Journal of Advanced Applied Scientific Research
K. Kadharsha, JOAASR-Vol-4-5-December-2022:50-63 ISSN(O): 2454-3225

# Fish as bio-indicator tool for assessing estuarine health

K. Kadharsha[2]*, Job Paul[1], S. Ajmal Khan[1], P.S. Lyla[1], Bryan Raveen Nelson[3], Akbar John[4]

[1] Centre of Advanced Study in Marine Biology, Annamalai University, Parangipettai, Tamil Nadu, India
[2]P.G & Research Department of Zoology, C. Abdul Hakeem College (Autonomous) Melvisharam, Affiliated to Thiruvalluvar University, Tamil Nadu, India.
[3]Institute of Tropical Biodiversity and Sustainable Development, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia.
[4]Institute of Oceanography and Maritime Studies (INOCEM), Kulliyyah of Science, International Islamic University Malaysia (IIUM), Kuantan 25200, Pahang Malaysia.

***Corresponding author email:** kadharsha87@gmail.com

## ABSTRACT

Fish Health Index and Index of Biotic Integrity directly indicates environmental health and was used in our monitoring at Coleroon, Vellar and Uppanar, estuaries in the southeast coast of India. The use of cast nets revealed 104 species of fish that belongs to 69 genera, 44 families and 10 orders. Assessment using fish health index at Coleroon, Vellar and Uppanar estuaries produced scores of 4.8692, 8.4981 and 1.4042 which means Vellar has better health than Coleroon and Uppanar. In addition, 12 metrics were used to produce the index of biotic integrity where total scores varied from 18 to 51. With Vellar achieving higher scores than Coleroon and Uppanar estuary, a Two-way ANOVA was employed to validate the data with significant achievement ($P<0.005$). Therefore, we can safely associate Coleroon, Vellar and Uppanar with 'Fair', 'Good' and 'Very poor' grades. Also, visual depiction of Vellar demarcates it as pristine in comparison to Coleroon and Uppanar that are subject to impairments along with dominance of omnivorous fishes. Knowledge from this study eases monitoring of important estuaries particularly for food security so that management sustains community livelihood.

**KEYWORDS:** Ecology, diversity, fisheries, food security, management, resource

## 1. INTRODUCTION

Estuaries are an important intermediary water bodies for fisheries that lay between freshwater and marine habitats [1,2] that traps both, autochthonous and allochthonous materials for its productivity [3,4]. While leaching and run-off into rivers make estuaries a 'sink' for fluvial discharges, chemical fluctuations in estuaries make this ecosystem harsh while serving as pathway for fishing, transport, tourism in coastal areas. Moreover, the change in landscape and river morphology from upstream fluvial discharges make estuaries vulnerable to physical alterations that can impact downstream aquatic life [5-9]. Over the last decade, water quality *vis-à-vis* biological indicators were evaluated together for better assessments on environmental stressors towards biological systems [10,11]. While organisms are reliable tools, it must be readily present, easy to acquire and have relationship with the assessed area so that interpretations indicate the ecosystem health [12-14]. Fish are sensitive indicators to environment change because their homeostasis are influenced by external environments (water

and sediment) and the type of organisms they interact [15]. Therefore, our objective is to evaluate the health of estuaries in India using Fish Health Index (FHI) and Index for Biotic Integrity (IBI). We learnt about the accuracy of both indices to determine fish wellbeing by the valuation of their interaction with abiotic components [16,17]. While estuaries like Coleroon and Vellar were evaluated for their environment health [18], only Uppanar [19-21] was evaluated using fish and benthic organisms as biological indicators for environment health but, their findings focused conditions that exceeds ambience (heavy metals, pH, dissolved oxygen and ammonia) or nutritional composition (protein, lipid, and carbohydrate composition) rather than establishing baseline relationships for total environment (abiotic and biotic) evaluation.

## 2. MATERIALS AND METHODS

### 2.1 Study area description

The three estuaries namely Coleroon (latitude 11˚21' N; longitude 79˚49' E, Vellar (latitude 11º 29'N; longitude, 79º 46'E) and Uppanar (latitude, 11º42'N; longitude, 79º 49' E) are situated in the Southeast coast of India (Figure 1). The Coleroon estuary represents the downstream section where Cauvery river mouth is used as flood water outlet. It ends at the Bay of Bengal in the northern region of Nagapattinam district in Tamil Nadu. This estuary has year-round connection with Bay of Bengal and receives freshwater inflow during the northeast monsoon and the southwest monsoon. The river Vellar debouches into the Bay of Bengal as Vellar estuary at the Parangipettai coast after flowing over about 480 km from the Servarayan Hills in Salem district, Tamil Nadu, India. This is a true estuary with fragmented mangrove patches and supports as nursery for numerous fins and shellfishes. The Uppanar estuary is situated near Cuddalore coast and ends at the Bay of Bengal at Thaikkal Thonithurai, a small coastal village where State Industries Promotion Corporation of Tamil Nadu industrial cluster comprising fifty chemical and pharmaceutical units are located. Among them more than ten industries are handling hazardous chemicals like sulphuric acid, hydrochloric acid, chromic acid, ethyl acetate, ammonium fluoride, diethyl ether, CPC blue, hydroquinone, caustic soda, mono chlorobenzene and chlorine. Almost all the industries situated along this stretch release their treated water into the Uppanar estuary.

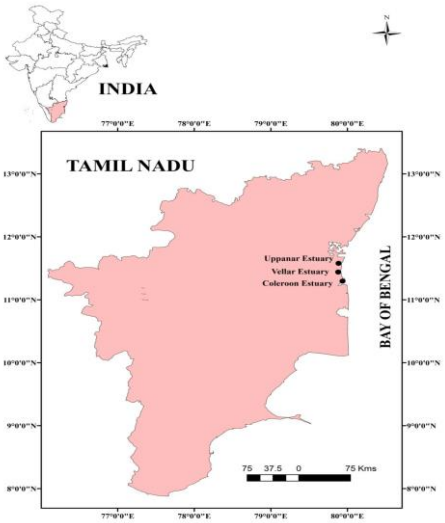


**Fig. 1.** Map showing the three estuaries (Coleroon, Vellar and Uppanar estuaries)

### 2.2 Sampling design

Bi-monthly sampling was carried out for 8 months (June 2016 to January 2017) at Coleroon, Vellar and Uppanar estuaries. At each site, five fixed (bearings recorded using handheld GPS - Garmin, USA) finfish sample collection points with 100 m distance between each points (total distance of 500 m) were visited by researchers and fishermen where cast nets (5.5 inch mesh size) were used to trap fish. We dedicated a total of 2 hours per site with soaking time of 1-2 minutes per net. All fish were identified using FAO species identification sheets (Fishing areas 51 and 57) before counting their abundance.

**2.3 Data analysis**

The Fish Health Index with scores ranging from 0 (poor) to 10 (good) is adopted from Cooper et al. (1993) through the following:

$$FHI = 10(J)[Ln(P) / Ln(P_{max})]$$

Where,

J = Number of species in system divided by number of species in reference community

P = Number of species in reference community

$P_{max}$ = Maximum number of species from all reference communities.

A total of 12 metrics were used to produce the index of biotic integrity (Table 1) which was adopted from Harris (1995). The score range for each metric is 1-5 where sum of scores indicate the health of each site. We adopted the score scale of Karr et al. (1981; 1986) along with the following classifications: excellent (58-60), good (48-52), fair (40-44), poor (28-34) and very poor (12-22) and 'no fish' when samples are unavailable. A two-way analysis of variance is employed to validate scores by the indices using SPSS v.16. In addition, performance of metrics were examined with Principal Component Analysis (Primer v.6.1) whereby correlation of each (from the twelve) metrics are compared with their own factors (as variance) for each of the principal components.

**Table 1.** Fish community metrics used to calculate Index of Biotic Integrity for Coleroon, Vellar and Uppanar estuaries

| Category | Metrics | Scores and criteria | | |
|---|---|---|---|---|
| | | 5 | 3 | 1 |
| **Species richness & composition** | 1.Total number of native species | Expectations for metrics 1-5 vary with stream size and region | | |
| | 2.Number of benthic species in impaired area | | | |
| | 3.Number of benthic species | | | |
| | 4.Number of pelagic species | | | |
| | 5.Number of intolerant species | | | |
| | 6.Percent of native fish individuals | >67% | 33-67% | <33% |
| | 7.Percent native species | >67% | 33-67% | <33% |
| **Trophic composition** | 8.Proportion of individuals as microphagic omnivores | <33% | 33-67% | >67% |
| | 9. Proportion of individuals as microphagic carnivores | >67% | 33-67% | <33% |
| | 10. Proportion of individuals as macrophagic carnivores | >10% | 3-10% | <3% |
| **Fish abundance & condition** | 11. Number of individuals in sample | Expectations for metrics 1-5 vary with stream size and region | | |
| | 12. Proportion of individuals with abnormalities | 0-2% | 2-5% | >5% |

## 3. RESULTS

### 3.1 Fish abundance

Fish recovered in this study belong to 69 genera, 44 families and 10 orders (Table 2) with the fish health index; site-wise species breakdown of 4.87; 58 (Coleroon), 8.50; 91 (Vellar) and 1.40; 22 (Uppanar). From the total of 104 different fish species, we classified 60 fish species from orders Clupeiformes (17 species), Mugiliformes (8 species), Siluriformes (5 species), Cypriniformes (4 species) and Pleuronectiformes (3 species) with dominant counts. Other orders namely Elopiformes, Beloniformes and Anguilliformes were represented by 2 species each whereas Gonorynchiformes was represented by 1 species. The family group Mugilidae and Carngidae were dominant with 8 species each followed by Engraulidae (7 species), Clupeidae (6 species), Leiognathidae (5 species), Gerreidae (5 species), Ambassidae (4 species) and Ariidae (3 species).

**Table 2.** Checklist of species recorded from Coleroon, Vellar and Uppanar estuaries (+ - present; - absent)

| S. No | Species | Coleroon | Vellar | Uppanar |
|---|---|---|---|---|
| **1** | *Elops machnata* | + | + | - |
| **2** | *Megalops cyprinoides* | + | + | - |
| **3** | *Chanos chanos* | + | + | - |
| **4** | *Cynoglossus arel* | + | - | - |
| **5** | *Cynoglossus lida* | - | + | - |
| **6** | *Cynoglossus puncticeps* | + | + | - |
| **7** | *Arius maculatus* | - | - | + |
| **8** | *Arius subrostratus* | + | + | - |
| **9** | *Arius arius* | + | + | - |
| **10** | *Wallago attu* | - | + | - |
| **11** | *Plotosus canius* | + | + | - |
| **12** | *Hemiramphus far* | + | + | - |
| **13** | *Hemiramphus limbatus* | - | + | - |
| **14** | *Conger cinereus* | + | - | - |
| **15** | *Anguilla bicolor bicolor* | - | + | - |
| **16** | *Mugil cephalus* | + | + | + |
| **17** | *Chelon parsia* | + | + | + |
| **18** | *Chelon tade* | + | - | - |
| **19** | *Chelon planiceps* | - | + | + |
| **20** | *Chelon macrolepis* | + | + | - |
| **21** | *Chelon subviridis* | + | + | + |
| **22** | *Moolgarda seheli* | + | - | - |
| **23** | *Valamugil cunnesius* | - | + | - |
| **24** | *Catla catla* | - | + | - |
| **25** | *Labeo rohita* | - | + | - |
| **26** | *Cirrihinus mrigala* | - | + | - |
| **27** | *Cyprinus carpio* | - | + | - |
| **28** | *Nematalosa nasus* | + | + | - |
| **29** | *Sardinella fimbriata* | + | + | - |

| | | | | |
|---|---|---|---|---|
| **30** | *Sardinella longiceps* | + | + | - |
| **31** | *Sardinella sindensis* | - | + | - |
| **32** | *Escualosa thoracata* | + | + | - |
| **33** | *Hilsa kelee* | + | + | - |
| **34** | *Anodontostoma chacunda* | - | + | - |
| **35** | *Stolephorus commmersonnii* | + | + | + |
| **36** | *Thryssa dussumieri* | + | + | - |
| **37** | *Thryssa malabarica* | + | + | - |
| **38** | *Thryssa mystax* | + | + | - |
| **39** | *Thryssa vitrirostris* | + | + | - |
| **40** | *Coilia dussumieri* | + | + | - |
| **41** | *Setipinna taty* | - | + | - |
| **42** | *Opisthopterus tardoore* | - | + | - |
| **43** | *Ilisha kampeni* | + | + | - |
| **44** | *Ilisha melastoma* | - | + | - |
| **45** | *Oreochromis mossambicus* | - | + | - |
| **46** | *Etroplus suratensis* | + | + | - |
| **47** | *Lates calcarifer* | + | + | - |
| **48** | *Scatophagus argus* | + | + | - |
| **49** | *Siganus canaliculatus* | + | + | + |
| **50** | *Siganus javus* | + | + | - |
| **51** | *Eleutheronema tetradactylum* | + | + | - |
| **52** | *Sphyraena obtusata* | - | - | + |
| **53** | *Sphyraena barracuda* | - | + | - |
| **54** | *Sphyraena jello* | + | + | - |
| **55** | *Scomberomorus commerson* | - | + | - |
| **56** | *Pampus chinensis* | - | + | - |
| **57** | *Ambassis bleekeri* | - | - | + |
| **58** | *Ambassis gymnocephalus* | - | + | + |
| **59** | *Ambassis ambassis* | + | + | - |
| **60** | *Ambassis nalua* | - | - | + |
| **61** | *Epinephelus tauvina* | + | + | - |
| **62** | *Epinehelus bleekeri* | + | - | - |
| **63** | *Apogonichthyoides niger* | - | + | - |
| **64** | *Sillago sihama* | + | + | + |
| **65** | *Alectis ciliaris* | + | + | - |
| **66** | *Alectis indicus* | + | + | - |
| **67** | *Carangoides malabaricus* | + | + | - |
| **68** | *Alepes kleinii* | - | + | - |
| **69** | *Caranx ignobilis* | - | + | - |
| **70** | *Caranx heberi* | - | + | - |
| **71** | *Caranx sexfasciatus* | + | + | - |

| | | | | |
|---|---|---|---|---|
| **72** | *Scomberoides tol* | + | + | - |
| **73** | *Parastromateus niger* | - | + | - |
| **74** | *Lutjanus argentimaculatus* | + | + | - |
| **75** | *Lutjanus fulviflamma* | + | + | - |
| **76** | *Lutjanus johnii* | - | + | + |
| **77** | *Lutjanus russellii* | - | + | + |
| **78** | *Secutor ruconius* | - | + | + |
| **79** | *Secutor insidiator* | + | + | - |
| **80** | *Eubleekeria splendens* | + | + | - |
| **81** | *Leiognathus equulus* | + | + | - |
| **82** | *Photopectoralis bindus* | + | + | + |
| **83** | *Lethrinus nebulosus* | - | + | - |
| **84** | *Pomadasys kaakan* | + | + | + |
| **85** | *Pomadasys maculatum* | + | + | + |
| **86** | *Gerres filamentosus* | + | + | - |
| **87** | *Gerres abbreviatus* | + | - | - |
| **88** | *Gerres erythrourus* | - | + | + |
| **89** | *Gerres metheuni* | - | + | - |
| **90** | *Gerres limbatus* | - | + | - |
| **91** | *Lobotes surinamensis* | - | + | - |
| **92** | *Drepane punctata* | + | + | - |
| **93** | *Upeneus sulphureus* | - | + | - |
| **94** | *Kathala axillaris* | - | + | + |
| **95** | *Johnius carutta* | - | + | - |
| **96** | *Dendrophysa russelli* | - | + | - |
| **97** | *Terapon puta* | + | + | - |
| **98** | *Terapon jarbua* | + | + | - |
| **99** | *Acanthurus mata* | - | + | - |
| **100** | *Acanthocepola abbreviata* | - | + | - |
| **101** | *Platycephalus indicus* | + | - | - |
| **102** | *Acanthogobius fulvimanus* | - | - | + |
| **103** | *Butis butis* | - | - | + |
| **104** | *Anabas testidunes* | - | + | - |

### 3.2 Assessment using indices

The minimum score of 1 was obtained by metric 7 and the maximum score of 5 was for metrics 2, 3,10 and 11 for Coleroon estuary which means this estuary recorded a total score of 42 that denotes its condition as 'Fair' (Figure 2; Table 3). In comparison, maximum score of 5 was attained at Vellar estuary using the following five metrics 1, 2, 3, 10 and 12 while the score of 3 was recorded for metrics 5 and 8. These give rise to a total score of 51 that considers Vellar estuary as 'Good'. On the contrary, metrics of Uppanar estuary varied where the score 1 were produced by metrics 1, 4, 5, 6, 7, 8 and 9 while the score of 3 was produced by metric 10. By

producing a total score of 18 at Uppanar estuary, status of its ecology is classified as 'Very poor' (Table 3). We validated the scoring metrics with every estuary ($F=65.32$; $df=2$; $P<0.005$) and its scoring indicators ($F=54.08$; $df=11$; $P<0.005$) to produce 95.8 % variance between each of the scoring metrics (Figure 3).

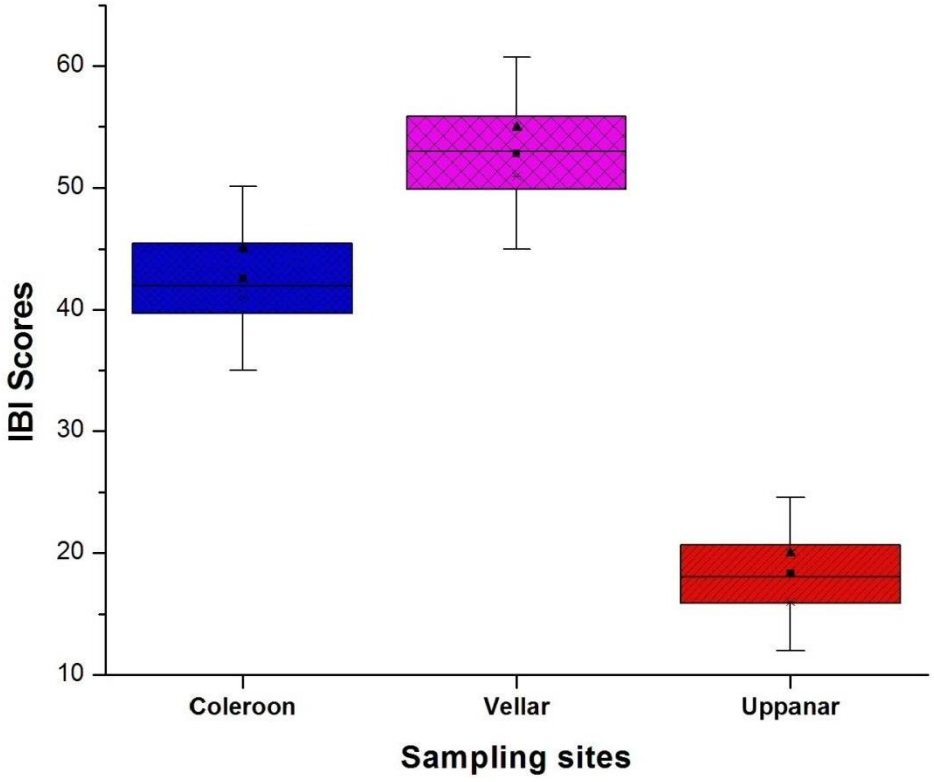


**Fig. 2. IBI score of three estuaries obtained from 13 metrics**

**Table 3. IBI metric score for Coleroon, Vellar and Uppanar estuaries**

| S. No | Metrics | Coleroon | Vellar | Uppanar |
|---|---|---|---|---|
| 1 | Total no of native species | 3 | 5 | 1 |
| 2 | No. of benthic species in impaired area | 5 | 5 | 2 |
| 3 | No. of benthic species | 5 | 5 | 2 |
| 4 | No. of pelagic species | 3 | 4 | 1 |
| 5 | No. of intolerant species | 2 | 3 | 1 |
| 6 | Percent of native fish individuals | 3 | 4 | 1 |
| 7 | Percent native species | 1 | 4 | 1 |
| 8 | Proportion of individuals as microphagic omnivores | 3 | 3 | 1 |
| 9 | Proportion of individuals as microphagic carnivores | 3 | 4 | 1 |
| 10 | Proportion of individuals as macrophagic carnivores | 5 | 5 | 3 |
| 11 | Number of individuals in sample | 5 | 4 | 2 |

| | | | | |
|---|---|---|---|---|
| 12 | Proportion of individuals with abnormalities | 4 | 5 | 2 |
| | **Total** | **42** | **51** | **18** |

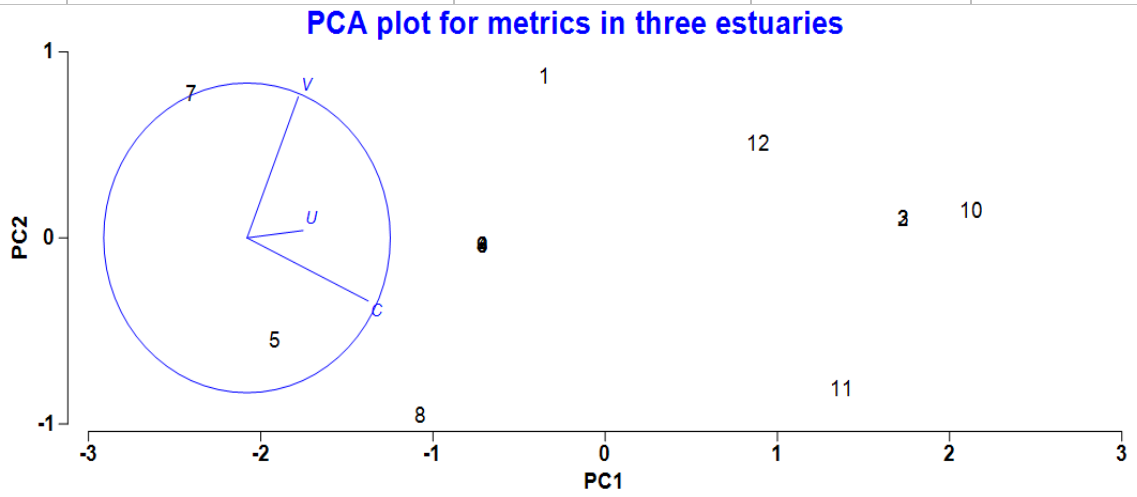


**Fig. 3. PCA plot for the metrics of three estuaries (C-Coleroon, V-Vellar, U- Uppanar)**

## 4. DISCUSSION

### 4.1 Ecological monitoring

We utilize fish spatial abundance, feeding habits and diversity to evaluate the health of three estuaries in the Southeast coast of India. However, the use of organisms to evaluate habitat conditions are reserved to pollution and gene hybridization [11,15] which means, studies that use species richness and fish biology limit their findings towards their populations and spatial-temporal occupancies [22-24]. Our findings acknowledge workers who used the combination of (a)biotic factors to derive relationships [25,3,10,1] and in need for conservation [5,6,14,22] but, insist that species occurrence in terms of abundance and diversity are directly related to carrying capacity of the water body.

Since the indices (biotic integrity and fish health) requires assessment of fish life stages (adult, juvenile and fingerling), feeding guilds (omnivore, herbivore, insectivore, planktivore, piscivore and carnivore), dwelling zones (nektonic, planktonic and benthic), morphology, taxonomic identification, size class, health and their sensitivity to ecological changes [26-28], we believe our findings completely covered on the fish's trophic interaction in Coleroon, Uppanar and Vellar estuaries. Fish health index revealed that one or more fish clustering in all three estuaries relates with resource availability and water quality. This hinders the need for sophisticated equipment [29,30], chemicals, handling and killing of test subjects [14,8,9] and also specific expertise [31,32,2,33] when intentions are limited to assessment of water quality for a water body.

### 4.2 Environment assessment using indices

Our study employs 12 metrics related to fish species richness and composition, trophic composition and fish abundance and water condition to assess the ecological statuses of three major estuaries in India. In fact, biotic integrity index was applied to assess four rivers in Australia [12] because it demands for information on function, fish hierarchy in the wild and also on fish diversity [34] (Franco et al., 2008) in their habitat [35,36]. Our study compared fish composition and richness as well as their dwelling zones in the water column, a practice identical with [37] for large lakes and [38] for nektonic and benthic in Malta estuary. With this, we recorded maximum scores for benthic fish in Vellar and Coleroon estuaries whereas for Uppanar, the estuary is dominated by nektonic fish. The different dwelling zones by fish in the present study associate with degradation (habitat loss) because the metric score of 4 was never maximum in Vellar, Uppanar and Coleroon estuaries. For instance, rivers having bottom waters colloid with sediments in Brazil are inhabitable to benthic fish [39] and also, nektonic fish actively swim in the water column and their schooling in groups reflects on favourable water quality in the area [40].

Our study evaluated Vellar, Uppanar and Coleroon estuaries with fish feeding guilds because it reflects on trophic patterns and nutrient sources [41] in these estuaries after considering the relationship between omnivore abundance and food source availability [42,43]. Uppanar estuary was given a score of 1 while Vellar and Coleroon estuaries received a score of 3 for metric 8. Lower scores in metric 8 would mean omnivorous species (%) are plenty (>80 %) or, the fish are very small (<1 %) because food chains are disturbed by the absence of carnivore species [44]. We treat the presence of carnivorous fish as an indicator of higher trophic network within an estuary and this is evident in Vellar and Coleroon estuaries that were scored 3 for metrics 9 and 10. Hence, we view Uppanar estuary achieving a total score of 18 which graded the water body as very poor health. The 22 species of fish (omnivore species: *Ambassis gymnocephalus*, *A. nalua* and *A. bleekeri*) occupying Uppanar estuary are highly specialized, opportunistic (*c.f. Prionospio* cirrobranchiata) and tolerant to an extremely polluted environment [45] alike the pollution of water bodies in New South Wales, Australia [12].

## 5. CONCLUSION

Biotic integrity assessment construes the ecological quality of Coleroon, Vellar and Uppanar with respective depictions of ‘Fair’, ‘Good’ and ‘Very poor’. Comparatively, fish health index rates fish species richness as evaluation of water quality whereby lower scores would mean the low richness of species. In view of the inherent advantages after ANOVA and Principal Component Analysis validation, both indices are non-invasive and can be used to swiftly assess the health of estuarine and river ecosystems in any region around the world.

## ACKNOWLEDGEMENT

The authors are thankful to the Dean and Director of the Centre for the encouragement, to the Authorities of Annamalai University for the facilities. The financial support by the Centre for Marine Living Resources and Ecology (CMLRE), Ministry of Earth Sciences (MoES), Government of India is gratefully acknowledged.

## CONFLICT OF INTEREST

The authors have no conflict of interest in developing the manuscript.

## REFERENCES

[1]. John BA, Nelson BR, Sheikh HI, Cheung SG, Wardiatno Y, Dash BP, Tsuchiya K, Iwasaki Y. Pati S, (2018). A review on fisheries and conservation status of Asian horseshoe crabs. Biodivers. Conserv. 27(14): 3573-3598. (https://doi.org/10.1007/s10531-018-1633-8)

[2]. Nelson BR, Zhong JMH, Zauki NAM, Satyanarayana B, Chowdhury AJK. (2019). Effects of shore sedimentation to *Tachypleus gigas* (Müller, 1785) spawning activity from Malaysian waters. J. Sustain. Sci. Manag. 14(1): 41-60. (Project: FRGS/1/2015/SG03/UMT/02/1)

[3]. Kennish MJ. (2002). Environmental threats and environmental future of estuaries. Environ Conserv. 29: 78-107. (DOI:10.1017/S0376892902000061)

[4]. Svensson CJ, Hyndes GA, Lavery PS. (2007). Food web analysis in two permanently open temperate estuaries: Consequences of saltmarsh loss? Mar. Env. Res. 64: 286-304. (DOI: 10.1016/j.marenvres.2007.02.002)

[5]. Nelson BR, Satyanarayana B, Zhong JMH, Shaharom F, Sukumaran M, Chatterji A. (2015). Episodic human activities and seasonal impacts on the *Tachypleus gigas* (Müller, 1785) population at Tanjung Selangor in Peninsular Malaysia. Estuar. Coast. Shelf Sci. 164: 313-323 (https://doi.org/10.1016/j.ecss.2015.08.003).

[6]. Nelson BR, Satyanarayana B, Moh JHZ, Ikhwanuddin M, Chatterji A, Shaharom F. (2016a). The final spawning ground of *Tachypleus gigas* (Müller, 1785) on the east Peninsular Malaysia is at risk: a call for action. Peer J. 4: e2232. (doi: 10.7717/peerj.2232)

[7]. Nelson BR, Satyanarayana B, Moh JH, Shaharom F, (2016b). Does human infringement at the spawning grounds challenge horseshoe crab eggs and their embryogenesis. J. Sustain. Sci. Manag. Special Issue 1: 1-10.

[8]. Zauki NAM, Satyanarayana B, Fairuz-Fozi N, Nelson BR, Martin MB, Akbar-John B, Chowdhury AJK. (2019a). Citizen science frontiers horseshoe crab population regain at their spawning beach in East Peninsular Malaysia. J. Env. Manag. 232: 1012-1020. (https://doi.org/10.1016/j.jenvman.2018.12.002)

[9]. Zauki NAM, Satyanarayana B, Fairuz-Fozi N, Nelson BR, Martin MB, Akbar-John B, Chowdhury AJK. (2019b). Horseshoe crab bio-ecological data from Balok, East coast Peninsular Malaysia. Data In Brief. 22: 458-463.(DOI: 10.1016/j.dib.2018.12.027)

[10]. Borja A, Dauer DM. (2008). Assessing the environmental quality status in estuarine and coastal systems: comparing methodologies and indices. Ecol. Indic. 8: 331-337. (https://doi.org/10.1016/j.ecolind.2007.05.004)

[11]. Shaari H, Raven B, Sultan K, Mohammad Y, Yunus K. (2016). Status of Heavy Metals Concentrations in Oysters (*Crassostrea* sp.) from Setiu Wetlands, Terengganu, Malaysia. Sains Malaysiana. 45(3): 417-424.

[12]. Harris JH, Silveira R. (1999). Large-scale assessments of river health using an Index of biotic Integrity with low-diversity fish communities. Freshw. Biol. 41: 235-252. (DOI:10.1046/j.1365-2427.1999.00428.x)

[13]. Jorgensen SE, Xu FL, Constanza R. (2010). Handbook of ecological indicators for assessment of ecosystem health (Eds.), CRC Press, London, pp. 484. (https://doi.org/10.1201/EBK1439809365)

[14]. Fairuz-Fozi N, Satyanarayana B, Zauki NAM, Muslim AM, Husain ML, Ibrahim S,Nelson BR. (2018). *Carcinoscorpius rotundicauda* (Latreille, 1802) population status and spawning behaviour at Pendas coast, Peninsular Malaysia. Global Ecology and Conservation. 15: e00422.(https://doi.org/10.1016/j.gecco.2018.e00422)

[15]. Jaffar M, Yunus NM, Nelson BR. (2019). Regional tinfoil barb imports can alter its native species genetic makeup. J. Sustain. Sci. Manag. 14(6): 51-65.

[16]. Blazer VS, Walsh HL, Braham RP, Smith C. (2018). Necropsy-based wild fish health assessment. J. Vis. Exp. *139*: e57946. (DOI: 10.3791/57946)

[17]. Cooper MJ, Lamberti GA, Moerke AH, Ruetz CR, Wilcox DA, Brady VJ, Brown TN, Ciborowski JJ, Gathman JP, Grabas GP, Johnson LB, Uzarski DG. (2018). An expanded fish-based index of biotic integrity for Great Lakes coastal wetlands. Environ. Monit. Assess., 190(10): 580-609. (DOI: 10.1007/s10661-018-6950-6)

[18]. Nethaji S, Kalaivanan R, Viswam A, & Jayaprakash M. (2017). Geochemical assessment of heavy metals pollution in surface sediments of Vellar and Coleroon estuaries, southeast coast of India. Mar. Pollut. Bul. 115(1-2): 469-479. (DOI: 10.1016/j.marpolbul.2016.11.045)

[19]. Jiyavudeen M, Puvaneswari S. (2016). A study on the effects of industrial effluents on the biochemical components of the fish *Mugil cephalus* in Uppanar estuary, southeast coast of India. Int. J. Mod. Res. Rev. 4(8): 1224-1227.

[20]. Nagendra R, Reddy AN. (2019). Benthic foraminifera response to ecosystem pollution in the Uppanar Estuary, Tamil Nadu Coast, India. J. Geol. Soc. India, 93(5): 555-566.
(DOI:10.1007/s12594-019-1217-6)

[21]. Sulieman HM, Suliman EAM. (2019). Appraisal of heavy metal levels in some marine organisms gathered from the Vellar and Uppanar estuaries Southeast Coast of Indian Ocean. J. Taibah Univ. Sci. 13(1): 338-343. (DOI:10.1080/16583655.2019.1576276)

[22]. Fakhrul-Hatta SNN, Nelson BR, Shafie NJ, Zahidin MA, Abdullah MT. (2018). Linkages between Chiropteran diversity and ecosystem services for sustainable fragmented forest conservation. Data In Brief. 21: 2089-2094. (https://doi.org/10.1016/j.dib.2018.11.058)

[23]. Khalib NKA, Shafie NJ, Basri HH, Nelson BR, Abdullah MT. (2018). Non-volant small mammal data from fragmented forests in Terengganu State. Data In Brief, 21: 1514-1520. (https://doi.org/10.1016/j.dib.2018.10.061)

[24]. Nelson BR, David G, Mokhtar AF, Mamat MA, Rahman AJA. (2018). Avian data from Kenyir rainforest trail. Data In Brief. 21: 2633-2637. (https://doi.org/10.1016/j.dib.2018.11.119)

[25]. Vannote RL, Minshall GW, Cummins KW, Sedell JR, Cushing CE. (1980). The river continuum concept. Can. J. Fish. Aquat. Sci. 37: 130-137. (https://cdnsciencepub.com/doi/abs/10.1139/f80-017)

[26]. Fausch KD, Lyon J, Karr JR, Angermeier PL. (1990). Fish communities as indicators of environmental degradation. Am. Fish. Soc. Symp. 8: 123-144.

[27]. Ganasan, V. & Hughes, R. M. (1998). Application of an index of biotic integrity (IBI) to fish assemblages of the rivers Khan and Kshipra (Madhya Pradesh), India. Freshw. Biol. 40: 367-383. (https://doi.org/10.1046/j.1365-2427.1998.00347.x)

[28]. Belpaire C, Smolders R, Auweele IVD, Ercken D, Breine J, Van Thuyne G, Ollevier F. (2000) An index of biotic integrity characterizing fish population and the ecological quality of Flandrian water bodies. Hydrobiol. 434: 17-33. (10.1023/A:1004026121254)

[29]. Karr, J. R. (1981). Assessment of biotic integrity using fish communities. *Fisheries, 6,* 21-27. (https://doi.org/10.1577/1548-8446(1981)006%3C0021:AOBIUF%3E2.0.CO;2)

[30]. Bonada N, Dallas H, Rieradevall M, Day J, Prat N. (2006). A comparison of rapid bioassessment protocols used in 2 regions with Mediterranean climates, the Iberian Peninsula and South Africa. J. North Am. Benthol. Soc. 25: 487-500. (DOI:10.1899/0887-3593(2006)25[487:ACORBP]2.0.CO;2)

[31]. John BA, Kamaruzzaman BY, Jalal KCA, Zaleha K. (2011). Hydrology of the horseshoe crab nesting grounds at Pahang coast, Malaysia. Orient. J. Chem. 27(4): 1475 - 1480.

[32]. Chatterji A, Mithun S, Muhd Haniff MY, Pradeep PJ, Srijaya TC, Bryan RN, Ali MM, Anuar H, Shaharoum-Harrison F. (2012). Diurnal variations in the physicochemical characteristics at Como region in a man-made reservoir, Kenyir Lake, Malaysia. Malaysian Fisheries Journal. 11(1): 1-10.

[33]. Nelson BR, Mamat MA, Cheeho W, Shahimi S. (2020). Forest birds as diversity indicator in suburban and residential areas. Ecofeminism and Climate Change. 1(1): 57-62. (https://doi.org/10.1108/EFCC-03-2020-0007)

[34]. Franco A, Elliott M, Franzoi P, Torricelli P. (2008). Life strategies of fishes in European estuaries: the functional guild approach. Mar. Ecol. Prog. Ser. 354: 219-228. (DOI:10.3354/meps07203)

[35]. Elliott M, Dewailly F. (1995). The structure and component of European estuarine fish assemblages. Neth. J. Aquat. Ecol. 29: 397-417. (https://doi.org/10.1007/BF02084239)

[36]. Mathieson S, Cattrijsse A, Costa MJ, Drake P, Elliott M, Gardner J, Marchand J. (2000). Fish assemblages of European tidal marshes: a comparison based on species, families and functional guilds. Mar. Ecol. Prog. Ser. 204: 225-242. (http://dx.doi.org/10.3354/meps204225)

[37]. Quinn JW, Kwak, T. J. (2003). Fish assemblage changes in an Ozark river after impoundment: a long-term perspective. Trans. Am. Fish. Soc. 132: 110-119.

[38]. Mukherjee S. (2013). Multiscale and multimetric study of fish metacommunity in an estuarine habitat and assessment of biotic integrity. Ph.D., Thesis, University of Calcutta, India, 302 p.

[39]. Bozzetti M. Schulz UH. (2004). An index of biotic integrity based on fish assemblages for subtropical streams for southern Brazil. Hydrobiol. 529: 133-144.(DOI:10.1007/s10750-004-5738-6)

[40]. Cassatti L, Ferreira CP, Langeani F. (2009). A fish-based biotic integrity index for assessment of lowland streams in south-eastern Brazil. Hydrobiol. 623: 173-189. (http://dx.doi.org/10.1007/s10750-008-9656-x)

[41]. Elliott M, Hemingway KL, Costello MJ, Duhamel S, Hostens K, Labropoulou M, Marshall S, Winkler H. (2002). Links between fish and other trophic levels. In *Fishes in estuaries* (Eds. Elliott, M. and Hemingway, L.), Oxford: Blackwell Science, pp. 124-216. (https://doi.org/10.1002/9780470995228.CH4)

[42]. Mikkelson GM. (1993). How do food webs fall apart? A study of changes in trophic structure during relaxation habitat fragments. Oikos, 67: 539-547.
[43]. Deegan LA, Finn JT, Ayvazian SG, Ryder-Kiefer CA, Buonaccorsi J. (1997). Development and validation of an estuarine biotic integrity index. *Estuaries, 20,* 601-617. (http://dx.doi.org/10.2307/1352618)
[44]. Borja A, Franco J, Muxika I. (2004). The biotic indices and the water framework directive: the required consensus in the new benthic monitoring tools. Mar. Pollut. Bul. 48: 405-408. (http://dx.doi.org/10.1016/j.marpolbul.2003.10.024)
[45]. Ajmal Khan S, Murugesan P, Lyla PS, Jaganathan S. (2004) A new indicator macro invertebrate of pollution and utility of graphical tools and diversity indices in pollution monitoring studies. Curr Sci. 87(11): 1508-1510.