Environmental factors structuring the Fish assemblage distribution and Production potential in Vembanad estuarine system, India

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Abstract Vembanad wetland system, a Ramsar site on the West coast of India is the largest estuarine system, renowned for its rich fishery diversity and endemicity. In 1976, to regulate salinity intrusion into the Vembanad estuarine system, the Thanneermukkom barrage was constructed across the estuary dividing it into fresh water dominated southern and a northern region dominated with brackish water, which has grossly altered the eco-biology of the region. In this context, the influence of environmental factors on fish assemblage structure has been poorly recognised in Vembanad estuarine system mainly for effectively implementing proper management and conservation measures. Information on fish assemblage in relation to environmental parameters collected from February 2012 to January 2013 is reported in this contribution. Estimates of annual average fishery production indicated a catch of 4774.46 t in the estuary, in which 10.1% and 89.9% was contributed by southern and northern zones respectively. Seventy four species of finfishes, eleven species of shell fishes were identified for the study period. Multidimensional scaling and canonical correspondence analysis significantly demarcated the spatio – temporal variation of fish species distribution and observed a strong correspondence between fish assemblage and environmental variables. Depth, temperature, pH and salinity were the most important parameters explaining the variation in fish assemblage composition and abundance in Vembanad estuarine system. The aging Thanneermukkom barrage and its faulty operation reduced the tidal flushing altering the circulation and mixing process, especially in the southern part of estuary. This influenced the hydrological characteristics leading to a decline in estuarine fishery and its production potential.

Keywords Environmental factors; Fish assemblage; Ramsar site; Vembanad wetland system

Introduction

In an aquatic environment, understanding the dynamics of fish population and species distribution in response to environmental factors are essential. Variation in the abundance and composition of fish species in an ecosystem provide the basic idea for implementing the ecosystem – based fisheries management. For the evaluation of environmental variables on organisms, fishes are important because they participate in multiple trophic levels in aquatic community and are having long life span and are easily sampled. Estimation of fish assemblage structure has high value in estuarine quality assessment. Species assemblage is an important ecological unit that interact trophically and respond to environmental and habitat conditions (Craig and Bosman, 2013). Fish communities of coastal estuarine environment possess a mixture of euryhaline species adapted to brackish environments, along with true marine and fresh water species. Therefore, the diversity of fish species in estuaries are very high and are composed of marine, estuarine, freshwater and migrating species (Henderson, 1988; Lobry et al., 2003). Biological condition of aquatic environment is important because fishes react with external aquatic environmental parameters. It leads to shift in the assemblage composition of fish species. Fish assemblages are recognized as sensitive indicators of habitat degradation, environmental contamination and overall ecosystem productivity. The fish assemblages in the estuarine systems are typically dynamic, reflecting the changing environmental conditions in which they are exposed (Tremain and Adams, 1995; Able and Fahay, 1998; Idelberger and Greenwood,
2005). Our attempt was to gather all information on the distribution of fish species to provide a spatial context for understanding the relationship of environmental factors on fish assemblage in Vembanad estuarine system.

The backwaters in Kerala form a habitat for over 200 resident and migratory fish and shellfish species and fishing activities in these water bodies provide the livelihood to about 2,00,000 fishermen (Bijoy Nandan, 2008). There is limited information on the fishery catch and its production trends from the coastal backwaters of the west coast of India. But, scattered information is available on the fishery composition, abundance and catch from the Vembanad backwater (Shetty, 1965; Kurup., 1982; Kurup et al., 1993; Bijoy Nandan, 2008; Harikrishnan et al., 2011; Bijoy Nandan et al., 2012; Asha et al., 2014). Jayachandran et al., (2013) observed the influence of environmental factors on fish assemblage in Kodungaloor – Azhikode estuary, south west coast of India. The study on physical habitat characteristics structuring the fish assemblage in the Vembanad estuary is also limited. In view of this, the study is significantly aimed to observe the environmental factors structuring the fish assemblage of an estuarine system on the west coast of India.

1 Materials and Methods

1.1 Study area

Vembanad estuarine system is one of the largest estuaries on the south west coast of India and an important Ramsar site. It is bordered by Alappuzha, Kottayam and Ernakulam districts of Kerala covering an area of about 200 sq. km and extending 80 km in a NW-SE direction from Munambam in the north to Alleppey in the south (09°00’ -10°40’N and 76°00’-77°30’E). The width of the estuary varies from 500m to 4km and the depth from <1m to 9m. The backwater has two permanent openings into the Arabian sea – one at Cochin and the other at Azhikode. Manimala, Meenachil, Pamba and Achenkovel rivers flows into the estuary south of Thanneermukkom and Muvattupuzha river flows into north of Thanneermukkom barrage. The Vembanad estuarine system has a freshwater dominant southern zone and a salt water dominant northern zone, both separated by the Thanneermukkom barrage (1,400 metres) where the estuary has its minimum width. The barrage, a bridge cum - regulator was constructed in 1976, to prevent salt water intrusion and to promote double cropping of paddy in about 55,000 ha. of low lying fields in the area (Padasekharams). The barrage remains closed during summer months (January – May) and with no proper flushing in the upper reaches of the estuary. The faulty condition of the barrage and the reclaimed areas that is filled with red earth forming road along the Thanneermukkom barrage permanently prevented the connectivity of the south and northern parts of the estuary. The unscientific operation of the sluice gates of the barrage, their rusted condition failed to safeguard the fishery as well as agricultural activity that have also blocked the connectivity of the wetland to the Lakshadweep Sea (Arabian Sea) for a major part of the year. This has severely affected the ecological characteristics of the estuarine ecosystem and restrained the seasonal intermixing of fresh and saline water and thereby interfering with the natural cleansing mechanism of the estuary, threatening accelerated loss of habitats and biodiversity (Anon, 2007). Construction of the new shutters have been initiated in the 470m long reclaimed portion in the middle part of the barrage (Anon, 2014).

1.2 Data collection

Ten sampling stations were selected in the estuary, (9°30’ 069’’N & 76°21’ 268’’ E - 9°53’ 519’’N & 76°18’ 139’’E) for sampling and analysis of various parameters (Figure 1). Catch composition, diversity of fish species and environmental parameters were collected on a monthly basis from February 2012 to January 2013 period. Observations were made seasonally viz., pre monsoon (March – May), monsoon (June – September) and post monsoon (October –January) periods. Landing centre based direct data collection method was adopted for the fish landing estimation and the major landing centres; Alappuzha, Kamarakam, Muhamma, Thanneermukkom, Vaikkom, Chembu, South Paravoor, Aroor, Arookutty and Thevara were spread around the backwater system (FAO, 2002; FAO. 2003; Sparre and Venema, 1992). Gill net was widely used in Vembanad estuary along with stake net, seines, Chinese dip net, cast net and hook and line. Gill net size varied from 30 - 150m and mesh size in the range 22 – 150mm in different designs. Finfishes from the gill net were used for the fish catch composition, fish diversity and assemblage...
Catch per unit effort (CPUE) is defined as one operation of the net which occurred once per site or the number of fish collected per operation. CPUE was expressed as No. 100 m-net hr-1 and used as index of relative abundance (FAO, 2002; Sparre and Venema, 1992). Total catch was collected and sorted into finfish and shell fish. After sorting and counting, representative finfish samples were preserved in 10% formalin for taxonomic studies. Species level identification was made with help of standard references (Talwar and Jhingran, 1991; Bijoy Nandan, 2012; Fish Base (www.fishbase.org)).

Water temperature was measured at the time of sampling using mercury thermometer; pH with Systronics pH meter (No. 317; accuracy ± 0.01); transparency using Secchi Disc (Strickland and Parsons, 1972); dissolved oxygen by modified Winklers method (Strickland and Parsons, 1972) and salinity by Systronics water analyser (No. 317; accuracy ± 0.01) calibrated with standard seawater.

1.3 Data Analysis
Two-way analysis of variance (ANOVA) was used for hydrological parameters (temperature, pH, transparency, dissolve oxygen and salinity) to calculate any existence of difference among the stations, months and seasons. Species diversity, richness and evenness index of fin fishes were calculated for each gill net sample based on species numerical abundance.
Diversity indices such as, Shannon-Wiener diversity (H’), Margalef’s richness index (d) and Pielou’s evenness index (J’) were computed using PRIMER Vs. 6.0 (Clarke and Gorley, 2006). Multidimensional scaling (MDS) was used to graphically display the two-dimensional ordination plots showing differences of organization of the fish abundance. A stress value of <0.2 gives a useful representation of results (Clarke and Warwick, 2001). Species numeric abundance in relation to environmental variables was analysed using the canonical correspondence analysis (CCA). It is an example of direct gradient analysis, where the gradient in environmental variables is known a prior and the species abundances (or presence/absences) are considered to be a response to this gradient. This ordination method was used to detect patterns of species association directly related to environmental variables. A perpendicular line is traced between the species and environmental vector, that represents the relation between the species and the factor (Ter Braak and Verdonschot, 1995).

2 Results
2.1 Physico-Chemical characteristics

The depth of the estuary ranged between 1.4 to 8.5m with an average of 3.93 ± 1.93m. Seasonal average values of major physico-chemical parameters are given in Table 1. The lowest temperature of 28ºC was observed in Station 1, Station 2, Station 3 and Station 4 and maximum of 33ºC in Station 9 and Station 10. The pre monsoon season (31.03 ± 1.14 ºC) showed the maximum temperature as compared to post monsoon (31.4 ± 0.68 ºC) and monsoon (30.25 ± 1 ºC). The average minimum temperature of 29.2 ± 0.95 ºC was recorded during February 2012 and maximum 32.05 ± 0.64 ºC during April 2012. The ANOVA of temperature showed that variation between seasons was significant (F= 11.08, p < 0.01). The transparency value ranged between 0.25m (March, 2012, Station 3) to 2.25m (December 2012, Station 6) with an average of 1.74m. The pH varied from 6.25 (August 2012, Station 1) to 10.02 (March 2012, Station 4). The mean pH of the estuarine system during the study period was 7.06 ± 0.56. The lowest mean value was recorded in August 2012 (6.37 ± 0.98), while highest in February 2012 (8.39 ± 0.66). Generally alkaline condition was observed in the northern sector of the estuary. On an average, pH of the study stations in the southern sector was 7.06, whereas that of the northern sector was 7.2. Compared to pre monsoon and post monsoon, a relatively low alkaline condition was observed during monsoon (6.72 ± 0.24). The ANOVA of pH showed that the variation between seasons were significant (F=17.24, p < 0.01). The dissolved oxygen ranged from 4mg/l, recorded during November 2012 at station 1 and 2 to 9.6 mg/l, recorded during June at Station 2 and 8 with mean value of 6.8 ± 1.2 mg/l. When compared to stations of southern sector (6.78 ± 0.28 mg/l), higher dissolved oxygen values were observed in stations of northern sector (6.92 ± 0.14 mg/l). Maximum dissolved oxygen concentration was observed during monsoon (7.6 ± 1.3 mg/l) followed by pre monsoon (6.8 ± 1.1 mg/l) and post monsoon period (6.1 ± 0.87 mg/l). The ANOVA showed that seasonal variation of dissolved oxygen was significant (F= 16.57, p < 0.01).

Table 1 Seasonal average values of physico-chemical variables in Vembanad estuarine system [Depth (m), Temperature (ºC), Salinity (ppt), Dissolved oxygen (mg/l)]

| Parameter | Premonsoon | Monsoon | Postmonsoon | Range |
|-----------|------------|---------|-------------|-------|
| Depth     | 4.06±2.03  | 3.82±1.88 | 3.93±1.9  | 1.4 – 8.5 |
| Temp      | 31.03±1.45 | 30.25±1  | 31.44±0.68 | 28 – 33  |
| pH        | 7.4±0.69   | 6.72±0.24 | 7.06±0.41 | 6.25 – 10.02 |
| DO        | 6.85±1.06  | 7.6±1.23  | 6.14±0.88 | 4 – 9.6  |
| Salinity  | 7.58±8.16  | 1.38±2.1  | 7.89±1.15 | 1.1 – 33  |
| Parameter | Premonsoon | Monsoon | Postmonsoon | Range |
| Depth     | 4.06±2.03  | 3.82±1.88 | 3.93±1.9  | 1.4 – 8.5 |
| Temp      | 31.03±1.45 | 30.25±1  | 31.44±0.68 | 28 – 33  |
| pH        | 7.4±0.69   | 6.72±0.24 | 7.06±0.41 | 6.25 – 10.02 |
| DO        | 6.85±1.06  | 7.6±1.23  | 6.14±0.88 | 4 – 9.6  |
| Salinity  | 7.58±8.16  | 1.38±2.1  | 7.89±1.15 | 0.1 – 33  |
A clear seasonality was observed in the salinity pattern. During the southwest monsoon the salinity declined nearly zero mainly due to the heavy rainfall and river discharge. In Alappuzha district the annual rainfall was observed as 2113.6 mm and in Ernakulam district it was 2780.7 mm. The maximum salinity of 33 ppt was observed in Station 10 and minimum 0.1 ppt in Station 2. The average salinity of $1.37 \pm 2.1$ ppt was observed during the monsoon and followed by pre monsoon ($7.58 \pm 8.2$ ppt) and post monsoon ($7.89 \pm 1.15$ ppt) periods. ANOVA showed that station wise and seasonal variations of salinity were significant ($F=11.74, p < 0.01$). The annual average salinity showed that the southern region of the estuary was oligohaline (2.45 ppt) whereas northern region was mesohaline (11.85 ppt) in nature. According to salinity gradient and general morphology, the estuarine system was divided into two zones (upper and lower). The upper part is located between Alappuzha to Thaneermukkom barrage and lower part extends from north of Thaneermukkom barrage to Thevara which is influenced by coastal waters.

### 2.2 Fishery abundance

Seventy four species of finfishes belonging to forty families were recorded during the study period (Table 2). The finfish species, *Ambassis ambassis* (15.16%), *Etroplus maculatus* (11.14%), *Amblypharyngodon microlepis* (9.7%), *Mugil cephalus* (4.65%), *Hyporhamphus xanthopterus* (4.02%), *Liza parsia* (3.95%), *Puntius filamentosus* (3.53%) and *Liza microlepis* (3.5%) were the major contributing groups in Vembanad estuarine system. Annual average landing was estimated at 4774.46t from the Vembanad estuarine system, of which 4292.59t was contributed by northern zone and 481.87t by southern zone. Maximum number of species was observed during March 2012 and minimum during August 2012. Highest Shannon diversity index ($H'$) was found in March 2012 (4.14) whereas it was low during July 2012 (2.79) (Figure 2). The maximum diversity index was observed in Station 8 (4.70) and minimum in Station 1 (2.84). The highest Margalef’s richness (d) values were observed during March 2012 (5.27) and lowest in August 2012 (2.91). Maximum richness index was observed in station 8 (5.34) and minimum in station 3 (2.34). The highest Pielou’s evenness index ($J'$) was observed during November 2012 (0.84) and lowest in July 2012 (0.60). Compared to the southern region the species diversity index, richness index and evenness were always higher in the northern region (Table 3). MDS analysis indicated that fish assemblages significantly varied within the estuarine system. This was however due to clear differences in the presence of finfish communities at each site. In MDS plot, samples showing similarities were grouped together and dissimilar ones, far away. In the case of months such as June, July and March, May were grouped closely and showed 80% similarity in fin fish abundance (Figure 3). The stress coefficient in the case of monthly distribution pattern was 0.06. CCA biplot showed the eigen values of the first two axes as 0.604 and 0.075 respectively (Table 4). The first two CCA axes explained 90.22% variability of environmental parameters in which the first axis that explained 80.25% of the total variance and the second axis represented 9.97% of the total variance (Figure 4).

![Figure 2 Temporal variation of species diversity of fish species (Margalef’s species richness (d), Pielou’s evenness (J’), Shannon index (H)) in the Vembanad estuarine system](image2)

![Figure 3 MDS plot based on the temporal variation of fish assemblage in Vembanad estuarine system](image3)
Figure 4 CCA analysis of fin fish species and water quality parameters in the Vembanad estuarine system

Table 2 Species composition, Family, Habitat and CPUE of fin fishes collected from the Vembanad estuarine system during February 2012 to January 2013 period

| Species                        | Family            | Habitat | CPUE          |
|--------------------------------|-------------------|---------|---------------|
| Ambassia ambassis             | Ambassidae        | M F B   | 70.21 ± 90.62 |
| Paraambassia dayi             | Ambassidae        | F B     | 11.63 ± 27.42 |
| Anabas testudineus            | Anabantidae       | F B     | 0.18 ± 0.4    |
| Anguilla bengalensis          | Anguillidae       | M F B   | 0.18 ± 0.4    |
| Horabagrus brachysoma         | Bagaridae         | F B     | 3.81 ± 3.65   |
| Mystus oculatus               | Bagaridae         | F B     | 3.21 ± 2.87   |
| Xenentodon cancila            | Belonidae         | M F B   | 2.45 ± 76.91  |
| Brachirus orientalis          | Bonthidae         | M B     | 2.8 ± 4.2     |
| Megalopsis cordyla            | Carangidae        | M B     | 1.4 ± 3.7     |
| Chanos chanos                 | Chiridae          | M F B   | 6.67 ± 9.45   |
| Etroplus maculatus            | Cichilidae        | F B     | 51.56 ± 20.36 |
| Etroplus suratensis           | Cichilidae        | B       | 9.45 ± 12.14  |
| Oreochromis mossambicus       | Cichilidae        | F B     | 3.68 ± 4.21   |
| Sardinella longiceps          | Clupidae          | M       | 1.1 ± 0.01    |
| Cynoglossus cynoglossus       | Cynoglossidae     | M B     | 1.54 ±1.37    |
| Cynoglossus microlepis        | Cynoglossidae     | F       | 0.67 ± 3.65   |
| Amblypharyngodon microlepis   | Cyprinidae        | F       | 45 ± 28.24    |
| Catla catla                   | Cyprinidae        | F B     | 1.21 ± 0.42   |
| Labeo dussaneri               | Cyprinidae        | F B     | 8.09 ± 8.58   |
| Labeo dussaneri               | Cyprinidae        | F B     | 0.18 ± 0.40   |
| Puntius amphibius             | Cyprinidae        | F B     | 4.87 ± 12.38  |
| Puntius filamentous           | Cyprinidae        | F B     | 16.36 ± 25.06 |
| Puntius sarana                | Cyprinidae        | F B     | 8.18 ± 11.49  |
| Anatodostoma chacunda         | Dorosomidae       | M F B   | 10.27 ± 5.09  |
| Nematalosa nasus              | Dorosomidae       | M F B   | 5.90 ± 2.74   |
| Eleotris fascia               | Eleotridae        | M F B   | 1.21 ± 0.42   |
| Species                  | Family     | Habitat | CPUE         |
|-------------------------|------------|---------|--------------|
| Elops machanta          | Elopidae   | M B     | 0.18 ± 0.40  |
| Stolephorus commersonii | Engraulidae| M B     | 4.67 ± 0.26  |
| Stolephorus indicus     | Engraulidae| M B     | 2.26 ± 0.31  |
| Thryssa dassumeri       | Engraulidae| M B     | 11.54 ± 9.32 |
| Thryssa malabarica      | Engraulidae| M B     | 9.53 ± 12.85 |
| Gerres filamentosus     | Gerridae   | M F B   | 11.27 ± 6.07 |
| Gerres setifer          | Gerridae   | M B     | 4.43 ± 1.4   |
| Glossogobius giurius    | Gobiidae   | M F B   | 0.67 ± 0.0   |
| Hyporhampus xanthopterus| Hemirhampidae| M F B | 18.63 ± 10.31|
| Heteropneustus fossilis | Heteropneustidae| F B | 0.31 ± 0.85  |
| Leiognathus brevirostris| Leiognathidae| M B   | 6.72 ± 16.21 |
| Leiognathus dassumieri  | Leiognathidae| M B   | 9 ± 10.03    |
| Leiognathus equulus     | Leiognathidae| M F B | 4.34 ± 1.4   |
| Megalops cyprinoides    | Megaloniidae| M F B | 6.09 ± 8.25  |
| Liza microlepis         | Mugilidae  | M F B   | 16.22 ± 11.62|
| Liza parsa              | Mugilidae  | M F B   | 18.32 ± 10.03|
| Magil cephalus          | Mugilidae  | M F B   | 21.54 ± 11.77|
| Valamagil speigleri     | Mugilidae  | M F B   | 14 ± 2.7     |
| Nandus nandus           | Nandidae   | F B     | 1.6 ± 0.40   |
| Pristolepis fasciata    | Nandidae   | F       | 0.54 ± 2.31  |
| Channa maralitius       | Ophiocephalidae| F     | 2.36 ±9.45   |
| Channa striatus         | Ophiocephalidae| F B | 2.96 ± 2.9   |
| Eleatheronema tetradactylum| Polynemidae| M F B | 1.64 ± 0.54  |
| Scatophagus argus       | Scatophagidae| M F B | 3.18 ± 4.33  |
| Johnius coitor          | Sciaenidae | M F B   | 4.00 ± 4.54  |
| Siganus javus           | Siganidae  | M B     | 0.16 ± 0.87  |
| Sillago sinhama         | Sillaginidae| M B   | 0.51 ± 0.70  |
| Ompok binaculatus       | Siluridae  | F B     | 0.67 ± 0.84  |
| Wallago attu            | Siluridae  | F B     | 2.02 ± 0.04  |
| Arius maculatus         | Tachysuridae| M F B | 4.6 ± 8.5    |
| Arius substratus        | Tachysuridae| M B   | 6.4 ± 16.43  |
| Plicofollis platystomus | Tachysuridae| M B   | 0.89 ± 0.62  |

Note: F: Fresh Water; B: Brackish Water; M: Marine water

Table 3 Comparison of fish species diversity [Margalef’s species richness (d), Pielou’s evenness (J’), Shannon index (H)] in the Southern and Northern sector of Vembanad estuarine system

| Region   | Station | Margalef’s richness index | Pielou’s evenness index | Shannon Wiener diversity index |
|----------|---------|---------------------------|-------------------------|--------------------------------|
| Southern | S1      | 2.562                     | 0.7259                  | 2.836                          |
|          | S2      | 2.665                     | 0.8235                  | 3.294                          |
|          | S3      | 2.327                     | 0.9053                  | 3.447                          |
|          | S4      | 3.667                     | 0.8435                  | 3.762                          |
|          | S5      | 3.398                     | 0.8212                  | 3.549                          |
|          | S6      | 4.22                      | 0.8692                  | 3.876                          |
| Averge   |         | 3.14                      | 0.83                    | 3.46                           |
| Northern | S7      | 4.751                     | 0.9001                  | 4.28                           |
|          | S8      | 5.336                     | 0.932                   | 4.701                          |
|          | S9      | 4.627                     | 0.8279                  | 4.176                          |
|          | S10     | 4.331                     | 0.7693                  | 3.914                          |
| Averge   |         | 4.76                      | 0.86                    | 4.27                           |
Table 4 Results of CCA for fish assemblages between selected environmental parameters and the first two CCA axes

|             | Axis 1     | Axis 2     |
|-------------|------------|------------|
| Eigenvalue  | 0.604      | 0.075      |
| Constrained inertia (%) | 80.248     | 9.971      |
| Cumulative % | 80.248     | 90.219     |
| Total inertia | 71.533     | 8.888      |
| Cumulative % (%) | 71.533     | 80.420     |

Environmental parameters

| Parameter           | CCA Axis 1 | CCA Axis 2 |
|---------------------|------------|------------|
| pH                  | 0.677675   | 0.099365   |
| Depth               | 0.704023   | 0.08974    |
| Water temperature   | 0.726389   | -0.05726   |
| Dissolved oxygen    | -0.45776   | -0.12314   |
| Salinity            | 0.73969    | 0.071924   |
| Transparency        | -0.3749    | 0.045261   |

3 Discussion

Environmental factors are considered as essential to determine the composition, distribution and assemblage of fish species in an aquatic environment (Mansor et al., 2012). In Vembanad estuarine system depth was associated with the occurrence of species of Mugilidae, Chanidae, Sciaenidae, Cichilidae, Cyprinidae and Hemiramphidae. Depth in tropical waters formed an important factor in structuring the species assemblages (Bianchi, 1992). Depth was generally low in the present study where the northern part was higher as compared to the southern zone that also influenced the distribution of species as evident from the CCA analysis. Fish in estuaries appears to show a preference for relatively shallow waters (Blaber, 1985); this provide shelter and refuge from larger fish predators, which are normally confined to deeper waters (Whitfield and Blaber, 1978). Water depths control the habitats for fishes from biotic and abiotic threats. Shallow water provides shelter from piscivorous fishes, and deeper water shelters fishes from avian and terrestrial predation (Power, 1987; Gorman, 1988). During the study period an alkaline condition was predominant in all stations of Vembanad estuarine system. Joseph and Ouseph (2010) and Jayachandran et al., (2013) also observed an alkaline condition in Vembanad wetland system. Generally the pH increases towards the northern zone of estuary where the influence of sea water was higher. Rainfall in Vembanad is mainly concentrated from June to September (southwest monsoon) and October to December (northeast monsoon); this is reflected by higher river discharge into the estuary. During monsoon season, the upper area of Vembanad estuary is flushed with annual monsoonal flood water which carries the river fish species that move down stream concentrating in the estuarine area (Anon., 2007). During this period the southern zone was dominated by fresh water species such as Amblypharyngodon microlepis, Puntius sarana, Labeo dussumieri and Channa marulius. Seasonal variations in rainfall create or eliminate micro-habitats which are important for fishery abundance (Olukolajo and Oluwaseum, 2008). This indicates that rainfall has a direct relationship with the species present in the water body. Seasonal variations in rainfall act as a main factor, which affects the strategies of the life cycle of fish, such as their movement, feeding, growth and spawning (Roessig et al., 2004). The dissolved oxygen was consistently higher in the present study and it varied spatially from 4 to 9.6 mg/l. Martin, (2013) reported dissolved oxygen concentration of Cochin backwater that varied from 4-7 mg/l. The higher oxygen values are an indication of higher photosynthetic activity. So it should be able to support good fauna and flora especially the fish species. Usually dense macrophyte (Eichhornia crassipes) cover on the water surface that shaded the water column and decreased the turbulent mixing and transfer of oxygen from the atmosphere happened in the Vembanad estuarine system. During the study period macrophytes from the agriculture field are trapped and so the weed infestation is reduced in the estuary (Anon, 2012). The average oxygen concentration in the oligohaline zone
(southern zone) was little lower (av. 6.7 mg/l), compared to the mesohaline zone (northern zone) that exhibited a higher oxygen concentration (av. 7.3 mg/l). This may be due to oxygen rich fresh water from the Muvattupuzha river and also due to the wind and tidal action from the Arabian sea. All the season, the lower estuary (northern region) always showed the highest salinity, whereas the upper estuary (southern region) depicted lower values. During monsoon season a near limnetic condition prevailed in the southern part of estuary (av. 0.66 ppt), whereas an oligohaline condition prevailed in the northern part (av. 2.4 ppt). During the premonsoon season the average salinity pattern in the southern part of estuary showed oligohaline condition (av. 3.1 ppt) and mesohaline condition in northern part (av. 14.3 ppt) of the backwater.

Sabo et al., (1991) suggests that larval fish density was positively correlated with dissolved oxygen, conductivity and turbidity. The effect of temperature on tropical species in low water temperatures (<14 ºC) have occasionally resulted in mass mortalities of fishes in St Lucia (Cyrus and McLean, 1996) and Kosi Bay (Kyle, 1989) estuaries on the subtropical KwaZulu-Natal coast. Temperature plays an important role in the difference in estuarine fish assemblages on the northeast coast of the United States where the fauna south of Cape Cod was represented by warm-temperate species with cold-temperate taxa dominating ichthyofauna to the north (Ayvazian et al., 1992). The distribution of tropical fish species in South African estuaries is strongly linked to the decrease in sea temperatures along the southeast coast (Day et al., 1981). The endemic species such as \textit{Horabagrus brachysoma} and \textit{Hyporhamphus xanthopterus} in Vembanad backwater were influenced by the prevailing temperature regime. Fluctuations in temperature could affect the sudden or possible changes in benthic and column feeding fishes such as \textit{Horabagrus brachysoma} and \textit{Hyporhamphus xanthopterus} respectively. The mass mortality of species such as \textit{Diplodus capensis}, \textit{Galeichthys feliceps}, \textit{Lithognathus lithognathus} and \textit{Liza richardsonii} occurred in the Bot estuary on the southwest coast of South Africa, when salinity declined to 2-3 ppt (Bennett, 1985). Temperature and salinity formed major factors affecting the distribution and abundance of fishes in estuaries in many parts of the world. The fish species assemblages in the North American West Coast estuaries were structured mainly by salinity and temperature (Monaco et al., 1992; Emmett et al., 2000). The assemblage structure of fishes in estuaries depend upon salinity (Marshall and Elliott 1998., Plavan et al., 2010; Neves et al., 2011) and the effects of salinity appear to be regulating the distribution of fish and in the attraction of larvae, post- larvae and juveniles into the estuaries (Elliott and Hemingway, 2002).

Among the environmental variables, salinity, temperature, turbidity, dissolved oxygen and their regular or irregular fluctuations at different time scales affect the estuarine fish ecology (Whitefield, 1999; Blaber, 2000). Individual fish populations and communities have strong physiological and behavioural responses to environmental changes (Boesch and Turner, 1984). CCA analysis showed that salinity, water temperature, depth and pH are important in relation to fish assemblages (Monte Carlo permutation test, p<0.05). The first CCA axis positively correlated with salinity (r = 0.74), water temperature (0.73), depth (0.7) and pH (0.68). Large vector length of these parameters shows their importance in making assemblage structure of fish species in Vembanad estuary. The vector length of a given variable showed significant correlation with stations. Smaller the angle of an environmental vector relative to another environmental vector representing higher correlation between the two environmental factors. This indicates their importance in shaping assemblage structure of fish species across the study site. The longest vector of salinity, pH and depth showed significant correlation with station 10. The high value of salinity, alkaline pH and depth were associated with fish groups such as Mugilidae, Channidae and Sciaenidae. The meso-polyhaline environment in the northern zone supported the marine-estuarine and marine-dependent fish species such as Mugilidae, Channidae, Sciaenidae, Carangidae, Leiognathidae, Engraulidae and cat fishes (Tachysuridae). Where, Mugilidae and Channidae were catadromous, Sciaenidae and Engraulidae were oceanodromous and Leiognathidae was Amphidromous fishes. This observation is supported by Akin et al., (2005). According to Smith and Parrish (2002) most of the species in the upper reaches of estuaries were estuarine dependent species, while the species in the
lower reaches of estuary was related to other factors such as migration of marine – dependent species, rather than to salinity and temperature. Around 90% of the fish species must require brackish water environment to complete their life cycle. Freshwater-dominated estuaries and deltas are well known as important nursery areas for large numbers of marine fish species (McHugh, 1967; Haedrich, 1983). The juveniles of these fishes in the near shore nurseries are facing lower predation pressure and increased food supply (Miller et al., 1985). The ability of fishes to adjust to the changes in salinity may be gradual, as in a temporarily closed estuary or sudden as in tidal estuaries. This magnitude of change in salinity depends mainly upon the balance between the fresh water inflow and tidal regime (Whitfield, 1999). In the estuarine environment, the ability to adjust the changes in salinity was considered the most essential adaptation for fish and other organisms (Panikkar, 1960). But among fishes the ability for adjusting the salinity variation differed from species to species and it affects its distribution (Blaber, 2000). Temporal shift in the normal discharge pattern due to regulation or an overall decrease in the water body alters the migration of fish species. The construction of dam’s reduced upstream migrations of shad (Hilsa ilisha) in several rivers in southern India through reductions of high freshwater flow rates was reported by Ganapati, (1973).

One fifty species of fishes belonging to hundred genera and fifty six families were identified in Vembanad estuary by Kurup (1982) and later Kurup et al., (1993) reported 115 species of fishes belonging to 84 genera, 6 species of penaeid prawns, 4 species of palaemonid prawns and 3 species of crabs. Bijoy Nandan et al., (2012) and Jayachandran et al., (2013) observed 78 species of fishes from the Kodungallor – Azhikode Estuary, the northern most part of Vembanad estuarine ecosystem. Comparing the pre and post barrage phases a significant change in the fish fauna composition was noted by Anon., (2001). Atree, (2009) identified 65 species of finfish and 14 species of shell fish in the southern part. Asha et al., (2014) identified 80 of fin fishes, 5 species of penaeid shrimps, 3 species of palaemonid prawns and 2 species of crabs during 2012-2013 period, in which three were vulnerable and one was near threatened from the Vembanad estuarine system. All these noted that in the Vembanad estuarine system, the fish species are facing various threats due to anthropogenic interference and other disturbances in the habitat. During closure of barrage, the continuity of the estuarine system was lost especially in the pre monsoon season. This led to limited flushing of the system with heavy accumulation of agricultural waste – fertilizers, oil residues from house boat tourism and other toxic contaminants in the southern part of the backwater that triggered the proliferation of weeds, deterioration in water quality and related ecological impacts. So the periodic tidal inflow was completely prevented, along with the interruption in migration routes of marine and estuarine dependent fish fauna. Moreover, the southern zone of barrage was inaccessible to majority of the euryhaline migratory fishes.

Increased fishing activities, habitat loss, human intervention also affected the fishery of Vembanad estuarine system. A maximum of 56 species of finfishes were observed in northern region (station 10), which was due to the mesohaline condition (average salinity10 ppt) that prevailed throughout the year and also the optimum environmental conditions which provide suitable habitat for the species. According to Barletta et al., (2005) numerical abundance of fishes was normally highest in the upper part of estuary mainly due to the migration of a few fresh water and marine species and the presence of the estuarine species. But in Vembanad estuary the upper part was less diverse and only 36 numbers of finfish species was observed in southern part. The operation of Thaneermukkom barrage could negatively affect the species diversity; reduction of upstream migration of marine fish and prawns in Vembanad estuary (Revichandran, 2012). The opening/closing of the Thaneermukkom barrage limited the numerical abundance of finfish species. Average Shannon – Wiener diversity index, Margalef index and evenness index of southern zone of the estuary was less as compared to northern part (Table 3). The number of fishes increased during pre monsoon season, in which the whole estuarine system displayed a mesohaline condition. The juvenile estuarine fish populations were strongly affected by climatic variability, which may affect fish production potential through changes in either growth or abundance (Martin and Michael, 2002). Atree, (2009) reported threats to fishery of Vembanad Lake system from Invasive Alien Species...
4 Conclusion
The fishery in Vembanad estuarine system is facing tremendous pressure due to the aging Thaneermukkom barrage as well as its faulty construction along with non-synchronized opening and closing of the barrage. This has affected the tidal rhythm and fishery patterns of the estuary that maintained the hydro-biological balance in the ecosystem. From the CCA analysis it could be concluded that depth, temperature, pH and salinity invariably had significant bearing on the diversity, distribution and fishery production in the southern and northern sectors of Vembanad estuary. The northern part exhibited a euryhaline fish species structure as compared to stenohaline grouping in the southern sectors of the estuary. So, effective steps are to be initiated for co-ordinating the proper management of the Thaneermukkom barrage, so that the life cycle processes of the fishery are not affected. Recently Govt. of Kerala has initiated measures to replace damaged shutters of the barrage as well as opening the reclaimed areas by fixing with shutters for proper functioning and connectivity of the wetland system. However further studies are necessary to understand the effects of such renewed changes on the fishery on a long term basis.

Authors contribution
SBN is the supervisor of the project. CVA, RIC, PSS and SBN made significant contributions to experimental design, data analysis and interpretation and also involved in manuscript drafting.

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