

Recruitment of Larval and Juvenile Fishes to the Gong-Shy-Tyan River Estuary of Taiwan: Relative Abundance, Species Composition, and Seasonality

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Abstract.—The fish assemblage in the estuary of Gong-Shy-Tyan River, a pollution-free river, in north Taiwan was sampled for a period of one year from June 1984 through June 1985 using an anchored bag-net with mesh size of 0.8–1.8 mm at night-time spring flood tide. The water temperature in the estuary was lowest in February (15°C) and highest in September (30°C); the salinity varied from 0.5 to 32‰. A total of 65,968 individuals representing 46 families and 111 species was collected from 55 field trips. The fish assemblage was dominated by a few species: *Terapon jarbua* (Teraponidae) was numerically the most dominant (51.3% of the total), followed by *Eleotris acanthopoma* (Eleotridae) (13.4%), *Gerres macrosoma* (Gerreidae) (8.7%), *Liza macrolepis* (Mugilidae) (5.0%), *Taenioides cirratus* (Gobioididae) (4.2%), *Sillago sihama* (Sillaginidae) (3.0%), *Yongeichthys caninus* (Gobiidae) (1.4%), *Anguilla japonica* (Anguillidae) (1.3%), *Bathygobius fuscus* (Gobiidae) (1.2%), and *Chanos chanos* (Chanidae) (1.1%). These 10 species constituted approximately 90% of the total. Most fishes enter the estuary as juveniles, and use this river estuary as an important nursery ground. More species and individuals were usually present from late spring through autumn than from winter through early spring. A sudden drop in the abundance sometimes occurred during the summer months. The recruitment pattern of the fish into the estuary was described based on monthly length frequency distribution.

The estuary is one of the most productive areas on the earth, comparable to that of the coastal upwelling area (Haedrich and Hall 1976). It functions as a nursery and feeding ground for the juveniles of many inshore and offshore commercially important fishes (Wallace and van der Elst 1975; Blaber and Blaber 1980; Day et al. 1981; Lenanton 1982; Bell et al. 1984). This is because the estuary provides suitable food resources as well as shelter, absence of turbulence, and a reduction of predation (Blaber et al. 1985). The abundant food is utilized to accelerate growth during their first year of fish life.

The fish resources conservation of the estuary in Taiwan is of great concern because of increased pollution of this very important local fishing ground for juveniles of Engraulidae and Clupeidae, and for collecting fish fry of Anguillidae, Mugilidae, and Sparidae for cultivation. A limited number of studies on the estuarine fish community in Taiwan have been conducted previously (Chen 1985; Huang et al. 1985; Tzeng and Wang 1986, 1992; Wang et al. 1991). A number of well-documented studies have been reported for other countries (Shenker and Dean 1979; Bell et

al. 1984; Berkley 1984; Yamashita and Aoyama 1984; Jenkins 1986; Reina-Herva and Serrano 1987; Bennett 1989). However, baseline ecological studies for conservation policy are meager compared with the vastly increased level of pollution worldwide.

The aim of this study, therefore, is (1) to determine the relative abundance, species composition, and recruitment seasonality of the fish larvae and juveniles in the river estuary of north Taiwan; (2) to understand the role of such an estuary as a nursery habitat for the fish; and (3) to correlate recruitment patterns of the fish community with surface temperature and salinity. For this purpose, the fish species entering the estuary of Gong-Shy-Tyan River were sampled over a period of one year. The species and size of the fish and their seasonal abundance were examined. Variations in numbers of species and in total number caught, as well as the species diversity and species evenness in relation to water temperature and salinity are discussed.

Materials and Methods

Gong-Shy-Tyan River estuary in the north coast of Taiwan (Figure 1) is defined by a rocky north shore and a sandy south shore. The estuary is a coastal plain estuary. Due to sand deposition in the river mouth, the estuary narrows slightly at the inlet to about 50 m and widens in the inner part to about 100 m. The geomorphological feature resembling a small bay is a favorite nursery ground for fish larvae and juveniles. The sediment in the estuary is dominated by sand. The peripheral area of the river is dominated by rice fields and grassland; no apparent pollution source was found upstream. The river discharge was small except during the rainy season. The estuary is flushed by a semidiurnal tide, ranging from 3 m at spring tide to 1.5 m at neap tide (Chu 1963). The water circulation in the estuary was vertically mixed and slightly stratified during large river discharge.

Fishes were collected using an anchored bag-net with mesh size of 0.8–1.8 mm extended to completely block the river inlet (Figure 2). Fish entering the estuary with the flood tide were collected at night for 2–3 consecutive days at approximately 2-week intervals during the period from June 1984 to June 1985. Specimens collected were fixed immediately with 10% buffered formalin, and classified and identified to the species level if possible. Total length (TL) of the fish was measured to the nearest 0.1 mm using a profile projector (Nikon V-16) at 10 $\times$ magnification. For comparison, the fish collected from other studies during April 1988 through March 1989 (Miu et al. 1990) were also analyzed.

The structure of the fish community was estimated according to Margalef's (1969) index of species richness (d'), and Pielou's (1966) index of evenness (J'). The similarity of species composition of fish larvae and juveniles was analyzed by applying Kimoto's (1976) index for degree of overlap and cluster analysis was used to construct similarity dendrograms to show seasonal variations (Mountford 1962).

The surface water temperature and salinity were measured with an oceanographic salinity and temperature bridge (Model MC5/2 Electronic Instruments Ltd/England). The numbers of fish and species, as well as the community structure indexes in relation to water temperature and salinity were analyzed.

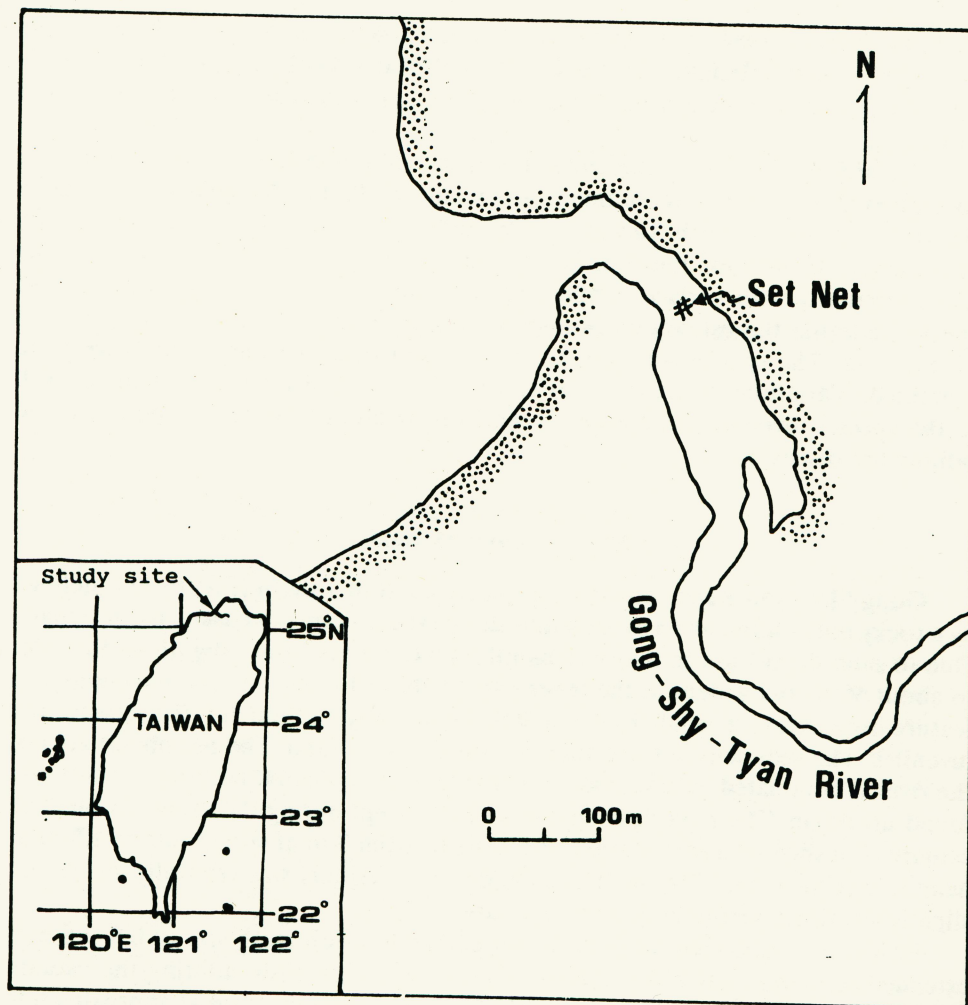


FIGURE 1.—The sampling station in the Gong-Shy-Tyan River estuary, north Taiwan.

Results

Environmental Characteristics

Surface water temperature in the estuary changed with season, reaching a maximum of 30°C between July and September and a minimum of 15°C in February (Figure 3). Surface salinity in the estuary fluctuates greatly from approximately 32‰ to less than 0.5‰ during rainy season (Figure 3).

Species Composition

Terapon jarbua (Teraponidae) was the most numerous and accounted for 51.3% of the 65,968 individuals representing 46 families and 111 species that were collected in the Gong-Shy-Tyan River estuary during June 1984 through June 1985. They were followed by *Eleotris acanthopoma* (Eleotridae) (13.4%), *Gerres macrosoma* (Gerreidae) (8.7%), *Liza macrolepis* (Mugilidae) (5.0%), *Taenioides cirratus* (Gobioididae)

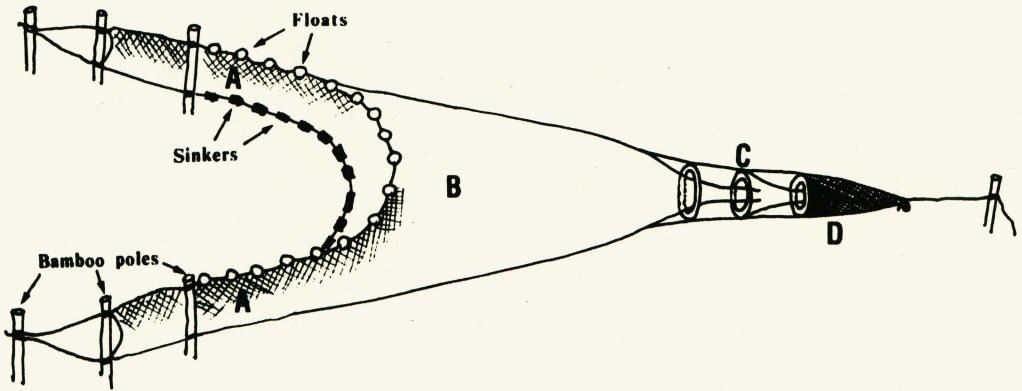


FIGURE 2.—Anchored bag-net used to collect fish during flood tide. A: wing net, B: Bag net, C: ring, and D: cod end. Length = 16 m(A), 18 m(B); Mesh size = 1.8 mm(A,B), 0.83 mm(D).

(4.2%), *Sillago sihama* (Sillaginidae) (3.0%), *Yongeichthys caninus* (Gobiidae) (1.4%), *Anguilla japonica* (Anguillidae) (1.3%), *Bathygobius fuscus* (Gobiidae) (1.2%) and *Chanos chanos* (Chanidae) (1.1%). These 10 species constituted approximately 90% of the total catch; the remaining 10% was accounted for more than 101 species (Table 1).

According to the differences in life cycle, the fish larvae and juveniles in the estuary were classified into marine, estuarine-dependent marine, estuarine, and freshwater species (Deegan and Thompson 1985). Most larvae and juveniles collected in the Gong-Shy-Tyan River estuary seemed to be originated from inshore waters. Offshore marine species were seldom found in the estuary. The estuarine species included Gobiidae (18 species), *Taenioides cirratus*, Eleotridae (4 species) and *Kuhlia* spp., which may complete their entire life cycle in the estuary. Species from freshwater were few; only Cyprinidae (2 species) and *Gambusia affinis* were found. *Anguilla* spp. were a diadromous species, appearing in the study area as elvers during their upstream migration. These results indicate that the species composition of marine origin was more diversified than that from freshwater (Table 1).

Seasonal Abundance in Number of Species and Individuals

The total number of species and individuals found in the estuary showed large variations within and between seasons. The number of species was higher during the period from late spring to autumn than that from winter to early spring for the year 1984–1985 (Figure 4); whereas the number of fishes caught was higher in spring and autumn than in summer and winter for the years 1984–1985 and 1988–1989 (Figure 5 A,B). A depression in the relative abundance of the fish was observed both in late summer when temperature was high and in November through February when temperature was low. The monthly variation in the total number of fishes caught followed closely that of *Terapon jarbua*.

The number of species was positively correlated with water temperature ($r = 0.70$; $p < 0.001$), but not significantly correlated with salinity ($r = 0.4$; $p > 0.05$). The number of individuals was not significantly correlated with either water temperature ($r = 0.33$) or salinity ($r = 0.08$).

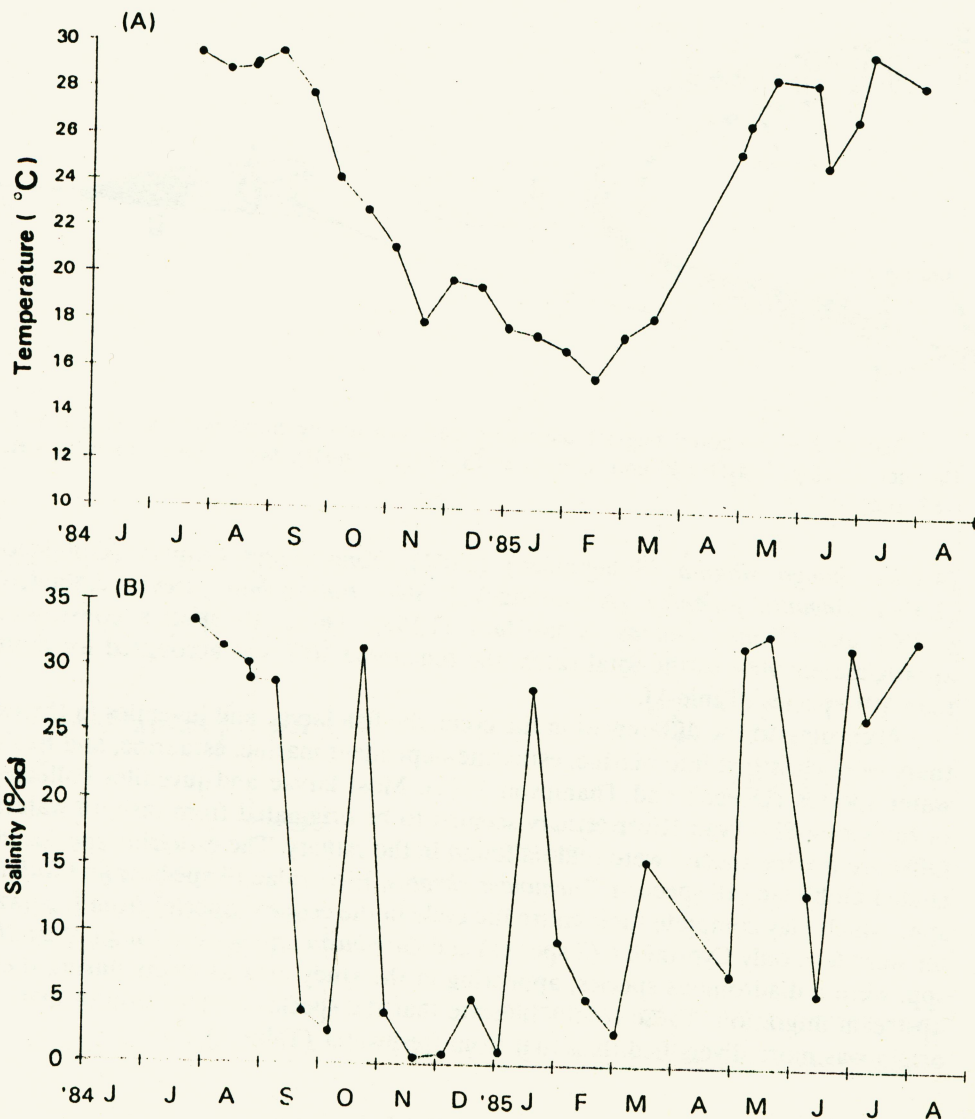


FIGURE 3.—Seasonal variations of surface water temperature (A) and salinity (B) in the Gong-Shy-Tyan River estuary, July 1984–June 1985.

Recruitment Patterns

Most species recruited into the estuary during the period from late spring to autumn (Table 1), e.g., *Terapon jarbua*, *Sillago sihama*, lutjanids, gerreids, eleotrids, gobiids, and gobioids. In contrast, anguillids, cyprinids, poeciliids, centropomids and mugilids were the dominant taxa during the period from winter through early spring. The duration of recruitment in the estuary varied with species from one month (e.g., *Lateolabrax japonicus*) to almost year-round (e.g., *Liza macrolepis*). The seasonal recruitment pattern of the fishes in the estuary was described based on the monthly length-frequency distributions of 19 dominant species (Figure 6).

(1) Freshwater species migrated into the estuary during winter. *Gambusia affinis* originated from upstream freshwater with wide length ranges, indicating that they

TABLE 1.—Species composition of juvenile fishes collected in the estuary of Gony-Shy-Tyan River, northern Taiwan, June 1984–June 1985.

Family and species	Number of Fish												Total	%		
	1984						1985									
	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May			June	
1 ELOPIDAE																
<i>Elops hawaiiensis</i>	11	27	43	13	60	9						2	134	25	324	0.49
2 MEGALOPIDAE																
<i>Megalops cyprinoides</i>	2	7	7	2	9	26	9								62	0.09
3 ANGUILLIDAE																
<i>Anguilla japonica</i>	1		1		3		41	627	57	125					855	1.30
<i>Anguilla marmorata</i>	5	1	13	2		1	7	44	8	66	7	7			161	0.24
<i>Anguilla bicolor pacifica</i>			2	2	1					2	10				17	0.03
4 OPHICHTHYIDAE																
<i>Ophichthys urolophus</i>		1													1	0.00
<i>Pisodonophis boro</i>		1				1									2	0.00
<i>Pisodonophis cancerivorus</i>					1										1	0.00
5 ENGRAULIDAE																
<i>Stolephorus buccaneeri</i>		5	21	4	13	1									44	0.07
<i>Thryssa kammalensis</i>		1		55	26	1	2				1				86	0.13
6 CHANIDAE																
<i>Chanos chanos</i>					700	13									713	1.08
7 CYPRINIDAE																
<i>Rhodeus spinalis</i>									6	5				1	12	0.02
<i>Pseudorasbora parva</i>								2		3					5	0.01
8 PLOTOSIDAE																
<i>Plotosus anguillaris</i>				1	1							2			4	0.01
9 SYNODONTIDAE																
<i>Synodus variegatus</i>				6											6	0.01

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17 TERAPONIDAE	1,652	14,877	403	629	11,985	1,784	1,088	4	7	52	827	527	33,835	51.29
<i>Terapon jarbua</i>														
18 KUHLIIDAE														
<i>Kuhlia rupestris</i>							2	5					7	0.01
<i>Kuhlia marginata</i>							1	6					7	0.01
19 APOGONIDAE														
<i>Apogon robustus</i>											2		2	0.00
<i>Apogon</i> sp.													1	0.00
sp.				2			1						3	0.00
20 SILLAGINIDAE														
<i>Sillago sihama</i>	3	258	390	51	20		1				689	594	2,006	3.04
21 CARANGIDAE														
<i>Scomberoides tol</i>		1	2										3	0.00
<i>Scomberoides orientalis</i>		2											2	0.00
<i>Caranx sexfasciatus</i>	2	14	4	1	1	1	2	2			5	1	31	0.05
<i>Alectis ciliaris</i>													2	0.00
<i>Trachinotus ovatus</i>							3						3	0.00
22 LEIOGNATHIDAE														
<i>Leiognathus splendens</i>	10		2	26	2	37					24	2	103	0.16
<i>Leiognathus brevirostris</i>		1											1	0.00
23 LUTJANIDAE														
<i>Lutjanus monostigma</i>			1				7				1		9	0.01
<i>Lutjanus argenteimaculatus</i>	23	42		37	39	4	6						151	0.23
<i>Lutjanus russellii</i>	12	131	52	62	112	3							372	0.56
sp.			1										1	0.00
24 GERREIDAE														
<i>Gerres filamentosus</i>	1	9	34									63	319	0.48
<i>Gerres macrostoma</i>	239	122	46	148	3,461	685	30		6	45	846	123	5,751	8.72
<i>Gerres</i> sp.				1,050	14	30							1,094	1.66

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Table 1 (continued)

Family and species	Number of Fish												Total	%	
	1984						1985								
	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May			June
25 HAEMULIDAE															
<i>Plectorhinchus cinctus</i>													3	3	0.00
<i>Haplogeryn mucronatus</i>												43	1	44	0.07
26 LETHRINIDAE															
sp.	1				1									2	0.00
27 SPARIDAE															
<i>Acanthopagrus latus</i>					28	95	108	4						235	0.36
<i>Acanthopagrus schlegelii</i>											79	220		299	0.45
sp.	17	119	82	216	7	18								459	0.70
28 MULLIDAE															
<i>Parupeneus indicus</i>								1						1	0.00
sp. 1	1													1	0.00
sp. 2								1						1	0.00
29 SCATOPHAGIDAE															
<i>Scatophagus argus</i>															
30 CHAETODONTIDAE															
<i>Chaetodon argentatus</i>								1						1	0.00
<i>Chaetodon lineolatus</i>								3						3	0.00
<i>Chaetodon auriga</i>								1						1	0.00
<i>Chaetodon melanotus</i>								1						1	0.00
<i>Heniochus</i> sp.	1													1	0.00
31 POMACENTRIDAE															
<i>Abudefduf sordidus</i>												1		1	0.00
<i>Pomacentrus</i> sp.														9	0.01
32 APLODACTYLIDAE															
<i>Goniistius zonatus</i>	1				8									2	0.00

33 MUGILIDAE													
<i>Mugil cephalus</i>													
<i>Liza carinata</i>	3	9		48	90	339	32	92	88	2	691	1.05	
<i>Liza macrolepis</i>	41	168	75	74	212	208	233	1	9	1,439	31	0.05	
34 SPHYRAENIDAE													
<i>Sphyraena jello</i>	1	1								1	3	0.00	
<i>Sphyraena forsteri</i>	1	1		1	1						3	0.00	
35 POLYNEMIDAE													
<i>Polynemus plebeius</i>			1								1	0.00	
36 LABRIDAE													
sp. 1	2			12	3					3	20	0.03	
sp. 2					4						4	0.01	
37 ELEOTRIDAE													
<i>Eleotris acanthopoma</i>	1,841	727	1,898	503	1,351	2,135	3	4		84	291	8,837	13.40
<i>Eleotris melanotoma</i>						1					1	0.00	
<i>Prionobutis koilomatodon</i>	1		1							1	3	0.00	
<i>Ophiocara porocephala</i>						1					1	0.00	
38 GOBIIDAE													
<i>Bathygobius padangensis</i>						1					1	0.00	
<i>Bathygobius fuscus</i>	55	33	205	80	109	174	1			128	35	820	1.24
<i>Periophthalmus cantonensis</i>				1								1	0.00
<i>Oxurichthys tentacularis</i>		2	13	1			1			1	18	0.03	
<i>Oxurichthys microlepis</i>		6				3				3	12	0.02	
<i>Oxurichthys ophthalmonema</i>	1	1	25								27	0.04	
<i>Favonigobius reichei</i>	2	63	21	11	5	3			7	3	115	0.17	
<i>Eutaeniichthys gilli</i>											37	0.06	
<i>Apocryptodon madurensis</i>		1									1	0.00	
<i>Gobiopsis quinqueincta</i>							1				1	0.00	
<i>Magilogobius abei</i>							1	1			2	0.00	
<i>Yongeichthys caninus</i>	52	638	92	75						1	41	899	1.36
<i>Oligolepis acutipinnis</i>		23	6	1	1						31	0.05	

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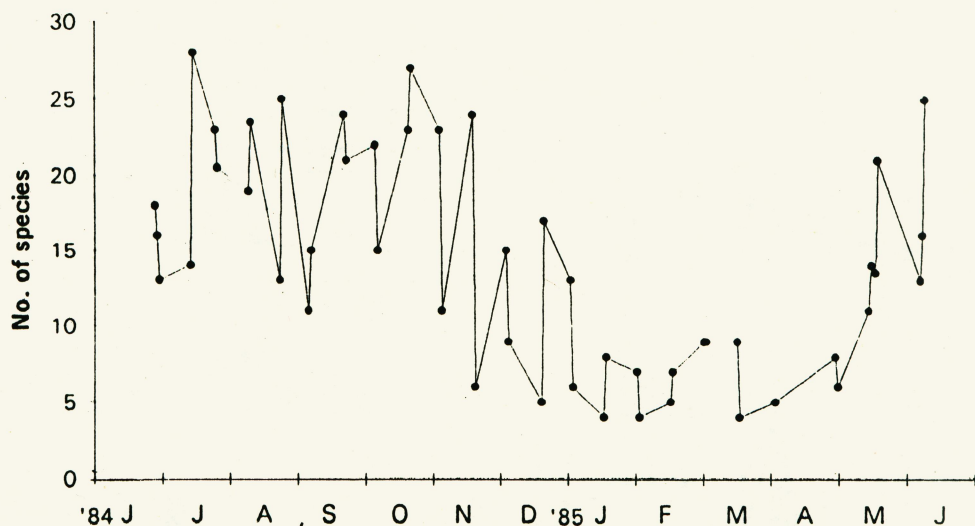


FIGURE 4.—Seasonal fluctuations in total number of fish species in the Gong-Shy-Tyan River estuary, June 1984–June 1985.

frequently recruited into the estuary; *Anguilla japonica* and *Anguilla marmorata* spawned in the open ocean, appearing in the estuary as elvers during upstream migration. Their size composition was rather uniform, because they remained in the estuary for a short duration.

(2) The estuarine species were characterized by a long recruitment duration (May–October) and mixed populations of various sizes, e.g., *Eleotris acanthopoma*, *Bathygobius fuscus*, and *Taenioides cirratus*.

(3) The marine species can be further divided into two categories based upon monthly changes of length-frequency distributions. *Terapon jarbua* and *Gerres macrosoma* recruited into the estuary during 9 months (April–December) with constant recruitment size modes of approximately 10–15 mm TL, and *Sillago sihama* was recruited for six months with a size mode at about 15 mm TL. The continuous migration into the estuary at a constant size suggested that the spawning season of the fish may last quite long. Because few large-sized fish was caught, these fishes stayed in the estuary probably for a short period of time. In contrast, *Mugil cephalus*, *Liza macrolepis*, and *Lutjanus russellii* seemed to remain in the estuary for a long period of time because there were large-sized fish to be found as indicated from length-frequency distribution. However, all of the estuarine-dependent marine species seemed to stay in the estuary only during their first year of life; no adult was found for these species.

Species Diversity and Community Structure

Few species were caught at high frequency and many species were caught at low frequency (Figure 7). The data showed that the number of species with a frequency of 2^3 or less accounted for 62 species, or 55.8% of the total number of species. Only seven species occurred in a frequency greater than 2^{10} (Figure 7).

The species richness index (d') showed large day-to-day and seasonal variations. The average value of the d' was higher during the period from late spring to autumn than that from winter to early spring (Figure 8). This indicates that the fish

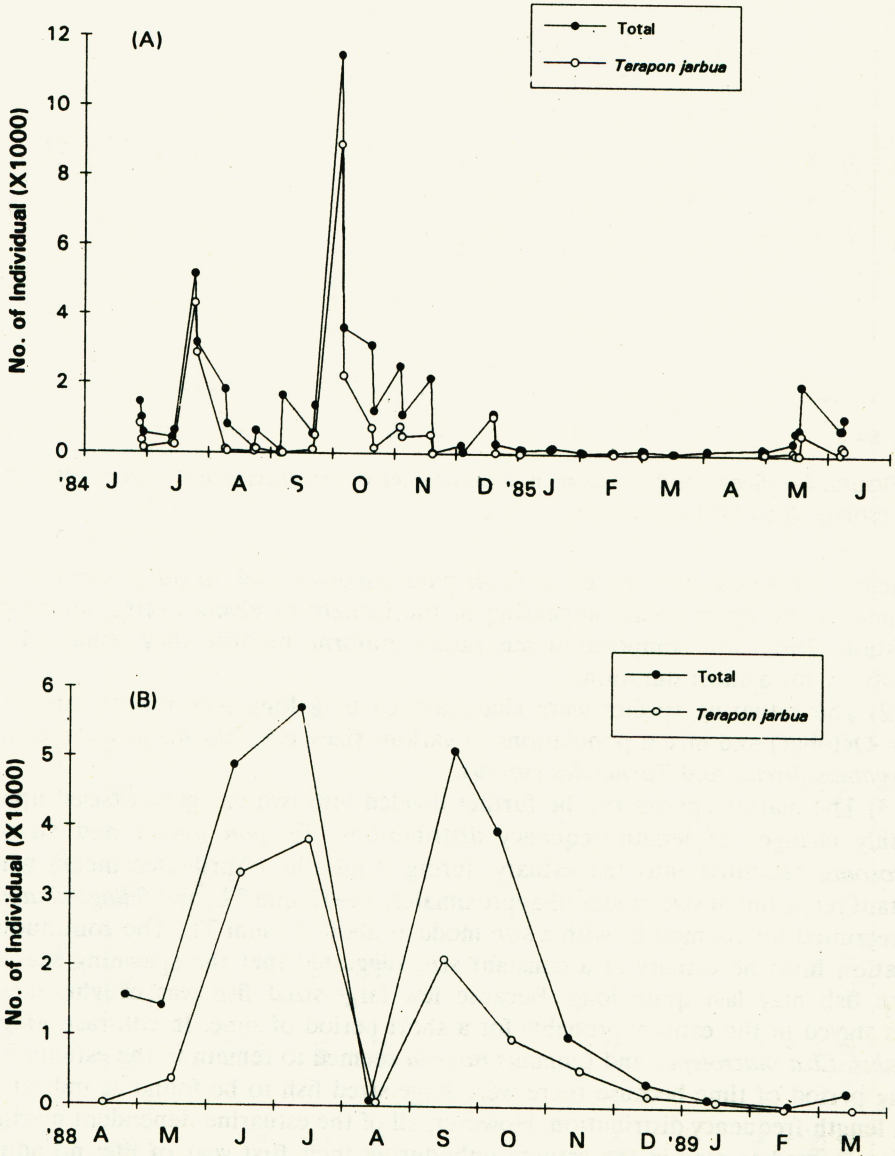


FIGURE 5.—Seasonal fluctuations in number of individuals for all species and *Terapon jarbua* collected in the Gony-Shy-Tyan River estuary. (A): June 1984–June 1985, (B): April 1988–March 1989.

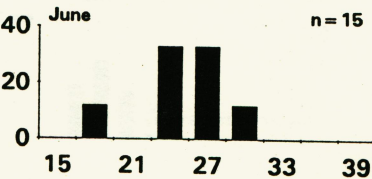
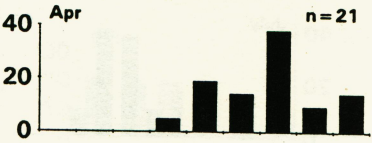
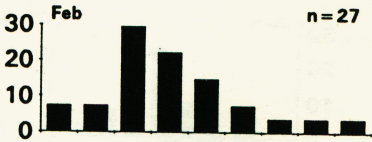
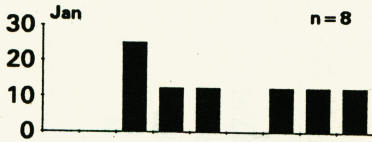
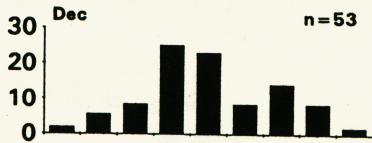
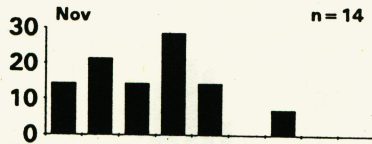
community contains more species in the former period than the latter one. On the other hand, species evenness (J') was relatively lower in July, October, December, and March than in the other months (Figure 8). Thus, there were dominant species during these months. *Terapon jarbua* was the first dominant in the first three months, whereas *Anguilla japonica* was the dominant species in March (Table 1).

The species richness index was positively correlated with water temperature ($r=0.65$; $p < 0.001$), but not significantly correlated with salinity ($r=0.35$; $p > 0.05$).

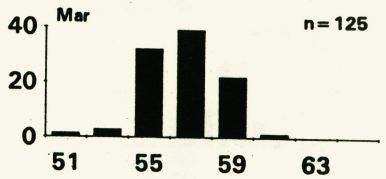
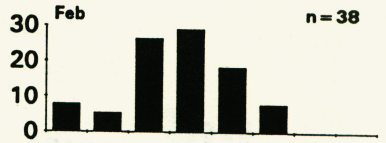
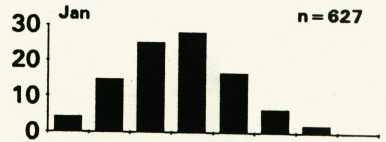
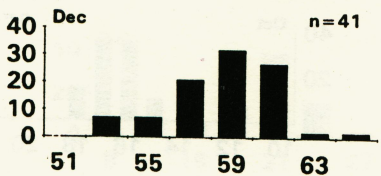
Gambusia affinis

Anguilla japonica

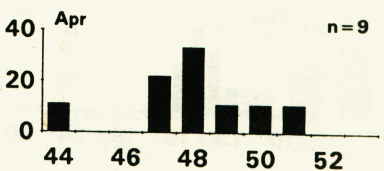
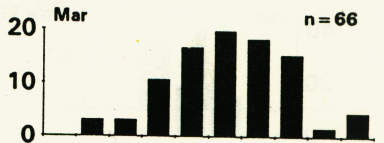
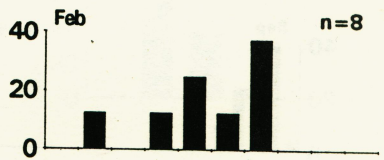
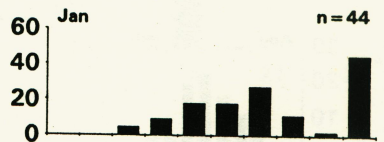
Frequency (%)



Anguilla japonica



Anguilla marmorata

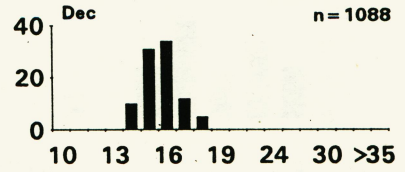
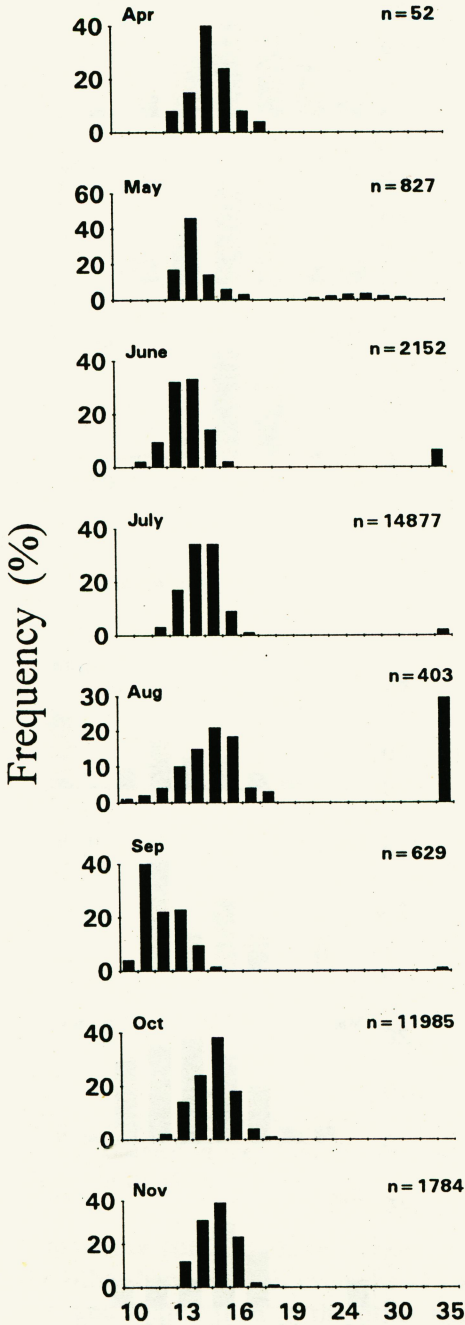


Total length in mm

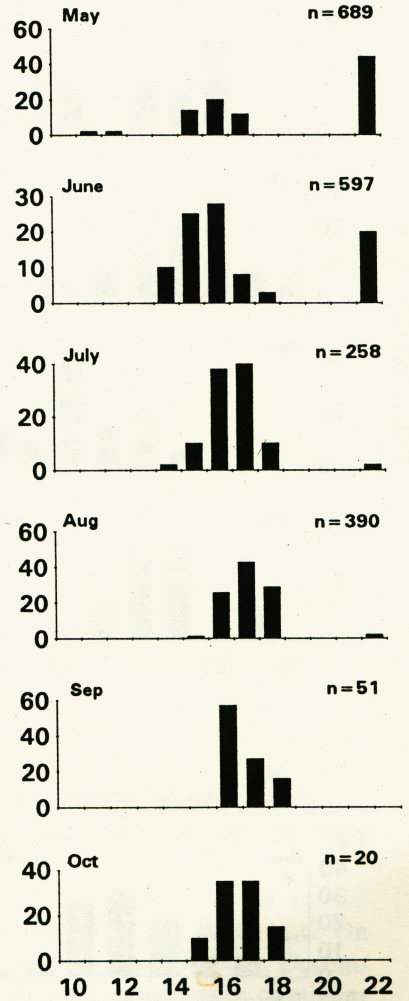
FIGURE 6.—Monthly length-frequency distributions for 19 dominant species. n = sample size.

Terapon jarbua

Terapon jarbua

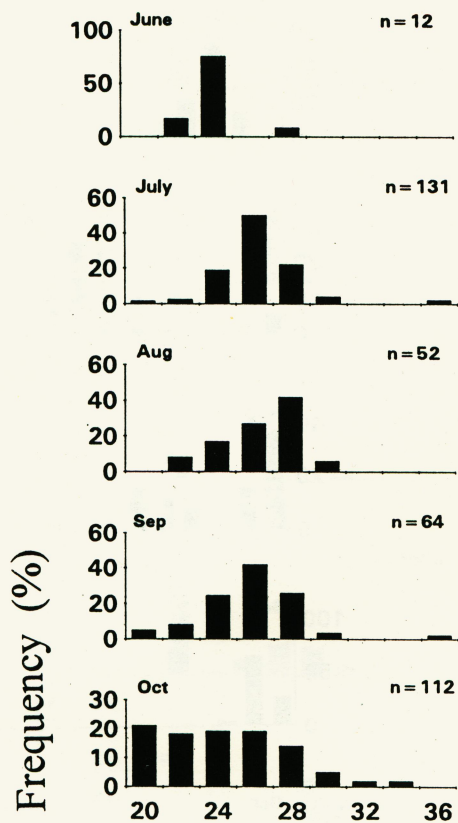
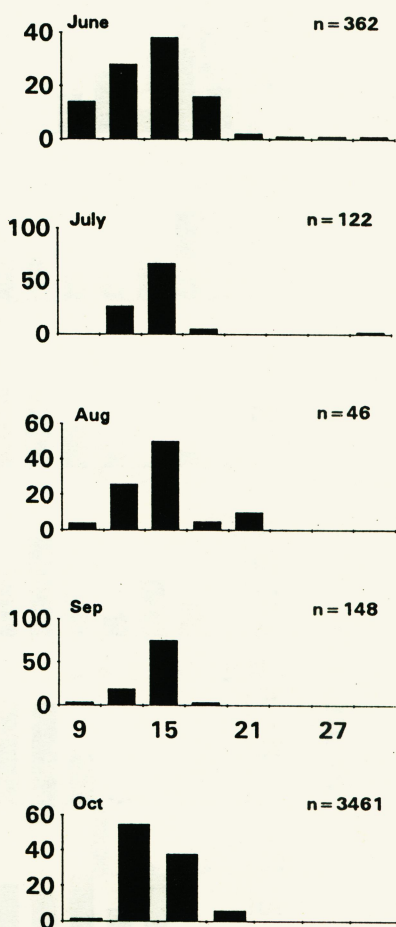
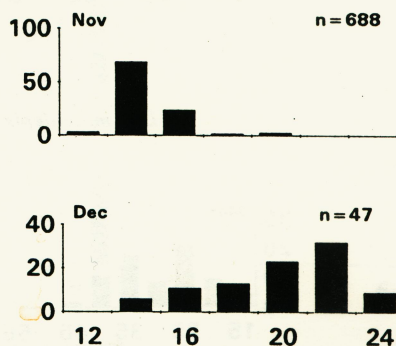
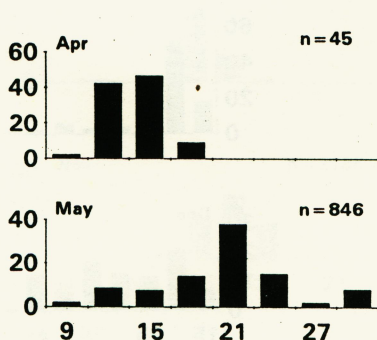


Sillago sihama



Total length in mm

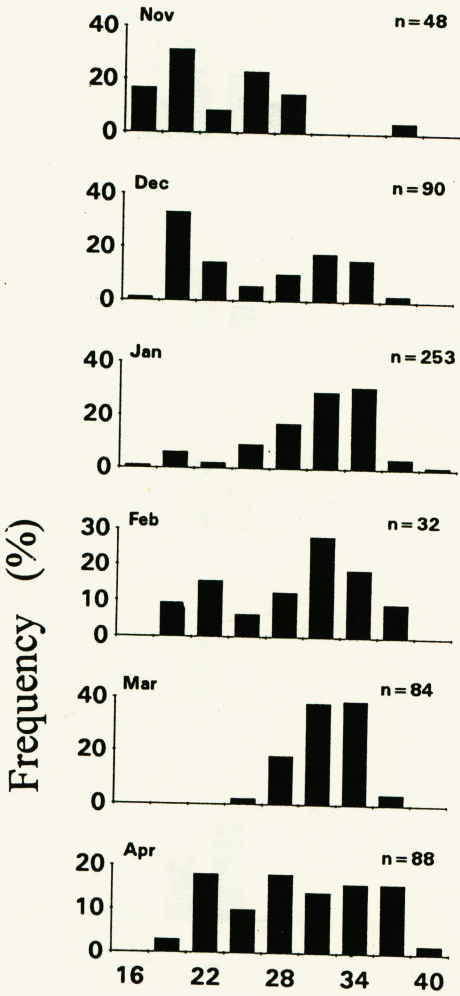
Fig. 6 (Continued)

Lutjanus russellii

Gerres macrosoma

Gerres macrosoma


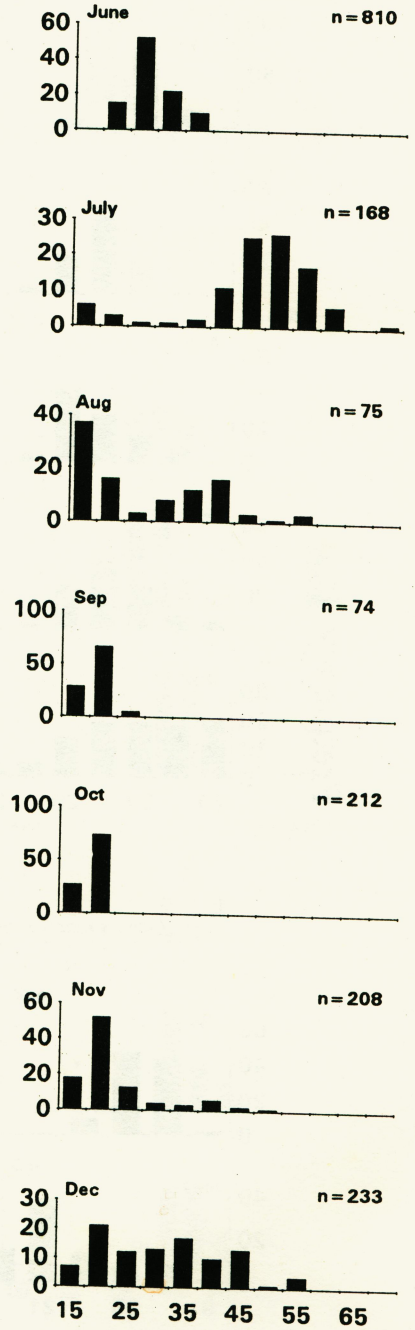
Total length in mm

Fig. 6 (Continued)

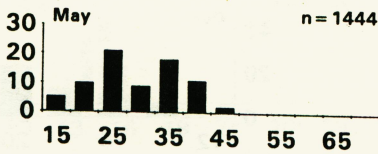
Mugil cephalus



Liza macrolepis



Liza macrolepis



Total length in mm

Fig. 6 (Continued)

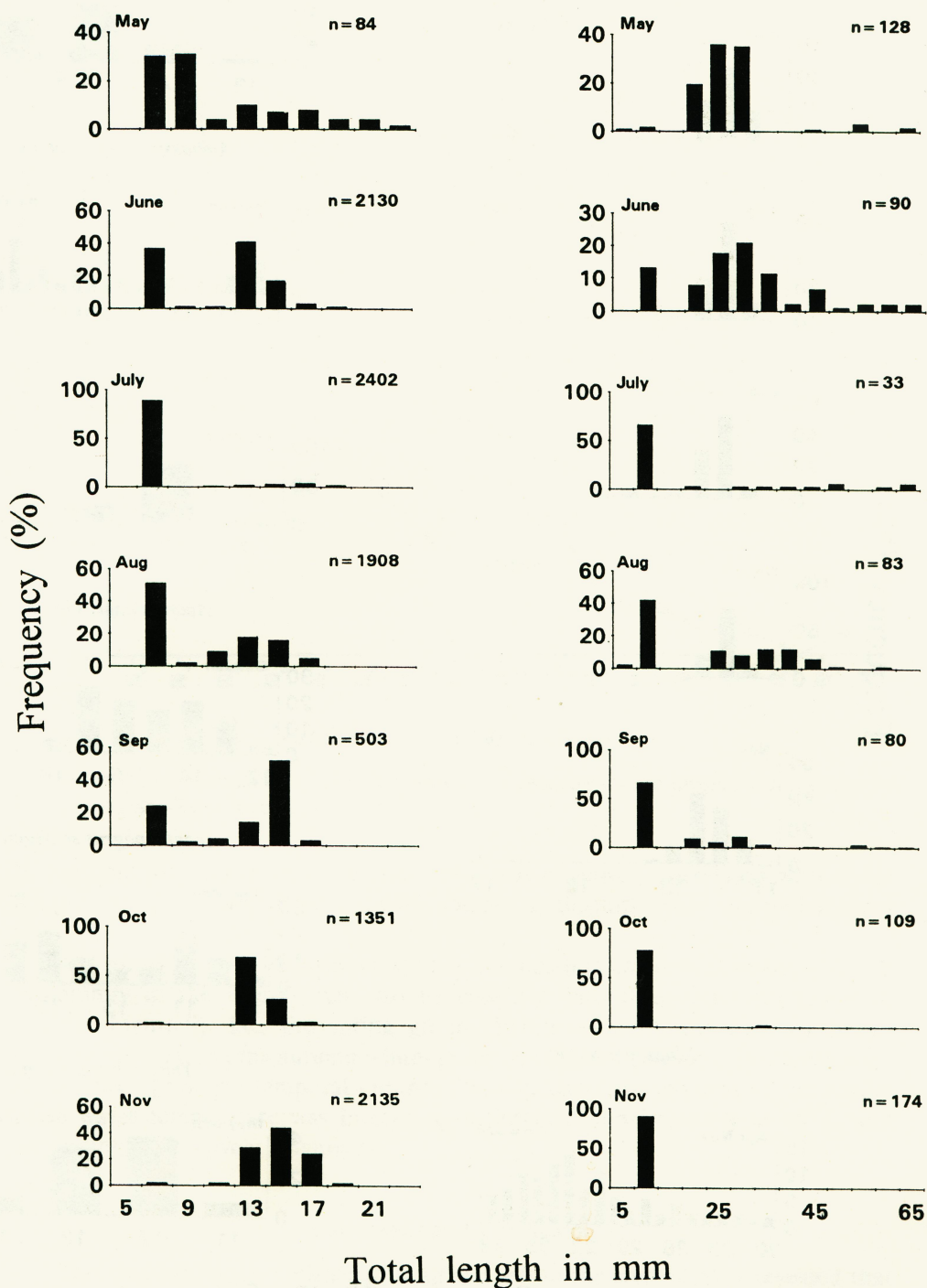
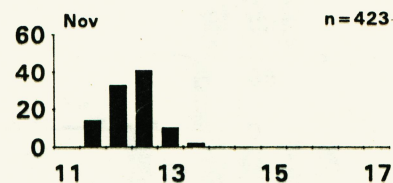
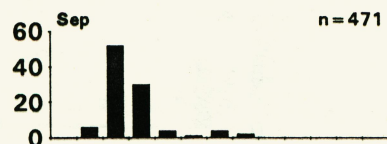
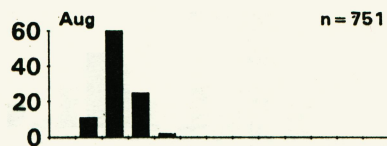
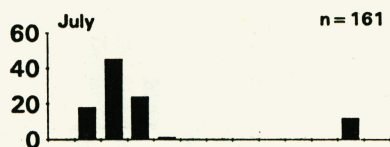
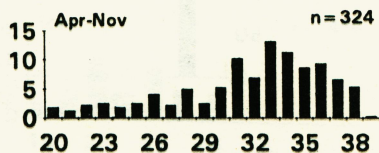
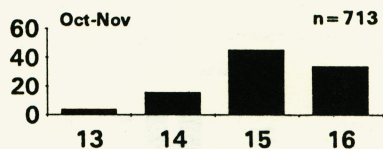
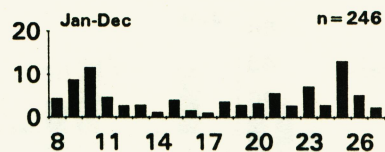
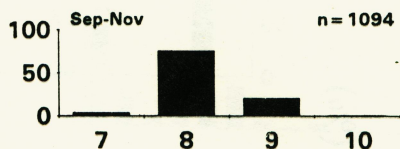
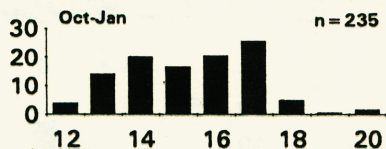
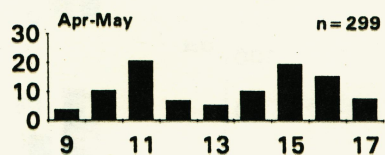
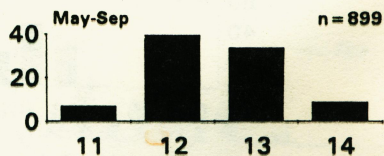
Eleotris acanthopoma
Bathygobius fuscus


Fig. 6 (Continued)

Taeniodes cirratus*Elops hawaiiensis**Chanos chanos**Ambassis gymnocephalus**Gerres sp.**Acanthopagrus latus**Acanthopagrus schlegelii**Yongeichthys caninus*

Total length in mm

Fig. 6 (Continued)

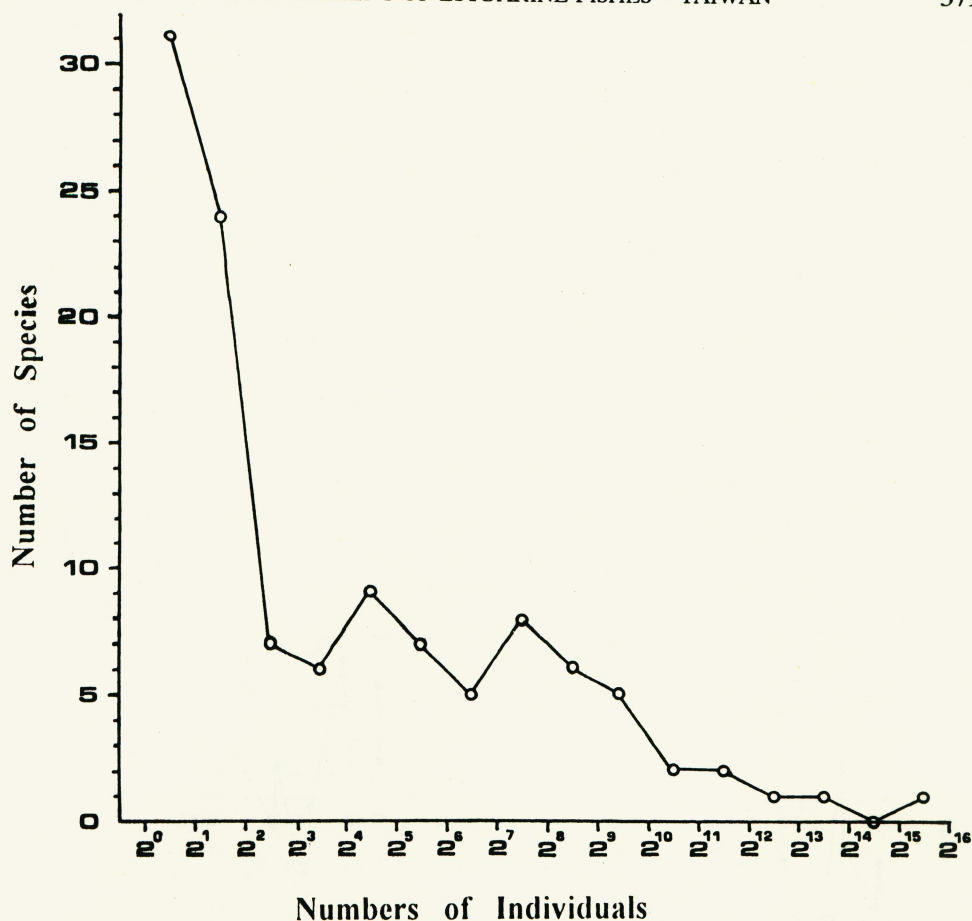


FIGURE 7.—Number of species vs. number of individuals for the juvenile fish community in the Gong-Shy-Tyan River estuary.

In the contrast, the species evenness index was negatively correlated with water temperature ($r = 0.48$; $0.01 < p < 0.05$) and not significantly correlated with salinity ($r = -0.45$; $p > 0.05$).

According to the similarity of species composition in these samples, the fish community in the estuary can also be classified into three principal temporal groups (Figure 9), i.e., the spring group (February–June), the summer group (June–October), and the autumn–winter group (October–February). The occurrence of the three principal temporal groups of fish species corresponded to the period when water temperature was increasing, maintained approximately at 30°C, and decreasing, respectively (Figure 3).

Discussion and Conclusion

The length-frequency distribution of the fish in the studied area revealed that most fish migrated to the estuary during their larval and juvenile stage (Figure 6). Fish larger than 70 mm were seldom collected. The larger fish may avoid or escape from gear, however, the absence of the larger fish in the estuary is probably not due

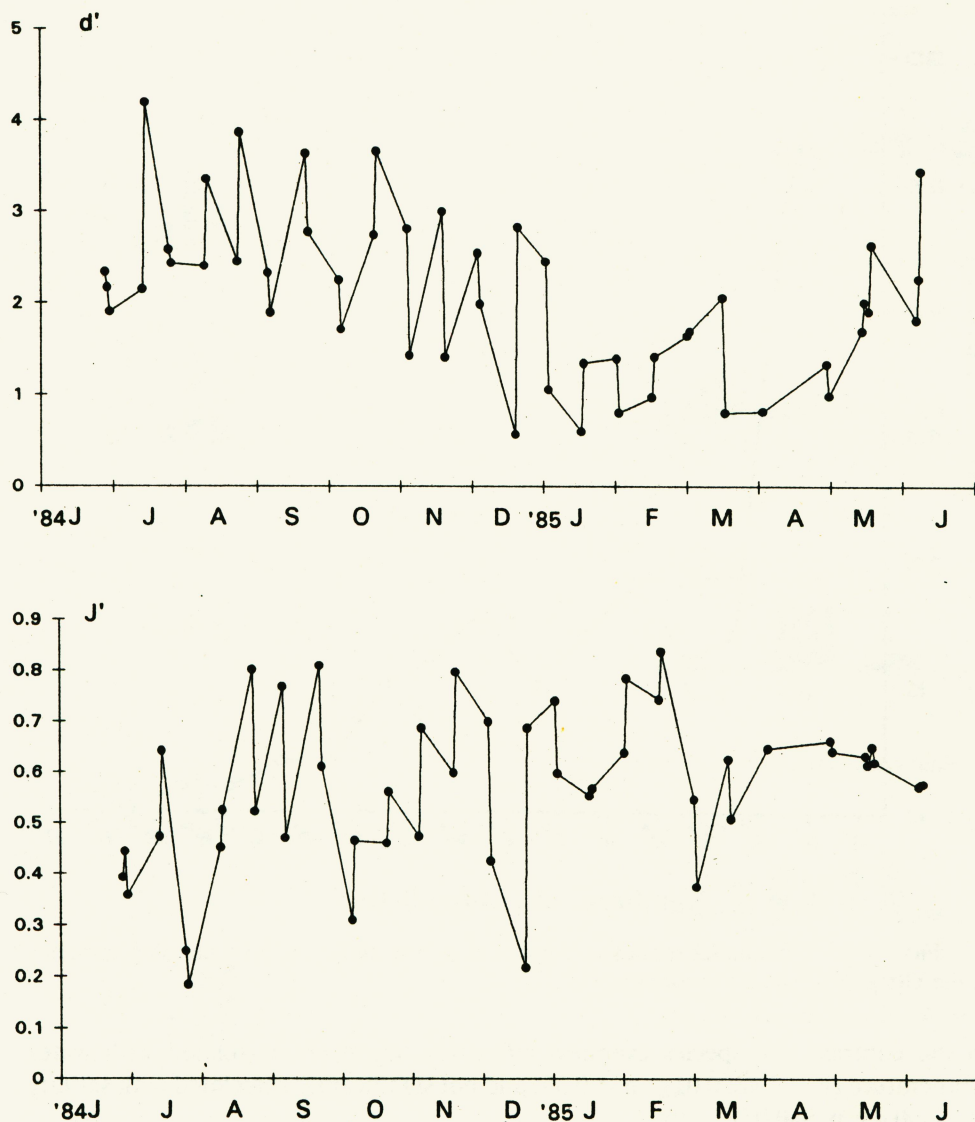


FIGURE 8.—Seasonal variation of species richness (d') and evenness (j') indexes for the larval and juvenile fish community in the Gong-Shy-Tyan River estuary, June 1984–June 1985.

to gear selectivity, because many juveniles prefer shallow estuarine waters (Blaber 1981; Russell and Garrett 1983; Cyrus 1984) and their adults occur mainly in clear offshore waters (Blaber et al. 1985). Accordingly, the estuary seemed to play an important role as nursery ground for fishes inhabiting adjacent freshwater, estuarine, and inshore marine habitats as adults (Gunter 1967; Zijlstra 1972; Jhingran and Gopalakrishnan 1973; Poxton et al. 1983; Bell et al. 1984; Wallace et al. 1984; Bennett 1989). Such areas can provide suitable food as well as shelter, absence of turbulence, and reduction of predation, which is essential for early development of many species (Blaber et al. 1985).

Based on the duration of recruitment into the estuary, fish in the estuary were classified into three categories of permanent resident, temporary resident, and rare

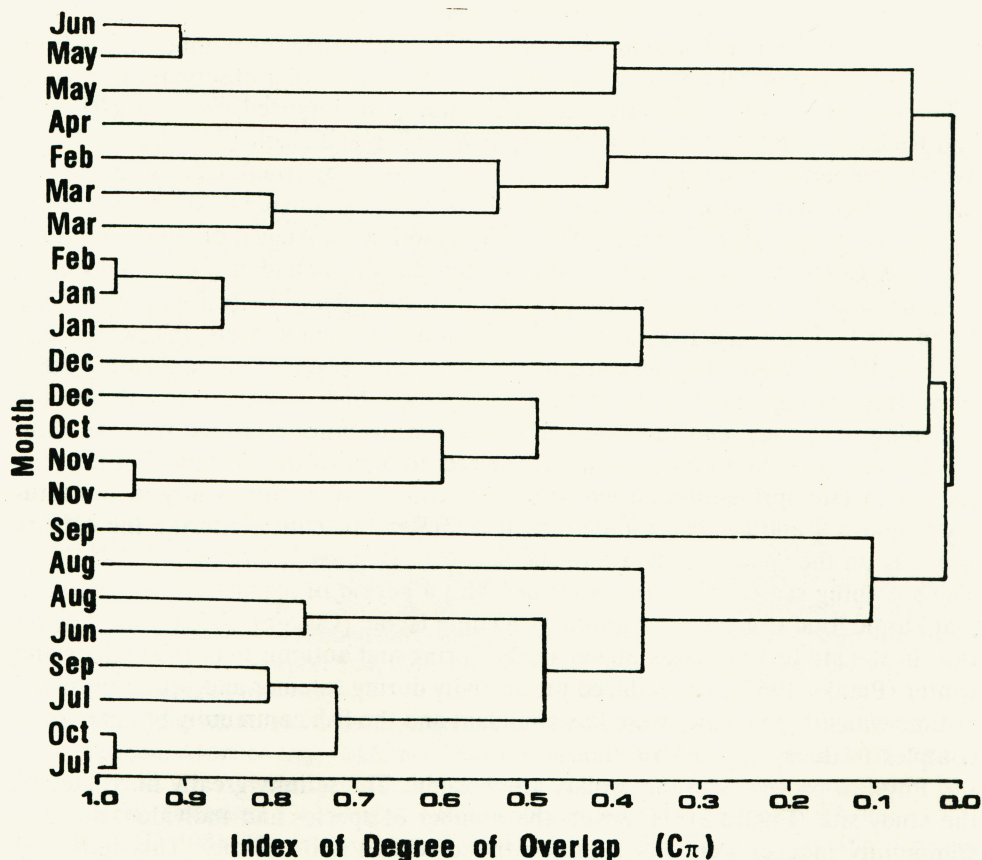


FIGURE 9.—Cluster dendrogram showing the month group of juvenile fish community in the Gong-Shy-Tyan River estuary. The similarity of species composition between samples was analyzed by Kimoto's (1976) index of degree of overlap and clustered by Mountford's (1962) average-linkage method. Species composition data were combined by semimonthly period.

species (Bell et al. 1984). The permanent residents were estuarine species that remained in the estuary throughout their entire life cycle, e.g., Kuhliidae, Eleotridae, Gobiidae and Gobioididae (Table 1). Although specimens collected do not represent the entire life cycles of these permanent residents (Figure 6), this is probably due to a size-related reduction in vulnerability to the present sampling method.

Temporary species constitute a great percentage of the total catch in this study. These species were similar in body length at recruitment and continuously migrated to the estuary for several months due to their long spawning season, e.g., *Terapon jarbua*, (Miu et al. 1990). On the other hand, a wide variation in size was observed among some temporary species as they entered the estuary, e.g., *Liza macrolepis* (Figure 6). This phenomenon indicated that the fish used the estuary not only as juveniles but also as young.

Rare species were occasionally found in the estuary and their number was usually less than 10 individuals for a given species in a one-year collection. However, they constituted a great proportion of the total number of species caught (Table 1, Figure 7). Most of these rare species belonged to the marine species and they occasionally drifted in with the tidal current.

A seasonal increase both in the number of species and in the number of juveniles from late spring to fall was observed (Figures 4 and 5). Similar observations in many other studies of temperate bay-estuarine fishes were reported previously (Pearcy and Richards 1962; Dahlberg and Odum 1970; Allen and Horn 1975; Adams 1976). Water temperature seemed to be one of the most important factors in triggering this observed seasonal fluctuation. The number of individuals dramatically decreased in August–September of 1984–1985 as well as in August of 1988–1989 during peak catch season (Figure 5). The sudden drop in abundance detected during summer months was also observed in other studies (Allen 1976; Livingston 1976; Horn 1980). Estuarine fish usually have a preferred temperature (Copeland and Bechtel 1974). Water temperature in this study site reached approximately 30°C from July through September (Figure 3). Perhaps high temperature inhibits the spawning of the fish and thus the fish larvae and juveniles recruited into the estuary decreased in the summer months. The recruitment of the juvenile fish into the estuary in late spring-autumn led to a more complex fish community in the estuary (Figures 4 and 8). The timing of fish larvae and juveniles entering the estuary depends on the spawning season of the fish, e.g., *Terapon jarbua* (Miu et al. 1990). The spawning season generally coincides with a period of maximum production of planktonic food organisms required by feeding larvae (Cushing 1975). The production in the studied area was higher in the spring and autumn than in summer and winter (Pianka 1967). The reduced productivity during summer and winter occurred at time when the juveniles were less abundant and the fish community became more complex in the spring and autumn.

Physical processes in the estuary are dynamic. The salinity greatly fluctuated in the study site (Figure 3). However, the number of species and individual and the community indexes were not significantly correlated with salinity. This indicated that the recruitment of juveniles was not influenced by salinity and that juveniles were able to withstand the extreme salinity regimes of the estuary. Austin (1971) suggested that higher salinity tolerances of juveniles than their adult accounted for the abundance of juveniles in the estuary. In the case of the estuarine-dependent marine species, *Terapon jarbua*—the most dominant one in the estuary—could survive in brackish water as well as in 100% fresh water (Liu 1978). The estuarine and estuarine-dependent marine fish have evolved to tolerate the variable of salinity, usually by secreting a thick mucous layer over the skin (e.g., gobiids, eleotrids, gobioidids, *Anguilla* spp.), developing large scales (e.g., *Terapon jarbua*, *Gerres* spp., *Liza macrolepis*), or other physiological modifications to adapt to osmotic change (Thia-Eng 1973). Probably these modifications permit the juvenile fish to survive in the estuary in large number.

The species composition of larval and juvenile fish community in the Gong-Shy-Tyan River estuary was extremely different from that in a 2-km area far from the neighboring Tanshui River estuary. The most dominant species in the Tanshui River estuary was *Sardinella melanura* (Clupeidae), making up 70.2% of the total catch, followed by *Stolephorus buccaneeri* (Engraulidae) (19.6%), *Thryssa kamalensis* (Engraulidae) (3.0%) and *Gerres abbreviatus* (Gerreidae) (2.6%) (Tzeng and Wang 1992); whereas *Terapon jarbua*, the most numerically dominant species in this study, was rare. The fish community in the Gong-Shy-Tyan River estuary was mainly constituted of demersal fishes, but pelagic fishes dominated in the Tanshui River estuary. Whether the differences are due to gear selectivity, eco-behavior of the fish, or geomorphology of the estuary is an interesting subject of future study.

Acknowledgments

This study was conducted under the financial support of National Science Foundation of the Republic of China (NSC 74-0201-8002-22). The author is grateful to Mr. G. S. Lu for setting the net, Mr. J. F. Ku, Miss S. Y. Yu, Miss I. L. Chai, Mr. Y. T. Wang, Mr. Y. F. Shen, Miss Y. C. Tsai and Miss H. Y. Deng of the Fisheries Biology Laboratory, Department of Zoology, National Taiwan University (NTU) in field collection and laboratory work, Dr. S. C. Lee of the Institute of Zoology, Academia Sinica for identifying the specimens of Gobiidae, and Dr. L. K. Lee of the Institute of Fisheries Science, NTU, Dr. N. B. Armantrout, Bureau of Land Management, US Department of the Interior, and two anonymous referees for helpful comments on the manuscript.

References

- Adams, S. M. 1976. The ecology of eelgrass, *Zostera marina* (L.), fish communities. I. Structural analysis. *Journal of Experimental Marine Biology and Ecology* 22:269–291.
- Allen, L. G. 1976. Abundance, diversity, seasonality and community structure of fish populations in Newport Bay, California. M.A. Thesis, California State University, Fullerton.
- Allen, L. G. 1982. Seasonal abundance, composition, and productivity of the littoral fish assemblage in upper Newport Bay, California. U.S. National Marine Fisheries Service, Fishery Bulletin 80(4):769–790.
- Allen, L. G., and M. H. Horn. 1975. Abundance, diversity and seasonality of fishes in Colorado Lagoon, Alamitos Bay, California. *Estuarine and Coastal Marine Science* 3:371–380.
- Austin, H. M. 1971. A survey of the ichthyofauna of the mangroves of western Puerto Rico during December 1967–August 1968. *Caribbean Journal of Science* 11:27–39.
- Beckley, L. E. 1984. The ichthyofauna of the Sundays estuary, South Africa, with particular reference to the juvenile marine component. *Estuaries* 7(3):248–258.
- Bell, J. D., D. A. Pollard, J. J. Burchmore, B. C. Pease, and M. J. Middleton. 1984. Structure of a fish community in a temperate tidal mangrove creek in Botany Bay, New South Wales. *Australian Journal of Marine and Freshwater Research* 35:33–46.
- Bennett, B. A. 1989. The fish community of a moderately exposed beach on the southwestern cape coast of South Africa and an assessment of this habitat as a nursery for juvenile fish. *Estuarine, Coastal and Shelf Science* 28:293–305.
- Blaber, S. J. M., and T. G. Blaber. 1980. Factors affecting distribution of juvenile estuarine and inshore fish. *Journal of Fish Biology* 17:143–162.
- Blaber, S. J. M., J. W. Young, and M. C. Dunning. 1985. Community structure and zoogeographic affinities of the coastal fishes of Dampier region of north-western Australia. *Australian Journal of Marine and Freshwater Research* 36:247–266.
- Chen, C. S. 1985. Occurrence of fish larvae in the Kau-Ping River estuary. *Journal of the Fisheries Society of Taiwan* 12(1):1–20.
- Chu, T. Y. 1963. The oceanography of the surrounding water of Taiwan. Report of the Institute of Fishery Biology of Ministry of Economic Affairs and National Taiwan University 1(4):29–44 (in Chinese with English summary).
- Copeland, B. J., and T. J. Bechtel. 1974. Some environmental limits of six Gulf coast estuarine organisms. *Contributions in Marine Science* 18:169–204.
- Cushing, D. H. 1975. *Marine ecology and fisheries*. Cambridge University Press, Cambridge, England.
- Dahlberg, M. D., and E. P. Odum. 1970. Annual cycles of species occurrence, abundance and diversity in Georgia estuarine fish populations. *American Midland Naturalist* 83:382–392.

- Day, J. H., S. J. M. Blaber, and J. H. Wallace. 1981. Estuarine fishes. Pages 197–221 in J. H. Day, editor. Estuarine ecology with particular reference to southern Africa. A. A. Balkema, Rotterdam.
- Deegan, L. A., and B. A. Thompson. 1985. The ecology of fish communities in the Mississippi River deltaic plain. Pages 35–56 in A. Yáñez-Arancibia, editor. Fish community ecology in estuaries and coastal lagoons: toward an ecosystem integration. Editorial University, UNAM-PUAL-ICML, Mexico, D. F.
- Gunter, G. 1967. Some relations of estuaries to the fisheries of the Gulf of Mexico. Pages 621–638 in G. H. Lauff, editor. Estuaries. American Association for the Advancement of Science, Washington D.C.
- Haedrich, R. L., and S. O. Haedrich. 1974. A seasonal survey of the fishes in the Mystic River, a polluted estuary in downtown Boston, Massachusetts. Estuarine and Coastal Marine Science 2:59–73.
- Haedrich, R. L., and C. A. S. Hall. 1976. Fishes and estuaries. Oceanus 19(5):55–63.
- Horn, M. H. 1980. Diel and seasonal variation in the abundance and diversity of shallow-water fish populations in Morro Bay, California. U.S. National Marine Fisheries Service, Fishery Bulletin 75:759–770.
- Huang, C. C., W. N. Tzeng, and S. C. Lee. 1985. Preliminary survey of larval fishes of Yen-Liao Bay, northeastern Taiwan. Bulletin of the Institute of Zoology, Academia Sinica 24(1):147–154.
- Jenkins, G. P. 1986. Composition, seasonality and distribution of ichthyoplankton in Port Philip Bay, Victoria. Australian Journal of Marine and Freshwater Research 37:507–520.
- Jhingran, V. G., and V. Gopalakrishnan. 1973. Estuarine fishes resources in India in relation to adjacent ecosystems. Journal of the Marine Biological Association of India 15:323–334.
- Kimoto, S. 1976. Some quantitative analysis on the Chrysomelid fauna of the Ryukyu Archipelago. Esakia 6:27–54.
- Lenanton, T. C. J. 1982. Alternative non-estuarine nursery habitats for some commercially and recreationally important fish species of south-western Australia. Australian Journal of Marine and Freshwater Research 33:881–900.
- Liu, C. H. 1978. Ecological investigation and experiment on *Terapon jarbua* (Forsskal) around Taiwan waters. Bulletin of Taiwan Fisheries Research Institute 30:321–326 (in Chinese with English summary).
- Livingston, R. J. 1976. Diurnal and seasonal fluctuations of organisms in a north Florida estuary. Estuarine and Coastal Marine Science 4:373–400.
- Margalef, R. 1969. Perspectives in ecological theory. University of Chicago Press, Chicago.
- Miu, T. C., S. C. Lee, and W. N. Tzeng. 1990. Reproductive biology of *Terapon jarbua* from the estuary of Tamshui River. Journal of the Fisheries Society of Taiwan 17(1):9–20.
- Modde, T. 1980. Growth and residency of juvenile fishes within a surf zone habitat in the Gulf of Mexico. Gulf Research Report 6:377–385.
- Mountford, M. D. 1962. An index of similarity and its application to classificatory problem. Pages 43–50 in P. W. Murphy, editor. Progress in soil zoology. Butterworths. London.
- Pearcy, W. G., and S. W. Richards. 1962. Distribution and ecology of fishes of the Mystic River estuary, Connecticut. Ecology 43:248–259.
- Pianka, E. R. 1967. Covexity, desert lizard, and spatial heterogeneity. Ecology 47:1055–1059.
- Pielou, E. C. 1966. The measurement of diversity in different types of biological collections. Journal of Theoretical Biology 13:131–144.
- Poxton, M. G., A. Eleftheriou, and A. D. McIntyre. 1983. Food and growth of 0-group flat-fish on nursery grounds in the Clyde Sea area. Estuarine, Coastal and Shelf Science 17:319–337.
- Quinn, N. J. 1980. Analysis of temporal changes in fish assemblages in Serpentine Creek, Queensland. Environmental Biology of Fishes 5(2):117–133.
- Reina-Hervas, J. A., and P. Serrano. 1987. Structure and seasonal variations of inshore fish populations in Malaga bay, southeastern Spain. Marine Biology 95:501–508.

- Shenker, J. M., and J. M. Dean. 1979. The utilization of an intertidal salt marsh creek by larval and juvenile fishes: abundance, diversity and temporal variations. *Estuaries* 2(3):154-163.
- Thia-Eng, C. 1973. An ecological study of the Ponggol estuary in Singapore. *Hydrobiologia* 43:505-533.
- Tzeng, W. N., and Y. T. Wang. 1986. Seasonal occurrence, abundance and diversity of larval fishes in the Shuang-Hsi River estuary, northeastern Taiwan. *Proceedings of the Symposium on Marine Biological Research Center, National Science Council Monograph Series* 14:135-154.
- Tzeng, W. N., and Y. T. Wang. 1992. Structure, composition and seasonal dynamics of fish larvae and juvenile community in the mangrove estuary of Tanshui River, Taiwan. *Marine Biology* 113:481-490.
- Wallace, J. H., and R. P. van der Elst. 1975. The estuarine fishes of the east coast of South Africa. Part IV. Occurrence of juveniles in estuaries. Part V. Ecology, estuarine dependence and status. *Oceanographic Research Institute (Durban) Investigation Report* No. 42.
- Wallace, J. H., H. M. Kok, L. E. Beckley, B. A. Bennett, S. J. M. Blaber, and A. K. Whitfield. 1984. South African estuaries and their importance to fishes. *South African Journal of Science* 80:203-207.
- Wang, Y. T., W. N. Tzeng, and S. C. Lee. 1991. A preliminary study on species composition and seasonal abundance of fish eggs and larvae from the coastal waters adjacent to the Tamshui River estuary, Taiwan (1984-1985). *Journal of the Fisheries Society of Taiwan* 18:7-20.
- Yamashita, Y., and T. Aoyama. 1984. Ichthyoplankton in Otsuchi Bay on northeastern Honshu with reference to the time-space segregation of their habitats. *Bulletin of the Japanese Society of Scientific Fisheries* 50(2):189-198.
- Zijlstra, J. J. 1972. On the importance of the Wadden Sea as a nursery area in relation to the conservation of the southern North Sea fishery resources. *Symposia of the Zoological Society of London*, No. 29:233-258.