Marine Biology 113, 481–490 (1992)

Marine Biology
International Journal on Life in Oceans and Coastal Waters

Structure, composition and seasonal dynamics of the larval and juvenile fish community in the mangrove estuary of Tanshui River, Taiwan

Wann-Nian Tzeng and Yu-Tzu Wang

Department of Zoology, College of Science, National Taiwan University, Taipei, Taiwan 10617, Republic of China

Date of final manuscript acceptance: February 24, 1992. Communicated by T. Ikeda, Niigata

Abstract. The temporal and spatial patterns of species composition and abundance of fish larvae and juveniles in the Tanshui River mangrove estuary (Taiwan) were studied monthly using a drift bag-net in daylight. A total of 44591 individuals representing 55 families and 105 species were collected over 12 mo (August 1989 to July 1990). The community was dominated numerically by a few species. *Sardinella melanura* was most numerous, making up 70.15% of the total catch, followed by *Stolephorus buccaneeri* (19.59%), *Thryssa kammalensis* (2.96%), and *Gerres abbreviatus* (2.61%). These four species constituted ca. 95% of the total catch, the remaining 5% consisted of another 101 species. This estuary functions as a nursery and feeding area in the early life history of these fish. There was a separation in peak-immigration and seasonal utilization of the estuary by the dominant species. The abundance of fish larvae and juveniles decreased in an upstream direction.

Introduction

Mangroves in the estuaries are able to absorb inorganic compounds from freshwater runoff for photosynthesis and thus play an important role as primary producers. The organic nitrogen compounds of the falling leaves of mangroves are either incorporated into the sediment and converted into peat for detritus-feeding shell fish, or broken up to become food for bacteria, fungi, and finfish. Accordingly, estuaries play a role in energy transfer between a river and the sea, which is especially important for many commercial coastal fishes whose fish larvae and juveniles are dependent on the estuary as a nursery and feeding ground.

For the management of estuarine mangroves, baseline information (including species composition, diversity and biomass of the estuarine fish community) has been documented in many mangrove estuaries found in tropical areas (Austin 1971, Odum and Heald 1972, McErlean et al. 1973, Haedrich and Haedrich 1974, Yáñez-Arancibia et al. 1980, Beckley 1984, Bell et al. 1984, Blaber et al. 1985, Robertson and Duke 1987 and 1990, Blaber and Milton 1990). These studies indicated that most fish populations in the mangrove estuary are relatively short-lived and euryhaline and represent one phase of an inshore-offshore migration life history pattern. Meanwhile, the spatial and temporal variations of the fish community in the estuarine area are influenced both by the physico-chemical environment and the biological function (Haines 1979).

The Tanshui River, the largest river in northern Taiwan, is ca. 159 km long, and flows through the Taipei basin. At the mouth of the river, there is a rare and endangered mangrove species, *Kandelia candel* (Rhizophoraceae) (Chou et al. 1987). Due to rapid economic and population growth, the river receives sewage from Taipei city and industrial wastewater from nearby factories. As a result, it has been severely polluted for a long time, to the extent that the dissolved oxygen level declines to zero in mid-estuary. Furthermore, clear-cutting for land-development such as housing and tourism projects has severely reduced the mangrove forests. For restoration of the river, baseline information concerning the flora and fauna, as well as the rare mangrove trees and the associated physico-chemical factors in the estuary, is essential. However, previous investigations in this area are very limited and incomplete (Lee and Chu 1965, Liaw 1965, Tan 1971). Thus, a team of scientists from many disciplines was formed in 1987 by the National Science Council, Republic of China, to study the ecosystem of the mangrove estuary in the Tanshui River (Chou and Bi 1990).

The purpose of the present paper is to document the fauna of fish larvae and juveniles and to combine our work with the work of other researchers in order to understand the role of this fauna in the mangrove estuarine ecosystem of the Tanshui River.

Materials and methods

Study site

The Tanshui River flows through the Kuan-Do plain and merges with the sea in the area between Tanshui and Bali on the northwestern coast of Taiwan. The estuary is well-influenced by tidal current, with a tidal range from 1.5 m in neap tide to >3.0 m in spring tide (Lee and Chu 1965). The climatic data indicate that precipitation obviously varies with the season (Chou et al. 1987); river flooding is thus higher in spring and summer than in autumn and winter. The estuary is basically a well-mixed type. In the lower estuary, near the Ju-Wei area, there is a mangrove forest, covering ca. 60 hectares. This species of the mangrove tree is *Kandelia candel*, a rare and endangered species in tropical areas (Chou et al. 1987). At the mouth of the river and in its adjacent waters, there is a traditional fishing ground in which, between spring and autumn, fishermen catch the larvae and juveniles of engraulids and clupeids for local consumers, while in winter anguillid elvers are caught to be used as fry for cultivation purposes.

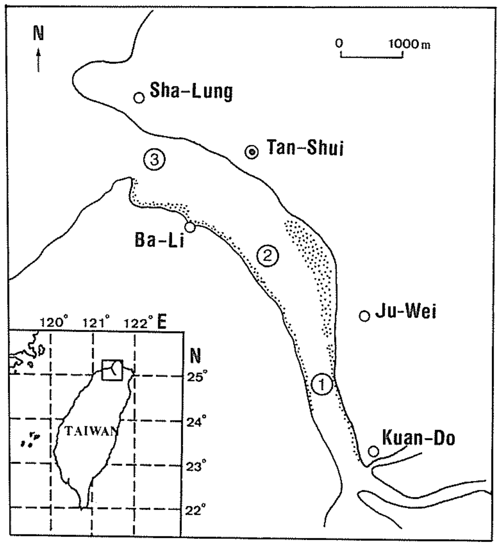

Fig. 1. Location of the sampling stations (1 to 3) in the Tanshui River estuary. Dotted areas indicate the distribution of mangrove forests

Sampling design

Fish larvae and juveniles were sampled monthly at three stations in the lower Tanshui River estuary during the period from November 1987 through July 1990 (Fig. 1). A modified drift bag-net, approximately one-sixth the size of a commercial type, was used to collect the fish larvae and juveniles. The net is 3 m high, 5 m wide and 17 m long, with mesh size ranging from 11 cm at the frontal part of the net to 0.1 cm at cod end (Fig. 2). The net was set against the current for ca. 10 min at each station during daylight flood tide. The fish larvae and juveniles were caught as they drifted with the tidal current in the river. A flowmeter mounted in the net mouth recorded the water filtered. The fish collected were fixed immediately in a 10% formalin-seawater solution. The species was identified, the developmental stage was determined (Kendall et al. 1984), and total length to 0.1 mm was also measured in the laboratory.

Environmental factors were also monitored during sampling. Temperature was measured with a mercury thermometer, salinity with a salinometer, dissolved oxygen (DO) with Winkler's method, pH with a pH meter, transparency with a Secchi disc, the depth of capture with an echo sounder and current velocity with a current meter.

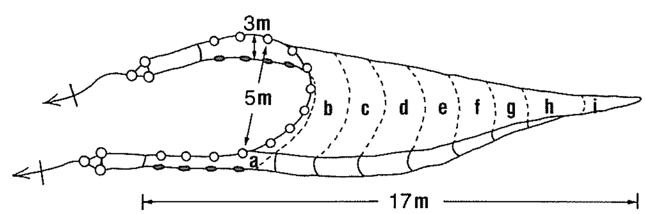

Fig. 2. Drift bag-net used to collect fish larvae and juveniles in the Tanshui River estuary. The dimensions of the net are: 5 m wide, 3 m high and 17 m long; mesh size: a=11 cm, b=7 cm, c=3 cm, d=2 cm, e=1 cm, f=0.8 cm, g=0.3 cm, h=0.2 cm, i=0.1 cm

Data analysis

The relationship of species composition between the three stations was compared using Spearman's rank-correlation test on the basis of the yearly catch in terms of number of each individual species. The differences in abundance of fish larvae and juveniles between stations was compared using Wilcoxon signed rank test (Siegel 1956). Community structure was evaluated using Shannon-Weaver's index of species diversity (Pielou 1966), Margalef's index of species richness (Margalef 1969), Pielou's index of evenness (Pielou 1966) and Simpson's index of concentration (Peet 1974). The relationship between biotic and abiotic factors was analyzed by means of a correlation matrix.

Results

Physical characteristics

Seasonal variations of six abiotic factors monitored at three stations in the Tanshui River estuary from August 1989 through July 1990 are shown in Fig. 3, and the comparison of these six abiotic factors is shown in Table 1.

Surface water temperature was the highest (29.9 °C) in September and the lowest (15.8 °C) in March, with no significant difference in temperature between the three stations. Salinity ranged from 4.2 to 33.1‰ with a mean (±SD) from 12.0±6.65‰ at Stn 1 to 28.6±5.29‰ at Stn 3. The variability of salinity depended on the state of the tide during the sampling period and the distance of the station from the river mouth. The difference in salinity between stations was relatively large, compared with the seasonal change. The station and seasonal changes in DO, pH and transparency almost paralleled with that of salinity. The correlation coefficients (r) of salinity to DO, pH and transparency were 0.53, 0.73 and 0.54, respectively ($p<0.0001$). Current velocity varied from 0.8 to 2.5 knots during the sampling period, depending on the state of the tide.

Species composition and developmental stage

A total of 44591 individuals representing 55 families and 105 species was collected from August 1989 to July 1990.

Developmental stages ranged from flexion larva stage to young stage. The stages of postflexion larva and juvenile were the most dominant (Table 2). This indicates that the mangrove estuary acts as a nursery and feeding ground in the early life history of fish.

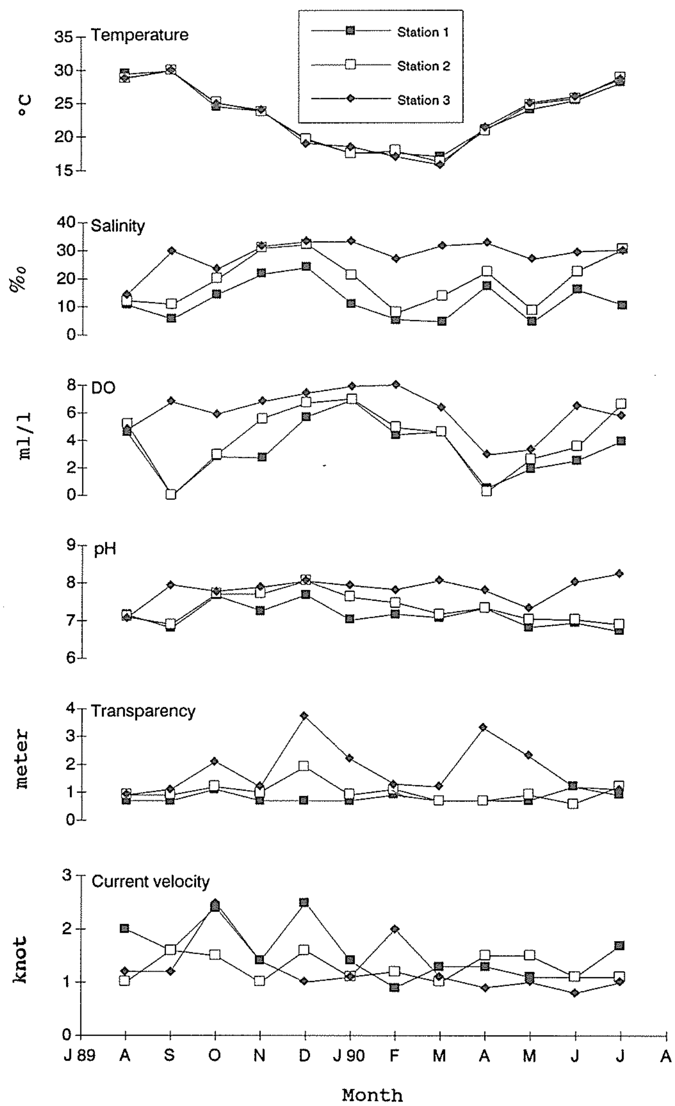

Fig. 3. Monthly variations of water temperature, salinity, dissolved oxygen, pH, transparency and current velocity at three stations in the Tanshui River estuary, August 1989 to July 1990

Species composition of fish larvae and juveniles indicates that the larval and juvenile fish assemblage in the mangrove estuary is constituted of a few species in large numbers. *Sardinella melanura* was the most dominant species, constituting 70.15% of the total catch, followed by *Stolephorus buccaneeri* (19.59%), *Thryssa kammalensis* (2.96%), and *Gerres abbreviatus* (2.61%). These four species constituted approximately 95% of the total catch, the other 5% being shared by ca. 101 species (Tables 2 and 3). The species composition of fish larvae and juveniles varied with season and location in the estuary. The number of species was lower in winter and summer than in spring and autumn (Table 2). Both numbers of species and individuals significantly decreased from the river mouth station (Stn 3) to the upstream station (Stn 1) (Table 3). Spearman's rank correlation coefficients of the species composition between the three stations was significant ($p < 0.01$), indicating that the rank of species composition was highly correlated among stations. Wilcoxon ranked sign test indicated that the difference in abundance of fish larvae and juveniles was not significant between Stns 2 and 3 ($p > 0.05$). But the abundance of the fish at Stn 1 was significantly less than at Stns 2 and 3 ($p < 0.0001$). The freshwater-preferred species clearly increased at Stn 1, e.g. *Thryssa kammalensis*, *Ambassis gymnocephalus*, *Elops hawaiensis*, *Pomadasys argenteus*, *Megalops cyprinoides* and *Arius* spp., all of which could migrate further upstream than other species (Table 3).

Seasonal abundance and species succession

From monthly variations of the abundance of fish larvae and juveniles in the estuary during the period from November 1987 to July 1990, two peak catches were found for each year, one in March when water temperature began to increase, the other in June or July before the water temperature reached its highest value. The first peak was dominated by *Stolephorus buccaneeri* (Engraulidae), the second one by *Sardinella melanura* (Clupeidae) (Fig. 4). The dominant species obviously alternated seasonally. On the other hand, the peak catch of dominant species in the estuary only lasted ca. 1 mo.

Temporal and spatial variations of community structure

The monthly variations in numbers of species and abundance of fish larvae and juveniles collected from the three

Table 1. Comparison of annual mean temperature, salinity, dissolved oxygen (DO), pH, transparency and current velocity between three stations in the Tanshui River estuary, August 1989 to July 1990

Factor	Stn 1				Stn 2				Stn 3			
	n	Range	$\bar{x}$	SD	n	Range	$\bar{x}$	SD	n	Range	$\bar{x}$	SD
Temperature (°C)	12	17.0 –29.9	23.1	4.62	12	16.2 –29.9	23.2	4.77	12	15.8 –29.9	23.2	4.81
Salinity (‰)	12	4.2 –23.8	12.0	6.65	12	7.8 –32.0	19.4	8.67	12	14.5 –33.1	28.6	5.29
D.O. (ml l^{-1})	12	0.0 – 6.9	3.4	2.03	12	0.0 – 7.0	4.2	2.37	12	2.9 – 8.0	6.0	1.64
pH	12	6.71– 7.68	7.14	0.31	12	6.89– 8.05	7.33	0.37	12	7.08– 8.24	7.82	0.33
Transparency (m)	12	0.7 – 1.2	0.8	0.18	12	0.7 – 1.9	1.0	0.34	12	0.9 – 3.7	1.8	0.93
Current velocity (knot)	12	0.9 – 2.5	1.6	0.51	12	1.0 – 1.6	1.3	0.25	12	0.8 – 2.5	1.3	0.50

Table 2. Monthly changes in species composition of fish larvae and juveniles collected using drift bag-net in the Tanshui River estuary, August 1989 to July 1990. Le: leptocephalus larva, Pr: preflexion larva, Fl: flexion larva, Po: postflexion larva, Ju: Juvenile and Yg: Young. Asterisks indicate the dominant stages; –: not caught

Serial no.	Family and species	Development stage	No. of fish												Total	%
			1989 Aug	Sep	Oct	Nov	Dec	1990 Jan	Feb	Mar	Apr	May	Jun	Jul		
	Elopidae															
1	*Elops hawaiensis*	Le	–	1	–	4	3	16	13	4	1	2	14	8	66	0.15
	Megalopidae															
2	*Megalops cyprinoides*	Le	–	7	–	1	1	–	–	–	–	–	–	8	17	0.04
	Albulidae															
3	*Albula vulpes*	Le	–	–	–	–	–	–	–	–	2	–	–	–	2	<0.01
4	Muraenidae sp.	Le	–	–	–	–	–	–	–	–	–	–	1	–	1	<0.01
5	Ophichthyidae sp.	Le	–	–	–	1	–	–	–	–	–	–	–	–	1	<0.01
	Dussumieridae															
6	*Etrumeus terres*	Po*, Ju	–	–	–	–	–	–	–	34	130	–	–	–	164	0.37
7	*Dussumieria* sp.	Ju	–	–	–	–	–	–	–	–	–	1	–	–	1	<0.01
8	*Spratelloides gracilis*	Po	–	–	–	–	–	–	–	–	–	–	–	84	84	0.19
	Clupeidae															
9	*Sardinella melanura*	Po, Ju*, Yg	102	17	38	5	3	6	–	–	–	–	66	31 044	31 281	70.15
	Engraulidae															
10	*Engraulis japonicus*	Yg	–	–	–	–	–	–	–	–	–	–	–	6	6	0.01
11	*Stolephorus buccaneeri*	Fl, Po*, Ju, Yg	3	20	21	286	737	685	4	4 613	1470	48	720	127	8 734	19.59
12	*Stolephorus insularis*	Po*, Ju	–	–	24	24	9	–	–	–	–	–	–	48	105	0.23
13	*Thryssa kammalensis*	Po, Ju*, Yg	–	–	162	–	–	–	–	–	1	7	–	1 150	1 320	2.96
	Chirocentridae															
14	*Chirocentrus dorab*	Ju	–	–	–	–	–	–	–	–	–	–	–	1	1	<0.01
	Ariidae															
15	*Arius* spp. (2 species)	Yg	–	–	–	5	–	–	4	2	–	–	–	–	11	0.02
	Gonostomatidae															
16	*Vinciguerria nimbaria*	Po	–	–	9	–	–	–	–	–	–	1	–	–	10	0.02
	Synodontidae															
17	*Trachinocephalus myops*	Ju	–	1	1	–	–	–	–	–	–	–	1	48	51	0.11
18	*Saurida elongata*	Ju	–	–	–	–	–	–	–	–	3	–	1	1	5	0.01
19	*Saurida wanieso*	Ju	–	–	–	–	–	–	–	–	–	–	2	–	2	<0.01
20	*Synodus macrops*	Po	–	–	1	–	1	–	–	–	–	–	–	–	2	<0.01
	Paralepidae															
21	*Lestidium atlanticum*	Po	–	–	–	–	1	–	–	–	–	–	–	–	1	<0.01
22	*Lestrolepis* sp.	Po	–	–	–	–	–	–	–	–	1	–	–	–	1	<0.01
	Myctophidae															
23	*Benthosema pterotum*	Po	–	–	3	13	56	–	–	–	2	–	–	–	74	0.17
	Moridae															
24	*Physiculus tosaensis*	Ju	–	–	–	–	–	1	–	–	–	–	–	–	1	<0.01
25	Carapidae sp.	Ju	–	–	–	1	–	–	–	–	–	–	–	–	1	<0.01
26	Antennaridae sp.	Ju	–	–	–	–	–	–	–	1	–	–	–	–	1	<0.01
27	Hemiramphidae sp.	Po	–	1	–	–	–	–	–	–	–	–	–	–	1	<0.01
	Scorpaenidae															
28	*Sebastiscus marmoratus*	Po*, Ju, Yg	–	–	–	–	–	39	–	4	4	–	–	–	47	0.11
29	sp.	Fl, Po*	–	–	–	8	–	1	–	–	–	–	–	–	9	0.02
	Platycephalidae															
30	*Platycephalus indicus*	Fl*, Po, Ju	–	–	2	–	–	–	–	–	5	1	–	1	9	0.02
	Centropomidae															
31	*Ambassis gymnocephalus*	Po*, Ju	–	10	–	–	–	–	–	–	–	1	4	84	99	0.22
	Percichthyidae															
32	*Lateolabrax japonicus*	Po	–	–	–	–	–	1	2	37	–	–	–	–	40	0.09
33	Serranidae sp.	Fl	–	–	–	–	–	–	–	–	–	1	–	–	1	<0.01
	Theraponidae															
34	*Therapon jarbua*	Ju, Yg*	–	1	–	1	–	–	–	–	–	–	1	–	3	<0.01
	Apogonidae															
35	*Apogon bifasciatus*	Po	–	–	–	–	1	–	–	–	–	–	–	–	1	<0.01
36	*Apogon kiensis*	Ju	–	–	–	–	–	–	–	–	–	–	–	16	16	0.04
37	*Apogon notatus*	Po	–	–	–	–	–	–	–	–	–	2	–	–	2	<0.01
38	*Apogon* spp. (2 species)	Fl, Po*, Ju	–	1	1	1	–	–	–	–	4	–	4	2	13	0.03
	Sillaginidae															
39	*Sillago sihama*	Po*, Ju	1	18	9	5	–	1	–	–	1	1	9	76	121	0.27
40	*Sillago japonica*	Po*, Ju	–	1	5	5	9	–	–	–	5	3	1	41	70	0.16
41	*Sillago maculata*	Po*, Ju	–	4	–	–	–	–	–	–	–	5	7	29	45	0.10
42	*Sillago* sp.	Po	–	–	–	–	–	–	–	–	–	–	1	3	4	0.01
	Lactariidae															

Table 2 (continued)

Serial no.	Family and species	Development stage	No. of fish												Total	%
			1989 Aug	Sep	Oct	Nov	Dec	1990 Jan	Feb	Mar	Apr	May	Jun	Jul		
43	*Lactarius lactarius*	Yg	–	–	–	–	–	1	–	–	–	–	–	–	1	<0.01
	Carangidae															
44	*Decapterus maruadsi*	Fl, Po, Ju, Yg*	–	–	–	–	–	–	–	–	7	–	72	–	79	0.18
45	*Caranx sexfasciatus*	Yg	–	2	–	–	–	–	–	–	–	–	1	–	3	0.01
46	*Scomberoides tol*	Yg	4	–	–	1	–	–	–	–	–	–	–	11	16	0.04
47	*Elagatis bipinnulata*	Po	–	–	–	–	–	–	–	1	–	–	–	–	1	<0.01
48	sp.	Fl, Ju*	–	–	–	–	–	–	–	–	1	–	–	2	3	<0.01
	Menidae															
49	*Mene maculata*	Po	–	–	1	–	–	–	–	–	–	–	–	–	1	<0.01
	Leiognathidae															
50	*Leiognathus nuchalis*	Ju, Yg	–	–	–	–	–	–	–	1	–	–	–	1	2	<0.01
51	*Secutor* sp.	Po	–	–	21	–	1	–	–	–	–	–	–	–	22	0.05
52	spp. (2 species)	Fl, Po*, Ju, Yg	–	7	4	4	–	1	–	1	17	19	63	21	137	0.30
	Lutjanidae															
53	*Lutjanus* sp.	Ju	–	–	–	–	–	–	–	–	–	–	–	8	8	0.02
	Gerreidae															
54	*Gerres abbreviatus*	Po, Ju*	–	4	1	–	–	–	–	–	–	98	1 053	10	1 166	2.61
55	*Gerres oyena*	Po	–	–	–	–	–	–	–	–	–	–	6	8	14	0.03
56	*Gerres macrosoma*	Ju	–	–	–	–	–	–	–	–	–	–	1	12	13	0.03
	Haemulidae															
57	*Pomadasys argenteus*	Yg	–	–	28	–	–	–	–	–	–	–	–	–	28	0.06
	Sparidae															
58	*Sparus major*	Po	–	–	–	–	–	–	–	4	6	–	–	–	10	0.02
59	sp.	Po, Ju, Yg	–	–	–	–	–	–	–	–	32	7	–	–	39	0.08
60	Sciaenidae spp. (3 species)	Fl, Po, Ju*	–	–	1	–	–	1	–	–	10	–	1	35	48	0.11
	Ephippidae															
61	*Ephippus orbis*	Po	–	–	–	–	–	–	–	–	–	–	–	1	1	<0.01
	Scatophagidae															
62	*Scatophagus argus*	Po	–	–	–	–	–	–	–	–	–	–	–	4	4	0.01
63	Pomacentridae sp.	Yg	–	–	–	–	–	–	–	–	1	–	–	–	1	<0.01
	Cepolidae															
64	*Acanthocepola limbata*	Po	–	–	–	–	–	–	–	–	–	–	2	–	2	<0.01
	Mugilidae															
65	*Mugil cephalus*	Yg	–	–	–	–	–	–	–	4	–	–	–	–	4	0.01
66	*Liza macrolepis*	Ju, Yg*	–	–	–	1	1	–	1	2	7	–	82	67	161	0.36
	Sphyraenidae															
67	*Sphyraena genie*	Yg	–	–	–	–	–	–	–	–	–	–	–	1	1	<0.01
68	*Sphyraena* sp.	Ju	–	–	–	–	–	–	–	–	–	–	–	49	49	0.11
69	Scaridae sp.	Po	–	–	1	5	–	–	–	–	–	–	–	–	6	0.01
	Mugiloididae															
70	*Parapercis* sp.	Fl, Po	–	–	–	1	–	–	–	–	3	–	–	–	4	<0.01
71	Percophididae sp.	Po	–	–	–	–	–	–	–	–	–	1	–	–	1	<0.01
	Blenniidae															
72	*Scartella cristata*	Po	–	–	–	–	2	–	–	–	–	–	–	–	2	<0.01
73	spp. (3 species)	Po, Ju	–	1	–	1	1	–	–	–	–	1	3	131	138	0.31
	Gobiidae															
74	*Apocryptodon madurensis*	Ju	–	–	–	–	–	–	–	–	–	–	–	3	3	0.01
75	spp. (9 species)	Po, Ju	–	1	6	24	20	1	–	4	2	1	2	8	69	0.15
	Siganidae															
76	*Siganus* sp.	Ju	–	–	–	–	–	–	–	–	–	–	–	1	1	<0.01
	Scombridae															
77	*Scomber japonicus*	Yg	–	–	–	–	–	–	–	2	–	–	–	–	2	<0.01
78	*Scomber australasicus*	Po, Ju	–	–	–	–	–	–	–	–	7	–	–	–	7	0.01
79	*Euthynnus affinis*	Ju	–	–	–	–	–	–	–	–	–	–	–	1	1	<0.01
	Trichiuridae															
80	*Trichiurus lepturus*	Ju	–	–	2	–	–	–	–	–	–	–	–	–	2	<0.01
81	Callionymidae sp.	Fl, Po, Ju	–	–	1	–	1	2	–	–	11	–	1	–	16	0.04
82	Bothidae sp.	Fl, Po	–	–	–	–	–	–	–	–	2	–	–	–	2	<0.01
83	Pleuronectidae sp.	Po	–	–	–	–	–	–	–	–	1	–	–	–	1	<0.01
84	Cynoglossidae sp.	Po	–	–	–	–	–	–	–	–	2	–	–	–	2	<0.01
85	Monacanthidae sp.	Po, Ju, Yg	–	–	–	–	–	–	–	–	–	–	2	8	10	0.01
	Tetraodontidae															

Table 2 (continued)

Serial no.	Family and species	Development stage	No. of fish 1989 Aug	Sep	Oct	Nov	Dec	1990 Jan	Feb	Mar	Apr	May	Jun	Jul	Total	%
86	*Lagocephalus lunaris*	Yg	–	–	–	–	–	–	–	–	–	–	–	29	29	0.07
87	*Fugu niphobles*	Ju	–	–	–	–	–	–	–	–	–	7	–	–	7	0.02
88	spp. (2 species)	Pr, Fl, Po, Yg	–	–	–	–	–	–	–	1	14	–	19	–	34	0.07
89	Unidentified sp.	Po, Ju	–	–	1	–	1	–	–	–	–	12	2	–	16	0.04
	Total no. of species		4	20	24	21	17	12	5	17	31	20	32	43		
	Total no. of individuals		110	97	343	397	848	756	24	4715	1752	219	2142	33188	44591	100

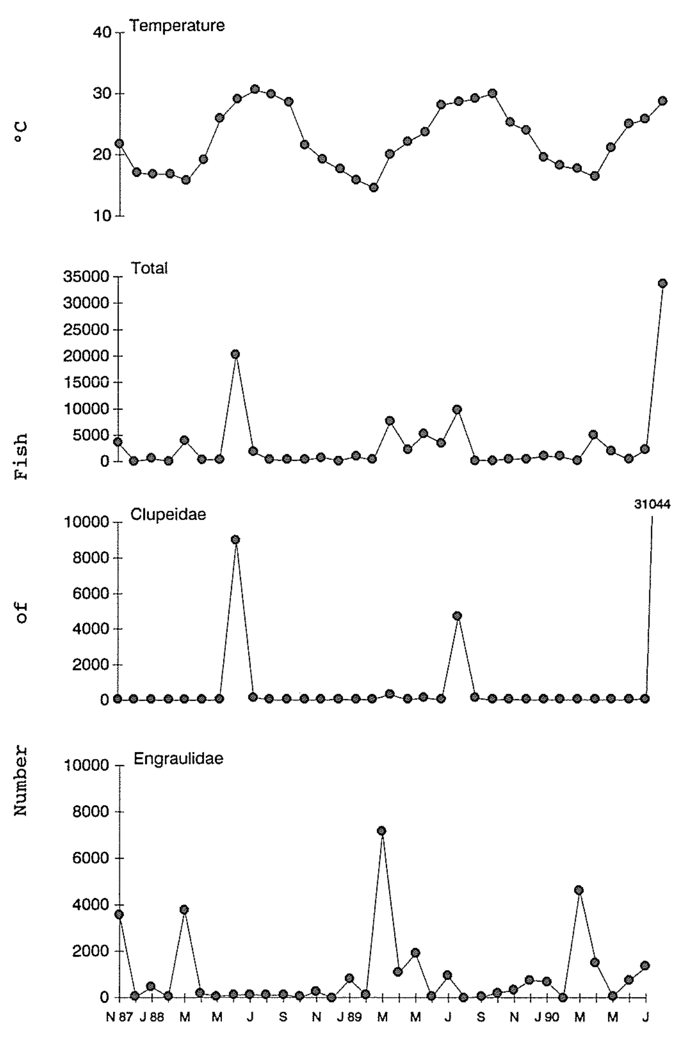

Fig. 4. 3-year continuous time-series of surface water temperature and the no. of total species and two dominant species groups of fish larvae and juveniles collected from three stations in the estuary of Tanshui River

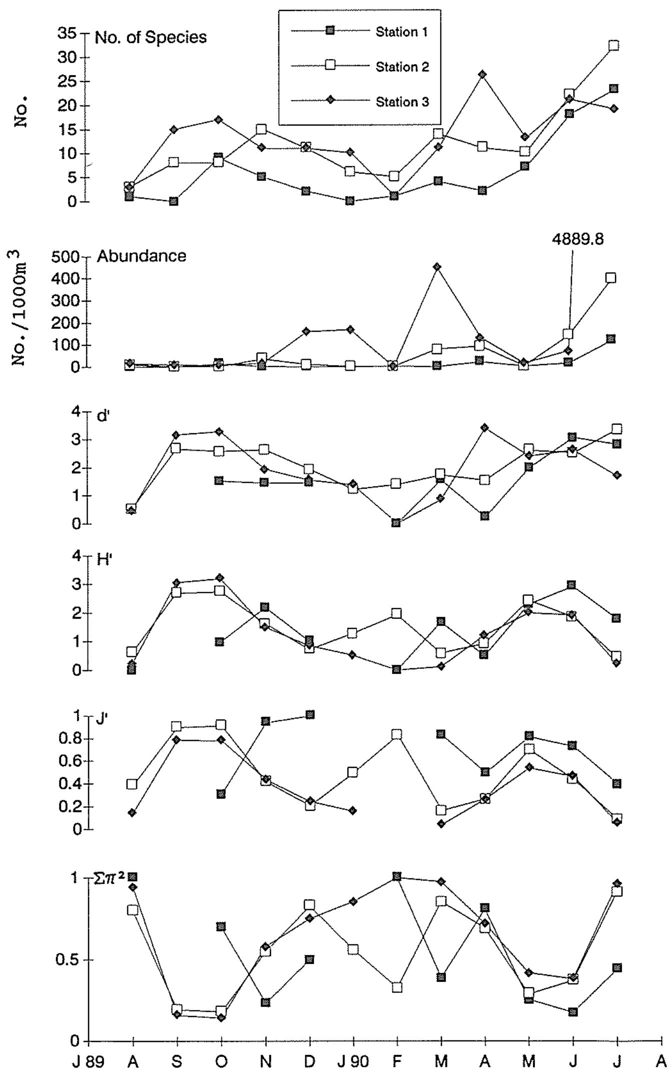

Fig. 5. Monthly variations in no. of species, abundance and diversity indices of fish larvae and juveniles collected from three stations in the Tanshui River estuary, August 1989 to July 1990. d′: species richness, H′: Shannon-Weaver diversity index, J′: Evenness, $\Sigma\pi^2$: Simpson's index of concentration

Table 3. Species composition of fish larvae and juveniles, by stations, collected from Tanshui River estuary, August 1989 to July 1990

Serial no.	Species	No. of fish				%
		Stn 1	Stn 2	Stn 3	Total	
9	*Sardinella melanura*	415	4 287	26 579	31 281	70.15
11	*Stolephorus buccaneeri*	255	1 951	6 528	8 734	19.59
13	*Thryssa kammalensis*	1293	27	0	1 320	2.96
54	*Gerres abbreviatus*	30	680	456	1 166	2.61
6	*Etrumeus terres*	15	110	39	164	0.37
66	*Liza macrolepis*	22	60	79	161	0.36
73	Blenniidae spp.	2	21	115	138	0.31
52	Leiognathidae spp.	54	30	53	137	0.31
39	*Sillago sihama*	55	17	49	121	0.27
12	*Stolephorus insularis*	3	71	31	105	0.24
31	*Ambassis gymnocephalus*	69	20	10	99	0.22
8	*Spratelloides gracilis*	0	4	80	84	0.19
44	*Decapterus maruadsi*	0	49	30	79	0.18
23	*Benthosema pterotum*	0	1	73	74	0.17
40	*Sillago japonica*	2	7	61	70	0.16
75	Gobiidae spp.	12	21	36	69	0.15
1	*Elops hawaiensis*	20	34	12	66	0.15
17	*Trachinocephalus myops*	0	17	34	51	0.11
68	*Sphyraena* sp.	0	1	48	49	0.11
60	Sciaenidae spp.	7	12	29	48	0.11
28	*Sebastiscus marmoratus*	1	3	43	47	0.11
41	*Sillago maculata*	6	5	34	45	0.10
32	*Lateolabrax japonicus*	0	24	16	40	0.09
59	Sparidae sp.	0	2	37	39	0.09
88	Tetraodontidae spp.	0	19	15	34	0.08
86	*Lagocephalus lunaris*	1	20	8	29	0.07
57	*Pomadasys argenteus*	22	5	1	28	0.06
51	*Secutor* sp.	0	0	22	22	0.05
2	*Megalops cyprinoides*	9	6	2	17	0.04
46	*Scomberoides tol*	2	6	8	16	0.04
36	*Apogon kiensis*	0	0	16	16	0.04
89	Unidentified sp.	0	0	16	16	0.04
81	Callionymidae sp.	1	1	14	16	0.04
55	*Gerres oyena*	0	0	14	14	0.03
38	*Apogon* spp.	4	3	6	13	0.03
56	*Gerres macrosoma*	4	1	8	13	0.03
15	*Arius* spp.	6	5	0	11	0.02
16	*Vinciguerria nimbaria*	0	0	10	10	0.02
58	*Sparus major*	0	3	7	10	0.02
85	Monacanthidae sp.	3	6	1	10	0.02
29	Scorpaenidae sp.	0	4	5	9	0.02
30	*Platycephalus indicus*	3	1	5	9	0.02
53	*Lutjanus* sp.	0	0	8	8	0.02
87	*Fugu niphobles*	0	7	0	7	0.02
78	*Scomber australasicus*	0	0	7	7	0.02
69	Scaridae sp.	0	4	2	6	0.01
10	*Engraulis japonicus*	4	2	0	6	0.01
18	*Saurida elongata*	0	2	3	5	0.01
70	*Parapercis* sp.	0	1	3	4	0.01
42	*Sillago* sp.	4	0	0	4	0.01
65	*Mugil cephalus*	4	0	0	4	0.01
62	*Scatophagus argus*	0	4	0	4	0.01
45	*Caranx sexfasciatus*	1	1	1	3	0.01
34	*Therapon jarbua*	0	3	0	3	0.01
74	*Apocryptodon madurensis*	3	0	0	3	0.01
48	Carangidae sp	0	2	1	3	0.01
72	*Scartella cristata*	0	2	0	2	0.00
19	*Saurida wanieso*	0	2	0	2	0.00
64	*Acanthocepola limbata*	0	0	2	2	0.00
37	*Apogon notatus*	0	0	2	2	0.00
80	*Trichiurus lepturus*	0	0	2	2	0.00
84	Cynoglossidae sp.	0	0	2	2	0.00
20	*Synodus macrops*	1	1	0	2	0.00
50	*Leiognathus nuchalis*	0	2	0	2	0.00
82	Bothidae sp.	0	0	2	2	0.00
3	*Albula vulpes*	0	0	2	2	0.00
77	*Scomber japonicus*	0	0	2	2	0.00
49	*Mene maculata*	0	0	1	1	0.00
79	*Euthynnus affinis*	0	1	0	1	0.00
33	Serranidae sp.	0	0	1	1	0.00
24	*Physiculus tosaensis*	0	0	1	1	0.00
63	Pomacentridae sp.	0	0	1	1	0.00
26	Antennaridae sp.	0	1	0	1	0.00
47	*Elagatis bipinnulata*	0	1	0	1	0.00
43	*Lactarius lactarius*	0	0	1	1	0.00
83	Pleuronectidae sp.	0	1	0	1	0.00
76	*Siganus* sp.	0	1	0	1	0.00
61	*Ephippus orbis*	0	1	0	1	0.00
27	Hemiramphidae sp.	0	0	1	1	0.00
14	*Chirocentrus dorab*	0	1	0	1	0.00
71	Percophididae sp.	0	0	1	1	0.00
7	*Dussumieria* sp.	0	1	0	1	0.00
21	*Lestidium atlanticum*	0	0	1	1	0.00
5	Ophichthyidae sp.	0	0	1	1	0.00
25	Carapidae sp.	0	0	1	1	0.00
67	*Sphyraena genie*	1	0	0	1	0.00
22	*Lestrolepis* sp.	0	0	1	1	0.00
4	Muraenidae sp.	0	0	1	1	0.00
35	*Apogon bifasciatus*	0	1	0	1	0.00
	Total no. of species	34	79	90	105	
	Total no. of individuals	2 334	7 576	34 681	44 591	

stations in the Tanshui River estuary are shown in Fig. 5. The numbers of species were more abundant from mid-spring through mid-summer (April to July) and in autumn (September to November) than in late summer (August) and winter (January and February). However, the abundance peaked in early spring (March) and mid-summer (July). Meanwhile, the numbers of species and abundance were significantly different between stations, being more abundant at the river mouth station (Stn 3) than at the upstream station (Stn 1).

The diversity indices of community structure of fish larvae and juveniles showed similar tendencies in seasonal variations between the three stations (Fig. 5). The indices of species richness (d′), species diversity (H′) and species evenness (J′) were higher, while the index of concentration ($\Sigma\pi^2$) was lower, in autumn and spring than in winter and summer. These indicate that the community structure is more complicated in autumn and spring than in summer and winter.

Fish abundance and diversity indices in relation to abiotic factors

The numbers of species, abundance, and indices of species richness and diversity of the community of fish larvae and juveniles were positively correlated with temperature and salinity, respectively. Negative correlations existed between the index of species concentration and temperature, and between the index of species evenness and salinity. Similarly, DO, pH, transparency and current velocity also positively or negatively correlated with the numbers of species, abundance, and the aforementioned community indices, respectively (Table 4). These facts indicate that the abundance and the community structure of fish larvae and juveniles in the estuary are influenced by these abiotic factors. In other words, when temperature and salinity increased, fish larvae and juveniles become more abundant and the community more complex.

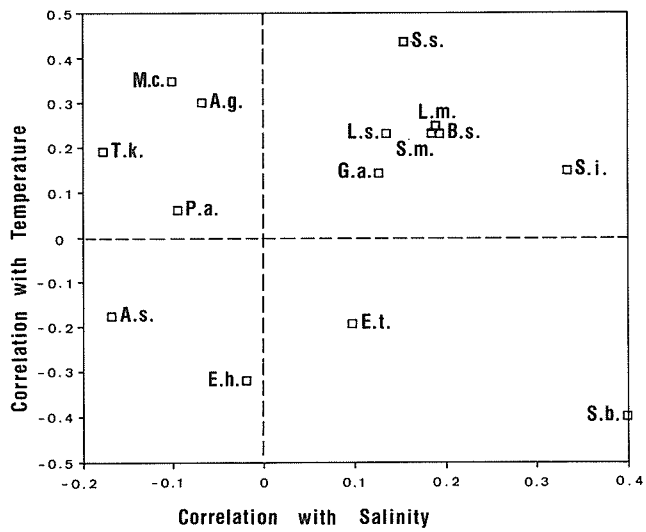

Fig. 6. Ordination of 15 dominant species in the Tanshui River estuary on correlation coefficients (r) for temperature (y-axis) and salinity (x-axis). A.g.: *Ambassis gymnocephalus*, A.s.: *Arius* spp., B.s.: Blenniidae spp., E.h.: *Elops hawaiensis*, E.t.: *Etrumeus terres*, G.a.: *Gerres abbreviatus*, L.m.: *Liza macrolepis*, L.s.: Leiognathidae spp., M.c.: *Megalops cyprinoides*, P.a.: *Pomadasys argenteus*, S.b.: *Stolephorus buccaneeri*, S.i.: *Stolephorus insularis*, S.m.: *Sardinella melanura*, S.s.: *Sillago sihama*, T.k.: *Thryssa kammalensis*

Furthermore, the abundance of fifteen selected dominant species was correlated, respectively, with the aforementioned abiotic factors to test whether the effect of abiotic factors on the fish community is species-specific (Table 4). It was found that six of 15 species positively or negatively correlated with temperature, indicating that temperature preference for the individual species is different. Two species were positively correlated with salinity while the other 13 species correlations were insignificant. This indicates that most species could tolerate wide variation of salinity. Similarly, six species significantly correlated with pH, five species correlated with depth, four species correlated with current, two species correlated with DO, and one species with transparency. These facts indicate that the abundance of fish larvae and juveniles is greatly influenced by the changes of abiotic factors and that the selection of environmental preference of the fish is diverse. Furthermore, the correlation coefficients between temperature and salinity and the abundance of 15 individual species were plotted in Fig. 6. Seven of 15 species were found in the area with high salinity and high temperature, four species in low salinity and high temperature, two species in high salinity and low temperature, and two species in low salinity and low temperature. This

Table 4. Correlation coefficients between biotic and abiotic factors. TEMP: temperature, SAL: salinity, DO: dissolved oxygen, DEP: depth of capture, TRANS: transparency, CUR: current velocity. **: $p<0.01$, *: $0.01<p<0.05$

	Abiotic factors						
	TEMP	SAL	DO	pH	DEP	TRANS	CUR
Overall species							
No. of species	0.29**	0.50**	0.11	0.13	0.29**	0.34**	−0.28**
Abundance (No./1 000 m^3)	0.23*	0.23*	0.12	0.33**	−0.09	0.01	−0.18
Species richness (d′)	0.31**	0.35**	−0.04	0.09	0.21	0.31**	−0.09
Species diversity (H′)	0.23*	−0.05	−0.24*	−0.08	−0.01	0.03	0.04
Species evenness (J′)	0.10	−0.26**	−0.18	−0.16	−0.16	0.11	−0.04
Species concentration ($\Sigma\pi^2$)	−0.22*	0.31**	0.33**	0.31**	0.06	0.16	−0.14
Dominant species (No./1 000 m^3)							
Elops hawaiensis	−0.32**	−0.02	0.19	−0.01	−0.01	0.07	−0.34**
Megalops cyprinoides	0.35**	−0.10	−0.12	−0.22*	−0.04	−0.12	0.12
Etrumeus terres	−0.18	0.09	−0.35**	0.02	0.01	−0.08	−0.01
Sardinella melanura	0.22	0.19	0.10	0.30**	−0.12	−0.02	−0.15
Stolephorus buccaneeri	−0.40**	0.40**	0.20	0.37**	0.29**	0.30**	−0.25**
Stolephorus insularis	0.14	0.34**	0.25**	0.01	0.16	0.19	−0.10
Thryssa kammalensis	0.19	−0.18	−0.06	−0.27**	−0.07	−0.08	0.18
Arius spp.	−0.19	−0.16	−0.09	−0.08	−0.22*	−0.16	−0.06
Ambassis gymnocephalus	0.30**	−0.07	0.03	−0.30**	−0.04	−0.08	0.07
Sillago sihama	0.43**	0.15	0.14	0.07	−0.17	−0.06	−0.05
Leiognathidiae spp.	0.21	0.14	−0.14	−0.07	0.24*	0.18	−0.31**
Gerres abbreviatus	0.14	0.13	−0.02	−0.05	0.38**	−0.10	−0.21
Pomadasys argenateus	0.07	−0.10	−0.15	0.12	−0.27**	−0.02	0.42**
Liza macrolepis	0.23*	0.19	0.03	0.22	−0.01	−0.09	−0.21
Blenniidae spp.	0.22	0.20	0.10	0.30**	−0.12	−0.02	−0.15

indicates that the effect of abiotic factors on the fish community is species-specific.

Discussion and conclusions

The larval and juvenile fish assemblage in the estuary of the Tanshui River, has a common feature with those found in many other estuarine fish populations (Austin 1971, Odum and Heald 1972, Allen and Horn 1975, Lasserre and Toffart 1977, Yáñez-Arancibia et al. 1980, Allen 1982, Bell et al. 1984), that of being constituted of a few species in large numbers. Four species, *Sardinella melanura* (Clupeidae), *Stolephorus buccaneeri* (Engraulidae), *Thryssa kammalensis* (Engraulidae) and *Gerres abbreviatus* (Gerreidae) accounted for >95% in terms of numbers of total catch; the other 5% was shared by more than 100 species (Table 2). The dominant species of the fish community in this study area belonged to the productive and low trophic level species with high ecological efficiency. These dominant species are economically important and linked to the existing larval fishery in the coastal waters.

The fish immigrating to the Tanshui River estuary were mainly in the larval and juvenile stages of development, and very few adults were found. These facts indicate that this estuary plays a very important role as a nursery ground for fish in inshore-offshore migration during their early life history. The nursery function of estuaries and inshore waters has been well-documented among Indo-Pacific regions and elsewhere in the world (Gunter 1967, McHugh 1967, Pillay 1967, Wallace and van der Elst 1975, Blaber and Blaber 1980, Day et al. 1981, Lenanton 1982, Robertson and Duke 1987, Blaber and Milton 1990), and it has been postulated that such areas provided suitable food, shelter, absence of turbulence and a reduction of predation. Our study supports this hypothesis, because the mangroves in the Tanshui River estuary are linked to the food web of the estuarine-dependent fish larvae and juveniles, while also providing shelter for the larvae and juveniles allowing them to avoid predation.

The second most distinctive feature of the fish assemblage in the estuary is the seasonal alternation of the occurrence of fish larvae and juveniles of the dominant species, *Stolephorus buccaneeri* and *Sardinella melanura*, recruited to the estuary around March and July, respectively. The duration of the fish larvae and juveniles in the estuary only lasted ca. 1 mo and subsequently decreased in numbers due to emigration (Fig. 4). This ecological separation of the dominant species by recruitment timing allowed for efficient use of the estuary, and species did not compete with each other for the same niche.

The distributional pattern of fish larvae and juveniles revealed that the total numbers of species and abundance in the estuary clearly decreased from the river mouth to the upstream area (Table 3 and Fig. 5). This indicates that fish larvae and juveniles in the estuary originated from the coastal waters. Advection and diffusion caused by tidal current were the principle forces transporting the fish larvae and juveniles from offshore into the estuary. Thus, fish abundance in the estuary was positively correlated with salinity and the salinity-associated factors (Table 4).

However, the correlation coefficients between abiotic factors and fish abundance were not consistent in the individual species (Table 4). This fact reveals the differentiation of the eco-behavior of the individual species after entering the estuary. The dominant species, *Stolephorus buccaneeri*, *S. insularis* and *Sardinella melanura*, tended to live in the higher saline waters. In contrast, several species were found further upstream in lower saline waters, e.g. *Thryssa kammalensis*, *Ambassis gymnocephalus*, *Elops hawaiensis*, *Pomadasys argenteus*, *Megalops cyprinoides*, and *Arius* spp. (Table 3, Fig. 6). These facts indicate that the larvae and juveniles actively migrated and selected preferred habitats in the estuary during passive-transport by tidal current.

Acknowledgement. This study was conducted with the financial support of the National Science Foundation, Republic of China (Contrast No. NSC79-0421-B002-07Z). We are grateful to Mr. Y. C. Chen and Mr. T. Chen-Yang for their help with field collections, Mr. K. K. Ang, Miss H. F. Lee, Miss Y. C. Tsai and Mr. M. A. Bolainos for their assistance in the laboratory, two anonymous reviewers for helpful comments on the manuscript and Miss S. MacLeod for reading the English text.

Literature cited

Allen, L. G. (1982). Seasonal abundance, composition and productivity of the littoral fish assemblage in upper Newport Bay, California. Fish. Bull. U.S. 80(4): 769–790

Allen, L. G., Horn, M. H. (1975). Abundance, diversity and seasonality of fishes in Colorado Lagoon, Alamitos Bay, California. Estuar. cstl mar. Sci. 3: 371–380

Austin, H. M. (1971). A survey of the ichthyofauna of the mangroves of western Puerto Rico during December, 1967–August, 1968. Caribb. J. Sci. 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., Pollard, D. A., Burchmore, J. J., Pease, B. C., Middleton, M. J. (1984). Structure of a fish community in a temperate tidal mangrove creek in Botany Bay, New South Wales. Aust. J. mar. Freshwat. Res. 35: 33–46

Blaber, S. J. M., Blaber, T. G. (1980). Factors affecting the distribution of juvenile estuarine and inshore fish. J. Fish Biol. 17: 143–162

Blaber, S. J. M., Milton, D. A. (1990). Species composition, community structure and zoogeography of fishes of mangrove estuaries in the Solomon Islands. Mar. Biol. 105: 259–267

Blaber, S. J. M., Young, J. W., Dunning, M. C. (1985). Community structure and zoogeographic affinities of the coastal fishes of the Dampier Region of Northwestern Australia. Aust. J. mar. freshwat. Res. 36: 247–266

Chou, C. H., Bi, C. C. (1990). Dynamic distribution of nutrients and variation of environmental factors in Tamshui estuary ecosystem. Proc. natl. Sci. Counc., Republic of China. Part B, 14(3): 131–141

Chou, C. H., Chang, F. C., Hwang, Y. S. (1987). Ecological research of mangrove forests: a review. In: Chou, C. H., Peng, C. I., Chaw, S. M. (eds.) Plant resources and conservation in Taiwan. Society of Wildlife and Nature, Republic of China, p. 23–48

Day, J. H., Blaber, S. J. M., Wallace, J. H. (1981). Estuarine fishes. In: Day, J. H. (ed.) Estuarine ecology with particular reference to southern Africa. A. A. Balkema, Cape Town, p. 197–221

Gunter, G. (1967). Some relationships of estuaries to the fisheries of the Gulf of Mexico. In: Lauff, G. H. (ed.) Estuaries. American Association for the Advancenent of Science, Washington D.C., p. 621–638

Haedrich, R. L., Haedrich, S. O. (1974). A seasonal survey of the fishes in the Mystic River, a polluted estuary in downtown Boston, Massachusetts. Estuar. cstl mar. Sci. 2: 59–73

Haines, E. B. (1979). Interactions between Georgia salt marshes and coastal waters: a changing paradigm. In: Livingston, R. J. (ed.) Ecological processes in coastal and marine systems. Plenyin Press, New York, p. 35–46

Kendall, A. W. Jr., Ahlstrom, E. H., Moser, H. G. (1984). Early life history stages of fishes and their characters. In: Moser, H. G., Richards, W. J., Cohen, D. M., Fahay, M. P., Kendall, A. W. Jr., Richardson S. L. (eds.) Ontogeny and systematics of fishes. Spec. Publ. No. 1. Am. Soc. Ichthyol. Herpetol., Allen Press Inc., Lawrence, Kansas, p. 11–22

Lasserre, G., Toffart, J. L. (1977). Echantillonnage et structure des populations ichtyologiques des mangroves de Guadeloupe en septembre 1975. Cybium 2: 115–127

Lee, C. W., Chu, T. Y. (1965). A general survey of Tanshui River and its tributary estuaries. Rep. Inst. fish. Biol., Natl. Taiwan Univ. 2(1): 34–45

Lenanton, R. C. J. (1982). Alternative non-estuarine nursery habitats for some commercially and recreationally important fish species of south-western Australia. Aust. J. mar. Freshwat. Res. 33: 881–900

Liaw, W. K. (1965). A preliminary survey on the zooplankton of Tanshui River estuary. Rep. Inst. fish. Biol., Natl. Taiwan Univ. 2(1): 27–33

Margalef, R. (1969). Perspectives in ecological theory. Univ. Chicago Press, Chicago

McErlean, A. J., O'Connor, S. G., Mihursky, J. A., Gibson, C. I. (1973). Abundance, diversity and seasonal patterns of estuarine fish populations. Estuar. cstl mar. Sci. 1: 19–36

McHugh, J. I. (1967). Estuarine nekton. In: Lauff, G. H. (ed.) Estuaries. American Association for the Advancement of Science, Washington D.C., p. 581–620

Odum, W. E., Heald, E. J. (1972). Trophic analyses of an estuarine mangrove community. Bull. mar. Sci. 22: 671–738

Peet, R. K. (1974). The measurement of species diversity. A. Rev. Ecol. Syst. 5: 285–307

Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. J. theor. Biol. 13: 131–144

Pillay, T. V. R. (1967). Estuarine fishes of the Indian Ocean coastal zone. In: Lauff, G. H. (ed.) Estuaries. American Association for the Advancement of Science, Washington D.C., p. 647–657

Robertson, A. I., Duke, N. C. (1987). Mangroves as nursery sites: comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in tropical Australia. Mar. Biol. 96: 193–205

Robertson, A. I., Duke, N. C. (1990). Mangrove fish-communities in tropical Queensland, Australia: spatial and temporal patterns in densities, biomass and community structure. Mar. Biol. 104: 369–379

Siegel, S. (1956). Nonparametric statistics for the behavioral sciences. McGraw-Hill, New York

Tan, T. H. (1971). On occurrence and ecological adaptation of zooplankton in Tanshui River, Taiwan. Rep. Inst. fish. Biol., Natl. Taiwan Univ. 2(4): 40–48

Wallace, J. H., van der Elst, R. P. (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. Oceanogr. Res. Inst. Invest. Rep. No. 42, Durban, South Africa

Yáñez-Arancibia, A., Linares, F. A., Day, J. W. Jr. (1980). Fish community structure and function in Terminos Lagoon, a tropical estuary in the southern Gulf of Mexico. In: Kennedy, V. S. (ed.) Estuarine perspectives. Academic Press, New York, p. 465–482