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Influence of habitat structure and environmental variables on larval fish assemblage in the Johor Strait, Malaysia

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Abstract

Our previous study demonstrated that among different habitat sites (mangrove, estuary, river, seagrass and Open Sea) in Johor Strait, Malaysia, seagrass showed highest family diversity and abundance of larval fish. However, it is unclear whether this was due to difference in habitat complexity or water quality parameters. To test this, larval fish were collected by using a bongo net equipped with a flow meter by subsurface horizontal towing from different habitats in Johor Strait between October 2007 and September 2008. Various physico-chemical parameters were measured and then examined for any relationship to fish larvae diversity and abundance. Among the 24 families identified from the sites, seven families (Blenniidae, Clupeidae, Mullidae, Nemipteridae, Syngnathidae, Terapontidae and Uranoscopeidae) were significantly correlated with the tested waters quality parameters. Salinity showed a positive and negative significant correlation with Clupeidae ($p < 0.01$) and Uranoscopeidae ($p < 0.05$), respectively. Terapontidae was significantly correlated with dissolved oxygen ($p < 0.01$), while both Mullidae and Syngnathidae were significantly correlated with pH ($p < 0.05$). However, a canonical correspondence analysis test indicated weak overall correlation (36.4%) between larval assemblage and in the seagrass-mangrove ecosystem of Johor Strait, Malaysia. This likely indicates that habitat structure was more important in determining larval abundance (highest in the seagrass habitat) as compared to water quality at the tested sites. This study emphasizes the need to conserve seagrass beds as important nursery grounds for various fish larvae to ensure adequate recruitment and ultimately sustainable fisheries management.

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Introduction

Studies on the composition and structure of larval fish communities and their relation to the environment are important in order to know about the profitable use of fishery resources (Sebates and Oliver, 1996). Ichthyoplankton survey help to detect spatial and temporal variations in the abundance and composition of larvae over wide areas, thus providing more comprehensive information for production and management options (Gullstrom and Dahlberg, 2004). Spatial and temporal patterns of diversity, distribution and species composition of larval fish are useful to examine factors influencing the structure of larval fish communities (Galactos *et al.,* 2004). As fish are exposed to potentially high mortalities during egg and larval stages, studies on larval diversity and survival rates of commercially important fish are one of the main research areas in fisheries science (Kawaguchi, 2002).

Local hydrological environments associated with transport processes, seasonal variability, prey and predator densities, and the spawning patterns of adult fish are recognized as factors influencing the survival and distribution in the early lives of various fish (Cowen *et al.,* 1993; Day Jr *et al.,* 1989; Franco-Gordo *et al.,* 2003; Hare *et al.,* 2001; Ramos *et al.,* 2006). Moreover, environmental features may indirectly affect communities by influencing the physiological responses of organisms and directly by affecting the distribution and abundance patterns of individual larva (Moser and Smith, 1993; Pearcy *et al.,* 1996). As such, salinity and temperature are both important abiotic factors play are important role in the occurrence, density and development of various larval fish (Rakocinski *et al.,* 1996; Strydom *et al.,* 2003). These are well known to change rapidly in estuary ecosystems, along with other factors including oxygen and turbidity due to the influence of tides and constant mixing of marine and fresh waters (McLusky and Elliott, 2004; Ramos *et al.,* 2006). At the same time, estuaries are very dynamic and diverse regions of high productivity, with fish faunas exhibiting variable abundance and composition (Gunter, 1961; Haedrich, 1983; Ramos *et al.,* 2006).

It is reported that fish larvae are 'effective' swimmers that are capable of swimming faster than local currents, sometimes up to nearly three times as fast (Leis and Carson-Ewart, 2003). Hence, it could be assumed that the most suitable habitat and environment for fish larval abundance can be actively selected and chosen. It is well known that coastal ecosystems are frequently used by fish as spawning and breeding areas and, in these areas, fish larval assemblages are structured by a combination of biological and physical processes (Mafalda *et al.,* 2008). In particular, habitat complexity has been shown to be highly important for larval fish nursery grounds and both mangroves and seagrass beds (Beck *et al.,* 2001). These habitats typically show greater fish diversities since the fish can more easily seek protection from predators and are often abundant with food (Hemminga and Duarte, 2000).

Throughout the world, there are many seagrass-mangrove ecosystems but among the 60 described seagrass species worldwide, the majority of species are found in the Indo-Pacific region (Leis and Carson-Ewart, 2000). In Peninsular Malaysia, the Merambong Shoal seagrass beds are among the densest seagrass ecosystems and larval densities as well as biodiversity were reported to be higher than other nearby habitats that included the open ocean or mangrove systems (Ara *et al.,* 2013). This finding may be due to differences in habitat complexity, since it is well known this is greatly influences biodiversity and abundance; however another factor may be water quality (Whitfield, 1999). Understanding such relationships would likely be important for fisheries management, particularly since many seagrass habitats in the Peninsular Malaysia has been gradually degraded and destroyed resulted from various coastal development projects (Jimmy, 2007). The present study was undertaken to examine the abundance of fish larvae and their relationship with various water quality parameters from different habitats (mangrove estuary, seagrass ecosystem and open sea) of Johor Strait, Malaysia.

Materials and Methods

Study site and sampling : The study was conducted in a seagrass-mangrove ecosystem in Gelang Patah, Johor Strait, Peninsular Malaysia. This is a unique ecosystem as it includes mangroves, estuaries and seagras beds. Five sampling stations (Fig. 1) were selected along the axis of the Pendas river estuary and Johor Strait. Among these, two stations were established inside the mangrove river estuary (S1 and S2), two were outside of the river mouth along the Strait (S3 and S4) and the other was in the open sea (S5). Each of the stations is characterized by unique habitats such as S1 being in the upper mangrove area, S2 being a mangrove estuary, S3 being a Strait ecosystem, S4 is dominated by seagrass beds and S5 is outside the seagrass beds. The specific location of the sampling stations were S1 (N 01^0 23.345; E 103^0 36.741), upper estuary; S2 (N 01^0 22.79; E 103^0 38.140), middle estuary; S3 (N 01^0 21.597; E 103^0 37.491), lower estuary; S4 (N 01^0 19.414; E 103^0 35.628), Merambong seagrass beds and S5 (N 01^0 18.799; E 103^0 35.246), outside seagrass areas (open sea).

Sampling was conducted monthly during the full moon/new moon period in daylight and at high tide from October 2007 to September 2008. Larval fish samples were collected using a Bongo net for 30 min. of towing the subsurface at each station. A flowmeter (Hydro-Bios) was attached to the net in order to determine the volume of filtered water. After each tow, samples were immediately fixed in 5%

formalin and were transported to the laboratory. Water temperature (^{o}C), salinity, dissolved oxygen (DO) and pH were recorded onboard during each cruise using a multi digital probe (YSI 650 MDS, YSI Incorporated, USA). Each water parameter was taken at a minimum of three replicates at all stations.

Total suspended solids (TSS), consisting of soil particles and organic matter held in suspension by water turbulence was analyzed following the APHA (2012) procedure. Briefly, 50 ml of water sample was taken from a thoroughly mixed sample and filtered using a pre-weighed millipore membrane filter paper (0.45 m). The filter was then carefully transferred to an aluminum tray and dried at 105^{o}C in an oven for 1 hr to constant weight after being cooled in a desiccator. Each test was run in triplicate and TSS was calculated as follows:

$$\text{TSS (mg l}^{-1}\text{)} = \frac{(A\text{-}B)}{V} \times 100$$

Where. A is the weight of filter + dried residue (mg); B is the weight of filter (mg); V is the volume of sample (ml)

Sample processing : In the laboratory, larval fish were sorted from the rest of the zooplankton and preserved in 75% alcohol. Individual fish larvae were identified to the family and species taxonomic level using the appropriate literature (Leis and Carson-Ewart, 2000; Okiyama, 1988; Ghaffar *et al.,* 2010). The raw catch data of larvae at each tow were standardized to per 100 m^{3} based on the flow meter readings.

Data analysis : Pearson's correlation coefficient (r) was used to identify relationships between the abundance of fish larvae and habitat parameters. Stepwise multiple regression analysis was used to examine the effect of fish larval abundance with water parameters. Multiple regression coefficients (R^2) were conducted using the following formula:

$$\text{Abundance Fish Larvae} = \beta 0 + \beta 1\,(\text{temp.}) + \beta 2\,(\text{DO}) + \beta 3\,(\text{sal.}) + \beta 4\,(\text{pH}) + \beta 5\,(\text{TSS})$$

where, $\beta 0$ is the intercept (constant) and $\beta 1$ to $\beta 5$ are the un-standardized coefficients of water parameters. All the above analysis was performed using SPSS version 11.5.

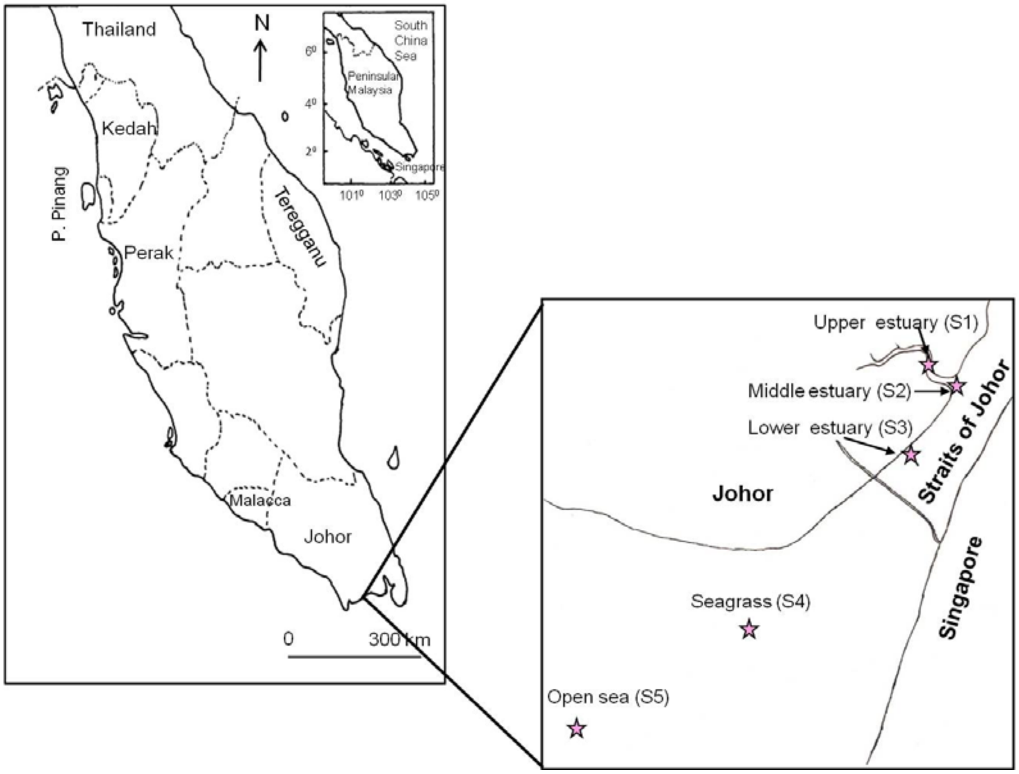

Fig. 1 : Geographical location of the sampling sites in the seagrass-mangrove ecosystem of Gelang Patah, Johor Strait, Peninsular Malaysia

Association between larval fish and environmental variables were examined with canonical correspondence analysis (CCA) using CANOCO (Canonical Community Ordination) ver. 4.5 software (ter Braak and Šmilauer, 2002).

Results and Discussion

Water quality : The temporal and spatial variations of the environmental parameters are summarized in Fig. 2 (a-j). Water temperature ranged from 23.24°C (March 2008, at S1) to 31.29°C (May 2008, S3) (mean ± SD, 28.64 ± 1.49°C), which was significantly higher during the southwest monsoon season (May) than those of inter-monsoon (February, March) season ($p < 0.001$) (Fig. 2a & b). Meanwhile, the mean water temperature tended to increase from station 1 (27.78 ± 0.57) to station 4 (29.11± 0.34) and this was statistically significant ($p < 0.001$) (Fig. 2b).

The monthly average values of dissolved oxygen (DO) ranged from 3.03 mg l^{-1} (April 2008 at S1) to 7.27 mg l^{-1} (September 2007 at S5) with significant differences among the months, with DO being significantly lower in March and May as compared to September (Fig. 2c and d). The annual mean DO varied from 4.00 0.17 mg l^{-1} to 6.21 0.17 mg l^{-1} in

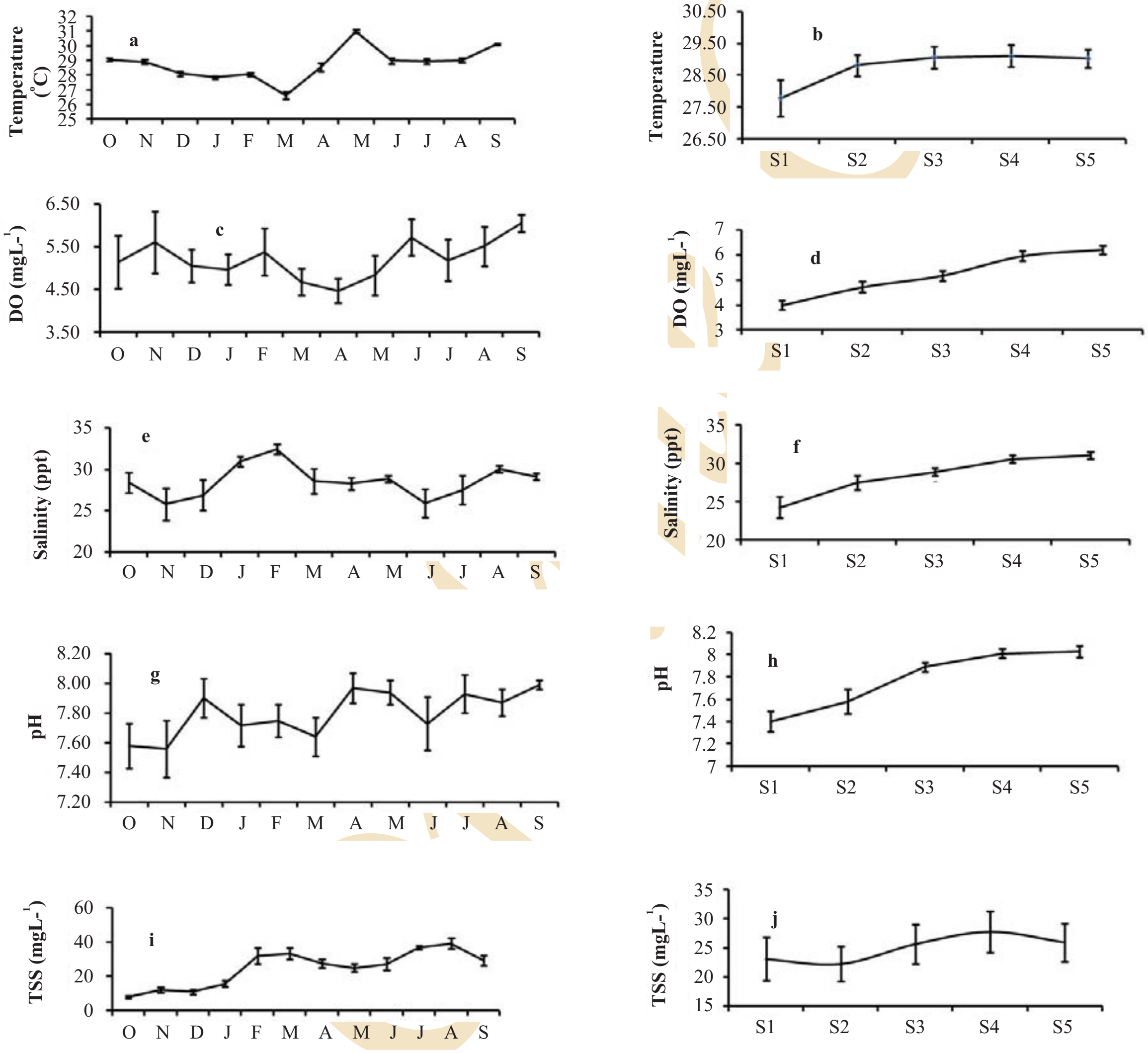

Fig. 2 (a-j) : Temporal and spatial variations of environmental variables (mean ± SE) water temperature (°C), dissolved oxygen (mg l^{-1}), salinity, pH and total suspended solids (mg l^{-1}) in the seagrass-mangrove ecosystem the investigated areas (Fig. 2d) and the mean DO value at station 5 (6.21 ± 0.17 mg l^{-1}) was significantly higher than those at all the other stations ($p < 0.05$) (Fig. 2d).

Salinity ranged from 14.82 (November 2007 at S1) to 34.33 (February 2008, at S5) (Fig. 2e and f) and similarly, the highest and lowest mean salinity was recorded at station 5 (31.05 0.49) and 1 (24.27 ± 1.39), respectively (Fig. 2f). Significant differences were observed among the months and stations ($p < 0.05$).

Highest pH value (8.03) was observed during the month of September at station 1, while lowest pH value (7.40) was observed in November, at station 5 (Fig. 2g and h). The mean pH value was found to be 7.75 ± 0.36. Significant differences were detected for pH among the stations (p <

Table 1 : Mean body size (mm) parameters of larval fish captured in the Seagrass-mangrove ecosystem of Johor Strait.

Family/species	**Mean ± SE (range, sample number)**				
	S1	**S2**	**S3**	**S4**	**S5**
Clupeidae	4.35 ± 0.18 (2.34-10.79, 83)	4.98 ± 0.15 (2.40-10.75)	5.41 ± 0.18 (2.69-12.16)	5.70 ± 0.15 (2.00-12.14)	4.52 ± 0.12 (2.43-9.91)
Engraulidae	7.19 ± 0.19 (6.74-7.63, 2)	5.21 ± 0.27 (4.24-6.49)	5.75 ± 0.71 (3.54-8.12)	6.78 ± 0.35 (6.17-7.38)	6.31 ± 0.23 (3.85-8.94)
Ambassidae	-	-	4.73 ± 0.45 (3.47-5.59)	2.73 ± 0.07 (2.29-3.95)	2.25 ± 0.08 (1.75-2.67)
Blenniidae	2.58 ± 0.07 (1.32-6.21, 96)	2.61 ± 0.05 (1.49-4.30)	2.79 ± 0.07 (1.29-7.87)	2.99 ± 0.05 (2.07-4.51)	3.12 ± 0.12 (2.03-4.96)
Carangidae	-	2.37 ± 0.16 (2.06-2.61)	1.93 ± 0.11 (1.73-2.12)	2.43 ± 0.02 (2.42-2.45)	-
Gobiidae	4.09 ± 0.28 (1.33-9.70, 33)	2.28 ± 0.20 (1.18-6.88)	2.29 ± 0.11 (1.97-2.56)	2.63 ± 0.09 (1.91-3.80)	2.66 ± 0.09 (1.68-3.90)
Leiognathidae	-	-	-	1.94 ± 0.02 (1.90-1.98)	1.97 ± 0.28 (1.69-2.25)
Monodactylidae/ *Monodactylus argentus*	1.52 ± 0.02 (1.46-1.58, 5)	1.99 ± 0.21 (1.47-2.41)	4.94 ± 0.78 (3.46-6.12)	5.20 ± 0.05 (5.16-5.25)	-
Mullidae	2.34 ± 0.08 (2.03-2.68, 5)	2.34 ± 0.08 (2.03-2.68)	2.72 ± 0.14 (2.12-3.52)	3.03 ± 0.10 (2.90-3.23)	2.89 ± 0.09 (2.18-3.72)
Nemipteridae/ Ambassidae sp. and Leiognathidae sp.	1.93 ± 0.13 (1.49-2.99, 6)	1.93 ± 0.13 (1.49-2.99)	2.99 ± 0.29 (1.50-6.02)	3.45 ± 0.14 (1.20-9.78)	2.29 ± 0.12 (1.55-3.82)
Rachycentridae	-	-	-	2.35 ± 0.14 (2.07-2.55)	-
Scatophagidae	-	-	-	13.93 ± 0.58 (12.80-15.52)	12.48 ± 0.65 (11.31-13.56)
Sillaginidae	3.28 ± 0.39 (1.57-7.41, 18)	3.28 ± 0.39 (1.57-7.41)	5.12 ± 1.02 (2.45-7.57)	5.67 ± 0.83 (2.99-10.30)	3.19 ± 0.15 (2.06-6.15)
Terapontidae/ *Terapon theraps*	3.17 ± 0.15 (1.89-6.80, 39)	3.17 ± 0.15 (1.89-6.80)	5.27 ± 0.21 (2.64-7.33)	4.05 ± 0.12 (1.96-7.04)	2.05 ± 0.12 (0.88-5.39)
Toxotidae	2.76 ± 0.26 (2.24-3.66, 2)	3.36 ± 0.32 (2.68-4.12)	2.33 ± 0.03 (2.30-2.36)	-	3.34 ± 0.23 (2.66-3.91)
Uranoscopidae/ Pomacentridae sp.	-	3.42 ± 1.17 (1.38-5.63)	-	-	-
Cynoglossidae	-	-	-	2.60 ± 0.26 (1.85-3.36)	-
Samaridae	-	-	-	2.19 ± 0.25 (1.75-2.62)	-
Syngnathidae	7.32 ± 0.12 (6.76-7.68, 5)	7.32 ± 0.12 (6.76-7.68)	-	-	-
Monacanthidae	-	-	-	2.19 ± 0.17 (1.64-2.71)	-
Triacanthidae	-	3.22 ± 0.76 (1.85-5.40)	3.48 ± 0.55 (2.41-5.94)	4.08 ± 0.49 (2.17-7.12)	2.78 ± 0.11 (2.56-2.99)
Overall mean	3.68 ± 0.17 (1.32-10.79)	3.40 ± 0.30 (1.18-10.75)	3.83 ± 0.36 (1.29-12.16)	3.52 ± 0.18 (1.20 -12.14	3.83 ± 0.18 (90.88-13.56)

0.05) and months ($p < 0.05$).

Highest TSS value (27.75 3.58 mg L^{-1}) was recorded at station 4 (seagrass beds) and lowest value (22.23 ± 3.02 mg l^{-1}) was found at station 2 (middle estuary) (Fig. 2i). Higher TSS value was observed in August (Fig. 2j). Significant ($p < 0.05$) variations were observed for TSS amongst different sampling stations ($p < 0.05$), as well as different months ($p < 0.05$) during the study period.

Size structure of larval fishes : Overall the larval fish assemblage included 24 families in the investigated areas. Highest mean body length (13.93 ± 0.58 mm) was observed in family Scatophagidae at S4 and ranged from 12.80 to 15.52 mm (Table 1). The lowest mean body length (1.52 ± 0.02 mm) was found in family Monodactylidae at S1 and ranged between 1.46 and 1.58 mm (Table 1). It revealed that the size of 10 families were less than 4 mm TL, 6 were between 4 and 6 mm TL and 2 families were higher than 6 mm TL. This indicates that larvae of smaller size (< 6 mm TL) were dominant in the seagrass-mangrove ecosystem sampled with bongo net (Table 1).

Relationship between fish larval assemblages and environmental variables: The abundance of 18 families was found to have correlations (positive or negative) with the water parameters, which are presented in Table 2. Nevertheless, seven families (Blenniidae, Clupeidae, Mullidae, Nemipteridae, Syngnathidae, Terapontidae and Uranoscopeidae) were significantly correlated with water quality parameters. Although none of the families was significantly correlated with temperature. Salinity showed a positive significant correlation with Clupeidae ($p < 0.01$) but a negative correlation with Uranoscopeidae ($p < 0.05$). Terapontidae was significantly correlated with dissolved oxygen ($p < 0.01$) (Table 2). Mullidae and Syngnathidae were both significantly correlated with pH ($p < 0.05$).

In order to obtain more specific correlations between the water quality and fish larval abundance, a multiple regression was performed and the results are presented in Table 3. The multiple regression coefficients (R^2) between abundance of fish larval families and water parameters ranged from 0.02 to 0.72 (Table 3). It is revealed that mainly four families (Sillaginidae, Engraulidae, Terapontidae and Cynoglossidae) were significantly influenced by the abiotic factors. The highest and most significant regression coefficient ($R^2 = 0.72$, $p < 0.05$) was observed for Sillaginidae, which indicated that 72% abundance of Sillaginidae were influenced by the water parameters and the remaining 28% by other factors. Similarly, the second highest regression coefficient ($R^2 = 0.63$, $p < 0.05$) was found for Engraulidae, which revealed that 63% of their abundance was directly related with abiotic factors and the remaining 37% responsible by other factors.

Canonical correspondence analysis : The eigenvalues of canonical correspondence analysis (CCA) for the first four multivariate axes were 0.15 (CCA1), 0.09 (CCA2), 0.05 (CCA3) and 0.03 (CCA4). Family-environment correlation

Table 2 : Correlation coefficient (r) between biotic and abiotic factors in the seagrass-mangrove ecosystem of Gelang Patah, Johor

Family	Temperature	Salinity	Dissolved oxygen	pH	TSS
Ambassidae	0.059	0.132	0.195	0.238	0.133
Blenniidae	**0.024**	**0.155**	**-0.217**	**0.043**	**0.273***
Carangidae	-0.060	-0.012	0.087	0.205	0.015
Clupeidae	**0.019**	**0.346****	**0.213**	**0.201**	**0.213**
Cynoglossidae	0.043	0.045	0.141	0.111	0.224
Engraulidae	0.202	0.141	0.054	0.172	0.074
Gobiidae	-0.003	0.147	0.130	0.050	0.126
Leiognathidae	0.025	0.186	0.251	0.139	0.222
Monacanthidae	-0.053	-0.097	0.130	-0.126	-0.047
Monodactylidae	0.750	-0.013	-0.016	-0.038	-0.054
Mullidae	**0.023**	**0.248**	**0.093**	**0.271***	**0.246**
Nemipteridae	**0.008**	**0.180**	**0.258**	**0.179**	**0.267***
Sillaginidae	0.142	0.041	0.092	0.071	0.126
Syngnathidae	**-0.147**	**-0.144**	**-0.221**	**-0.270***	**-0.175**
Terapontidae	**0.052**	**0.243**	**0.275****	**0.246**	**0.204**
Toxotidae	0.148	-0.188	-0.121	0.036	-0.082
Triacanthidae	0.079	0.136	0.073	0.012	-0.221
Uranoscopeidae	**-0.057**	**-0.270***	**-0.008**	**-0.200**	**0.025**

Note: * Significant at 0.05 level, ** Significant at 0.01 level coefficients for the first four axes were 0.98, 0.74, 0.76 and 0.81, respectively (Table 4). Cumulative percentage variances of family for the first four axes was represented as 51.9%, where the first and second axes modeled were 23.4% and 38.1% of species data. The first CCA axis (eigenvalue = 0.147) alone modeled 40.4% of the explained variance, demonstrating the highest family-environment correlation (0.984) (Table 4). The second axis represented 25.4% of the explained variance of family-environment relationship (Table 4), while the third and fourth axis explained 14.80% and 9.10% of the variance of species-environment relationship, respectively. Since the first two CCA axes explained 65% of the cumulative percentage variance of family-environment relation (Table 4), the results obtained from the first two axes were plotted (Fig. 3). The CCA test indicated a weak correlation (36.4%) between larval assemblage and physico-chemical parameters (Table 4). This revealed that fish larval abundance in the seagrass mangrove ecosystem of Johor Strait was only slightly influenced by the different tested water quality parameters (i.e. temperature, salinity, dissolved oxygen, pH and TSS).

During the present study, significant spatial variations were found for temperature, dissolved oxygen, salinity, pH and TSS. A significant variation with lowest water temperature was observed at S1 as compared to other four stations. This is most probably due to influx of freshwater coming upstream of this river. In case of DO, salinity and pH, the lowest values were found at S1 and the highest value was at S5. Comparatively higher values of DO

Table 3 : Multiple regression equation of 19 families of larval fish with water quality parameters in the Johor Strait

Multiple regression equations	**R^2**	**p**
Ambassidae		
Y= - 11.55 – 0.27Tem + 0.47DO – 0.07Sal + 2.36pH + 0.02TSS	0.22	0.02
Belonidae		
Y= 1.06 – 0.00Tem – 0.02DO + 0.01Sal – 0.16 pH + 0.00TSS	0.09	0.52
Blenniidae		
Y = 1.49 + 0.47Tem -4.68DO + 0.83Sal – 1.02pH + 0.32TSS	0.17	0.17
Carangidae		
Y= - 9.34 – 0.10Tem – 0.19DO – 0.16Sal + 1.85pH– 0.01TSS	0.09	0.47
Clupeidae		
Y = 97.50 – 7.11Tem + 17.63DO + 10.22Sal – 35.35pH + 1.5TSS	0.17	0.10
Cynoglossidae		
Y= 0.26 – 0.00Tem – 0.00DO + 0.00Sal – 0.03pH + 0.00TSS	**0.28**	**0.00**
Engraulidae		
Y= - 5.94 + 0.04Tem + 0.16DO – 0.14Sal + 0.84pH – 0.00TSS	**0.68**	**0.00**
Gobiidae		
Y = 69.62 – 0.90Tem + 3.02DO + 0.85Sal – 11.11pH + 0.21TSS	0.11	0.37
Leiognathidae		
Y = 3.36 – 0.08Tem + 0.25DO + 0.08Sal – 0.70pH + 0.02TSS	0.17	0.12
Monacanthide		
Y= 4.15 + 0.01Tem – 0.08DO + 0.09Sal – 0.81 pH – TSS0.00	0.10	0.44
Monodactylidae		
Y = 0.58 + 0.02Tem -0.01DO + 0.00sal – 0.14pH. - 0.003TSS	0.02	0.95
Mullidae		
Y= - 17.10 – 0.46Tem + 1.14DO – 0.32Sal + 4.13pH + 0.109TSS	0.20	0.05
Nemipteridae		
Y= 1.20 – 0.29Tem + 0.96DO +0.27Sal - 0.67pH +0.125TSS	0.13	0.25
Sillaginidae		
Y = 33.73 – 0.05Tem + 0.51DO – 0.08Sal – 4.94pH + 0.049TSS	**0.73**	**0.00**
Syngnathidae		
Y = 5.35 – 0.01Tem – 0.00DO -0.01Sal – 0.53pH– 0.00TSS	0.08	0.59
Terapontidae		
Y = 8.14 – 3.25Tem + 7.63DO + 0.86Sal + 1.26pH + 0.38TSS	**0.42**	**0.00**
Thiacanthidae		
Y = - 0.49 + 0.05Tem + 0.11DO + 0.05Sal – 0.24pH – 0.03TSS	0.10	0.44
Toxotidae		
Y = -2.25 + 0.033Tem -0.14DO -0.02Sal + 0.35pH - 0.006TSS	0.15	0.17
Uranoscopeidae		
Y = 1.55 + 0.01Tem – 0.08DO – 0.02Sal - 0.269pH + 0.00TSS	0.12	0.34

and salinity at S5 are likely related to being located in the open sea. However, significant variations in TSS were recorded between S4 and the other stations. This was probably due to high water turbulence at S4 site due to strong tidal fluctuations caused the presence of a newly established harbor nearby. Various abiotic factors such as salinity, temperature, pH, TSS and DO play important roles for fish larval abundance and diversity (Whitfield, 1999). Significant spatio-temporal variations were observed for salinity, temperature, dissolved oxygen, pH and TSS during the present investigation, which might influence the assemblage of larval fish.

The seagrass-mangrove ecosystem of Johor Strait has been demonstrated to be inhabited, on a temporary or permanently basis, by 24 families of larval fish whereas spatial variations in density of larval fish were significant ($P < 0.05$) between seagrass and other four sampling sites (Ara *et al.,* 2013). Moreover, relatively high amount of larval fishes captured from the study sites were in the yolk sac (< 4 mm) and preflexion (< 6 mm) stages, which demonstrates the importance of these areas as nursery grounds for the developing larvae. Although the all specimens were not identified to the species level, there were some significant relationships found with water quality and families. Salinity showed a positive significant correlation with family Clupeidae ($r = 0.346$, $p < 0.01$) and Nemipteridae ($r = 0.258$, $p < 0.05$). Terapontidae ($r = 0.264$, $p < 0.05$) and Mullidae ($r = 0.281$, $p < 0.05$) were significantly correlated with dissolved oxygen, while Syngnathidae showed a significantly negative correlation with pH ($r = - 0.270$, $p < 0.05$). Positive highly significant correlations were also observed between total suspended solid (TSS) and two families that included, Blenniidae ($r = 0.273$, $p < 0.01$) and Nemipteridae ($r = 0.273$, $p < 0.05$) (Table 4). Among the four families of Cynoglossidae, Engraulidae, Sillaginidae and Terapontidae,

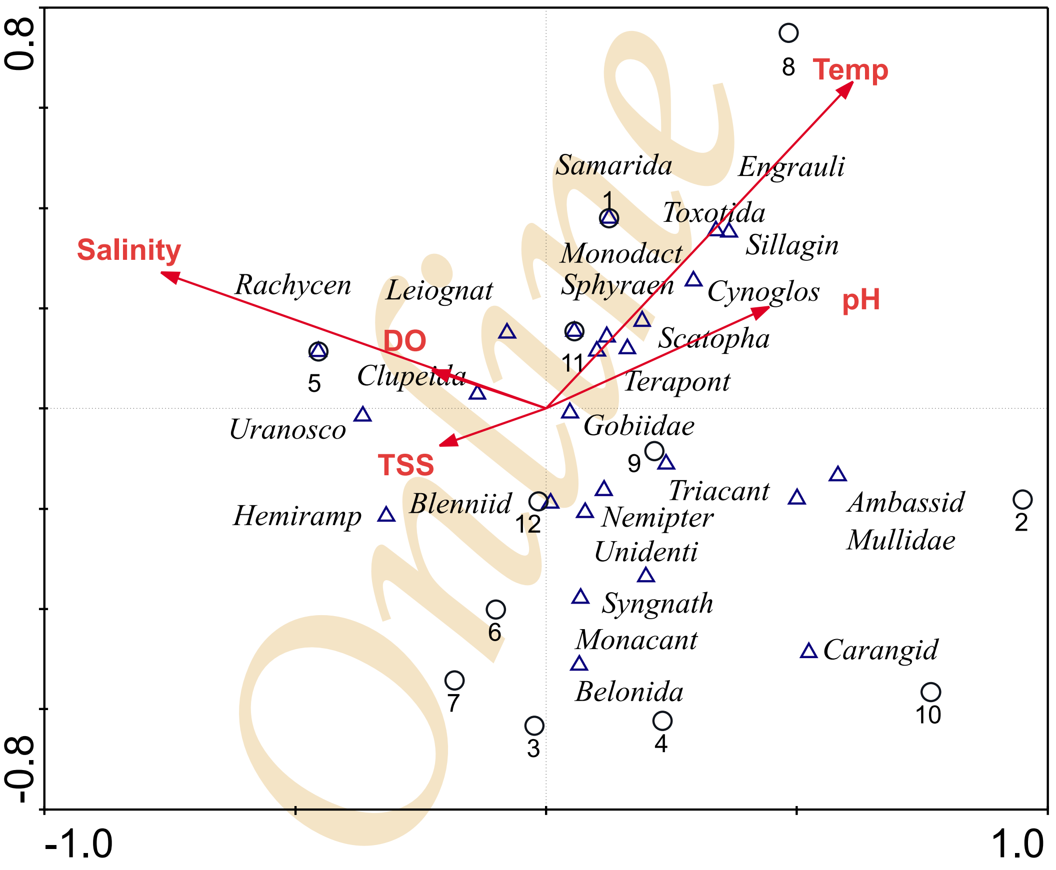

Fig. 3 : Canonical correspondence analysis ordination of monthly (dots) variations in fish larval abundance and environmental variables (physico-chemical conditions)

Table 4 : Results of the canonical correspondence analysis (CCA) between fish larval abundance and environmental variables

Axes	1	2	3	4	Total
Eigenvalues	0.147	0.093	0.054	0.033	0.629
Species-environment correlations	0.984	0.743	0.764	0.814	
Cumulative percentage variance of species data	23.4	38.1	46.6	51.9	
Cumulative percentage variance of species-environment relation	40.4	65.8	80.6	89.7	
Sum of all eigenvalues					0.629
Sum of all canonical eigenvalues					0.364

these were significantly ($p < 0.05$) influenced by the measured environmental variables (Table 5). The major water parameters had a 26% influence over the abundance of Cynoglossidae larvae while the remaining 74% were influenced by other factors. Similarly, Terapontidae, Engraulidae and Sillaginidae were influenced by the tested water parameters at 41%, 63% and 72%, respectively. Nevertheless, results suggest that abiotic conditions have a weak influence on the total ichthyo-fauna population within the seagrass-mangrove ecosystems of Johor Strait. It has been suggested that abiotic parameters can have indirect effects on fish larval abundance by influencing food (plankton) availability (Ramos *et al.,* 2006). In fact, in several estuarine ecosystems, peaks in larval fish abundance appear to be correlated with peaks in phytoplankton production and biomass (Martin *et al.,* 1992; Livingston *et al.,* 1997; Garcia *et al.,* 2003). Therefore, further research on the planktonic distribution and abundance should be carried out in the seagrass mangrove ecosystems of Johor Strait and any influence this might have on fish larval abundance.

Variations in fish larval distribution explained by the first four axes of CCA were 51.9%, which indicates that other factors were influential and some of these might include different types and densities of aquatic vegetation (Zimmerman and Minello, 1984; Akin *et al.,* 2005), sediment type (Marchand, 1993) and biological factors (i.e., group behavior, competition, and predation) (Martino and Able, 2003). Nevertheless, the five environmental variables measured in this study did explain fish larval distributions relatively well compared with other estuarine studies. For example, Mafalda *et al.* (2008) found that four petrochemical variables accounted for 27.4% of the total species variation off the coastal waters of Brazil. Meanwhile, for the ichthyoplankton assemblage structure in Mississippi Sound, Rakocinski *et al.* (1996) measured 11 environmental variables and, overall, these explained 21.9% of the total species variation in CCA. Finally, Martino and Able (2003) explained 29.9% of the total species variation in the Mullica River Estuary, New Jersey, using five environmental variables that included salinity and spatial distance. In the present study, the environmental variables accounted for 36.4% of the total fish variation on the basis of total canonical eigenvalues, which was slightly higher as compared to the above mentioned studies. Biotic interactions and seagrass-mangrove habitats may account for some of the unexplained variation in larval fish assemblage structure of the study area. Therefore, it could be concluded that seagrass are highly important nursery grounds and it is essential that these habitats are protected to ensure adequate larval fish recruitment and ultimately sustainable fisheries management.

Out of the 24 families identified, the abundance of seven families was found to have correlation (positive or negative) with the water parameters and a CCA test indicated a weak overall correlation (36.4%) between larval assemblage and the physico-chemical parameters in the seagrass-mangrove ecosystem of Johor Strait, Malaysia. Further research should be conducted on the influence of water quality on larvae fish to the species level to better understand the relationship between water quality and fish larvae in this area. However, considering our previous investigation demonstrated significant differences in larval density and family richness of larvae fish in seagrass beds, as compared to other surrounding habitats (Ara *et al.,* 2013), this underscores the importance for these habitats to be protected.

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