity can be responsible for the generally low population of zooplankton. There does not seem to be a remarkable relationship between the environmental features of the river and the frequent species, except that, just as the trophic status of the river indicates that the river is oligotrophic, the densities of the more frequent zooplankton at the different sampling stations were also low and there was a homogenous distribution of species, as shown by their similar relative abundances.

Conclusion

The zooplankton community of Ovia River an oligotrophic system with very little primary production and low densities of zooplankton appears to be controlled by bottom-up mechanisms, where nutrient inputs are probably low, thus limiting phytoplankton abundance and primary production, which limits zooplankton densities. Zooplankton size, however, appears to be limited by the nature of zooplanktivory. Ovia River was not strongly affected by cultural eutrophication at the time of sampling; extensive forests in the watershed may have helped to alleviate anthropogenic nutrient input. Most of the land surrounding the lake is forested and no residential homes or farming, which are typical sources of nutrient loading exist.

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