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Movement of Fish Larvae with Tidal Flux in the Tanshui River Estuary, Northern Taiwan

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Wann-Nian Tzeng and Yu-Tzu Wang (1997) Movement of fish larvae with tidal flux in the Tanshui River estuary, northern Taiwan. *Zoological Studies* **36**(3): 178-185. Movement of fish larvae in relation to tidal flux in the Tanshui River estuary was studied for 4 seasons during 1989 and 1990. The dominant species were *Engraulis japonicus* in spring, *Sardinella* spp. in summer, *Encrasicholina punctifer* in autumn, and *Arius thalassinus* in winter. The estuary had 2 flood tides daily, but the larvae were abundant only at 1 of the 2 flood tides. The timing of occurrence of peak abundance was independent of the diel period of light and dark. Size and stage compositions were not significantly different between surface and bottom water layers ($p > 0.05$), but were significantly different between 2 successive flood tides ($p < 0.01$), indicating that larvae in the estuary are evenly distributed in the water column, and that the larvae in the 2 successive flood tides were perhaps from different shoals.

Key words: Fish larvae, Community structure, Movement, Tide, Estuary.

The Tanshui River estuary and its adjacent coastal waters are important commercial fishing grounds for the larvae of engraulid and clupeid fishes for local consumption and for provision of anguillid elvers for pond culture (Tzeng and Wang 1992 1993). There is a rare species of mangrove, *Kandelia candel* (Rhizophoraceae), in the lower portion of the estuary (Chou et al. 1987), which provides plentiful detritus that is linked to the food chain of estuarine-dependent marine fish populations during their early life stages (McErlean et al. 1973, Haedrich and Haedrich 1974, Bell et al. 1984, Robertson and Duke 1987, Blaber and Milton 1990). The estuary is the nursery and feeding ground for onshore-offshore migratory fishes (McHugh 1967, Hall 1977, Ross and Epperly 1985, Deegan and Day 1985 1986).

Spawning and nursery areas of estuarine fishes are often spatially segregated (Harden-Jones 1968, Tzeng and Wang 1993). The mechanisms by which larvae are transported toward and retained in nursery areas are still poorly understood (Rijnsdorp et al. 1985, Lyczkowski-Shultz et al. 1990). The temporal and spatial use of estuary and nearshore waters by estuarine, marine, freshwater, and estuarine-dependent marine species has been schematically described by Deegan and Thompson (1985). A conceptual model of the transport of larval fishes between nearshore and estuarine nursery areas was proposed on the basis of physical processes, fish activity and behavior, and environmental cues (Boehlert and Mundy 1988). Moving to and remaining in the estuary are important parts of the early life history of many fish species. The transportation of larvae to the estuary for species that spawn in offshore waters has been considered to be a 2-stage process dependent first upon factors in the offshore planktonic environments and then upon estuarine factors related to tidal flux (Bohlert and Mundy 1988).

Effect of tidal flux on migratory behavior of estuarine fishes has been described for a variety of organisms, particularly perciform, anguilliform, and pleuronectiform fishes which migrate by selective

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tidal stream transport (Blaxter and Staines 1971, Creutzberg 1978, Tsuruta 1978, Weinstein et al. 1980, McCleave and Kleckner 1982, Tzeng 1982 1984 1985, Fukuhara 1985, McCleave and Wippelhauser 1987). However, it has been indicated that the active components of transport are easily overemphasized and that passive transport is probably more general than suggested in the literature (Fortier and Leggett 1982 1983, Norcross and Shaw 1984, Weisberg and Burton 1993, Rowe and Epifanio 1994a,b, Richards et al. 1995, Gibson et al. 1996).

There are 3 types of tides that are recognized in the world: semidiurnal (twice a day), diurnal (once a day), and mixed (Thurman 1991). The Tanshui River estuary is characterized by a semidiurnal tide with 2 flood and 2 ebb tides during each tidal day, but the heights of the 2 flood tides are unequal due to diurnal inequality of the tides (Tzeng 1985). The tidal ranges vary from 1.5 m to 3.0 m between neap and spring tides (Chu 1963, Lee and Chu 1965). Larval clupeoid fishes are dominant in the estuary and are harvested by a net set against the tidal current (Wang et al. 1991, Tzeng and Wang 1992). However, the relationship between the movement of larval clupeoid fishes and tidal flux in the estuary is not completely understood (Wang and Hwang 1992, Tzeng and Wang 1993). This study aims to clarify the recruitment behavior of larval fishes in relation to tidal flux in the estuary.

MATERIALS AND METHODS

Sampling design

The Tanshui River, at approximately 159 km long, is the largest river in northern Taiwan. The river mouth faces the shallow continental shelf of the northern part of the Taiwan Strait. A station in the Tanshui River estuary was selected for larval sampling (Fig. 1). Larval fishes in the estuary were collected with a set net for the 4 seasons: autumn (11 ~ 12 October 1989), winter (1 ~ 2 February), spring (31 March ~ 1 April), and summer (12 ~ 13 July 1990). During each sampling period, 8 collection of larvae were made at 3-h intervals over a 24-h cycle. For each collection the net was set for approximately 20 min. The set net used in this study was 5 m wide, 3 m high, and 17 m long, with mesh sizes of 11 cm at the mouth and 0.1 cm at the cod end, as described previously by Tzeng and Wang (1992). The net was extended from surface to bottom and set against the current according to the flood and ebb tides.

To understand the vertical distribution, a Maruchi-D larval net was used to collect fish larvae at surface and bottom water layers in the estuary, 31 March ~ 1 April 1990. The net has a mouth diameter of 1.3 m, length of 4.5 m, and bar mesh of 0.5 mm (Nakai 1962).

The larvae collected were fixed immediately in a 10% formalin-seawater solution. For each individual larva, species was identified, and the stage was determined (Kendall et al. 1984). Total lengths of approximately 30 individuals from each stage of larvae were measured to the nearest 0.1 mm.

Environmental data were collected during sampling. Water temperature and salinity were measured with a salinometer (WTW microprocessor conductivity meter: LF 196), dissolved oxygen (DO) with Winkler's method, pH with a digital pH meter (JENCO 609), transparency with Secchi's disc, tidal current velocity with current meter, and depth with an echo sounder.

Data analysis

The number of fish larvae collected was standardized as number per 1000 m^3 seawater. The

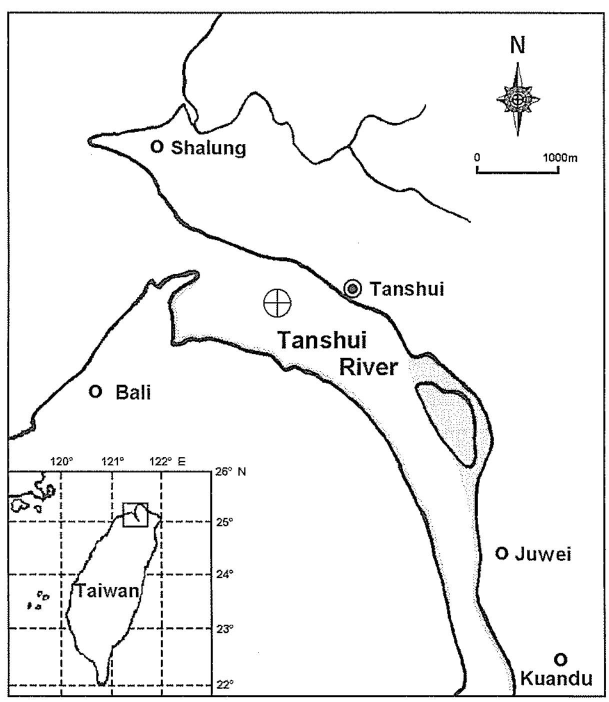

Fig. 1. Location of sampling station (⊕) in the Tanshui River estuary (Shadow areas indicated the distribution of mangrove swamps).

changes in numbers of species and individuals in relation to tidal flux were analyzed for spring, summer, and autumn, but not for winter because of a small sample size. The difference in frequency distribution of total lengths and developmental stages of fish larvae between 2 successive flood tides and between surface and bottom water layers was evaluated by use of the Chi-square test.

RESULTS

Estuarine environment

Water levels were different between 2 flood tides and between 2 ebb tides in each tidal day (Table 1). Values of DO, pH, salinity, transparency, current velocity, and depth of the station changed with tidal flux (Fig. 2). Salinity fluctuated from 6.1‰ at the ebb tide to 33.3‰ at the flood tide. DO was 7.26 mg/l at the flood tide (Fig. 2e, 01:44, 1 April, 1990) and declined to as low as 0.67 mg/l at the ebb tide (Fig. 2e, 10:28, 1 April, 1990). The low DO was due to the intrusion of domestic water from upstream. Transparency and pH values followed the same trend as those of DO and salinity. DO and salinity were slightly different between surface and bottom water layers in spring and summer, indicating that the water was slightly stratified in the estuary, particularly in the ebb tide.

Community structure

The species composition of fish larval samplings changed with season. The number of species was greatest in summer (126 species), moderate in spring (48) and autumn (48), and lowest in winter

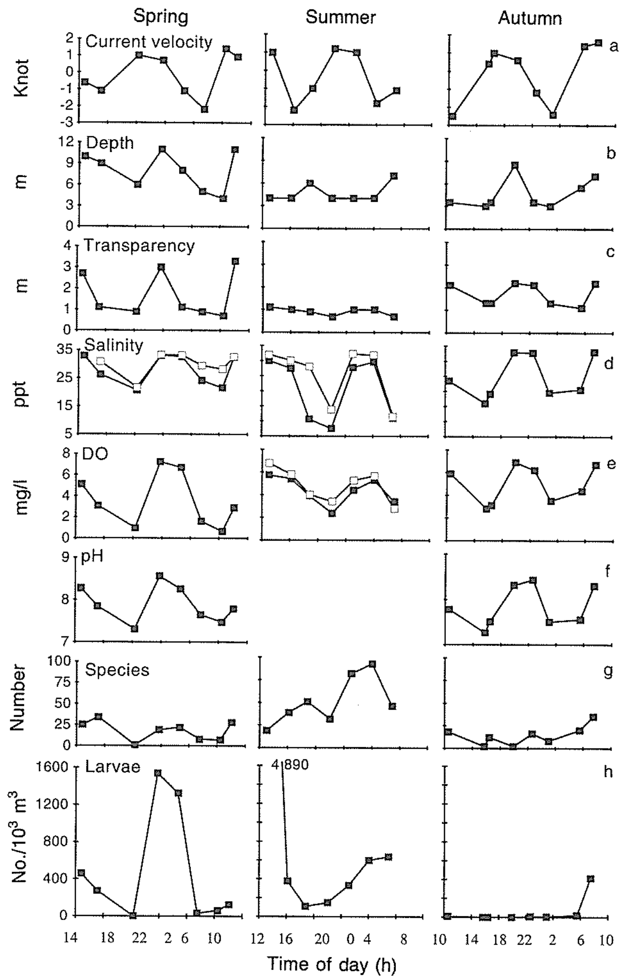

Fig. 2. Circatidal changes in current velocity, water depth, salinity, pH, dissolved oxygen (DO) and transparency, in surface (solid square) and bottom water layers (open square), and total number of species and abundance of fish larvae in the Tanshui River estuary in spring (31 March ~ 1 April), summer (11 ~ 12 July), and autumn (10 ~ 11 October).

Table 1. Two high and two low water measurements over a tidal day at Tanshui Harbor on 10 ~ 11 October 1989, 1 ~ 2 February, 31 March ~ 1 April, and 11 ~ 12 July 1990

Date	Flood				Ebb			
	HHW[a]		LHW		HLW		LLW	
	Height[a]	Time	Height	Time	Height	Time	Height	Time
31 March ~ 1 April	3.86	13:52	3.59	03:06	1.94	08:31	0.98	20:19
11 ~ 12 July	3.78	12:54	3.68	01:52	1.67	07:24	0.90	19:13
10 ~ 11 October	3.54	07:22	3.49	19:40	1.97	01:12	1.33	12:41
1 ~ 2 February	3.77	14:59	3.58	03:27	1.45	09:15	1.23	21:01

[a] Height (m); Time (h:min); HHW, high high water; LHW, low high water; HLW, high low water; LLW, low low water.

(15). Dominant species differed among the seasons: *Engraulis japonicus* in spring; *Sardinella* spp., *Leiognathus nuchalis*, and *Thryssa chefuensis* in summer; *Encrasicholina punctifer* in autumn; and *Arius thalassinus* in winter. Most of the species in the estuary were at the larval and pre-juvenile stages, except *Arius thalassinus* which was at the young and adult stages (Table 2). The community was dominated by a few species, particularly in spring and summer.

Larval abundance in relation to tidal flux

The rise and fall in the abundance of fish larvae over a tidal day did not correspond with a similar fluctuation in the number of species (Fig. 2g, h). The peak abundance of larvae in the estuary was contributed to by a few dominant species in spring and summer but by more numerous species in autumn (Table 2).

The abundance of larvae varied with the time of day in spring, summer, and autumn. The peak abundance occurred at the nighttime flood tide in spring, but in the daytime flood tide in summer and autumn (Fig. 2h). This phenomenon suggests that the movement of larval shoals in the estuary follows one of the 2 flood tides in each tidal day and is independent of diel periods of light and dark.

Spatio-temporal distribution of fish shoals

The size and stage compositions of the larvae of *E. japonicus* collected by the set net were significantly different between 2 successive flood tides (Fig. 3c, f; $\chi^2 = 118.96$, $p < 0.001$ for size; $\chi^2 = 59.88$, $p < 0.01$ for stage). This indicates that the larvae in 2 successive flood tides might be from different shoals. In addition, the size composition with a higher percentage of large larvae (Fig. 3c, d) corresponded to the peak catch in spring (Fig. 2h). However, size compositions of larvae collected by Maruchi-D larval net were not significantly different between surface and bottom water layers (Fig. 4; $\chi^2 = 4.04$, $p > 0.05$ for size; $\chi^2 = 2.92$, $p > 0.05$ for stage), indicating that the distribution of fish shoals was even between the 2 layers.

DISCUSSION

Most of the larvae collected were at the flexion and postflexion stages, and few fish eggs and preflexion larvae were collected (Fig. 4). The latter 2 stages in the estuary were negligible in number in comparison to those collected in coastal waters adjacent to the estuary (Wang et al. 1991, Tzeng and Wang 1993). This implies that the study area

Table 2. Species composition of fish larvae in the Tanshui River estuary in autumn (10~11 October 1989), winter (1~2 February), spring (31 March ~ 1 April), and summer (11~12 July 1990)

		Species composition (%)			
	Developmental stage[a]	Spring	Summer	Autumn	Winter
Engraulis japonicus	Fl,Po+,Ju,Yo	94.91	0.01		
Etrumeus teres	Po+,Ju	1.47			0.91
Sardinella spp.	Po+,Ju,Yo	0.01	80.29	5.77	
Leiognathus nuchalis	Ju,Yo+,Ad	0.01	9.94		0.46
Thryssa chefuensis	Po,Ju,Yo+		1.93		1.37
Encrasicholina punctifer	Fl,Po+,Ju		0.01	36.39	19.63
Secutor insidiator	Po+,Ju,Yo		0.04	25.11	
Leiognathus spp. (4 species)	Fl,Po+	0.34	0.04	16.29	
Stolephorus insularis	Po+,Ju		0.19	3.16	
Sillago sihama	Po,Ju+,Yo	0.01	0.18	1.75	
Gerres abbreviatus	Po,Ju+		0.05	1.53	
Sillago japonica	Po,Ju+	0.06	0.19	1.19	
Elops hawaiensis	Le	0.01	0.01	0.11	4.57
Arius thalassinus	Yo+,Ad	0.04	0.81	0.03	61.64
Anguilla japonica	Elver				3.65
Lateolabrax japonicus	Po				4.11
Others		3.12	6.31	8.77	3.65
Number of species		48	126	48	15
Number of individuals		27 815	47 818	3604	219

[a]Le, leptocephalus; Fl, flexion; Po, postflexion; Ju, juvenile; Yo, young; Ad, adult; +, dominant.

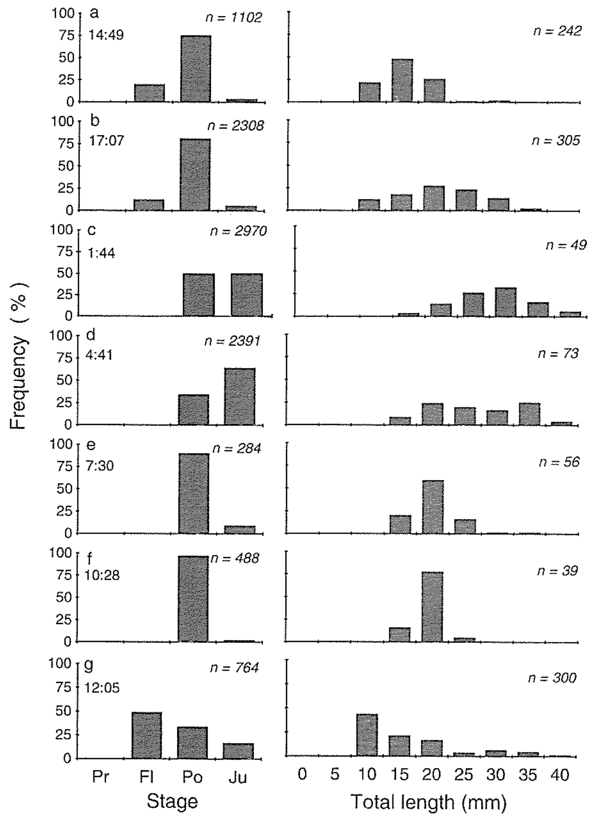

Fig. 3. Changes in size and stage compositions of *Engraulis japonicus* collected by set net at approximately 3-h intervals over a tidal cycle from 14:49, 31 March to 12:05, 1 April 1990 (No fish were caught at 22:18; *n*, sample size; for stages, Pr, Fl, Po, and Ju, refer to Table 2).

is not the spawning ground but the nursery area of these fishes. Larval clupeoid fishes, *E. japonicus*, *Sardinella* spp., and *E. punctifer*, were dominant in the larval community in the estuary (Table 2), which is similar to previous findings (Wang et al. 1991, Tzeng and Wang 1992 1993). They are estuarine-dependent marine species and migrate to the estuary for feeding from spring through autumn during the 1st year of their life cycle.

Fish abundance significantly decreased when DO decreased at ebb tide (e.g., in spring, Fig. 2e, h), indicating that low DO profoundly influenced the movement of the larvae. On the other hand, fish abundance also significantly decreased when salinity decreased at ebb tide (e.g., in summer, Fig. 2d, h), indicating that the larvae remained in high-saline waters and did not penetrate to the low-salinity areas of the estuary. They moved into and out of the estuary with flood and ebb tides. Size compositions were similar between the surface and bottom water layers, indicating that the distribution of larvae in the water column was even (Fig. 4). This may be due to the water being well mixed during flood tides in the study site (Fig. 2). This phenomenon was also observed elsewhere (Fortier and Leggett 1982 1983).

The estuary is characterized by a semidiurnal type of tide, with 2 flood tides daily (Fig. 2). If the larvae were homogeneously distributed and were simply passively transported by the tidal current,

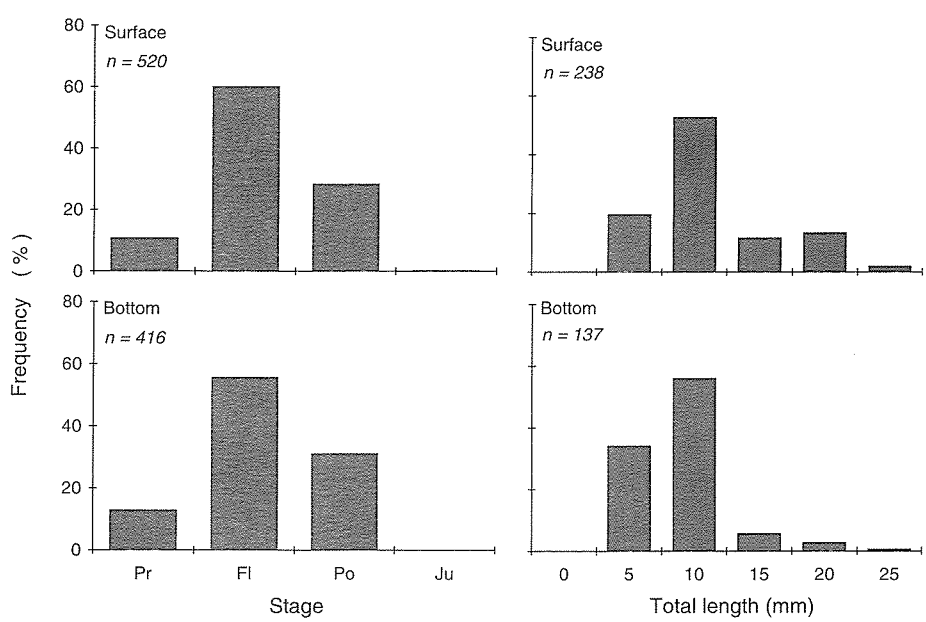

Fig. 4. Comparison of size and stage compositions of *Engraulis japonicus* collected by Maruchi-D larval net in surface and bottom layers (*n*, sample size; for stages, Pr, Fl, Po, and Ju, refer to Table 2).

there should be 2 peak abundances corresponding to the peaks of 2 flood tides. However, there was only 1 peak abundance in nighttime in spring and in daytime in summer and autumn, respectively (Fig. 2h). This suggests that in addition to tidal flux, the movement of fish larvae in the estuary may be influenced by other factors: such as the physical gradient of the water (Blaber and Blaber 1980), frequency of onshore winds (Nelson et al. 1977, Parrish et al. 1981, Shlossman and Chittenden 1981, Pauly 1985), distribution and abundance of larvae in the offshore region (MacGregor and Houde 1996), schooling behavior (Blaxter and Holliday 1963, Blaxter and Hunter 1982, Galakionov 1984, Luo 1993, Robinson et al. 1995, Higgs and Fuiman 1996), food availability (Milinski 1979, Godin and Keenleyside 1984, Drake and Arias 1991), predation pressure (Werner et al. 1983, Huntingford et al. 1988), or a combination of these factors. Further study is required to understand how these factors, superimposed on tidal flux, influence the movement of fish larvae in the estuary.

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臺灣北部淡水河口仔魚之移動與潮汐週期之關係

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爲了瞭解仔魚的數量變動與潮汐週期之關係。利用兩種採集網於臺灣北部淡水河口進行 24 小時的連續採集，同時測定流速、水深、透明度、鹽度、pH 及溶氧等環境因子。多數仔魚屬於河口依賴型的海洋性種類。仔魚的種類組成及數量隨季節而改變。春季以日本鯷 (*Engraulis japonicus*) 爲主，夏季以小砂丁魚類 (*Sardinella* spp.) 爲主，秋季以刺公鯷 (*Encrasicholina punctifer*) 爲主，冬季以泰來海鯰 (*Arius thalassinus*) 爲主。大部分種類爲後期仔魚階段，河口域扮演著哺育場的功能。淡水河口屬於半日週潮，在一天的兩次漲潮中，仔魚的高峰只出現一次，高峰出現時間與 24 小時的明暗週期無關。仔魚的發育階段及體長組成，表底層之間無顯著性差異，但兩次漲潮有顯著性差異；顯示仔魚均勻地分布於水層中，但兩次漲潮的仔魚來自不同魚群。

關鍵詞：仔稚魚, 群聚構造, 移動行爲, 潮汐, 淡水河口。

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