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Ichthyofauna on a Tropical Mudflat: Implications of Spatial and Temporal Variability in Assemblage Structure and Abundance

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Abstract Often seen as nonvegetated unutilized wastelands, mudflats pose the least resistance to land claim for coastal development. Here, we studied the large Klang mudflat (Straits of Malacca) from September 2011 to September 2014 to determine the fish species that utilize it and the abiotic factors that influence species composition and abundance, to evaluate the ecological role of the mudflat in support of coastal fisheries. The spatial and temporal assemblage of fish species and their abundance was examined at two sites, during two monsoon seasons, and under the effect of period (wet/dry), moon phase (full/new moon), and diel cycle (day/night). Fish were sampled during ebb tide by a stationary large barrier net that enclosed a calculable area of sampling. A total of 119 species belonging to 46 families of mainly small-sized and juvenile fish made regular ingressions into the mudflat throughout the year. Fish abundance varied spatially and temporally, suggesting site preference and variability in juvenile recruitment. Higher fish abundance due to recruitment occurred during the northeast monsoon season (NEM), as compared to the southwest monsoon. Fish composition but not total fish abundance during the NEM differed between wet/dry periods and diel cycles. Ariidae and Sciaenidae were dominant families during the wet period, whereas Engraulidae dominated during the dry period. Predatory fish species (e.g., *Lagocephalus lunaris*, *Otolithes ruber*, and *Hexanematichthys sagor*) were recorded during the daytime, whereas planktivorous and detrivorous species (e.g., *Ambassis gymnocephalus* and *Liza subviridis*) were more abundant during the night.

Keywords Mudflat · Fish assemblage · Abundance · Biomass · Environmental variables · Canonical analysis

Introduction

Intertidal mudflats being a regular feature of calm, shallow coastal waters are prime targets for land reclamation. Often seen as nonvegetated unutilized wastelands, tropical mudflats among all the common coastal biotopes (e.g., mangroves) pose the least resistance to land claim for coastal development. Since the early 1980s, East Asian countries especially the small nations have increasingly reclaimed land from the sea for development in order to support their increasing populations (Kao et al. 1998). The problem is that there is almost no or very little scientific information regarding the significance of tropical mudflats (to humans) to garner support for their protection in the tropics. Mudflats are generally characterized as covering a considerable part of the total estuarine area that harbors high productivity (Elliot and Dewailly 1995). They frequently occur as part of the natural transition of habitat between the sublittoral zone and mangroves. Although structurally much less complex than mangroves or other vegetated estuarine systems, the mudflat contains a high abundance and diversity of fauna, including infauna, epifauna, as well as fauna that periodically enter it during high tide (Laegdsgaard and Johnson 2001; Chong et al. 2012b). The importance of coastal

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mudflats as feeding areas for marine fish and invertebrates has gained attention from fishery ecologists (de Boer and Prins 2002; Morrison et al. 2002; Tse et al. 2008; Nip and Wong 2010; Chaudhuri et al. 2013).

The fish assemblage on the mudflat depends on its high productivity (Laegdsgaard and Johnson 2001; Nagelkerken and Van Der Velde 2002) making it a suitable feeding and nursery area (Mumby et al. 2004; Cardoso et al. 2011). Intertidal flats have long been referred to as ecological turntables between land and sea, where tidal flats receive nutrients, detritus, and plankton derived from the adjacent land and open sea, utilizing the energy inputs and in turn exporting their production off-shore (Reise 1985). The input of energy as well as high in situ microphytobenthic production (Guarini et al. 2000) provides ample food resources for resident benthic consumers such as crabs (Dittmann 1993) and molluscs (Boehs et al. 2004). The resident macrofauna and meiofauna are in turn exploited by periodic visitors to the tidal flats during flood tide such as fish and shrimps including commercially important species belonging to the genera *Parapenaeopsis* and *Metapenaeus* (Leh and Sasekumar 1984; Marsitah and Chong 2002; Melville and Connolly 2005; Franca et al. 2008; Chong et al. 2012a), as well as shore birds and mammals (Riak et al. 2003; Norhayati et al. 2009; Norma-Rashid and Teoh 2012). Moreover, Hill et al. (1982) described the use of mudflats by mud crabs (*Scylla* spp.) as nursery habitat in Australia, where the juveniles live and feed on intertidal mudflats and gradually migrate to the subtidal area as they mature. In several Southeast Asian countries, blood cockles are naturally found or artificially seeded on coastal mudflats to produce significant harvests of commercial importance (Broom 1982; Jarernpornnipat et al. 2003; Yurimoto et al. 2014). Where coastal biotopes co-occur such as among mangroves, seagrass meadows, or coral reefs, the mudflat often acts as a corridor for fish to travel between these habitats, e.g., during ontogenetic migration (Clark and Pessanha 2015) and foraging (Nagelkerken and Van Der Velde 2002; Connolly et al. 2005). The connectivity between mudflats and other adjacent biotopes also influences fish community structure due to diel and tidal migration of fish (Unsworth et al. 2008; Kundu et al. 2012).

Environmental variables may modify fish species distribution and abundance under different spatial and temporal scales (e.g., seasonally, interannually) (Thiel et al. 1995; Salgado et al. 2004; Terlizzi et al. 2005; Franca et al. 2008; Cardoso et al. 2011; Ooi and Chong 2011; Chaudhuri et al. 2013). In tropical areas, long-term or seasonal variability in fish composition is usually related to high rainfall and dry periods which may significantly influence environmental variables such as salinity (Satpathy 1996), temperature (Blaber 2000), and pH (Chaudhuri et al. 2013). In contrast, short-term variability in fish composition results from daily fish movements into and out of the mudflat; this may be related to not only feeding dynamics but also to avoidance of predators. Since the scale of tidal inundation is related to the tidal cycle, and predation is affected by light intensity, the pattern of fish ingression into the mudflat is hypothesized to be affected by diel light (day-night) and lunar (moon light) cycles. In spite of the diel nocturnal activity exhibited by many fish species, stronger light intensity during the full moon at night may facilitate the hunt of prey fish by predators (Horký et al. 2006), whereas prey species may make use of the new moon to avoid predators (Stokesbury and Dadswell 1989).

Despite the ecological and economic contributions of intertidal mudflats, studies on intertidal mudflats in Malaysia are unfortunately few. Yet, coastal mudflats such as those in Selangor can produce up to 40,000 tonnes of blood cockles or 8 tonnes ha^{-1} annually with a total market value of 20 million USD (DOF 2010). Compared to mangrove studies (e.g., Sasekumar et al. 1992; Tanaka et al. 2011; Chew and Chong 2011), the study of mudflats in Malaysia has been sporadic in the past (Broom 1982; McIntosh 1984; Sasekumar and Chong 1991; Riak et al. 2003) but has gained recent attention (Chong et al. 2012b; Ramarn et al. 2012; Teoh and Chong 2013; Norazlimi and Ramli 2014). Recent work based on stable isotope analysis has unequivocally shown the mudflat's trophic support for coastal zooplankton (Chew and Chong 2011; Ooi and Chong 2011), mysid shrimps (Ramarn et al. 2012), penaeid shrimps (Newell et al. 1995; Chong et al. 2001), hermit crabs (Teoh and Chong 2013), and fish (Chong et al. 2012a; Tanaka et al. 2011).

This study thus aimed to determine what species of fish utilize the coastal mudflat in order to gain some measure of mudflat contribution to fisheries support, and to determine the abiotic factors that may influence fish ingression into the mudflat. More specifically, we tested the hypothesis that mudflat usage by fish fauna (composition and abundance) is dependent on location (site), diel cycle (day/night), lunar light (new/full moon), and wet/dry period.

Materials and Methods

Study Areas and Sampling Design

The study area was located on the most extensive mudflat in the state of Selangor, west coast of Peninsular Malaysia. The Klang mudflat continuously flanks the eastern seaboard of Klang Strait, spanning 55 km from Kapar to Sekinchan in the north, being interrupted only by the mouths of three major rivers (Fig. 1). The mudflat extends between 1 and 2 km from the sea to the shoreline where fragmented mangrove forests still remained, especially south of the Selangor estuary. The entire mudflat has no seagrass meadows found only at the southern end of the peninsula (Bujang et al. 2006). The Klang mudflat covers about 8000 ha and almost 63 % of its

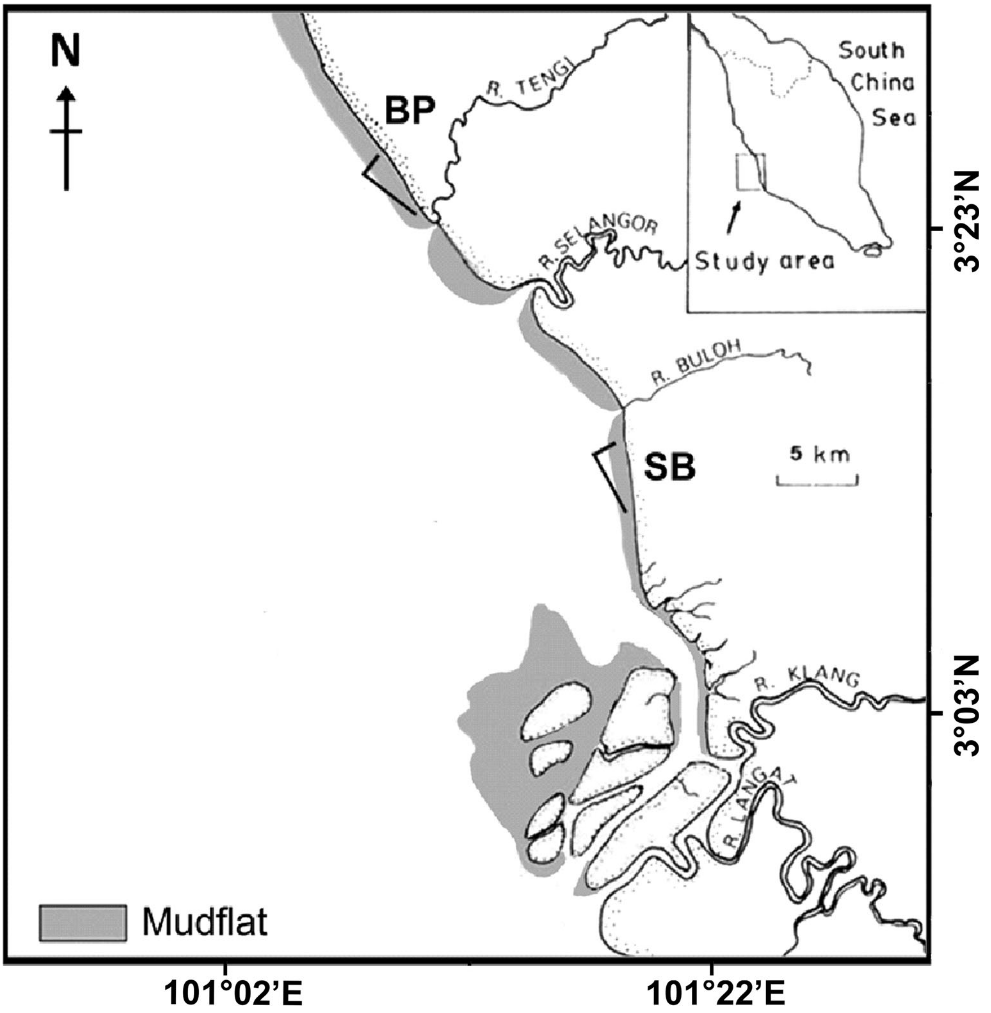

Fig. 1 Map showing coastal mudflat areas (*shaded gray*) at Klang Strait, Peninsular Malaysia. Study sites labeled BP (Bagan Pasir) and SB (Bagan Sungai Buloh) are marked as "L" depicting the enclosure net as sampling gear

area serves as culture beds for the blood cockle. This study examined the influence of the seasonal monsoon and diel/lunar light cycles on fish ingression at two locations (sites) on the Klang Strait mudflat, one at Bagan Pasir (BP) and other at Bagan Sungai Buloh (SB) (Fig. 1). Monthly field collections of fish from September 2011 to November 2014 were conducted to cover two seasonal reversals of weather pattern due to the northeast monsoon (NEM, November–March) and southwest monsoon (SWM, May–September). The onset of the NEM is characterized by a period of very heavy rainfall followed by dry spells during the later part. The SWM, however, starts with a period of relatively less rainfall until later when the monsoon "breaks" between July and September, and heavy rainfall may result due to the convergence of low-level easterly and southwesterly winds over the Sumatran region (Cheang 1988). Although the SWM season signifies drier weather, there is no distinct wet and dry season in the study area.

Fish sampling in the mudflat was conducted using a traditional fishing net or barrier net (*belat lengkong*), deployed in the daytime (10:00 a.m. to 2:00 a.m.) during the spring tide from September 2011 to November 2013, except on May 2013 (at BP and SB) and October 2013 (at SB) when sampling was not possible due to extremely rough weather. This sampling regime constituted the "a posteriori" study to distinguish it from the "a priori" study. For the a priori study, diel light (day-night) sampling using the barrier net was conducted on two occasions each during the wet period (November 2013 and March 2014) and dry period (June and September 2014) at both sites. Samples were collected during the day (10:00 a.m. to 2:00 p.m.) and at night (10:00 p.m. to 2:00 a.m.) on the new moon and full moon phase of each month sampled. Day and night sampling represented the diel light factor, whereas the new moon and full moon represented the moon light factor.

The commercial barrier net is designed to catch vagile fish and invertebrates on the mudflat when they retreat to the sea during spring ebb tide. This commercial gear operates about 6 days during the two spring tides of each month. The gear was deployed during high slack when the water depth was not more than 1.5 m depth. The wooden stakes of the attached net were manually driven into the mud to form an approximately

"L" configuration. The longer net wing was deployed along the direction of ebb flow (southwesterly) and the shorter wing deployed nearly perpendicular and as close as 400 m to the mangrove fringe (see Fig. 1). The set barrier net enclosed a large triangular area calculated to vary between 1.5 and 4.0 ha. The enclosed area was estimated by using a three-point GPS determination of the coordinates of its two ends and vertex. Based on the great circle distance formula (Weisstein 2014a), the distance among the three-point GPS was calculated. These distances were then applied to Heron's formula (Weisstein 2014b) to calculate the area for an irregular triangle (the enclosed area of the barrier net).

The great circle distance between any two (1, 2) of three GPS points was calculated from

$$d = e\cos^{-1}\left[\cos\delta_1\cos\delta_2\cos(\lambda_1 - \lambda_2) + \sin\delta_1\sin\delta_2\right]$$

where d is equatorial radius of the earth ≈6378 km; δ is latitude in radians, i.e., degree * $\pi/180$; and λ is longitude in radians.

The area (A) for an irregular triangle was then calculated viz.

$$A = \sqrt{(s^*(s - d1)^*(s - d2)^*(s - d3))}$$

where $s = (d1 + d2 + d3)/2$, and $d1$, $d2$, and $d3$ are the length of each side.

Fish were trapped mainly at the net's vertex during the subsequent ebb tide when water completely receded from the mudflat. Fish were taken out from the cod-end bag (mesh size 3.81 cm) at the net's vertex and subsampled when the catch was too large. This was done by filling the catch into sampling baskets and taking the required number of baskets (80 cm × 55 cm × 60 cm) as subsample, usually representing one fifth to half of the total catch. Fish were kept on ice while in the field and then promptly frozen in the laboratory at −20 °C before analysis. Environmental variables (i.e., salinity, pH, temperature, and dissolved oxygen concentration) were measured during high slack at 0.5 m depth using a multiparameter sonde (Model YSI 556). When the shore was exposed during low tide, nine sediment core samples (32 mm diameter × 140 mm length) were taken at each site (BP and SB) and the top 0.0–0.5 cm was taken for subsequent particulate organic content (POM) and grain size analysis. Rainfall data during sampling periods was obtained from the Malaysian Meteorological Department based on measurements recorded at Sungai Buloh Estate located 15 km to the southeast of Kuala Selangor river mouth.

Laboratory Procedures

All catch samples in the laboratory were sorted, and the fish were identified before they were counted, measured (standard length, mm), and weighed (g). Fish were identified to the species level using the following references: Munro (1974), De Bruin et al. (1994), Mohsin and Ambak (1996), and Carpenter and Niem (1998a, b).

Sediment chlorophyll pigments were extracted by acetone for at least 12 h inside a −20 °C freezer. Chlorophyll *a* concentration was then measured fluorometrically (Parson et al. 1984) by a Turner 10 AU fluorometer. Chlorophyll *a* concentration was calculated using the formula by Lorenzen (1967) and expressed in microgram per gram dry weight.

Sediment samples for grain size analysis and total organic matter content were dried in an oven at 60 °C for a week. The dried sediment samples were subject to prior treatments in 6 % hydrogen peroxide overnight and then sodium hexametaphosphate (6.2 g/l aqueous) overnight (Holme and Mclntyre 1971). Grain size of the treated samples was subsequently analyzed by a Coulter 230L Particle Size Analyzer. The soil particle groups were categorized according to the Wentworth grade scale (Buchanan 1984). The organic matter content of the sediment was estimated by subtracting the weight of combusted sediment (at 500 °C for 6 h in a muffle furnace) from the weight of dried sediment (at 60 °C for at least 3 days in an oven) (Holme and Mclntyre 1971).

Data Analysis

The dry or wet period was determined based on the standardized precipitation index (SPI), where precipitation of below average (SPI < 0) was regarded as a dry period, whereas precipitation of above average (SPI > 0) was regarded as a wet period. The SPI was calculated using the following equation:

$$\mathrm{SPI} = \frac{X_i - X}{\mathrm{SD}}$$

where X_i is the total rainfall of the ith month, X is the mean monthly rainfall over a 4-year timescale, and SD is the standard deviation of the monthly total rainfall (McKee et al. 1993). Four years (2010–2013) of rainfall data from the Malaysian Meteorological Department were analyzed.

Fish abundance expressed as number per hectare was calculated by using the following equation:

$$\text{Abundance} = \frac{N}{a}d$$

where N is the total number of fish, a is the enclosed area, and d is the raising factor due to subsampling.

Fish biomass was expressed as kilogram per hectare and calculated using the following equation:

$$\text{Biomass} = \frac{G}{a}d$$

where G is the total weight of fish, a is the enclosed area, and d is the raising factor due to subsampling.

Environmental variables (temperature, salinity, dissolved oxygen concentration, and pH value) were considered as the abiotic variables in the analysis. Biotic indices including Shannon-Wiener diversity index (Shannon 1948) and Pielou's evenness (Pielou 1969) were determined for each factor level using the DIVERSE routine of PRIMER software version 6.1.13 (PRIMER-E Ltd, Plymouth, UK) (Clarke and Gorley 2006; Anderson et al. 2008).

Monthly fish abundance and biomass data were grouped by site (BP and SB) and season (SWM and NEM) for a posteriori analysis. Fish abundance data were also subjected to a priori testing of the effects of site (BP/SB), period (dry/wet), moonlight (new moon/full moon), and diel light cycle (day/night). Results from both a posteriori and a priori studies were subjected to similar but independent univariate and multivariate analyses. Univariate analyses were performed to test the null hypothesis of no significant difference in fish abundance, biomass, environmental parameters (temperature, salinity, dissolved oxygen concentration, pH value, sediment chlorophyll *a* content, sediment particle size, sediment organic matter), or diversity indices (Shannon-Wiener diversity index or Pielou's evenness) among factor levels by using multiway ANOVA test in the STATISTICA software, version 8.0. A two-way ANOVA was used for the a posteriori test, while a four-way ANOVA was used for the a priori test. Prior to univariate analysis, the assumption of homogeneity of variance was tested. Skewed data were transformed with square root transformation to homogenize the variance. Following unsuccessful transformation, Kruskal-Wallis test was used for significant test. All mean values are reported with standard error (SE) unless stated otherwise. Significance level at $p = 0.05$ was applied for all tests to determine significant difference.

Distance-based permutational multivariate analysis of variance (PERMANOVA) in the PRIMER software was performed on transformed data. Prior to multivariate analysis, all fish abundance data were square rooted to downweigh the contribution of dominant species (Clarke and Warwick 2001). The Bray-Curtis dissimilarity distance was used to test the null hypothesis of no differences in fish assemblage between the stated levels for each factor (i.e., site, period, lunar phase, and sampling time). Each factor was analyzed as fixed factors with two levels each using 4999 permutations. The null hypothesis of no difference in dispersions among a priori groups was tested using test of homogeneity of dispersions (PERMDISP) (Anderson et al. 2008), followed by post hoc pairwise test if the test was significant. Following pairwise tests on abundance data between and within each factor by PERMANOVA, the similarity percentage (SIMPER) tests were carried out on pairs with significant *p* values to identify the significant distinguishing fish species. Species that fulfilled the criteria $\%\overline{\delta}_i > 3\ \%$ and $\overline{\delta}_i/\mathrm{SD} > 1$ (where $\overline{\delta}_i$ is the overall dissimilarity between two groups and SD is the standard deviation) were arbitrarily accepted as important contributors to dissimilarity among each factor.

The groupings or patterns were visualized on a constrained ordination using canonical analysis of principal coordinates (CAP), which maintained a priori site, period, lunar phase, and sampling time classifications (Clarke and Gorley 2006). Null hypothesis of no difference between groups, formed by combining each factor, was tested using 4999 random permutations. An appropriate subset of canonical axes (*m*) for the CAP analysis was determined by maximizing the leave-one-out allocation success (Anderson and Willis 2003). A Spearman correlation coefficient of >0.40 was used as an arbitrary limit to display potential correlation between individual species abundances relative to the canonical axes.

Results

Environmental Parameters

Based on the SPI of 4 years of rainfall data recorded at Sungai Buloh Estate station, the NEM from November–March was the wetter season compared to the SWM from May to September (Fig. 2).

Water temperature, salinity, and dissolved oxygen (DO) concentration were not significantly different ($p > 0.05$) between BP and SB and between SWM and NEM season (Table 1). Water temperature in BP ranged from 28.9 to 31.2 °C and 28.6 to 30.6 °C for SB. The lowest mean salinity (30.2) was recorded at SB during the NEM period of high rainfall (October 2012) and the highest salinity (35.1) was recorded in February 2012. Mean DO concentration showed no significant difference between sites and between monsoon seasons, ranging from 5.4 to 5.7 mg/l. Although both sites did not show a significant difference in terms of pH value, the SWM period had a significantly ($p < 0.05$) higher pH value (8.0 ± 0.2) than in the NEM period (7.7 ± 0.3). No interaction effects were found for all factors. Mean water temperature and DO concentration collected during the a priori study revealed rather consistent mean values at both sites and seasons. However, water temperature at the new moon phase (30.44 ± 0.84 °C) and at nighttime (30.44 ± 0.63 °C) was significantly higher ($p < 0.05$) than during the full moon phase (29.75 ± 0.66 °C) and daytime (29.75 ± 0.85 °C). Post hoc analysis revealed that water temperature at SB was significantly higher during nighttime than daytime. Water temperature was significantly higher at new moon than full moon during both the dry and wet periods. Although no significant difference was generally observed for water parameters in the a posteriori study, only mean salinity recorded in the dry period (32.73 ± 1.15) was significantly ($p < 0.05$) higher than in the wet period (31.53 ± 1.40).

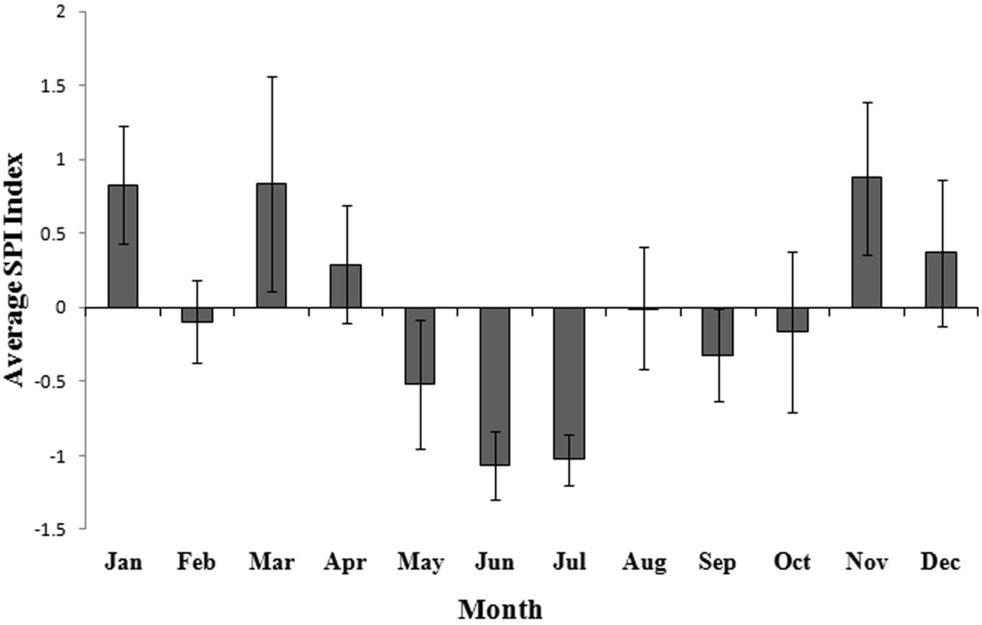

Fig. 2 Monthly standard precipitation index (SPI) with standard error (*whiskers*) based on 4 years monthly rainfall data obtained from the Meteorology Department, Malaysia. Dry or wet period was determined based on the SPI, where precipitation of below average (SPI < 0) was regarded as dry period whereas precipitation of above average (SPI > 0) was regarded as wet period

Analysis of sediment for both sites revealed that percentage organic matter in sediment at SB (10.1 ± 0.2 %) was significantly higher than at BP (7.1 ± 0.5 %). In terms of particle size, SB (clay 16.1 ± 0.3 %; silt 63.2 ± 0.6 %) had significantly higher percentage of clay but lower percentage of silt than BP (clay 9.5 ± 0.4 %; silt 69 ± 1.8 %). No significant difference ($p > 0.05$) was observed for percentage of fine sand (SB 20.7 ± 0.8 % vs. BP 21.5 ± 2.1 %) and coarse sand was absent in both sites. In terms of sediment chlorophyll *a* content, SB (9.3 ± 0.6 μg/g DW) was significantly higher ($p < 0.05$) than BP (5.8 ± 0.4 μg/g DW).

Species Diversity

A total of 119 species belonging to 46 families of fish were sampled from September 2011 to September 2014 (30 months). The Sciaenidae was the most speciose family (12 species), followed by Ariidae (10 species) and Engraulidae (7 species) (Appendix). The most abundant species was the Caroun croaker (*Johnius carouna*), followed the anchovy Kammal thryssa (*Thryssa kammalensis*) and the Sagor catfish (*Hexanematichthys sagor*) (Appendix). The majority of the fish sampled had standard lengths (SL) of less than 120 mm and were thus made of juvenile or subadult fish (*He. sagor*, *Eleutheronema tetradactylum*, *Plotosus canius*), or the adult of small-sized fish (*Ambassis gymnocephalus*, *Th. kammalensis*, and *Leiognathus brevirostris*). Based on the results of univariate ANOVA for both the a posteriori and a priori studies, Shannon diversity was significantly higher ($p < 0.05$) at SB compared to BP, whereas no significant difference ($p > 0.05$) in diversity was observed between SWM vs. NEM, dry vs. wet period, new moon vs. full moon, or day vs. night (Table 1). In terms of Pielou's evenness, ANOVA shows no significant difference between levels for all four factors examined in both a priori and a posteriori studies.

Spatial and Temporal Distribution

Mean total fish abundance in the a posteriori study was significantly higher ($p < 0.05$) at NEM (5152 ± 1068 ind. ha^{-1}) compared to SWM (2178 ± 362 ind. ha^{-1}). Fish abundance in SB (2744 ± 948 ind. ha^{-1}) and BP (4722 ± 698 ind. ha^{-1}) mudflat did not show significant difference in fish abundance ($p > 0.05$). The highest monthly fish density recorded at both sites also fell in the NEM period (Fig. 3), i.e., January 2012 (16,473 ind. ha^{-1}) for BP and November 2012 (24,337 ind. ha^{-1}) for SB. Caroun croakers contributed the most to both density peaks, accounting for about 66 % of total fish abundance in January 2012 at BP and 38 % in November 2012 at SB. In terms of total fish biomass, BP had significantly higher ($p < 0.05$) mean biomass (109.4 ± 29.3 g/ha) than SB (58.0 ± 28.6 g/ha), but no significant difference ($p > 0.05$) was found between seasons (SWM 65.0 ± 26.4 g/ha; NEM 103.9 ± 32.1 g/ha). The highest fish biomass (531.2 kg/ha) was recorded in September 2012 and the lowest biomass (15.9 kg/ha) in August 2013 for BP. In the SB, the highest (554.7 kg/ha) and lowest (5.6 kg/ha) biomass were obtained in November 2012 and May 2012, respectively. The high catches of fish during these months were attributed to large catches of ariids (>90 %).

The 10 species of highly abundant and commercially important fish species were found to be more abundant during the NEM period compared to the SWM period (Fig. 4). Only three species of fish (*Cynoglossus cynoglossus*, *J. carouna* and *Pl. canius*) were more abundant at BP, whereas the other seven species were more abundant at SB. The majority of fish

Table 1 Summary results of ANOVA on various environmental parameters, diversity indices, and standing stock of fish for the a posteriori and a priori studies

Sampling		A posteriori study (September 2011–November 2013)				A priori study (wet period = November 2013, March 2014; dry period = June, September 2014)							
Factor		Site		Season		Site		Period		Moon phase		Diel	
Level		BP	SB	SWM	NEM	BP	SB	Dry	Wet	Full	New	Day	Night
n		26	25	24	27	16	16	16	16	16	16	16	16
Environmental parameter													
Temperature (°C)	Mean	29.9	29.7	29.9	29.7	30.1	30.1	30.2	30.0	*29.8*	*30.4*	*29.8*	*30.4*
	±SE	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2
Salinity	Mean	32.2	32.0	32.4	31.8	32.2	32.0	*32.7*	*31.5*	31.8	32.5	32.3	32.0
	±SE	0.3	0.3	0.1	1.4	0.3	0.4	0.3	0.4	0.4	0.3	0.3	0.4
pH	Mean	7.8	7.8	*8.0*	**7.7**	7.8	7.9	7.7	8.0	7.8	7.9	8.0	7.7
	±SE	0.1	0.1	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.2	0.2
Dissolved oxygen (mg/l)	Mean	5.4	5.7	5.5	5.5	5.1	5.1	5.4	4.8	5.2	5.0	5.0	5.2
	±SE	0.2	0.7	0.2	0.7	0.2	0.3	0.3	0.2	0.2	0.3	0.2	0.3
Diversity indices													
Richness		84	92	86	94	82	89	85	87	85	89	93	83
Evenness (*J′*)	Mean	0.87	0.90	0.89	0.88	0.90	0.91	0.90	0.91	0.90	0.90	0.90	0.90
	±SE	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Diversity index (*H′*)	Mean	*2.77*	*3.07*	2.85	2.98	*2.96*	*3.18*	3.04	3.10	3.05	3.08	3.12	3.02
	±SE	0.06	0.07	0.07	0.06	0.07	0.06	0.07	0.06	0.07	0.07	0.07	0.07
Standing stock													
Abundance (no. ind. ha^{-1})	Mean	4722	2744	*2178*	*5152*	*4086*	*1035*	2869	2252	2701	2420	2346	2776
	±SE	698	948	362	1068	670	159	710	517	704	535	390	791
Biomass (kg/ha)	Mean	*109.4*	*58.0*	65.0	103.9	*73.2*	*16.2*	38.3	51.1	45.3	44.1	39.5	49.9
	±SE	29.3	28.6	26.4	32.1	13.3	2.1	12.9	10.9	10.9	13.1	9.6	14.0
Average weight per fish (g)	Mean	28.23	20.90	28.46	21.23	18.90	18.56	21.10	16.36	18.19	19.27	15.41	22.05
	±SE	5.49	3.40	5.58	3.27	2.00	2.25	2.50	1.75	2.25	2.25	1.50	2.25

Numerals in italics indicate significant difference at $p < 0.05$

(*BP* Bagan Pasir, *SB* Bagan Sungai Buloh, *SWM* southwest monsoon, *NEM* northeast monsoon, *n* number of samples, *SE* standard error

sampled (62.7 %) were small-sized (<120 mm) and considered juvenile fish based on their sampled lengths relative to their maximum lengths (Nagelkerken and Van Der Velde 2002), such as the tongue sole *Cy. cynoglossus*, Indian threadfin *E. tetradactylum*, Sagor catfish *He. sagor*, and silver pomfret *Pampus argenteus*. Most individuals of the gray mullet *Liza subviridis* and three sciaenid species (*J. carouna*, *Otolithes ruber*, and *Panna microdon*) were often found slightly larger than their minimum juvenile size.

In the a priori study, the mean total fish abundance and biomass were significantly higher in BP (4086 ± 2678 ind. ha^{-1}; 73.2 ± 53.2 kg/ha) than in SB (1035 ± 635 ind. ha^{-1}; 16.2 ± 8.2 kg/ha) mudflat ($p < 0.05$). However, there was neither significant difference between levels for period, moon light, and diel light effect nor their interaction effects ($p > 0.05$).

Fish Assemblage Structure

The fish assemblage (species composition and abundance) examined according to four influencing factors differed significantly between sites, wet/dry periods, and day/night ($p < 0.05$), but there was no significant difference between full/new moon ($p > 0.05$). There were also no significant interactions among factors at all levels ($p > 0.05$; Table 3).

The test of homogeneity of dispersions showed no significant assemblage dispersion for site ($p = 0.545$), period ($p = 0.803$), moon light ($p = 0.810$), and diel light ($p = 0.308$). This result, together with PERMANOVA results showed that the fish assemblage structure did not show dispersion effect but differed significantly within the factors (site, period, and daytime-nighttime). Fish assemblage structure under new moon and full moon phase was not significantly different

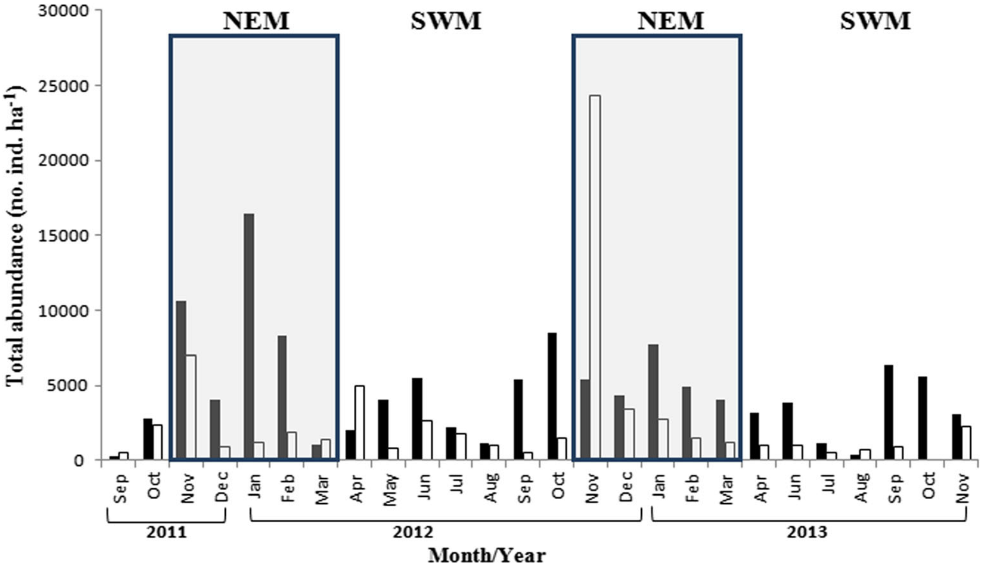

Fig. 3 Monthly and seasonal variability in total fish abundance on coastal mudflat sites from September 2011 to November 2013. *Shaded area* indicates northeast monsoon (NEM) season; *unshaded area* indicates southwest monsoon (SWM); *filled bar*, Bagan Pasir (BP); *empty bar*, Bagan Sungai Buloh (SB)

among and within levels; therefore, the moon light factor was omitted in subsequent constrained CAP analyses.

The separation of species assemblages between sites (BP/SB), period (dry/wet), and diel light (day/night) is visualized in constrained CAP ordination results (Fig. 5). The null hypothesis of no differences between the six groups of fish (for each level) due to the effect of site, period, and diel light was rejected ($p < 0.05$) based on CAP test. The leave-one-out allocation success was maximized at $m = 8$, where 40.63 % (canonical correlation, $\delta^2 = 0.88$) of the samples were allocated to the correct group. The spread along the first canonical axis separated the fish assemblage at BP (squares, right) from the fish assemblage at SB (circles, left), whereas the second canonical axis separated those from the dry/wet period (wet at the top, dry at the bottom) and diel light (day on the top, night at the bottom). Distinct groups of fish were identified from CAP analysis (Fig. 5b) with abundances significantly correlated (Spearman correlation > 0.40) with site, period, and diel light. The abundance of seven species of fish namely *Anodontostoma chacunda*, *Kurtus indicus*, *Upeneus sulphureus*, *Dasyatis zugeii*, *Le. brevirostris*, *Pa. argenteus*, and *Coilia dussumieri* were significantly associated with SB, whereas BP was characterized by fish assemblage comprising mainly *Th. kammalensis*, *Am. gymnocephalus*, *Scatophagus argus*, *Strongylura strongylura*, *Hemiramphus far*, *Pl. canius*, *Li. subviridis*, and *Stolephorus baganensis*. There were seven species of fish whose abundance were significantly associated with wet period and daytime (*Takifugu oblongus*, *Aspericorvina jubata*, *Johnius belangerii*, *Plicofollis argypleuron*, *Liza melinoptera*, *He. sagor*, and *Ot. ruber*), and three species of fish were found significantly associated with dry period and night sampling (*Congresox talabonoides*, *Ilisha melastoma*, and *Nibea soldado*).

SIMPER analysis indicated that four species of fish (*Th. kammalensis*, *J. carouna*, *He. sagor*, and *Am. gymnocephalus*) showed the most differences between levels of site, period, moon light, and diel light ($\bar{\delta}_i > 3\,\%$ and $\bar{\delta}_i/\mathrm{SD} > 1$). Abundance of all four species was higher in BP than SB. Both Kammal anchovy and Caroun croaker had higher abundance at full moon (moonlit night) during the dry period compared to new moon and wet period. On the other hand, Sagor catfish and bald glassy were more abundant at new moon during the wet period compared to full moon during the dry period. Both Caroun croaker and Sagor catfish recorded higher abundance during daytime, while *Th. kammalensis* and *Am. gymnocephalus* had higher abundance at nighttime.

Discussion

This study recorded the ingression of 119 species of fish into two sites at the coastal Klang mudflat (i.e., BP/SB) during high tide based on samplings using a stationary large barrier net. Previously, Chong et al. (1990) only recorded 70 fish species at SB using the same sampling gear; however, the dominant fish families were consistent among the two studies. Species richness was generally higher in the present study compared to similar habitats in other geographical areas; however, this result is likely influenced by differences among studies in terms of the type of gear used, sampling effort, and/or season sampled. For example, 31 fish species were recorded in a tropical mudflat of the Indian Sundarbans sampled seasonally using a gill net (Chaudhuri et al. 2013), 39 species on a mudflat in southern Australia (Hindell and Jenkins 2004: sampled seasonally using a fyke net, gill net, and beach seine), 20 species in the Tama River mudflat in central Japan (Kanou et al. 2005: sampled day and night with a beach seine), and 51 species in a Hong Kong mudflat (Tse et al. 2008: seasonally with beach seine). Thus, differences in

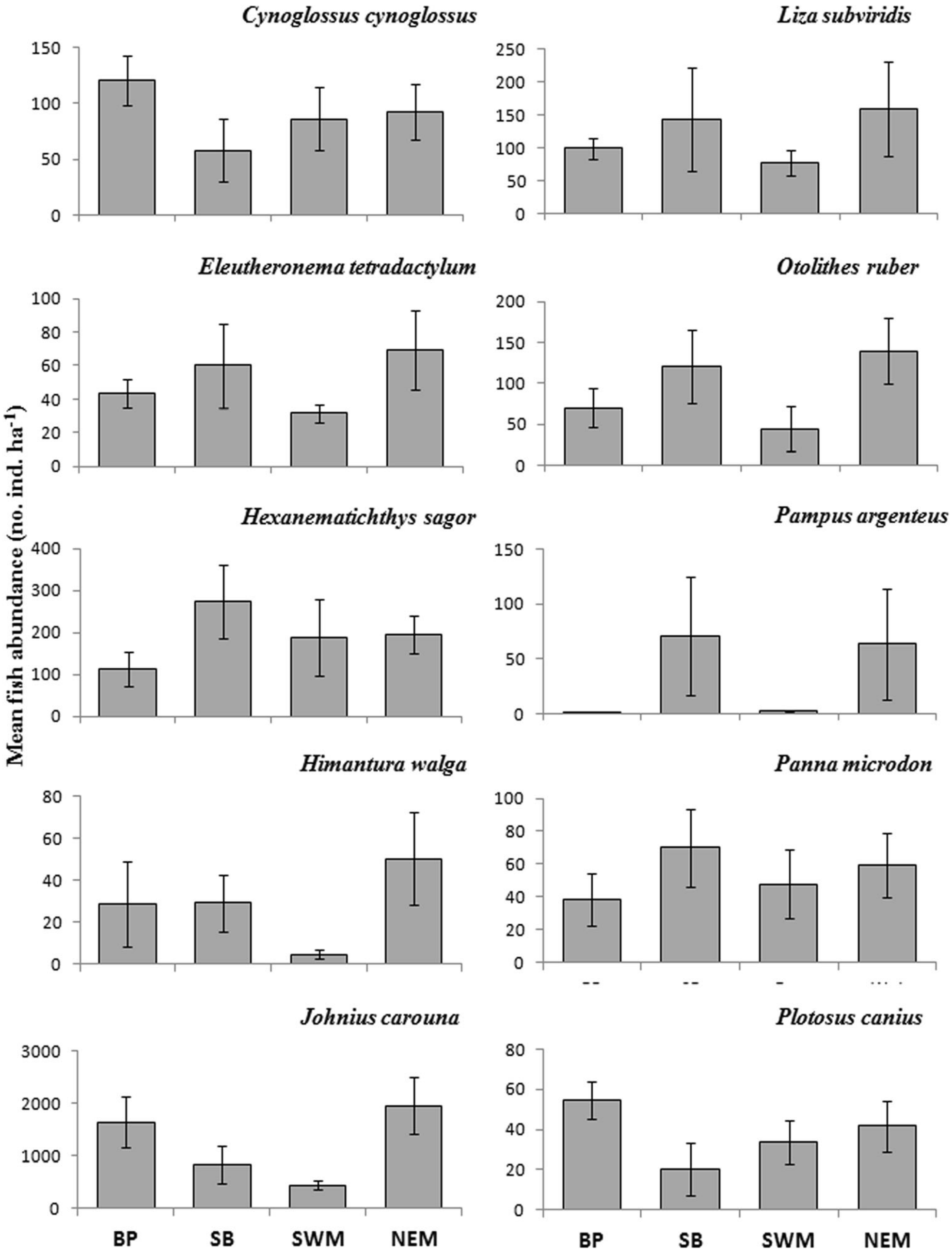

Fig. 4 Mean fish abundance (no. ind. ha^{-1}) and standard error (*whiskers*) of highly abundant and commercially important fish species at BP (Bagan Pasir) and SB (Bagan Sungai Buloh) mudflat sites and during SWM (southwest monsoon) and NEM (northeast monsoon) seasons. Scale of the vertical axis is different among some species

the number of species sampled could be due to different locations, sampling gears, effort, and/or seasons. The Klang mudflat fish community was comprised of several distinct groups discernable from one another by a few dominant species. These groups of fish species displayed their favored period of ingression into the mudflat (see Figs. 4 and 5), apparently driven by suitable abiotic (see Tables 1, 2, and 3) and biotic factors (Chong et al. 2012a). Previous studies in the Klang mudflat reported a mean fish biomass of 10.53 kg/ha (Sasekumar and Chong 1991) using similar sampling gear and 5.96 kg/ha (Chong et al. 1990) using a trawl net. Chong et al. (1990) further estimated the mean biomass of the juvenile fish stock in the adjacent Klang mangroves at 17.7 kg/ha. All fish biomass estimates are generally lower than those found in the present study (Table 1) which ranged from 5.6 to 554.7 kg/ha. Another study by Chong et al. (2012b) at Matang coastal mudflat, located farther north of the current study site, estimated total faunal standing biomass of 21.23–34.89 kg/ha. The standing stock biomass of invertebrates at Matang mudflat constituted approximately 87 % of the total fauna sampled by a small beam trawl. Compared to the present study, the mean invertebrate biomass at BP mudflat was 3.6 kg/ha and at SB mudflat 6.7 kg/ha (unpublished data). However, the passive barrier net in Klang mudflat was ineffective in catching molluscs, and the majority of invertebrates caught were shrimp (~82 %) (unpublished data).

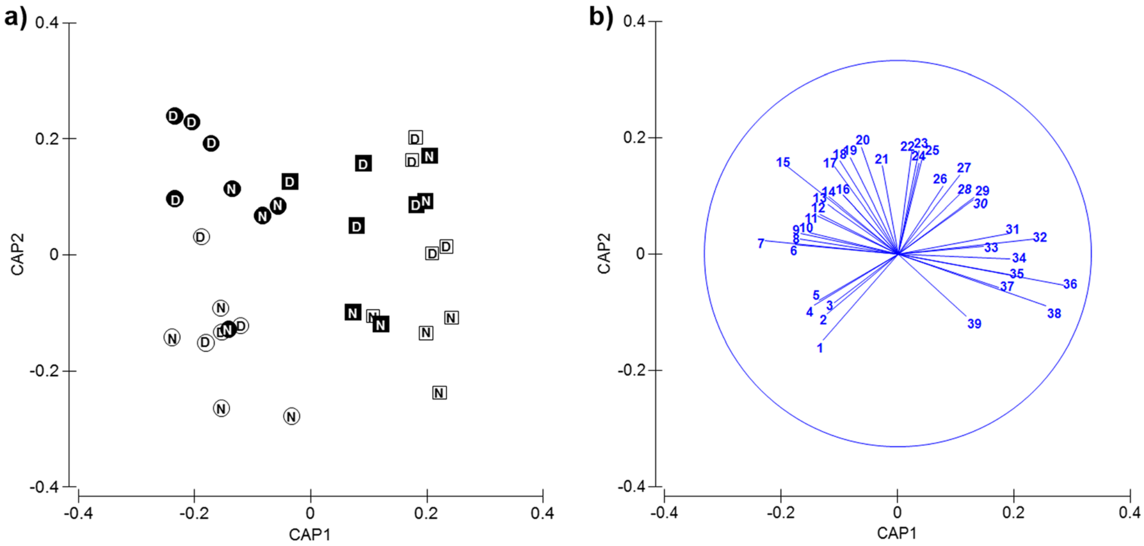

Fig. 5 Canonical analysis of principal coordinates (CAP) ordination of fish abundance data (**a**) with corresponding strength and direction of Spearman correlation >0.40 of fish species shown as line vectors (**b**). *Square*, Bagan Pasir mudflat site; *circle*, Bagan Sungai Buloh mudflat site; *filled symbol*, wet period; *empty symbol*, dry period; *D* daytime; *N* nighttime. Fish species include *Congresox talabonoides* (*1*), *Ilisha melastoma* (*2*), *Toxotes jaculatrix* (*3*), *Oreochromis mossambicus* (*4*), *Harpadon nehereus* (*5*), *Coilia dussumieri* (*6*), *Pampus argenteus* (*7*), *Leiognathus brevirostris* (*8*), *Dasyatis zugei* (*9*), *Upeneus sulpureus* (*10*), *Kurtus indicus* (*11*), *Anodontostoma chacunda* (*12*), *Opisthopterus tardoore* (*13*), *Pampus chinensis* (*14*), *Lagocephalus lunaris* (*15*), *Scomberomorus tol* (*16*), *Platycephalus indicus* (*17*), *Dasyatis bennenti* (*18*), *Otolithes ruber* (*19*), *Hexanematichthys sagor* (*20*), *Liza melinoptera* (*21*), *Plicofollis argypleuron* (*22*), *Takifugu oblongus* (*23*), *Aspericorvina jubata* (*24*), *Johnius belangerii* (*25*), *Eleutheronema tetradactylum* (*26*), *Drepane punctata* (*27*), *Synaptura commersonnii* (*28*), *Nemapteryx caelata* (*20*), *Tetraodon fluviatilis* (*30*), *Plotosus canius* (*31*), *Scatophagus argus* (*32*), *Stolephorus baganensis* (*33*), *Hemiramphus far* (*34*), *Strongylura strongylura* (*35*), *Thryssa kammalensis* (*36*), *Liza subviridis* (*37*), *Ambassis gymnocephalus* (*38*), and *Nibea soldado* (*39*)

Although there were no significant differences in water temperature, salinity, pH, and dissolved oxygen between seasons (NEM vs. SWM) in the present study, mean fish abundance on the mudflat was higher during the NEM compared to the SWM. Most studies that have found the monsoon to be an important influence on fish assemblages indicate that major shifts in environmental parameters, such as salinity, dissolved oxygen, and wind strength, were important in influencing species composition, abundance, biomass, and recruitment (Abesamis and Russ 2010; Bijoy Nandan et al. 2012; Mukherjee et al. 2013). At both sites in the present study, two peaks in fish ingression were observed: a small one during the SWM and a larger one during the NEM. These peaks likely reflect the main fish recruitment months resulting from two peak spawnings coinciding with the onset of the two tropical monsoons as reported by previous workers (Barlow 1981; Pauly and Navaluna 1983). Monsoon winds may enhance recruitment by influencing the dispersal of fish larvae over larger spatial scales (Sponaugle and Cowen 1994) and increasing the encounter rates between larval fish and their prey due to turbulent mixing of water column (MacKenzie and Kiorboe 1995; Utne-Palm 2004).

The water parameters examined (i.e., salinity, temperature, dissolved oxygen, and pH) at SB and BP sites did not differ significantly (see Fig. 3). This was not surprising since the two sites were located in the same general area; however, interestingly, differences in species assemblage and the timing of peak fish ingression were observed. The peak ingression at

Table 2 Summary results of ANOVA on sediment parameters at two mudflat sites

	Sample size (*n*)	BP (mean ± SE)	Sample size (*n*)	SB (mean ± SE)
SOM (%)	12	*7.1 ± 1.6*	15	*10.1 ± 0.6*
Sediment Chl-*a* (μg/g DW)	18	*5.8 ± 1.7*	25	*9.9 ± 2.8*
Clay (%)	36	*9.5 ± 2.3*	42	*16.1 ± 1.9*
Silt (%)	36	*69.0 ± 10.6*	42	*63.2 ± 4.1*
Fine sand (%)	36	21.5 ± 12.5	42	20.7 ± 5.0
Coarse sand (%)	36	0 ± 0	42	0 ± 0

Numerals in italics indicate significant difference at $p < 0.05$

BP Bagan Pasir, *SB* Bagan Sungai Buloh, *POM* sediment organic matter, *Chl-a* chlorophyll *a*, *SE* standard error

Table 3 PERMANOVA results comparing the composition of fish assemblage among and across site (BP/SB), period (dry/wet), lunar light (new moon/full moon), and diel light cycle (day/night)

Source	*df*	SS	MS	Pseudo-*F*	*P* (perm)	Unique perms
Site	1	10,188	10,188	7.0161	*0.0002*	4984
Period	1	2748.6	2748.6	1.8928	*0.0328*	4982
Lunar	1	1121.9	1121.9	0.77262	0.6916	4981
Diel	1	2674.6	2674.6	1.8419	*0.0390*	4984
Site × period	1	1532.9	1532.9	1.0556	0.3780	4971
Site × lunar	1	1739.7	1739.7	1.1981	0.2858	4988
Site x diel	1	1250.1	1250.1	0.86087	0.5956	4975
Period × lunar	1	1509.3	1509.3	1.0394	0.4002	4983
Period × diel	1	1280.2	1280.2	0.88164	0.5728	4980
Lunar × diel	1	1043.7	1043.7	0.71877	0.7524	4980
Site × period × lunar	1	1345.3	1345.3	0.92641	0.5178	4979
Site × period × diel	1	1286.4	1286.4	0.88586	0.5662	4981
Site × lunar × diel	1	1425.4	1425.4	0.98157	0.4680	4981
Period × lunar × diel	1	1024.1	1024.1	0.70524	0.7606	4983
Site × period × lunar × diel	1	1208.6	1208.6	0.8323	0.6264	4983
Residual	16	23,234	1452.1			
Total	31	54,613				

Significant differences in italics

SB occurred 2 months earlier than at BP. This may suggest that substrate differences, mudflat productivity, or/and other factors may be important in determining the type of fish species and when they are attracted to the mudflats. Sediment grain size analyses indicated that BP contained a greater percentage of silt and sand-sized particles than at SB, whereas sedimentary organic carbon and chlorophyll *a* content was higher in the finer sediments at SB. Fine-grained sediments generally have a higher organic content compared to coarse sediment (Köster and Meyer-Reil 2001). High organic matter may also indicate higher food availability in sediment that can support benthic feeders including shrimps, stingrays, and catfish. In particular, the benthic feeding Sagor catfish (Hajisamae et al. 2003) was found to be abundant at SB.

Compared to BP, SB is anthropogenically disturbed, being an extensive culture bed (2500 ha) for blood cockles that are artificially seeded throughout the year. Bivalve culture beds can influence the local system in three ways namely food and waste production, alteration of physical structure (such as substrate), and disturbance through harvesting activities (Dumbauld et al. 2009). Several manipulative studies on bivalves have shown that the physical structure of the bivalve itself may be more important than the bivalve's biological role in modifying the local habitat (Bódis et al. 2014; Dumbauld et al. 2009; Ricciardi et al. 1997). Densely cultured shells create nooks and crannies on and among them, allowing sediments to accumulate within the matrix, thus forming different microhabitats and increasing habitat heterogeneity (Lohse 1993; Mohammed 1992; Borthagaray and Carranza 2007). This may explain the high species diversity of fish as observed at SB and may contribute to the relatively higher POM content in the sediments (Gutierrez et al. 2003). The culture of cockles also attracts their natural predators into the culture area, such as gastropods (Vermeij 1980; Broom 1982).

At both sites, the majority of fish caught were small in size, including the bald glassy and anchovies, and juvenile Caroun croakers. Juvenile fish are more prone to predation by large predatory fish (Fuiman 1989; Cowan and Houde 1992). Therefore, smaller fish that periodically ingress into the mudflat during high tide may be doing so to avoid their predators. Morrison et al. (2002) also showed that tidal flats are utilized as nursery habitats by large numbers of small fish and juveniles. Examples of large predatory fish that preyed on anchovies include the threadfin (*Leptomelanosoma indicum*), Spanish mackerel (*Scomberomorus commerson*), and barramundi (*Lates calcarifer*). These large predatory fish were more common in SB than in BP, where anchovies and Caroun croaker were abundant. Other than small species and juvenile fish caught, large predatory fish species that were commonly present in BP included the eel catfish (*Pl. canius*) and spotted needlefish (*Str. strongylura*). The main diet of the eel catfish at SB consisted of bivalves such as blood cockles (Leh et al. 2012). However, preliminary stomach content analysis of *Pl. canius* revealed very low consumption of blood cockles and a high abundance of sesarmid crabs and polychaetes in our samples.

The dry period of Klang mudflat recorded significantly higher salinity than the wet period. Seasonal fluctuations of both salinity and temperature were generally small in Klang Strait (Chong et al. 1996). Although heavy rainfall during the wet period resulted in high input of freshwater into the intertidal area via the three major rivers (Fig. 1), there appears to be significant mixing by high salinity seawater at both study sites (Table 1). Nevertheless, the wet period appears to have more fish species compared to the dry period. The fish consisted of mainly predatory fish such as sciaenid species (*J. carouna*, *Ot. ruber*, *J. belangerii*, and *As. jubata*) and catfishes (*He. sagor* and *Pli. argypleuron*). In particular, the Caroun croaker's density peaked during the NEM between October 2012 and January 2013. The catfish *Cryptarius truncatus* and soldier croaker *Ni. soldado* were however found abundantly during the dry period, particularly at BP. The high occurrence of the soldier croaker was similarly observed during the SWM period (June–September) on the west coast of India (Ansari et al. 1995). A study by Pang (1990) revealed that the maturation process for both *Cr. truncatus* (total length 300–340 mm) and *Nemapteryx caelata* (220–260 mm) could start in August and reached its peak from December to January. In the present study, *Cr. truncatus* recorded a peak density during September and *Ne. caelata* in November. Most specimens of these two species had a size range of 220 to 330 mm during these periods, which indicate that both catfish ingressed into the mudflat as mature stages; hence, it is conceivable that the catfish spawned here. Interestingly, many small juveniles of *Ne. caelata* were recorded subsequently except *Cr. truncatus* which indicate that the latter may spawn farther offshore. Other than for feeding or spawning, the movement of fish may also be a result of wind forcing. Several studies had revealed that fish movement and larval recruitment were positively correlated with wind force and direction (Findlay and Allen 2002; Thorrold et al. 1994).

Although the moon light intensity has been reported to have an impact on the composition and breeding of fish (Horký et al. 2006; Ikegami et al. 2014; Krumme et al. 2015) and invertebrates (Nascimento et al. 1991; Camargo et al. 2002; Bentley et al. 1999), full moon or new moon appears to have no effect on the mudflat fish species assemblage in Klang Strait. This may be due to the high turbidity of the mudflat water so that moon light may offer little advantage to visual predators. In fact, turbid shallow waters provide protection to young fish from predators (Blaber 2000; McLusky and Elliot 2004), which is further enhanced by darkness provided by the new moon (Krumme et al. 2015). The effect of moon light may have a more pronounced effect on the molting and spawning of local shrimp species compared to fish species (Pushparajan et al. 2012; Ramarn et al. 2014).

The majority of fish species that were found to be abundant during the day were predatory fish such as Caroun croaker (*J. carouna*), Lunartail puffer (*Lagocephalus lunaris*), Tardoore (*Opisthopterus tardoore*), Indian Threadfin (*E. tetradactylum*), Tigertooth croaker (*Ot. ruber*), and Belanger's croaker (*J. belangerii*). Analysis of fish diet of these species revealed that the majority of food items were shrimp (unpublished data). These visual predatory fish may hunt their prey during daylight. On the other hand, small fodder fish such as *Am. gymnocephalus* occurred abundantly in the mudflat at night. This is consistent with the findings of previous studies (Martin and Blaber 1983; Krumme et al. 2015) which reported that ambassids feed and occur mainly during the night. The present study also recorded that the ambassids were abundant especially during the NEM (November to January). According to Chew et al. (2012), common mangrove and mudflat fish species such as ariids, engraulids, and ambassids fed primarily on copepods. Interestingly, copepod and phytoplankton density peaked during the wetter months (November and February) of the NEM (Chew and Chong 2011). In contrast, several studies showed that ambassids were scarce in the mudflat as compared to mangrove forest (Tse et al. 2008), as they prefer sheltered (Shao and Chen 2003) and structurally complex habitats (Laegdsgaard and Johnson 2001). This may indicate that ambassids utilize the shallow coastal mudflats in Klang Strait more for nocturnal feeding rather than to seek refuge from predators, or perhaps they, like other marine stragglers, irregularly visit the coastal mudflat without any apparent estuarine requirement (Elliot and Dewailly 1995; Franca et al. 2008).

The coastal ichthyofauna that utilize the Klang mudflat are mainly juvenile fish of which 82 % are commercially exploited on maturity, while the remainder constitute fodder fish integral to the coastal food web. Among the six major feeding guilds of fish on the mudflat, the shrimp feeders (45 %) constituted the largest group, and penaeid shrimps were the most dominant prey item (32 %) followed by molluscs (12 %) (Lee, unpublished). This underlines the importance of the coastal mudflat as rich feeding ground, nursery, and habitat for coastal fishes, shrimps, and molluscs. Mudflat productivity also enables the successful culture of blood cockles over large areas of the mudflat (Broom 1985). It is not known to what extent Klang mudflat is functionally connected to coastal mangrove, the only other coastal biotope present and occurring adjacent to one another. They may be ecologically connected via upwelling of organic matter and nutrients from the mangrove (Alongi 1996), but stable isotope or δ^{13}C studies of mudflat consumers have shown negligible assimilation of mangrove carbon (Newell et al. 1995; Lee, unpublished). Nevertheless, regardless of whether mudflats are in fact powerhouses in their own right (i.e., fueled by in situ benthic diatoms and phytoplankton) or receiving allochthonous energy sources, the Klang mudflat is increasing threatened by both coastal reclamation and shrinking mangrove forests, as well as coastal erosion and pollution (Bird and Teh 1990; Leong et al. 2005; Lee and Bong 2012; Chew et al. 2015).

Conclusion

Site and monsoon influence the fish species diversity and abundance on Klang mudflat. The site factor could be attributed to cockle farming on the mudflat and/or differences in soil substrate, which may increase species diversity and modulate community structure. The fish assemblage at SB was comprised of fish from many taxa, but Ariidae, Clupeidae, Engraulidae, and Tetraodontidae were numerically dominant. In contrast, BP's fish assemblage consisted of mainly Cynoglossidae, Plotosidae, and Ambassidae. Most species occurred throughout the year. Although no major differences in the water parameters were observed between the monsoons, the NEM appeared to attract more fish into the mudflat as compared to SWM. Species composition but not total abundance differed between the dry and wet period and between day and night; however, there was no difference between full and new moon. Daytime attracted more large predatory fish species into the mudflat, while nighttime attracted large numbers of small fish and nocturnal feeders into the mudflat. Future studies on predator-prey relationships and diet analysis may give clearer reasons why fish are attracted to the mudflat throughout the year. Conservation efforts to protect coastal mangrove forests or seagrass meadows must also include the adjacent mudflats, for these barren muddy lands are not wastelands but powerhouses generating food both directly and indirectly for fisheries and aquaculture.

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Appendix

Table 4 All fish species checklist and abbreviations (Abb.) used at Bagan Pasir (BP) and Bagan Sungai Buloh (SB) mudflat sites

	Families/species	Abb.	BP	SB
Ambassidae				
	Ambassis gymnocephalus	Amb gyn	1	1
Ariidae				
*	*Arius arius*	Ariu ariu	1	1
*	*Arius maculatus*	Ariu mac	1	1
*	*Arius microcephalus*	Ariu mic	1	0
*	*Arius utik*	Ariu utik	1	1
*	*Arius venosus*	Ariu veno	1	1
*	*Cryptarius truncatus*	Cry trun	1	1
*	*Hexanematichthys sagor*	Hex sag	1	1
*	*Nemapteryx caelata*	Nem cae	1	1
*	*Nemapteryx nenga*	Nem nen	1	1
*	*Osteogeneiosus militaris*	Ost mili	1	1
*	*Plicofollis argyropleuron*	Pli argy	1	1
Batrachoididae				
	Allenbatrachus grunniens	All gru	0	1
Belonidae				
*	*Strongylura strongylura*	Str str	1	1
*	*Tylosurus crocodilus*	Tylo croc	0	1
Carangidae				
*	*Carangoides malabaricus*	Car mal	1	0
*	*Scomberoides commersonnianus*	Scom com	1	1
*	*Scomberoides tala*	Scom tal	0	1
*	*Scomberoides tol*	Scom tol	0	1
*	*Trachinothus blochii*	Tra blo	1	1
Chirocentridae				
*	*Chirocentrus nudus*	Chi nud	1	0
Cichlidae				
*	*Oreochromis mossambicus*	Oreo sp.	1	1
Clupeidae				
*	*Anodontostoma chacunda*	Ano cha	1	1
	Escualosa thoracata	Esc thr	1	1
*	*Hilsa kelee*	Hil kel	1	0
*	*Opisthopterus tardoore*	Opis tar	1	1
Cynoglossidae				
*	*Cynoglossus arel*	Cyno arel	0	1
*	*Cynoglossus bilineatus*	Cyno bili	1	1
*	*Cynoglossus cynoglossus*	Cyno cyno	1	1
*	*Cynoglossus lingua*	Cyno lin	1	1
*	*Cynoglossus puncticeps*	Cyno pun	1	1
	Families/Species	Abb.	BP	SB
Dasyatidae				
*	*Dasyatis bennetti*	Dasy ben	1	1
*	*Dasyatis zugei*	Dasy zug	1	1
*	*Himantura pastinacoides*	Him pas	1	1
*	*Himantura walga*	Him wal	1	1
*	*Neotrygon kuhlii*	Neo kuh	0	1
*	*Taeniura lymma*	Tae lym	1	0
Drepaneidae				
*	*Drepane longimana*	Dre long	1	1
*	*Drepane punctata*	Dre pun	1	1
Eleotridae				
	Butis koilomatodon	But koi	1	0
Engraulidae				
*	*Coilia dussumieri*	Coi duss	1	1
*	*Setipinna taty*	Set tat	1	1
*	*Stolephorus baganensis*	Stol bag	1	1
*	*Stolephorus tri*	Stol tri	1	1
*	*Thryssa hamiltonii*	Thr ham	1	1

Table 4 (continued)

	Families/species	Abb.	BP	SB
*	*Thryssa kammalensis*	Thr kam	1	1
*	*Thryssa mystax*	Thr mys	0	1
Ephippidae				
*	*Platax teira*	Pla tie	1	1
Gerreidae				
*	*Gerres abbreviatus*	Ger abb	1	1
Gobiidae				
	Boleophthalmus boddarti	Bol bod	0	1
	Odontamblyopus rubicundus	Odo rub	1	1
	Oxuderes dentatus	Oxu den	0	1
	Taenioides nigromarginatus	Tae nig	1	1
	Trypauchen vagina	Try vag	1	1
Haemulidae				
*	*Plectorhinchus gibbosus*	Ple gib	1	0
*	*Pomadasys kaakan*	Poma kaa	1	1
*	*Pomadasys maculatus*	Poma mac	1	0
Hemiramphidae				
	Hemiramphus far	Hem far	1	1
Hemiscylliidae				
*	*Chiloscyllium hasselti*	Chil hass	1	0
*	*Chiloscyllium indicum*	Chil ind	1	0
*	*Chiloscyllium plagiosum*	Chil pla	1	1
Kurtidae				
	Kurtus indicus	Kur ind	1	1
Latidae				
*	*Lates calcarifer*	Lat cal	1	1
Leiognathidae				
	Leiognathus brevirostris	Leio bre	1	1
	Secutor insidiator	Sec ins	1	1
	Secutor ruconius	Sec ruc	1	1
Lobotidae				
*	*Lobotes surinamensis*	Lobo suri	1	1
Mugilidae				
	Liza melinoptera	Liza mel	1	1
*	*Liza subviridis*	Liza sub	1	1
*	*Liza vaigiensis*	Liza vaig	1	1
*	*Paramugil parmatus*	Par par	1	0
Mullidae				
*	*Upeneus sulphureus*	Upe sulp	1	1
Muraenesocidae				
*	*Congresox talabonoides*	Cong tala	0	1
Platycephalidae				
*	*Platycephalus indicus*	Plat ind	1	1
Plotosidae				
*	*Plotosus canius*	Plo can	1	1
*	*Plotosus lineatus*	Plo lin	1	0
Polynemidae				
*	*Eleutheronema tetradactylum*	Ele tet	1	1
*	*Leptomelanosoma indicum*	Lep ind	1	1

Table 4 (continued)

	Families/species	Abb.	BP	SB
*	*Polynemus paradiseus*	Poly para	1	1
*	*Polynemus sextarius*	Poly sex	0	1
Pristigasteridae				
*	*Ilisha elongata*	Ili elo	0	1
*	*Ilisha macrogaster*	Ili mac	0	1
*	*Ilisha melastoma*	Ili mel	1	1
Scatophagidae				
*	*Scatophagus argus*	Scat arg	1	1
Sciaenidae				
*	*Aspericorvina jubata*	Asp jub	1	1
*	*Dendrophysa russelii*	Dend russ	1	1
*	*Johnius belangerii*	John bela	1	1
*	*Johnius borneensis*	John born	1	1
*	*Johnius carouna*	John caro	1	1
*	*Johnius carutta*	John caru	0	0
*	*Johnius trachycephalus*	John tra	0	1
*	*Nibea soldado*	Nib sal	1	1
*	*Otolithes ruber*	Oto rub	1	1
*	*Otolithoides biauritus*	Oto bir	1	1
*	*Panna microdon*	Pan mic	1	1
*	*Pennahia anea*	Pen anea	1	1
*	*Protonibea diacanthus*	Pro dia	1	0
Scombridae				
*	*Rastrelliger brachysoma*	Ras bra	1	0
*	*Scomberomorus commerson*	Scb com	0	1
Serranidae				
*	*Epinephelus* sp.	Epi sp.	0	1
Siganidae				
*	*Siganus canaliculatus*	Sig cana	1	1
*	*Siganus vermiculatus*	Sig ver	1	0
Sillaginidae				
*	*Sillago sihama*	Sil sih	1	1
Soleidae				
*	*Synaptura commersonnii*	Syn com	1	1
Sphyraenidae				
*	*Sphyraena putnamae*	Sph put	0	1
Stromateidae				
*	*Pampus argenteus*	Pamp arg	1	1
*	*Pampus chinensis*	Pamp chi	1	1
Syngnathidae				
	Doryichthys boaja	Dor boa	0	1
Synodontidae				
*	*Harpadon nehereus*	Har neh	1	1
Terapontidae				
*	*Terapon jarbua*	Tera jar	1	1
*	*Terapon theraps*	Tera the	1	1
Tetraodontidae				
	Lagocephalus lunaris	Lago luna	0	1
	Tetraodon fluvialitis	Tetra flu	1	1

Table 4 (continued)

	Families/species	Abb.	BP	SB
	Takifugu oblongus	Taki obl	1	1
Toxotidae				
*	*Toxotes jaculatrix*	Tox jac	1	1
*	*Toxotes microlepis*	Tox mic	1	1
Triacanthidae				
	Triacanthus nieuhofii	Tri nei	1	1
Trichiuridae				
*	*Lepturacanthus savala*	Lep sava	1	1
*	*Trichiurus lepturus*	Tri lep	1	1
		Total	99	103

1 indicates present and 0 indicates absent. Asterisk (*) indicates commercially important/exploited

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