Characterization of Fish Community Structure And Development of An Estuarine Fish Community Index For Temporarily Closed Estuaries (TCEs) From India's Western Coast

Kiranya Bella (✉ kiranya.kikry@gmail.com)

Kerala University of Fisheries and Ocean Studies <https://orcid.org/0000-0001-8596-6864>

Pramila Sahadevan

Kerala University of Fisheries and Ocean Studies

Sreekanth Giri Bhavan

ICAR Central Coastal Agricultural Research Institute

Appukkuttannair Bijukumar

KERALA UNIVERSITY, DEPARTMENT OF AQUATIC BIOLOGY AND FISHERIES

Rajeev Raghavan

Kerala University of Fisheries and Ocean Studies

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Abstract

We present for the first-time data on fish assemblage structure for ten temporarily closed estuaries (TCEs) along the western coast of India. Fish community structure differed significantly between TCEs based on species presence/absence, estuarine use and feeding mode - differences based on estuarine surface area and geographical position (northern and southern locations). Marine migrant and freshwater stragglers dominated the 'fish guilds' in all estuaries, while piscivores and zoobenthivores were the major feeding guilds. We used the estuarine fish community index (EFCI) and a combined anthropogenic pressure index (CPI) to determine ecological quality of the TCEs. The application of functional guilds and EFCI could represent the use of TCEs by fish communities, and functional similarities existing between fish assemblages of these estuaries, despite considerable taxonomic, physical and chemical differences. Analysis of EFCI indicated that the ecological health of TCEs in south-western India ranges from "poor" to "good". Through this index, we also established a significant relationship between CPI, EFCI and ecological quality in various TCEs ($EFCI = A + (b \times CPI)$). Thus, the EFCI provides an integrated measure of the ecological status of fish community for TCEs along Indian coast.

Introduction

Temporarily closed estuaries (TCEs) are microtidal estuarine systems, which remain open to the sea for a short period of time are very common in tropical region (Whitfield 1992; Elliott et al. 2007). TCEs are more variable and complicated ecosystems than permanently open estuaries due to the frequent alteration between open and closed mouth phases (Perissinotto et al. 2010; Human et al. 2016). The mouth state of TCEs is mainly driven by the interaction between sediment transport as a result of waves, tides or stream inflow (Harrison and Whitfield 2004; 2006). As a result of frequent variation in physico-chemical parameters, TCEs are more sensitive to changes in flow conditions caused by anthropogenic activities such as sewage effluent discharges (Lawrie et al. 2010). Mouth closure events associated with high river-flow cuts off tidal exchanges (i.e. the scouring force of high river flow which helps keep the mouth open) with the ocean, resulting in extended periods of conditions under which salinity and temperature stratification can develop, as well as in the depletion of oxygen and nutrients create considerable physiological demands of the fishes that occupy these systems (Whitfield, 1999).

The predominance of estuarine and estuarine-associated marine fish species (which caters for both dependant and non-dependent taxa) in TCEs is an indication of the important nursery function of these systems, as it serves as migration routes and refuge areas for a variety of fish species (Whitfield 1999; Elliott et al. 2002). Marine juvenile fish recruit into TCEs not only when the mouth opens, but also during marine overwash events when waves from the sea wash over the sand bar at the mouth (Cowley and Whitfield 2001; Whitfield and Bate 2007). The longer open mouth phase, together with the greater habitat variation in large TCEs, promotes high fish diversity within these systems (Vorwerk et al. 2003). Unfortunately, as a result of global change, TCEs are now undergoing rapid and critical changes that, in some cases, have already led to the loss, or the significant deterioration of their natural condition (Human et al. 2016). Land use and erosion in catchments, barriers, impoundments and uncontrolled water abstractions, mining operations, eutrophication, chemical pollution, overexploitation of both living and non-living resources, and alien invasive species are threatening the integrity of TCEs in the tropics (Human et al. 2016). Addressing the challenges facing sustainable management of TCEs is therefore critical, as in some cases the ecological integrity, biodiversity and nursery function of such estuarine systems have already been compromised (James et al. 2007).

The TCEs in India, particularly along the south west coast is poorly known with regard to their status, threats and fish community structure, except for a few preliminary studies (Bijukumar and Sushama 2000; Johny et al. 2016; and Kiranya et al. 2018), which are however restricted to a general description of spatial and temporal variations in species diversity, and mostly limited to a single estuary. No comprehensive studies have yet been undertaken to quantify fish assemblage structure, habitat quality and the influence of anthropogenic stressors on fish communities in these TCEs.

For many TCEs, the guild approach could represent a simple tool to define the extent of marine influence and freshwater discharge, and the estuarine fish community index (EFCI), a simple and composite index defined separately for permanently open, and temporarily closed estuaries can help determine the ecological quality of estuaries (Harrison and Whitfield 2004). In general, the guild approach is useful to determine functioning, hierarchical structure and connectivity and to simplify complex ecosystems (Dewailly 1995; Albaret et al. 2004; Garrison and Link 2000; Lobry et al. 2008; Franco et al. 2006). Guilds have a high value as a tool for understanding the functional structure of complex ecosystems such as estuaries (Garrison and Link 2000), especially about estuarine fish assemblage studies (e.g., Dewailly 1995). Such studies have been undertaken in estuaries of South Africa (Harrison and Whitefield 2006) and Europe (Dewailly 1995). Globally, the use of fish as an index for assessing the quality of transitional water bodies such as estuaries are well documented (Pérez-Dominguez et al. 2012). The fish-based multi-metric indices for monitoring the environmental quality was initially proposed by Karr (1981) Multi-metric indices are constructed from an array of fish ecological attributes and are therefore, considered to be superior to single metric assessments (Perez-Dominguez et al. 2010; Fonseca et al. 2013). In particular, these indices are considered to have greater relevance to different ecological regions (Fausch et al. 1990). The EFCI is a novel index for monitoring the status of ecological condition of the estuaries on the verge of deterioration from anthropogenic and natural pressures, as well it is also a tool to document the recovery of estuaries due to rehabilitation and restoration measures implemented by management authorities, (Roset 2007) due to the absence of rehabilitation or restoration activities in the selected TCEs, the EFCI could serve as a tool to evaluate the ecological condition of the same.

The aim of our study was to improve the knowledge of TCEs along the south west coast of India through fulfilling the following objectives 1) to delineate similarities/dissimilarities between fish guild (estuarine use and feeding mode) structure of TCEs, 2) to develop and compare EFCI and CPI to investigate the health status of TCEs and 3) to establish a relationship between the EFCI and anthropogenic stressors identified in TCEs. Overall, our results would help improve the management of poorly-known TCEs from India, which are important not only for food security and livelihoods, but also for a range of ecosystem services.

Material And Methods

2.1. Study area

Ten TCEs located along the south-western (Kerala) coast of India, Ponnani, Chettuva, Kodungallur-Azhikode (Northern region: between 10.1° and 10.7°N) and Vembanad (Central region: between 9.5° and 9.7°N), Veli-Akkulam, Kadinamkulam, Akathumuri, Anchuthengu, Poovar and Poonthura (Southern region: between 8.5° and 8.7°N) (Fig. 1) were selected for the study. The size, origin, depth, nature of the adjacent freshwater and marine habitat, ecological features of each estuaries were illustrated in Table 1. They have some form of narrow connection to the Arabian Sea, and also simultaneously receive freshwater input from adjacent river systems. In all these estuaries, tides are semi-diurnal and microtidal, with average tidal range between 1 to < 2m, except for the northern estuaries (Ponnani and Kodungallur-Azhikode), which are meso-tidal with an average tidal range between 2 to 3m. Proximity of these estuaries to urban settlements triggers various anthropogenic stressors in addition to large scale seasonal changes in their biotic and abiotic components (Coast et al. 2020). Many of these estuaries are ecologically important, and have international significance, especially the Vembanad estuary, which is designated as a Ramsar site (MoEFCC (2020)). Despite the variation between sampling sites, all TCEs included in this study are, by virtue of their location, relatively shallow and small except the Veli-Akkulam estuary.

Table 1
Details of estuaries covered in the present study

Name of estuary	District (in Kerala State)	Latitude	Longitude	Area (km ²)	Major fish groups	Source
PON Ponnani	Malappuram	10.767	75.974	9.08	Clupeids, anchovies, carangids, silver bellies, mullets, gobies	Bijukumar & Sushama, 2000
CHT Chettuva	Thrissur	10.537	76.051	7.14	Cichlids, groupers, mullets and clupeids	Johny et al., 2016
KOD Kodungallur-Azhikode	Thrissur	10.196	76.160	7	Cichlids, leiognathids and catfishes	Jayachandran et al., 2013
Vembanad	Cochin	9.613	76.402	96.5	Pearl spot, mullets, catfishes, clupeids and soles	Asha et al., 2014
VEL Veli-Akkulam	Thiruvananthapuram	8.510	76.888	135	Cichlids, catfishes, carangids and soles	Regi & Bijukumar, 2012
KAD Kadinamkulam	Thiruvananthapuram	8.620	76.816	3.47	Cichlids and mullets	Grace, 2014
AKA Akathumuri	Thiruvananthapuram	8.881	76.661	not known	Cichlids, catfishes, carangids and soles	Deepa et al., 2014
ANC Anchuthengu	Thiruvananthapuram	8.698	76.746	not known	Tarpons, clupeids and mullets	Raju Kumar, 2005
PT Poonthura	Thiruvananthapuram	8.426	76.957	0.97	Cichlids, mullets, catfishes and carangids	Kiranya et al., 2018
POV Poovar	Thiruvananthapuram	8.310	77.080	not known	Cichlids, mullets and catfishes	Premjith et al., 2017

2.2. Data collection and analysis

Relevant physiographic, biological and ecological information for the ten TCEs were gathered and presented in Appendix A and B. A master checklist was compiled by combining all the species observed from the ten TCEs using presence-absence data. For small coastal ecosystems such as estuaries, using fish guilds is more efficient than using taxonomic identities (Elliott et al. 2007) to analyse standard features of ecosystems and community functioning. Accordingly, for comparing the ecological structures of fish assemblages between estuaries, fish species were grouped into guilds based on their estuarine use and feeding mode as defined by Elliot et al. (2007), and Dewailly (1995). Guilds based on estuarine use comprised of estuarine resident species (ES), freshwater migrants (FM), marine migrants (MM), and marine stragglers (MS), anadromous (AN) and freshwater stragglers (FS) (see Appendix C for definitions). Feeding mode functional groups consisted of zoobenthivores (ZB), herbivores (HV), omnivores (OV), zooplanktivores (ZP), detritivores (DV) and piscivores (PV). Cluster analysis, using the Bray-Curtis similarity measure, was used for estimating similarity between estuarine fish assemblages based on species presence/absence, estuarine use guild and diet categorization guild. Software package Primer 6 was used for determining the similarity measure (Clarke and Warwick 2001).

2.2.1 Development of estuarine fish community index (EFCI)

1. Metric selection

A number of metrics were considered to develop the EFCI index, following standard methods applied for tropical estuaries (Seegert 2002; Harrison and Whitfield 2004). Harrison and Whitfield (2004) defined a total of 14 metrics to evaluate the estuarine integrity, which covers four broad fish community aspects, viz., (i) species diversity (ii) species abundance (iii) nursery function and (iv) trophic integrity. Description of these metrics is as follows: 1) species richness represents the number of fish fauna present in the ecosystem, 2) rare or threatened species is a measure of the number of rare or threatened species, 3) introduced species identifies the threat to native fish populations caused by non-native species (Harrison and Whitfield 2004), 4) species composition, a measure of the amount of similarity in the fish assemblage composition (Harrison and Whitfield 2004), 5) species relative abundance quantifies the relative proportion of species in a TCEs with a reference estuarine fish community, 6) number of species that make up 90% of the abundance is a measure of dominance, 7) number of estuarine resident species, 8) number of estuarine-dependent marine taxa quantifies how successfully an estuary fulfills its role as a nursery habitat, 9) relative abundance of estuarine resident species, 10) relative abundance of estuarine-dependent marine species (both 9 and 10 are complementary to quantitatively assess estuarine habitat quality and nursery function), 11) number of benthic invertebrate feeding fish taxa provides an indirect measure of the condition of benthic invertebrate fauna, 12) number of piscivorous taxa was included on the basis that diverse and abundant top carnivores are typically representative of the broader trophic network within estuaries (USEPA 1997), 13) percentage abundance of benthic invertebrate feeding fishes and 14) percentage abundance of piscivorous fishes (both 13 and 14 provides a quantitative, and complementary analysis of trophic integrity).

2. Reference conditions and metric calculation

Each metric varies in their measurement from numbers of taxa, to similarity values, and measures of abundance. To effectively combine these measurements into a single index, it is necessary to transform the metrics into standard scores. Each metric was allocated a discrete score between 1 and 5 according to degree of deviation from the reference (Appendix D). Metric scores and thresholds were established using a combination of a review of other metrics that vary in their measurement from numbers of taxa, to similarity values and measures of abundance. To effectively combine these various measurements into a single index, it is necessary to transform the metrics into standard scores. Each metric was therefore allocated a discrete score between 1 and 5 according to the degree of deviation from the reference. Metric scores and thresholds were established using literature from tropical estuaries (Lepage et al. 2016), and personal discussions with experts in estuarine research in the study region. Thresholds fixed for evaluating the habitat quality were (1) 0–40 = Poor condition, (2) 41–70 = Moderate condition, and (3) > 70 = Excellent condition.

2.2.2 Composite pressure index (CPI)

A simple composite pressure index (CPI) for an estuary was calculated as a summation of corresponding scores of various pressures. Scores were given based on the severity of anthropogenic pressure in each estuary. The following indicators were quantified: 1) habitat loss (including a percentage reduction in bathymetry and topography, 2) water pollution, including nutrient enrichment and eutrophication (in %), 3) destructive fishing and overexploitation, 4) climate change-induced pressures including extreme climatic events, 5) alien invasive species, 6) tourism and recreation, 7) barriers for fish migration, and 8) sand mining. The least score of 1 was given for those pressures that range from 10 to 30%, score 3 and 5 were allocated if these pressures were in the range of 30–60% and 60–90% respectively. Absence and presence of an individual pressure were scored 1 and 5, respectively. Thus, the anthropogenic pressures identified in different estuaries (a total of eight stressors) were scored on a scale ranging from 1 to 5 (pressure index). The CPI was estimated (statistically) to determine any significant relationship between EFCI and anthropogenic pressures. Final pressure index or the CPI was calculated for the entire TCEs as the sum of all indicator scores, and were within values of 0 (no disturbance) and 72 (very high disturbance). To determine the relationship between CPI and EFCI, Pearson correlation coefficient was used. A simple linear regression model was also fitted following the least square method using the formula,

$$EFCI = A + (b \times CPI) \dots \dots \dots (1)$$

Results

Taxonomic distribution

Total of 212 fish species within 64 families were recorded from the ten TCEs covered in this study (Appendix E). Of these, 126 species were reported from at least one of the ten estuaries, and 44 species were found exclusively in a single estuary (PON). Five species, *Etroplus suratensis*, *Pseudetroplus maculatus*, *Oreochromis mossambicus*, *Mugil cephalus*, and *Megalops cyprinoides*, were common in all the TCEs. Cichlidae, Ambassidae, Megalopidae, Mugilidae, and Carangidae were the common families recorded in all the estuaries, with the number of families ranging from 17 (in KAD) to 50 (in PON).

Taxonomic similarity

Similarity in taxonomic composition between estuaries was determined using binary (presence/absence) and quantitative (percentage composition) data. The NMDS plot revealed the presence of four distinct clusters (Fig. 2). Similarly, the analysis of species' presence/absence data based on cluster analysis showed a clear division into four separate groups of estuaries with a high level of dissimilarity between the groups (Fig. 3). First group comprised of two estuaries, PON and CHT (35% similarity in taxonomic composition), second cluster comprised of two estuaries (KOD and VEM), which were more similar in their species composition (55%), the third cluster comprised of three estuaries (AKA, POV and VEL (with 50% similarity) The fourth cluster included three estuaries, ANC, PT and KAD, where KAD and PT found more similar in species composition (60%), while ANC showed 45% similarity in taxonomic contribution.

Analysis of functional guilds

Estuarine use guilds

Contributions of estuarine use guilds varied between the estuaries (Fig. 4.A). Major guilds were MM (45.1%), ER (15.5 %), FS (18.8%), MS (14.8%) and FM (3.9%). The AN guild was absent in six estuaries (ANC, AKA, KOD, VEL and KAD) and shared least proportions (1.9%) to the fish community. Though the presence of FM guild was recorded in all estuaries, it contributed only to 3.8% of the fish assemblages. NMDS plot of estuarine use guild demonstrated a division into five clusters (Fig. 5), with ANC, AKA and POV forming the first cluster; KAD, VEL and PT the second cluster; and VEM and KOD forming the third cluster. Fourth and fifth clusters comprised of single estuary each, viz., CHT and PON.

Cluster analysis of estuarine use guilds demonstrated a clear division of estuaries into four groups with low dissimilarity (Fig. 6). First group comprised of three estuaries; KOD, CHT and VEM, all of which were relatively dissimilar within the group, the second cluster also included three estuaries, AKA, ANC and PT, which were similar in their ecological guild composition, the third cluster comprised of three estuaries; KAD, VEL and POV. A single estuary, PON formed the final cluster, which was dissimilar in guild composition compared to the other three clusters.

Feeding mode guilds

Relative proportions of feeding mode guilds varied among the estuaries (Fig. 4.B) - major guilds being PV (31.5%), ZB (24.6%), OV (16.8%), DV (11.4%), HV (9.5%) and ZP (6.3%). NMDS plot for feeding mode guilds revealed the presence of four clusters (Fig. 7). Estuaries POV, VEL, PT, ANC, AKA and KAD formed the first cluster and KOD and VEM comprised the second cluster. The third and fourth clusters consisted of single estuary each - CHT and PON, respectively. Cluster analysis of feeding mode guilds showed a clear division into four separate groups with high dissimilarity (Fig. 8). The first group consisted of four estuaries, CHT, KOD, VEM and AKA of which two viz., VEM and AKA were relatively similar within the group. Second cluster comprised of three estuaries, VEL, ANC and PT, which were identical in their feeding mode functional group distributions. Third cluster comprised of only two estuaries KAD and POV, while PON was the only estuary that was classified into the fourth cluster.

Analysis of habitat quality

EFCl was measured for defining the ecological quality of the ten TCEs considered in this study. Through this index, we established significant relationships between anthropogenic stressors and EFCl. In addition, scoring thresholds were also identified for each metric per estuary, representing significant variations with increasing stressors over time. Major anthropogenic factors and extent of each stressor, which influences the habitat quality of the TCEs of Kerala were also analyzed. In VEM, the major anthropogenic stressor was habitat loss (60–80%), in PON, destructive fishing and overexploitation contributed to 30–60% of the anthropogenic stressors, and in VEL, both habitat loss and water pollution were the major stressors (up to 60%). Barriers for fish migration was detected in CHT, KOD and VEM. Stressors such as tourism and recreation activities, and alien invasive species were observed in all TCEs. The pressure, from alien species invasion was highest in VEL. The composite pressure index (CPI) yielded a minimum score between 16 (KAD, ANC, POV, PT and AKA) and 24 (VEM) (Table 2). Estuaries along the northern coast had greater values of CPI than those along the southern coast. Simple regression analysis revealed that EFCl has a significant relationship with the pressure index ($R^2 = 0.31$) (Fig. 9). Based on EFCl, it was realized that three estuaries, PT, AKA and POV were in “moderate” state; Four estuaries, VEM, PON, CHT and KOD were under ‘good’ condition, while remaining three estuaries, ANC, VEL and KAD were in a “poor” state (Table 3).

Table 2

Description and values used to score anthropogenic pressures in the ten TCEs covered in the present study (codes as per Table 1).

Score	1	3	5	PON	CHT	KOD	VEM	VEL	KAD	AKA	ANC	PT	POV
Habitat loss (including reduction in bathymetry and topography (%))	10–30%	30–60%	< 60%	1	1	1	5	3	1	1	1	1	1
Water pollution, including nutrient enrichment and eutrophication (%)	10–30%	30–60%	< 60%	1	1	1	1	3	1	1	1	1	1
Destructive fishing and over exploitation (%)	10–30%	30–60%	< 60%	3	1	1	1	1	1	1	1	1	1
Climate change-induced pressures including extreme climatic events (%)	10–30%	30–60%	< 60%	1	1	1	1	1	1	1	1	1	1
Invasive Alien Species (%)	10–30%	30–60%	< 60%	1	1	1	1	3	1	1	1	1	1
Tourism and recreation	Absent		present	5	5	5	5	5	5	5	5	5	5
Barriers for fish migration	Absent	< 60% and ≥ 40%	present	1	5	5	5	1	1	1	1	1	1
Sand mining	Absent	< 13 and ≥ 8	present	5	5	5	5	5	5	5	5	5	5
Total score				18	20	20	24	22	16	16	16	16	16

Table 3
Description and values used to score estuarine fish community index (EFCI) and composite pressure index (CPI) from the ten TCEs

Name of Estuary	Rating	EFCI	CPI
Ponnani	Good	42	18
Chettuva	Good	54	20
Kodungallur-Azhikode	Poor	34	20
Vembanad	Good	44	24
Veli-Akkulam	Poor	52	22
Kadinamkulam	Poor	48	16
Akathumuri	Moderate	54	16
Anchuthengu	Poor	40	16
Poonthura	Moderate	38	16
Poovar	Moderate	36	16

Discussion

Studies on fish guild structure and ecological quality of TCEs estuaries are scarce in the tropics, and therefore the present study, helps bridge this knowledge gap. A major constraint of this study was data comparability, i.e., the underlying data use for the analysis were collected over different time scales by different authors and involved varying objectives, methodologies and analysis, all of which might act as potential sources of variability between the datasets. Therefore, to overcome the bias in data quality and quantity, we attempted to present the fish assemblage structure of TCEs by following a guild approach using estuarine use, and feeding mode, as indicators.

Species diversity in TCEs

Total of 212 species of fish were compiled from the TCEs of Kerala, with the number of species in individual TCEs ranged from 28 in Poovar to 112 in Ponnani. Of the 10 TCEs covered in this study, six (Poovar, Anchuthengu, Poonthura, Akathumuri, Kadinamkulam and Veli-Akkulam) were occupied by less than 50 fish species. These results are comparable with the observations (< 50 species/estuary) made in South Africa (Whitfield 1999) and in Portugal (Nyitrai et al. 2012). According to Vorwerk et al (2003) and Selleslagh and Amara (2008), TCEs had a much lower fish species richness and density in contrast to permanently open estuaries. Species richness in estuarine systems are known to be influenced by estuarine size, depth of the mouth, geographic location (Kok and Whitfield 1986, Franco et al. 2008, Nicolas et al. 2010), width of the estuarine mouth (Connor et al. 2019), and duration of the open mouth phase (Whitfield 1999; Bennett 2010; Kok and Whitfield 1986). Thus, it can be assumed that the low fish diversity observed in most TCEs studies might be due to one or a combination of the above reasons.

Mugilidae was the most speciose family ($S = 32$), likely due to its successful ability to recruit during over-wash conditions when the estuarine mouth is closed (Cowley and Whitfield 2001). Dominance, as well as numerical abundance of short-lived estuarine resident species (*E. suratensis* and *P. maculatus*), were evident in all TCEs of Kerala, a phenomenon reported earlier in other parts of the world (Potter et al. 1990), that of estuarine resident species adapting and dominating estuarine fish communities, numerically. *Oreochromis mossambicus* was the only freshwater migrant and exotic species recorded in all TCEs of Kerala, being numerically abundant at all sites, and posing a great risk to native species (Regi and Biju Kumar 2018).

The invasion of *Clarius gariepinus* was reported in the Veli-Akkulam estuary by Regi and Bijukumar (2012). Though *C. gariepinus* cannot tolerate salinities above 10 psu (Whitfield 1996), reduced salinities (< 15 ppt) associated with high river flow allows this species to enter and colonize estuarine habitats (Harrison and Whitfield 2004). In this study, the presence of elasmobranchs such as *Carcharhinus limbatus* and *Scoliodon laticaudus* was reported only in a single estuary (Ponnani), and could be likely due to the high salinity ingress into the estuarine mouth. Several individual estuaries covered in this study such as Ponnani, Anchuthengu, Veli-Akkulam, Akathumuri and Poovar also contained a large percentage of juveniles of estuarine residents as well as marine migrants. It has been suggested by Cowley and Whitfield (2001) that, recruitment of juveniles into estuaries take place due to barrier over-wash resulting from tidal currents. In terms of taxonomic composition, Poonthura, Akathumuri, Kodungallur-Azhikode and Vembanad had higher similarity compared to other estuaries, as illustrated by the results of the cluster analysis and NMDS. Separation of these two gradients might have a result of by coastal deposition and anthropogenic pressures, as has been observed elsewhere by Cardoso et al. (2011).

Analysis of functional guilds

In the cluster analysis, our results showed that Veli-Akkulam, Kodungallur-Azhikode, Chettuva, Ponnani, Kadinamkulam, and Akathumuri estuaries were relatively dissimilar in their estuarine-use guild composition within the group, while Anchuthengu and Poonthura were similar. Despite the dissimilarity between the fish assemblages of the above-mentioned estuaries, fish diversity was higher in the Ponnani estuary, which is larger area in comparison to the others. This is consistent with the fact that the estuarine surface can directly influence estuarine fish assemblages (Harrison and Whitfield 2006; Selleslagh and Amara 2008; Selleslagh et al. 2012).

In this study, the highest represented ecological guilds were marine migrants (MM), a trend consistent with other TCEs (Elliott et al. 2007; Harrison and Whitfield 2004). In the present study, MM guild were mainly represented by *M. cephalus*, *G. filamentosus*, *Arius maculatus* and *Terapon jarbua*. As observed by Harrison and Whitfield (2008), and Connor et al (2019), open-mouth condition associated with near-permanent connection with the sea allows unrestricted entry of marine migrants to, and from, estuaries. The fact that marine migrants were the dominant components in temporarily closed estuaries, is in agreement with Nicolas et al (2010) who opined that higher seawater penetration generally led to the migration and consequently, higher densities of marine species in estuaries.

Estuarine residents were represented in all TCEs investigated in our study, dominating the fish assemblage in terms of numbers, but with relatively low number of species, similar to previous observations (Selleslagh et al. 2009; Franco et al. 2006). On the other hand, freshwater migrants contributed very low proportions to assemblage structure and were absent in Poonthura, Anchuthengu, Kadinamkulam and Ponnani estuaries. This observation is similar to those made in South African TCEs (Harrison and Whitfield 2008), and could be attributed to the increase in salinity associated with estuarine mouth opening limiting the appearance of freshwater species (Marshall and Elliott 1998; Dolbeth et al. 2013). *Oreochromis mossambicus*, *Ompok bimaculatus*, *Xenentodon cancila* and *Aplocheilichthys lineatus* were most common freshwater migrants (FM) recorded in all the TCEs.

Among the TCEs of Kerala, anadromous species (AN) were found to occur in Poonthura, Vembanad, Ponnani, Chettuva and Poovar estuaries. Elliott et al. (2007) stated that marine migrant opportunists and marine stragglers inhabit estuarine areas where salinity is high, and marine stragglers (MS) occur inside the estuary in lower densities, due to a small area and mouth opening (Dolbeth et al. 2013). It is thus presumed that the occurrence of marine stragglers in various TCEs of Kerala is decided by these factors.

The feeding guild system was designed to allow the aggregation of fish species that utilize similar food resources (Elliott et al. 2007). With respect to feeding mode functional groups, an overall dominance of piscivorous taxa (81 species) followed by zoobenthivores (53 species) was observed in the TCEs investigated in the current study. Some of the dominant piscivore guilds were represented by members of the family Carangidae, Ariidae, Sciaenidae, Epinephelidae, Clupeidae and Elopidae.

The guild, ZP was the least represented guild (15 species) and occurred in only two estuaries *viz.*, Anchuthengu and Poovar (single species in each TCEs), a contrasting pattern to those in the Forth estuary (UK) (Mathieson et al. 2000), where, planktivorous species (PS) dominated the fish assemblage. Franco et al. (2006) demonstrated that European estuaries were dominated by invertebrate feeders (IV), with invertebrates and fish feeders dominating most fish assemblage in Portuguese estuaries (Cardoso et al. 2011). A smaller representation of the ZP guild, in contrast to the high number of piscivores (PV) (81) reveals the presence of juveniles of marine migrants and other guilds in all TCEs of Kerala due to marine connectivity and reduced freshwater inflow (Bijoy Nandan et al. 2012). The strong marine influence that characterizes tropical estuaries probably provides reasonable access for marine piscivores to establish in the estuarine system. In this study, we found that the estuarine ichthyofauna of TCEs was dominated by piscivores and the presence of apex predators were absent in all the estuaries except Ponnani. Whitfield (1999) stated that the individuals that enter estuaries are usually juveniles whose diet is mainly composed of fish. Many Indian authors reported the abundance of piscivorous taxa in TCEs associated with the breaching of estuarine mouth (Grace, 2014; Kiranya et al. 2018), and so it can be assumed that the frequent breaching of the TCEs (both naturally and artificially) would lead to the abundance these taxa in almost all estuaries. Although the estuarine ecosystem mainly supports detritus food chain, many piscivores fishes depend on the estuaries for completing their larval or juvenile stages ((Morson et al. 2019).

Analysis of habitat quality

A fish-based index, EFCI was determined for defining the habitat quality of TCEs of Kerala. The use of fish community analyses as indicators of ecological health through the implementation of the EFCI has proven to be extremely useful in this study. The EFCI approach described in this study also represents a simplified method where values are set and evaluated directly according to the level of anthropogenic pressure using regression analysis, thus exhibiting a significant relationship with anthropogenic pressures. The EFCI scores in this study ranged from 34 to 56, indicating that the ecological health of the TCEs ranges from “Poor” to “Good” state. Harrison and Whitfield (2004) determined the EFCI for the Sezela estuary (South Africa) and reported the range of EFCI value between 30 and 46. In this study, only four estuaries, Vembanad, Kodungallur-Azhikode, Ponnani and Chettuva were in ‘Good’ state. Estuaries of least concern such as Veli-Akkulam, Kadinamkulam and Anchuthengu were in ‘Poor’ state. Estuaries such as Poonthura, Akathumuri and Poovar were assessed to be under ‘Moderate’ state but are likely to move to ‘Poor’ state in the absence of management measures or policies to protect these fragile ecosystems. Several studies have suggested the alarming decline in Kerala’s estuarine biodiversity primarily due to unsuitable and unethical fishing practices (Regi and Bijukumar 2012; Kiranya et al. 2018).

Large scale decline in health of estuaries in Kerala and reduction of fish stocks have occurred as a result of habitat degradation, water pollution, including nutrient enrichment and eutrophication, destructive fishing and overexploitation, climate change-induced pressures including extreme climatic events, invasive alien species, tourism and recreation, barriers for fish migration and sand mining (Personal communication). In TCEs investigated in the present study, pressures such as water pollution, tourism and recreation activities, destructive fishing and overexploitation, and invasive alien species showed significant impacts, contributing to 10–60% of the total stressors. The pressure index, CPI also revealed variations between the TCEs. We also tried to estimate a simple linear regression between EFCI and CPI to see the impact of anthropogenic pressures on EFCI. Lepage et al. (2016) also used this correlation to establish the impact of pressures on fish community structure and ecological quality. The relationship yielded satisfactory results, and EFCI and CPI were positively correlated. Though the regression fit was below reasonable estimates ($R^2 = 0.3$, might be a result of the limited number of estuaries analyzed here), the impact of anthropogenic pressures on EFCI was evident in the regression plot.

The estuary most affected by invasive alien species was Veli-Akkulam, which is also subjected to large-scale habitat degradation (Regi and Bijukumar 2018). The analysis of EFCI also confirmed the “poor state of the estuary. In Vembanad Lake, habitat loss is the primary anthropogenic stress factor, negatively affecting 60–80% of the ecosystem; however the estuary was revealed to be in a ‘good state’ according to the EFCI score. Compared to all TCEs, Ponnani estuary is the only one that suffers from destructive fishing activities, but the EFCI value indicated that the estuary is in a ‘good state’ mostly due to the remarkable resiliency of estuarine species. Among the ten estuaries, barriers of fish migration were noticed in

Chettuva, Kodungallur-Azhikode and Vembanad, while the remaining seven estuaries were free from any barriers to fish migration.

Conclusion

Our work highlighted the critical role played by temporarily closed estuaries (TCEs) in maintaining fish assemblages. Ichthyofaunal community structure in small (e.g., Poonthura, Poovar, Kadinamkulam etc.) and large (e.g., Vembanad and Ponnani) TCEs differed significantly. Variations in functional guilds were found in all of the approaches used to analyze fish assemblages such as species presence/absence, species composition, diversity, evenness, family level composition, and structure of fish guilds (estuarine use and feeding mode). Though the analysis presented here is preliminary, the EFCI and CPI classified TCEs of Kerala as poor, moderate and good. Proper pollution abatement measures and enforcement of environmental protection measures should be planned and implemented to restore/improve the habitat quality of the moderate and poor TCEs, besides long-term monitoring of fish faunal composition as indicators of ecosystem health.

Declarations

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Author's contribution

Kiranya B: Collection of data, analysis and Preparation of MS

Pramila S: Overall supervision, guidance and manuscript correction

Sreekanth G. B: Data analysis and interpretation

Rajeev Raghavan: Reviewing and editing

Biju Kumar: Technical guidance, reviewing and editing

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Data availability

All of the data generated or analysed during this study are included in this article [and its supplementary information files]

Ethical approval

The authors hereby declare that the research article entitled “Characterization of fish community structure and Development of an estuarine fish community index for temporarily closed estuaries (TCEs) from India’s western coast” is based on the secondary data no prior approval related to ethics were required.

Consent to publish

All the authors have consented for the communication and subsequent publication of the manuscript entitled “Characterization of fish community structure and Development of an estuarine fish community index for temporarily closed estuaries (TCEs) from India’s western coast” in the Journal: Environmental Science and Pollution Research.

Competing interests

The authors declare that they have no competing interests in the publication of the manuscript entitled “Characterization of fish community structure and Development of an estuarine fish community index for temporarily closed estuaries (TCEs) from India’s western coast” in the Journal: Environmental Science and Pollution Research.

Consent to participation

Not applicable

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Figures

Figure 1

Distribution of the temporarily closed estuaries along the west coast of India covered in this study: PON-Ponnani, CHT-Chettuva, KOD-Kodungallur-Azhikode, VEM-Vembanad, AKA-Akathumuri, ANC-Anchuthengu, VEL-Veli-Akkulam, KAD-Kadinamkulam, PT- Poonthura and POV-Poovar Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

The non-metric multidimensional scaling ordination diagram using Bray-Curtis similarity based on species presence/absence data for the ten temporarily closed estuaries: PON-Ponnani, CHT-Chettuva, KOD-Kodungallur-Azhikode, VEM-Vembanad, AKA-Akathumuri, ANC-Anchuthengu, VEL-Veli-Akkulam, KAD-Kadinamkulam, PT- Poonthura and POV- Poovar

Figure 3

Cluster dendrogram using the Bray-Curtis similarity measure for the temporary closed estuaries: PON-Ponnani, CHT-Chettuva, KOD-Kodungallur-Azhikode, VEM-Vembanad, AKA-Akathumuri, ANC-Anchuthengu, VEL-Veli-Akkulam, KAD-Kadinamkulam, PT-Poonthura and POV-Poovar) based on species presence/absence data

Figure 4

(A) Percentage of estuarine use guilds for TCEs by species composition. The guilds- marine migrants (MM), marine straggler (MS), estuarine resident (ER), freshwater migrants (FM), freshwater straggler (FS) and anadromous (AN). (B) Percentage of diet preference guilds for each estuary by species composition. The guilds- zoobenthivore (ZB), Piscivore (PV), Omnivore (OV), Detritivore (DV), Herbivore (HV) and Zooplanktivore (ZP). [PON-Ponnani, CHT-Chettuva, KOD-Kodungallur-Azhikode, VEM-Vembanad, AKA-Akathumuri, ANC-Anchuthengu, VEL-Veli-Akkulam, KAD-Kadinamkulam, PT-Poonthura and POV-Poovar]

Figure 5

Non-metric multidimensional scaling ordination diagram using Bray-Curtis similarity based on estuarine use guilds for the ten TCEs: PON-Ponnani, CHT-Chettuva, KOD-Kodungallur-Azhikode, VEM-Vembanad, AKA-Akathumuri, ANC-Anchuthengu, VEL-Veli-Akkulam, KAD-Kadinamkulam, PT- Poonthura and POV-Poovar

Figure 6

Cluster dendrogram using the Bray-Curtis similarity measure for the TCEs (PON-Ponnani, CHT-Chettuva, KOD-Kodungallur-Azhikode, VEM-Vembanad, AKA-Akathumuri, ANC-Anchuthengu, VEL-Veli-Akkulam, KAD-Kadinamkulam, PT- Poonthura and POV-Poovar) based on estuarine use guild composition

Figure 7

Non-metric multidimensional scaling ordination diagram using Bray-Curtis similarity based on diet preference guilds for ten TCEs: PON-Ponnani, CHT-Chettuva, KOD-Kodungallur-Azhikode, VEM-Vembanad, AKA-Akathumuri, ANC-Anchuthengu, VEL-

Figure 8

Cluster dendrogram based on Bray-Curtis similarity index for the diet preference guilds identified from the TCEs: PON- Ponnani, CHT-Chettuva, KOD-Kodungallur-Azhikode, VEM-Vembanad, AKA-Akathumuri, ANC-Anchuthengu, VEL-Veli-Akkulam, KAD-Kadinamkulam, PT- Poonthura and POV-Poovar

Figure 9

Regression equation of estuarine fish community index (EFCI) on composite pressure index (CPI) fitted for the ten TCEs

Supplementary Files

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