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Development and evaluation of fish index of biotic integrity (F-IBI) to assess biological integrity of a tropical lake Veli-Akkulam, South India

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Abstract
Multimetric index of index of biotic integrity using fish community was developed for the first time in Indian lake using seven candidate fish metrics such as native species richness, native family richness, benthic species richness, water column species richness, % non-native individuals, % tolerant individuals and % herbivores were applied in addition to five original metrics such as intolerant species richness, % omnivores individuals, % top carnivore individuals, total number of individuals and % individuals with anomalies. Tolerant species and non-native individuals were abundantly recorded at Veli-Akkulam Lake mainly at downstream sites where the water quality was highly degraded which is clearly reflected in water quality parameters such as BOD, COD, free Carbon-dioxide, phosphate, nitrite values and low levels of DO in water. Both traditional (5-3-1) and continuous IBI scores (0-10) examined were of similar pattern revealing maximum integrity at reference site with good water quality conditions. Modified score of fish biotic index decreased at both upstream and downstream sites of Veli-Akkulam Lake. But the score recorded at Vellayani Lake was higher than Veli-Akkulam Lake which was taken as the reference site which is far from the impact of major effluents sources of this ecoregion.

Keywords: Fish, biotic integrity, IBI, water quality, Veli-Akkulam, Vellayani Lake

1. Introduction
Wetland monitoring using fish as bioindicators particularly in lakes is gaining popularity across the globe and a systematic methodology of biomonitoring has proved to be more efficient and cost-effective. Bioassessment using fish assemblages gives an outstanding knowledge of ecosystem integrity and evaluation of the degree of aquatic impairments. A community is the assemblage of species inhabiting a definite area in terms of its species composition, species richness, trophic organization and food-web structure and function. These are governed by several attributes such as the composition of communities, physico-chemical conditions, biotic interactions, dispersal and biogeography [1].
Ecosystem degradation due to organic enrichment, habitat degradation and its loss has resulted in reduction of species richness, abundance or even the retardation of fish growth and health [2]. The surveys based on the assessment of aquatic ecosystems relating the water quality and biotic communities have strikingly gathered information regarding ecosystem health and management. Hence a stringent evaluation of biological resources to estimate the integrity is significant for the assessment of ecosystem. Biological integrity is the ability to support and maintain a well-balanced, adaptive and integrated community of organisms having a characteristic diversity, composition and structural and functional organization as that of natural habitats of any region concerned [3]. Ecosystem integrity can be measured by the differences in the faunal diversity, distribution, abundance and health, which can pertain as factors linking the level and type of alteration of water body [4]. Hence the approach of integrated assessment and evaluation of water quality and biological assemblage is very essential.
Fish communities act as excellent indicators of biotic integrity due to their continuous exposure to ambient water conditions and they display a variety of responses to environmental disturbance, such as habitat alterations, organic enrichment, chemical toxicity and thermal fluctuations. They are good indicators of long term effects because they are relatively long lived and mobile.

Obviously, fishes are important tools in measuring impacts due to point source pollution as they impart temporal and spatial changes in communities to these changes and serve as ideal biotic factors for assessing aquatic life impairments [5-7]. So the presence, absence, abundance and distribution of fish assemblages indicate the water quality of aquatic ecosystems.
For monitoring and management of aquatic ecosystems, a large number of fish-based indices, especially at community-level have been developed in the past decades [8]. These include, using reference condition, accounting for natural fish assemblage variability, evaluating metric precision and selecting the most sensitive and complementary metrics [9-11]. In bioassessment the selection of multimetrics has a crucial role since it represents various attributes of the targeted aquatic assemblage. These metrics can either be aggregated into an index or retained as individual measures. Along with multimetric approaches i.e. adding up scores for dimensionless metrics to create a multimetric index, multivariate analysis can be used for validating the data for pollution evaluation. These multivariate techniques are useful for estimating the spatio-temporal trends in community structure to predict the probability that a biological assemblage at an assessed site is different from assemblages observed at reference sites or is a member of a particular aquatic life [12]. In ecosystem health evaluation fish assemblages as indicators had been adopted and standardized by European countries and well established all over the world. In India investigation of integrity of an ecosystem using fish community remains scarce despite prominent taxonomic knowledge regarding the diversity of fish in our lentic as well as lotic ecosystems exists. In some pioneer works studied in central Himalayan rivers and Hooghly estuary, the application of index of biotic integrity have found an initiative appraisal with regard to integrity assessment [13,14]. The present study explores the pollution status of Veli-Akkulam and Vellayani lakes by the application of multimetric index of biotic integrity of fish assemblages in South India.
The main objectives of the study were to: (i) examine multimetric indices of fish correspond to diverse ecological conditions and to use the data derived from these to evaluate the health and ecological status of the lake; (ii) demonstrate a reliable method for developing and applying index of biotic integrity (IBI) of fish in lentic ecosystems of India; (iii) perform multivariate analyses to derive spatial and temporal variations of fish communities among the study sites; and (iv) enumerate the performance of multimetric indices of fish with various water quality parameters of the study lake thereby validate the reference condition approach in biomonitoring studies.

2. Materials and Methods

2.1 Study area

Veli-Akkulam is a small and shallow lake in the southwest coast of India (08°30´– 08°31´ N and 76°52´–76°53´ E; area=1 km^2; depth= <1 m), which remain separated from the Arabian sea by a sand bar during most months of the year, except during monsoon season (Fig. 1). Akkulam lake is an extension of Veli lake lies in North eastern part. Mud flats in the shallow regions of the Akkulam part of the lake get exposed during ebb tide and the siltation in Akkulam lake affects the free flow of water towards the Veli lake. The canals that drain into the Veli-Akkulam lake are the Kulathur canal at its northern western region and Kannamoola canal at its north eastern part. Pollutants from the factories, urban settlements and agricultural fields empty into the lucustrine ecosystem. Vellayani freshwater lake of Kerala, is located in the outskirts of Thiruvananthapuram city (8"24’09" - 8"26’30" N; 76°59'08"-76°59’47" E) of India was selected as the reference site for comparing the water quality and biotic integrity of Veli-Akkulam lake. The length of the lake is about 3.15 km and maximum width is about 1000 m; depth of the lake varies from 2 to 6 m. It has a water spread area of 450 ha. The depth of the lake varies from 2 to 6 m. The north-western part of the lake is converted to a temporary reservoir for irrigation purpose and this lake act as a major source of drinking water supplies. Six different sites of Veli-Akkulam lake were chosen, which includes Veli Bar mouth (site 1), Veli Boat club (site 2), Veli Parvathy Puthen Ar (site 3), Akkulam Bridge (site 4), Akkulam Boat club (site 5) and Akkulam Kannammoola canal (site 6). The reference/comparative site was fixed as Vellayani Vazhavila (site 7) at Vellayani Lake.

2.2 Sampling methods

Rapid Bioassessment Protocol for fish as bioindicators adopted by United States Environmental Protection Agency was standardized for bioassessment of lakes [7]. For systematic biomonitoring of lakes, sampling sites were fixed through an accurate estimation of water quality parameters, degrees of human interference and pollution and geographic peculiarities of the lakes. After a scoping study at all the sites of Veli-Akkulam lake it was found that none of the regions of lake revealed a pristine condition or minimally impacted condition for fish biosurveys. Therefore, based on the historical data, qualitative analysis of physical and habitat assessment, expert judgment and according to the reference concept approach for biosurveys mentioned in RBP, Vellayani lake was selected as the regional reference site for evaluating and estimating the health of the Veli-Akkulam lake. Biosurveys (RBP) using fish assemblages as indicators of water quality were applied and successfully performed in Veli-Akkulam lake Southwest coast of Kerala.
For estimating various physico-chemical qualities monthly water samples were collected from six different sites of Veli-Akkulam lake and reference lake, Vellayani for a period of two years from October 2008 to September 2010. Physicochemical parameters such as pH, water temperature, salinity, electrical conductivity, dissolved oxygen (DO), free carbon-dioxide (CO_2), total hardness, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), nitrate, nitrite, phosphate and sulfate were estimated [15-17]. Mean water quality parameters of Veli-Akkulam lake sites showed characteristic variations with standards of inland surface water quality criteria [18, 19]. Parameters such as electrical conductivity, total hardness, TDS, free carbon-dioxide, BOD, COD, nitrite and phosphate were beyond the permissible standard limits of US EPA and CPCB at Veli-Akkulam lake sites (Table 1). Dissolved Oxygen levels at sites 4, 5, 6 of Akkulam lake were highly depleted and were below the desirable limits of US EPA and CPCB standards, indicating anoxic condition at these sites.
Monthly collections of fish samples were performed at six sites of Veli-Akkulam and Vellayani lakes. Fish were sampled using cast net, encircling net and gill net in the morning hours (08.00 am - 12.00 pm), covering the shallow and deep areas of the lake and mouth of the canals opening to it. Fishes with confirmed identification were released back into the lake, while specimens with doubtful identity were preserved in

10% formaldehyde and brought to the laboratory for identification after recording its original colouration. The establishment of reference site at Vellayani lake was done for the development of metrics and biotic integrity index (IBI) for evaluating ecosystem health.

2.3 Metrics and index development

As the fish samples of Veli-Akkulam and Vellayani lakes collected monthly were insufficient to evaluate IBI scores and metrics, 24 samples taken at each site were compiled into a single value for the efficient purpose of analysis. The resident species from Veli-Akkulam and Vellayani lakes were included for fish metric preparation and index developments. A compilation of samples would become necessary since the incomplete data from a single qualitative sample could result inappropriate assessment and for the IBI preparation [13].

2.4 Modifying IBI for Veli-Akkulam and Vellayani Lake

For a new ecoregion the basic ecological information needed to modify the IBI included the knowledge of native and non-native fish species, trophic and habitat guilds, and their relative tolerance to environmental conditions. Accordingly, the following regional references were referred for the details of the taxonomy and biology of fishes [20-22]. A set of candidate metrics represents major aspects of fish assemblage integrity were identified as taxonomic richness, habitat composition, trophic guilds, fish health and abundance [5].

Taxonomic richness. The total number of species was substituted with a number of native species and number of native families [23]. The number of native species typically decreases with increasing degradation and non-native species represent biological degradation. It increases with increasing degradation affecting the natural habitats of native ones. Hence it is significant to distinguish native and non-native species in the metric [5].

Habitat composition. The metrics such as ‘the number of intolerant species’ was included in the IBI development as these estimates the fish assemblage components to decrease in number in response to habitat degradation [5]. This metric was also used in seven of ten modifications of the IBI for use outside the USA and Canada [24]. Usually the intolerant species disappear once a pollution cascade happens due to urban and industrial pollution and they reappear when the system restores its natural condition.

Other four metrics such as number of darter species, number of sunfish species, number of sucker species and percentage green sunfish species were replaced by the number of benthic species, number of water column species and percentage individuals as tolerant species [23]. The benthic and water column species are sensitive to siltation, low dissolved oxygen concentration, BOD, low pH and their diversity decreases substantially. With increased habitat and water quality these benthic and water column species richness increases [5, 25]. The metric percentage tolerant species are indicators of increased habitat degradation and such species are generally successful in high silt loads, low pH, low DO and turbid water conditions [26-28]. The percentage tolerant species are the last group to disappear followed by a disturbance and the first to return as the system begins to recover suggested [13].

Trophic composition. The metric which determines the trophic composition is based on the feeding patterns of fish assemblage. This metric reflects trophic dynamics and is used to assess changes in ecological processes by strengthening the IBI. Percentage individuals as omnivores, piscivores and insectivores can be used to evaluate the status of the trophic structure and food base [5]. In this study two of the original metrics such as percent individuals as omnivores and percent individuals as carnivores were retained. Omnivore groups comprise fish species which typically eat substantial amount of 25% plant and 25% animal food and are adapted easily to disrupted environmental conditions. Another metric, the top carnivores, include species in which adult primarily feed on fish, other small vertebrates or large invertebrates. This metric tend to decrease with disturbance and differentiate moderate to high water quality. The present study also adopted percent individuals as herbivores by replacing proportion of individuals as insectivores. The herbivore metrics include species which are predominantly plant feeders and are considered sensitive to habitat alterations.

Fish health and abundance. Two metrics such as total number of individuals in the sample and percentage of individuals with disease or anomalies were retained as in the original metrics [5]. The present study calculated total number of individual metrics, although both in oligotrophic to highly eutrophicated waters it is a direct measure of fish productivity of the lake. Its value decreases in highly disturbed waters and nutrient poor waters. Fish anomaly metric is typically most useful with larger fish and in waters that are severely degraded by chemical contaminants [25]. No such data was obtained during the present study. A new metric percent individual as non-native was included in the present investigation. Non-native groups dominate in highly disturbed water and are generally successful more where native species are less due to severe anthropogenic pressures.

2.5 Calculation of metrics scoring and IBI index

IBI metric scoring criteria were developed by trisections of maximum obtained values when those were considered indicative of least disturbed conditions [29]. Metrics were scored as 5, 3, or 1 if their data approximates, deviated slightly from, or were markedly different from reference conditions [5]. The metric which was indicative to undisturbed conditions were number of native species, number of native families, benthic species, water column species, intolerant species and individuals and percentage herbivores and top carnivores. These metrics will decrease when degradation increases. However, metrics which were considered indicative of disturbed conditions included % tolerant, % omnivores that increases with degradation, due to the adaptation of the individuals to impacted environmental situations. Since no undisturbed reference site was available in Veli-Akkulam lake, the hypothetic reference site Vellayani lake was used for analysis. For each parameter, the reference was the best (highest) or worst (lowest) value obtained among all sites, depending on the ecological significance of the metrics (Table 2).

In the present study continuous scores of 0 to 10 for metrics and 0 to100 for IBI were applied, presenting that this decreases the step changes in scoring when metric values differ by only one unit [30]. Such scoring ranges of zero to 10 or 100 were also done in other studies [13, 14]. Upper thresholds are based on the highest value gained for most metrics and are scored under 10. Lower thresholds are based on the lowest value gained for most metrics and are scored under 0 in the case of continuous scores. Metrics which increase with increasing degradation like omnivore, tolerant species, non-natives their highest scores were considered undesirable. In this case, the upper thresholds having highest values were given lowest scores (scored as 0), set at 50% as upper limit and lowest threshold were given highest scores (scored as 10) set at lower limit 0%. The continuous score between upper and lower thresholds were calculated by dividing a metric value by their range. In the cases where the values of the metrics decreased with a pollution increase (for example: species richness) the best highest value was used as reference [31]. Metrics that increased with habitat degradation, the worst highest value was used as reference. In the present study traditional scores of (1, 3, 5) for IBI were also prepared along with continuous scores for better evaluation of lake ecosystems. To obtain IBI index ranging from 0 to 100, individual metric scores were summed, multiplied by 10 and divided by the number of metrics scored to get a maximum IBI score of 100. Then it will be taken for qualitative evaluation such as acceptable, marginally impaired and impaired conditions to the total IBI scores [5, 25]. An IBI score which is higher than 80% is considered as acceptable. A score which ranges from 60% and 80% is considered as marginally impaired and a score which is less than 60% is considered as unacceptable or impaired water quality condition. IBI scoring ranges from 11 to 55 for traditional IBI score. Here an IBI score greater than 44 were considered as acceptable, 33-44 were considered as moderately impaired and less than 33 were considered as impaired. But in this present study continuous IBI score ranges from 0 to 100, greater than 80 is acceptable, 60 to 80 as marginally impaired, less than 60 was considered as impaired water quality conditions of the system.

Cluster analysis was conducted on a Bray-Curtis similarity matrix using group average linkage after square-root transformed of the fish abundance data were used to investigate similarity in fish community among sites. SIMPROF (similarity profile) permutation test was also carried out in conjunction with this cluster. Non-metric multidimensional scaling (MDS) plot was used to demonstrate clustering of sites using PRIMER v.6 software. Canonical Correspondence Analysis (CCA) was performed to find out the fish multimetric performance with various environmental parameters of the study lakes. The metrics were subjected to transformation and normalization procedures and candidate metrics meant for index preparation were subjected to CCA and vectors determining individual metrics, parameters and sites were plotted by means of CCA triplot using PAST software. This analysis helped to determine the distribution of fish assemblage indices in response to varying water quality characteristics of the lake ecosystems.

3. Results

A total of 39 fish species under 21 families were recorded from seven sites of Veli-Akkulam and Vellayani lakes. Various habitats and trophic guilds based on the data provided from FishBase are given in Table 3. In Veli-Akkulam lake 22 resident fish species representing under 8 orders and 16 families were considered for index preparation and the nonresident marine species were excluded for analysis. In Vellayani lake 37 species of fish representing under 9 orders and 21 families were included for index preparation. Tolerant and intolerant species were categorized based on the resilience index provided by the FishBase. Two non-native species (*Oreochromis mossambicus* and *Clarias gariepinus*) were recorded from Veli-Akkulam lake and one species (*Oreochromis mossambicus*) was recorded from Vellayani lake.

3.1 Scoring of Fish metrics

A total of 12 significant metrics under taxonomic richness, habitat composition, trophic composition, fish health and abundance groups is validated according to the scoring criteria of Index of Biological Integrity (IBI) for Veli-Akkulam and Vellayani lakes (Table 2).

3.2 Development of IBI and IBI metrics

Multimetric values for fish biotic integrity of Veli-Akkulam and Vellayani lakes and their continuous and traditional scores that making up the fish Biotic Integrity Index (F-IBI) are given (Table 4; Fig. 2).

The result showed that continuous fish IBI score ranged from 19 to 97 during the study period. Of these, site 7 recorded highest fish IBI score of 97, indicated acceptable water quality conditions of the lake. However, lowest score of 19 was obtained from site 5 showing impaired water quality. The maximum range of fish IBI score in Veli-Akkulam lake sites varied from 19 to 66 indicating moderately impaired to highly impaired water quality conditions. Here a maximum IBI score of 66 recorded at site 2 was the only moderately impaired site in Veli-Akkulam lake when compared to other impaired sites representing degraded water quality conditions. In addition to continuous IBI score, traditional fish IBI score was also evaluated to determine water quality conditions of the lake. The traditional fish IBI score of the present study ranged from 13 to 53. Highest score of 53 was found at site 7 Vellayani lake (reference site) and very less value 13 was found at site 5 of Veli-Akkulam lake. The traditional score thus developed also concord with the results of continuous score thereby confirming similar water quality trend regarding integrity evaluation. Here also acceptable water quality condition was determined at site 7 and moderately impaired water quality at site 2 and relatively high impaired conditions at all other sites of Veli-Akkulam lake.

All the selected 12 multimetrics showed characteristic difference among sites between two lakes. 36 species of fishes were recorded from Vellayani lake and 19 species from Veli-Akkulam lake. Only one species, *Oreochromis mossambicus*, was a non-native among other native fish species contributing 0.8% at Vellayani lake whereas two non-native species such as *Oreochromis mossambicus* and *Clarias gariepinus* contributed maximum (14%) at Veli-Akkulam lake. The non-native species abundance reflected the abundance of tolerant fish species which were more abundant at upstream sites of Veli-Akkulam lake especially at site 4. Three most common tolerant species recorded at upstream sites 4, 5, and 6 were *Anabas testudineus*, *Aplocheilus lineatus* and *Rasbora dandia*. The percentage contribution of tolerant species was recorded 76% at site 4 of Akkulam lake. In upstream sites of Veli-Akkulam lake (sites 4, 5, 6) the continuous score for tolerant forms ranged from 0 to 2. But in downstream region the tolerant species represented at sites1 and 2 were predominantly represented by cichlid species *Etroplus maculatus*. While in Vellayani lake very low contribution of tolerant species (14%) was recorded with a highest continuous score of 8.2.

With regard to species intolerance to pollution the important species that dominated at Vellayani reference site was *Anguilla bicolor bicolor* and *Anguilla bengalensis bengalensis* while *A. bicolor bicolor* was the only species encountered at Veli-Akkulam sites 1 and 2. Absence of intolerant species was noticed at sites 3, 4, 5 and 6 during the present study. Regarding the trophic status of fish assemblages, the metric which dominated was the percentage of omnivores which is considered as an indicator of perturbations and the site 4 of Veli-Akkulam lake showed highest omnivore populations. Major species representing these functional feeding guilds were *Systomus sarana*, *Hyporhamphus xanthopterus*, *Anabas testudineus* and *Etroplus maculates* and were abundant at upstream sites of Veli-Akkulam lake. Among these species *A. testudineus* dominated at upstream sites of Veli-Akkulam lake when compared to other omnivore species. Very low score recorded at site 5 was due to high percentage of omnivore taxa. The continuous scores for omnivores ranged from 0-9.2 with relatively high scores recorded at site 7 (reference site) because of low omnivore percentage. Species contributed at reference site were *Systomus sarana*, *Puntius parrah*, *Amblypharyngodon microlepis* and *Devario aequipinnatus* which were of moderate resilience to perturbations. During the present study herbivores contributed a maximum of 37% at site 7 and minimum of 4% at site 6. The species contributed at site 7 were *Etroplus suratensis*, *Garra mullya* and *Dawkinsia filamentosa.* Lowest % herbivores was recorded at site 5 (5%) and 6 (4%) and the species contributed was *Oreochromis mossambicus*. Similarly top carnivore metric showed highest score at site 7 (58%) and the species contributed mainly were *Mystus oculatus*, *Eleotris fusca*, *Channa striata* and *Ompok bimaculatus.* Minimum % carnivores were recorded at site 5 (21%) and site 6 (22%) and the species represented were *Rasbora dandia*, *Mystus gulio*, *Clarias gariepinus*, *Glossogobius giuris* and *Pseudosphromenus cupanus* respectively.

3.3 Bray-Curtis Similarity Cluster
Cluster plot distinguished 3 distinct groups sharing 20% similarity in fish community structure between Vellayani and Veli-Akkulam lakes (Fig. 3). In Veli-Akkulam sites two distinct groups (Group II and III) were identified, indicating clear distinction of upstream and downstream faunal assemblages, with only 40% similarity between them spatially. Here sites represented by upstream (site 4, 5, 6) and downstream (site 1, 2, 3) region formed by the groups II and III showed 80% similarity seasonally. The results of this analysis revealed a clear distinction in the distribution of fish communities as an upstream, downstream and a reference one.

3.4 Non-metric Multidimensional Scaling (MDS)
Multidimensional plot showed the same pattern of fish community structure as illustrated in cluster diagram (Fig. 4). Three groups (Group I, II and III) were clearly distinguished in the MDS plot sharing 20% similarity in fish communities among the lakes. Vellayani, reference site (Group I) found as a distinct group sharing 20% similarity with Veli-Akkulam lakes. Groups II formed by the upstream sites 4, 5, 6 distinguished from group III formed by downstream sites 1, 2 and 3 revealing distinct fish community assemblages in Veli-Akkulam lake.

3.5 Canonical Correspondence Analysis
CCA analysis illustrates the relation of fish multimetric values and water quality parameters between sites showing 87.96% of cumulative variance of the two axes (Fig. 5). In CCA analysis the metrics, number of intolerant species, number of benthic species and taxonomic richness were influenced by the environmental parameter dissolved oxygen (DO) at site 7 whereas the metrics, number of native species, number of native families, % herbivores (% H), % total carnivores (% TC) and number of water column species were influenced by electrical conductivity of water at sites 1 and 2. These metrics had showed a negative relation with pH, nitrate, nitrite, phosphate, BOD, COD and free CO_2. The metric % omnivore species (% OM) was more influenced by the parameters water temperature, pH, nitrate, nitrite, phosphate, BOD, COD and free CO_2 at sites 3, 4, 5 and 6. But the metrics such as % tolerant species and % non-native species were found abundant at site 4 and the parameters controlling the species distribution were hardness and salinity respectively.

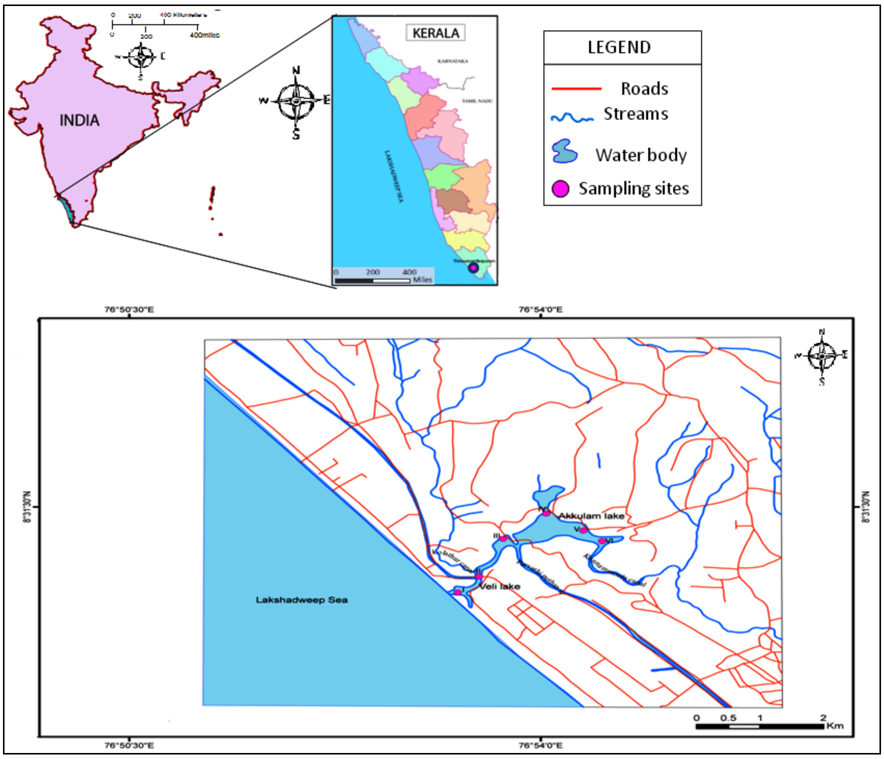

Fig 1: Location map of Veli-Akkulam Lake, South India showing study sites

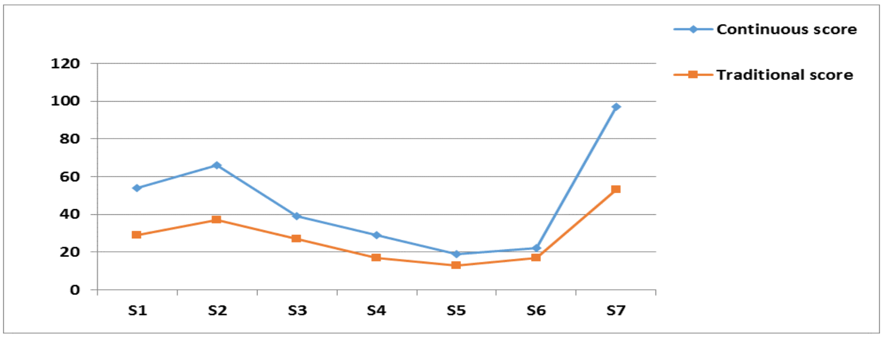

Fig 2: Fish Index of biological integrity scores for each sites of Veli-Akkulam and Vellayani lake using traditional (1, 3, 5) and continuous metric scoring (0-10). Maximum index for continuous score is 97 out of 100 and for traditional score is 53 out of 55

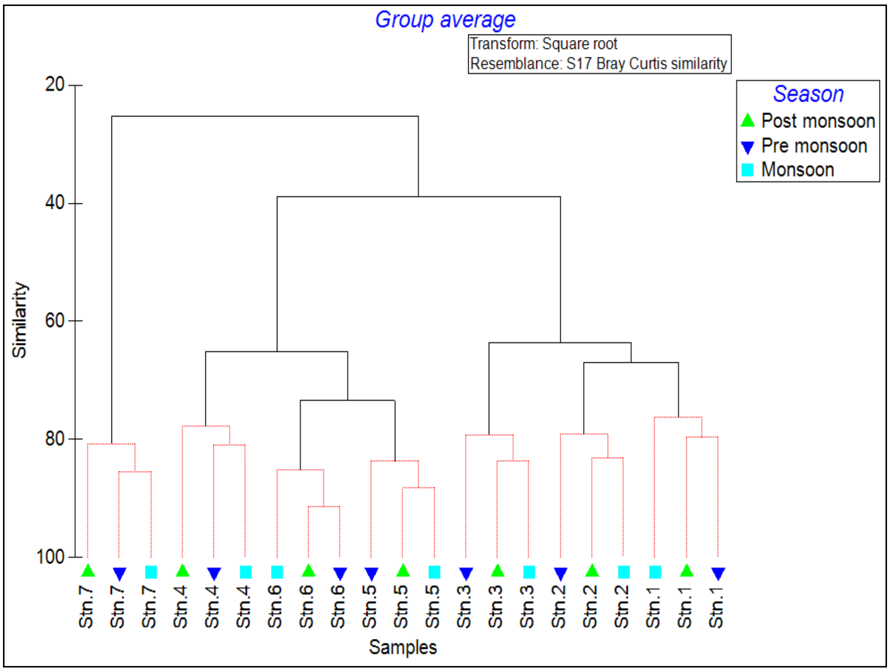

Fig 3: Bray-Curtis similarity cluster of fish community structure at all sites of Veli-Akkulam and Vellayani lakes during pre-monsoon, monsoon and post-monsoon seasons. Data represents all sampling sites of Veli-Akkulam lake (site 1, site 2, site 3, site 4, site 5 and site 6) and reference Vellayani lake (site 7). Solid black lines indicate significant difference between sites (SIMPROF, p = <0.05) and black dashed lines indicate no significant difference (SIMPROF, p = >0.05).

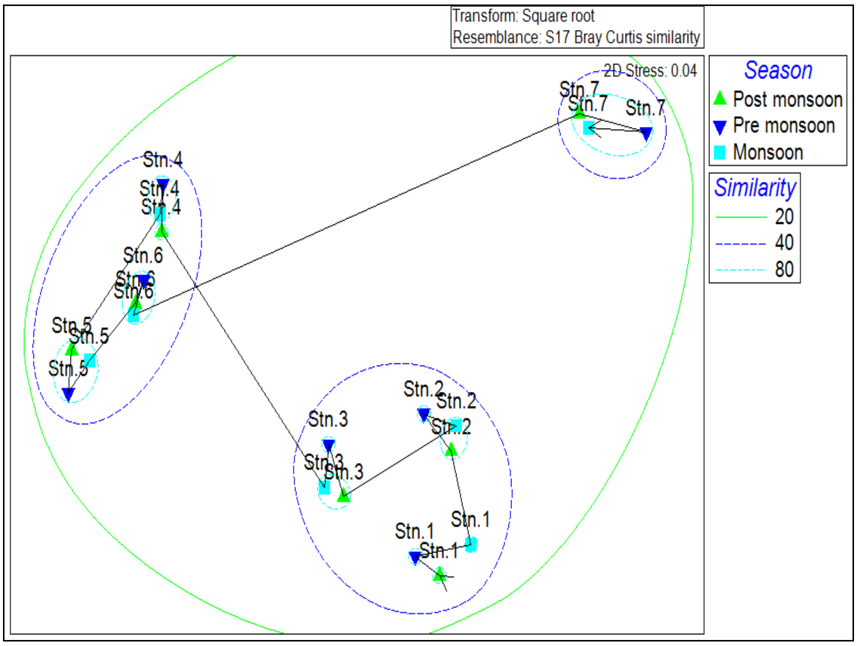

Fig 4: MDS plot illustrating percentage similarity in fish community structure of Veli-Akkulam and Vellayani lakes based on Bray-Curtis similarity matrix. Data represents 6 sites of Veli-Akkulam and a reference site, Vellayani Lake with 3 seasons (pre-monsoon, monsoon and post-monsoon)

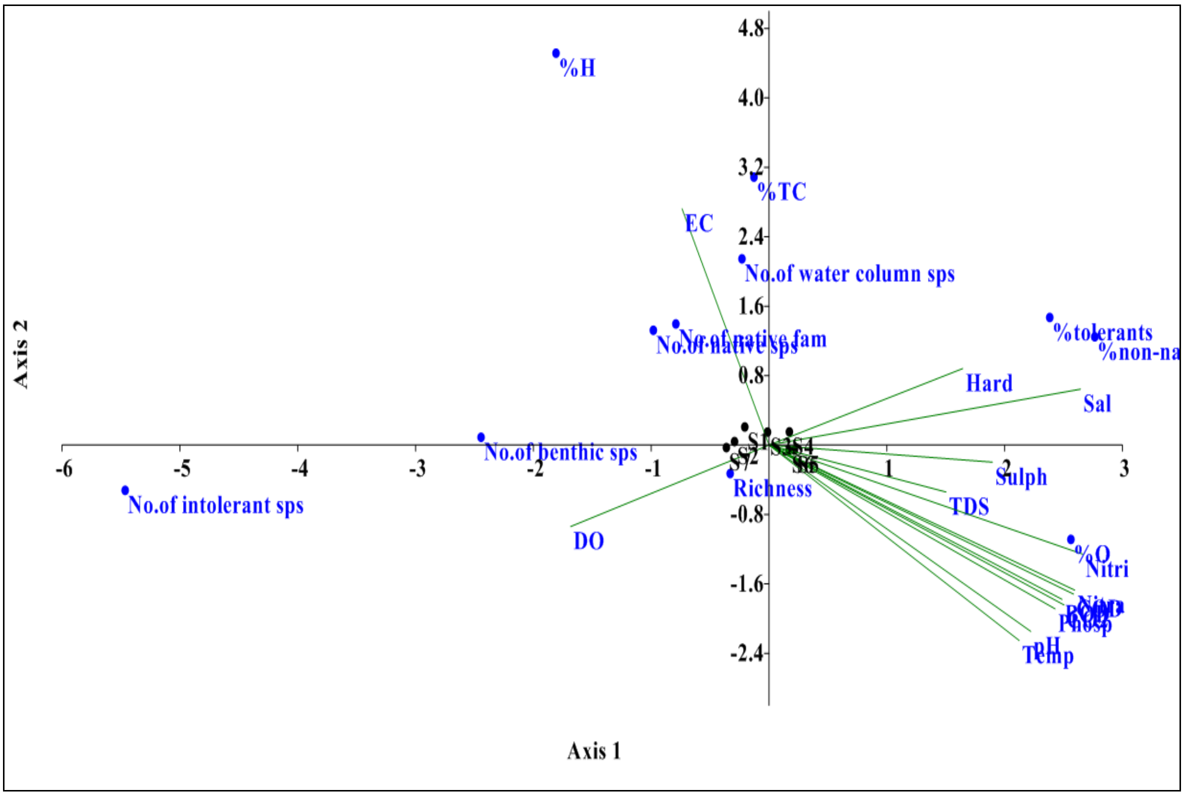

Fig 5: Canonical Correspondence analysis (CCA) plot illustrating candidate fish multimetrics, environmental variables and sites based on first two axes

Table 1: Mean value of water quality parameters of Veli-Akkulam and Vellayani Lake and the standards of inland surface water quality criteria of US EPA and CPCB (India)

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	US EPA (2001)	CPCB (2008)
Temperature (°C)	27.58	29.08	28.83	26.58	27.75	28.19	30.30	--	--
pH	7.05	7.25	7.17	7.05	6.92	6.94	6.96	5.5-9.0	6.5-8.5
Salinity	9.87	2.94	4.84	2.04	1.01	0.99	0.50	--	--
Electrical Conductance at 25° C (µScm^{-1})	9415.81	2249.59	4282.45	607.87	58.61	106.13	137.16	1000	1000
Dissolved Oxygen (mgL^{-1}), min.	3.55	3.19	2.82	1.28	0.29	0.50	6.94	5	6
Total Dissolved Solids (mgL^{-1}), max.	2851.55	2373.17	831.21	695.13	431.38	414.04	92.28	--	500
Total Hardness (mgL^{-1}), max.	1277.12	483.22	261.96	312.18	99.60	98.83	33.14	200	300
Free Carbon dioxide (mgL^{-1}), max.	12.69	15.04	16.72	26.93	39.16	37.35	4.65	--	6
Nitrate-Nitrogen(mgL^{-1})	0.24	0.22	0.24	0.21	0.21	0.25	0.03	50	20
Nitrite-Nitrogen, (mgL^{-1})	0.30	0.34	0.27	0.32	0.21	0.25	0.03	0.03	0.03
Dissolved Phosphates (mgL^{-1}), max	1.13	1.38	1.99	2.55	5.23	4.50	0.16	0.5-0.7	5
Sulphates (mgL^{-1}), max.	19.97	14.70	8.63	5.59	3.45	2.42	0.64	200	400
BOD (mgL^{-1}), min	5.75	6.30	7.23	16.35	18.84	24.58	2.19	3	2
COD (mgL^{-1}), max.	30.24	34.95	46.15	50.36	56.82	65.12	5.57	40	250

Table 2: Criteria of scoring metrics for fish Index of Biological Integrity (IBI) for Veli-Akkulam and Vellayani lakes. Traditional scoring criteria scores of 5, 3, 1 are assigned to each metric according to whether its value approximates, deviates somewhat from, or deviates strongly from the value at the least disturbed site in this study. Continuous scoring criteria scores are determined as proportions of the maximum or 'best' value

Category	Metrics	Traditional scoring criteria			Continuous scoring criteria	
		5 (best)	3	1 (worst)	10 (best)	0 (worst)
Taxonomic richness	1. No. of native species	>24	12 to 24	<12	37	0
	2. No. of native families	>12	6 to 12	<6	21	0
Habitat composition	3. No. of benthic species	> 8	5 to 8	<5	14	0
	4. No. of water column species	>12	6 to 12	<6	14	0
	5. No. of intolerant species	>2	2	<2	2	0
	6. % Individual as tolerant species	<18	18 to 36	>36	14	50
Trophic composition	7. % Individual as omnivores	<24	24 to 48	>48	7	50
	8. % Individual as herbivore	>28	14 to 28	<14	37	0
	9. % Individuals as top carnivores	>48	24 to 48	<24	57	0
Fish health and abundance	10. Total no. of individuals	>1200	600 to 1000	<600	1587	0
	11. % Individuals as non-native	<1	1 to 10	>10	0.00	50
	12. % Individuals with anomalies or disease	NA	NA	NA	NA	NA

Table 3: Fish species collected from Veli-Akkulam Lake and Vellayani Lake monthly in 2008, 2009, 2010. Habitat guilds: subsurface SS, water column WC, benthic B. Trophic guilds: Top Carnivore TC, Herbivore H, Top Predator TP, Omnivore OM. Tolerance guilds: Intolerant I, Mo derately tolerant M, Tolerant T. Origin guilds: Native N, non-native NN

Family/Species	Habitat guild	Trophic guild	Species tolerance	Origin
Anguillidae				
Anguilla bicolor bicolor (McClelland, 1844)	B	TC	I	N
Anguilla bengalensis bengalensis (Gray, 1831	B	TC	I	N
Clupeidae				
Dayella malabarica (Day, 1873)	SS	TC	T	N
Cyprinidae				
Amblypharyngodon microlepis (Bleeker, 1853)	SS	OM	M	N
Devario aequipinnatus (McClelland, 1839)	SS	OM	M	N
Rasbora dandia (Valenciennes, 1844)	WC	TC	T	N
Dawkinsia filamentosa (Valenciennes, 1844)	WC	H	M	N
Systomus sarana (Hamilton, 1822)	WC	OM	M	N
Puntius parrah (Day, 1865)	WC	OM	T	N
Pethia ticto (Hamilton, 1822)	WC	H	T	N
Puntius vittatus (Day, 1865)	WC	H	T	N
Puntius amphibious (Valenciennes, 1842)	WC	H	M	N
Garra mullya (Sykes, 1839)	B	H	M	N
Cobitidae				
Lepidocephalus thermalis (Valenciennes, 1846)	B	OM	T	N
Bagridae				
Mystus gulio (Hamilton, 1822)	WC	TC	M	N
Mystus oculatus (Valenciennes, 1840)	WC	TC	M	N
Clariidae				
Clarias gareipenus (Burchell, 1822)	B	TC	M	NN
Clarias dussumieri (Valenciennes, 1840)	B	TC	T	N
Siluridae				
Ompok bimaculatus (Bloch, 1794)	B	TC	M	N
Wallago attu (Bloch & Schneider, 1801)	B	TC	T	N
Heteropneustidae				
Heteropneustus fossilis (Bloch, 1794)	B	TC	M	N
Belonidae				
Xenentodon cancilla (Hamilton, 1822)	SS	TC	T	N
Hemirhamphidae				
Hyporhampus xanthopterus (Valenciennes, 1847)	SS	OM	T	N
Cyprinodontidae				
Aplocheilus lineatus (Valenciennes, 1846)	SS	TC	T	N
Syngnathidae				
Microphis cuncalus (Hamilton, 1822)	WC	TC	T	N
Mastacembelidae				
Mastacembelus armatus (Lacepède, 1800)	WC	TC	T	N
Synbranchidae				
Ophisternon bengalense (McClelland, 1844)	B	TC	M	N
Ambassidae				
Ambassis ambassis (Lacepède, 1802)	SS	TC	T	N
Parambassis thomassi (Day, 1870)	SS	TC	T	N
Cichlidae				
Etroplus maculates (Bloch, 1795)	WC	OM	T	N
Etroplus suratensis (Bloch, 1790)	WC	H	M	N
Oreochromis mossambicus (Peters, 1852)	WC	H	M	NN
Eleotridae				
Eleotris fusca (Forster, 1801)	B	TC	M	N
Gobiidae				
Glossogobius giuris (Hamilton, 1822)	B	TC	T	N
Awous grammepomus (Bleeker, 1849)	B	TC	M	N
Anabantidae				
Anabas testudineus (Bloch, 1792)	WC	OM	T	N
Belontidae				
Pseudosphromenus cupanus (Cuvier, 1831)	SS	TC	T	N
Channidae				
Channa marulius (Hamilton, 1822)	B	TP	M	N
Channa striata (Bloch, 1793)	B	TC	M	N

Table 4: Fish Index of Biotic Integrity multimetric values, continuous scores (bold), traditional scores (italics), F-IBI scores and subjective integrity assessment for Veli-Akkulam and Vellayani lakes based on composite monthly collections in 2008, 2009 and 2010

	Veli-Akkulam Lake sites						Vellayani Lake (reference lake)
Metrics	S1	S2	S3	S4	S5	S6	S7
No. of native species	16	21	18	11	8	10	37
	4.3	5.7	4.9	3	2.2	2.7	10
	3	3	3	1	1	1	5
No. of native families	11	15	11	7	5	7	21
	5.2	7.1	3	3.3	2.4	3.3	10
	3	5	3	3	3	3	5
No. of benthic species	3	4	3	2	1	2	14
	2.1	2.9	2.1	1.4	0.7	1.4	10
	3	3	3	1	1	1	5
No. of water column species	7	10	9	7	5	5	14
	5	7.1	6.4	5	3.6	3.6	10
	3	3	3	3	1	3	5
No. of intolerant species	1	1	0	0	0	0	2
	5	5	0	0	0	0	10
	1	1	1	1	1	1	5
% Individuals as tolerant species	21	19	42	76	61	67	14
	7.2	7.5	4.5	0	2	1.2	8.2
	3	3	1	1	1	1	5
% Individual as omnivores	28	19	47	51	75	71	6
	6.4	9	4	3.5	0	0.9	9.2
	3	5	3	1	1	1	5
% Individual as herbivore	28	30	19	13	5	4	37
	7.6	8.1	5.1	3.5	1.4	1.1	10
	3	3	3	1	1	1	5
% Individuals as top carnivores	44	46	35	36	21	22	58
	7.6	7.9	6	6.2	3.6	3.8	10
	3	5	3	3	1	1	5
Total number of individuals	527	948	503	521	554	614	1587
	3.3	6	3.2	3.3	3.5	3.9	10
	1	3	1	1	1	3	5
% Individuals as non-native	2	1	4	14	12	11	0.88
	8.6	9.3	7.1	0	1.4	2.1	9.4
	3	3	3	1	1	1	5
% Individuals with anomalies[a]	NA	NA	NA	NA	NA	NA	NA
IBI score Traditional IBI score	54	66	39	29	19	22	97
	29	37	27	17	13	17	53
Integrity classes	I	M	I	I	I	I	A

[a] Data not available
[b]I = impaired. M = moderately impaired, A = acceptable.

4. Discussion

Biological integrity for evaluating the health of aquatic ecosystem with the help of potential fish indicator species at the community or assemblage level is proved to be a valuable framework, since fish assemblages can be able to integrate overall ecological integrity of a system [32, 33]. Integrity of lake ecosystems using fish index integrate structural, compositional, ecological characteristics [5, 23]. The study of integrity using fish indices for lake was less evident [34, 35]. The present study envisaged the preliminary application and development of fish index of biotic integrity (F-IBI) for better evaluation of health of Veli-Akkulam Lake of South India. There is no other significant data available regarding the biomonitoring of freshwater lakes using fish index in Indian lucustrine ecosystems so far. The present study could develop index of biotic integrity successfully to efficiently forecast the fish assemblage variations using standard metrics as these selected metrics reflect environmental perturbations.

The present study gave a better picture of the community structure of fish of the study area and emphasized that fish assemblages could act as potential indicators of anthropogenic stress and its impacts on lakes. About 6 species recorded during the present study were tolerant species according to the Fish Base data and the species were *Dayella malabarica*, *Hyporhamphus xanthopterus*, *Aplocheilus lineatus*, *Eleotris fusca*, *Mastacembelus armatus*, *Parambassis thomassi* and *Pseudosphromenus cupanus*. There was found a decline in the presence of a sensitive/intolerant species, *Anguilla bengalensis bengalensis* and emergence of non-indigenous species *Clarias gariepinus*, which was not reported in earlier findings in Veli-Akkulam Lake. In Vellayani lake high species diversity and the occurrence of abundant sensitive fish fauna indicated its less disturbed condition and high fishery potential.

Regarding the metrics selected for the study, all the metrics ensured significant response to ecological disturbances. Furthermore, most of the selected metrics for IBI development, even if they were modified, could achieve equilibrium between composition, tolerance/intolerance guilds, trophic guilds and abundance. In the present study the species richness of fish showed distinct variation with high species richness in Vellayani Lake indicated undisturbed ecosystem with less human intervention. But site 2 in Veli-Akkulam Lake had a considerable species richness, when compared to other sites of Veli Lake. But in Akkulam region very less species richness was found that revealed significant amount of organic pollution due to the disruption of water quality factors. These anthropogenic disturbances are able to disrupt native fauna of the ecosystem [13]. There was noticed extensive decline of native species and native families in Veli-Akkulam Lake. Similar findings in decline of native species and native families were reported in Hooghly estuary [14]. Also the relative contribution of non-native species at Veli-Akkulam Lake indicates heavy anthropogenic stress and the degradation of water quality parameters of the lake.

In Veli-Akkulam Lake the distribution and abundance of tolerant fish species are attributed to eutrophication, industrial and municipal waste disposal and hospital discharges which ultimately resulted habitat degradation and its continuous loss. Highest percentage of tolerant species recorded at site 4 owing to eutrophication, dredging activities, input of sewages, agricultural and hospital wastes from both tidal inlets of the lake. But in Vellayani Lake tolerant species were less predominant and those present were not non-native and dominant ones at all. These findings of high percentage of non-native species agree with the studies conducted in Khan River and Hooghly estuary [13, 14]. Besides this, the increased number of tolerant species in the disturbed sites of Veli-Akkulam lake sites 3, 4, 5, 6 indicated deteriorated habitat as well as water quality. The presence of intolerant species populations is found to be an important criterion to distinguish water quality, since these species are the first to disappear when a pollution event just happens [23]. Absence of intolerant species at sites 3, 4, 5 and 6 may be due to degradation in water quality and loss of habitats in Veli-Akkulam Lake. The present findings also agree with the studies done in Hooghly estuary, India [14].

All the metrics concerning the trophic status, feeding guilds appeared to be very useful for giving information to IBI. Any alteration of habitat can lead to the limitation of food availability and affects its subsequent selection. Of this the metrics such as percentage individuals as omnivores could classify during the present study since their abundance indicated deteriorated water quality conditions. Veli-Akkulam sites 4, 5 and 6 showed highest omnivore populations, indicated deteriorated habitat attributed by habitat modification, land drainage or dumping of sewages. Most degraded water body supports large population of omnivores and its dominance arises most likely as an outcome of depletion of food resources, especially invertebrates [23]. Whereas the two metrics, decrease of percentage herbivores and top carnivores in the disturbed site especially at the Akkulam lake region shows its degraded condition and similar findings were also reported in river Khan and Kshipra [13]. It is important to note that the sites at the Akkulam region of the lake were highly deteriorated in water quality that was due to municipal wastes, hospital wastes, eutrophication, siltation etc., and these might lead to the dominance of tolerant exotic fish species and might have impeded the survival of many resident sensitive species and removal of many native food fishes. The continuous IBI score showed significant reduction at these sites and considerable increase at the reference site. Percent individuals as herbivores and top carnivores were maximum at site 7 indicated a relatively healthy and tropically diverse fish community at Vellayani Lake. Very least contribution of herbivores and top carnivores at site 6 showed that these species have declined and disappeared from there.

Index of Biotic Integrity of the study lakes with two different aspects of metrics compilation such as continuous fish IBI and traditional fish IBI scores showed similar characteristic of integrity classification in the present study. The highest continuous and traditional score found at Vellayani Lake indicated acceptable water quality conditions with high species richness and diversity of fish fauna. Maximum score of 66 recorded at site 2 of Veli-Akkulam lake revealed moderately impaired water quality conditions that was due to abundance of tolerant fish species whereas the least IBI score at other monitoring sites 1, 3, 4, 5 and 6 showed huge impairment that was due to deteriorated water quality owing to the pollution loads from industries, municipal wastes, hospital wastes, oil pollution as a result of tourism activities, dredging activities, sedimentation, eutrophication. The use of multimetric index as well as multivariate analysis is more useful than indicator species concepts in order to expedite pollution evaluation and subsequent management [13].

Similarity cluster plot for fish showed three distinct faunal assemblages with Vellayani Lake forming a unique group showing only 20% similarity with Veli-Akkulam Lake. Conversely, Veli-Akkulam Lake exhibited two distinct faunal characteristics, a downstream and a upstream communities. This trend was obvious and consistent with MDS ordination. These community level changes could be the resultant habitat disturbances due to pollution, organic enrichment and invasive species which reduce species diversity and lead to the dominance of opportunists [36-39]. The application of CCA to find the influence of environmental parameters with fish resources revealed the response of fish communities to varying water quality factors. The relation between dissolved oxygen (DO) and number of intolerant species, number of benthic species and species richness metrics at site 7 showed high level of dissolved oxygen available for fish distribution indicating good water quality conditions prevailing in the lake. Negative relation of metrics such as number of native species, number of native families, % herbivores (% H), % total carnivores (% TC) and number of water column species with parameters pH, nitrate, nitrite, phosphate, BOD, COD and free CO_2 revealed the sensitivity of the fish assemblages to these parameters. But fish distribution at sites 3, 4, 5 and 6 of Veli-Akkulam lake characterized by the metrics % omnivore species (% OM) was mainly determined by the parameters BOD, COD, phosphate, nitrite, nitrate, temperature, pH, total hardness and salinity revealing degraded water quality conditions. Hardness and salinity determined the metrics such as % tolerant species and % non-native species at site 4 indicating highly stressed habitat conditions as this site existed as a domain of transition zone of the Veli-Akkulam lake.

Thus the biotic integrity using multimetric fish Index of Biotic Integrity could efficiently reveal that Veli-Akkulam lake system is extremely affected by deteriorating water quality and that might have resulted in the decline of native fish fauna. Since the fishery potential of this lake forms a major resource for the livelihood of fisherman, this evaluation can make a step for management aspects to some extent to reinstate fishery potential. It can be concluded that the newly developed multimetric index of fish applied in the biomonitoring programme of Veli-Akkulam lake contributed an important tool in assessing the quality of water along with physico-chemical parameters. This index could be used to monitor other freshwater bodies also since this Rapid Bio-assessment method would be more cost-effective way of ecosystem survey. Furthermore the present study pinpoints that the development of a reliable index of biotic integrity (IBI) based on fish assemblages were sufficient enough to comply the health of Veli-Akkulam lake with a robust reference lake Vellayani.

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