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RESEARCH ARTICLE

Study of Nestedness Index using Diatoms from selected fresh water bodies of Goa

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Abstract: Nestedness has been recognized as a characteristic pattern of community organization. Present study was carried out by selecting four fresh water bodies from the state of Goa, to understand whether freshwater diatom communities exhibit nested structure; to know the possible drivers of species nestedness and also to find out the habitat showing best nested pattern. Physico-chemical parameters of water bodies like turbidity, temperature, total chlorophyll, BOD, nitrates and phosphates were analyzed. The presence - absence matrices for diatoms were built using nestedness software. In all 21species of diatoms belonging to 12 genera were recorded during 24 month study. The study revealed that Syngenta, Lotus and Curtorim Lakes, are most hospitable sites while Khandola Pond having idiosyncratic species lies at the bottom position in supporting the growth of diatoms. *Pinnularia graciloids, P. gibba, Navicula halophila, N. mutica, N. radiosa, N. rhynococephala* and *Synedra ulna,* had common niche requirements. Selected water bodies were organically as well as anthropogenically polluted. Presence of *Navicula halophila* and *N. mutica* indicated organic pollution in all four water bodies. Presence of *Synedra ulna* indicated anthropogenic pollution in Syngenta, Lotus and Curtorim lakes while *N. rhynococephala* indicated anthropogenic pollution in Khandola Pond. Idiosyncratic species like *Gomphonema subtiles, G. parabolum, Pinnularia graciloids, Eunotia tumida, Melosira islandica and Navicula microcephala* were also observed in the study sites. The matrix fill was 79% at Syngenta Lake, 66.6% at Khandola Pond, 78.7% at Lotus Lake and 71.2% at Curtorim Lake with respective system temperatures of 12.73^0, 2.12^0, $4.73^0$and 12.86^0. Physico- chemical parameters tested during study proved to be the possible drivers of nestedness. Principal component analysis identified total chlorophyll, BOD, turbidity, temperature, nitrates, and phosphates as the key factors that controlled structure of diatom communities. Analysis revealed that the diatom assemblages of selected water bodies are highly nested.

Key words -*Nestedness; Idiosyncratic; Diatoms; Presence–absence matrix; System temperature.*

Introduction

A common biogeographic pattern is species nestedness: smaller communities form proper subsets of larger communities (Atmar and Patterson, 1993). It is a measure of structure in an ecological system, usually applied to species-sites systems (describing the distribution of species across locations), or species-species interaction networks (describing the interactions between species). Nestedness is particularly common in mutualistic networks, such as those involving plants species and their pollinators or seed dispersers (Bascompte *et al.* 2003, Ollerton *et al.* 2007) or other mutualistic systems. In the study of biogeographic patterns of species occurrence, nestedness analysis has become increasingly popular. Nestedness analysis was initially developed for species distribution on places like islands and well delimited land patches. Lake biota is well suited to be studied through this approach hence present study was undertaken aiming to evaluate nestedness pattern with respect to effect of environmental variables on the distributional pattern of diatom assemblages, to understand the structuring process of metacommunities in selected water bodies from the state of Goa and to determine whether the indicator diatoms were autocathonous or allocathonous to each of the water body.

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Materials and methods

Two water bodies each from North Goa (Syngenta Lake and Khandola Pond) and South Goa (Lotus Lake and Curtorim Lake) were selected for the present study (Figure 1).

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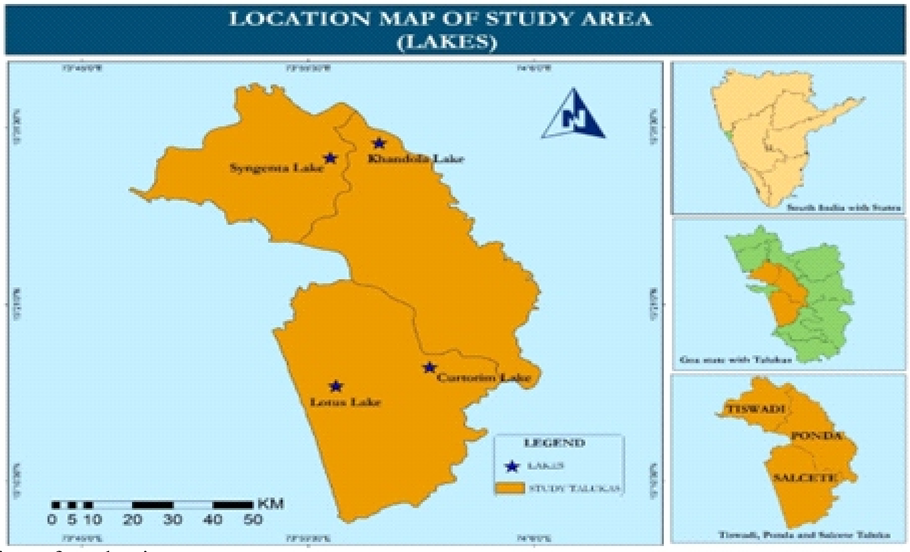

Figure 1: Location of study sites

Water samples were collected from selected waterbodies on monthly basis for a period of two years viz; Jan. 14 to Dec. 15. in the early hours, as daily vertical migrations of organisms occur in response to sunlight and nutrient concentrations from the surface near the landward margins. One litre of water sample was collected in sterile plastic bottles (three replicates were taken) and Lugol's solution was added immediately for sedimentation and retaining of color. The bottles were subsequently left undisturbed for 24 hours. The phytoplanktons fixed and settled at the bottom of the containers, were filtered through net of mesh size 63 µm and 30 cm diameter, making final volume to 50ml and then preserved in 100 ml bottles containing 4% formaldehyde. Enumeration of diatoms was done by modified Lackey's drop method Suxena (1987). Organisms were counted in each drop. This procedure was repeated three times for each samples and number of organism is measured as organism per liter.

Formula used for the calculation of plankton as Org/L is

$$\text{Plankton Org/L} = \frac{n \times c \times 100}{V}$$

n= No. of plankton counted in 0.1ml of sample c= total volume of concentrated in ml V= total volume of water filtered through net

Dimensions of the cells were measured using micrometry technique and photomicrographs were taken using Nikon DS Fi 2 camera. Identification

A

	1	2	3	4	5
a	1	0	0	1	0
b	1	1	1	1	1
c	0	0	0	1	0
d	1	0	1	1	0

B

	4	1	3	5	2
b	1	1	1	1	1
d	1	1	1	0	0
a	1	1	0	0	0
c	1	0	0	0	0

Figure.2: Species composition of a perfectly nested metacommunity

was done using relevant literature; Edmondson (1966), Gandhi (1998), Gandhi (1998), Krammer (2003) Karthick *et al.* (2011). Diatoms were chosen for calculation of nestedness as their cells do not dissolve in water for a longer duration and hence can serve as important indicators of organic as well as anthropogenic pollution. Environmental variables like temperature, turbidity, nitrates, and phosphates were analyzed using standard procedures (APHA 2012). Using the data generated nestedness of diatoms was studied with the help of nestedness temperature calculator software. Figure 2 shows a perfectly nested community wherein numbered columns represent species and rows represent sites. During nestedness study, presences and absences of a species in a given site are denoted by 1 and 0, respectively: (A) species and sites sorted in an arbitrary order and (B) packed matrix, where nestedness is made evident after reordering species and sites by decreasing incidence and richness (Mc Koy and Heck 1987).

Results

Using nestedness calculator presence-absence matrices for diatoms were built. For each matrix, their degree of nestedness was calculated. During two years of study period a total 21species of diatoms belonging to 12 genera were recorded from the selected water bodies. The nestedness shown by the diatom community was highly significant, even though it had idiosyncratic species like *Gomphonema subtiles, G. parabolum, Pinnularia graciloids, Eunotia tumida,* Melosira *islandica* and *Navicula microcephala*. Among the environmental variables analyzed during this study, PCA identified total chlorophyll, BOD, turbidity,

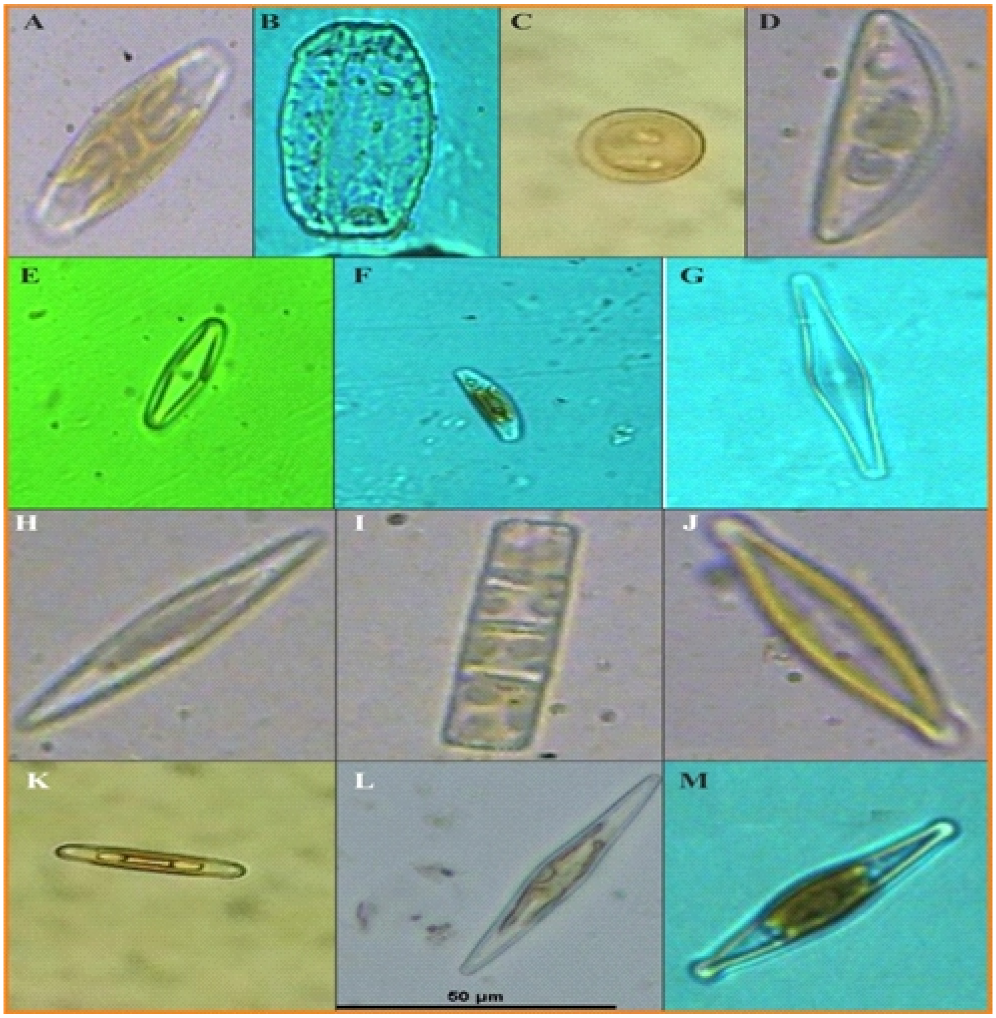

Plate 1: Diatoms recovered from study sites **A.** *Navicula microcephala* Grunow, **B**. *Navicula sphaerophora* Kutzing, **C**. *Synedra ulna* (Nitzsch) Ehrenberg, **D**. *Pinnularia dolosa* H. P. Gandhi, **E**. *Pinnularia gibba* Ehrenberg, **F**. *Pinnularia graciloids* Huste, **G**. *Stauroneis anceps* Ehrenberg, **H**. *Stauroneis phoenicenteron* (Nitzsch) Ehrenberg

Table 1: Diatoms encountered during study from selected water bodies

Sr. No.	Species	SL	KP	LL	CL
1	*Ahninthes exigua* Gurnow	+	-	+	+
2	*Amphora ovalis* (Kutzing) Kutzing	+	-	+	+
3	*Cocconeis placentula* Ehrenberg	+	+	+	+
4	*Cymbella chandolensis* Gandhi	+	-	+	+
5	*Diploneis elliptica* (Kutzing) Cleve	+	-	+	+
6	*Eunotia tumida* Gandhi	+	-	+	+
7	*Gomphonema parabolum* Kuetzing	+	-	+	+
8	*Gomphonema subtiles* Ehrenberg	+	-	+	+
9	*Melosira islandica* O. Muller	+	-	+	+
10	*Navicula halophila* (Gurnow) Cleve	+	+	+	+
11	*Navicula microcephala* Grunow	+	-	+	+
12	*Navicula radiosa* Kutzing	+	+	+	+
13	*Navicula rhynococephala*	+	+	+	+
14	*Navicula mutica* Kutzing	+	+	+	+
15	*Navicula sphaerophora* Kutzing	+	-	+	+
16	*Pinnularia dolosa* H.P.Gandhi	+	+	+	+
17	*Pinnularia gibba* Ehrenberg	+	-	+	+
18	*Pinnularia graciloids* Huste	+	-	+	+
19	*Stauroneis phoenicenteron* (Nitzsch) Ehrenberg	+	-	+	+
20	*Stauroneis anceps* Ehrenberg	+	-	+	+
21	*Synedra ulna* (Nitzsch) Ehrenberg	+	-	+	+

Legend: SL = Syngenta Lake; KP = Khandola Pond; LL = Lotus Lake; CL = Curtorim Lake

temperature, nitrates, and phosphates as the principal components which controlled diatom community structure in the water bodies (Figure 3). Diatoms encountered during study are listed in Table 1 (showing their presence and absence during the study period) and plate 1 and 2 are showing the photomicrographs. Nestedness pattern with matrix fill of selected water bodies are shown in figures 4 to 7

Discussion

Nestedness has profound implications for the conservations of species assemblages since the few species present on poor sites can be found everywhere, whereas only richer sites will support uncommon species in need of preservation (Patterson 1987). According to Atmar and Patterson (1995), matrix is ordered as per the marginal row and column sums, with highly nested species placed in the upper rows, and species rich sites placed in the left hand columns. Presence-absence matrices specify which species occur at which sites, and also reflect the relative hospitality of sites to the species under study, as well as the prevalence of environmental conditions needed to support each species. Diatoms documented in this study showed highly packed matrix thereby proving maximum nestedness, by reordeing entire rows and columns. Nested matrices can be readily distinguished because their presences are tightly clustered into the upper-left corner of the matrix (Fig. 4-7). Present study reveals that Syngenta, Lotus and Curtorim Lakes greatly supported the growth of diatoms compared to Khandola Pond. Eight species of diatoms viz., *Navicula halophila, N. mutica, N. radiosa, N. rhynococephala, Synedra ulna, Pinnularia gibba, P. dolosa* and *P. graciloidis* were common to all the study sites indicated a common niche requirement. These forms were present throughout the study and hence described as autochthonous species. In perfectly nested meta communities, the richest site contain complete set of species. In contrast, real imperfectly nested meta communities contain poor sites with particular species compositions (Cabeza and Moilanen, 2001). Species like *Gomphonema subtiles*, *Amphora ovalis, Eunotia tumida, Ahninthes exigua*

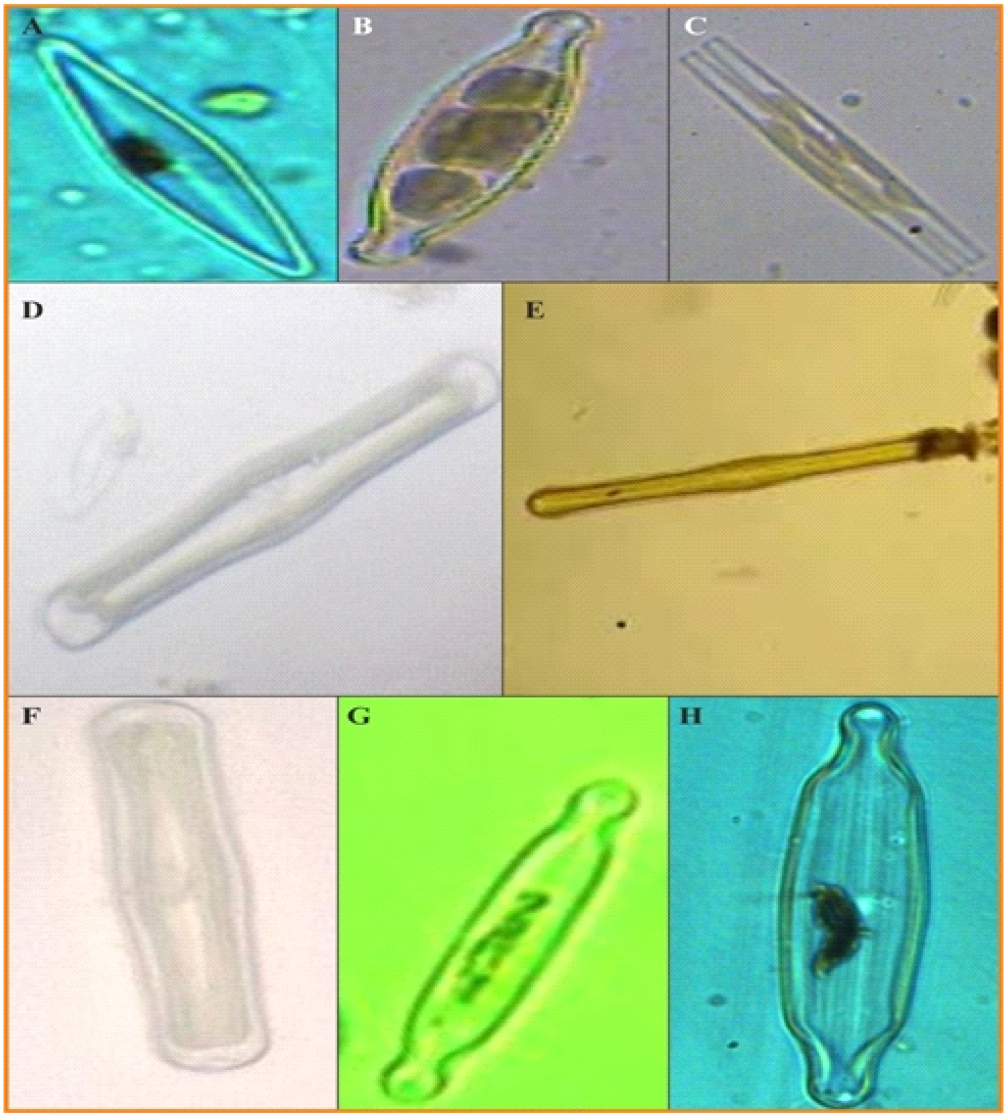

Plate 2: Diatoms recovered from study sites A.*Navicula microcephala* Grunow, **B**. *Navicula sphaerophora* Kutzing, **C**. *Synedra ulna* (Nitzsch) Ehrenberg, **D**. *Pinnularia dolosa* H. P. Gandhi, **E**. *Pinnularia gibba* Ehrenberg, **F**. *Pinnularia graciloids* Huste, **G**. *Stauroneis anceps* Ehrenberg, **H**. *Stauroneis phoenicenteron* (Nitzsch) Ehrenberg

from Syngenta Lake, *Cocconeis placentula, Pinnularia graciloids* from Khandola Pond, *Eunotia tumida, Melosira islandica, Stauroneis phoenicenteron* from Lotus Lake, and *Ahninthes exigua, Gomphonema parabolum, Eunotia tumida* from Curtorim Lake recorded during study were appearing occasionally. The matrix fill of the species in the Syngenta Lake was 79% with system temperature of 12.73°, at Lotus Lake it was 78.7% with temperature 4.73°, while at Curtorim Lake it was 71.2% matrix fill with 12.86° system temperature with high nestedness index. Even though lesser number of species was recorded in Khandola Pond, the matrix fill was 66.6% with highly nested species having cooler system temperature of 2.12°C. This may be attributed to lack of species distribution in the water body. It was observed that physical and chemical variables tested during study, were possible drivers of diatom metacommunity nestedness. The water temperature throughout the sites varied from 25 to 32^{o}C, maximum in May (late summer and early rainy season) and minimum in January (winter season). Water temperature plays an important role in controlling the occurrence and abundance of phytoplanktons (Nazneen, 1980). Turbidity of the selected study sites varied from 22 to 53 NTU at Syngenta, 15.40 to 31 at Khandola, 29 to 54.78 at

Table 2 : Variations in temperature, turbidity, nitrates and phosphates of selected water bodies

Months of Study	Syngenta Lake				Khandola Pond				Lotus Lake				Curtorim Lake			
	Temp	Turb	Nitr.	Phos.	Temp	Turb	Nitr.	Phos.	Temp	Turb	Nitr.	Phos.	Temp	Turb	Nitr.	Phos.
Jan’14	25	22.0	0.20	0.10	25	17.2	0.27	0.01	25	29.0	1.43	0.01	25	26.0	0.80	0.01
Feb’14	28	28.0	0.72	0.12	28	19.0	0.23	0.02	29	33.0	1.58	0.03	29	32.0	1.27	0.02
Mar’14	28	34.0	0.82	0.23	28	18.0	0.56	0.01	29	33.0	1.66	0.10	29	33.0	1.50	0.01
Apr’14	30	42.0	0.31	0.10	30	18.4	0.47	0.04	30	38.0	1.76	0.25	30	33.0	1.78	0.04
May’14	31	49.0	0.54	0.24	31	18.7	0.36	0.02	31	42.0	1.81	0.25	31	34.0	2.57	0.12
June’14	30	46.0	0.33	0.27	30	16.4	0.50	0.02	30	37.4	2.16	0.30	30	35.0	1.32	0.15
July’14	28	48.0	0.41	0.25	30	24.3	0.58	0.30	30	43.0	4.55	2.41	30	42.0	2.27	1.72
Aug’14	27	51.0	0.50	0.19	28	30.4	0.34	0.25	26	52.7	3.16	1.92	26	45.0	2.76	0.49
Sept’14	28	46.0	0.53	0.20	27	27.2	0.38	0.15	28	42.1	3.38	0.78	28	41.0	1.43	0.55
Oct’14	29	41.0	0.48	0.15	28	21.3	0.31	0.15	29	37.2	4.45	0.60	29	37.0	1.27	0.30
Nov’14	29	37.0	0.31	0.19	29	17.7	0.30	0.10	29	31.2	3.06	0.19	29	32.0	1.19	0.19
Dec’14	28	33.0	0.29	0.10	28	14.4	0.29	0.02	28	29.8	2.38	0.10	28	29.0	1.27	0.10
Jan’15	23	29.0	0.21	0.11	23	17.2	0.21	0.01	25	31.0	1.76	0.27	25	27.5	0.93	0.19
Feb’15	25	26.0	0.34	0.07	25	18.0	0.23	0.02	29	37.0	1.65	0.20	29	34.0	1.43	0.30
Mar’15	29	34.0	0.73	0.09	29	18.0	0.50	0.01	29	43.0	1.75	0.21	29	36.0	1.67	0.48
Apr’15	30	42.0	0.24	0.10	30	18.4	0.49	0.04	30	48.0	1.70	0.18	30	37.3	1.51	0.40
May’15	32	49.0	0.32	0.20	32	18.7	0.32	0.02	32	52.0	1.81	0.25	32	41.0	1.55	0.47
June’15	31	48.0	0.37	0.25	31	16.4	0.35	0.02	31	53.4	2.24	0.39	31	45.0	2.30	1.15
July’15	28	51.0	0.43	0.29	28	28.3	0.28	0.01	30	48.0	2.95	1.01	30	54.0	2.45	1.22
Aug’15	27	53.0	0.59	0.31	27	31.0	0.33	0.02	26	54.7	3.19	1.62	26	56.7	2.64	1.54
Sept’15	28	47.0	0.57	0.28	28	28.2	0.38	0.04	28	52.1	3.38	1.70	28	41.3	2.40	0.95
Oct’15	29	43.0	0.53	0.22	29	23.3	0.32	0.03	29	48.7	2.55	1.03	29	39.0	1.73	0.40
Nov’15	29	41.0	0.45	0.17	29	18.7	0.29	0.02	29	41.2	2.17	0.17	29	35.6	1.65	0.20
Dec’15	28	39.0	0.37	0.12	28	15.4	0.27	0.01	28	39.5	2.02	0.11	31	34.0	2.57	0.12

Legand: Values are average of three readings; Temp- Temperature, Turb - Turbidity, Nitr.- Nitrates, Phos. - Phosphates

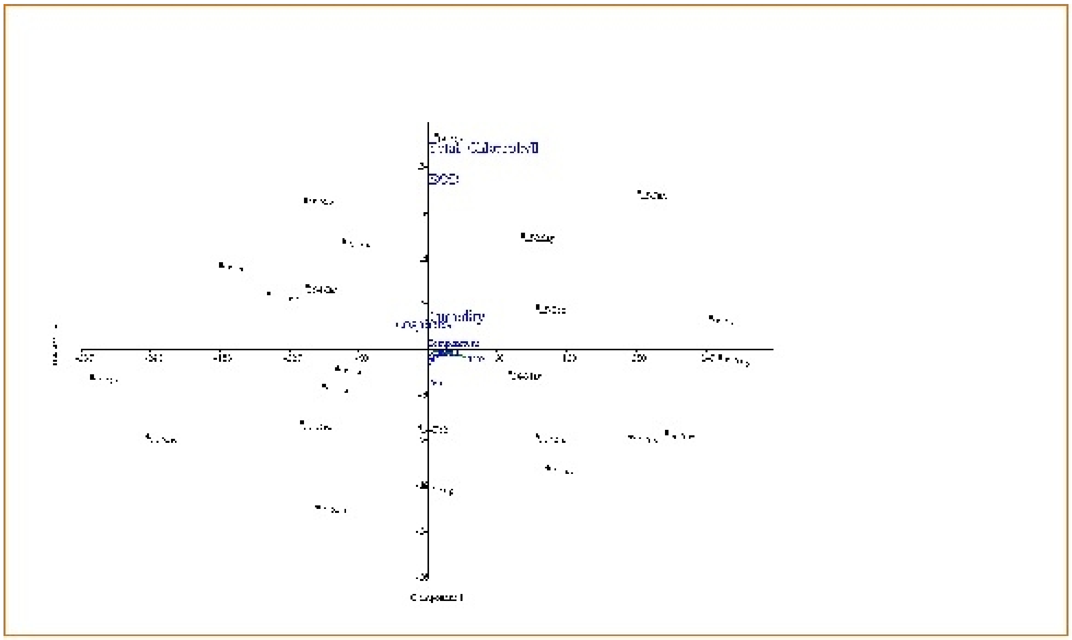

Figure 3: Principal component Analysis

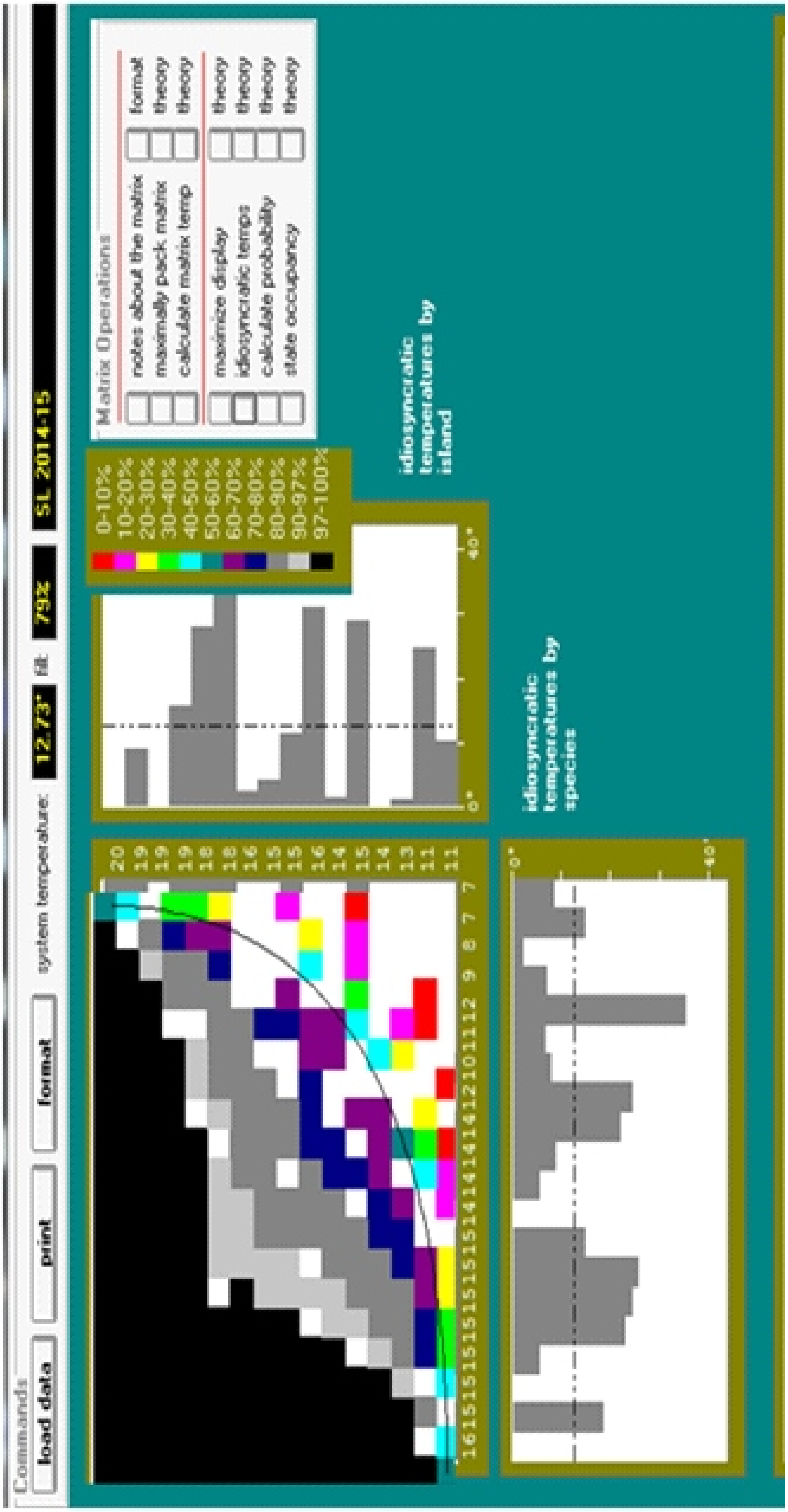

Figure 4: Nestedness pattern in Syngenta lake.

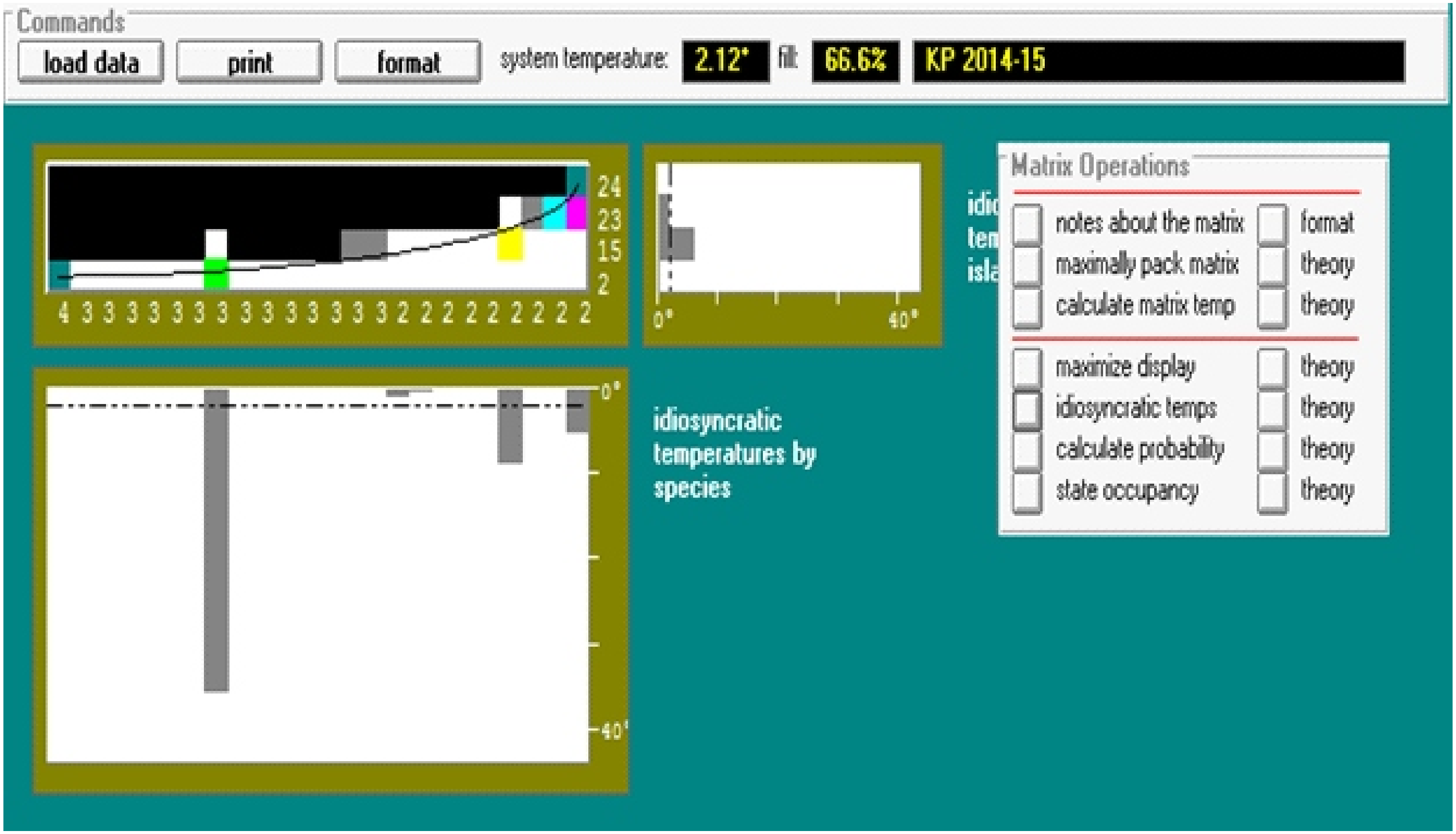

Figure 5: Nestedness pattern in Khandola Pond

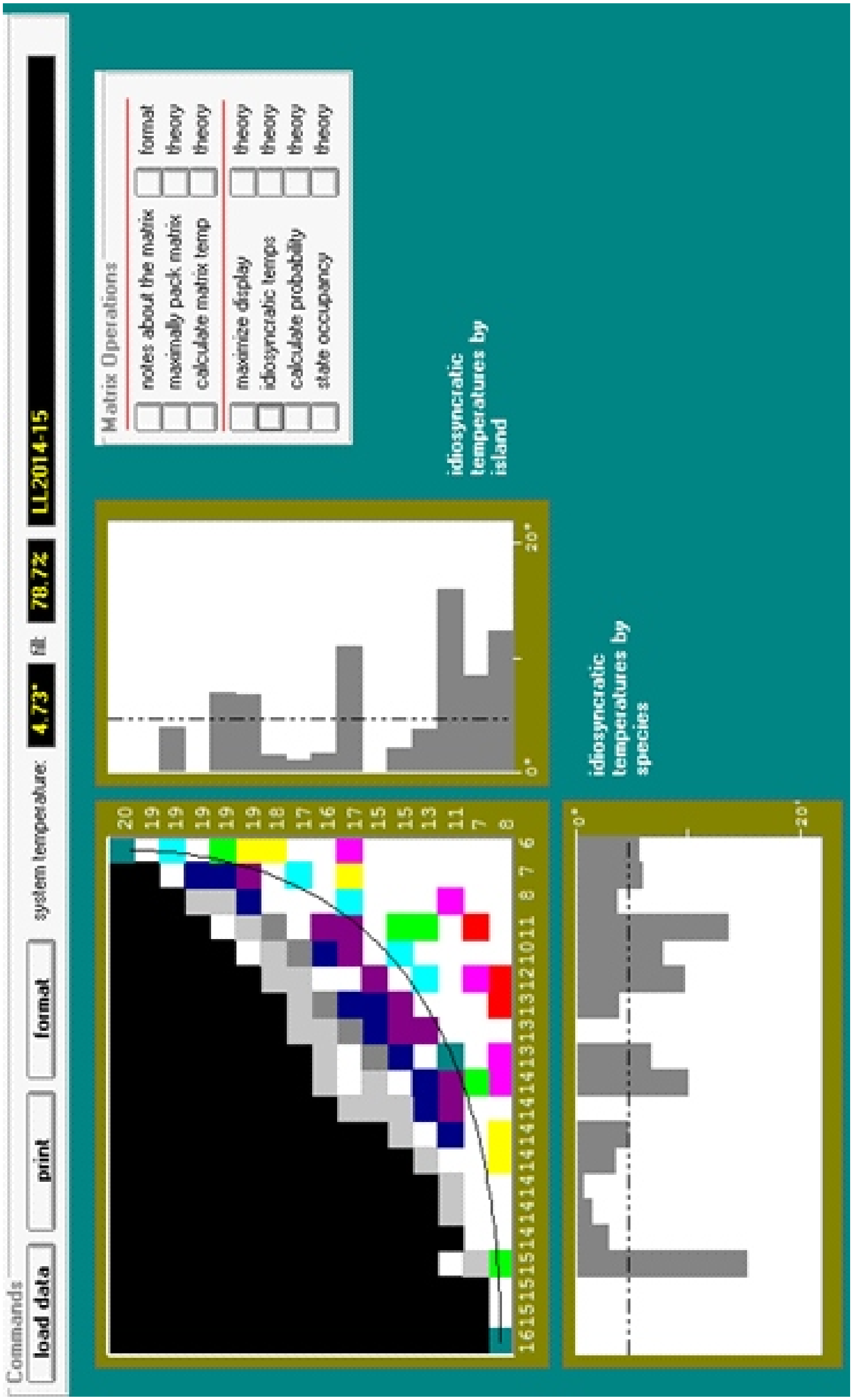

Figure 6: Nestedness pattern in Lotus Lake

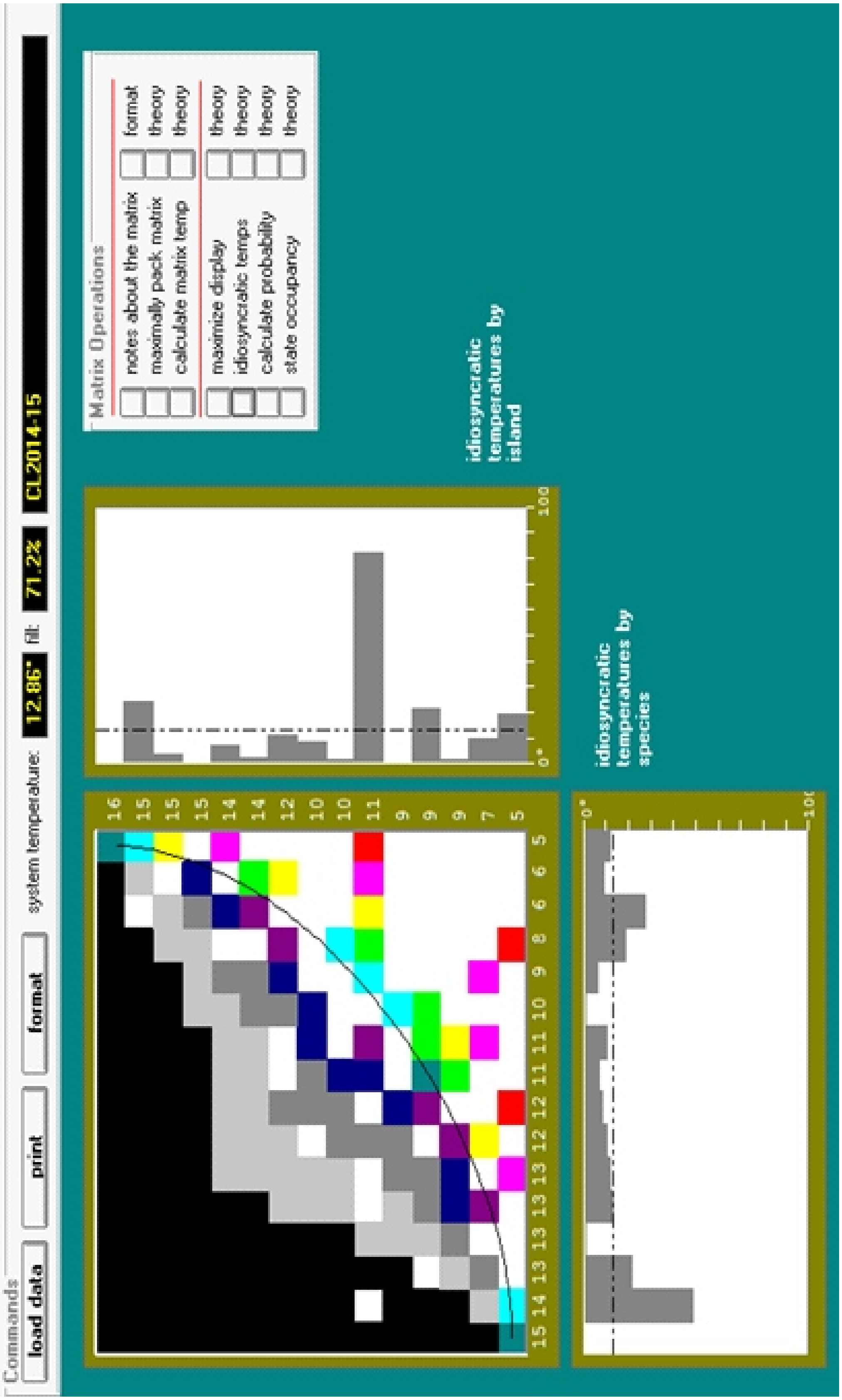

Figure 7: Nestedness pattern in Curtorim Lake.

Lotus lake and 26 to 56.76 at Curtorim Lake. Highest value was recorded during monsoon season and low value was recorded during winter season. According to Ansari and Prakash (2000), the maximum values of turbidity in monsoon may be due to rainfall and surface runoff of water bringing a lot of nutrients and sediments from the surrounding areas which trigger growth of planktons. The nitrate levels showed variations in the water bodies and ranged from 0.20 to 0.73 mg /L in Syngenta Lake, 0.20 to 0.73 mg /L in Khandola Pond, 1.43 to 4.55 mg/ L in Lotus Lake and 0.80 to 2.76 mg /L in Curtorim Lake. The high amount of nitrate was recorded during monsoon season except at Syngenta and the low amount was recorded during winter season. Similar observations were made by Das (2003) and Sehgal (2003). Phosphate concentrations showed variations and ranged from 0.07 to 0.31 mg /L in Syngenta Lake, 0.01 to 0.30 mg/L in Khandola Pond, 0.01 to 2. 41 mg/L in Lotus Lake and 0.01 to 1.72 mg/ L in Curtorim Lake. Phosphates and nitrates occur in small amounts in all aquatic environments and are required to maintain the growth and metabolism of aquatic organisms. Due to heavy monsoon in the state, nutrients like nitrates and phosphates enter the water bodies from the surrounding area, especially from farmlands and sewage, resulting in their elevation (Sawaiker and Rodrigues, 2016). The main cause of deterioration of lake ecosystems is due to eutrophication brought about by high amounts of phosphates and nitrates (Ansar and Khad, 2005). According to Lampert (1987), ecological factors such as nutrient limitation and predation pressure constitutes main biotic determinants of population abundance and persistence in freshwaters. Declerck et al; (2007), observed a nested pattern in plankton communities and concluded that high-productivity systems contained fewer species which were subsets of larger species pools from lower productivity communities. All the water bodies were organically as well as anthropogenically polluted. Navicula halophila, Navicula mutica indicate organic pollution in the water bodies. Synedra ulna indicates anthropogenic pollution in Syngenta, Lotus and Curtorim lakes while Navicula rhynococephala indicate anthropogenic pollution in Khandola Pond. While determining the water quality of any water body it is important to utilize developed software's that can give precise results and thus can be applied for conservation of heavily polluted lakes. This work will serve as base for further studies on freshwater bodies in Goa, as well as a guide for regional freshwater conservation planning.

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