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Fish in the Pak Panang River and Bay in Relation to the Anti-Salt Dam Operation, Part II: Trophic Model

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ABSTRACT

The ECOPATH software program was used to study the mass-balanced trophic structures and functioning of the aquatic organisms of the Pak Panang Bay and River (lower portion) to gain insight into the ecosystem due to the operation of the Uthokvibhajaprasid Dam. The resulting models were authenticated as indicated by the output parameters. There were 20 and 25 compartments for the estuary and river models, respectively. The trophic levels varied from 1.0 for primary producers and detritus to about 3.0 for carnivorous fish. Gross efficiency of the fishery indicated intensive efforts in both areas. Both systems were considered intact, since the transfer efficiency was between 10 to 15%. Small-sized brackish-water plankton feeders played an important role in linking the lower trophic organisms and top predators. Improper regulation of the sluice gates would impact these groups and result in an imbalance of the ecosystems.
Key words: Pak Panang bay, trophic model, ECOPATH

INTRODUCTION

The hypopotamon zone (i.e. the lower river portion connected to the estuary) is productive and extremely dynamic, providing a zone in which environmental fluctuations and changing species compositions are common. Food webs, and the pathways of energy flow within the food web, are temporally variable due to changes in river flow, water temperature, water column stratification, salinity gradients and seasonal variation in biota (Althauser, 2003). Apart from natural factors, human activities also affect the ecosystem, such as urbanization, sewage, and coastal and infrastructure developments. Among the anthropogenic activities, damming in this area has been recognized as the most influential activity to fish (Vasconcelos *et al.*, 2007), since it has blocked the migratory routes of the diadromy fish and altered the flow pattern, which is very crucial to maintaining the integrity of the ecosystem through environmental flow (IUCN, 2003). Environmental problems from infrastructure development in the hypopotamon zone have been highlighted by a case in Thailand, where the Uthokvibhajaprasid Dam was constructed commencing in 1995, for the purpose of anti-salt intrusion into the upriver zone of the Pak Panang

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River, Nakhon Srithammmarat. The dam is located 6 km from the confluence with Pak Panang Bay and is irregularly operated depending on the demand for freshwater upstream (Prabnarong and Kaewrat, 2006), which results in inevitable changes in the ecosystem.

To understand the possible impacts on ecological changes in an aquatic ecosystem requires quantification of the trophic relationships between different living groups in the system (Chookajorn *et al*., 1994). Ecosystem modeling is an alternative approach that can be used to predict ecosystem responses to perturbations in any factors (Althauser, 2003) and the ECOPATH model (Christensen *et al*., 2005) has been widely applied to describe the ecosystem using a multi-species trophic model under balanced and static ecosystems (J∅rgensen and Bendorichchio, 2001). Moreover, when the model is properly used, it can also explain the evolution of fish stock in the ecosystem over a long time period (Chookajorn *et al*., 1994). In this study, the trophic networks were constructed in two different areas: upstream and downstream of the Uthokvibhajaprasid dam, using the ECOPATH program (Christensen and Pauly, 1992; Christensen *et al*., 2005) to provide a quantitative description to assist in understanding different functions and the interrelationships of various components within the two ecosystems.

MATERIALS AND METHODS

Fish samples

Fish sampling was conducted from March 2006 to June 2007 at six stations in the estuary and the river (Figure 1), with three stations in each area. Sampling protocols have already been described in Jutagate *et al*. (2009). After taxonomical identification, all the fish in the same species were weighed and the number in each species counted and then standardized to $t.km^{-2}$ fresh weight (Jackson and Harvey, 1997)

The ECOPATH model

In structuring the model, the various organisms inhabiting the ecosystem had to be

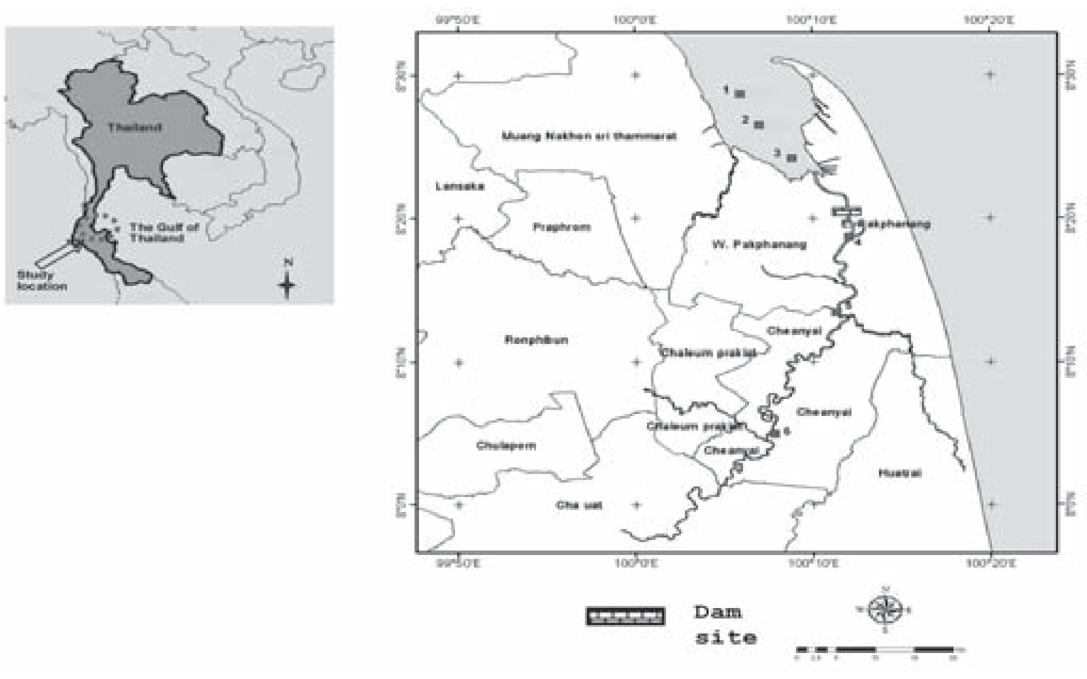

Figure 1 Location of study area and sampling stations.

grouped into boxes or functional groups according to their common physical habitats, similar food preferences and life history characteristics (Yodzis and Winemiller, 1999; Villanueva *et al*., 2008). The basic condition considered for the ECOPATH model was that the input to each group was equal to the output from it (equilibrium conditions). Therefore, the biomass budget equations for each group are given by Equation 1:

$$B_i \times (P / B)_i \times EE_i - \Sigma_j (B_j \times (Q / B)_j \times DC_{ji}) - EX_i = 0 \quad (1)$$

where, B_i is the biomass of the group (i); $(P / B)_i$ is the production/biomass ratio, EE_i is the ecotrophic efficiency, i.e. the proportion of the ecological production which is consumed by predators or exported and usually assumed to range from 0.7 to 0.99 (Polovina, 1984); B_j the biomass of predator (j); $(Q / B)_j$ is the food consumption per unit of biomass for predator j and DC_{ji} is the fraction of i in the diet of j; EX_i is the export of (i).

Production/biomass ratio *(P / B)*

All values of P / B were presented per annum. Two methods of P / B -estimation were applied 1) P / B is equal to the total mortality (Z_i) (Allen, 1971) when the von Bertalanffy growth function (VBFG) of the species can be obtained and 2) for a few groups,was taken from the estimation of (Q / B) × EE (Chookajorn *et al*., 1994). Groups other than fish were derived from the literature (Christensen, 1998; Froese and Pauly 2008; Villanueva *et al*, 2008 among others).

Diet composition

The diet composition of each consumer group was estimated by stomach content analyses of the dominant species, which were recorded in terms of the percentage by weight of prey groups. When data was not available for some groups, information from published articles was assembled (Yamashita *et al*., 1987; Froese and Pauly, 2008).

Food consumption/biomass ratio(Q / B)

Q / B can be obtained from 1) field data on the variation of the abundance of food within a 24-hour diet survey using Maxims model (Jarre *et al*., 1990) and 2) estimation from the model of Palomares and Pauly (1998), which was applied in this study, using Equation 2:

$$\log((Q / B) = 5.847 - 0.52\log(W_\infty) + 0.28\log(P / B) - 1.36T + 0.062A + 0.51H + 0.39D \quad (2)$$

where, W_∞ is the asymptotic weight of fish (g), W_∞ of individual species was calculated from the length-weight relationship, assuming that all groups are isometric and L_∞ was equal to the maximum length divided by 0.95 for each individual species (Sparre and Venema, 1998). T iss the mean habitat temperature (°C), which was 30.2°C in this study; A is an index of activity of the fish related to the aspect ratio of its caudal fin (Equation 3):

$$A=h^2 / S \quad (3)$$

where, h and S are the height and surface area of the caudal fin, respectively. Finally, the parameters H and D express the diet, where H = 1 for a phytophagous species (D = 0) and H = 0 for a detritivorous species (D =1).

Balancing the model

The equilibrium assumption implicit in Equation 1 was very crucial. Therefore, the balance of the model was authenticated by two steps. The first step in verifying the realism of the model was to check whether the EE was less than 1.0 for all groups, since it was assumed that all groups were not to be consumed in excess of their production and EE should be close to 1 for most groups. In this study, EE was set at 0.95 for all groups to reflect the fact that there was a high fishing intensity in this area, as well as the emigration of the brackish fish from the upstream area.

The second step was to check if the gross food conversion efficiency (the ratio between production and consumption, GE) was in the range of 0.1–0.3, as the consumption of most groups is about 3–10 times higher than their production. In general, the GE cannot be higher than the net efficiency (the ratio between production and assimilated food), except that it may be lower for the top predators and higher for fish larvae (Christensen *et al*., 2005).

RESULTS

For the two reservoirs, estimates of *B*, *EE*, gross conversion rates (*GE*), *P/B*, *Q/B* and trophic level (*TL*) obtained from the input parameters for each group are presented in Tables 1 and 2. The total fish biomass in the estuary (2.767 $t.km^{-2}.yr^{-1}$) was slightly higher than the biomass obtained from the river portion (2.600 $t.km^{-2}.yr^{-1}$). Interestingly, the proportion of the brackish water species in the upstream area was very high (68%), which indicated the importance of these species to the ecosystem. Gross efficiency of the fishery *(GEF* = actual catch/primary production) estimated in the river portion (0.0079) was higher than in the bay (0.0045), which implied intensive exploitation of the fishery resources in both areas. The mean trophic level from fishery operations in both areas was about three (2.79 and 2.94 in the estuary and the river portion, respectively). This indicated that the zoophagous fish were targets.

Table 1 Basic parameter inputs and outputs (in bold) from ECOPATH for Pak Panang Bay from March 2006 to June 2007.

Groups	Habitat area	TL	Catch ($t\ km^{-2}$)	Biomass ($t\ km^{-2}$)	P/B	Q/B	EE	GE
Acanthopagrus berda	1.00	3.49	0.002	0.0015	1.42	8.9	0.95	0.160
Plotosus canius	1.00	3.19	0.020	0.0141	1.49	13.4	0.95	0.111
Mystus gulio	1.00	3.23	0.068	0.0281	2.61	10.1	0.95	0.258
Osteogeniosus millitaris	1.00	3.48	0.038	0.0580	0.89	10.5	0.95	0.085
Acentrogobius caninus	1.00	3.27	0.001	0.0012	9.84	42.0	0.95	0.234
Trypauchen vagina	1.00	3.18	0.112	0.0623	2.08	18.2	0.95	0.114
Scattophagus argus	1.00	2.73	0.223	0.0371	7.28	45.5	0.95	0.160
Liza subviridis	1.00	2.39	0.190	0.0536	3.82	13.4	0.95	0.285
Thryssa hamiltonii	1.00	2.79	0.008	0.0069	6.83	19.7	0.95	0.347
Panna sp.	1.00	3.09	0.063	0.5001	0.18	20.8	0.95	0.009
Siganus sp.	1.00	2.00	0.067	0.0050	18.87	61.5	0.95	0.307
Cynoglossus arel	1.00	2.72	0.102	0.0163	8.05	19.3	0.95	0.417
Encrasicholina devisi	1.00	2.70	0.159	0.0709	12.7	32.4	0.95	0.392
Leiognathus sp.	1.00	2.87	0.116	0.2584	7.04	18.6	0.95	0.378
Ambassis sp.	1.00	2.87	0.210	1.4320	1.29	25.7	0.95	0.050
Stolephorus sp.	1.00	2.87	0.068	0.2206	10.7	65.6	0.95	0.163
benthic fauna	1.00	2.40		2.7499	5	25.0	0.95	0.200
Zooplankton	1.00	2.00		1.6924	40	160.0	0.95	0.250
Phytoplankton	1.00	1.00		1.6120	200	8.9	0.95	
Detritus	1.00	1.00		0.0015	1.42	13.4	0.23	

Gross efficiency of the fishery = 0.0045
Mean trophic level = 2.79

The transfer efficiency at trophic level II was high (Table 3), which showed the high utilization of primary producers by the herbivores in both areas. However, it revealed that the food webs of the two systems were quite intact, since the average transfer efficiency was between 10% and 15%. Figures 2 and 3 show the compartment model for the "balanced situation" of the both ecosystems. The boxes are aligned along the y-axis, as a function of the estimated trophic level and the area is proportional to the square root of the biomass. The trophic levels estimated by the ECOPATH model from the weighted average of prey trophic levels varied from 1.0 for primary producers and detritus, to about 3.5 for carnivorous fish in both areas.

Table 2 Basic parameter inputs and outputs (in bold) from ECOPATH for Pak Panang River (lower portion) from March 2006 to June 2007.

Groups	Habitat area	TL ($t\ km^{-2}$)	Catch ($t\ km^{-2}$)	Biomass	P/B	Q/B	EE	GE
Plotosus canius	1.00	3.19	0.020	0.0141	1.49	13.4	0.95	0.111
Channa spp.	1.0	3.61	0.0164	0.0185	1.09	14.8	0.95	0.074
Clarias spp.	1.0	3.32	0.0258	0.0145	1.87	9.8	0.95	0.191
Hampala spp.	1.0	3.53	0.1765	0.1573	1.20	10.5	0.95	0.114
Mystus singaringan	1.0	3.21	0.0213	0.0147	1.72	12.9	0.95	0.133
Mystus gulio [b]	0.6	3.20	0.0290	0.0453	1.01	6.7	0.95	0.151
Pomadasys kaakan	0.6	3.29	0.0088	0.0194	1.07	5.5	0.95	0.196
Megalop cyprinoides	0.6	3.32	0.0032	0.0122	1.41	27.1	0.95	0.052
Toxotes chatoreus	1.0	3.30	0.0074	0.0185	1.60	45.1	0.95	0.035
Oxyeleotris marmorata	1.0	3.38	0.0583	0.1015	0.85	12.1	0.95	0.070
Pristolepis fasciatus	1.0	2.54	0.1776	0.1009	2.10	9.9	0.95	0.212
Notopterus notopterus	1.0	2.98	0.4650	0.2662	1.94	7.2	0.95	0.269
Puntius brevis	1.0	2.88	0.0172	0.0183	2.65	14.7	0.95	0.180
Cyclochelichthys apogon	1.0	3.09	0.0316	0.0206	3.41	40.6	0.95	0.084
Osteochilus hasselti	1.0	2.10	0.0446	0.0265	3.70	22.3	0.95	0.166
Labiobarbus lineata	1.0	2.21	0.0085	0.0185	3.25	32.2	0.95	0.101
Oreochromis niloticus	1.0	2.21	0.0019	0.0148	3.59	17.2	0.95	0.209
Barbodes gonionotus	1.0	2.37	0.0949	0.0183	8.24	49.0	0.95	0.168
Acanthopsis sp.	1.0	2.19	0.0007	0.0115	6.12	28.3	0.95	0.216
Leiognathus sp.[a]	0.3	2.79	0.1395	1.4424	2.04	12.5	0.95	0.164
Stolephorus sp.	0.3	2.79	0.0292	0.2595	10.70	43.7	0.95	0.245
Aquatic insects	1.0	2.10		1.3003	7.00	50.0	0.95	0.140
Zooplankton	1.0	2.10		0.4822	50.00	200.0	0.95	0.250
Aquatic plant	1.0	1.00		8.0115	7.00	14.8	0.5	
Phytoplankton	1.0	1.00		0.3158	365.00	9.8	0.95	
Detritus	1.0	1.00				10.5	0.37	

Gross efficiency of the fishery = 0.0079

Mean trophic level = 2.94

Note:

[a] *Leiognathus* spp. included *Ambasis* spp.

[b] *Mystus gulio* included *Plotosus canius*.

Table 3 Transfers efficiency obtained from the ECOPATH model.

(a) Pak Panang Bay

Source/TL	II	III	IV	V	VI
Producer	22.8	12.6	6.6	3.6	6
Detritus	17.8	7.7	3.4	5.8	13.1
All flows	22.4	12.3	6.5	3.6	6.1

Proportion of total flow originating from detritus: 0.16
Transfer efficiencies (calculated as geometric mean for TL II-IV)
From primary producers: 12.4
From detritus: 7.8
Total: 12.2

(b) Pak Panang River (lower portion)

Source/TL	II	III	IV	V	VI
Producer	20.7	12.8	11.5	10.6	9.8
Detritus	13.3	12.7	10.9	9.9	8.8
All flows	19.4	12.8	11.5	10.6	9.8

Proportion of total flow originating from detritus: 0.24
Transfer efficiencies (calculated as geometric mean for TL II-IV)
From primary producers: 14.5%
From detritus: 12.3%
Total: 14.2%

The effect of change in the biomass of one group on the biomass of other groups in a system can be indicated by the mixed trophic impacts (Figures 4 and 5). In the estuary, an increase in phytoplankton biomass resulted in an increase in the biomass of almost all groups. Consequently, the increase in zooplankton increased the abundance of the higher trophic level species. In the river system, an increase in the phytoplankton biomass had a great positive effect on the small-sized brackish water species (*Stolephorus* sp., *Leiognathus* sp. and *Ambassis* sp.), which fed largely on phytoplankton. Consequently, an increase in the numbers of these small fish species, which are a food source for carnivores species, would increase the biomass of the fish target species. An increase in detritus in the estuary had a larger positive effect on the biomasses of other groups than did an increase in detritus in the river.

DISCUSSION

From the simulations, both systems were balanced and validated as indicated by: 1) the estimated EE value of detritus was much less than 1, which indicated that the detritus group had more entering than leaving (Lin *et al*., 2007); and 2) the GE values were physiologically realistic, since, as suggested by Christensen et al. (2005), the consumption of most groups was about 3-10 times higher than their reproduction, with GE ranges from 0.1 to 0.3. The biomass of 2.8 $t.km^{-2}.yr^{-1}$ in the Pak Panang estuary was reasonable compared to the biomass of 7.2 $t.km^{-2}.yr^{-1}$ in the whole inner area of the Gulf of Thailand (Christensen, 1998) and 3.1 $t.km^{-2}.yr^{-1}$ from the coastal area of Terenganu, Malaysia (Liew and Chan, 1987). However, the biomass estimated in the river portion (2.6 $t.km^{-2}.yr^{-1}$) was very low compared to the value determined for the Pasak Jolasid

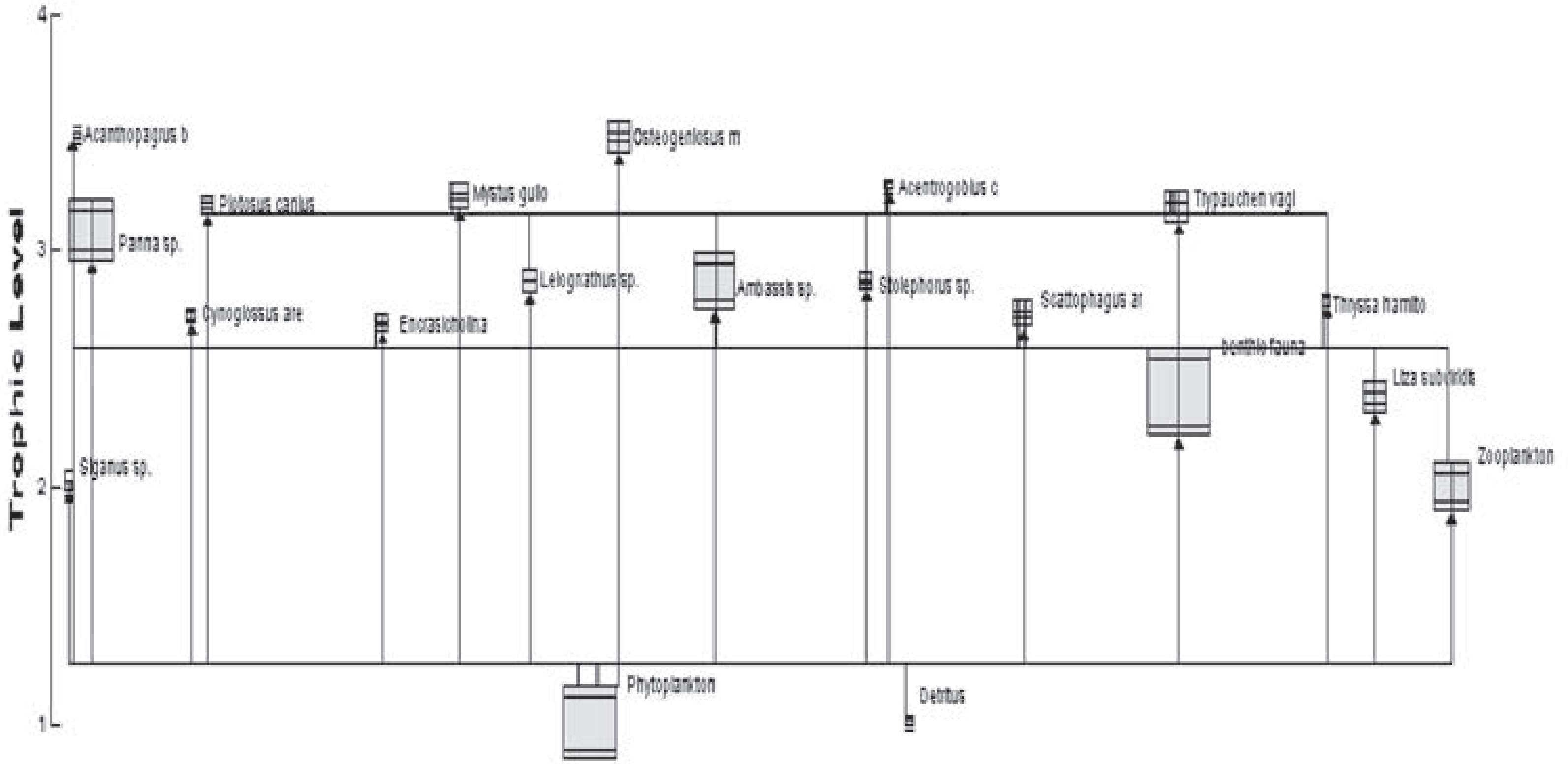

Figure 2 Trophic model of Pak Panang Bay from from March 2006 to June 2007, indicating the relative biomass of each group (box proportional to log *B* in t/km^{-2}) and the major flows connecting them.

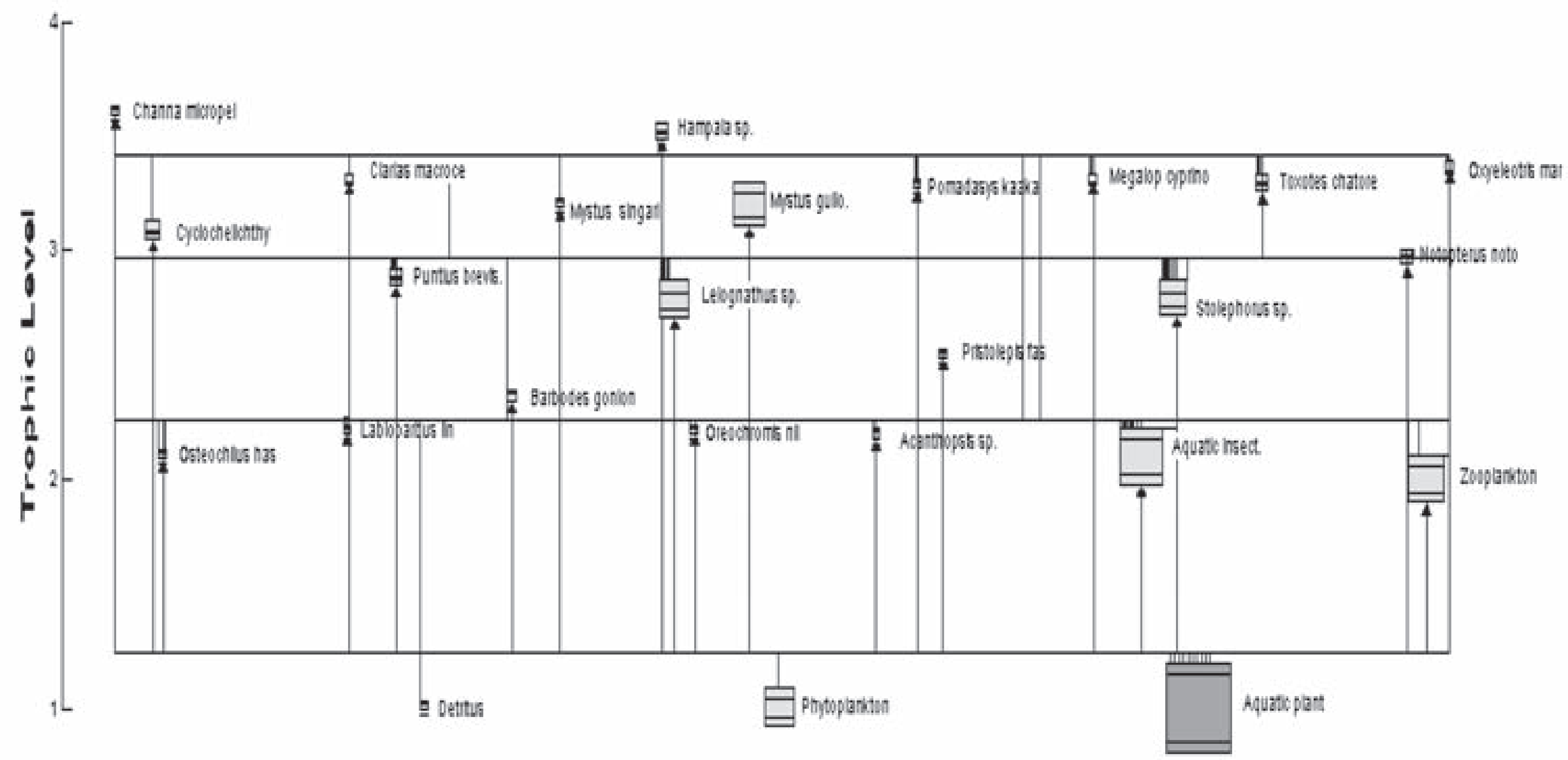

Figure 3 Trophic model of Pak Panang River (lower portion) from March 2006 to June 2007, indicating the relative biomass of each group (box proportional to log B in t./km^{-2}) and the major flows connecting them.

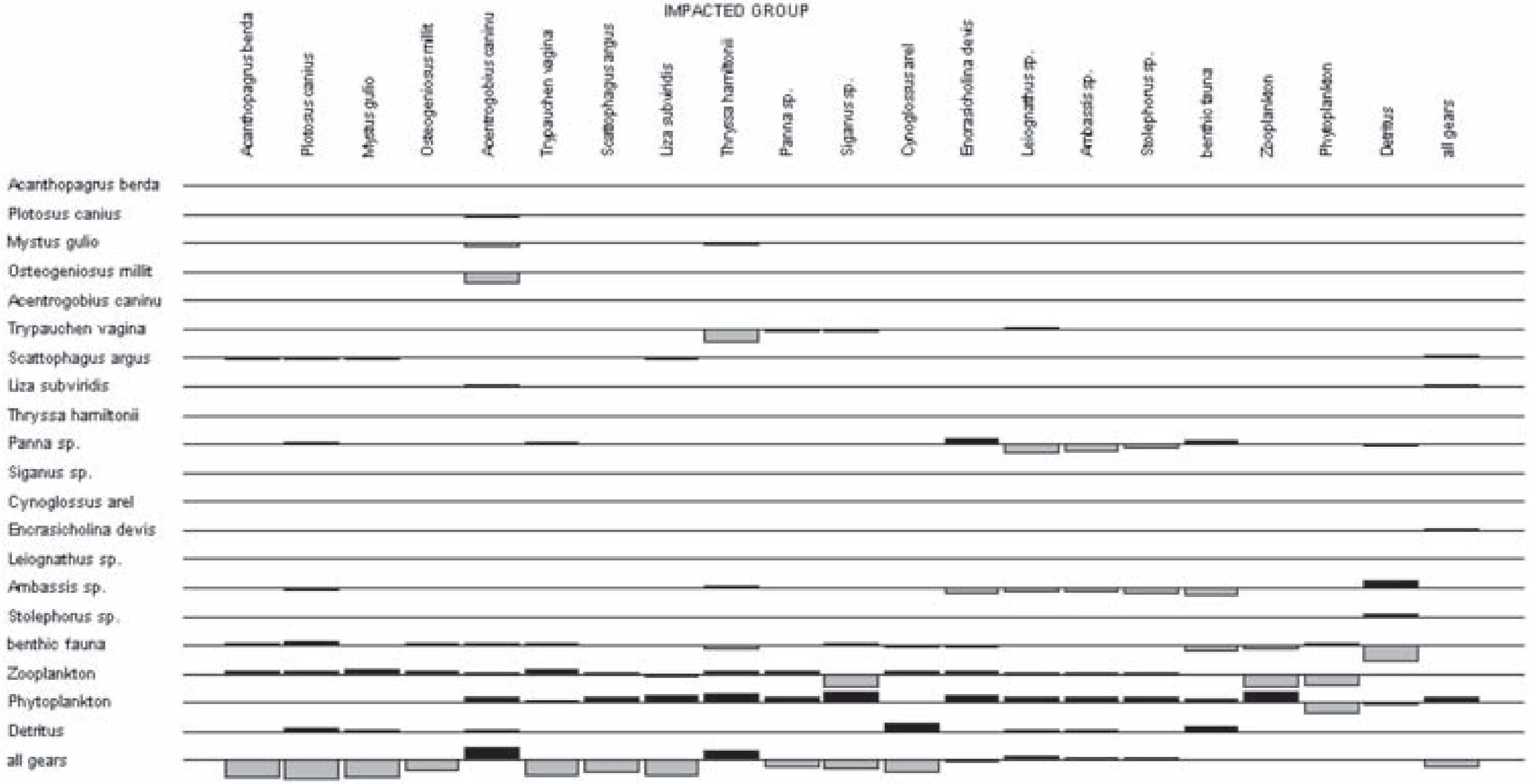

Figure 4 Mixed trophic impacts of the Pak Panang Bay model. Direct and indirect impacts that an increase in the biomass of groups to the left of the histograms would have on the groups positioned above them. The bars pointing upwards show positive impacts, while those pointing downwards show negative impacts.

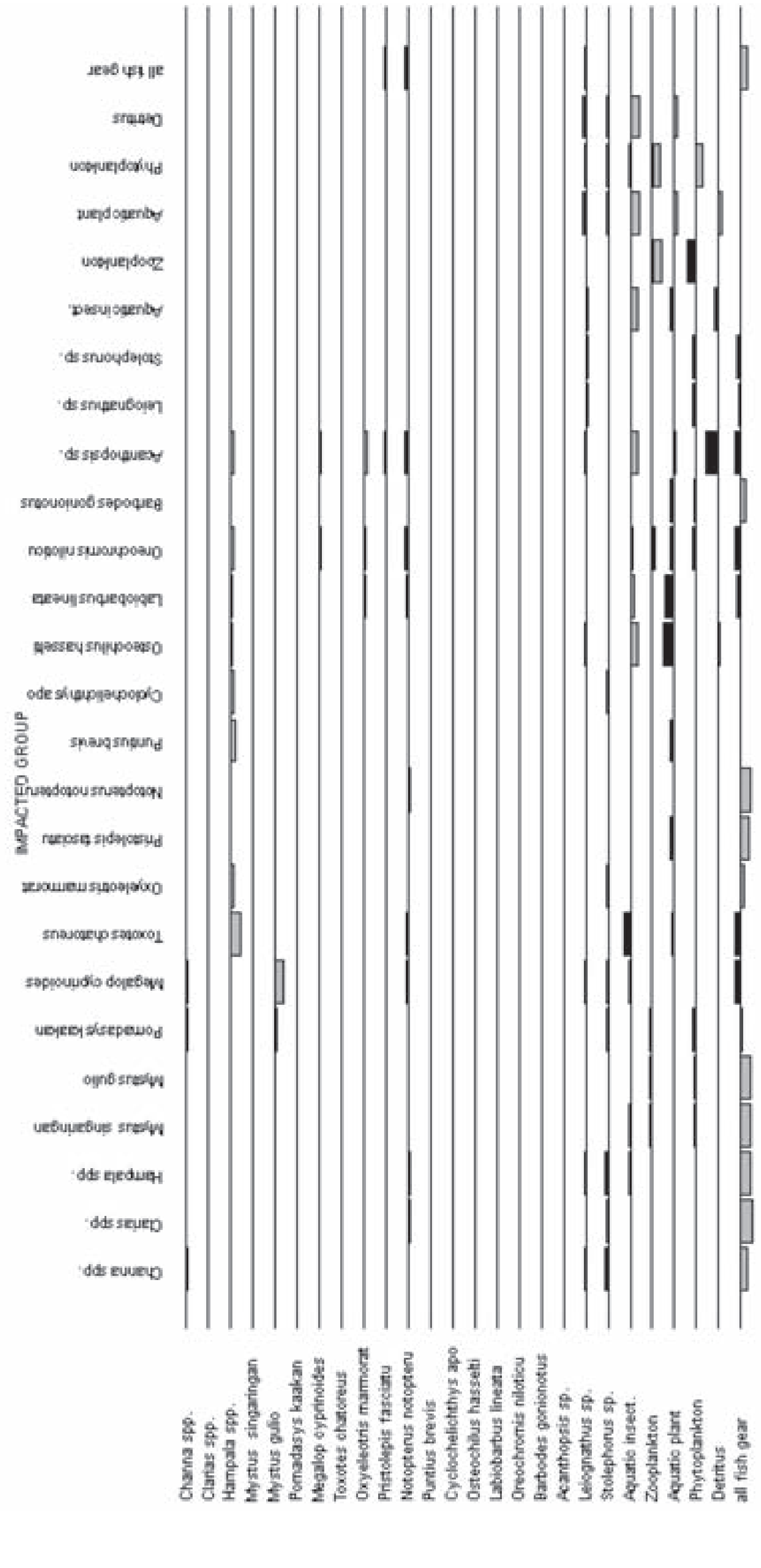

Figure 5 Mixed trophic impacts of the Pak Panang River (lower portion) model. Direct and indirect impacts that an increase in the biomass of groups to the left of the histograms would have on the groups positioned above them. The bars pointing upwards show positive impacts, while those pointing downwards show negative impacts.

Reservoir (10.1 $t.km^{-2}.yr^{-1}$: Thapanand *et al.*, 2007), which was impounded during a relatively recent period (1998). This was because of the vast littoral zone for the lake-type reservoir in the latter case.

Duldic *et al.* (1997) mentioned that estuarine areas were usually comprised of low trophic level species with high ecological efficiency and productivity, which support the carnivores within or beyond the system (the lower river area and open sea). In the lower river portion, a high trophic level of freshwater species is always found (Pusey *et al.*, 1995). A mean trophic level slightly lower than 3 would be the result of two factors. Firstly, the proliferation of the benthic herbivores, which was likely, caused by the nutrient-rich trap from the river near the dam (MacIntyre *et al.*, 2000) that promoted the expansion of aquatic plants. Secondly, from the raising of the importance of the small-sized plankton feeders in the system, as experienced in the Ubolratana Reservoir, in northeast Thailand (Chookajorn *et al.*, 1994). The maximum trophic amount in the estuary was 3.49 compared to 4.1 for the inner Gulf of Thailand, except for sharks with a value of 4.5 (Christensen, 1998). This estimated figure was in the range of 3.6–4.0 for the top predators recorded in tropical estuaries (Wolff *et al.*, 2000; Lin *et al.*, 2004). For the river portion, the maximum trophic level of 3.61 confirmed the importance of small-sized fish to the system, while for other inland water bodies in Thailand, the value was about 3.4 (Chookajorn *et al.*, 1994; Jutagate *et al.*, 2002).

The average transfer efficiency of 12.2 and 14.2 in the estuary and river portion, respectively, was within the range (8–14%) reported by Christensen and Pauly (1993) for 41 aquatic systems. The mixed trophic impact showed that an increase in fishing activities in both areas would have a negative impact on carnivorous fishes. In the end, the long-term over-exploitation of top predators would result in low total catches and low gross efficiency and lowering of the length of the food chain (Pauly *et al.*, 1998; Lin *et al*, 2007). The small brackish water fish seemed to be little impacted by an increase in fishing intensity. This was because of the prohibition on various fishing equipment types, especially the use of luring lights, which are employed to catch these fish 3,000 m offshore.

CONCLUSION

Two different areas, which were connected, but divided by the fragmentation of the river course, were described by the ECOPATH model. Complex ecosystems were found in both areas. Fisheries were found to have strong influence over food webs through the exploitation of top predators. Moreover, the fragmentation of the system focused on addressing an important question on the impact of the small-sized brackish water plankton feeders on ecosystem functioning, as these fish supported the fishery targets in both areas. If the changes in the flow pattern and salinity were not suitable for them, this would result in unbalancing of the systems and finally the collapse of the ecosystem (Layman *et al.*, 2007).

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