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Effects of an anti-salt intrusion dam on tropical fish assemblages

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Abstract. Following the construction of an anti-salt intrusion dam in Pak Panang River, Thailand, changes in the environmental conditions and fish assemblages were monitored both in the estuary and in the river. The present study was conducted during two different phases: when the sluices were open; and when they were closed. Salinity in the estuary declined ($P < 0.001$), but increased in the river during the open phase ($P = 0.002$). In the river, the pH increased ($P < 0.001$) during the closed phase, but was relatively constant in the estuary. No differences were found for water temperatures, chlorophyll *a* and abundance of phytoplankton. During the closed phase, the abundance of zooplankton was higher in the estuary, but the abundance of benthos in the river declined. Ninety-four fish species were collected. Species richness and the diversity index did not differ in the estuary, but were significantly different in the river; abundance was higher during the open phase. Fish moved between the two systems during the open phase and changes in fish assemblages correlated with salinity gradients and food sources. Sluice regulation to allow fish to move between the river and the estuary is recommended.

Additional keywords: community composition, hypopotamon, salinity, Thailand.

Introduction

Changes in aquatic communities are likely to occur when the system is disturbed by modifications of physical habitats and water quality (Ector and Rimet 2005). This situation may be more serious in the aquatic ecotone of the hypopotamon zone of a river course; that is, the lower reaches of the river channel connected to the brackish-water estuary (Welcomme *et al*. 2006). In general, this zone has high species richness at the interface between the freshwater and marine domains (Guégan *et al*. 1998; Blaber 2002). The fish assemblages of this environment are heterogeneous and comprise marine coastal species, strictly estuarine species and freshwater species, depending on the degree of connection with the adjacent environments (Ecoutin *et al*. 2005). The assemblages and movements of fish in this area result from temporally and spatially structured environmental gradients (Jaureguizar *et al*. 2003).

Damming in the hypopotamon area, either large or low-head dams, significantly alters the distribution, composition and abundance of the fish fauna by blocking migratory pathways (March *et al*. 2003). Da Costa *et al*. (2000) reported that damming a river channel near the estuarine/delta area in the Bia River Basin, West Africa, impeded estuarine/marine fish from migrating upstream during floods and vice versa, which seriously disturbed their life cycle. This also occurred in Europe where the Alqueva Dam in the Guadiana River, Portugal, changed fish assemblages in the estuary (Veiga *et al*. 2006) and the trophic relationship of fish in that ecosystem (Sá *et al*. 2006). A downstream dam also resulted in the absence of some fish species in an upstream area in Hokkaido, Japan (Fukushima *et al*. 2007).

The construction of dams in lower river courses also alters the physical habitat and hydrological regime in reaches both upstream and downstream of the dams. Areas downstream of dams can experience decreased river flow and water depth (Fievet *et al*. 2001). This decrease in freshwater can result in increased salinity, particularly at sites near the upstream boundary of the estuarine tidal influence. Areas upstream of dams experience decreased flow rates and increased water depth (March *et al*. 2003). The reduction in river flow lessens nutrient loads to the

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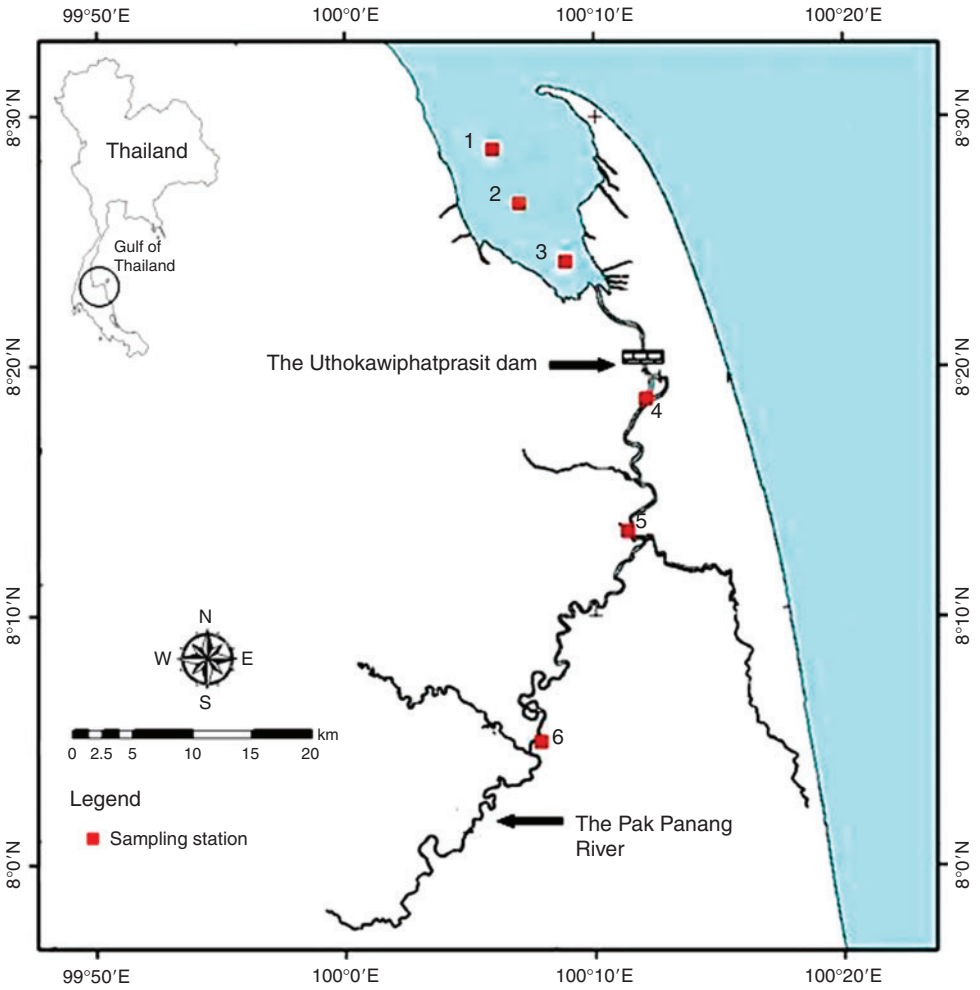

Fig. 1. Location of the Pak Panang River Basin.

estuary (Vörösmarty *et al*. 1997), but leads to an excess of nutrients in the upstream area (Downing *et al*. 1999). Moreover, owing to regulation of the dam, the environmental conditions in this area are highly variable and affect the structure and function of fish faunas (Sheaves *et al*. 2007).

In recent years, there has been increasing concern about the impacts of lower river course regulation on the role of the area as a nursery and feeding area for young and adult fish in lowland floodplains and estuaries (Jutagate *et al*. 2007; Atapattu and Kodituwakku 2009). However, there is no information on the effect of damming on the assemblages of riverine and estuarine fish faunas in this tropical region. In the present study, we investigated water quality, potential food sources for fish and fish assemblage composition at the *Uthokawiphatprasit* anti-salt intrusion dam in the Pak Panang River, southern Thailand. We compared upstream from the dam (i.e. river course) and downstream (i.e. estuary/delta area) to assess the effects of water regulation at the dam (i.e. open and closed phases). The open phase is when the sluices are opened and water flows freely between the upstream and downstream areas, allowing the passage of fish in both directions and the closed phase is when the sluices are closed. We hypothesised that: (*i*) there would be differences in the environmental conditions and fish assemblages as a result of the operation of the dam; and (*ii*) the patterns of fish assemblages would correspond to variation in the environmental conditions. Because downstream influences can affect upstream structures, disconnecting downstream areas can potentially act as a population 'sink' for native riverine species (Pringle 1997) as well as amphidromous and diadromous species (March *et al*. 2003; Welcomme *et al*. 2006). Thus, when the sluices are opened, more fish develop in the river because they can move between the estuary and the river.

Materials and methods

Study area

The Pak Panang River Basin (Fig. 1) is a fertile basin on the south-east coast of Thailand. The Pak Panang River runs through to the sea at Pak Panang Bay in the Gulf of Thailand, which is one of the most productive and heavily exploited marine fishing areas in the world (Christensen 1998). The basin experiences a tropical monsoon climate with a short dry season (February–April) and a long rainy season (May–January). The average annual rainfall is 2380 mm and the average air temperature is

27.3°C. Although there is a high rate of precipitation in the area, many areas experience soil-moisture deficits because of the high evaporation rates of the soil and plants. There is a high rate of water discharge to the sea (maximum of 1426 $m^3 s^{-1}$), as well as the intrusion of salt water, which has been recorded as far as 100 km upstream (Coastal Resources Institute 1991), resulting in inadequate freshwater for agricultural and domestic consumption. In addition, water in the downstream area of the river is slightly acidic because of peaty areas along the river banks. Therefore, in 1995, construction of the *Uthokawiphatprasit* (meaning 'effectively divide fresh and marine waters') anti-salt intrusion dam was started and the dam commenced operation in 1999. The dam is located 6 km upstream from the delta (Fig. 1) and contains 10 sluice gates, each 20 m wide. The water elevation during full storage at the dam site is 8 m. The major purposes of the dam are to prevent the intrusion of salt water into the river, to neutralise the pH of the river and to maintain freshwater for irrigation (Prabnarong and Kaewrat 2006). The sluice gates are opened occasionally when there is excessive water in the wet season.

Data collection and fish sampling

The study area covered the zone that had had fluctuations in salinity because of the flush of freshwater into the estuary and the intrusion of salt water into the river before the dam was constructed (Coastal Resources Institute 1991). Six sampling stations were selected: three stations in the estuary and three stations in the river (Fig. 1). Data collection and fish sampling were conducted monthly during the period of highest water level in the estuary in each month.

Water-quality parameters were sampled at three depths: surface, mid-water and 1 m above the bottom from three subsampling points in each station area. The sampled water was pooled as representative of a station. Salinity, pH and water temperature were obtained from a portable YSI 63–50FT (ENVCO, Auckland, New Zealand). Chlorophyll *a* was analysed using the method described in ROPME (1999).

Phytoplankton and zooplankton were collected using plankton nets with mesh sizes of 22 and 69 μm respectively. Both nets were 30 cm in diameter and were vertically dragged from a depth of 1 m to the surface at three subsampling points in each station area and the contents were pooled. In total, 288 samples were collected for each phytoplankton and zooplankton sampling. Biomass was expressed as biovolume (Lorenzen 1967) after the plankton were allowed to settle for at least 24 h before recording the settled volume. Benthos was collected using a grab (225 cm^2 covered area), with three grabs at each station, and then sieved (0.5 and 1.0 mm apertures) to collect and weigh the samples.

Fish were sampled in the estuary (i.e. Pak Panang Bay) by dragging a push net (30-mm mesh) for 30 min to circumscribe the sampling area. Because the push net could not operate in the river, a beach seine net of 30-mm mesh was used to collect fish, as well as multi-mesh gillnets (five nets at each station; mesh size ranging from 20 to 100 mm at 20 mm intervals) that were set to cover the water column and left overnight. All fish were classified to species level where possible (Nelson 1976; Froese and Pauly 2008). The numbers of individuals by species were counted and the fish were then weighed (nearest 0.01 g). Both the environmental measurements and fish sampling were carried out for 16 months from March 2006 to June 2007. During the study period, the sluice gates of the *Uthokawiphatprasit* dam were opened occasionally (8 months), but they were all closed during May, July, August and September 2006 and February, March, April and June 2007.

Data analysis

Statistical analyses examining differences in the environmental variables, species richness (SR) and the Shannon–Wiener diversity index (H′ index: Magurran 2004) of fish were conducted separately in each area (i.e. compared among the three stations) when the sluices were open and closed. There were six combinations in each area and eight replicates in each combination. Because of the non-normality of the data, the statistical differences were analysed using Kruskal–Wallis (*H*) and Dunn's post-hoc tests.

Temporal changes in the ecological dominance of fish species in each area were presented as the percentage index of relative importance (%IRI), which aggregates the main evaluation methods, namely abundance (%N), biomass (%W) and frequency of occurrence (%F) within a single index (Pinkas *et al.* 1971):

$$\%IRI = \left(\frac{(\%W_i + \%N_i) \times \%F_i}{\sum_{i=1}^{n} (\%W_i + \%N_i) \times \%F_i} \right) \times 100.$$

Hierarchical agglomerative clustering was used to classify the fish assemblages in each survey. Co-inertia analysis (Doledec and Chessel 1994) was carried out to assess the association between fish assemblage structure and the environmental variables. The significance of the resulting co-structure between the environmental and fish datasets was checked by a Monte-Carlo permutation test. This procedure repeated 1000 co-inertia analyses of both datasets after random permutations of their rows. The *P*-value represented the probability of the same covariance between environmental and fish axes occurring by chance (Cattanéo *et al.* 2001). All statistical analyses were carried out with R software (R Development Core Team 2008).

Results

Differences in water-quality parameters between the open and closed phases

The greatest difference in salinity between the open and closed phases (Fig. 2*a*) was at Station 3 (14) followed by Station 2 (12). Salinity in the estuary during the open phase was significantly lower than that during the closed phase ($H_5 = 22.06$, $P < 0.001$). Salinity levels within the river were higher during the open phase ($H_5 = 18.63$, $P = 0.002$), but the difference was less than 1. The pH (Fig. 2*b*) during the closed phase in the river was significantly higher than that during the open phase ($H_5 = 30.45$, $P < 0.001$) and tended to be neutral (pH ≈7), but there was no statistical difference between the phases in the estuary ($P = 0.491$). The average water temperature was ~30°C during the study and there was no statistical difference in both the estuary and river areas ($P > 0.05$) between the open and closed times (Fig. 2*c*). Chlorophyll *a* was higher in the estuary, but there was no statistical

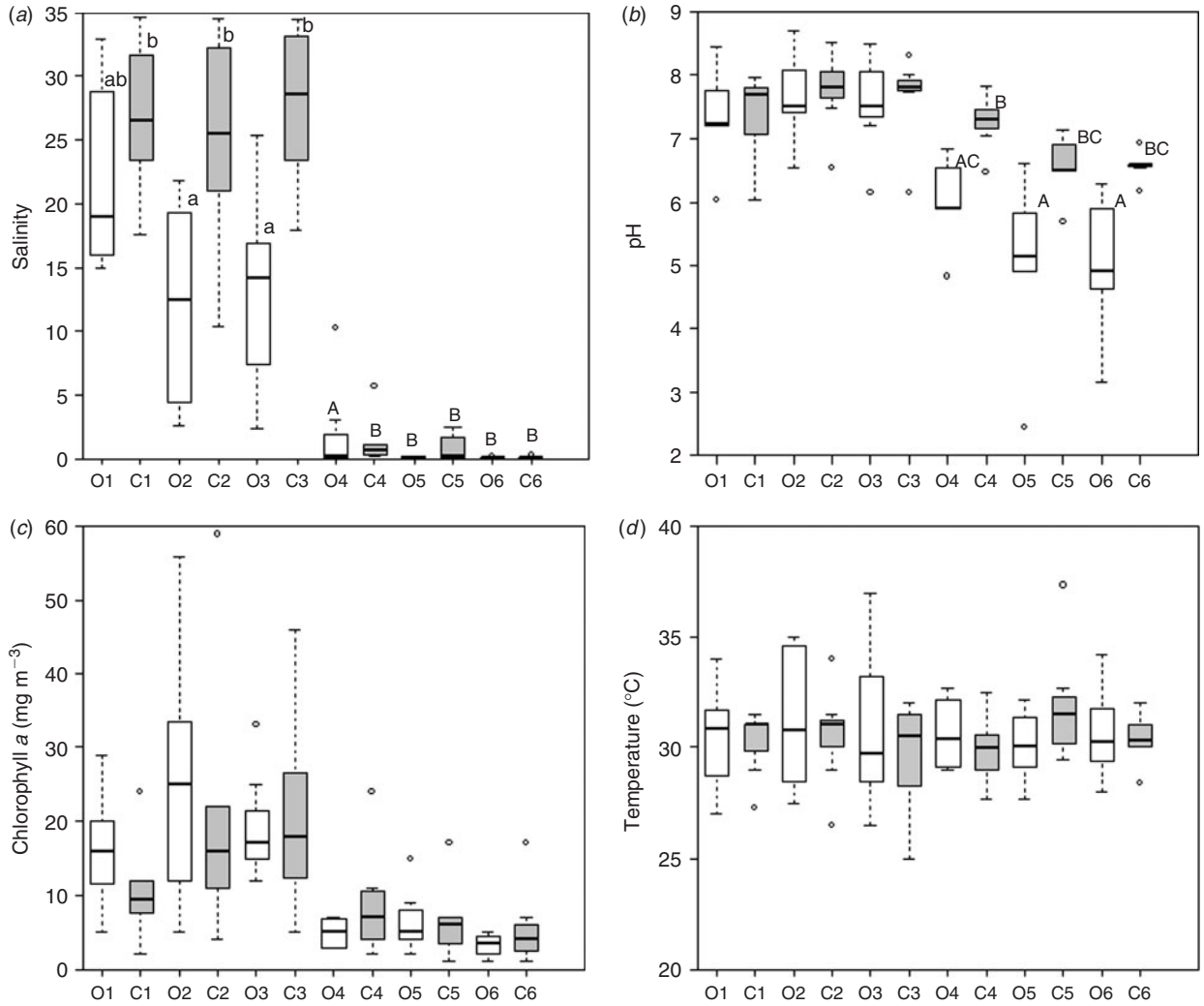

Fig. 2. Environmental attributes of the sampling stations comparing between sluice closing (C) and opening (O) periods based on mean values among all measured water parameters (numbers indicate the sampling stations). The same letter above a box indicates that the values are not statistically different (Dunn's post-hoc tests; $\alpha = 0.05$) when Kruskal–Wallis (H) $P < 0.05$. Lowercase and uppercase letters are for the estuary and river areas respectively.

difference in either area between the open and closed periods (Fig. 2*d*).

Differences in potential food sources between the open and closed phases

The abundance of potential food sources (i.e. phytoplankton, zooplankton and benthos; Fig. 3) was higher in the estuary than in the river, but changes in each parameter as a result of the operation of the dam (i.e. opening/closing) differed. No statistical differences were obtained for the abundance of phytoplankton in either area ($P > 0.05$). Chlorophyll *a* and phytoplankton were highly correlated ($r^2 = 0.78$). The abundance of zooplankton differed significantly in the estuarine area ($H_5 = 14.93$, $P = 0.011$), but not in the river ($P = 0.479$) because during the closed phase the zooplankton tended to decline in the stations further offshore (i.e. Stations 1 and 2). In contrast to zooplankton, the abundance of benthos did not differ in the estuary ($P = 0.871$), but increased in the river ($H_5 = 16.72$, $P = 0.005$) during the open phase.

Composition, abundance and importance index of fish

A total of 109 466 individual fish (414 889 g) were sampled. Ninety-four fish species belonging to 48 families were identified, comprising 44, 26 and 24 estuarine, marine and freshwater fish species respectively (Table 1). Most of the species caught were economically important (71.2%). Many subadult fish were collected in the samples, illustrated by the low weight of individuals in many large-sized species. No true marine species were found in the stations upstream of the dam and no freshwater species were found downstream at Stations 1 and 2. The most diverse families were estuarine and freshwater fish, such as Gobiidae and Cyprinidae (eight species each), followed by Clupeidae and Engraulidae (five species each) (Table 1). In terms

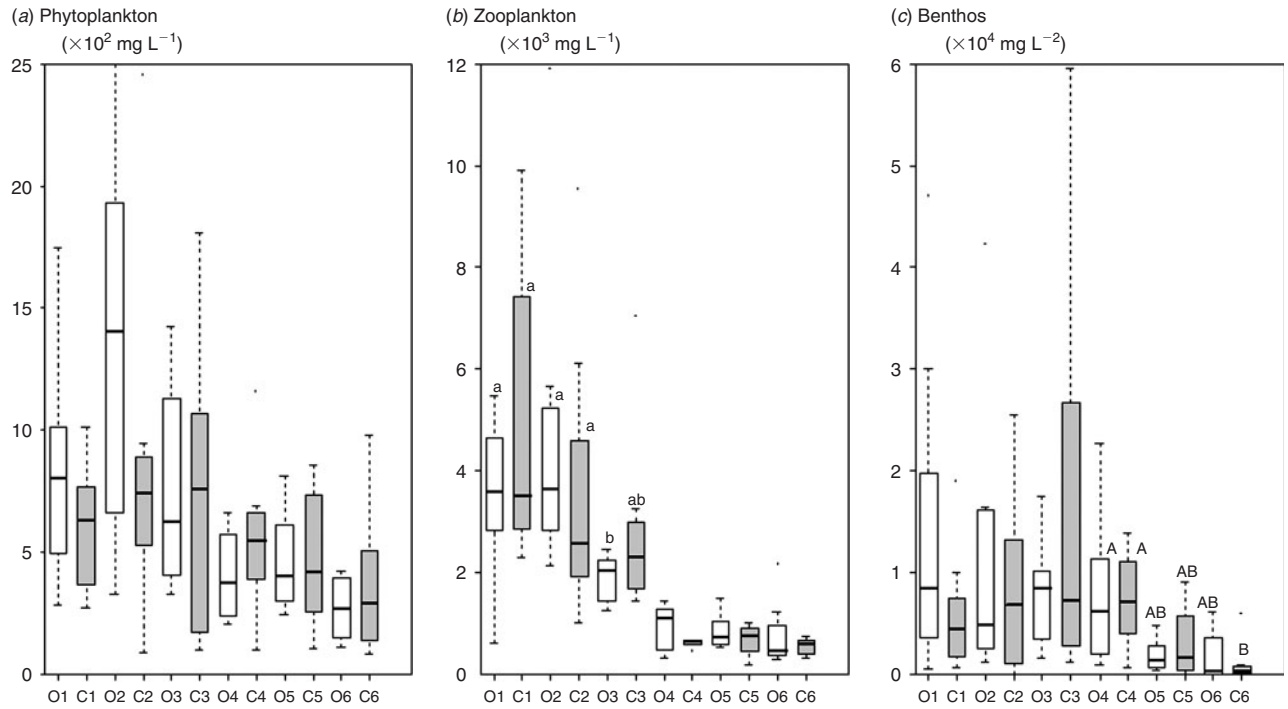

Fig. 3. Variation in the abundance of potential food sources comparing between sluice closing (C) and opening (O) periods among stations (numbers indicate the sampling stations). The same letter above a box indicates that the values are not statistically different (Dunn's post-hoc tests; $\alpha = 0.05$) when Kruskal–Wallis (H) $P < 0.05$. Lowercase and uppercase letters are for the estuary and river areas respectively.

of weight, *Notopterus notopterus*, *Ambassis gymnocephalus*, *Escualosa thorocota*, *Scatophagus argus*, *Liza subviridis*, *Pristolepis fasciatus* and *Leiognathus* spp. dominated the fish fauna, and accounted for 43.4% of the weight of the total samples. However, in terms of individual fish, the most abundant species were all schooling small-sized (i.e. adult <10 cm) marine fish species (70.4%), such as *Secuter insidiator*, *Encrasicholina devisi*, *Escualosa thorocota*, *Leiognathus* spp. and *A. gymnocephalus* (Table 1).

The highest average SR value (28) was obtained at Station 3 during the open sluice regime and the lowest value (4) was recorded at Station 6 during the closed period. The highest and lowest diversities were obtained during the closed phase at Stations 2 and 6 respectively. Between the closed/open phases, there were no significant differences in SR ($P = 0.667$) and H′ index ($P = 0.096$) in the estuary (Fig. 4). In contrast, the highest SR ($H_5 = 15.96$, $P = 0.007$) and H′ index ($H_5 = 15.52$, $P = 0.008$) values in the river were recorded during the opening phase (Fig. 4).

Encrasicholina devisi, *Leiognathus* spp., *A. gymnocephalus*, *S. insidiator* and *S. argus* were dominant in catches from the estuarine/marine area throughout most of the study period, and together accounted for 55.0% of the total %IRI. The %IRI values of *E. devisi* were significantly higher during the months when freshwater flushed into the delta. In contrast, *Leiognathus* spp. and *A. gymnocephalus* had high %IRI values during the period when the sluice gates were closed (Table 2). Meanwhile in the freshwater area, the major catches were *N. notopterus*, *P. fasciatus*, *Mystus gulio*, *Hampala macrolepidota* and *Barbonymus gonionotus*, which contributed to 66% of the total %IRI. During the months when the sluice gates were open, the numbers of fish that contributed to over 80% of the total %IRI were higher than those when the sluice gates were closed. In addition, during this period, euryhaline species such as *Osteogeneinosus militaris*, *Leiognathus* spp. and *M. gulio* contributed more to the %IRI (Table 3). However, no freshwater fish species was common in the estuarine/marine area over the study period.

Fish assemblages in relation to environmental factors

The cluster analysis of the fish assemblages produced four clusters of combinations of sluice gate functions (closed/open), station and sampling period (Fig. 5). Cluster A included most of the combinations of the river. Three combinations of the estuarine area, during the open phase in the river mouth area (i.e. Station 3), were included in this cluster. Cluster B contained samples from Stations 3 and 4 during the open period, which implied extensive movement of fish between these two stations. Cluster D included exclusively the stations further down towards the sea during the closed phase of the sluice gates. The remaining combinations of fish assemblages in the estuary were in Cluster C.

Owing to its high correlation with phytoplankton, chlorophyll *a* was excluded from the co-inertia analysis matching environmental variables and fish data. The co-structure between the environmental and fish datasets was significantly correlated (Monte-Carlo permutation test, $P < 0.001$). The first two axes explained 48% of the total inertia. Salinity, potential food sources and pH correlated along the first axis (F1, 40.3% of explained variance). Water temperature associated with axis F2 (17.7% of explained variance). Potential food sources, as well as pH,

Table 1. Species composition, occurrence, number and weight of fish collected in the hypopotamon of the Pak Panang River Bay between March 2006 and June 2007

✓, presence; o, absence; ES, estuarine; FW, freshwater; MA, marine

Scientific name	Abbreviation	Origin	Economic importance	Occurrence						Number	Weight of individual ± sd (g)
				1	2	3	4	5	6		
Ambassidae											
Ambassis gymnocephalus (Lacepède, 1802)	AMG	ES	N	✓	✓	✓	✓	✓	o	11 948	2.51 ± 0.57
Parambassis siamensis (Fowler, 1937)	PASi	ES	N	o	✓	✓	o	o	o	125	0.96 ± 0.63
Anabantidae											
Anabas testudineus (Bloch, 1792)	ANT	FW	Y	o	o	✓	✓	✓	o	4	57.81 ± 5.26
Aploactinidae											
Acanthosphex leurynnis (Jordan and Seale, 1905)	ACL	ES	N	o	o	✓	o	o	o	10	1.80 ± 1.62
Ariidae											
Arius caelatus (Valenciennes, 1840)	ARC	ES	Y	✓	✓	o	o	o	o	56	79.39 ± 11.19
Hemipimelodus bicolor (Fowler, 1935)	HEB	ES	Y	✓	o	✓	✓	o	o	12	77.83 ± 6.27
Osteogeneiosus militaris (Linnaeus, 1758)	OSM	ES	Y	✓	✓	✓	✓	✓	o	71	53.87 ± 8.04
Atherinidae											
Atherinomorus duodecimalis (Valenciennes, 1835)	ATD	ES	N	✓	o	o	o	o	o	6	4.78 ± 1.13
Hypoatherina valenciennesi (Bleeker, 1853)	HYV	MA	N	✓	✓	✓	o	o	o	2366	1.84 ± 0.39
Bagridae											
Hemibagrus nemurus (Valenciennes, 1840)	HEN	FW	Y	o	o	o	✓	✓	✓	5	371.28 ± 60.22
Mystus gulio (Hamilton, 1822)	MYG	ES	Y	✓	✓	✓	✓	✓	o	303	63.21 ± 25.68
Mystus singaringan (Bleeker, 1846)	MYS	FW	Y	o	o	o	✓	✓	✓	80	39.07 ± 20.16
Belonidae											
Tylosurus crocodylus (Lesueur, 1821)	TYC	ES	N	✓	✓	✓	o	o	o	70	63.50 ± 31.11
Bregmacerotidae											
Bregmaceros mcclellandi (Thompson, 1840)	BRM	MA	Y	o	✓	o	o	o	o	10	9.42 ± 0.66
Carangidae											
Carangoides praeustus (Bennett, 1830)	CAP	MA	Y	✓	✓	✓	o	o	o	66	33.41 ± 23.21
Parastromateus niger (Bloch, 1795)	PAN	MA	Y	✓	✓	o	o	o	o	8	82.49 ± 15.03
Channidae											
Channa micropeltes (Cuvier, 1831)	CHM	FW	Y	o	o	o	✓	✓	✓	20	90.77 ± 38.56
Cichlidae											
Oreochromis niloticus (Linnaeus, 1758)	ORN	FW	Y	o	o	o	✓	✓	o	3	64.26 ± 29.12
Clariidae											
Clarias macrocephalus (Günther, 1864)	CLM	FW	Y	o	o	o	✓	✓	✓	14	184.14 ± 21.08
Clupeidae											
Anodontostoma chacunda (Hamilton, 1822)	ANC	ES	Y	✓	✓	✓	✓	o	o	2662	55.24 ± 35.03
Coilia macrognathus (Bleeker, 1858)	COM	MA	N	✓	✓	✓	o	o	o	738	7.09 ± 1.67
Escualosa thoracata (Valenciennes, 1847)	ENT	ES	Y	✓	✓	✓	o	o	o	15 704	1.66 ± 0.78
Hilsa kelee (Cuvier, 1829)	HIK	ES	Y	✓	✓	✓	✓	o	o	3247	48.74 ± 11.28
Sardinella gibbosa (Bleeker, 1849)	SAG	MA	Y	✓	✓	✓	o	o	o	402	35.99 ± 6.57

(*Continued*)

Table 1. (Continued)

Scientific name	Abbreviation	Origin	Economic importance	Occurrence						Number	Weight of individual ± sd (g)
				1	2	3	4	5	6		
Cobitidae											
Acanthopsis sp.	ACS	FW	Y	o	o	o	o	✓	o	2	34.91 ± 16.22
Cynoglossidae											
Cynoglossus arel (Bloch and Schneider, 1801)	CYAr	ES	Y	✓	✓	✓	o	o	o	1065	9.58 ± 2.47
Cyprinidae											
Barbodes gonionotus (Bleeker, 1850)	BAG	FW	Y	o	o	o	✓	✓	✓	164	76.50 ± 36.34
Cyclocheilichthys apogon (Valenciennes, 1842)	CYA	FW	Y	o	o	o	✓	✓	✓	138	66.39 ± 19.54
Hampala dispar (Smith, 1934)	HAD	FW	Y	o	o	o	✓	✓	✓	219	97.56 ± 26.39
Hampala macrolepidota (Valenciennes, 1842)	HAM	FW	Y	o	o	o	✓	✓	✓	88	114.12 ± 40.16
Labiobarbus lineata (Sauvage, 1878)	LAL	FW	Y	o	o	o	✓	o	✓	20	42.36 ± 20.17
Osteocheilus hasselti (Valenciennes, 1842)	OSH	FW	Y	o	o	o	✓	✓	✓	64	69.69 ± 17.88
Parachela siamensis (Günther, 1868)	PASa	FW	N	o	o	o	o	o	✓	11	7.82 ± 1.95
Puntius brevis (Bleeker, 1850)	PUB	FW	Y	o	o	✓	✓	✓	✓	4	129.73 ± 28.24
Dasyatidae											
Himantura imbricata (Bloch and Schneider, 1801)	HII	ES	Y	o	✓	✓	o	o	o	5	256.31 ± 28.25
Eleotridae											
Butis butis (Hamilton, 1822).	BUB	ES	N	✓	✓	✓	o	o	o	481	3.19 ± 0.93
Oxyeleotris marmorata (Bleeker, 1852)	OXM	FW	Y	o	o	✓	✓	✓	✓	14	416.34 ± 98.72
Engraulidae											
Encrasicholina devisi (Whitley, 1940)	END	MA	Y	✓	✓	✓	✓	o	o	19 488	0.97 ± 0.57
Encrasicholina heteroloba (Rüppell, 1837)	ENH	MA	N	✓	✓	✓	o	o	o	1872	1.79 ± 0.31
Lycothrissa crocodilus (Bleeker, 1851)	LYC	FW	N	o	o	o	✓	o	o	5	3.12 ± 0.56
Stolephorus dubiosus (Wongratana, 1983)	STD	ES	Y	✓	✓	✓	✓	o	o	2547	3.82 ± 1.17
Thryssa hamiltonii (Gray, 1835)	THH	ES	N	✓	✓	✓	o	o	o	833	0.97 ± 0.34
Gerreidae											
Gerres abbreviatus (Bleeker, 1850)	GEA	ES	Y	✓	✓	✓	✓	o	o	56	13.11 ± 4.65
Gobiidae											
Acentrogobius caninus (Valenciennes, 1837)	ACC	ES	Y	✓	o	✓	o	o	o	10	6.53 ± 3.71
Aulopareia chlorostigmatoides (Bleeker, 1849)	AUC	ES	Y	o	o	✓	o	o	o	3	10.33 ± 3.95
Glossogobius giuris (Hamilton, 1822)	GLG	ES	N	✓	✓	✓	o	o	o	1582	3.02 ± 1.24
Papilogobius reichei	PAR	ES	N	✓	✓	✓	✓	o	o	279	2.50 ± 1.62
Parapocryptes serperaster (Richardson, 1846)	PASe	ES	Y	✓	✓	✓	o	o	o	147	9.75 ± 3.22
Pseudapocryptes lanceolatus (Bloch and Schneider, 1801)	PSL	MA	N	✓	✓	✓	o	o	o	503	5.46 ± 1.65
Taenioides cirratus (Blyth, 1860)	TAC	ES	Y	✓	o	✓	o	o	o	2	5.75 ± 2.03
Trypauchen vagina (Bloch and Schneider, 1801)	TRV	ES	Y	✓	✓	✓	o	o	o	1143	9.81 ± 3.25
Haemulidae											
Pomadasys kaakan (Cuvier, 1830)	POK	ES	Y	o	o	✓	✓	✓	o	5	1461.68 ± 125.76

Hemirhamphidae												
Hyporhamphus dussumieri (Valenciennes, 1847)	HYD	MA	Y	✓	✓	✓	o	o	o	39	4.62 ± 1.21
Holocentridae												
Sargocentron sp.	SAS	MA	N	o	✓	o	o	o	o	2	0.70 ± 0.14
Leiognathidae												
Leiognathus spp.	LEB	ES	N	✓	✓	✓	✓	✓	o	15 241	1.35 ± 0.79
Secuter insidiator	SEI	MA	N	✓	✓	✓	o	o	o	20 706	0.64 ± 0.12
Lutjanidae												
Lutjanus russelli (Bleeker, 1849)	LUR	MA	Y	✓	✓	✓	o	o	o	5	74.64 ± 15.23
Mastacembelidae												
Mastacembelus armatus (Lacepède, 1800)	MAA	FW	N	o	o	o	o	✓	o	3	159.42 ± 33.85
Megalopidae												
Megalops cyprinoides (Broussonet, 1782)	MEC	ES	Y	o	o	✓	✓	✓	o	4	296.78 ± 65.32
Mugilidae												
Liza oligolepis (Bleeker, 1859).	LIO	ES	Y	✓	✓	✓	o	o	o	181	10.99 ± 5.24
Liza subviridis (Valenciennes, 1836)	LIS	ES	Y	✓	✓	✓	o	o	o	1350	19.96 ± 10.04
Valamugil cunnesius (Valenciennes, 1836)	VAC	MA	Y	o	✓	✓	o	o	o	3	46.37 ± 19.02
Muraenesocidae												
Muraenesox cinereus (Forsskål, 1775)	MUC	MA	Y	✓	✓	✓	o	o	o	31	61.95 ± 10.04
Nandidae												
Pristolepis fasciatus (Bleeker, 1851)	PRF	FW	Y	o	o	✓	✓	✓	✓	188	94.49 ± 33.27
Notopteridae												
Notopterus notopterus (Pallas, 1769)	NON	FW	Y	o	o	o	✓	✓	✓	426	109.16 ± 24.56
Ophichthidae												
Pisodonopis boro (Hamilton, 1822)	PIB	ES	Y	✓	✓	✓	o	o	o	44	41.57 ± 24.63
Osphronemidae												
Osphronemus goramy (Lacepède, 1801)	OSG	FW	Y	o	o	o	o	✓	o	2	81.51 ± 14.33
Trichogaster pectoralis (Regan, 1910)	TRP	FW	Y	o	o	o	o	✓	✓	2	140.05 ± 50.14
Trichogaster trichopterus (Pallas, 1770)	TRT	FW	Y	o	o	o	o	✓	o	2	15.14 ± 3.97
Platycephalidae												
Grammoplites scarber	GRS	MA	N	✓	✓	✓	o	o	o	655	2.22 ± 0.56
Platycephalidae												
Platycephalus indicus (Linnaeus, 1758)	PLI	ES	Y	✓	✓	✓	o	o	o	92	2.46 ± 0.56
Plotosidae												
Plotosus canius (Hamilton, 1822)	PLC	ES	Y	✓	✓	✓	o	o	o	49	40.69 ± 17.72
Polynemidae												
Eleutheronema tetradactylum (Shaw, 1804)	ELT	MA	Y	✓	✓	✓	o	o	o	158	5.99 ± 1.85

(*Continued*)

Table 1. (Continued)

Scientific name	Abbreviation	Origin	Economic importance	Occurrence						Number	Weight of individual ± sd (g)
				1	2	3	4	5	6		
Scatophagidae											
Scatophagus argus (Linnaeus, 1766)	SCA	ES	Y	✓	✓	✓	✓	o	o	1481	15.04 ± 12.02
Sciaenidae											
Panna perarmatus (Chabanaud, 1926)	PAP	MA	Y	✓	✓	✓	o	o	o	5339	1.18 ± 0.32
Scombridae											
Rastrelliger brachysoma (Cuvier, 1817)	RAB	MA	Y	✓	✓	o	o	o	o	4	45.00 ± 9.14
Scomberomorus commerson (Lacepède, 1800)	SCC	ES	Y	✓	o	o	o	o	o	2	51.57 ± 7.29
Scorpaenidae											
Vespicula trachinoides (Cuvier, 1829)	VET	ES	N	✓	✓	✓	o	o	o	254	1.02 ± 0.47
Siganidae											
Siganus canaliculatus (Park, 1797)	SIC	ES	Y	✓	✓	✓	o	o	o	6430	1.04 ± 0.65
Sillaginidae											
Sillago sihama (Forsskål, 1775)	SIS	MA	Y	✓	✓	✓	o	o	o	124	6.34 ± 2.21
Siluridae											
Ompok bimaculatus (Bloch, 1794)	OMB	FW	Y	o	o	o	o	✓	✓	15	55.71 ± 3.26
Sparidae											
Acanthopagrus berda (Forsskål, 1775)	ACB	MA	Y	✓	✓	✓	o	o	o	20	10.33 ± 4.42
Sphyraenidae											
Sphyraena jello (Cuvier, 1829)	SPJ	MA	Y	✓	✓	✓	o	o	o	16	71.06 ± 7.01
Stromateidae											
Pampus argenteus (Euphrasen, 1788)	PAA	MA	Y	✓	✓	o	o	o	o	8	55.11 ± 12.12
Synbranchidae											
Macrotrema caligans (Cantor, 1849)	MAC	ES	Y	✓	✓	✓	o	o	o	34	3.37 ± 1.05
Ophisternon bengalense (McClelland, 1844)	OPB	ES	Y	✓	o	✓	o	o	o	3	58.43 ± 13.67
Syngnathidae											
Hippichthys penicillus	HIP	ES	N	o	✓	o	o	o	o	11	0.75 ± 0.24
Teraponidae											
Therapon jabua (Forsskål, 1775)	THJ	ES	N	✓	✓	✓	o	o	o	31	38.59 ± 12.41
Tetraodontidae											
Lagocephalus spadiceus (Richardson, 1845)	LAS	MA	N	✓	✓	✓	o	o	o	16	1.26 ± 0.46
Takifugu oblongus (Bloch, 1786)	TAO	ES	N	o	o	✓	o	o	o	7	18.19 ± 6.75
Tetraodon nigroviridis (Marion de Procé, 1822)	TEN	ES	N	✓	✓	✓	✓	o	o	145	9.43 ± 4.51
Toxotidae											
Toxotes chatareus (Hamilton, 1822)	TOC	ES	Y	o	o	o	✓	✓	✓	10	74.47 ± 20.09
Triacanthidae											
Triacanthus biaculeatus (Bloch, 1786)	TRB	MA	N	o	✓	✓	o	o	o	6	4.96 ± 1.05
Trichiuridae											
Trichiurus lepturus (Day, 1865)	TRL	MA	Y	✓	✓	✓	o	o	o	73	1.98 ± 0.65

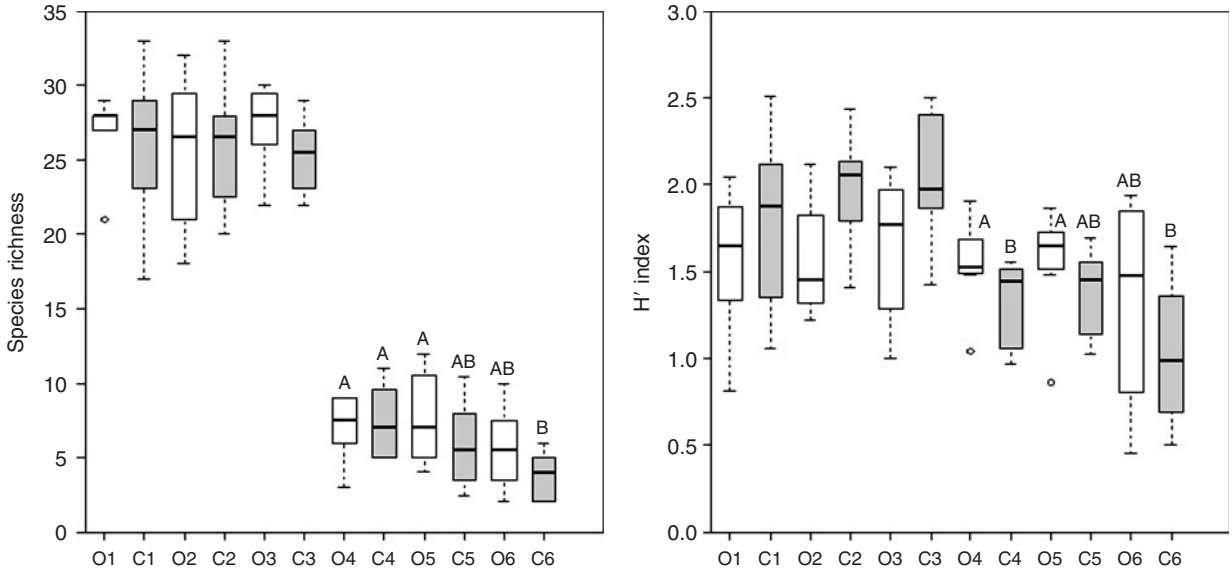

Fig. 4. Fluctuations in fish species richness and diversity index between sluice closing (C) and opening (O) periods among stations (numbers indicate the sampling stations). The same letter above a box indicates that the values are not statistically different (Dunn's post-hoc tests; $\alpha = 0.05$) when Kruskal–Wallis (H) $P < 0.05$. Lowercase and uppercase letters are for the estuary and river areas respectively.

showed a positive correlation with salinity. Therefore, the first axis represented a salinity gradient, with high salinity (estuary) associated with rich food sources on the left, and low salinity (river) on the right (Fig. 6*a*). There is a clear separation between freshwater species (on the right) and estuarine/marine species (on the left), linked to the gradient of salinity. Meanwhile, the species around the centre are freshwater species, such as *N. notopterus* (NON), *Oxyeleotris marmorata* (OXM) and *O. militaris* (OSM), and euryhaline estuarine species, such as *Platycephalus indicus* (PLI), *Glossogobius giuris* (GLG) and *M. gulio* (MYG).

Discussion

Spatio-temporal changes in water quality and potential food sources

Salinity in the river upstream dropped significantly from an average of 19 (Preedalumpaburt *et al*. 1999) to an average of 0.65 in the present study after the dam was built. Fluctuations in salinity in both areas caused by opening and closing the sluice gates depended on the water level in the river and massive freshwater inflows (Champalbert *et al*. 2007). Another objective of the Pak Panang Project was to neutralise the pH in the river (Prabnarong and Kaewrat 2006) and this was also successful as the pH tended to increase during the closed period. Productivity (i.e. chlorophyll *a* concentration) was higher in the estuary and lower in the river, and tended to increase during the open period in the estuary, which was most likely caused by nutrient-rich effluent from the river (MacIntyre *et al*. 2000; Struski and Bacher 2006). Although there was no significant difference in temperature over the study period, the temperature in the river decreased slightly during the open phase compared with the closed phase.

The abundance of phytoplankton correlated with the chlorophyll *a* concentration. The decrease in phytoplankton abundance at Station 3 when the sluice gates were open compared with the other combinations in the estuary probably resulted from light limitation caused by suspended matter from the river (MacIntyre *et al*. 2000). The abundance of zooplankton during the closed period in the estuary resembled findings by Champalbert *et al*. (2007) in an estuary downstream from a Sengalese anti-salt intrusion dam. Champalbert *et al*. (2007) reported that during the low flow and closed period, marine and euryhaline zooplankton colonised the estuary and moved to the dam. Meanwhile, during high flow and when freshwater was released, zooplankton in the estuary were less abundant, but more diverse and were dominated by freshwater species. The abundance of benthos in the upper dam area is controlled by fluctuations in water level and sedimentation, which make the bottom unstable (de Brouwer *et al*. 2000) and this probably caused a reduction in the benthos in the river zone during the closed period. Moreover, anoxic conditions resulting from denitrification in the upper dam (Downing *et al*. 1999) would also affect benthic fauna.

Fish assemblages

Sirimontraporn *et al*. (1997) reported that before the dam was built, 45 estuarine, 39 marine and 34 freshwater species were recorded from Stations 1 to 6. The freshwater species not found in the current study included rheophilic species, such as *Botia* spp. and *Rasbora* spp., which had been abundant in the area even a few years after impoundment (Sritakon *et al*. 2003) and there were also many lotic fish species, particularly in the Family Cyprinidae (Sirimontraporn *et al*. 1997). Welcomme *et al*. (2006) suggested that damming near the mouth of a river can have negative or positive impacts for fish species in the river system. Lotic species tend to disappear because of inappropriate river flow and amplitude and duration of flooding. The brackish portion within the river is removed from impounded freshwater, resulting in the disappearance of brackish water fish. Meanwhile,

Table 2. Percentage of the index of relative importance (%IRI) of fish species (comprising together ≥80%) caught in the Pak Panang Bay from March 2006 to June 2007

Note: *E. devisi*: *Encrasicholina devisi*; *L. subviridis*: *Liza subviridis*; *G. guiaris*: *Glossogobius guiaris*; *S. argus*: *Scatophagus argus*; *C. macrognathus*: *Coilia macrognathus*; *S. insidiator*: *Secuter insidiator*; *A. gymnocephalus*: *Ambassis gymnocephalus*; *S. dubiosus*: *Stolephorus dubiosus*; *A. chacunda*: *Anodontostoma chacunda*; *P. perarmatus*: *Panna perarmatus*; *P. serperaster*: *Parapocryptes serperaster*; *M. gulio*: *Mystus gulio*; *P. canius*: *Plotosus canius*; *E. thoracata*: *Escualosa thoracata*; *P. lanceolatus*: *Pseudapocryptes lanceolatus*; *S. canaliculatus*: *Siganus canaliculatus*; *T. vagina*: *Trypauchen vagina*; *H. kelee*: *Hilsa kelee*; *L. oligolepis*: *Liza oligolepis*; *S. gibbosa*: *Sardinella gibbosa*; *H. valenciennesi*: *Hypoatherina valenciennesi*; *P. indicus*: *Platycephalus indicus*

Species	%IRI	Species	%IRI	Species	%IRI	Species	%IRI
Mar-06		Apr-06		May-06		Jun-06	
E. devisi	50.1	*S. insidiator*	40.9	*E. devisi*	24.8	*S. insidiator*	34.7
L. subviridis	12.9	*E. devisi*	29.1	*A. chacunda*	16.1	*E. devisi*	20.5
G. guiaris	7.3	*A. gymnocephalus*	6.5	*S. argus*	11.8	*S. argus*	9.4
S. argus	6.8	*S. dubiosus*	5.0	*Leiognathus* spp.	7.7	*A. gymnocephalus*	4.8
C. macrognathus	3.2			*P. perarmatus*	7.4	*A. chacunda*	2.6
				S. dubiosus	6.1	*P. serperaster*	2.3
				A. gymnocephalus	5.1	*P. perarmatus*	2.0
				L. subviridis	3.9	*G. guiaris*	2.0
						M. gulio	1.1
						P. canius	0.8
Jul-06		Aug-06		Sep-06		Oct-06	
A. gymnocephalus	34.9	*Leiognathus* spp.	27.6	*Leiognathus* spp.	42.2	*S. canaliculatus*	39.7
S. insidiator	20.2	*S. dubiosus*	19.0	*A. gymnocephalus*	12.2	*Leiognathus* spp.	18.1
S. dubiosus	10.9	*S. insidiator*	13.6	*E. devisi*	9.7	*T. vagina*	16.7
E. thoracata	7.4	*A. gymnocephalus*	8.8	*S. dubiosus*	9.2	*A. gymnocephalus*	4.2
E. devisi	3.1	*A. chacunda*	8.8	*S. argus*	6.3	*S. argus*	3.8
P. larceolotus	3.1	*E. devisi*	5.1	*P. perarmatus*	6.2		
A. chacunda	2.7						
Nov-06		Dec-06		Jan-07		Feb-07	
Leiognathus spp.	21.4	*Leiognathus* spp.	20.4	*E. devisi*	27.8	*S. argus*	22.3
E. devisi	14.4	*E. devisi*	19.3	*H. valenciennesi*	19.9	*E. devisi*	13.0
A. gymnocephalus	18.3	*P. perarmatus*	13.8	*Leiognathus* spp.	16.5	*C. macrognathus*	12.3
H. kelee	6.6	*A. gymnocephalus*	9.0	*P. perarmatus*	9.2	*P. perarmatus*	9.5
S. argus	5.7	*S. argus*	6.3	*S. gibbosa*	4.1	*E. thorocota*	8.9
L. subviridis	5.2	*A. chacunda*	4.8	*T. vagina*	3.4	*H. valenciennesi*	6.0
L. oligolepis	3.4	*T. vagina*	4.5			*S. canaliculatus*	5.4
S. gibbosa	3.1	*S. canaliculatus*	4.2			*Leiognathus* spp.	2.8
P. serperaster	3.1						
Mar-07		Apr-07		May-07		Jun-07	
T. vagina	15.3	*E. thorocota*	46.1	*E. thorocota*	36.4	*E. thorocota*	39.8
Leiognathus spp.	13.1	*L. subviridis*	13.8	*A. gymnocephalus*	21.3	*A. gymnocephalus*	15.6
Cynoglossus spp.	10.0	*A. gymnocephalus*	7.6	*Leiognathus* spp.	14.3	*L. subviridis*	12.7
Butis spp.	8.9	*Leiognathus* spp.	7.4	*S. argus*	6.1	*H. kelee*	8.4
E. devisi	8.4	*Cynoglossus* spp.	6.4	*Cynoglossus* spp.	5.6	*Leiognathus* spp.	4.7
P. perarmatus	4.3						
G. guiaris	4.2						
S. argus	3.8						
A. gymnocephalus	3.5						
E. thoracata	2.7						
S. subviridis	2.7						
P. larceolotus	2.6						
P. indicus	2.6						

freshwater estuarine fish (i.e. secondary freshwater fish) would benefit because the impounded water would have low salinity and less saline intrusion into the river portion.

In the estuarine area, the species found were similar to a previous study, particularly the species of economic importance (FAO 2000; Barbier *et al*. 2002). Low H′ index values in the freshwater section indicated that it was dominated by very few species. Meanwhile the distribution of fishes in the estuarine area during the closed period was more evenly distributed than during the open period because the estuarine/marine species dispersed over the whole estuarine sampling area and there were less freshwater immigrants. Duldic *et al*. (1997) reported that estuarine areas usually support low trophic level species with high ecological efficiency and productivity, and this was true in

Table 3. Percentage of the index of relative importance (%IRI) of fish species (comprising together ≥80%) caught in the lower Pak Panang River from March 2006 to June 2007

O. militaris: *Osteogeneiosus militaris*; *O. marmorata*: *Oxyeleotris marmorata*; *N. notopterus*: *Notopterus notopterus*; *M. cyprinoides*: *Megalops cyprinoides*; *M. gulio*: *Mystus gulio*; *O. hasselti*: *Osteochilus hasselti*; *P. fasciatus*: *Pristolepis fasciatus*; *H. macrolepidota*: *Hampala macrolepidota*; *M. singaringan*: *Mystus singaringan*; *B. gonionotus*: *Barbodes gonionotus*; *H. dispar*: *Hampala dispar*; *C. apogon*: *Cyclocheilichthys apogon*; *T. chatareus*: *Toxotes chatareus*; *H. bicolor*: *Hemipimelodus bicolour*; *C. macrocephalus*: *Clarias macrocephalus*; *L. lineata*: *Labiobarbus lineata*

Species	%IRI	Species	%IRI	Species	%IRI	Species	%IRI
Mar-06		Apr-06		May-06		Jun-06	
O. militaris	21.8	*N. notopterus*	39.9	*N. notopterus*	33.2	*H. macrolepidota*	35.3
P. fasciatus	20.1	*M. gulio*	14.0	*M. gulio*	17.1	*N. notopterus*	17.5
O. marmorata	15.0	*P. fasciatus*	12.7	*O. hasselti*	14.6	*M. gulio*	14.1
N. notopterus	7.5	*O. hasselti*	10.4	*H. macrolepidota*	9.1	*M. singaringan*	12.0
M. cyprinoides	7.5	*O. militaris*	5.5	*O. militaris*	6.9	*B. gonionotus*	4.9
M. gulio	5.0						
O. hasselti	4.8						
Jul-06		Aug-06		Sep-06		Oct-06	
B. gonionotus	30.5	*N. notopterus*	52.4	*N. notopterus*	32.4	H. dispar	42.3
M. gulio	18.0	*O. hasselti*	11.2	*M. gulio*	20.0	*N. notopterus*	22.4
H. dispar	13.6	*P. fasciatus*	6.5	*H. dispar*	10.3	*B. gonionotus*	9.6
N. notopterus	9.3	*B. gonionotus*	5.3	*P. fasciatus*	8.5	*M. gulio*	8.7
M. singaringan	8.8	*H. dispar*	4.6	*H. macrolepidota*	7.7		
				B. gonionotus	6.9		
Nov-06		Dec-06		Jan-07		Feb-07	
M. gulio	22.7	*H. macrolepidota*	23.2	*C. apogon*	25.6	*N. notopterus*	38.0
Leiognathus spp.	15.1	*C. apogon*	20.2	*N. notopterus*	18.4	*B. gonionotus*	20.2
C. apogon	15.0	*N. notopterus*	19.0	*P. fasciatus*	10.8	*M. gulio*	11.8
O. marmorata	7.8	*L.limeata*	16.9	*M. gulio*	8.2	*P. fasciatus*	10.7
T. chatoreus	7.1	*O. militaris*	5.8	*B. gonionotus*	7.5		
H. bicolor	6.2			*O. hasselti*	7.3		
C. macrocephalus	4.3			*H. macrolepidota*	7.0		
O. hasselti	4.0						
Mar-07		Apr-07		May-07		Jun-07	
N. notopterus	50.7	*N. notopterus*	55.3	*N. notopterus*	61.6	*P. fasciatus*	42.0
P. fasciatus	25.6	*P. fasciatus*	20.1	*P. fasciatus*	26.1	*H. dispar*	23.6
B. gonionotus	10.0	*O. militaris*	6.3			*N. notopterus*	17.7

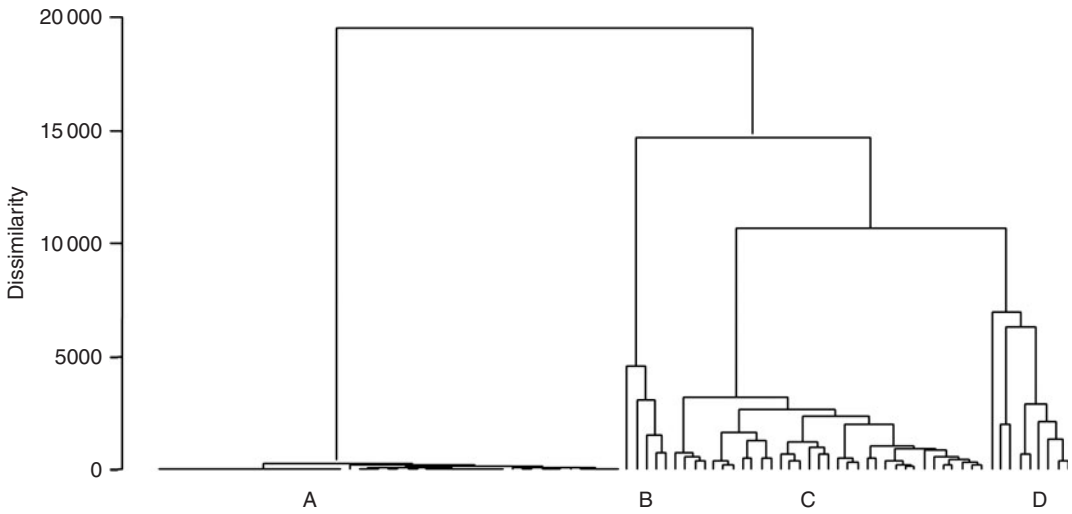

Fig. 5. Dendrogram of the cluster analysis results corresponding to the combination of stations and months of sampling.

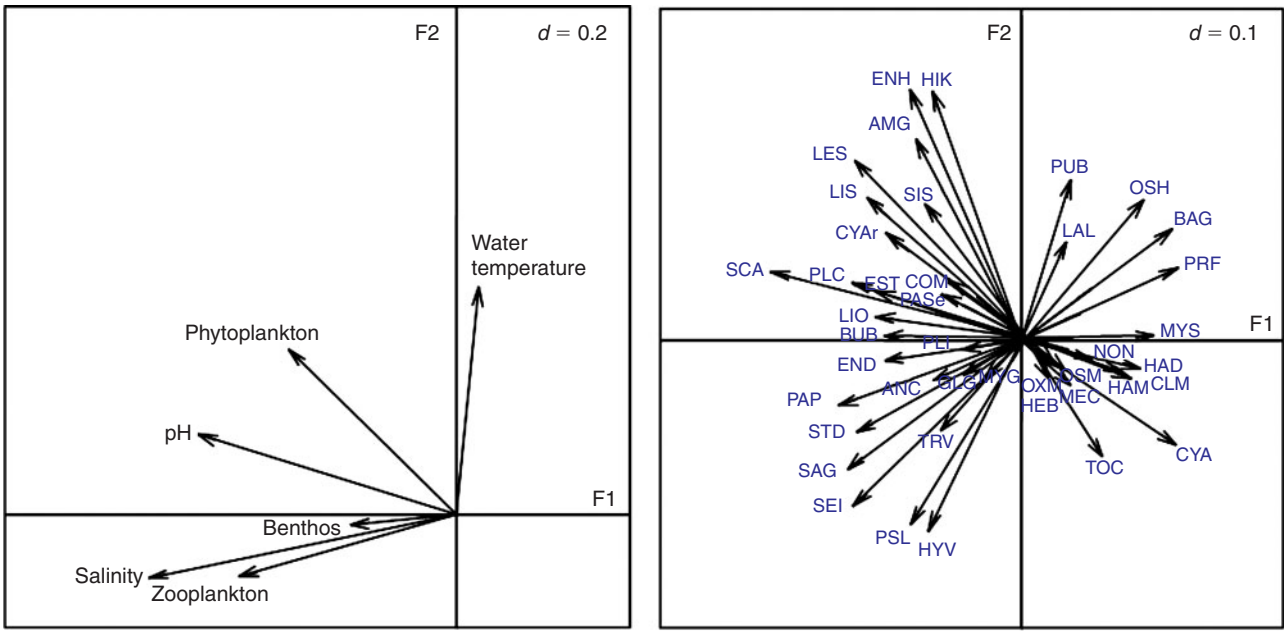

Fig. 6. Results of the co-inertia analysis of environmental variables to fish species found in the study (showing only the ecologically dominant species)

the present study as small-sized phytoplankton feeders, such as *E. devisi*, *Leiognathus* spp. and *A. gymnocephalus*, were major contributors to the %IRI in the estuary.

It is widely accepted that the major key factor controlling fish assemblages in the hypotamonic zone is salinity (Jaureguizar *et al*. 2003; Martino and Able 2003), which also influences the diversity and distribution of the phytoplankton (Huang *et al*. 2004), zooplankton (Champalbert *et al*. 2007) and benthic fauna (Wu and Richards 1981). The high correlation to axis F1 of the ordination of fish assemblage composition implies that most of the fish in the present study were distributed along a salinity gradient in the hypotamonic zone (Hajisamae *et al*. 2003).

Conclusion

The present study illustrates the impacts of dam operation in a lower river course on key ecological components (i.e. water quality parameters, potential food sources for fish and fish assemblages) in a tropical area. Although the dam is not a permanent barrier (i.e. the sluice gates are opened occasionally), differences resulting from the operation of the dam (opening/closing) were observed. Our findings concur with the suggestions by Pringle (1997) that damming the lower reach of a river has effects in terms of ecosystem changes (e.g. water quality and primary productivity) and fish community level changes. Further study is needed to examine the effect of dam operation on: (*i*) the life cycle of diadromous species; and (*ii*) the development of marine fish larvae in the delta area because many larvae use this area as a nursery ground and require optimum salinity and an abundance of food resources.

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