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Fish Community Structure and Trophic Status - A Measure of Ecological Degradation: A Case Study From Powai Lake Mumbai

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ABSTRACT

Powai lake, a monomictic shallow lake, presenting some characteristics typical of a progressive trophic state specifically the permanent turbid water, the recurrent occurrence of cyanobacterial blooms which occasionally leads to large fish kills and the reduction in biodiversity. The study was carried out to understand the ecological degradation of Powai lake by using the abiotic and biotic factors. Twenty-four fish species were recorded and the fish yield was found to be 98 kg ha^{-1} yr^{-1} where the actual potential lies about 363 kg ha^{-1} yr^{-1}. The diet composition of 10 of the most abundant fishes in the lake revealed that, there were about 13 major food items from the gut contents, includes phytoplankton green algae, phytoplankton blue-green algae, diatoms, cladocerans, copepods, benthic algae, benthic weeds, macrophytes, detritus, fish eggs and larvae, shrimps, fish scales and insects parts. The Food Richness index (N) varied from 12 (*Heteropneustes fossilis*) to 29 (*Oreochromis mossambicus*), Diet Breadth (D) from 0.12 (*Heteropneustes fossilis*) to 0.77 (*Oreochromis mossambicus*) and the Gut repletion index (GRI) as 100% for all the species. Most of the fish species in the lake were either planktivores or detritivores with high feeding avidity and trophic adaptability, hence are capable of altering diet according to availability. The estimated trophic level indicates that almost all the fishes in the lake depend on primary producers or consumers as their diet. The dominance of omnivores and planktivores and the submissive occurrence of carnivores in the lake indicates the rampant ecological degradation of the lake.

Key Words: Trophic State; Ecological Degradation; Food Richness; Diet Breadth; Gut Repletion Index

INTRODUCTION

Powai Lake, an artificial lake, located in the northern suburb of Mumbai, constructed in 1891, had a water spread area of about 2100 ha and the depth varied from about 3 m (at the periphery) to 12 m at its deepest. It was said to be populated by 37 species of fishes (Kulkarni 1947 and Amore 1955). Bhagat (1977) has listed 32 species in the lake and reported that the population of major fish species is meagre and occupied mostly by *Oreochromis mossambicus*, while Kohli (1995) listed 10 main fish species from the lake. The fishing right of the lake is authorized with Maharashtra State Angling Association (MSAA), which release 2-5 lakh fish fingerlings every year. The catchment area of the lake is densely populated and a lot of construction works and quarrying activities are taking place around the lake. Though sewage and domestic wastes are not directly released into the lake, the surface runoff brought nutrients into the lake from the human settlement areas. The use of phosphorus-containing detergents resulting in phosphorus load in the water body and progressively resulting in eutrophication and this condition is further deteriorated by immersion of thousands of Ganesh idols made of plaster of parries during Ganapati Festival every year. This has led to heavy siltation and reduction in depth of the lake. Today the lake is extensively used for multipurpose activity requiring the authority to take action to conserve the ecosystem.

The fishes act as good indicators of ecosystem functioning and degradation because of their ability to occupy different trophic levels (Schlosser 1985, Schiemer and Spindler 1989, Copp et al. 1991). Fish community can be used to assess the ecological variations because of its specific habitat requirements and thereby depends on the various aquatic characteristics for its survival (Magoulik 2004, Smol 2010). An aquatic ecosystem can be described in terms of the information that is exchanged by different biotic and abiotic components, perhaps the right way is the feeding interactions, which can be analysed by studying their stomach contents (Froese and Pauly 2006). The gut content analysis provides information on the niche of the particular fish in its habitat (Pillay 1952). The food and feeding studies always gives information on the availability of prey and predator that is to say the seasonal changes in the components of the aquatic system, their type and magnitude of food available as well as the season its occurs (Akpan and Isangedhi 2005). The distribution of fish as related to the distribution of prey has not been studied extensively, even though there are reports that discuss these issues (Hadzley 1997, Khan et al. 2008). Therefore, the study of fish community structure of Powai lake not only reflects the intrinsic relationship between the components but also becomes important as an index to evaluate and monitor the entire ecology of the lake thereby providing information on the aquatic ecosystem dynamics, biodiversity and fishery manage-ment (Pauly et al. 2001). The present study of trophic relationship in the aquatic community of Powai lake helps to assess the ecological degradation of the lake.

MATERIAL AND METHODS

Powai lake (19° 8' N, 72° 54' E) is one of the five fresh-water resources in Mumbai. The attributes of Powai lake are given in Table 1 and the study site is shown in Figure 1. The hydrobiological samplings were conducted in the lake fortnightly from September 2011 to March 2012. Samples of water, benthos, plankton and fishes were collected from three different locations of the lake which were decided after making a pilot survey of the lake. The three different stations are described below.

Table 1: Attributes of Powai Lake

Location	Northern suburb of Mumbai
State	Maharashtra
Coordinates	19 08'N 72 54'E
Lake type	Reservoir, Fresh water
Construction year	1891
Primary inflow	Mithi River
Surface area	2.10 km^2
Catchment area	6.61 km^2
Maximum depth	12 m
Surface elevation	58.5 m

Station –I

It is the portion of the lake lying towards the small dam site and is the deepest portion. Depth of the station varied between 3.5 to 5 meters. It is located between two hillocks, Sighania and Lobo. There is also a small and low dam near Sighania house over the crest of which the excess flood water overflows into Vihar-Powai rivulet during monsoon. This rivulet named Mithi river finds its way through Mahim creek into Arabian Sea.

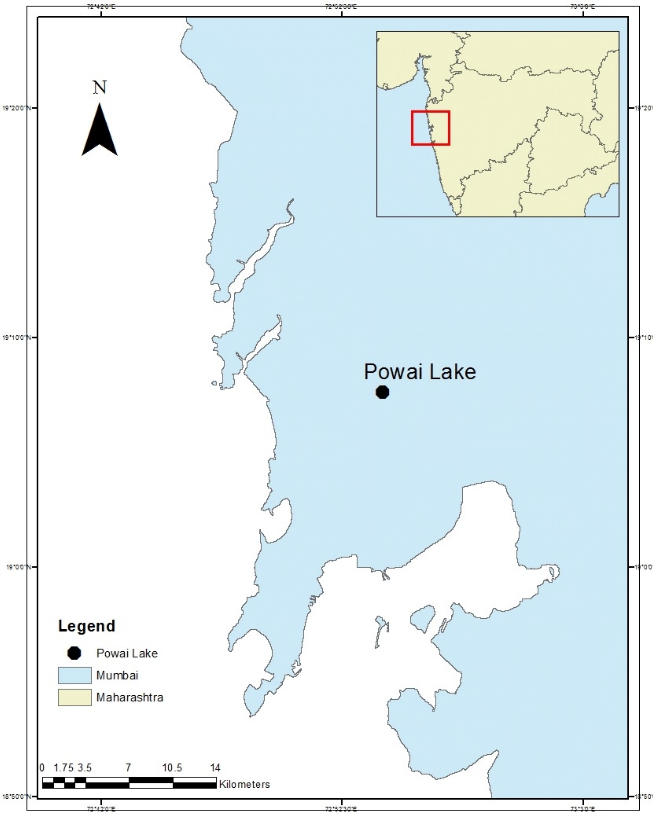

Figure 1. Location of the Lake Powai

Station – II

Central portion of the lake lies between Lobo hillock and Indian Institute of Technology (IIT) campus. It receives domestic effluent from IIT. The depth of the water in this station ranged between 2.5 to 5.3 meters. All along the shore of this station is populated with dense growth of *Ipomea aquatica* at the margins and intense growth of floating macrophyte *Eichhornia crassipes* from shore towards open water.

Station – III (Ganesh immersion site)

This part of the lake is very close to the shore. At this site every year thousands of Ganesh idols are immersed. The depth of this site ranges from 2 to 5 meters. At one point from road side, the site has steps leading to the lake. Both sides of the station are covered with macrophytes like *Eichhornia crassipes*, *Ipomea aquatica* and also duckweeds like *Lemna major* and *Lemna minor*, *Azolla*, *Ceratophyllum* , *Hydrilla* etc

Standard methods were used for the examination of water (APHA 1995). Fish samples were identified by following Elvira (1987) for the Cyprinids, Teugels (1982) for the Clariidae and for the other fishes, Jayaram (2010) and Fricke et al (2018). To check the fish diversity of the lake, samples were collected from all reaches of anglers and fishers. Among the fishes identified, top ten fishes which are landed heavily were taken for studying the gut contents and thereby evaluating the relationship between various components of the lake. Fish samples were brought to the laboratory under the ice and the specimens were analyzed on the same day. After taking the measurements for total length (mm) and total weight (g) the samples were dissected properly and the entire gut contents were emptied into a petridish and observed under a microscope. For the qualitative analysis of gut contents, two indexes used were the frequency of occurrence and percentage composition by number (Ricker 1975, Offem 2009) and as much as possible every food items were identified to its species level. The quantitative study of different food items was computed by food indices given by Hynes (1950), Natarajan and Jhingran (1961) and Hyslop (1980). In the present study, the indices used were Gut Repletion Index, Diet breadth, Frequency of occurrence and Food richness index (Offem 2009). The number of non empty guts divided by a total number of guts examined multiplied by 100 gives the gut replexion index. The percentage of the number of stomachs each food item present to the total number of stomach gives the frequency of occurrence, the number of each individual food item in the diet gives the food richness and diet breadth is the measure of food spectrum obtained by Simpson's diversity index (Simpson 1959 and Offem 2009). The trophic level (troph) of each fish species is determined according to the method followed by fish base considering both diet composition and the trophs of their food items. The trophic level of a fish is determined by, Troph = 1 + mean troph of the food items (Fish base). The Potential Fish Yield and Fish Production of Powai lake were estimated from Morphometric and Edaphic factors which show the relationship:

Fish yield = 0.9897 MEI 1.3888

where MEI= Conductivity/ Mean depth.

The fish yield is expressed in kg ha^{-1} yr^{-1}. The morpho-edaphic index (MEI) method is widely accepted, and this method is most suited for Indian waters because it combines the morphometric as well as chemical parameters considering that the ionic composition and depth are important parameters under Indian conditions (Yadava and Sugunan 2009).

The trophic state index (TSI) of the lake was computed by using two variables like chlorophyll pigments and Secchi depth which forms the basis for Carlson (1977) Trophic State Index. The variables like chlorophyll content and Secchi depth independently estimate the algal biomass which in turn classify the trophic status of the water body whether eutrophic, mesotrophic or oligotrophic. The simplified equations of Carlson TSI utilizing Secchi depth and Chlorophyll pigments are (Carlson 1977):

TSI(SD) = 60 - 14.41 ln(SD),

TSI(CHL) = 9.81 ln(CHL) + 30.6

Phytoplankton samples were collected by filling, one L of water in a clean plastic bottle, and immediately preserved with formaldehyde and Lugol's iodine solution, kept it for 1 to 2 days. A settling and syphoning procedure were followed to get 100 mL concentrates. For zooplankton samples, filtering 50 L of surface water through plankton net made of bolting silk cloth (No.25; #64 µm) and the samples were immediately preserved in 5% formaldehyde and Lugol's iodine solution. The qualitative analysis of the preserved plankton samples was made in the laboratory. Phyto - and zooplankton were counted by direct census method' using a Sedgewick-Rafter plankton counting cell. The plankton were identified up to the level of genus (Whipple 1954, Desikachry 1959, Edmondson 1959, Philipose 1967). The percentage composition of major groups of phyto - and zooplankton was computed. The value is expressed as numbers per litre of water. The significant sources of variation for the physicochemical parameters and biological parameters were analysed using the PROC GLM procedure of SAS as per Cody and Smith (1997) and Hatcher (2003). Simple linear correlation of these parameters is estimated using the PROC CORR procedure (SAS Institute 2000).

RESULTS

The physicochemical and biological properties give each lake its own specific character. Correlation matrix between various physicochemical and biological parameters of Powai lake is given in Table 2. Phytoplankton and zooplankton samples collected from three different sampling station of Powai lake revealed the occurrence of four groups of Phytoplankton (Cyanophyceae (69.6%), Euglenophyceae (18.08%), Chlorophyceae (8.95%) and Bacillariophyceae(3.2%)) and three groups of zooplankton namely, (Cladocera (49.92%), Copepoda(25.39%) and Rotifera (24.79%)). The overall average abundance of total phytoplankton and zooplankton groups were shown in Figures 2 and 3. The visual assessment of macro vegetation of Powai lake was made and it was observed that marginal areas of the lake having water depth of 1 to 1.5 m were covered by *Eichhornia crassipes* which is most dominant species in Powai lake (approximately 85%) followed by *Ipomea aquatica* (approximately 10%) and apart from the above two, other species like, *Lemna major*, *Lemna minor*, *Azolla, sp*., *Ceratophyllum sp*., and *Hydrilla sp*. were also found (all these later species roughly constitute approximately 5%). The benthic fauna of the lake comprises three classes mainly class Insecta which includes *Chironomus*, class Oligochaeta consists of *Tubifex* and finally, the molluscan community consists of *Tipula, Viviparus, Lymnaea,* and, *Gyraulus*. Trophic State Index of the lake was calculated by using chlorophyll content and Secchi depth and the estimated TSI was shown in Figure 4. The fish production potential of the lake was estimated as 368.47 kg ha^{-1} yr^{-1} from the Morpho-Edaphic index of the lake (Figure 5) which is quite higher than the average fish production from the lake. 315 fish specimens comprise 24 species under 18 genera of 10 families were identified, and to determine the relationship of the prey and fish distribution 10 of the most abundant fishes were selected based on high demand and increase in landings during the sampling period. They were *Labeo catla, Labeo rohita, Cirrhinus mrigala, Labeo calbasu, Oreochromis mosambicus, Hypopthalamichthys molitrix, Ctenopharyngodon idella, Clarius gariepinus, Heteropneustes fossilis and Puntius sp*. The diet composition and food indices of 10 important species are illustrated in Table 3, Figures 6 and 7 respectively. The gut content analysis of 10 of the most abundant fishes in the lake revealed that there were about 13 major food objects observed from the gut contents of the selected fishes, includes phytoplankton green algae, phytoplankton blue-green algae, phytoplankton diatoms, cladocerans, copepods, benthic algae, benthic weeds, macrophytes, detritus, fish eggs and larvae, shrimps, fish scales and insects parts. From the gut content analysis, it is observed that the Food Richness (N) varied from 12 (*H. fossilis*) to 29 (*O. mossambicus*), Diet Breadth (D) from 0.12 (*H. fossilis*) to 0.77 (*O. mossambicus*) and the Gut repletion index (GRI) as 100% for all the species. The Trophic level of the aforesaid fishes was estimated to compared with fish base trophic level to check whether the trophic level was altered or not and it was shown in Figure 8.

Table 2. Correlation coefficients of various physicochemical and biological parameters of the lake

	Chloro	Conduct	DO	pH	Transparency	Alkalinity	Nitrate	Phosphate	Phytoplankton	Water Temp
Chlorophyll	-									
Conductivity	0.21*									
DO	0.64*	0.81*								
pH	0.15*	0.89**	0.67*							
Transparency	0.05*	-0.90**	-0.69*	-0.70*						
Alkalinity	0.84**	0.63*	0.89**	0.49*	-0.43*					
Nitrate	0.89**	0.42*	0.80*	0.29*	-0.19*	0.88**				
Phosphate	-0.50*	-0.81*	-0.78*	-0.57*	0.67*	-0.77*	-0.69*			
Phytoplankton	0.29*	0.25*	0.11*	0.24*	-0.07*	0.40*	0.14*	-0.43*		
Water temp	-0.72*	-0.64*	-0.85**	-0.35*	0.51*	-0.90**	-0.82*	0.79*	-0.27*	
Zooplankton	0.63*	-0.38*	0.03*	-0.40*	0.478	0.40*	0.36*	0.05*	0.48*	-0.26*

** Highly significant (P< 0.001)

Table 3. Diet composition and food indices of commercially important fishes of Powai Lake

Fish species	Sample size	Maximum length, cm	Minimum length, cm	Major diet composition	Food richness	Diet breadth	Gut Repletion Index
Labeo catla	14	62	32	Cladocerans(36%), copepods(29%)	23	0.47	100%
Labeo rohita	12	56	29	green algae (28%), blue green algae(26%), diatoms(29%)	20	0.35	100%
Labeo calbasu	8	50	24	diatom (44%), blue green algae(35%), detritus(21%)	21	0.39	100%
Cirrhinus cirrhosis	9	59	24	green algae (34%), Detritu s(31%), Cladocerans (18%), Copepods (18%)	26	0.61	100%
Ctenopharyngodon idella	15	63	28	Benthic algae(52%), Benthic weeds(26%), Macrophytes(21%)	17	0.25	100%
Hypophthalmichthys molitrix	12	69	31	green algae (28%), blue green algae (45%), diatoms (28%)	24	0.52	100%
Oreochromis mossambicus	60	25	12.5	green algae (25%), blue green algae (21%), diatoms (21%)	29	0.77	100%
Clarius gariepinus	6	82	36	Detritus (28%), green algae (15%), Cladocerans (18%), Copepods (15%)	27	0.67	100%
Heteropneustus fossilis	11	18	9	Cladocerans (70%), detritus (27%)	12	0.12	100%
Puntius spp.	35	16	8	Benthic algae (73%), Benthic weeds (22%),	14	0.17	100%

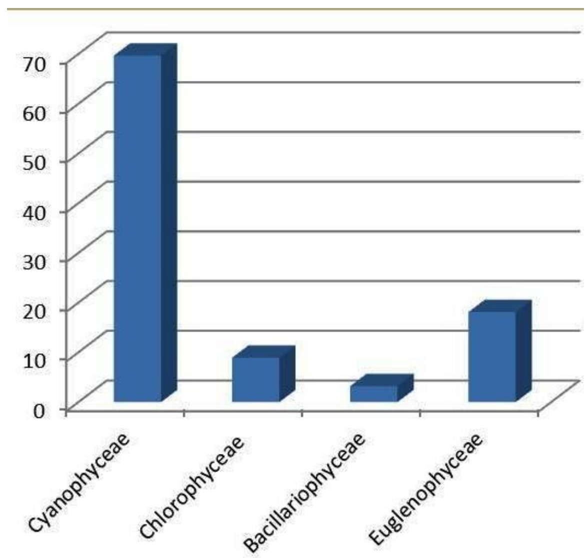

Figure 2. Percent composition of phytoplankton from Powai lake

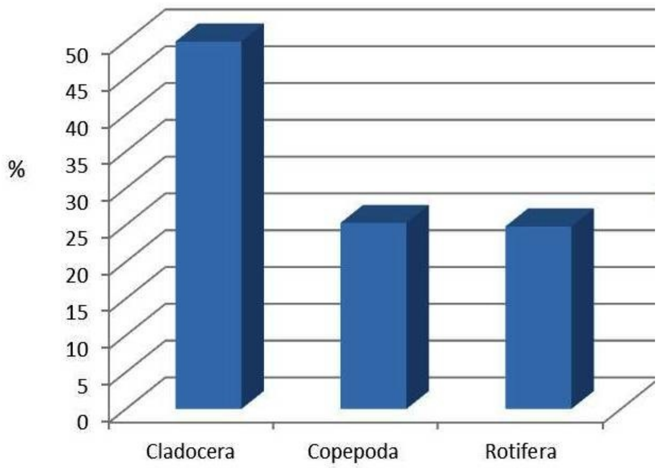

Figure 3. Percent composition of zooplankton from Powai lake

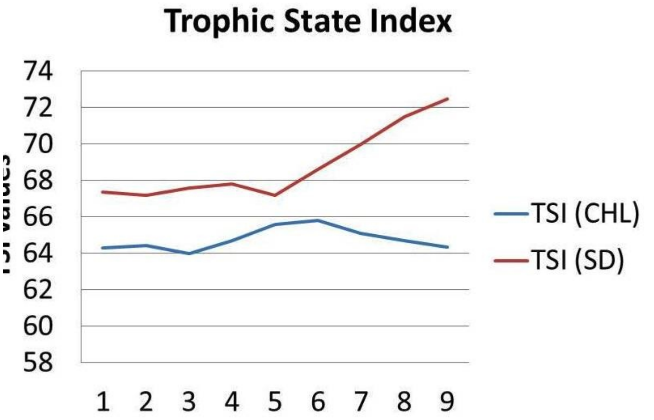

Figure 4. Trophic State Index (TSI) of Powai Lake from Chlorophyll content and Secchi depth

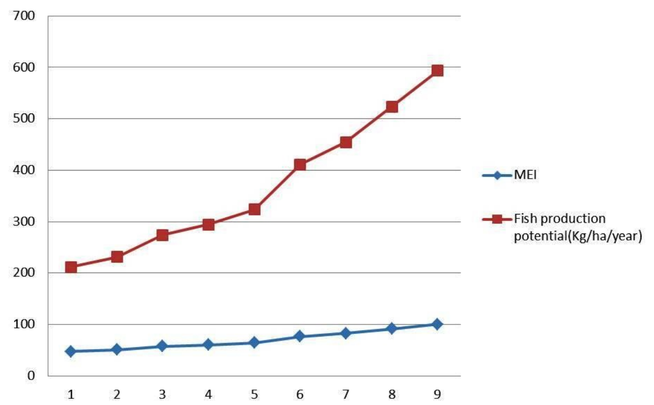

Figure 5: Fish production potential of Powai lake from Morpho Edaphic Index (MEI from Conductivity and Mean depth)

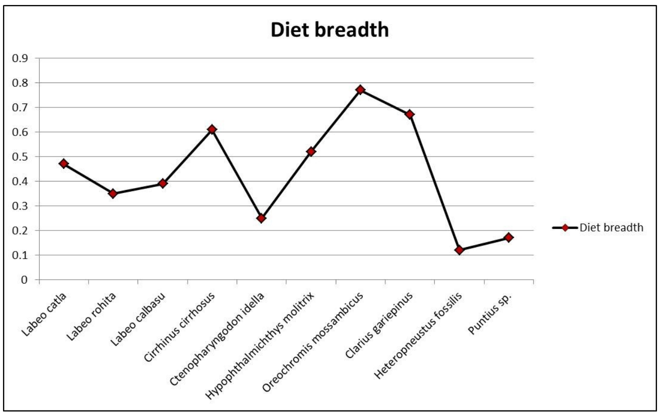

Figure 6. Diet breadth of selected fish species of Powai lake

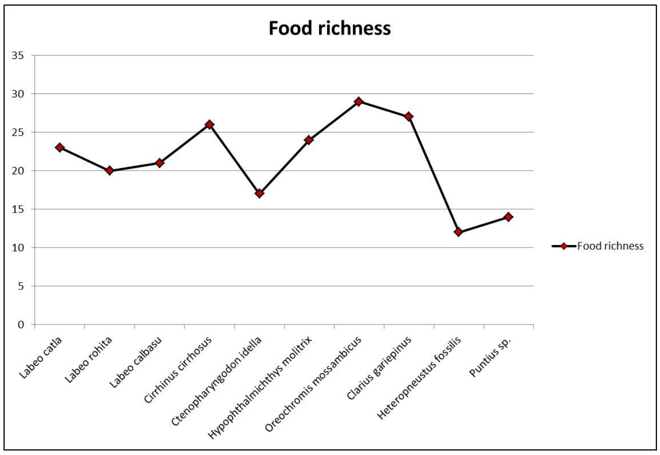

Figure 7. Food richness of selected fish species of Powai lake

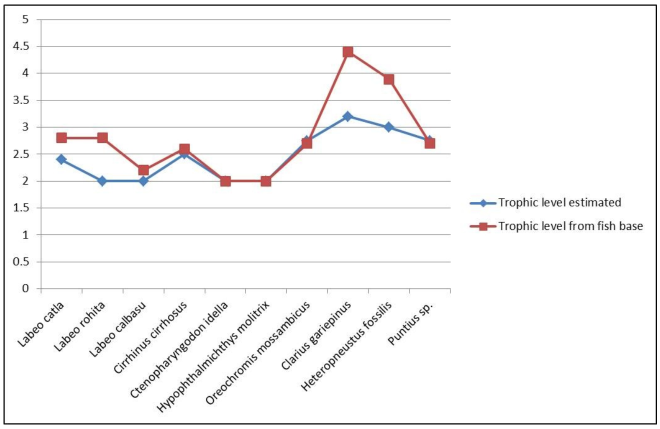

Figure 8. Trophic level estimated for commercially important fishes of Powai lake

DISCUSSION

Most of the parameters computed for the lake were extremely high to backing the ecological degradation. Water temperature, one of the most important parameters which influence the physicochemical and biological processes in aquatic ecosystem, fluctuated between 21 °C and 28 °C in Powai lake, which shows a negative correlation with dissolved oxygen (r= -0.85, P>0.0001) - an important parameter for assessing the productivity status, as it indicates the net outcome in terms of production, consumption and decomposition processes in the lake ecosystem. The dissolved oxygen levels of Powai lake were found to fluctuate between 2.8 ppm and 8 ppm which occasionally leads to large fish kills mainly during the early hours. The occurrence of a large number of dead fishes floating on the surface was a regular phenomenon during the sampling days. Srinivasan (1970a and b) and Mathew (1975) observed the inverse relation between oxygen and rainfall as well as water temperature, which is in confirmation with the present observations.

Mortality of fishes is mainly related to the overwhelming cyanobacterial blooms and the associated aquatic parameters. The dominance of cyanobacteria in a water body is mainly due to the presence of various macronutrients such as nitrogen, phosphorus (Reynolds et al. 2000), temperature, pH and light (Lee and Rhee 1999, Chellappa et al. 2008). pH ($r=0.24$; $P>0.0001$) and Total alkalinity ($r=0.40$, $P>0.0001$) shown the positive significant correlation with total phytoplankton count, while water temperature ($r= -0.27$; $P> 0.0001$) and transparency($r= -0.07$; $P> 0.0001$)shown a negative correlation with the phytoplankton and the same was supported by Salskar and Yeragi (2003) Khan and Siddiqui (1971) and Landge (2007). The chlorophyll(a) content of the water is more or less correlated to total phytoplankton counts throughout the study. This is in agreement with other studies (Ahmed 1986 and Tolstoy 1977) which recorded a linear relationship between the chlorophyll (a) content and cell counts, while others pointed out that there were several limitations in using chlorophyll (a) as a measure of phytoplankton volume. In the present study chlorophyll (a) shows significant positive correlation with phytoplankton count. ($r= 0.29$, $P> 0.01$). The dominance of Cyanophyceae groups followed by Euglenophyceae and low desmid population clearly states the eutrophic condition of the lake. Heavy blooms of Cyanophyceae and euglenoid species may be the reason for the less abundance of zooplankton. The quality and quantity of phytoplankton determine the exact productivity and proper transfer of energy from the lower level to a higher level. It is evident that Cyanobacteria are low-quality food for zooplankton, due to their filamentous or colonial structure, low digestibility and toxin production, inducing limitations to the growth and reproduction of zooplanktonic organisms (DeMott et al. 2001, Rohrlack et al. 2001, Ghadouani et al. 2003). Therefore it is observed that there is a huge gap between the potential and present fish production, which is mainly due to the improper transfer of energy from lower trophic level to the higher trophic level of the lake. Most of the time the ecosystem balance is lost due to an unnatural break in the food chain. The topmost predator remains in the best of health, if the bottom level (primary producers) of the food chain remains intact, thus conserving the system. In the lake also the quality and quantity of top predators mainly the carnivores were very less during the entire sampling. The macro vegetation also plays an important role in the lake ecosystem as they are good indicators of the eutrophic state of the lake. Submerged macro vegetation was scanty whereas floating marginal and emergent species were more dominant. Every year Maharashtra state Angling asso-ciation put efforts to eradicate this aquatic macro-vegetation mainly *Eichhornia sp.* and *Ipomea sp*. which are most dominant but due to the eutrophic nature of lake every year these weeds equally flourishes and hinder in fish angling activities, thus creating an imbalance in the lake ecosystem.

The benthic fauna of the lake also undergone a tragic change, moreover, the community comprises of 12 species of Insects, 12 species of Oligochaeta and 4 species of Molluscs by the earlier study (Kislay 2001). Water depth, silt load, light intensity, fish utilisation, food availability and water quality parameters are some of the factors determine the intact nature of benthic fauna. Any variation of above from its optimum cause considerable changes in their population and biodiversity and thus the study relating to their population abundance clearly indicates the ecological degradation. The dominance of Oligochaeta indicates the enhanced organic load of the water body and thereby the water quality degradation and ecosystem dysfunction. The trophic state index computed by Carlson's table by make use of Secchi depth and chlorophyll (a) lies between 60 to 70 in both the instances and clearly depicted the eutrophic status of the lake. The commonly observed lake features according to the present study are anoxia, algal scums, the dominance of blue-green algae, macrophytes, fish kills etc. Powai lake has a fairly rich fauna of fishes, but nowadays due to the high discharge of sewage water, the raw material from construction works, silt load from quarrying activities degraded the water quality of the lake and lost its diverse nature of the fish population. The average catch in 1950 was 22 kg day^{-1} through angling mainly by pole and line (Annual report of Department of Fisheries Mumbai). It has gone down to 8 kg day^{-1} in 1989 (Kohli 1995) and in 1996 fish catch recorded 7.07 kg day^{-1} (Salaskar and Yeragi 2004). The fish productivity of the lake was 44.72 kg ha^{-1} yr^{-1} in 1995 and 45.63 kg ha^{-1} yr^{-1} in 1996 (Salaskar and Yeragi 2004). The fish production potential of the lake was estimated as 368.47 kg ha^{-1} yr^{-1} from the morphoedaphic index of the lake. The average fish productivity of the lake during the study was about 98 kg ha^{-1} yr^{-1} including the tilapia catch by gillnets. Earlier the fishery of Powai lake revealed that *L. rohita* dominates in number and *H. molitrix* dominates as weight were concerned (Salaskar and Yeragi 2004). This study helps to identify 24 species from the lake, among the identified fishes, eight to ten species were dominant in the daily catches of the lake. They are *L. catla, L. rohita, C. mrigala, L. calbasu, O. mossambicus, H. molitrix, C. idella, C. gariepinus, H. fossilis* etc. According to the study, *O. mosambicus* dominates in number but as far as weight is concerned *H. molitrix* dominates in the production of the lake. The remaining others were aquarium fishes which includes *Mystus spp., Ambassis sp., Oxygaster bacaila, Danio malabaricus, Rasbora daniconius, Aplocheilus lineatus, Puntius spp., Garra mullaya, Osphronemus goramy, Mastacembalus armatus, Glossogobius giuris, Etroplus suratensis* etc. The gut content analysis depicted that *O. mossambicus* is showing maximum food richness and diet breadth which in turn enhanced the trophic flexibility of the species. It is apparent that omnivores are often the most tolerant of degradation or ecosystem dysfunction because they are able to consume food from a wide variety of sources in a changing ecosystem (Wichert and Rapport 1998). This is one of the possible reasons that the remarkable diversity and abundance of omnivorous species in the lake. It is also indicated that in the least disturbed system, a higher proportion of species present would belong to the benthic feeders and carnivorous groups than at heavily degraded sites (Das and Chakrabarty 2007). As degradation intensifies, those species at the top of the trophic structure, i.e., the carnivorous, would disappear first, followed in sequence by benthic insectivorous, general insectivorous, planktivorous and omnivorous (Wichert and Rapport 1998). So the present study also formed the ground to support the above statements, that the carnivorous species can be used as an indicator of pollution because the diversity and abundance of carnivorous fishes were very less and the dominance of omnivores and planktivores were very high during the entire study period. The dominance of tilapia in the water body not only disrupted the entire ecosystem functioning but also altered the overall aquatic community structure of the lake raised a massive ecological degradation. The trophic levels thus estimated were compared with the fish base and the value lies at the lower range of fish base trophic level. This indicates that almost all the fishes in the lake depend on primary producers or primary consumers as their diet and the major diet composition of fishes also supports the above statement. The physicochemical analysis, plankton abundance, macro vegetation, benthic community structure, gut content analysis and the trophic level estimation of the lake provides evidence showing its eutrophic status. Thus, further information on competitive interactions within plankton, toxic cyanobacteria, anti-predator defences, should be included in future research of Powai lake in to understand the intricate trophic relationships of aquatic systems. The study recommends the authority to properly considered the species combination and appropriate stock size during stocking, the usage of Bioremediation techniques to improve the water quality, the control of non-point sources of pollution, the introduction of phytophagous, planktivorous, insectivorous and mollusc-feeder fishes in judicious combination, steps should be taken to remove the floating aquatic weeds, the introduction of freshwater prawn to improve the water quality and finally insist the regular Environment Impact Assessment of Powai lake. Thus, the study of trophic dynamics of Powai lake, act as an index to evaluate and monitor the aquatic ecosystem dynamics, biodiversity, fishery status and management. The entire dynamics of the lake was disturbed by various natural and anthropogenic activities, so detailed studies and appropriate cooperation and management by MSAA is very much required for the revival of the lake.

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