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Spatial and temporal variations of the estuarine larval fish community on the west coast of Taiwan

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Abstract. Spatio–temporal variations in the distribution and community structure of the estuarine larval fishes on the west coast of Taiwan was examined in the estuaries of Shuangchi Creek (SC), Gongshytyan Creek (GST), Tatu Creek (TT) and Tongkang River (TK). Fish were collected by a net (mesh 0.8–1.8 mm) set against the flood tide at night during the new- and full-moon periods from September 1997 through December 1998; 28–49 families (56–94 species) were collected from the four estuaries. Fish larvae were abundant from spring to autumn. Fish communities differed among estuaries: Mugilidae were the most abundant in SC, *Terapon jarbua* in GST, *Stolephorus insularis* in TT and *Ambassis urotaenia* in TK. The 15 most dominant species constituted 88–94% of the total catch. The relationship of fish abundance and species diversity to water temperature and salinity differed among estuaries. Species composition could be classified into northern (SC, GST winter and TT winter) and southern (TK, GST summer and TT summer) groups. The species composition of the larval fish communities was more diverse in spring–autumn than in winter, and in southern than in northern estuaries. Monsoon-driven coastal currents may influence seasonal dispersal and community structure of the estuarine larval fishes on the western coast of Taiwan.

Extra keywords: larval dispersal, community structure, seasonal variation, monsoon, coastal currents, estuary

Introduction

Estuaries are among the most productive ecosystems on the earth, comparable to areas of coastal upwelling (Haedrich and Hall 1976). They function as nursery grounds for estuarine-dependent marine fish populations during their early life stages because it provides food resources, shelter, absence of turbulence, and a reduced risk of predation (Wallace and van der Elst 1975; Blaber and Blaber 1980; Day *et al.* 1981; Lenanton 1982; Robertson and Duke 1987; Blaber and Milton 1990). The species composition and abundance of fish larvae and juveniles in the estuary are influenced by physico–chemical and biological factors and are important indicators for predicting forthcoming fishing stocks (Haines 1979; Blaber *et al.* 1985; Stephens *et al.* 1986, 1988; Tzeng and Wang 1993; Wang and Tzeng 1997).

Studies of the larval and juvenile fish communities in the estuaries of Taiwan have been limited to specific areas where environmental protection has been a concern, e.g. the sewage-polluted Tanshui River estuary (Tzeng and Wang 1992, 1993, 1997) and Yenliao Bay near a nuclear power plant under construction (Tzeng *et al.* 1985, 1997; Tzeng and Wang 1986). Thus, large-scale spatio–temporal variations of larval fish communities among estuaries in Taiwan are not clear. This study investigated the larval fish community structure in estuaries on the west coast of Taiwan with a view to understanding the effect of coastal currents on the dispersal of fish larvae and juveniles.

Materials and methods

Study area and sampling design

The coastal waters of western Taiwan comprise the Taiwan Strait, which has a wide and shallow continental shelf, suitable as a spawning and nursery area for coastal fishes. In contrast, the continental shelf on the eastern coast is narrow and strongly influenced by the oceanic Kuroshio Current (Fig. 1). The coastal currents on the western coast that transport larvae to estuaries change direction with the seasonal monsoon (Chu 1963). In winter, the China Coastal Current, induced by the north-eastern monsoon, flows from the coast of mainland China to the north-east and north-west coasts of Taiwan. In summer, this current is replaced by the south-western monsoon-driven coastal current, which flows from the South China Sea along the western coast of Taiwan.

A net was set against the tidal current in four estuaries, Shuangchi Creek (SC), Gongshytyan Creek (GST), Tatu Creek (TT) and Tongkang River (TK) (Fig. 1), to collect fish larvae and juveniles during the nighttime flood tide around the new- and full-moon periods from September 1997 to December 1998. The mesh size of the net ranged from 0.8 to 1.8 mm, similar to the commercial fishing gear used for collecting fish fry for restocking in Taiwan. The fish were preserved in

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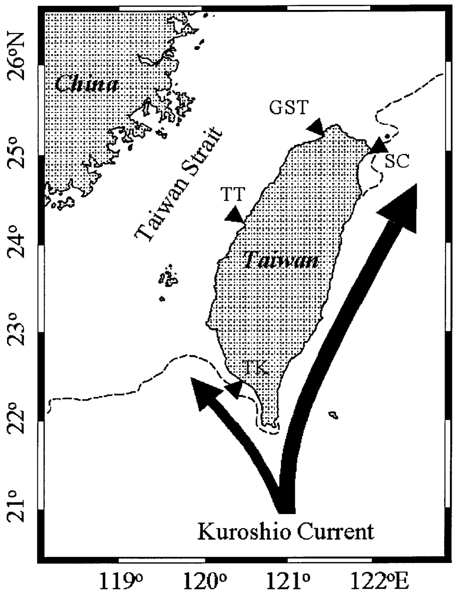

Fig. 1. Sampling sites of fish larvae and juveniles in the estuaries of Shuangchi Creek (SC), Gongshytyan Creek (GST), Tatu Creek (TT) and Tongkang River (TK). Dashed line: 200 m depth contour.

95% alcohol after collection and identified to species level when possible (Leis and Rennis 1983; Ozawa 1986; Wang 1987; Okiyama 1988; Leis and Trnski 1989). Surface water temperature and salinity were measured to 0.1°C and 0.1 psu by use of a microprocessor conductivity meter during sampling.

Data analysis

The abundance of fish larvae and juveniles was estimated roughly by the number of fish per hour (CPUE). The cumulative abundance of dominant species among the four estuaries was compared by K-dominance curves. When two different K-dominance curves do not overlap, the upper curve represents the community most dominated by a few species and thus that which is less diverse (Lambshead *et al.* 1983; Clarke and Warwick 1994). The species diversity of each larval fish community was calculated by use of the Shannon–Wiener index of species diversity (H') (Pielou 1966) and Simpson's index of species concentration (Σp_i^2) (Peet 1974). The Shannon–Wiener index emphasizes the contribution of rare species, whereas Simpson's index gives greater weight to dominant species. The similarity of species compositions of fish larvae and juveniles in the four estuaries among sampling dates was analysed by clustering (Bray–Curtis similarity index; unweighted pair-group using arithmetic average) and ordination (multiple dimensional scaling, MDS). Indicator species for each of the seasonal and geographic groups and the species that discriminated groups were examined by the similarity percentage routine (SIMPER; Clarke and Warwick 1994). The data used for clustering and ordination were log (n+1) transformed and selected to span one year from December 1997 through November 1998 because the period investigated differed among estuaries. All computation of diversity indices and cluster and ordination analyses used the software 'PRIMER 5' (Clarke and Warwick 1994). Relationships between abiotic and biotic factors of the four estuaries were analysed by Kendall rank correlations (Siegel 1956).

Results

Water temperature and salinity

Trends in water temperature were similar among the GST, SC and TT estuaries, but there was much less seasonal variation in the TK estuary where winter water temperatures did not decline to the same degree as those in the other systems. The water temperatures in the four estuaries ranged from 14.0 to 33.0°C. Annual mean (± s.d.) water temperatures increased from 23.2±3.9°C in SC in the north to 29.1±2.5°C in TK in the south (Fig. 2*a*). Salinities in the four estuaries varied from 0.3 to 36.5 psu; the annual mean (± s.d.) salinity ranged from 17.5±10.3 in TT to 29.6±7.2 in TK (Fig. 2*b*). A geographic cline in mean salinity was not obvious among estuaries; however, the maximum value of the range was higher in both SC and TK than in either GST or TT, because SC and TK were influenced to a greater degree by the highly saline Kuroshio Current than were GST and TT (Fig. 1).

Seasonal changes in number of species, abundance and indices of community structure

In total, 30, 33, 26 and 26 samples were collected from the SC, GST, TT and TK estuaries, respectively: 28 families and 56 species from SC, 49 families and 94 species from GST, 44 families and 73 species from TT and 46 families and 77 species from TK. The dominant species differed among estuaries. Mugilidae were the most abundant in SC, *Terapon jarbua* in GST, *Stolephorus insularis* in TT and *Ambassis urotaenia* in TK (Appendix 1).

The number of species increased from spring to autumn (April to September) in GST estuary, but no seasonal trend was apparent in the other three (Fig. 2*c*). Marked seasonal variation in abundance (CPUE) was noted in all four estuaries. Two periods of peak abundance occurred in the northern estuaries (SC and GST), one in the spring (March–June) and the other in the autumn (September), but the autumn peak did not occur in the southern estuaries (TT and TK). The peak abundance in spring occurred earlier in the south than in the north (Fig. 2*d*). Species diversity (H', 0.2–2.7) and concentration indices (Σp_i^2, 0.1–1.0) of the larval fish community greatly fluctuated with season and were inversely correlated (Figs 2*e*, 2*f*). This indicates that the larval fish community became uneven when dominant species occurred. Fish abundance was significantly positively correlated to the number of species except in SC, and was positively correlated with Σp_i^2 only in TK (Table 1).

The effect of temperature and salinity on the number of species, abundance and community indices differed among estuaries (Table 1). In SC, there was no significant correlation of the four biotic factors with temperature or salinity. However in GST, number of species, abundance and species diversity (H') were positively correlated with temperature (P <0.05), but not with salinity. In TT, the species diversity (H') and concentration indices (Σp_i^2) were correlated with salinity

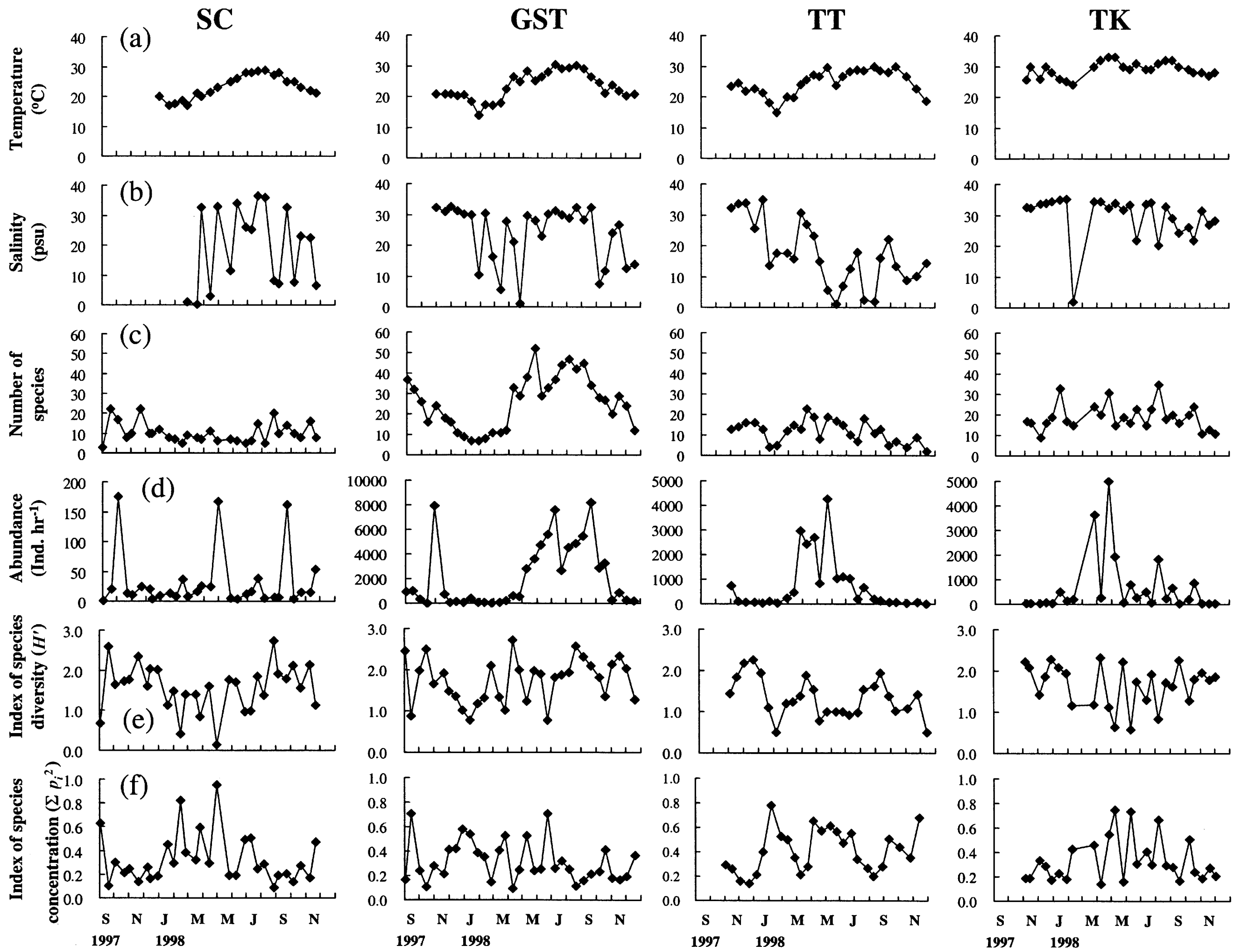

Fig. 2. Seasonal changes in *(a)* temperature, *(b)* salinity, *(c)* number of species, *(d)* abundance, *(e)* index of species diversity and *(f)* index of species concentration in the four estuaries (SC, GST, TT and TK refer to Fig. 1).

(positively and negatively, respectively; $P<0.05$). In TK, only abundance was positively correlated with temperature ($P<0.05$). This may be due to different geomorphology and hydrodynamics among estuaries.

Spatio–temporal similarity of species composition

Cluster and ordination analyses indicated that the species composition of all estuaries except SC comprised two seasonal groups at a similarity level of ~20% (Figs 3*a–d*). These two seasonal groups were a spring–autumn group (April–November) and a winter group (December–March). When the species data from the four estuaries were pooled together and analysed, the winter groups of both GST and TT clustered with SC into a northern group, while the summer groups of both GST and TT were more similar to TK samples and formed a southern group at a similarity level of ~10–15% (Fig. 3*e*). This indicates that the summer larval fish communities of GST and TT, as well as that of TK throughout the year, may originate from southern Taiwan, whereas the winter fish communities of GST and TT, together with that of SC, derive from northern Taiwan.

K-dominance curves showed higher cumulative percentage abundance in winter than in spring–autumn for both GST and TT estuaries, indicating that the communities of winter groups were less diverse than spring–autumn groups and were characterized by few dominant species (Fig. 4*a*). Similarly, the northern group was characterized by fewer dominant species (Fig. 4*b*).

Similarity percentage of species contribution to clustering

Species contributing to the similarities within seasonal groups shown in Figs 3*a-d* and to the southern and northern groups in Fig. 3*e* are listed in Tables 2 and 3. The larval

Table 1. Relationship between abiotic and biotic factors of four estuaries

SC, GST, TT and TK refer to Fig. 1. Temp, temperature; Sal, salinity; Sp, number of species; Ab, abundance; H', index of species diversity; Σp_i^2, index of species concentration

	Temp	Sal	Sp	Ab	H'
SC					
Sal	0.42*				
Sp	–0.03	–0.26			
Ab	–0.21	0.12	0.18		
H'	0.26	–0.12	0.66***	–0.14	
Σp_i^2	–0.32	0.08	–0.53***	0.25	–0.86***
GST					
Sal	0.16				
Sp	0.77***	0.08			
Ab	0.62***	0.22	0.59***		
H'	0.27*	–0.05	0.31*	0.07	
Σp_i^2	–0.17	0.09	–0.22	–0.04	–0.84***
TT					
Sal	–0.26				
Sp	0.12	0.08			
Ab	0.25	–0.12	0.47***		
H'	0.03	0.35*	0.39**	–0.05	
Σp_i^2	–0.07	–0.34*	–0.27	0.11	–0.85***
TK					
Sal	–0.03				
Sp	0.26	0.02			
Ab	0.36*	0.04	0.49***		
H'	–0.17	0.17	–0.03	–0.41**	
Σp_i^2	0.17	–0.10	0.07	0.40**	–0.83***

fish community of the SC estuary and the winter assemblages of the GST and TT estuaries were dominated by few species. The average percentage contribution of only five species in these groups ranged from 81.3% to 94.0%. Mugilidae spp. and *Mugil cephalus* were the most important, contributing 33.4–36.8% of total average similarity (Table 2). In contrast, the communities of the TK estuary together with the spring–autumn groups of GST and TT were more diverse and the average similarity contributed by the five most important species ranged from 38.3% to 70.1% (Table 2).

Similarly, the larval fish community was more diverse in the southern than in the northern groups (Table 3). The average similarity of the top 10 species in the northern group was 89.7%. Mugilidae spp., *Mugil cephalus* and *Sicyopterus japonicus* were the most important taxa contributing to this group similarity (67.2%). In the southern group ten species made relatively even contributions to account for only 63.1% of the group similarity. Species accounting for the dissimilarity between these two groups are also listed in Table 3 and comprised many minor species because the sum of the average dissimilarity for the top 10 species was only 37.8% (Table 3).

Discussion

An estuary is a semi-enclosed system influenced by both fresh water and seawater, and freshwater, estuarine and marine fishes might be expected in such a system (Blaber and Blaber 1980; Day *et al.* 1981). However, most larval fishes collected in this study were estuarine-dependent marine fishes (e.g. Mugilidae spp., *Mugil cephalus* and *Terapon jarbua*) and estuarine fishes (e.g. Gobiidae spp. and *Ambassis* spp.). Few freshwater fishes (e.g. Cyprinidae) were caught (Tables 2 and 3; Appendix 1). This is because we collected fishes on flood tides that transported the marine fishes to the estuaries. The dispersal of larval fishes from marine spawning grounds to the estuaries is influenced by coastal currents (Boehlert and Mundy 1988). The coastal currents on the west coast of Taiwan change direction with season (Chu 1963). Thus the recruitment of larval fishes to the estuary will be influenced in spatial and temporal terms by these coastal currents.

Larval fish communities in three of the four estuaries were classified into winter and spring–autumn seasonal groups, which reflected the change of seasonally monsoon-driven coastal currents on the western coast of Taiwan (Chu 1963). In winter, the north-eastern monsoon-driven, low-salinity, cold China Coastal Current flows southward and is impeded by the warm Kuroshio Current in the middle of the Taiwan Strait. In summer, the south-western monsoon-driven, high salinity, warm South China Sea surface current flows through the Taiwan Strait (Jan 1995; Shao *et al.* 1997). Most of the larvae in the four estuaries were estuarine-dependent marine fishes (Wallace and van der Elst 1975; Blaber and Blaber 1980). In general, larvae of these fishes passively migrate with the coastal currents from spawning grounds to estuaries (Boehlert and Mundy 1988). Thus, the monsoon-driven coastal current on the west coast of Taiwan may play an important role in the seasonal onshore movement of fish larvae and juveniles.

The fish communities of the SC estuary and the winter assemblages of both the GST and TT estuaries clustered together into a similar group, which was distinct from that of the TK estuary and the summer assemblages of the GST and TT estuaries. This suggests that the winter larval fish community transported from the north by the NE monsoon-driven China Coastal Current is distributed only as far as the middle part of the Taiwan Strait. In contrast, the summer larval fish community transported by the SW monsoon current from the south reaches the northern part of the Taiwan Strait. Shao *et al.* (1997) noted that the fish fauna differed with latitude on the west coast of Taiwan under the influence of the seasonal monsoons, and that the boundary separating northern and southern fish faunas may be located approximately at Penghu Island in the middle of Taiwan Strait. Kuo *et al.* (1999) found that mangrove fish assemblages on the west coast could be classified into

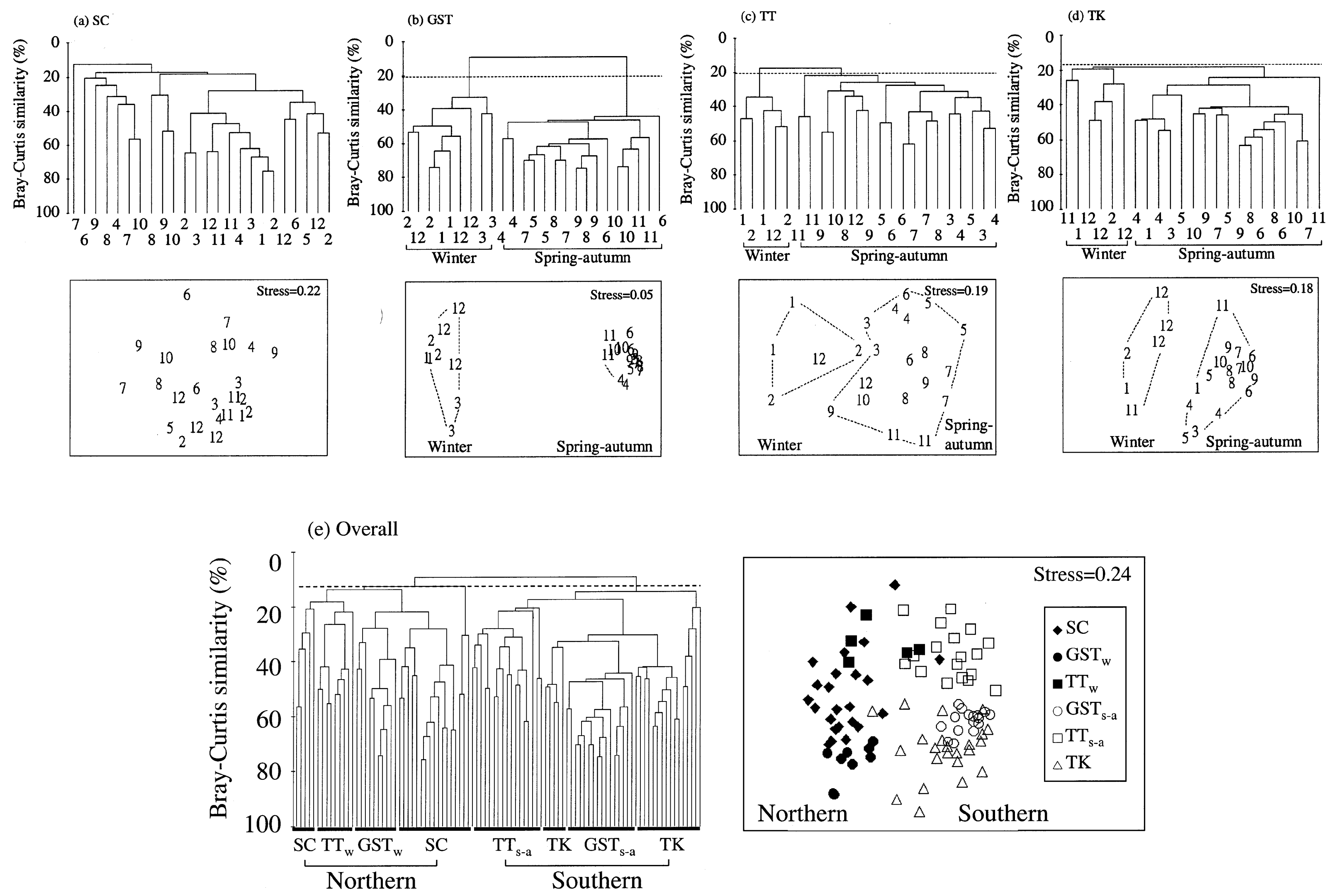

Fig. 3. Cluster dendrograms *(upper)* and MDS ordinations *(lower)*, based on Bray–Curtis similarities of larval and juvenile fish communities sampled in *(a)* SC, *(b)* GST, *(c)* TT, *(d)* TK and *(e)* overall data of a-d. Numerals 1–12 indicate the order of the months from January to December. w: winter, s-a: spring-autumn.

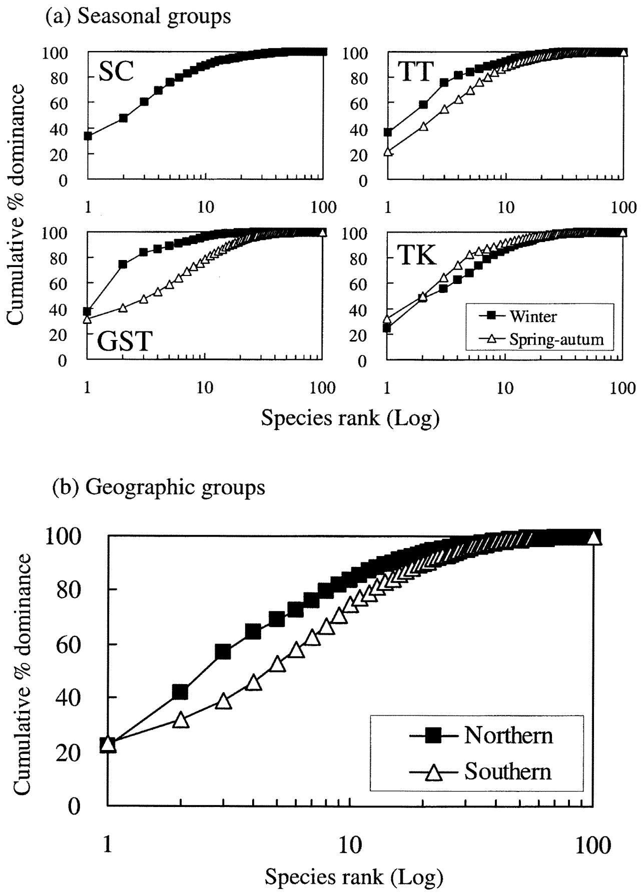

Fig. 4. K-dominance curves for the numbers of species of fish larvae and juveniles of *(a)* seasonal groups [except SC, which represents all data] and *(b)* geographic groups (SC, GST, TT and TK refer to Fig. 1).

northern and southern groups, which probably arise as a result of the oceanic currents around Taiwan. This study indicated that the spatial distribution of the larval fish community on the west coast of Taiwan changed seasonally. In the summer, the SW monsoon current transported fish larvae through the Taiwan Strait. In winter, the dispersal of larvae transported by the NE monsoon current was impeded in the middle of the Taiwan Strait by the Kuroshio Current.

The communities of the four estuaries exhibited high spatial and temporal variations in species diversity. Fish communities of spring–autumn groups originating in the south were more diverse than were the winter groups from the north. Pianka (1966, 1967) proposed that species diversity was influenced by eight principal factors, i.e. evolutionary time, ecological time, climatic stability, spatial heterogeneity, productivity, stability of primary production, competition and predation. Estuaries are highly variable and unstable environments (Whitfield 1990), and fish communities living in such habitats theoretically should reach an equilibrium state and contain fewer species when interspecific competition is prevalent (Sanders 1968; de Morais and de Morais 1994; Harris and Cyrus 2000). The salinities of the four estuaries fluctuated greatly, with a range of 0.3–36.5 psu. Highly variable salinities may influence species diversity and led to dominance of estuarine larval fish communities by a few species. In addition, the water mass of the coastal current from the north was more productive than that from the south. This may lead to the fish communities originating from the northern group being less diverse and dominated by fewer species than fish communities originating from the south. Furthermore, the differences in species composition among

Table 2. Average similarity percentage contributed by the major species in the seasonal groups of four estuaries
SC, GST, TT and TK refer to Fig. 1

Rank	SC	%	GST	%	TT	%	TK	%
	Whole year		**Winter group**		**Winter group**		**Winter group**	
1	Mugilidae spp.[A]	33.4	*Mugil cephalus*	34.3	Mugilidae spp.[A]	36.8	*Acanthopagrus schlegeli*	16.5
2	*Sicyopterus japonicus*	18.5	*Anguilla japonica*	21.3	*Sardinella* spp.	19.7	*Ambassis urotaenia*	16.3
3	*Ambassis gymnocephalus*	14.0	*Acanthopagrus latus*	17.2	*Acanthopagrus* spp.	18.0	Mugilidae spp.[A]	11.1
4	*Mugil cephalus*	10.6	Mugilidae spp.[A]	10.2	*Acanthopagrus latus*	17.0	Gobiidae spp.	10.6
5	*Leiognathus nuchalis*	4.8	*Anguilla marmorata*	2.9	*Stolephorus insularis*	2.5	*Omobranshus* spp.	8.6
6	Other (51 species)	18.7	Other (27 species)	14.1	Other (24 species)	6.0	Other (39 species)	37.0
			Spring–autumn group		**Spring–autumn group**		**Spring–autumn group**	
1			*Terapon jarbua*	11.0	*Stolephorus insularis*	38.8	Gobiidae sp.7	15.7
2			Gobiidae sp.9	7.9	*Sillago sihama*	9.2	*Taenioides cirratus*	12.8
3			Gobiidae sp.7	7.5	Gobiidae spp.	7.6	*Megalops cyprinoides*	8.6
4			*Megalops cyprinoides*	6.5	*Ambassis gymnocephalus*	7.2	Gobiidae spp.	7.7
5			*Rhinogobius giurinus*	5.4	Mugilidae spp. [A]	7.2	*Rhinogobius giurinus*	6.3
6			Other (91 species)	61.7	Other (61 species)	29.9	Other (67 species)	48.8

[A]Most are *Liza affinis* and *L. macrolepis*

Table 3. Average similarity and dissimilarity percentages contributed by the major species within and between groups

Rank	Northern group	%	Southern group	%	Between groups	%
1	Mugilidae spp.[A]	38.4	Gobiidae spp.	9.7	*Megalops cyprinoides*	4.5
2	*Mugil cephalus*	16.9	*Megalops cyprinoides*	8.2	*Stolephorus insularis*	4.2
3	*Sicyopterus japonicus*	11.9	Gobiidae sp. 7.	7.5	Gobiidae spp.	4.0
4	*Ambassis gymnocephalus*	6.1	*Rhinogobius giurinus*	6.7	Gobiidae sp. 7.	3.9
5	*Acanthopagrus latus*	4.8	*Terapon jarbua*	6.3	*Rhinogobius giurinus*	3.9
6	*Anguilla marmorata*	3.1	*Taenioides cirratus*	5.4	*Taenioides cirratus*	3.7
7	*Sillago sihama*	2.4	Mugilidae spp.[A]	5.2	*Terapon jarbua*	3.7
8	*Anguilla japonica*	2.2	*Stolephorus insularis*	5.1	Mugilidae spp.[A]	3.6
9	*Leiognathus nuchalis*	1.9	*Ambassis gymnocephalus*	4.5	*Ambassis gymnocephalus*	3.2
10	*Terapon jarbua*	1.9	*Sillago sihama*	4.5	*Mugil cephalus*	2.9
11	Other (74 species)	10.3	Other (107 species)	36.9	Other (121 species)	62.2

[A]Most are *Liza affinis* and *L. macrolepis*

the four estuaries were not only due to the influence of these two current systems on the recruitment of larval marine fishes. Spatial heterogeneity within the estuaries that provided a diversity of habitat for the estuarine fish species probably also played a role.

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Appendix 1. Species composition, developmental stage and geographic distribution of four estuaries from December 1997 through November 1998

SC, GST, TT and TK refer to Fig. 1. Le, *Leptocephalus* larva; Pr, preflexion larva; Fl, flexion larva; Ge, glass eel; Po, postflexion larva; Ju, juvenile; Yo, young; Te, temperate; Tr, tropic; W, world wide. *dominant stages; –, not caught

Family and species	Stage	No. of fish				Geog.
		SC	GST	TT	TK	
DASYATIDAE						
Dasyatis akajei	Yo	–	1	–	–	Te
ELOPIDAE						
Elops hawaiensis	Le	–	217	63	337	Tr
MEGALOPIDAE						
Megalops cyprinoides	Le	–	6526	1107	5988	Tr
ALBULIDAE						
Albula vulpes	Le	–	–	–	1	Tr
ANGUILLIDAE						
Anguilla bicolor pacifica	Ge	7	36	–	32	Tr
Anguilla celebesensis	Ge	–	4	–	–	Tr
Anguilla japonica	Ge	2	204	–	5	Te
Anguilla marmorata	Ge*, Yo	87	240	–	76	Tr
MURAENIDAE spp.	Le, Ge*	–	2	–	2	
OPHICHTHYIDAE spp.	Le, Ge*, Yo	–	7	1	80	
NETTASTOMATIDAE sp.	Le	–	–	1	–	
CONGRIDAE						
Conger myriaster	Yo	1	–	–	–	Te
Congridae spp.	Le	–	1	1	–	
CLUPEIDAE						
Sardinella spp.	Pr, Fl, Po*, Ju, Yo	12	33	814	4	Tr
Ilisha melastoma	Pr, Fl, Po*, Ju, Yo	–	–	211	–	Tr
ENGRAULIDAE						
Encrasicholina heteroloba	Ju	–	1	–	2	Tr
Encrasicholina punctifer	Ju*, Yo	–	19	14	–	Tr
Engraulis japonicus	Fl, Po, Ju*, Yo, Ad	8	2	81	1	Te
Stolephorus insularis	Fl, Po, Ju*, Yo	10	57	1858	13	Tr
Thryssa chefuensis	Fl, Po, Ju*, Yo	–	57	643	70	Tr
CHANIDAE						
Chanos chanos	Po*, Ju, Yo	13	168	9	158	Tr
CYPRINIDAE						
Carassius auratus	Yo	–	3	–	–	Te
Paracheilognathus himantegus	Yo	1	–	–	–	Te
Zacco platypus	Yo	6	–	–	–	Te
ARIIDAE						
Arius sp.	Yo	–	–	2	–	Tr
PLOTOSIDAE						
Plotosus lineatus	Yo	–	1	–	–	Tr
SYNODONTIDAE						
Saurida gracilis	Ju	1	–	–	–	Tr
Saurida wanieso	Ju	–	–	1	–	Tr
Trachinocephalus myops	Fl, Po, Ju*	–	1	6	–	Tr
Synodontidae spp.	Po, Ju*	–	1	–	2	
PARALEPIDIDAE spp.	Po, Ju*	–	3	1	–	
MYCTOPHIDAE						
Benthosema pterotum	Fl, Po*, Ju*, Yo	–	–	13	2	W
Myctophidae sp.	Fl	–	–	1	–	
BREGMACEROTIDAE						
Bregmaceros neonectabanus	Ju*, Yo	–	1	1	1	Tr
EXOCOETIDAE sp.	Yo	–	–	–	1	Tr
BELONIDAE						
Strongylura anastomella	Yo	–	1	–	–	Te

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Appendix 1. (continued)

Family and species	Stage	No. of fish SC	GST	TT	TK	Geog.
HEMIRAMPHIDAE sp.	Ju	–	–	1	–	Tr
POECILIIDAE						
Gambusia affinis	Ju, Yo*	–	49	2	1	Tr
ATHERINIDAE						
Atherinomorus lacunosus	Yo	1	–	–	–	Tr
Atherion elymus	Yo	2	–	–	–	Tr
Hypotherina valenciennei	Yo	5	–	–	–	Tr
Hypotherina woodwardi	Yo	4	–	–	–	Tr
Atherinidae spp.	Po, Ju, Yo*	3	–	1	1	
PEGASIDAE sp.	Ju	–	–	–	1	Tr
SYNGNATHIDAE						
Hippichthys spicifer	Yo	1	9	–	–	
Syngnathidae spp.	Yo	–	–	3	13	
SCORPAENIDAE						
Sebastiscus marmoratus	Pr*, Yo	–	–	1	–	Te
Scorpaenidae spp.	Pr*, Po, Ju	–	2	1	31	
PLATYCEPHALIDAE spp.	Ju*, Yo	–	104	8	44	Tr
CENTROPOMIDAE						
Ambassis gymnocephalus	Po*, Ju, Yo	186	2482	530	24	Tr
Ambassis urotaenia	Po, Ju*, Yo	–	–	46	11130	Tr
PERICHTHYIDAE						
Lateolabrax japonicus	Fl, Ju*, Yo	–	–	6	–	Te
SERRANIDAE spp.	Ju	–	15	–	30	
TERAPONIDAE						
Pelates quadrilineatus	Yo	–	1	–	–	Tr
Terapon jarbua	Po, Ju*, Yo	102	35770	19	723	Tr
KUHLIIDAE						
Kuhlia marginata	Pr, Fl, Po, Ju*, Yo	12	83	334	5086	Tr
PRIACANTHIDAE						
Priacanthus sp.	Fl	1	–	–	–	Tr
APOGONIDAE						
Apogon spp.	Po, Ju*	–	25	–	11	Tr
SILLAGINIDAE						
Sillago japonica	Fl, Po, Ju*, Yo	1	216	60	99	Te
Sillago maculata	Po, Ju*, Yo	4	655	31	–	Tr
Sillago sihama	Po, Ju*, Yo	64	6738	74	67	Tr
Sillaginidae spp.	Ju, Yo*	–	15	–	31	
CARANGIDAE						
Caranx lugubris	Yo	41	21	–	–	Tr
Caranx sexfasciatus	Yo	12	7	–	–	Tr
Scomberoides tol	Ju*, Yo	7	55	–	12	Tr
Selar crumenophthalmus	Po	–	–	1	–	Tr
Trachinotus baillonii	Yo	–	–	–	1	Tr
Carangidae spp.	Po, Ju*, Yo	5	3	2	13	
LEIOGNATHIDAE						
Gazza minuta	Yo	12	5	–	1	Tr
Leiognathus elongatus	Yo	–	–	–	–	Te
Leiognathus nuchalis	Po, Ju*, Yo	30	353	24	12	Tr
Secutor ruconius	Yo	1	7	21	13	Tr
Leiognathidae spp.	Pr, Fl, Po, Ju, Yo*	1	52	20	229	
LUTJANIDAE						
Lutjanus argentimaculata	Po, Ju*	1	143	–	1	Tr
Lutjanus fulviflamma	Ju	–	4	–	–	Tr
Lutjanus russellii	Ju*, Yo	–	62	–	–	Tr
Lutjanus vita	Ju	–	49	–	26	

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Appendix 1. (continued)

Family and species	Stage	No. of fish SC	GST	TT	TK	Geog.
GERREIDAE						
Gerreomorpha japonica	Po, Ju*, Yo	5	1508	–	8	Te
Gerres abbreviatus	Po, Ju*, Yo	241	2040	1	8	Tr
Gerres filamentosus	Ju*, Yo	89	1624	1	13	Tr
Gerres macrosoma	Ju*, Yo	37	9284	173	108	Tr
HAEMULIDAE						
Hapalogeny nitens	Yo	2	–	–	–	Te
Plectorhynchus sp.	Ju	–	–	–	1	
Pomadasys spp.	Pr, Fl, Po, Ju*, Yo	6	228	9	31	
SPARIDAE						
Acanthopagrus latus	Po, Ju*, Yo	6	811	38	–	Tr
Acanthopagrus schlegeli	Fl, Po, Ju*, Yo	–	281	125	240	Te
Acanthopagrus australis	Pr, Po, Ju*, Yo	–	4	95	1	
SCIAENIDAE spp.	Pr, Po*, Ju	–	8	1	2	
MULLIDAE sp.	Ju	–	–	–	1	
SCATOPHAGIDAE						
Scatophagus argus	Ju*, Yo	–	158	9	37	Tr
CICHLIDAE spp.	Ju*, Yo	1	22	29	6	
MUGILIDAE						
Mugil cephalus	Yo	408	904	1	57	Te
Mugilidae spp.[A]	Yo	937	10006	405	493	Tr
SPHYRAENIDAE						
Sphyraena barracuda	Yo	–	–	1	–	
Sphyraenidae spp.	Ju*, Yo	1	4	4	3	Tr
POLYNEMIDAE						
Polydactylus plebeius	Yo	2	–	–	–	Tr
LABRIDAE spp.	Po*, Ju	5	72	–	10	Tr
SCARIDAE spp.	Po*, Ju	–	47	1	5	Tr
PERCOPHIDAE sp.	Po	1	–	–	–	
BLENNIIDAE						
Omobranchus spp.	Po, Ju*	1	6	14	294	
CALLIONYMIDAE spp.	Pr, Po, Ju*, Yo	–	1	13	3	
GOBIIDAE						
Apocryptodon madurensis	Ju	–	–	40	–	
Bathygobius fuscus	Po*, Ju, Yo	15	2723	–	4	Tr
Eleotris acanthopoma	Po*, Ju, Yo	3	1334	–	477	Tr
Favonigobius reichei	Ju, Yo*	4	16	–	–	
Glossogobius biocellatus	Po*, Ju, Yo	–	140	–	–	
Mugilogobius tagala	Yo	–	3	–	–	
Periophthalmus cantonensis	Yo	–	1	–	–	
Rhinogobius brunneus	Po*, Ju, Yo	6	595	55	38	Te
Rhinogobius giurinus	Fl, Po*, Ju, Yo	9	5704	1644	3226	Te
Scartelaos viridis	Ju	–	56	10	–	
Sicyopterus japonicus	Po, Ju*	367	1157	–	89	Te
Taenioides cirratus	Po*, Ju	1	4205	3	2755	Tr
Gobiidae sp. 1	Po*, Ju, Yo	–	3119	12	122	
Gobiidae sp. 2	Po, Ju*, Yo	–	312	–	–	
Gobiidae sp. 3	Po*, Ju, Yo	–	–	–	230	
Gobiidae sp. 4	Po, Ju*	–	5773	3	892	
Gobiidae sp. 5	Po*, Ju, Yo	–	3376	4	367	
Gobiidae sp. 6	Po, Ju*	–	6	–	–	
Gobiidae sp. 7	Po, Ju*, Yo	–	804	–	–	
Gobiidae spp.	Pr, Fl, Po, Ju*, Yo	37	1956	113	527	
GOBIESOCIDAE sp.	Po	–	–	1	–	
SIGANIDAE						
Siganus fuscescens	Ju	–	28	1	43	Te

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Appendix 1. (continued)

Family and species	Stage	No. of fish				Geog.
		SC	GST	TT	TK	
TRICHIURIDAE						
Trichiurus lepturus	Po, Yo*	–	3	3	–	W
BOTHIDAE spp.	Po, Ju*, Yo	–	350	1	213	
PLEURONECTIDAE spp.	Ju	–	123	1	–	
CYNOGLOSSIDAE spp.	Pr, Ju*, Yo	–	1	2	52	
MONACANTHIDAE spp.	Po, Ju*, Yo	–	4	1	–	
TETRAODONTIDAE spp.	Ju*, Yo	–	26	11	27	
DIODONTIDAE spp.	Yo	–	6	–	14	
Total (fish)		2828	113340	8838	34772	
Total (family)		28	49	44	46	
Total (species)		56	94	73	77	

[A]Most are *Liza affinis* and *L. macrolepis*