Journal of Natural Sciences Research
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.2, No.7, 2012

Temporal and Spatial Variations in Fish Assemblage Structures in Relation to the Physicochemical Parameters of the Merbok Estuary, Kedah

Mansor, M.I.*[1,2], Mohammad-Zafrizal, M.Z.[2], Nur-Fadhilah, M.A.[1], Khairun, Y.[1,2] and Wan-Maznah, W.O.[1,2]

[1] School of Biological Sciences, Universiti Sains Malaysia, 11800 Minden, Pulau Pinang, MALAYSIA.

[2] Centre for Marine and Coastal Studies, Universiti Sains Malaysia, Muka Head, 11060, Teluk Bahang, Penang, MALAYSIA.

*Corresponding author: Mansor Mat Isa, E-mail: mmiusm@yahoo.com

Abstract

The effects of seven variables–rainfall, water depth, salinity, turbidity, temperature, conductivity and pH–on fish assemblages were evaluated in this study. Fish were sampled on a monthly basis using a barrier net deployed by artisanal fishermen at six physicochemical sampling stations. The Merbok estuary was influenced by variable river discharges and mainly affected by primary and secondary wet seasons in March–June and August–November, respectively. This impacted the salinity gradient which ranged from 3.50 ppt to almost 30.75 ppt, resulted in two different salinity regimes, *i.e.* mesohaline and polyhaline. The temperature varied with a pronounced peak in both the primary and secondary rainy seasons. Other parameters such as conductivity, turbidity and pH fluctuated temporally, but no significant differences were recorded among the sampling sites. Fish species accounted for 72.06% (897.9 g/b/t), while marine and freshwater shrimps accounted for 27.94% (350.7 g/b/t). Almost 80 species of fish, representatives of 45 genera from 36 were recorded in the present study. Temporally, the mean abundance of fish was lower during the primary wet season than during the secondary rainy periods while spatially, the mean abundance of fish species was higher in the middle zone of the estuarine systems. The correlations between species and variables, suggesting the importance of environmental parameters in determining fish distribution, abundance and assemblage. Some fish species such as *Butis gymnopomus* showed a strong correlation with turbidity and pH, whereas others such as *Lates calcarifer* were strongly correlated with salinity.

Key words: physicochemical, estuarine fishery, resource management, Merbok estuary

1. Introduction

The scenario on tropical estuaries can be briefly explained based on the relationship between environmental factors in the estuaries and complex spatial and temporal patterns in the composition, abundance and distribution of fish assemblages (McLusky & Elliott 2004, Pombo *et al*. 2005). Individual fish populations and communities have strong physiological and behavioural responses to environmental changes (Boesch & Turner 1984). Fishes that inhabit this environment can be classified as permanent, cyclic or occasional (Velazquez-Velazquez *et al*. 2008). Many fish species that inhabit these types of ecosystems undergo unique physiological adaptations that allow them to tolerate extreme environmental conditions (Day *et al*. 1989, Whitefield 1999) in terms of salinity, pH, temperature, and dissolved oxygen (DO) (Akin *et al*. 2005). Moreover, the distribution and abundance of these fish species differs between the rainy and dry seasons (Rueda and Defeo, 2003) and between marine and freshwater environments (Simier *et al.* 2006). Changes in fish distribution and abundance will undoubtedly affect human communities that harvest these stocks, and global climate change will certainly continue to impact marine and estuarine fish and fisheries (Roessig *et al*. 2004, Gibbs 2006).

The Merbok estuary is a mangrove reserve in the north-west of Peninsular Malaysia. It lies between latitude 100° 20' 57.33" and longitude 5° 40' 53.74" seawards, facing the Straits of Malacca and between latitude 100° 30' 24.56" and longitude 5° 42' 13.46" in the upper reaches. This estuary is associated with water body stretches for about 35 km. The width ranges from approximately 20 m at the upper reaches of the estuary to 2 km at the mouth of the estuary, and the estuary is supported by large and small tributaries with depths ranging from 3 to 15 m (Ong *et al*. 1991). This area experiences the primary maximum of the rainfall in September – November while the secondary maximum generally occurs in March – May and the primary minimum occurs in January – February with the secondary minimum in June – July (www.met.gov.my).

Merbok estuary is regarded as an important nursery ground for fishes and prawns and as a habitat for mussels and mollusks which support artisanal capture fisheries and mollusk collection. Consequently, mariculture with fish cages and shrimp pond activities contributes to the income of local residents and entrepreneurs (FAO/BOBP 1984). It is currently believed that the Merbok estuary is impacted by chemicals and pesticides released by agricultural activities, effluents discharged from aquaculture, solid wastes dumped from residential areas and fishing of juvenile fishes by local fishermen. Moreover, barrier nets, set nets, crab pods and recreational fishing are used by major capture fisheries. Venus clam, *Meretrix meretrix* culture and seed collection, oyster and other bivalve collections are important and contribute to the unsustainable manner of exploitation (Mansor *et al*. *in press*). In addition the length-weight analysis of the estuarine fishes by Mansor *et al*. (2012a), demonstrated that the estuary was a preferable nursery ground for ariids, and mature ariids are found throughout the year with two spawning peaks in the pre- and post-rainy seasons (Mansor *et al*. 2012b). Moreover, the reproductive strategy of these ariids is in-synchronised.

Little is known about the assemblage patterns of fish and the environmental variables involved in the Merbok estuary. Moreover, the manner in which these variables determine the spatial and temporal structures of fish assemblages in the estuary is not well defined. Hence, the present study is a preliminary analysis to investigate the influence of environmental parameters on spatial and temporal variations in fish assemblages in the Merbok estuary.

2. Materials and Methods

2.1. Study area

The sampling areas and sites are shown in Fig. 1, and these were divided into three different zones. The upper zone that stretches from Lalang River (St1) to Semeling River (St2) is associated with residential, pond culture, artisanal fishing and agricultural activities. The middle zone that extends from Keluang River (St3) to Teluk Wang (St4) is influenced by human activities, including agricultural, artisanal fishing, residential and cage culture activities. While the lower zone extends from Gelam River (St5) to Lubuk Pusing (St6) which is the seaward area is significantly affected by the effluent from cage culture, agricultural activity, pond culture, and artisanal fishing.

2.2. Physicochemical parameters

Between January and December 2010, samples were collected with appropriate equipment on a monthly basis at the six sampling stations (see Fig. 1) along the Merbok estuary to evaluate the following *in-situ* environmental parameters: water depth (WD), temperature (TEMP), salinity (SAL), pH (pH), conductivity (COND), and transparency/turbidity (TURB). The equipment used included a dissolved oxygen (DO) meter, salinity, conductivity and temperature (SCT) meter, pH meter, Secchi disc, and water sampler. Water samples were collected to analyse the levels of ammonium (NH_4), nitrite (NO_2), nitrate (NO_3), phosphate (PO_4), total suspended solids (TSS), biological oxygen demand (BOD), and DO. Phytoplankton and zooplankton samples were also collected using a plankton net of mesh size 150 µm which was deployed during the in-flux tidal (i.e. synchronised with the influx of living organisms into estuary and tributaries) and out-flux tidal (i.e. synchronised with the influx of living organisms and effluent from human activities) and these samples were preserved for further analysis.

Data on rainfall distribution, one of the parameters considered in the study area, were obtained from the meteorological station located in Sungai Petani Hospital (www.met.gov.my). Whereas the salinity regimes were categorized as freshwater (0 to <0.5), oligohaline (0.5 to <5.0), mesohaline (5.0 to <18.0) and polyhaline (18 to 30.0), following to Paperno and Brodie (2004).

2.3. Fish sample collection

Fish were sampled using barrier nets that were 100–120 m long and 3–5 m deep, with a mesh size of 2.5 cm. This net is designed without any bag or bunt and is regarded as non-selective gear. The nets were deployed by artisanal fishermen in the mudflat creek infront of the mangroves vegetation along the Merbok estuary, and the samples were obtained from an area that was within a 2-km radius of each physicochemical sampling stations (see Fig 1). Fishing operations were normally carried out 3–4 days before and after the full moon and 3–4 days before and after new moon associated with spring tides of the month. More importantly, deployment of the net requires strong water currents to effectively capture fish and shrimps in the net. Fishing activities were normally halted during neap tides. Net operations were usually conducted during low water, by securing the bottom of the net to the river bed of the tributaries. The head rope was then raised and secured to poles to stretch the net high during high tide and the catches were harvested during low water, i.e. 12 h after the net was set. The fishing locations were always changed to improve effectiveness and obtain a better catch.

Every month from January to December 2010, 6 to 10 fishermen were interviewed at the fish landing site, and the fish landing data, including fishing locations and catches, were matched to the sampling stations, as shown in Fig. 1. Sub-samples of the catches were collected and sorted at the species level, as described by De Bruin et al. (1994), Mohsin and Ambak (1993, 1996), Mansor *et al*. (1998) and Ambak *et al.* (2010). As a counter check, fish samples were also collected on a quarterly year basis to determine the species composition of the trash fish (smaller sizes of commercial fish). The species composition of the sub-samples was then raised to the total catch of the sampled boats. Three fishing boats were selected for this purpose, and the fishermen were requested to fish at a selected location that was within the 2-km radius of the physicochemical sampling stations. All necessary measurements such as the length and weight were recorded. The data were collated using Microsoft Excel. Fishes intended for population biology studies were randomly collected, kept on ice and transported to the laboratory for further analysis.

Fishes that inhabit the Merbok estuary were categorized as follows: marine (M), marine-estuarine-dependent (MED), estuarine resident (E), estuarine-freshwater-dependent (EFD), freshwater (FW), catadromous (C), and anadromous (A). Some marine species are also termed as occasional marine visitors (Day *et al*. 1989) because only a small proportion of their overall population uses estuaries (Potter *et al*. 1990, Whitfield 1999). Marine-estuarine-dependent species are also called marine migrants as these species use estuaries extensively during the juvenile and/or adult life stages (Potter *et al*. 1990, Whitfield 1999). Freshwater species are those that are restricted to rivers but occasionally enter estuaries when the conditions are favourable (Day *et al*. 1989). Estuarine residents refer to species of marine origin that reside in estuaries and can complete their life cycle within these systems (Whitfield 1999). Catadromous species are fishes that spawn in the sea but use freshwater catchment areas during the juvenile and sub-adult life stages and the opposite is true for anadromous fish species.

2.4. Statistical analysis

Species compositions on individual boats and trips were standardized to catch per unit effort (CPUE) in grams per boat per fishing trip (g/b/t). Physicochemical variables, fish species composition and community structure were analysed monthly, seasonally and per site. Prior to all analyses of variance, assessment of the assumptions of normality (Kolmogorov-Smirnov test) and homogeneity of variances were performed for all the descriptors. Variables not fulfilling any of these assumptions were transformed with different functions and tested by nonparametric analysis of variance (Spearman correlation - Sokal & Rohlf 1998).

Fish abundance at different sites and in various months was analysed using Spearman's correlation test (Sokal & Rohlf 1998). Species abundance in relation to environmental variables (TEMP, COND, TURB, WD, rainfall, pH and SAL) was also analyzed using the canonical correspondence analysis (CCA). This ordination method was used to detect patterns of species association directly related to environmental variables (ter Braak & Verdonschot 1995). To reduce the effect of rare species, only species with a number of observation greater than 5 ($n > 5$) were considered in the CCA. In the ordination diagram produced by CANOCO (ter Braak & Verdonschot 1995), the importance of environmental factors is indicated by the relative length of vectors, i.e. the longer the vector, the greater the influence on species distribution. In addition, the closer the species on the vector, the greater the relationship with the environmental parameters (ter Braak 1986). Any species that is highly influenced by variables would be positioned along the axis created by two vectors rather than at the end of any single vector (ter Braak 1986). These univariates of non-parametric statistical technique enable analysis of the relationship between species abundance and abiotic factors on an individual level and also allow the identification of factors responsible for the structure of fish assemblages.

3. Results

3.1. Temporal and spatial variations in physicochemical parameters

The sampling areas extended outward from the upper to the lower zones of the estuarine systems. The *in-situ* physicochemical parameters recorded on a monthly basis are summarised in Table 1. The temporal variation in rainfall and the temporal and spatial variations in the other physicochemical parameters, including TEMP, COND, TURB, SAL, pH and WD, are shown in Figs. 2 and 3, respectively.

Rainfall ranged from 0.0 mm to 79.00 mm with a mean value of 3.5 mm (±1.69). Temporal variations in the rainfall defined the seasons as follows. The dry season was the season occurring in January and February, secondary rainy season was from March to May, primary rainy season was from September to November (see Fig. 2).

During the study period, the recorded TEMP ranged from 27.70°C to 32.35°C with a mean value of 30.17°C ± 1.15°C. The differences in the TEMP between stations were not significant (see Table 1). The lowest mean TEMP was at St1 (29.65°C ± 0.44°C), and the highest mean was at St5 (30.51°C ± 0.40°C). TEMP differed markedly between the months, with a lower value (27.7°C) in September and a higher value (32.35°C) in May. Temporal variations in TEMP were significantly different ($P < 0.01$) and were strongly influenced by the dry season and rainy season (see Figs. 2 and 3).

The COND readings ranged between 900 and 45,365 µmHos cm^{-1}, with a mean value of 29,265.41 ± 8,740.76 µmHos cm^{-1}. The highest mean COND value was recorded in May (39,497.50 ± 2,871.65 µmHos cm^{-1}) and the lowest in December (14,833.33 ± 4,142.59 µmHos cm^{-1}). The COND values differed significantly across months ($P < 0.001$), but the difference was not spatially significant ($P > 0.05$). The variation was affected by continuous flush-off-effluent during the primary rainy season; these became lesser towards the end of the year, as demonstrated by the lower value (mean 20,027.08 ± 8,563.13 µmHos cm^{-1}) in the upper areas (St1 and St2) which was affected by the run-off sediment from adjacent tributaries. The COND readings gradually increased seawards (St6) with a mean value of 33,145.83 ± 7,434.74 µmHos cm^{-1}.

Transparency or turbidity (TURB) in the estuary ranged from 2.5 to 25 cm (mean 9.23 ± 4.87 cm). The lowest mean TURB value was recorded in June (4.17 ± 1.08 cm), while the highest was in October (19.5 ± 1.87 cm). The fluctuation corresponded with rainfall distribution, and high TURB values were recorded during the rainy periods. The spatial variation in TURB was not significant ($P > 0.05$), with the highest value recorded in St3 (12.16 ± 6.64 cm).

The SAL readings ranged from 3.50 to 30.75 ppt with a mean value of 21.36 (± 6.17 ppt). The value varied monthly (significant at $P = 0.001$), with the lowest mean value of 13.04 ± 7.19 ppt in December and the highest (25.54 ± 4.50 ppt) in August. The SAL values drastically decreased during rainy periods and towards the end of the year. In comparison with the five other sampling sites towards the mouth of the estuary systems, St1 recorded the lowest salinity (13.15 ± 6.13 ppt). However, no significant differences were recorded between months and sites. Generally, SAL fluctuated significantly between months, with higher values recorded at the beginning of the year (low rainfall) and lower values during the primary rainfall period. The SAL readings also gradually decreased towards the upper zone (St1) of the estuary due to freshwater inflow (see Figs. 2 and 3). Overall, SAL in the Merbok estuary ranged between 8 and 25 ppt. Therefore, the Merbok estuary was classified as mesohaline (5.0 to <18.0 ppt) in the upper areas and polyhaline (18 to 30.0 ppt) in the middle and lower zones.

The pH values ranged between 6.35 and 8.15, with a mean value of 7.15 (±0.37). The pH was found to vary significantly across months ($P < 0.001$), with a fluctuating mean value of 6.95 ± 0.52 in April and 7.63 ± 0.45 in August (Fig. 3). There was no significant difference in pH among the sampling sites (Table 1).

There were strong positive correlations between COND and SAL (0.603), followed by TEMP and COND (0.528), pH and COND (0.423) and SAL and pH (0.351). In contrast, there were strong negative correlations between TURB and pH (-0.363) at $P > 0.01$ (see Table 2). These correlations were probably strongly influenced by the rainfall distribution.

In general, rainfall distribution influenced TEMP, TURB and COND. The lowest mean values were recorded under low rainfall conditions and considerably higher values were observed during the rainy months (see Figs. 2 and 3).

3.2. Fish community structure

A total of 74 fishing boats were sampled. The fishermen were interviewed, and the catch composition was examined by species and size. Eleven boats were assessed from St1 in the Lalang River area, 14 from St2 in the Semeling River area, 14 from St3 in the Keluang River area, 11 from St4 in the Teluk Wang area, 11 from St5 in the Gelam River area and 13 from St6 in the Lubuk Pusing area.

Species occurrence in term of percentage, composition, catch rate, and habitat categories are tabulated in Appendix 1 which also lists the codes of the species. The data indicate that the Merbok estuary could be occupied by 69 species of fish, representatives of 45 genera and from 36 families of fish and two families of shrimps, 3 genera and 8 species of shrimps. The average CPUE of fishes and shrimps captured by barrier nets was 1,248.58 g/b/t, of which fish species contributed 72.06% (897.9 g/b/t) and marine and freshwater shrimps 27.94% (350.68 g/b/t).

Of the total fish caught, 31.56% belonged to Ariidae, 10.62% to Mugilidae, 6.23% to Gerreidae, 6.19% to Sciaenidae, 4.82% to Lutjanidae, 4.72% to Scatophagidae, 4.47% to Megalopidae, 3.79% to Sphyraenidae, 3.10% to Eleotridae, 2.66% to Latidae, and less than 2.5% to other families.

Although fish assemblage was structured by many species, only a few dominant species emerged (Fig. 4, Appendix 1). *Arius* spp; as estuarine-resident (E) such as *A. argyropleuron*, *A. maculatus and A. caelatus* was the most dominant species which estimated about 29.79%, followed by 4.72% of *Scatophagus argus (*estuarine-freshwater-dependent, EFD), 4.47% of *Megalops cyprinoids (*estuarine-dependent, E), 4.15% of *Gymnura poecilura* (marine-estuarine-dependent, MED), 3.19% of *Liza vaigensis* (MED), 3.06% of *Johnius belangerii* (MED), 2.79% of *Butis gymnopomus* (E), 2.73% of *Gerres filamentosus* (MED), 2.66% of *Lates calcarifer* (E) and below 2.5% including *Sphyraena barracuda, Lutjanus johni* and *L. russelli* (marine, M) fish species (see Fig. 4).

3.3. Temporal and spatial variations in fish assemblages

The catch rate of fish decreased with an increase in the value of environmental variables such as TEMP. TURB and rainfall positively influenced fish distribution. The catch rate of fish decreased as the TURB and rainfall values increased (see Fig. 3 and Fig. 5). The highest mean CPUE value was recorded in October (33,810.88 ± 23,319.80 g/b/t), and the lowest in May (4,737.50 ± 4,140.73 g/b/t). Some species such as *L. calcarifer, L. russelli* and *Plotosus canius* were recorded at each sampling station, with mean CPUE values ranging from 943.13 ± 618.04 g/b/t at St3 to 2,983.33 ± 2,237.33 g/b/t at St4, from 779.23 g/b/t (±403.34) at St2 to 1,569.2 g/b/t at St4 and from 746.5 g/b/t (±572.22) at St6 to 3,450 g/b/t (±4,503.75) at St4 (see Appendix 1). A similar pattern was also observed for *S. argus* with the mean CPUE ranging from 1985.35 ± 2069.65 g/b/t at St6 to 4500 g/b/t at St5. The mean CPUE of *B. gymnopomus* ranged from 318.85 ± 362.99 g/b/t at St6 to 3147.75 ± 3441.79 g/b/t at St2. *L. russelli* is a marine fish species but smaller sizes of these fish use the Merbok estuary as their nursery ground.

Fish catch rate was lower during the first half of the year but higher during the second half of the year. Coincidentally, it was associated with the rainy periods and type of migrant fish species. MED species were present in the primary rainy periods of the year, while marine species were found during the dry season towards the end of the year. Spatially higher abundance was recorded at St3, St4, and St6, probably due to the mixing of a larger volume of marine water. However, this finding differed from that observed for the shrimp population, which fluctuated throughout the year and sites.

3.4. Physicochemical parameters and fish and prawn assemblages

Associations between the environmental variables measured *in-situ* and the abundance of fish populations were analysed using the Spearman correlation (Table 2). A positive and strong correlation was observed between TURB and *B. gymnopomus* (EleBgym) (0.659, P = 0.01), whereas a strong and inverse correlation was observed with pH (-751, P = 0.01). SAL was strongly correlated with *L. calcarifer* (LatLcal) (-0.481, P = 0.01). However, other species such as *Batrachomoeus trispinosus* (BatBtri) and LatLcal were also positively correlated (P = 0.05) with WD. The pH was another parameter that influenced the distribution of estuarine-dependent species such as *Penaeus indicus* (PenPind), *Penaeus merguiensis* (PenPmer), *Pomadasys kaakan* (HaePkaa), and *Lutjanus russelli* (LutLrus).

The CCA diagram in Fig. 6 indicates the longer the vector, the greater the influence of *in-situ* parameters on species distribution. Moreover, the closer the species to the vector or other species, the stronger the relationship. The relative position along the vector indicates the type of effect. COND was found to be the most important parameter affecting the distribution of *A. caelatus* (AriAcea), *J. belengeri* (SciJbel), and *S. argus* (ScaSarg). However, these did not show any significant correlation. *L. calcarifer* (LatLcal), *P. kaakan* (HaePkaa) and *L. russelli* (LutLrus) showed a high correlation with TEMP. None of the fish species showed strong positive correlations with pH except for a very weak correlation with *L. vaigensis* (MugLvai) and *Sphyreana barracuda* (SphSbar). Overall, the distribution of most of the species in the Merbok estuary was actually impacted by COND, TEMP, and TURB, but the correlations were inversed for SAL and pH.

4. Discussion

Estuaries serve as a nursery ground for many commercially important fish species and crustaceans (Sasekumar 1992, Elliott & Dewailly 1995, Vasconcelos *et al*. 2010), including seagrass communities of resident and non-resident species (Laegdsgaard & Johnson 1995). These water bodies are known to be impacted by biotic and abiotic factors (Weinstein & Heck 1979). Abiotic factors associated with fish assemblages include salinity (Peterson & Ross 1991, Szedlmayer & Able 1996, Arceo-Carranza & Vega-Cendejas 2009), temperature (Rakocinski *et al*. 1992, Arceo-Carranza & Vega-Cendejas 2009), turbidity (Peterson & Ross 1991), depth (Keskin 2007) and hydrology patterns (Pritchett & Pyron 2011). In a tropical estuary, temperature is always inversely correlated with salinity, whereas transparency has a different structuring factor and is directly correlated with the salinity gradient during floods but has less correlation in the dry season (Simier *et al*. 2006). Temperature variation is normally triggered by rainfall, with was slightly increases during heavy rain and decreases in the dry season as recorded in the present study (see Figs. 2 and 3). These phenomena had significant effects in the Merbok estuary due to influx warm water from tributaries.

The distribution of juveniles of marine migrant species within estuarine grounds results from the responses of individuals to multiple environmental variables such as salinity, water temperature, food availability or sediment type such as the presence of seagrass which are highly dynamic (Stoner *et al*. 2001, Selleslagh *et al*. 2009). The distribution of fish was related to physicochemical parameters as can be observed in the Merbok estuary where most of fish species were strongly influenced by COND, TEMP and TURB and inversely correlated to SAL and pH.

Changing fish distribution and abundance will undoubtedly affect human communities that harvest these stocks (Roessig *et al*. 2004). Most of the fish caught from the Merbok estuary were at the juvenile stage (Mansor *et al*. 2011a) and exceptional for most estuarine-dependent species such as *L. calcarifer*. They were composed of juvenile marine migrant species, which were influenced by turbidity gradients in estuaries in agreement to Cyrus and Blaber (1987). Other factors such as calm water and food availability were also suggested to affect the distribution and abundance of juveniles (Cyrus & Blaber 1992). The effects of climate change (Roessig *et al*. 2004) on estuarine fish individuals, populations, communities and assemblages have been widely addressed (Gibbs 2006).

In this study, a barrier net used to sample fishes in mangrove mudflat habitats with a mesh size of 2.5 cm was considered non-selective as it managed to capture the smallest fish (represented by *S. argus*, 2.2 cm in TL) and the largest fish (represented by *L. calcarifer*, 82.0 cm in TL) of body weights 0.5 g and 6,600 g, respectively (Mansor *et al*. 2012a). Most of the estuarine-dependent fish collected in this study were juveniles, and fish abundance were higher during dry periods due to the fact that the mangrove sheltered the fish population from marine predators mingling around the coastal area. The dependence of many fish species on mangroves is species-specific (Nagelkerken *et al*. 2000, Hindell & Jenkins 2004, Chittaro *et al*. 2005). The results presented in this study suggest that the dependence of some species on mangrove habitats is also site-specific (Nip & Wong 2010).

Most of the parameters recorded *in-situ*, including TEMP, TURB, COND, SAL and pH, differed significantly on a monthly basis ($P < 0.001$) but not spatially. COND was strongly correlated with WD, SAL and pH, and was strongly influenced by the distribution of rainfall that caused the inflow of freshwater from nearby tributaries to the estuary. The pH was found to strongly affect SAL and TURB. Thus, these parameters are inter-correlated and can influence fish distribution as suggested by Nip and Wong (2010).

The water temperature plays an important role in structuring fish communities in mangroves, estuaries and coastal areas (Whitfield 1999, Blaber *et al*. 2000). Relatively small temperature variations affected the distribution and abundance of fish as recorded in the present study suggesting that more species were recruited into the area during high temperature months during the second half of the year and during the first half of the year. This was in agreement with the results of Nip and Wong (2010). The large inter- and intra-month variation in water temperature was due to the southwest monsoon season in March-May and during the northeast monsoon season in September-February and tidal fluctuation in the estuary with cold incoming seawater and warm outgoing freshwater.

The Spearman correlations shown in Table 2 demonstrated that there was no correlation between fish species and COND, with the exception of *B. gymnopomus* which showed significance at $P < 0.05$. This suggested that COND had no significant effects on fish distribution. Although many species lie close to the line factor (see Fig.

6), these were probably physically adapted and tolerated the large variations in turbidity associated with organic-rich areas (Whitfield 1994, Laegdsgaard & Johnson 1995, Kuo *et al*. 1999). For example, the upper reaches had a high abundance of FW species as observed for tilapia (see Appendix 1), but this area was apparently not preferred by marine migrants. Blaber *et al*. (2000) suggested that TURB had a positive effect on fish abundance. However, in the present study, there was a strong correlation between TURB and *B. gymnopomus* abundance (see Table 2 and Fig. 6), supporting the view that TURB is always a determinant factor in fish abundance (Whitfield 1994, Laroche *et al*. 1997, Strydom *et al*. 2002).

Most water bodies in tropical regions show two differentiable seasons (dry and wet), and the majority of these water bodies depend on seasonal changes to activate and deactivate environmental parameters (Fialho *et al*. 2007). Freshwater runoff increases during the rainy season, leading to a decrease in salinity. The dilution effect of marine water in the estuary is conducive for freshwater and brackish water species such as Scatophagidae, Eleotridae, and Cichlidae, which thrive in this environment. Similar effects were also observed by Simier *et al*. (2006). However, during the dry season, high salinity triggers the entry of some marine species (Carangidae) into the estuary due to the availability of food and shelter from predators (Blaber 1997, Marshall & Elliot 1998). These species tend to migrate seawards as they grow bigger in size, just before the next rainy season. This was supported by the fluctuation in CPUEs, which was lower than 10,000 g/b/t in March through July and increased at the end of the year and in January of the following year. These phenomena reveal that the higher catch rates were contributed by marine fish species that tend to migrate inwards to the estuary during the dry season at the beginning and end of the year.

Heavy rain (wet season) will lead to alterations in water quality. For example, the water depth and turbidity will increase but conductivity, salinity and pH will decrease. The reverse is observed during the dry season. High precipitation during the primary wet season (March to June) and secondary wet season (August to November) increased the water velocity and volume. It also loaded the estuary with silt, organic and inorganic materials which accumulated in the soil for the next dry and transitional period. The rainy season was favoured by marine-estuarine-dependent species of fish and shrimps such as *L. calcarifer* and estuarine-dependent species like *B. gymnopomus.* Although all the species did not show a correlation with rainfall (Spearman Test), CCA clearly shows that there was a strong correlation with species such as *S. argus.* This indicates that rainfall has an indirect relationship with the species present. Roessig *et al*. (2004) described seasonal rainfall as the main factor that affects the strategies of the life cycle of fish, such as their movement, feeding, growth and spawning. Seasonal variations in rainfall create and/or eliminate micro-habitats which are important for fish (Olukolajo & Oluwaseun 2008). In addition, precipitation promotes alterations in species abundance and richness over a large spatial scale, and this is also important over a small spatial scale such as in small creeks (Grossman *et al.* 1985). This was also observed in the present study.

Generally, salinity decreases gradually towards the upper reaches of the estuary where there is significant freshwater inflow. Salinity is regarded as a variable that influences the occurrence of some species (Akin et al., 2005); however, this was not the case in the Merbok estuary. This factor was not supported in the CCA diagram, where salinity was the weakest parameter to influence Merbok estuary fish assemblages. However, the Merbok estuary experiences fluctuation in salinity on both tidal and low frequency time scales. Three locations (St4, St5 and St6) were isohaline. Moreover, the estuary was considered mesohaline (5.0 to <18.0 ppt) in April, September and December and polyhaline (18 to 30 ppt) from January to March, May to August and October to November. This significant result was supported by the presence of euryhaline species such as the family of Sphyraenidae (marine-dependent) in the upper (St1 - St3) and lower regions (St6) near the river mouth.

Fish assemblages varied among locations, mainly in the upper zone, where estuarine-dependent fish species (such as Triachantidae and Labridae) and marine-estuarine-dependent fish species (such as Mugilidae) were more abundant, and in the lower zone, where marine-dependent species (such as Ariidae, Carangidae) were abundant. This finding is supported by Akin *et al*. (2005) who showed that the longitudinal position (location) was an important variable for fish in streams. In the Merbok estuary, fish species tended to be more abundant in the middle reaches (St3 and 4) than in the upper reaches (St1 and 2) due to the mixing of meso- and polyhaline sea nutrient sources. Most species in the upper reaches were estuarine-dependent species, while the species composition in the lower reaches was related to other factors, such as the migration of marine-dependent species, rather than to salinity and temperature (Smith & Parrish 2002). These variations were probably influenced by the phytoplankton biomass and nutrient availability in the spring tide due to out-welling from the mangrove swamp and creek (Tanaka & Choo 2000). Marine-dependent species in the Merbok estuary were mostly restricted to the lower reaches of the estuary, while more estuarine-dependent species were found in the upper reaches. These results were consistent with those of several other studies in which it was shown that the dependence of fish on mangrove is species-specific and is also site-specific (Nagelkerken *et al*. 2000, Smith & Parrish 2002, Hindell & Jenkins 2004, Chittaro *et al*. 2005).

Factors that contribute to high precipitation and contamination of water bodies include aquaculture activities along the Merbok estuary, influx of sediment from tributaries that link to residential areas and the release of agricultural waste. As the mature and immature individuals of many estuarine-dependent fish species are utilized commercially, preservation of estuarine habitats is critical for the maintenance of marine and estuarine fisheries. Anthropogenic effects on the Merbok estuary basin, arising from practices such as deforestation, agriculture, pond and cage culture together with significant use of fishing gears of artisanal fishing, require thorough monitoring because these factors affect fish assemblages in the area. The smaller catches of fish species, decreasing size of commercially important fishes and decreasing diversity and abundance of fish species coupled with the high contamination levels of the water body are indicators of the degradation level of the estuary and cannot be ignored (Gamito & Cabral 2003). Moreover, these wide variations in estuarine functioning are partly elevated by sharp increases in urban and agricultural pollution (Scheren *et al*. 2004) and in the case of the Merbok estuary, by highly diversified fishery exploitation.

In conclusion, this study has shown that rainfall is the most important environmental factor governing fish community structure in estuarine systems because it is associated with changes in turbidity, conductivity, salinity, temperature, water depth, and pH. These factors have significant effects on temporal fluctuation in fish abundance but not on spatial fluctuation. These distinctive physical characteristics indicate that the Merbok estuary has low seasonality in terms of the discharge of inland and marine waters, resulting in mesohaline and polyhaline waters that generate a stable environmental gradient. These gradients determine the persistent extension and penetration of marine-dependent species into the estuary and lead to the formation of fish assemblages in particular estuarine zones in the case of estuarine-dependent species. However, anthropogenic activities have had a much greater impact on the estuary than natural events. These needs further monitoring because this area is an important nursery ground for fishes, crustaceans, and molluscs, and local communities depend on it for their livelihood.

Acknowledgements

We would like to thank the Universiti Sains Malaysia for providing the physical facilities to carry out this research. This study would not have been possible without the support, cooperation and active involvement of the staff of the School of Biological Sciences and Center of Marine Coastal Studies. Special thank goes to Prof. Jackson, D. a lecturer of the Mississippi State University for his valuable comments and suggestions on the manuscript. This project was funded by USM Short Term Research Grant 304/Pbiologi/6311083.

References

Akin, S., Buhan, E., Winemiller, K.O. & Yilmaz, H., 2005. Fish assemblage structure of Koycegiz Lagoon Estuary, Turkey: Spatial and temporal distribution patterns in relation to environmental variation. Estuarine, Coastal and Shelf Science 64, 671-684.

Ambak, M.A., Mansor, M.I., Mond-Zaidi, Z. & Mazlan, A.-G., 2010. Fishes of Malaysia. Penerbitan Universiti Malaysia Terengganu. 344 pp.

Arceo-Carranza, D. & Vega-Cendejas, M.E., 2009. Spatial and temporal characterization of fish assemblages in a tropical coastal system influenced by freshwater inputs: northwestern Yucatan Peninsula. Revista de Biología Tropical 57(1-2), 89-103.

Barton, B.A., Morgan, J.D. & Vijayan, M.M., 2002. Physiological and condition-related indicators of environmental stress in fish. In: Biological Indicators of Ecosystem Stress (Adams, S.M., ed), pp. 111–148. Bethesda, MD: American Fisheries Society.

Blaber, S.J.M., 1997. Fish and Fisheries of Tropical Estuaries, 1st edn. London: Chapman & Hall.

Blaber, S.J.M., Cyrus, D.P., Albaret, J.J., Ching, C.V., Day, J.W. & Elliott, M., 2000. Effects of fishing on the structure and functioning of estuarine and nearshore ecosystems. ICES *Journal of Marine Science* 57, 590-602.

Boesch, D.F. & Turner, R.E., 1984. Dependence of fishery species on salt marshes: the role of food and refuge. Estuaries 7, 460-468.

Chittaro, P.M., Usseglio, P. & Sale, P.F., 2005. Variation in fish density, assemblage composition and relative rates of predation among mangrove, seagrass and coral reef habitats. Environmental Biology of Fishes 72, 175-187.

Cyrus, D.P. & Blaber, S.J.M., 1987. The influence of turbidity on juvenile marine fishes in estuaries. Part 1. Field studies at Lake St. Lucia on the southeast coast of Africa. Journal of Experimental Marine Biology and Ecology 109, 53-70.

Cyrus, D.P. & Blaber, S.J.M., 1992. Turbidity and salinity in a tropical Northern estuary and their influence on fish distribution. Estuarine, Coastal and Shelf Science 35, 545-563.

Day, Jr.J.W., Hall, C.A.S., Kemp, W.M. & Yanéz-Arancibia, A., 1989. Estuarine Ecology. New York: Wiley.

De Bruin, G.H.P., Russell, B.C. & Bogusch, A., 1994. The marine fishery resources of Sri Lanka. FAO Species Identification field guide for fishery purpopses. FAO of United Nation, Rome.

Ecoutin, J.-M., Richard, E., Simier, M. & Albaret, J.-J., 2005. Spatial versus temporal patterns in fish assemblages of a tropical estuarine coastal lake: The Ebrié Lagoon (Ivory Coast). Estuarine, Coastal and Shelf Science 64, 623-635.

Elliott, M. & Dewailly, F., 1995. The structure and components of European estuarine fish assemblages. Netherlands Journal of Aquatic Ecology 29(3-4), 397-417.

FAO/BOBP. (1984). Development of small scale fisheries: coastal agriculture demonstration project for shrimp and finfish at Ban Merbok, BOBP/REP/20.

Fialho, A.P., Oliveira, L.G., Tejerina-Garro, F.L. & Gomes, L.C., 2007. Fish assemblage structure in tributaries of the Meia Ponte River, Goiás, Brazil. Neotropical Ichthyology 5(1), 53-60.

Gamito, R. & Cabral, H., 2003. Mortality of brown-shrimp discards from the beam trawl fishery in the Tagus estuary, Portugal. Fisheries Research 63, 423–427.

Gibbs, P., 2006. Climate change and the fisheries of NSW - a background paper for NSW Department of Primary Industries.

Grosse, D.J., Scholz, P.M., Hirshfield, M.F., Meaburn, G.M. & Fletcher, M., 1997. Fisheries and pollution: a conference overview. Transactions of the American Fisheries Society 126, 504–505.

Grossman, G.D., Freeman, M.C., Moyle P.B. & Whittaker, J.O., 1985. Stochasticity and assemblage organization in an Indiana stream fish assemblage. American Naturalist 126, 275-285.

Hindell, J.S. & Jenkins, G.P., 2004. Spatial and temporal variability in the assemblage structure of fishes associated with mangroves (*Avicennia marina*) and intertidal mudflats in temperate Australian embayments. Marine Biology 144, 385-395.

Ikejima, K., Tongnunui, P., Medej, T. & Taniuchi, T., 2003. Juvenile and small fishes in a mangrove estuary in Trang Province, Thailand: seasonal and habitat differences. Estuarine, Coastal and Shelf Science 56, 447-457.

Keskin, C., 2007. Temporal variation of fish assemblages in different shallow-water habitats in Erdek Bay, Marmara Sea, Turkey. Journal of Black Sea/Mediterranean Environment 13, 215-234.

Kuo, S.-R., Lin, H.-J. & Shao, K.-T., 1999. Fish assemblages in the mangrove creeks of northern and southern Taiwan. Estuaries 22, 1004-1015.

Laegdsgaard, P. & Johnson, C.R., 1995. Mangrove habitats as nurseries: unique assemblages of juvenile fish in subtropical mangroves in eastern Australia. Marine Ecology Progress Series 126, 67-81.

Laroche, J., Baran, E. & Rasoanandrasana, N.B., 1997. Temporal patterns in a fish assemblage of a semiarid mangrove zone in Madagascar. Journal of Fish Biology 51, 3-20.

Little, M.C., Reay, P.J. & Grove, S.J., 1988. The fish community of an East African mangrove creek. Journal of Fish Biology 32, 729-747.

Mansor, M.I., Kohno, H., Ida, H., Nakamura, H.T., Aznan, Z. & Syed-Abdullah, S.A.K., 1998. Field guide to important commercial marine fishes of the South China Sea. Marine Fishery Resources Development and Management Department, Southeast Asian Fisheries Development Center (MFRDMD/SEAFDEC). 287 pp.

Mansor, M.I., Nur-Hidayyah, S. & Tan, S.H., (*in press*). Growth, mortality and recruitment patterns of venus clam, *Meretrix meretrix* (Linnaeus, 1758) in Merbok Estuary, Kedah.

Mansor, M.I., Najamuddin, A.B., Mohamad-Zafrizal, M.Z., Khairun, Y. & Siti-Azizah, M.N., 2012a. Length-weight relationships of some important estuarine fish species from Merbok estuary, Kedah. Journal of Natural Sciences Research 2(2), 8–17.

Mansor, M.I., Nurul-Shafikah, M.-N., Khairun Y. & Siti-Azizah, M.-N., 2012b. Size composition and reproductive biology of estuarine catfish, *Arius argyropleuron* (Siluriformes: Ariidae) in the Northern Part of Peninsular Malaysia. Journal of Biology, Agriculture and Healthcare 2(3), 14–27.

Marshall, S. & Elliott, M., 1998. Environmental influences on the fish assemblage of the Humber estuary, U.K. Estuarine, Coastal and Shelf Science 46, 175–184.

McLusky, D.S. & Elliott, M., 2004. The Estuarine Ecosystem: Ecology, Threats and Management. New York: Oxford University Press Inc.

Mohsin, M.A.K. & Ambak, M.A., 1993. Freshwater fishes of Peninsular Malaysia. Penerbit Universiti Pertanian Malaysia. 283 pp.

Mohsin, M.A.K. & Ambak, M.A., 1996. Marine Fishes and Fisheries of Malaysia and Neighbouring Countries. Universiti Pertanian Malaysia Press. Serdang Selangor, Malaysia: 744 pp.

Mwandya, A.W., Gullström, M., Öhman, M.C., Andersson, M.H. & Mgaya, Y.D., 2009. Fish assemblages in Tanzanian mangrove creek systems influenced by solar salt farm constructions. Estuarine, Coastal and Shelf Science 82, 193-200.

Nagelkerken, I., van-der-Velde, G., Gorissen, M.W., Meijer, G.J., van't Hof, T. & den Hartog, C., 2000. Importance of mangroves, seagrass beds and the shallow coral reef as a nursery for important coral reef fishes, using a visual census technique. Estuarine, Coastal and Shelf Science 51, 31-44.

Nip, T.H.M. & Wong, C.K., 2010. Juvenile fish assemblages in mangrove and non-mangrove soft-shore habitats in eastern Hong Kong. Zoological Studies 49(6), 760-778.

Olukolajo, S.O. & Oluwaseun, K.A., 2008. Seasonal variation in the distribution and fish species diversity of a tropical lagoon in South-West Nigeria. Journal of Fisheries and Aquatic Science 3(6), 375-383.

Ong, J.E., Gong, W.K., Wong, C.H., & Zubir, H.J.D., 1991. Characterization of a Malaysian mangrove estuary. Estuaries 14, 38-48.

Paperno, R. & Brodie, R., 2004. Effects of environmental variables upon the spatial and temporal structure of fish community in a small, freshwater tributary of the Indian River lagoon, Florida. Estuarine, Coastal and Shelf Science 61, 229-241.

Peterson, M.S. & Ross, S.T., 1991. Dynamics of littoral fishes and decapods along a coastal river-estuarine gradient. Estuarine, Coastal and Shelf Science 33, 467-483.

Pombo, L., Elliott, M. & Rebelo, J.E., 2005. Environmental influences on fish assemblage distribution of an estuarine coastal lagoon, Rio de Aveiro (Portugal). Scientia Marina 69, 143-59.

Potter, I.C., Beckley, L.E., Whitfield, A.K. & Lenanton, R.C.J., 1990. Comparisons between the roles played by estuaries in the life cycles of fishes in temperate Western Australia and Southern Africa. Environmental Biology of Fishes 28, 143-178.

Pritchard, D.W., 1967. What is an estuary: physical viewpoint. In *Estuaries* (Lauf, G.H., ed), A.A.A.S. Publ. No. 83, p. 3–5, Washington, D.C.

Pritchett, J. & Pyron, M., 2011. Fish assemblages respond to habitat and hydrology in the Wabash River, Indiana. River Research and Applications. doi:10.1002/rra.1528

Rakocinski, C.F., Baltz, D.M. & Fleeger, J.W., 1992. Correspondence between environmental gradients and the community structure in Mississippi sound as revealed by canonical correspondence analysis. Marine Ecology Progress Series 80, 135-257.

Roessig, J.M., Woodley, C.M., Cech, J.J. & Hansen, L.J., 2004. Effects of global climate change on marine and estuarine fishes and fisheries. Reviews in Fish Biology and Fisheries 14, 251-275

Rueda, M. & Defeo, O., 2003. Spatial structure of fish assemblages in a tropical estuarine lagoon: combining multivariate and geostatistical techniques. Journal of Experimental Marine Biology and Ecology 296, 93-112.

Sasekumar, A., Chong, V.C., Leh, M.U., D'Cruz, R.D., 1992. Mangroves as a habitat for fish and prawns. Hydrobiologia 247, 195–207.

Scheren, P.A.G.M., Kroeze, C., Janssen, F.J.J.G., Hordijk, L. & Ptasinski, K.J., 2004. Integrated water pollution assessment of the Ebrié Lagoon, Ivory Coast, West Africa. Journal of Marine Systems 44, 1-17.

Selleslagh, J., Amara, R., Laffargue, P., Lesourd, S., Lepage, M. & Girardin, M., 2009. Fish composition and assemblage structure in three Eastern English Channel macrotidal estuaries: a comparison with other French estuaries. Estuarine, Coastal and Shelf Science 81, 149-159.

Simier, M., Laurent, C., Ecoutin, J.-M. & Albaret, J.-J., 2006. The Gambia River estuary: A reference point for estuarine fish assemblages studies in West Africa. Estuarine, Coastal and Shelf Science 69, 615-628.

Smith, G.C. & Parrish, J.D., 2002. Estuaries as nurseries for the jacks *Caranx ignobilis* and *Caranx melampygus* (Carangidae) in Hawaii. Estuarine, Coastal and Shelf Science 55, 347-359.

Sokal, R.R. & Rohlf, F., 1998. Biometry: The Principles and Practice of Statistics in Biological Research. New York, USA: Freeman.

Stoner, A.W., Manderson, J.P. & Pessutti, J.P., 2001. Spatially explicit analysis of estuarine habitat for juvenile winter flounder: combining generalized additive models and geographic information systems. Marine Ecology Progress Series 213, 253-271.

Strydom, N.A., Whitfield, A.K. & Paterson, A.W., 2002. Influence of altered freshwater flow regimes on abundance of larval and juvenile *Gilchristella aestuaria* (Pisces: Clupeidae) in the upper reaches of two South African estuaries. Marine and Freshwater Research 53, 431-438.

Szedlmayer, S.T. & Able, K.W., 1996. Patterns of seasonal availability and habitat use by fishes and decapod crustaceans in a southern New Jersey estuary. Estuaries 19, 697-709.

Tanaka, K. & Choo, P.-S., 2000. Influences of nutrient outwelling from the mangrove swamp on the distribution of phytoplankton in the Matang Mangrove Estuary, Malaysia. Journal of Oceanography 56, 69-78.

ter Braak, C.J.F., 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. Ecology 67, 1167-1179.

ter Braak, C.J.F. & Verdonschot, P., 1995. Canonical correspondence analysis and related multivariate methods in aquatic ecology. Aquatic Science 57, 255-289.

Vasconcelos, R.P., Reis-Santos, P., Fonseca, V., Maia, A., Ruano, M., França, S., Vinagre, C., Costa, M.J. & Cabral, H., 2007. Assessing anthropogenic pressures on estuarine fish nurseries along the Portuguese coast: A multi-metric index and conceptual approach. Science of the Total Environment 374, 199-215.

Vasconcelos, R.P., Reis-Santos, P., Maia, A., Fonseca, V., França, S., Wouters, N., Costa, M.J. & Cabral, H.N., 2010. Nursery use patterns of commercially important marine fish species in estuarine systems along the Portuguese coast. Estuarine, Coastal and Shelf Science 86, 613-624.

Velazquez-Velazquez, E., Vega-Cendejas, E.M. & Navarro-Alberto, J., 2008. Spatial and temporal variation of fish assemblages in a coastal lagoon of the Biosphere Reserve La Encrucijada, Chiapas, Mexico. International Journal of Tropical Biology 56(2), 557-574.

Weinstein, M.P. & Heck, Jr.K.L., 1979. Ichthyofauna of seagrass meadows along the Caribbean coast of Panama and in the Gulf of Mexico: composition, structure, and community ecology. Marine Biology 50, 97-107.

Whitfield, A.K., 1994. Abundance of larval and 0+ juvenile marine fishes in the lower reaches of three southern African estuaries with differing freshwater inputs. Marine Ecology Progress Series 105, 257-267.

Whitfield, A.K., 1999. Ichthyofaunal assemblages in estuaries: A South African case study. Reviews in Fish Biology and Fisheries 9, 151-186.

Winemiller, K.O. & Leslie, M.A., 1992. Fish assemblage across a complex, tropical freshwater/marine ecotone. Environmental Biology of Fishes 34, 29-50.

www.met.gov.my. Meterological Department of Malaysia. Sccessed date 9th April 2012.

First Author:

MANSOR MAT ISA, born in Tokai, Kedah, Malaysia on 4th August 1955.

Graduated from National University of Malaysia in 1981.

Obtained Ph.D. on Fish Population Dynamics and Management
from University College of Swansea,Wales, United Kingdom in September 1993.

Became a Fisheries Officer from 1981 to 1989 at the Fisheries Research Institute, Penang Malaysia.

Appointed as a Fisheries Research Officer at the Fishery Resources Development and Management Department of the Southeast Asian Fisheries Development Center, Chendering, Kuala Terengganu, Malaysia from 1993 to 2005.

Took part as a part time tutor at the Open University of Malaysia, Sungai Petani Branch in 2006-2007.

Joining as a University Lecturer at the University Sains Malaysia from 2007 till present.

Table 1. The *in-situ* physicochemical parameters of the Merbok estuary with the chi-square values of temporal and spatial differences. Temperature (TEMP, °C), Conductivity (COND, µmHos cm^{-1}), Water depth (WD, m), Turbidity/transparency (TURB, cm), Salinity (SAL) and pH (pH).

Parameters	N	Mean	S.D.	Minimum	Maximum	Chi-square Temporal (df = 11)	Chi-square Spatial (df = 5)
TEMP	74	30.17	1.15	27.70	32.35	62.88***	2.84
COND	74	29265.41	8740.76	900.00	45365.00	43.28***	9.70
TURB	74	9.24	4.87	2.50	25.00	41.81***	5.87
SAL	74	21.36	6.17	3.50	30.75	44.75***	8.64
pH	74	7.15	0.37	6.35	8.15	34.52***	5.10
WD	74	3.73	2.03	0.48	10.75	17.06***	13.26*

Notes: * significant at P = 0.05, ** significant at P = 0.01, *** significant at P = 0.001, S.D.= standard deviation.

Table 2. Spearman correlation of fish abundance with physicochemical parameters in the Merbok estuary; Temperature (TEMP, °C), Conductivity (COND, µmHos cm^{-1}), Water depth (WD, m), Turbidity/transparency (TURB, cm), Salinity (SAL) and pH (pH).

Species name	**Species Code**	**TEMP**	**COND**	**WD**	**TURB**	**SAL**	**pH**
Batrachomoeus trispinosus	BatBtri	0.450	-0.357	0.821*	0.321	-0.679	-0.214
Butis gymnopomus	EleBgym	-0.369	-0.540*	-0.038	0.659**	-0.389	-0.751**
Pomadasys kaakan	HaePkaa	0.055	0.158	0.576	0.483	-0.067	-0.648*
Hyporhamphus quoyi	HemHquo	0.900*	-0.300	0.600	-0.051	-0.800	-0.100
Lates calcarifer	LatLcal	0.260	-0.142	0.336*	0.019	-0.481**	0.006
Lutjanus russelli	LutLrus	-0.104	-0.048	-0.326	0.127	0.122	-0.573*
Liza subviridis	MugLsub	0.237	0.146	0.600	0.0	0.152	-0.539
Liza tade	MugLtad	0.060	0.135	0.066	0.077	0.140	-0.151
Plotosus canius	PloPcan	0.189	0.082	-0.076	-0.107	0.186	0.287
Scatophagus argus	ScaSarg	-0.193	-0.102	-0.582*	0.024	0.084	-0.316
Dendrophysa russelii	SciDrus	0.714*	-0.216	0.690	0.265	-0.619	-0.524
Terapon jarbua	TerTjar	-0.086	-0.174	0.516	0.152	-0.829*	-0.543

Notes: * significant at P = 0.05, ** significant at P = 0.01.

Appendix 1. Fish composition in terms of catch per unit effort (CPUE, gram/boat/trip), collected using barrier nets in the Merbok estuary, Kedah. The Family Code (FmCode) and Species Code (SppCode) are given, and the organisms are categorised as follows; M: marine, MED: marine-estuarine-dependent, E: estuarine, FED: freshwater-estuarine-dependent, FW: Freshwater, CA: Catadromous, A: Anadromous.

Family name	FmCode	Fish species	SppCode	Category	Mean CPUE (g/b trip)	SD	% CPUE
Ariidae	Ari	*Arius argyropleuron*	AriAarg	E	8879.87	2714.82	13.36
"	Ari	*Arius caelatus*	AriAcae	MED	4800.00		7.22
"	Ari	*Arius maculatus*	AriAmac	MED	5592.68	3921.36	8.42
"	Ari	*Arius platystomus*	AriApla	M	130.00		0.20
"	Ari	*Arius sagor*	AriAsag	MED	1572.23	2364.16	2.37
Batrachoididae	Bat	*Batrachomoeus trispinosus*	BatBtri	MED	628.23	849.83	0.95
Belonidae	Bel	*Strongylura strongylura*	BelSstr	E	218.85	189.76	0.33
Carangidae	Car	*Carangoides praeustus*	CarCpra	M	10.66		0.02
"	Car	*Carangoides talamporoides*	CarCtal	M	40.00		0.06
"	Car	*Carangoides uii*	CarCuii	M	143.80	182.72	0.22
"	Car	*Caranx sexfasciatus*	CarCsex	M	33.09		0.05
Cichlidae	Cic	*Oreochromis mossambious*	CicCmos	FW	566.95	460.00	0.85
Clupeidae	Clu	*Anodontostoma chacunda*	CluAcha	M	45.60	20.36	0.07
Cynoglossidae	Cyn	*Cynoglossus bilineatus*	CynCbil	M	40.00		0.06
"	Cyn	*Cynoglossus lingua*	CynClin	M	472.70	155.14	0.71
"	Cyn	*Grammatobothus polyphthalmus*	CynGpol	M	36.15	24.25	0.05
Dasyatidae	Das	*Himantura walga*	DasHwal	MED	9.80		0.01
Eleotridae	Ele	*Butis butis*	EleBbut	E	227.44	167.01	0.34
"	Ele	*Butis gymnopomus*	EleBgym	E	1736.86	1018.52	2.61
Elopidae	Elo	*Elops hawaiensis*	EloEhaw	E	376.50	372.65	0.57
Engraulidae	Eng	*Encrasicholina punctifer*	EngEpun	M	37.50		0.06
"	Eng	*Stelophorus tri*	EngStri	M	34.90	16.97	0.05
Gerreidae	Ger	*Gerres filamentosus*	GerGfil	MED	2040.45	1489.61	3.07
"	Ger	*Gerres kapas*	GerGkap	M	1318.40	2149.25	1.98
"	Ger	*Gerres oyena*	GerGoye	M	920.00	1187.94	1.38
"	Ger	*Pentaprion longimanus*	GerPlon	MED	49.28	23.79	0.07
Gobiidae	Gob	*Acentrogobius audax*	GobAaud	MED	595.85	332.77	0.90
"	Gob	*Acentrogobius viridipunctatus*	GobAvir	MED	49.50		0.07
"	Gob	*Boleopthalmus pectinirostris*	GobBpec	MED	40.00		0.06
Gymnuridae	Gym	*Gynura poecilura*	GymGpoe	M	2700.00		4.06
Haemulidae	Hae	*Pomadasys kaakan*	HaePkaa	M	1336.28	1046.10	2.01
Hemiramphidae	Hem	*Hemiramphus far*	HemHfar	E	96.40		0.15
"	Hem	*Hyporhamphus quoyi*	HemHquo	E	63.02	38.62	0.09
Latidae	Lat	*Lates calcarifer*	LatLcal	E	1782.84	729.86	2.68
Leiognathidae	Lei	*Leiognathus nuchalis*	LeiLnuc	M	90.08	92.03	0.14
"	Lei	*Leiognathus smithursti*	LeiLsmi	M	340.00		0.51
Lethrinidae	Let	*Letrinus lentjan*	LetLlen	E	65.00		0.10
Lutjanidae	Lut	*Lutjanus russelli*	LutLrus	M	1311.41	664.58	1.97
"	Lut	*Lutjanus argentimaculatus*	LutLarg	M	1195.83	734.89	1.80
"	Lut	*Lutjanus johni*	LutLjoh	M	762.96	542.73	1.15
Megalopidae	Meg	*Megalops cyprinoides*	MegMcyp	EFD	2460.35	1911.24	3.70
Mugilidae	Mug	*Liza subviridis*	MugLsub	MED	1518.38	824.98	2.29
"	Mug	*Liza tade*	MugLtad	MED	973.94	481.92	1.47
"	Mug	*Liza vaigiensis*	MugLvai	MED	1851.39	1664.94	2.79
"	Mug	*Valamugil buchanani*	MugVbuc	MED	919.44	263.57	1.38
"	Mug	*Valamugil engeli*	MugVeng	MED	709.97	685.67	1.07
"	Mug	*Valamugil speigleri*	MugVspe	MED	741.26	839.62	1.12
Platycephalidae	Pla	*Platycephalus indicus*	PlaPind	M	652.20	664.60	0.98
Plotosidae	Plo	*Plotosus canius*	PloPcan	M	1490.36	1016.92	2.24
Polynemidae	Pol	*Eleutheronema tetradactylum*	PolEtet	M	1450.00		2.18
Scatophagidae	Sca	*Scatophagus argus*	ScaSarg	EFD	3293.58	874.25	4.96
Sciaenidae	Sci	*Dendrophysa russelii*	SciDrus	MED	245.34	84.70	0.37
"	Sci	*Johnius amblycephalus*	SciJamb	MED	30.65	0.78	0.05
"	Sci	*Johnius belangerii*	SciJbel	MED	2437.99	3787.31	3.67
"	Sci	*Johnius borneensis*	SciJbor	MED	1711.50		2.58
"	Sci	*Paranibea semiluctousa*	SciPsem	MED	20.50		0.03
Serranidae	Ser	*Epinephelus coioides*	SerEcoi	E	304.31	76.81	0.46
Siganidae	Sig	*Siganus canaliculatus*	SigScan	MED	895.00		1.35
"	Sig	*Siganus guttaus*	SigSgut	MED	305.00		0.46
"	Sig	*Siganus javus*	SigSjav	MED	152.84	103.34	0.23
Sillaginidae	Sil	*Sillago sihama*	SilSsih	M	218.81	218.77	0.33
Sphyraenidae	Sph	*Sphyraena baracuda*	SphSbar	M	1835.00	1027.07	2.76
"	Sph	*Sphyraena jello*	SphSjel	M	644.85	414.74	0.97
Stromathidae	Str	*Pampus argenteus*	StrParg	M	410.00		0.62
Terapontidae	Ter	*Terapon jarbua*	TerTjar	M	219.23	163.99	0.33
Tetraodonthidae	Tet	*Tetraodon fluviatilis*	TetTflu	MED	176.97	262.75	0.27
"	Tet	*Tetraodon nigroviridis*	TetTnig	MED	334.62	123.99	0.50

Journal of Natural Sciences Research
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.2, No.7, 2012

Triachantidae	Tri	*Pseudotriacanthus striglifer*	TriPstr	M	50.00	0.08

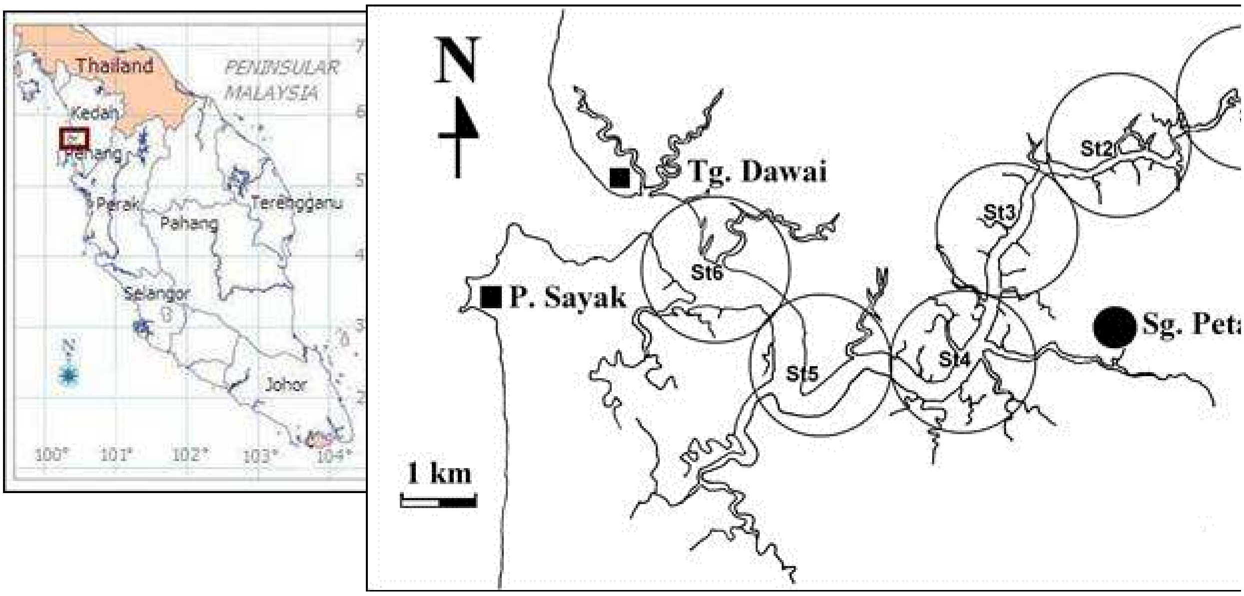

Figure 1. The Merbok estuary located in Kedah state with the six sampling stations. These were divided into three zones: upper (St1, Lalang River and St2, Semeling River), middle (St3, Keluang River and St4, Teluk Wang) and lower (St5, Gelam River and St6, Lubuk Pusing).

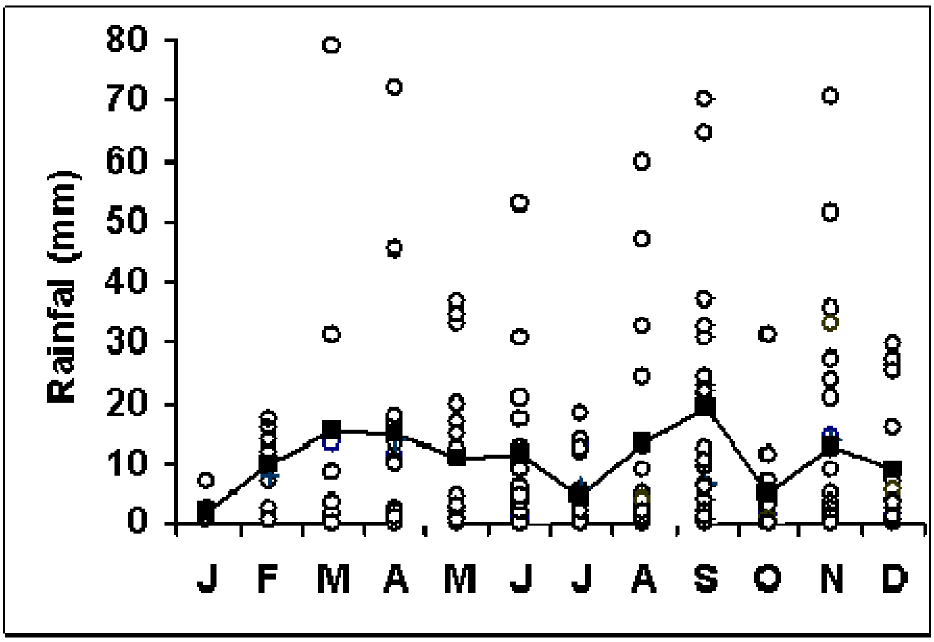

Figure 2. Monthly mean value (■) and daily rainfall (o) distribution in the area of Merbok estuary recorded in 2010 (supplied by Meteorological Department of Malaysia).

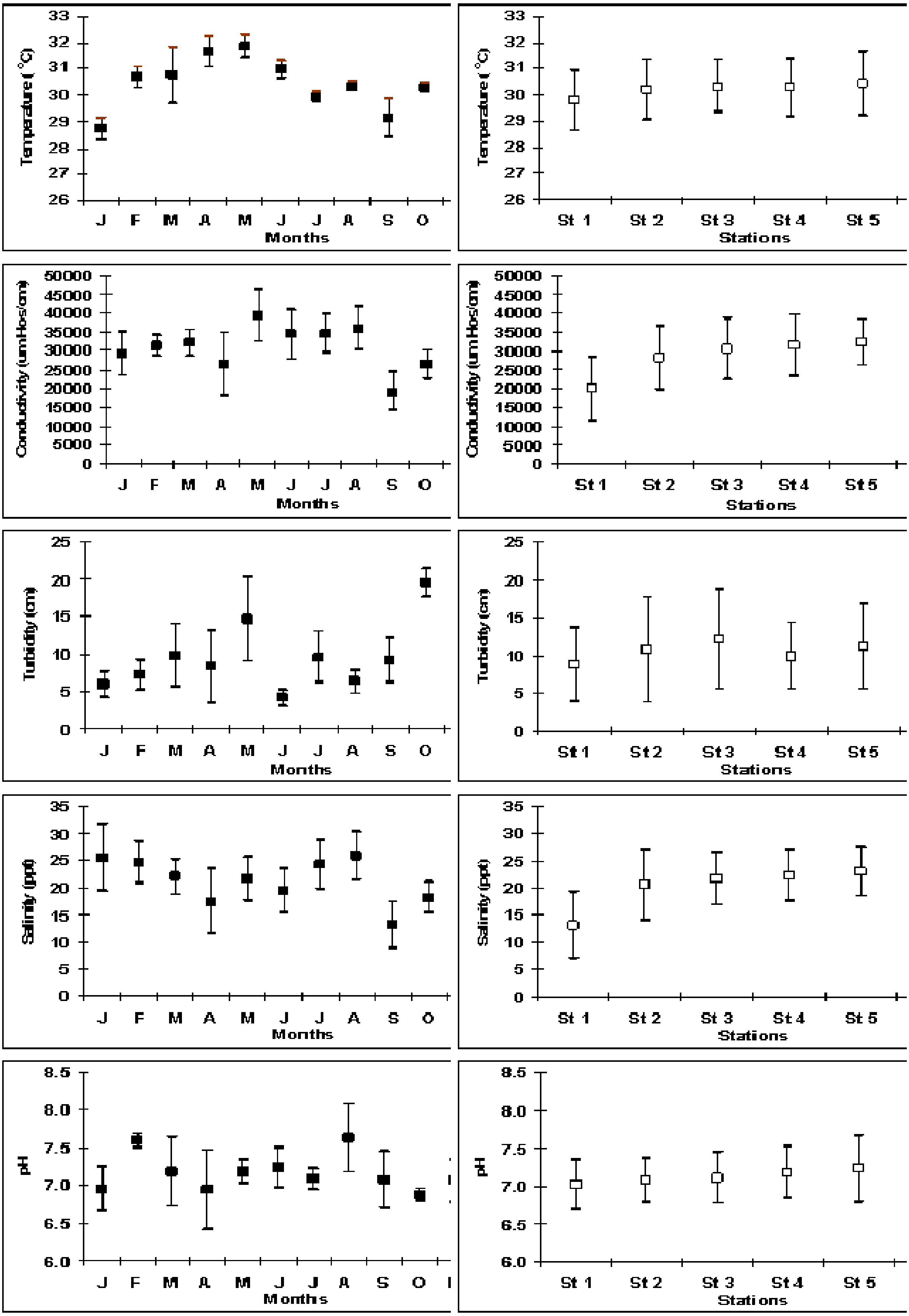

Figure 3. Temporal and spatial variations in physicochemical parameters (Temperature, Conductivity, Turbidity, Salinity and pH) in the Merbok estuary with mean (± SD).

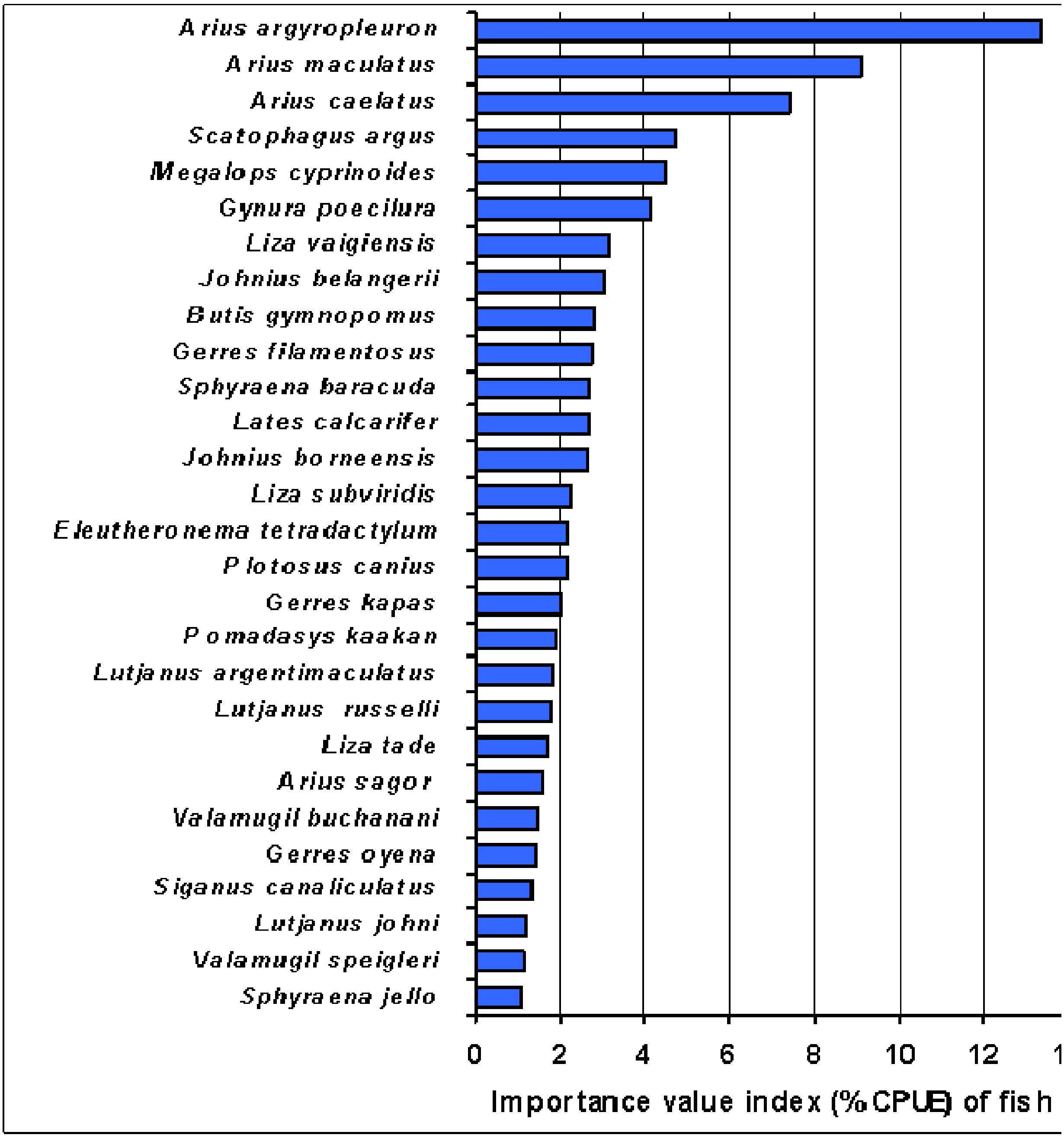

Figure 4. Importance value index of dominant fish species collected from the Merbok estuary. The ranking is based on percentage CPUE (gram/boat/trip).

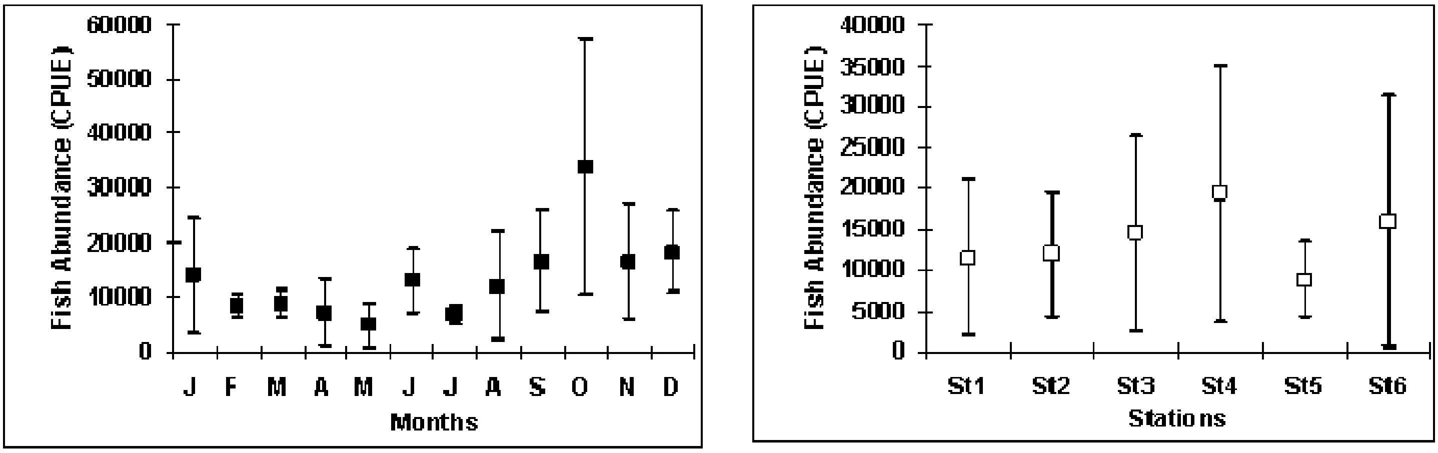

Figure 5. Temporal and spatial variations in fish abundance indicating by mean CPUE (g/boat/trip) ± S.D. in the Merbok estuary.

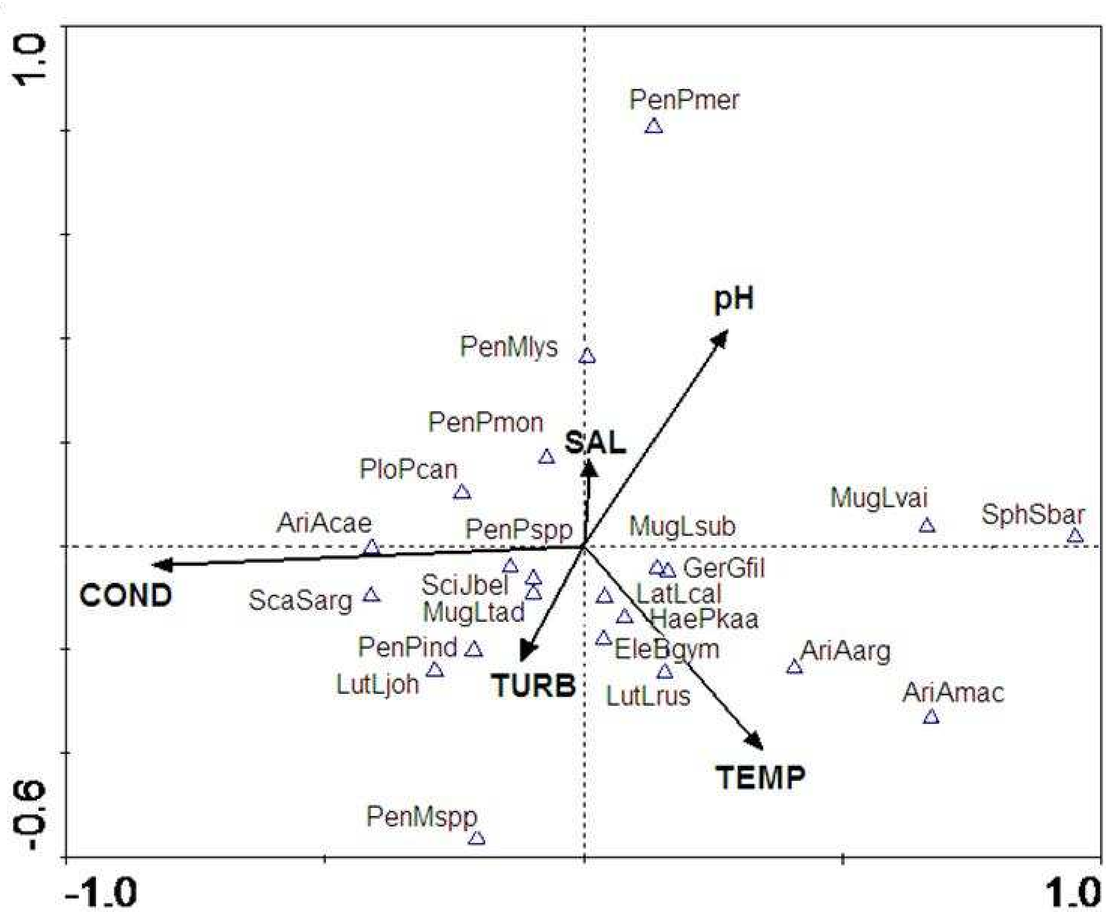

Figure 6. Ordination diagram from the canonical correspondence analysis (CCA) of fish species and environmental parameters; Temperature (TEMP, °C), Conductivity (COND, µmHos cm^{-1}), Turbidity/transparency (TURB, cm), Salinity (SAL) and pH (pH). Abbreviations (species code) of the species are provided in Appendix 1.