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Applying an Integral Biological Index to Assess Water Quality in Freshwater Ecosystems: Ktiban Channel

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ABSTRACT

Scientists consider biomonitoring necessary for identifying the response of living creatures to the causes of environmental degradation. This method relies on the description of river conditions so that plans to reduce dangers, or for restoration and environmental continuity, can be put into place. In this paper, we evaluated Ktiban stream water quality (Ktiban is one of the branches of Shatt Al-Arab's River) using fish as bioindicators. The biomonitoring platform in this paper includes diversity, bio-evidence, a multi-metric approach, IBI (Integrate biological index), and a multi-variate approach (PCA). Fish were monthly collected using four fishing methods. Twenty-four species belonging to 12 families were caught using those methods, 9 of which were native species and 7 were exotic species, with 8 marine species distributed in percentages of 5.46%, 80.92%, and 13.62%, respectively. IBI was divided into three groups; the species richness group had specific numerical abundances of exotic and native species, with the abundance of the exotic species *Oreochromis niloticus* showing dominance in the fish community composition, with high percentages of the probable species. The metrics of omnivore and herbivore species showed dominance in the stream's fish community. IBI's value reached 50.52% and the stream was considered to have a normal environment. PCA showed the effectiveness and percentage of IBI.

INTRODUCTION

The biodiversity of freshwater environments is facing a more severe crisis than in other habitats. Rivers and internal wetlands are home for an unusual variety of life **(Tickner *et al*., 2020)**, and freshwater ecosystems provide services to many people, including weakened and poor communities **(Lynch *et al*., 2016)**. Nonetheless, the management of these ecosystems normally prioritizes a narrow group of services for the benefit of the economy at the expense of habitat, animals, and plants and the various benefits that they provide. Thus, the current average loss of wetlands is three times the average rate of forest loss, and the number of vertebrates in freshwater has decreased at more than twice the rate of wild vertebrates or in oceans **(Gardner & Finlayson, 2018; Grooten & almond, 2018)**. Changes in the management of water flow, such as dams, reservoirs and established projects in the countries at the source of the Tigris and

Euphrates Rivers affect the environment of Shatt Al-Arab River and affects the management of the water used in industry, agriculture and the drinking water of Iraq. These changes have a direct effect on the physical characteristics and the ecosystems, such as sediment flow and habitat connectivity, as well as freshwater salinization due to the entrance of water from the Arabian Gulf. These changes affect the functional links between hydrological systems and the history of freshwater organisms, and thus result in the loss of its biodiversity **(Bunn & Arthington, 2002; Offem *et al*., 2011; Yang *et al*., 2012; Zhang *et al*., 2015)**. Pollution affects biodiversity heavily and can directly harm the operations of freshwater ecosystems. This pollution can consist of unsanitary discharge, pesticides, heavy metals, materials, plastic that is thrown onto the banks of rivers and its branches, and the generated heat from energy sectors. Choices of policies and management should be aimed at improving water quality and maintaining aquatic life and should include monitoring and environmental evaluation, using organisms as a rapid assessments of the condition of surface water. Integrated biological indices (IBI) have used fish to evaluate water quality in rivers and American warm streams. Indicators based on quantitative measurements of multiple properties related to fish assemblage in rivers help to evaluate the health of aquatic organisms. Until we achieve the evaluation of surface water conditions using historical and regional measurements, the indicators show the quality of the physical environment, the entrance of energy, biological overlap and water quality **(Karr, 1981; Machado *et al*., 2011; Caetano *et al*., 2016)**. This study aimed to evaluate the environmental situation and the quality of the water in the Ktiban stream (one of the branches of the Shatt Al-Arab River) using IBI, as well as checking the effectiveness of the selected metrics by application of a principal component analysis (PCA).

MATERIALS AND METHODS

Fishes of Ktiban stream were collected from October 2017 to July 2018 within the coordinates of the geographical position (47°45'11.5934"E 30°40'12.2654"N) shown in Fig. (1). Many fish-capturing tools were used, including drift gill nets, set gill nets, dragnets and bottom trawling. Dragnets were used to calculate fishing effort in all sample collection months, whereas the rest of the tools were used to measure the types and sizes of the fish. The classification of fishes relied on information from **Beckman (1962)** and **Carpenter *et al*. (1997)**. Fish types were divided according to geographical origin (freshwater native, exotic, and migratory marine), the nature of their diet (omnivores, herbivores, carnivores and detritivores) and sensitivity or tolerance using previous publications of fishers and researches pertaining to ecological assessment **(Mohamed *et al*., 2008; Coad, 2010; Mohamed & Hussein, 2012)**.

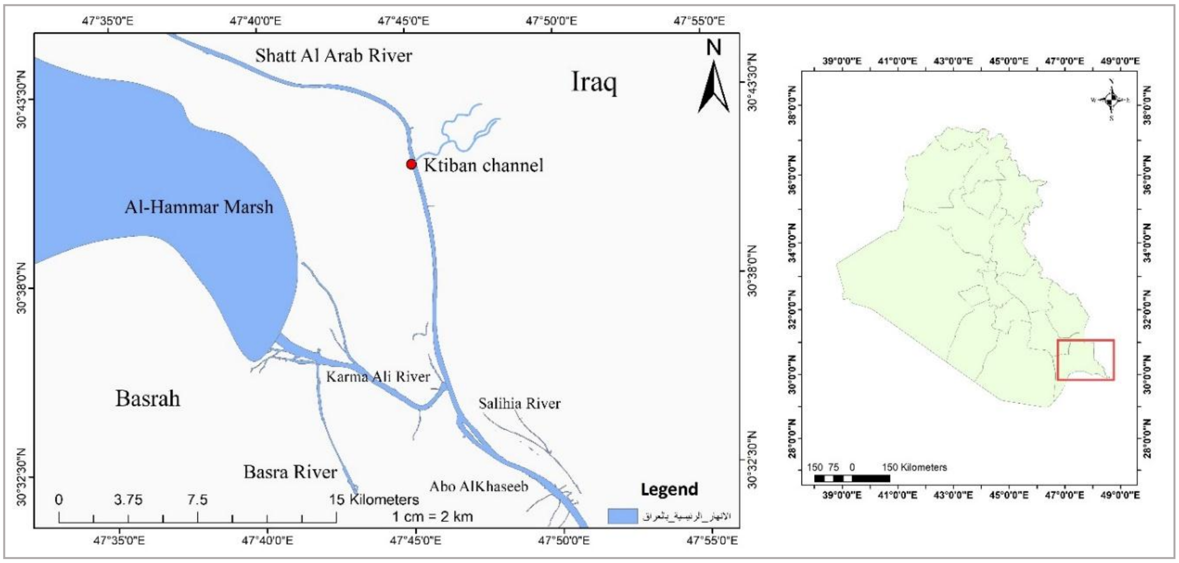

Fig. 1. A map of Ktiban stream showing the sampling sites

The integral biological index was calculated according to **Minns *et al*. (1994)**. The metrics score was selected from 0-10 and the metrics were divided into one group that increased the index's value and another group that decreased it. 10 points (score) were given to high metric values, which improve environmental quality, and the rest of the results were calculated using the equation [u.v. = (A/B) * 10], where A = value of the metrics, B = high value. As for the one that increases by reduction of environmental quality, they were given the value of (0) for its high metric values, and the rest of its results were calculated using the equation [u.v. = (1 - A/B) * 10]; index values calculated from 0-100. IBI values are rated as very poor (0-20), poor (21-40), fair (41-60), good (61-80), and excellent (>80). We selected twelve metrics to measure IBI with three main groups (Table 1). The species richness index (D) was defined by **Margalefe (1968)**: D = S – 1 / ln (N), where: S = number of species, and N = number of individuals. The program XLSTAT-premium 2016.02.28451 was used for multivariate analysis.

Table 1. The groups and metrics included in measuring IBI

A-Species richness metrics	B-Species composition metrics	C-Trophic groups metrics
1-No. of native species	5-% of tolerant species	9-% of herbivores species
2-No. of Exotic species	6-% of sensitive species	10-% of omnivores species
3-No. of Migratory species	7-% *Planiliza abu*	11-% of carnivores species
4-species richness	8-% *Oreochromis niloticus*	12-% of detritivores species

RESULTS

1. Compositions of fishes' population

The total composition of Ktiban stream included 24 Osteichthyes species belonging to 21 genera and 12 families, as shown in Table (2). Native species comprised nine species, constituting 13.62% of the fished population, whereas there were seven exotic species forming a percentage of 80.92%; the rest of the eight species were marine fish, with a percentage of 5.46%.

Table 2. Composition of families and species of fishes of Ktiban stream, with the description of some of the index's metrics

Family/species	guild Trophic	and Origin tolerance
Cyprinidae		
Leuciscus vorax (Heckel, 1843)	Carnivore	AD
Carasobarbus luteus (Heckel, 1843)	Omnivore	AD
Carassius gibelio (Linnaeus, 1758)	Omnivore	BC
Cyprinus carpio (Linnaeus, 1758)	Omnivore	BC
Acanthobrama marmid (Heckel, 1843)	Omnivore	A
Alburnus mossulensis (Heckel, 1843)	Omnivore	AC
Hemiculter leucisculus (Basilewsky, 1855)	Omnivore	BC
Garra rufa (Heckel, 1843)	Omnivore	AD
Cichlidae		
Oreochromis niloticus (Linnaeus, 1758)	Herbivore	BC
Coptodon zillii (Gervais, 1848)	Herbivore	BC
Oreochromis aureus (Steindachner, 1864)	Herbivore	BC
Mastacembelidae		
Mastacembelus mastacembelus (Banks andSolander,1794)	Carnivore	AD
Mugilidae		
Planiliza abu (Heckel, 1843)	Detritivore	AC
Planiliza subviridis (Valenciennes, 1836)	Detritivore	E
Siluridae		
Silurus triostegus (Heckel, 1843)	Carnivore	AD
Leiognathidae		
Photopectoralis bindus (Valenciennes, 1835)	Carnivore	E
Clupeidae		
Tenualosa ilisha (Hamilton, 1822)	Detritivore	E
Gobiidae		
Boleophthalmus dussumieri (Valenciennes, 1837)	Carnivore	E
Bathygobius fuscus (Rüppell, 1830)	Carnivore	E
Engraulidae		
Thryssa whiteheadi (Wongratana, 1983)	Carnivore	E
Thryssa hamiltonii (Gray, 1835)	Carnivore	E
Bagridae		
Mystus pelusius (Solander, 1794)	Carnivore	AD
Poeciliidae		
Poecilia latipinna (Lesueur, 1821)	Omnivore	B
Sparidae		
Acanthopagrus arabicus (Iwatsuki, 2013)	Carnivore	E
A-Native species **B**-Exotic species **C**-Tolerance **D**-Sensitive **E**-Marine Migratory species		

2. Environmental condition of index metrics

2. 1. Species richness group

The lowest values of native species during the study was three species in December, making up a percentage of 4.6%, whereas the highest was during February, March, May and July, when it reached six species and a percentage of 38.84%. The lowest value of exotic species was four (October) with a percentage of 10.40%, and the highest (August, September) reached seven species with a percentage of 11.56%. No individual marine fish species were found during December, and the most abundant six species appeared in May, with a percentage of 18.63%. The highest and lowest values of index richness were 1.59% and 2.69% (November 2017, July 2018), respectively.

2. 2. Species composition metrics

Table (3) shows the values of monthly metrics used in IBI during the study period. Relative abundance of *Planiliza abu* reached 5.79% of the tolerant species and 5.07% of the total relative abundance; the lowest percentage of these species was 0.20% in March, while the highest was 11.62% in August. The exotic *Oreochromis niloticus* had the highest total relative abundance and the highest abundance of tolerant species, reaching 27.73% and 31.67%, respectively. The lowest percentage was 6.96% in September and the highest was 41.10% in November. The individuals of the sensitive species metric were the second lowest in regard to fish assemblage at 7.19%, while the lowest percentage was 5.4% for marine fish species, with *Carasobarbus luteus* as the highest percentage of the metric at 81.74%. The lowest abundance for this metric was recorded in October 2017 at 1.85%, while the highest reached 21.87%. The individuals of the tolerant species metrics formed the highest percentages in the composition of the study fish community at 87.56%. The lowest percentage recorded was 77.22% in March and the highest relative abundance was 98.46% during December 2017. *Oreochromis aureus, Carassius auratus*, *Oreochromis niloticus* species maintained the highest percentages within this metric at 68.84%, as well as within the total composition of Ktiban River, with a percentage of 60.28%.

2. 3. Trophic groups metrics

The metric of herbivore fishes, as shown in Fig. (2) dominated this group and constituted a percentage of 53.90% despite few (only three) that was limited on species from Cichlidae family; *Oreochromis niloticus* species individuals formed approximately half of this metric at 51.45%, with the lowest percentage of the species caught in September being 9.40% and the highest at 80.31% in December 2017. The metric of omnivore fishes ranked second, forming an approximate percentage of 34.27% of the individuals included in the metric; *Carassius gibelio* species had the highest relative abundance of individuals at 55.26%; the lowest percentage of trophic groups metrics was 16% during December, while the highest was 73.67% in September. The percentages of the two metrics of carnivore and detritivore fish species were almost equal in this study at 5.99% and 5.48%, respectively; the lowest percentage was caught during January and

May, reaching 0.48% and 1.74% respectively; the highest percentage was during May and August at 9.03% and 12.68%, respectively.

Table 3. Monthly changes in the values of integration biological index metrics during the study period

IBI metrics	No. of Native species	No. of Exotic species	No. of Migratory species	Species richness	% *Planiliza abu*	% *Oreochromis niloticus*	% Of sensitive species	% Of tolerant species	% Of herbivores species	% Of carnivores species	% Of omnivores species	% Of detritivores species
Oct.2017	4	5	5	2.04	9.95	31.03	1.85	91.74	64.42	7.93	17.37	10.29
Nov.	4	4	3	1.6	9.47	41.1	5.68	95.27	68.37	4.36	17.42	9.85
Dec.	3	6	0	1.9	2.77	30.77	6.77	98.46	80.31	0.92	16	2.77
Jan.2018	5	6	1	1.82	1.92	33.57	7.43	93.53	75.3	0.48	22.06	2.16
Feb.	6	6	3	2.33	1.97	22.36	21.87	94.35	46.93	2.7	48.16	2.21
Mar.	6	6	4	2.42	0.2	28.23	12.1	77.22	59.88	8.06	29.23	2.82
Apr.	4	6	5	2.36	1.34	26.81	7.77	78.55	58.18	8.31	28.69	4.83
May	6	6	6	2.64	1.11	36.93	6.02	78.92	55.78	9.03	33.44	1.74
June	5	6	5	2.44	4.26	27.93	5.33	84.65	53.52	7.04	35.18	4.26
July	6	6	4	2.69	9.47	14.39	4.17	87.5	24.24	8.71	57.58	9.47
Aug.	4	7	5	2.66	11.62	8.1	4.23	85.92	11.27	5.63	70.42	12.68
Sept.	5	7	4	2.6	10.66	5.96	2.82	89.03	9.4	6.27	73.67	10.66

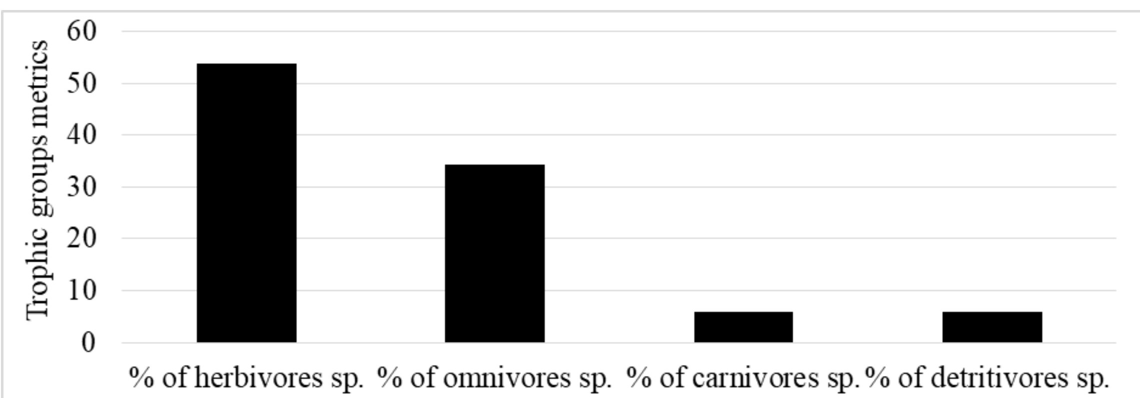

Fig. 2. The trophic composition of ktiban channel

3. Integral biological index (IBI)

Fig. (3) shows the changes in the values of IBI during the course of the study; the lowest measured value during August was 36.82%, and was rated as a poor environment, whereas the highest measured value during March was 64.93% and was evaluated as a good environment. Fig. (4) shows the monthly changes in the values of the metrics selected for the IBI in this paper during the study period, with Table (3) showing the changes of metric values according to the measurements that must go up or down with the increase or decrease of environmental degradation. Calculations showed that the ecosystem of Ktiban River was evaluated as a fair environment, and the IBI's final value was 50.52%.

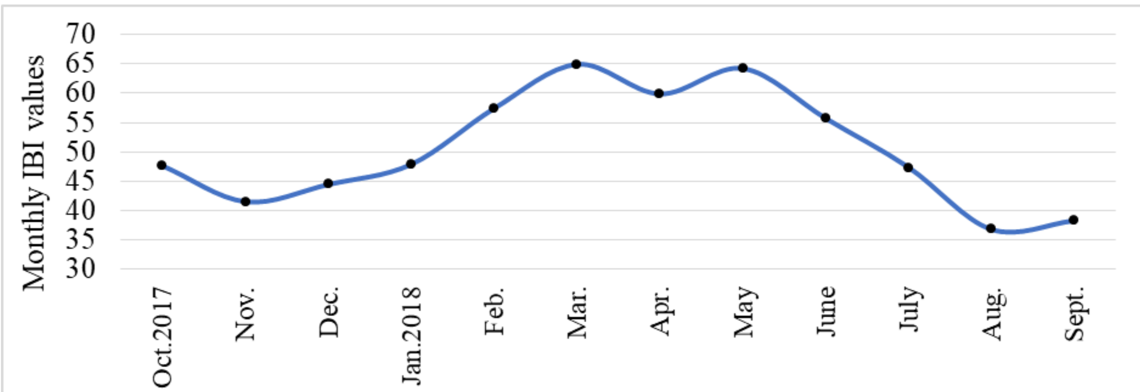

Fig. 3. Changes in the values of the monthly Integrate biological index

4. Principle component analysis

Fig. (5) displays the descriptive analysis of the simple two-vector distribution diagram (biplot), which shows the variables as related to the correlation matrix selected for the IBI with the vectors (F1, F2, F3), distribution and percentages of the monthly contributions of the observations. Additionally, the variable's effects and the observations and vectors are combined as a whole.

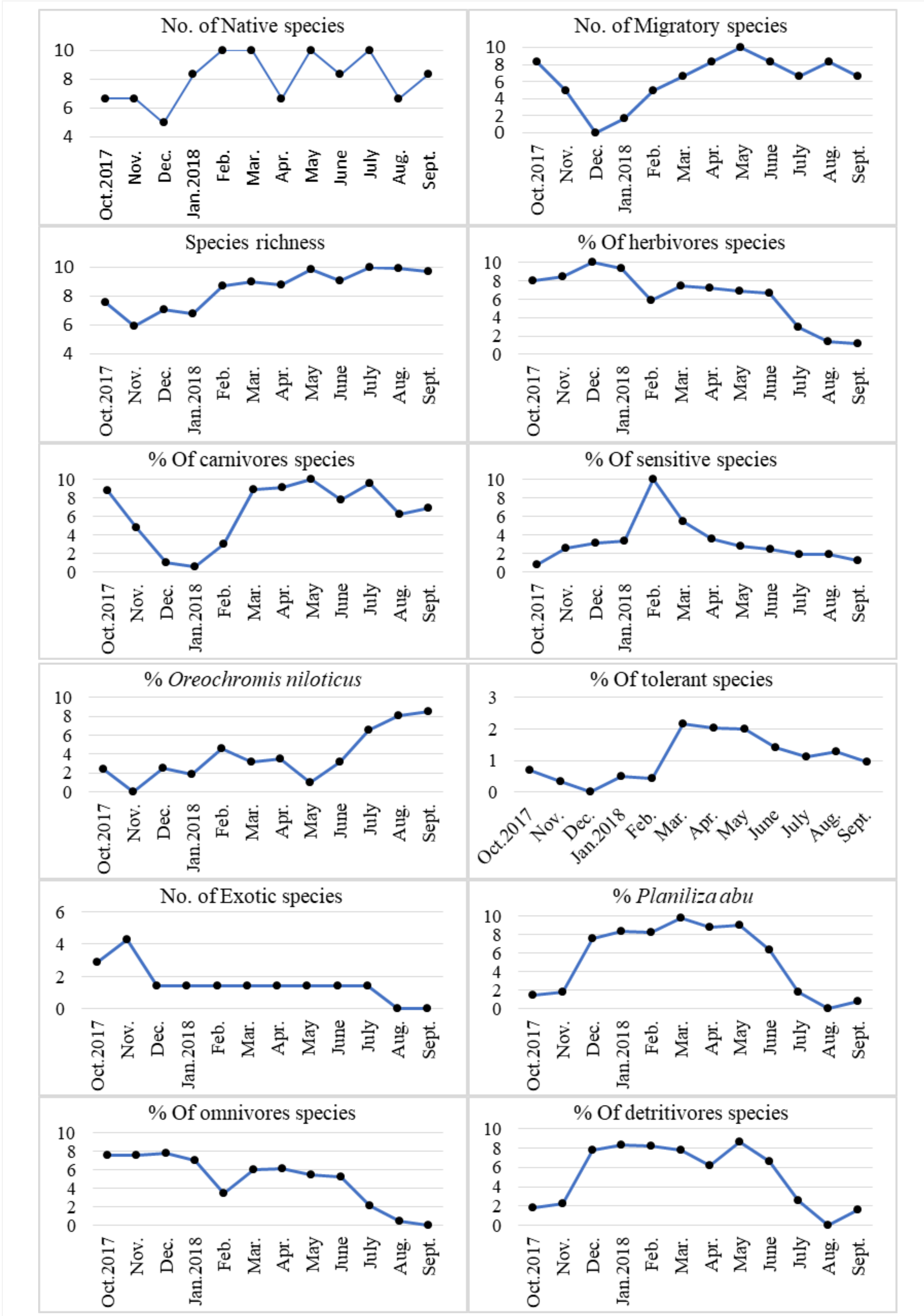

Fig. 4. Monthly changes in the values of scores for IBI during the study months

The total variation ratio related to the two vectors (F1, F2) was medium at some point (69.63%). To complete the explanation of the results, we provided the variation ratios with another diagram of the two vectors (F1, F3), which reached 62.66%. The total variation ratio, which we can rely on as a logical explanation reached 87.40%, which is a very good value as a statistically predictive explanation. Table (4) shows the results of the final values of the correlation between the index's values and the vectors, as well as the results of the eigenvalue of the principal component analysis. Columns (F1-a, F2-a, F3-a) show the sensitivity of the metrics used in the index. It is noticeable that the ranges of the metrics' correlation is wide (0.947/-0.895, 0.820/-0.681, 0.682/-0.563) and with averages reaching -0.211, -0.041 & 0.020, respectively. This means that those metrics responded widely to environmental effects in the studied region. Columns (F1-b, F2-b, F3-b) explain the percentages of the contributions of the variables (metrics) inside the three vectors, as shown in Table (4); the effective percentages were ≥ 7.736% in vector F1, and the effective percentages of the second vector (F2) were ≥15.61%, whereas the value of the third vector (F3) reached only two values (14.189%, 21.825%). Furthermore, Table (4) shows that the eigenvalue for vector F1 (5.29), with a cumulative variation percentage of 44.89%, whereas the eigenvalue and the cumulative variation percentage of vector F2 were 2.97 and 69.63%, respectively; the eigenvalue and the cumulative variation percentage of the third vector F3 were 2.13 and 87.40%, respectively.

Table 4. Correlation variables between index metrics and vector (F) and eigenvalue values for PCA analysis

Variables (IBI metrics)	Vector					
	F1		F2		F3	
	A	B	A	b	a	b
No. of Native species	-0.34	2.14	-0.68	15.61	-0.14	0.96
No. of Exotic species	-0.65	7.74	-0.18	1.06	-0.56	14.86
No. of Migratory species	-0.66	8.17	-0.31	3.17	0.6	16.77
Species richness	-0.89	14.69	-0.39	5.21	-0.08	0.28
% *Planiliza abu*	-0.49	4.42	0.82	22.62	0.18	1.57
% *Oreochromis niloticus*	0.84	13.06	-0.24	1.98	0.44	8.96
% Of sensitive species	0.27	1.31	-0.54	9.92	-0.55	14.19
% Of tolerant species	0.49	4.48	0.68	15.65	-0.41	7.75
% Of herbivores species	0.95	16.64	-0.19	1.18	0.21	2.02
% Of carnivores species	-0.61	6.94	-0.34	3.87	0.68	21.83
% Of omnivores species	-0.9	14.87	0.11	0.44	-0.4	7.34
% Of detritivores species	-0.55	5.54	0.76	19.28	0.27	3.48
Eigenvalue	5.39		2.97		2.13	
(%) Variability	44.89		24.74		17.77	
% Cumulative	44.89		69.63		87.4	
Correlations between variables and vectors = (a)						
Contribution of the variables (%) = (b)						

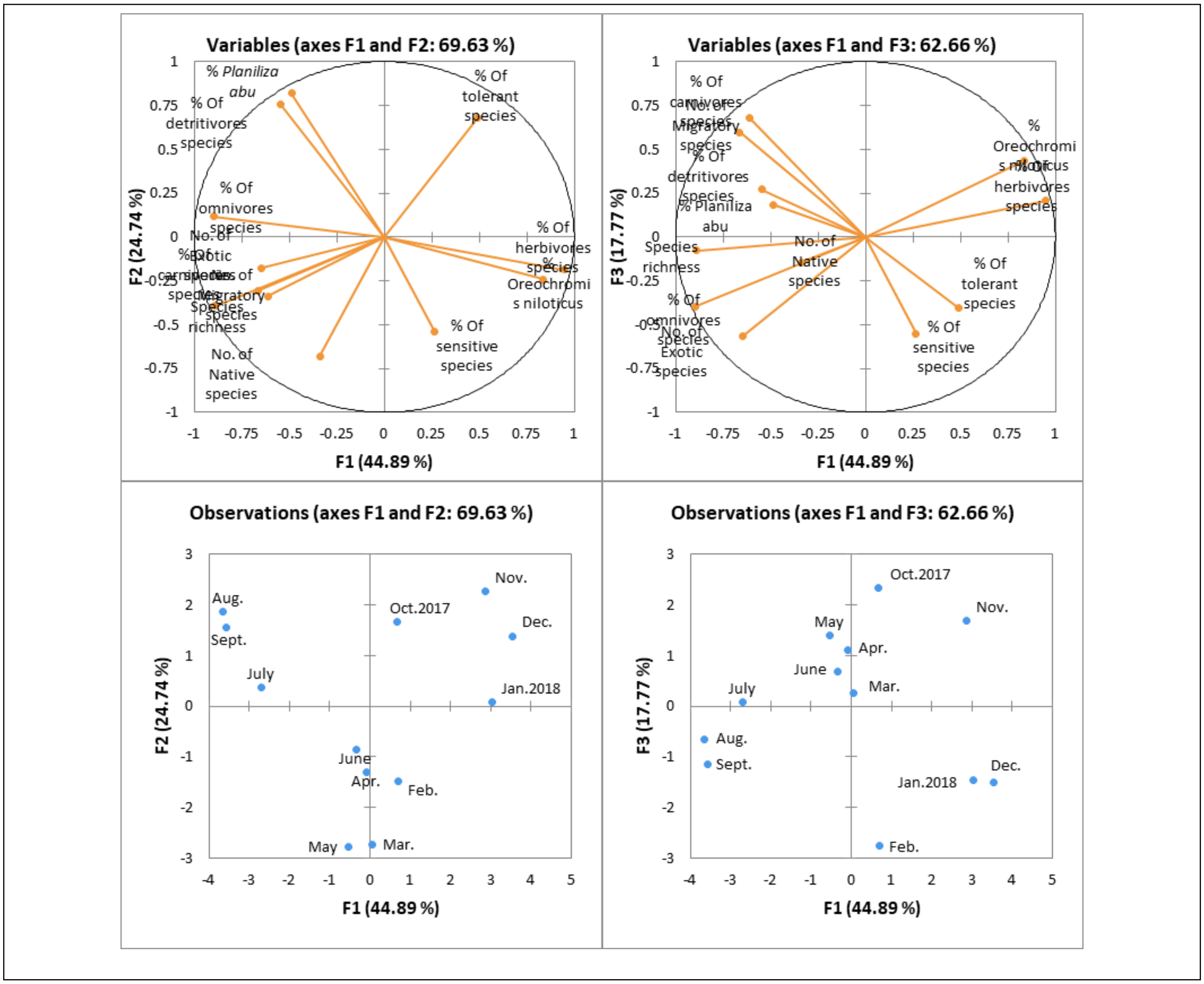

Fig. 5. Matrix correlation between metrics of index and vectors

DISCUSSION

Regional climate interaction, geology and ecological succession affect the distribution of habitats in water bodies, which generates a mosaic of unstable habitats across multiple spatial scales **(Whited *et al*., 2007; Turner, 2010)**. This creates changing opportunities that affect the survival, growth, and reproduction of its biocommunity, thus controlling its distribution **(Stanford *et al*., 2005; Willems & Hill, 2009)**. The abilities of organisms to reach suitable habitats for the continuation of their communities increase under the occurrence of environmental disturbance. For this reason, understanding the potential effect of environmental disturbance on population dynamics was the endeavor of the environmental conservation and management institutes **(Ovaskainen & Hanski, 2002; Elkin & Possingham, 2008)**. Biomonitoring is generally defined as systematic use of an organism or its responses to determine the state of the environment or changes in it **(Li *et al*., 2010)**; it is a way to monitor the effects of external factors and the evolution of an ecosystem over a given period. **Breure *et al*. (2003)** defined bioindicators as organisms containing information about environmental quality. IBI has been developed to evaluate the quality of stream water in the US and was applied on rivers, estuaries, and lakes outside the US and Canada **(Minns *et al*., 1994; Hughes & Oberdorff, 1998)**. This method requires the modification of metrics used in IBIs to reflect regional variation in fish distribution and assemblage composition **(Ganasan & Hughes, 1998)**. The group of species richness in this paper included four metrics, three of which were modified from the original metric of **Karr (1981)**, which relied on total species number (native, marine and exotic species number). The native species number is a measurement of biodiversity that usually decreases with the degradation of water. It is important to separate exotic species from native species when the native species are abundant **(Karr *et al*., 1986)**. Although the exotic species occupies the third place qualitatively, its relative abundance came in first place with the percentage of 80.92% of the caught samples, which suggests that the exotic species had always been dominant and competitive for the habitat and food of native fishes in the new invaded environments. We should point out here to the possibility to use the families within species richness group, especially families of native species; it's important to note that a number of native species families have only one species (e.g., Mastacembelidae; Mugilidae; Siluridae; Bagridae). Despite this metric not having been used by **Karr *et al*. (1986)** or **Miller *et al*. (1988)**, the number of the native families is a measurement for the biodiversity at the family level that also decreases with the increase of human-caused disruption **(Ruaro & Gubiani, 2013)**. The loss of the low specific abundance that belongs to a family is more dangerous than the loss of species of a family containing many species. Table (3) reveals that the range of richness index was between 1.6 & 2.69; this index expresses the fertility of the fishing region, for the numerical and specific abundance of fishes together. This allows comparison in the variation richness indices of the same region to determine the best seasons. Values of region richness indices were evaluated as degraded or much-degraded according to the classification of the environmental indicators prepared by **Jorgensen *et al*. (2005)** to match the range of environmental categories of freshwater bodies. The fish community composition group was one of the original groups suggested by **Karr (1981)**. We also used the percentage of the individuals of the tolerant species, as this is one of the important and widely used metrics due its relationship with chemical and physical habitat degradation. Tolerant species represents the last species to disappear after degradation and the first to come back after system recovery **(Ganasan & Hughes, 1998)**. It is noteworthy that, 83.18% of tolerant species individuals in this study were comprised of exotic species. In warm water fish communities, tolerant fishes are considered either opportunistic species or exotic species, which tend to spread to a wide range with locally high abundance **(Karr *et al*., 1986)**. The sensitive species disappear early in the timeline of environmental degradation related to agriculture and urban development, appearing again after environmental restoration. The abundance of the individuals and species of this metric is characterized by the presence of fair to high-quality conditions **(Karr *et al*., 1986; De Freitas *et al*., 2013)**. The existence and distribution of sensitive fishes during the study period was abundant for a few species. The species *Carasobarbus luteus* dominated, comprising 81.74% of the individuals of this metric. We should point out that *Garra rufa* is a benthic, sensitive species that hides between rocks and plants, and it was caught once in the study period, suggesting that it is an indicator of the environmental conditions in the study region. *Planiliza abu* is a native fish species that is highly tolerant to human-caused degradation. **Wahab (1986)** pointed out the ability of the species to adapt to the environmental conditions and their high resistance to changes. This species was the second most abundant, making up 37.27% of the native species, followed by the sensitive *Carasobarbus luteus* fish; this suggests that the quality of the stream water is improving. Exotic species threaten the ecosystems that they invade and all attempts to limit their abundance have failed **(Pofuk *et al*., 2017)**. *Oreochromis niloticus* dominated this group, with making up 27.73% of the caught samples and 34.27% of the exotic species, whereas all exotic species formed 80.92% of the numerical abundance of caught samples. The indices indicate that exotic species can change the behavior of the native species when they are numerically dominant or more aggressive than native species, and that change of behavior is correlated to the decrease of growth rate due to competition between species **(Cucherousset & Olden, 2011)**. Trophic group refers to the dynamics of fishes nutrition based on adult nutrition patterns, reflecting distances in the patterns of production and consumption of the expected power resulting from changes in water quality **(Hughes & Oberdorff, 1998)**. Results showed dominance by the herbivore species, which made up 53.9% of caught fish. This metric is considered important because it is in the base of the food pyramid and represents the beginning of trophic energy flow. In addition to its role in increasing the index value, all the individuals of the exotic species that dominated before of them overcame in their numerical abundance to dominate the energy flow and food chain. The metric of carnivore species included the species preying on fish, vertebrates or large invertebrates. This metric compares the properties of high and fair quality waters, and tends to decrease with environmental degradation. The percentage of that metric reached 5.99%, with the presence of top aquatic predators such as L. vorax, S. triostegus, M. mastacembelus indicating the existence of balanced and healthy nutrition levels **(Langdon, 2001; Terra *et al*., 2016)**. The metric of omnivore species included species with diets consisting of 25% plants and 25% animal food. In addition, it is designed to measure the change in the food supply from the invertebrate dominance to plant and detritus dominance; individuals of this group tend to increase under degraded conditions **(Hughes & Oberdorf, 1998)**; here, the group made up 34.27% of the area nutrition composition. The lowest rates of nutritional composition were 5.84% detritivores species; an increase in this metric, proposed by

Karr (1981), is considered an an indicator of environmental degradation, and that it is necessary to evaluate food availability in the ecosystem. Omnivores dominate at polluted sites because they use multiple types of food to survive. Toxic materials also accumulate in their bodies via bio magnification by way of this multi-food network **(Pinto & Araujo, 2007; De Carvalho *et al*., 2017)**. The reference case suggested by **Karr (1981)** requires comparison of the results of this study with those of historical studies for the same river. The value of IBI reached 67.8% in the study of **Hussian *et al*. (1989)**, and the river environment was described as in fair condition. It was valued at 44.8% in the later study of **Hussian *et al*. (1995)**. The lowest value of IBI was recorded in the study of **Younis (2005)** who described the conditions as very poor at 18.1%; the study area recovered its acceptable condition in the study of **Mohamed *et al*. (2012)**, reaching 53.8%. Finally, the study of **Yaseen *et al*. (2018)** reached 45.23% and was valued to be at a moderate environment level. The current study reached 50.52%. PCA provides information about the most meaningful factors that describe the full data set. To summarize data shown in Table and Fig. (4 & 5), respectively, there were 10.5 metrics from the origin of twelve, more effective on the IBI index values, and the least effective metrics were sensitive species % and the carnivores species %. The highest responses for the metrics were recorded in August, September, December, January, November, and July in proportions of 20.7, 19.8, 19.3, 14.1, 12.6, and 11.2%, respectively, that means through summer and winter.

CONCLUSION

From this study, it can concluded that, the environment is moderate, but the exotic species is still an environmental obstacle upon reflecting the deterioration of water quality due to their tolerance which is higher than that of the endemic species, and subsequently more environmentally tolerant species prevail. Hence, there are environmental pressures that must be fixed.

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