

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

Wann-Nian Tzeng* and Yu-Tzu Wang

Department of Zoology, College of Science, National Taiwan University, Taipei, Taiwan 106, R.O.C.

Tel: 886-2-3639570 Fax: 886-2-3636837 E-mail: WNT@ccms.ntu.edu.tw

(Accepted February 22, 1997)

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, fresh-water, 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

*To whom correspondence and reprint requests should be addressed.

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 Wipfelhauser 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 m³ seawater. The

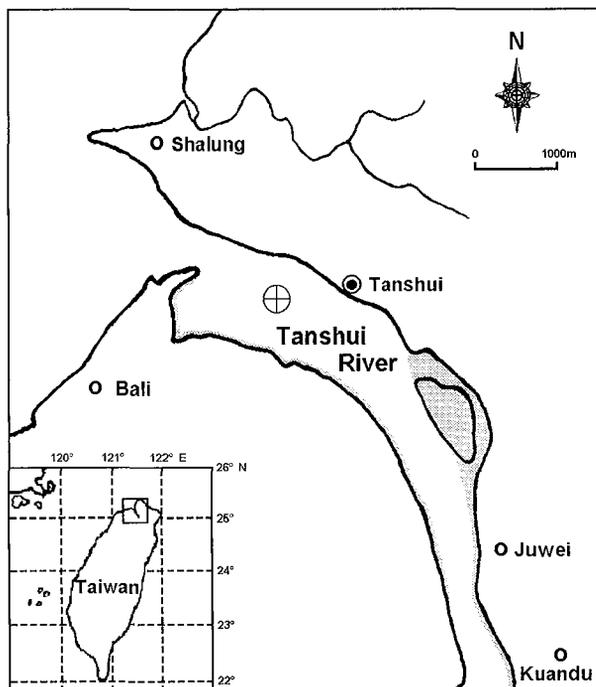


Fig. 1. Location of sampling station (⊕) in the Tanshui River estuary (Shadow areas indicated the distribution of mangrove swamps).

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

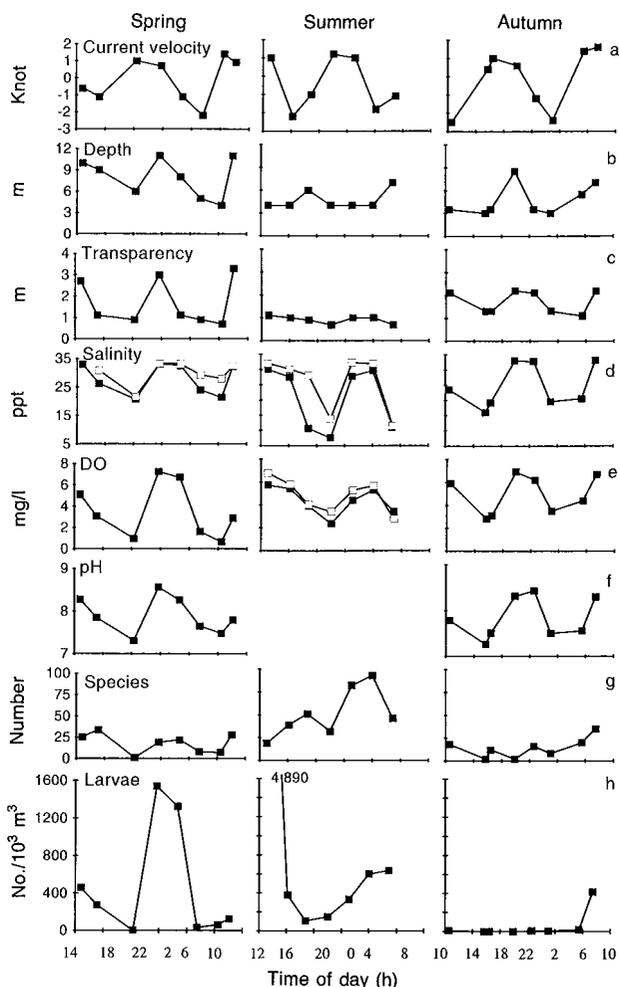


Fig. 2. Circatidal changes in current velocity, water depth, salinity, pH, dissolved oxygen (DO) and transparency, in surface (solid square) and bottom water layers (open square), and total number of species and abundance of fish larvae in the Tanshui River estuary in spring (31 March ~ 1 April), summer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

	Developmental stage ^a	Species composition (%)			
		Spring	Summer	Autumn	Winter
<i>Engraulis japonicus</i>	Fl,Po ⁺ ,Ju,Yo	94.91	0.01		
<i>Etrumeus teres</i>	Po ⁺ ,Ju	1.47			0.91
<i>Sardinella</i> spp.	Po ⁺ ,Ju,Yo	0.01	80.29	5.77	
<i>Leiognathus nuchalis</i>	Ju,Yo ⁺ ,Ad	0.01	9.94		0.46
<i>Thryssa chefuensis</i>	Po,Ju,Yo ⁺		1.93		1.37
<i>Encrasicholina punctifer</i>	Fl,Po ⁺ ,Ju		0.01	36.39	19.63
<i>Secutor insidiator</i>	Po ⁺ ,Ju,Yo		0.04	25.11	
<i>Leiognathus</i> spp. (4 species)	Fl,Po ⁺	0.34	0.04	16.29	
<i>Stolephorus insularis</i>	Po ⁺ ,Ju		0.19	3.16	
<i>Sillago sihama</i>	Po,Ju ⁺ ,Yo	0.01	0.18	1.75	
<i>Gerres abbreviatus</i>	Po,Ju ⁺		0.05	1.53	
<i>Sillago japonica</i>	Po,Ju ⁺	0.06	0.19	1.19	
<i>Elops hawaiiensis</i>	Le	0.01	0.01	0.11	4.57
<i>Arius thalassinus</i>	Yo ⁺ ,Ad	0.04	0.81	0.03	61.64
<i>Anguilla japonica</i>	Elver				3.65
<i>Lateolabrax japonicus</i>	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

^aLe, leptocephalus; Fl, flexion; Po, postflexion; Ju, juvenile; Yo, young; Ad, adult; +, dominant.

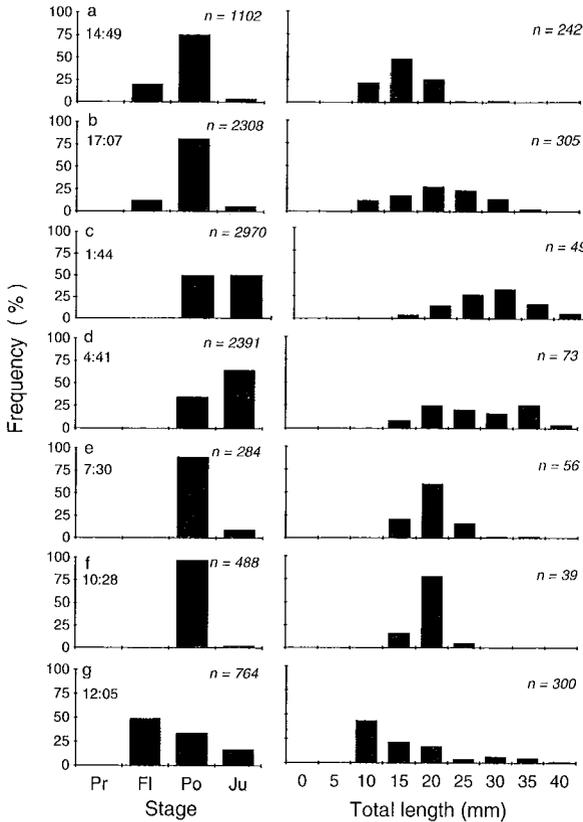


Fig. 3. Changes in size and stage compositions of *Engraulis japonicus* collected by set net at approximately 3-h intervals over a tidal cycle from 14:49, 31 March to 12:05, 1 April 1990 (No fish were caught at 22:18; n, sample size; for stages, Pr, FI, Po, and Ju, refer to Table 2).

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,

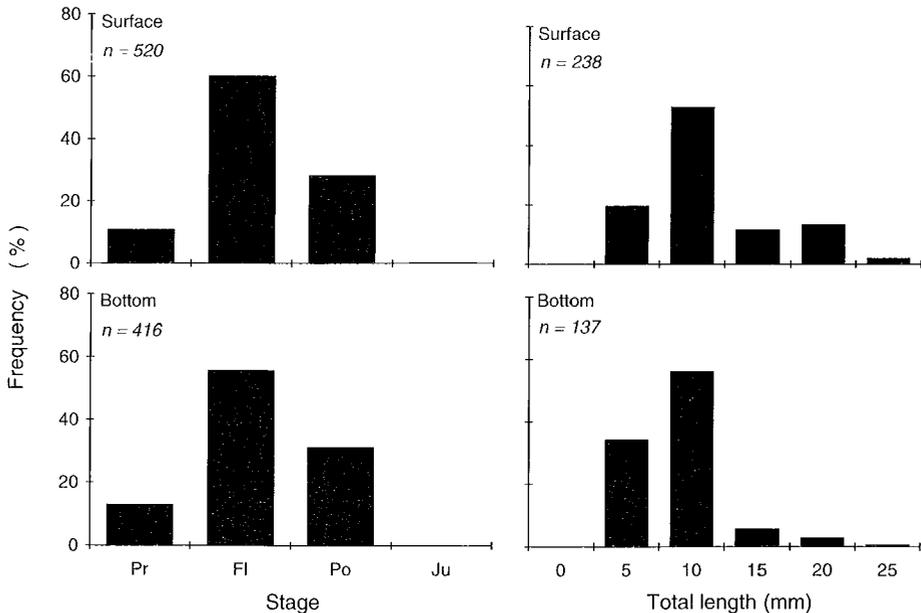


Fig. 4. Comparison of size and stage compositions of *Engraulis japonicus* collected by Maruchi-D larval net in surface and bottom layers (n, sample size; for stages, Pr, FI, Po, and Ju, refer to Table 2).

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, Galaktionov 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.

Acknowledgements: This study was financially supported by the National Science Council, Republic of China (NSC 80-0421-B002-05Z). We are grateful to Mr. Y.C. Chen, Mr. T. Chern-Yang, and other colleagues of the Laboratory of Fisheries Biology, Department of Zoology, National Taiwan University, for their help in field collection and laboratory work, and Dr. C.F. Tsai for critical review of the manuscript.

REFERENCES

- Bell JD, DA Pollard, JJ Burchmore, BC Pease, MJ Middleton. 1984. Structure of a fish community in a temperate tidal mangrove creek in Botany Bay, New South Wales. *Aust. J. Mar. Freshw. Res.* **35**: 33-46.
- Blaber SJM, TG Blaber. 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. *J. Fish Biol.* **17**: 143-162.
- Blaber SJM, DA Milton. 1990. Species composition, community structure and zoogeography of fishes of mangrove estuaries in the Solomon Islands. *Mar. Biol.* **105**: 259-267.
- Blaxter JHS, FGT Holliday. 1963. The behaviour and physiology of herring and other clupeids. In FS Russell, ed. *Advances in marine biology*. London: Academic Press, pp. 262-393.
- Blaxter JHS, JR Hunter. 1982. The biology of the clupeoid fishes. *Adv. Mar. Biol.* **20**: 1-223.
- Blaxter JHS, ME Staines. 1971. Food searching potential in marine fish larvae. In DJ Crisp, ed. *Fourth European marine biological symposium*. Cambridge: Cambridge Univ. Press, pp. 467-485.
- Boehlert GW, BC Mundy. 1988. Roles of behavioral and physical factors in larval and juvenile fish recruitment to estuarine nursery areas. *Am. Fish. Soc. Symp.* **3**: 51-67.
- Chou CH, FC Chang, YS Hwang. 1987. Ecological research of mangrove forests: a review. In CH Chou, FC Chang, YS Hwang, eds. *Plant resources and conservation in Taiwan*. Taipei: Society of Wildlife and Nature, pp. 23-48.
- Chu TY. 1963. The oceanography of the surrounding waters of Taiwan. *Rep. Inst. Fish. Biol., Natl. Taiwan Univ.* **1**: 29-44.
- Creutzberg F. 1978. Transport of marine organisms by tidal currents. In N Dankers, WJ Wolff, JJ Zijlstra, eds. *Fish and fisheries of the Wadden Sea*. Rotterdam: Balkema, pp. 26-32.
- Deegan LA, JW Day. 1985. Estuarine fish habitat requirements. In B Copeland, K Hart, N Davis, S Friday, eds. *Research for managing the nation's estuaries*. UNC Sea Grant College Publ. UNC-4-08. Raleigh: N. Carolina State Univ., pp. 315-336.
- Deegan LA, JW Day. 1986. Coastal fishery habitat requirements. In A Yáñez-Arancibia, D Pauly, eds. *Recruitment processes in tropical coastal demersal communities*. Ocean science in relation to living resources (OSLR), International recruitment project (IREP). IOC-FAO-UNESCO workshop OSLR/IREP project. Vol. 44. Paris: UNESCO, pp. 44-52.
- Deegan LA, BA Thompson. 1985. The ecology of fish communities in the Mississippi River deltaic plain. In A Yáñez-Arancibia, ed. *Fish community ecology in estuaries and coastal lagoons: towards an ecosystem integration*. Mexico: DR (R) UNAM Press, pp. 35-56.
- Drake P, AM Arias. 1991. Ichthyoplankton of a shallow coastal inlet in south-west Spain: factors contributing to colonization and retention. *Estuar. Cstl. Shelf Sci.* **32**: 347-364.
- Fortier L, WC Leggett. 1982. Fickian transport and the dispersal of fish larvae in estuaries. *Can. J. Fish. Aquat. Sci.* **39**: 1150-1163.
- Fortier L, WC Leggett. 1983. Vertical migrations and transport of larval fish in a partially mixed estuary. *Can. J. Fish. Aquat. Sci.* **40**: 1543-1555.
- Fukuhara O. 1985. Functional morphology and behavior of early life stages of red sea bream. *Bull. Jpn. Soc. Sci. Fish.* **51**: 731-743.
- Galaktionov GZ. 1984. Features of the schooling behavior of the alfonsina *Beryx splendens* (Berycidae), in the thalassobathyl depth of the Atlantic Ocean. *J. Ichthyol.* **24**: 148-151.
- Gibson RN, L Robb, MT Burrows, AD Ansell. 1996. Tidal, diel and long term changes in the distribution of fishes on a Scottish sandy beach. *Mar. Ecol. Prog. Ser.* **130**: 1-17.
- Godin JG, MH Keenleyside. 1984. Foraging on patchily distributed prey by a cichlid fish (Teleostei, Cichlidae): a test of the ideal free distribution theory. *Anim. Behav.* **32**: 120-131.
- Haedrich RL, SO Haedrich. 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.
- Hall C. 1977. Models and the decision making process. In C Hall, J Day, eds. *Ecosystem modeling in theory and practice*. New York: Wiley Interscience, pp. 346-364.
- Harden-Jones FR. 1968. *Fish migration*. London: Arnold Press.
- Higgs DM, LA Fuiman. 1996. Light intensity and schooling behaviour in larval gulf menhaden. *J. Fish Biol.* **48**: 979-991.
- Huntingford FA, NB Metcalfe, JE Thorpe. 1988. Choice of feeding station in Atlantic salmon, *Salmo salar*, parr: effects of predation risk, season and life history strategy. *J. Fish Biol.* **33**: 917-924.

- Kendall AW Jr., EH Ahlstrom, HG Moser. 1984. Early life history stages of fishes and their characters. In HG Moser, WJ Richards, DM Cohen, MP Fahay, AW Kendall, SL Richardson, eds. Ontogeny and systematics of fishes. Lawrence: Amer. Soc. Ichthyol. Herpetol., Spec. Pub. 1, pp. 11-22.
- Lee CW, TY Chu. 1965. A general survey of Tanshui River and its tributary estuaries. Rep. Inst. Fish. Biol., Natl. Taiwan Univ. 2: 34-45.
- Luo J. 1993. Tidal transport of the bay anchovy, *Anchoa mitchilli*, in darkness. J. Fish Biol. 42: 531-539.
- Lyczkowski-Shultz J, DL Ruple, SL Richardson, JH Cowan Jr. 1990. Distribution of fish larvae relative to time and tide in a Gulf of Mexico barrier island pass. Bull. Mar. Sci. 46: 563-577.
- MacGregor JM, ED Houde. 1996. Onshore-offshore pattern and variability in distribution and abundance of bay anchovy *Anchoa mitchilli* eggs and larvae in Chesapeake Bay. Mar. Ecol. Prog. Ser. 138: 15-25.
- McCleave JD, RC Kleckner. 1982. Selective tidal stream transport in the estuarine migration of glass eels of the American eel (*Anguilla rostrata*). J. Cons. Int. Explor. Mer. 40: 262-271.
- McCleave JD, GS Wippelhauser. 1987. Behavioral aspects of selective tidal stream transport in juvenile American eels. Am. Fish. Soc. Symp. 1: 138-150.
- McErlean AJ, SG O'Connor, JA Mihursky, CI Gibson. 1973. Abundance, diversity and seasonal patterns of estuarine fish populations. Estuar. Cstl. Shelf Sci. 1: 19-36.
- McHugh JL. 1967. Estuarine nekton. In GH Lauff, ed. Estuaries. Washington, D.C.: Am. Assoc. Adv. Sci. Spec. Publ. 83, pp. 581-619.
- Milinski M. 1979. An evolutionarily stable feeding strategy in sticklebacks. Zeitschrift fur Tierpsychologie 51: 36-40.
- Nakai Z. 1962. Apparatus for collecting macroplankton in the spawning survey of iwashi (sardine, anchovy and round herring) and others. Bull. Tokai Reg. Fish. Res. Lab. 9: 221-237.
- Nelson WR, MC Ingham, WE Schaaf. 1977. Larval transport and year-class strength of Atlantic menhaden, *Brevoortia tyrannus*. Fish. Bull. 75: 23-41.
- Norcross BL, RF Shaw. 1984. Oceanic and estuarine transport of fish eggs and larvae: a review. Trans. Am. Fish. Soc. 113: 153-165.
- Parrish RH, CS Nelson, A Bakun. 1981. Transport mechanisms and reproductive success of fishes in the California current. Biol. Oceanogr. 1: 175-203.
- Pauly D. 1985. Ecology of coastal and estuarine fishes in South-east Asia: a Philippine case study. In A Yáñez-Arancibia, ed. Fish community ecology in estuaries and coastal lagoons: towards an ecosystem integration. Mexico: DR (R) UNAM Press, pp. 499-514.
- Richards SA, HP Possingham, BJ Noye. 1995. Larval dispersion along a straight coast with tidal currents: complex distribution patterns from a simple model. Mar. Ecol. Prog. Ser. 122: 59-71.
- Rijnsdorp AD, M van Stralen, HW van der Veer. 1985. Selective tidal transport of North Sea plaice larvae *Pleuronectes platessa* in coastal nursery areas. Trans. Am. Fish. Soc. 114: 461-470.
- Robertson AI, NC Duke. 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.
- Robinson CJ, FV Arenas, GJ Gomez. 1995. Diel vertical and offshore-inshore movements of anchovies off the central Baja California coast. J. Fish Biol. 47: 877-892.
- Ross S, S Epperly. 1985. Utilization of shallow estuarine nursery areas by fishes in Pamlico Sound and adjacent tributaries. In A Yáñez-Arancibia, ed. Fish community ecology in estuaries and coastal lagoons: towards an ecosystem integration. Mexico: DR (R) UNAM Press, pp. 207-232.
- Rowe PM, CE Epifanio. 1994a. Tidal stream transport of weakfish larvae in Delaware Bay, USA. Mar. Ecol. Prog. Ser. 110: 105-114.
- Rowe PM, CE Epifanio. 1994b. Flux and transport of larval weakfish in Delaware Bay, USA. Mar. Ecol. Prog. Ser. 110: 115-120.
- Shlossman PA, ME Chittenden Jr. 1981. Reproduction, movements, and population dynamics of the sand seatrout, *Cynoscion nebulosus*. Fish. Bull. 79: 649-689.
- Thurman HV. 1991. Introductory oceanography. New York: Macmillan, pp. 241-268.
- Tsuruta Y. 1978. Field observations on the immigration of larval stone flounder into the nursery ground. Tohoku J. Agricult. Res. 29: 136-145.
- Tzeng WN. 1982. The availability of elvers in relation to tidal periodicity. Chinese Biosci. 20: 15-31.
- Tzeng WN. 1984. Dispersion and upstream migration of marked Anguillid eel, *Anguilla japonica*, elvers in the estuary of the Shuang-Chi River, Taiwan. Bull. Jpn. Soc. Fish. Oceanogr. 45: 10-20.
- Tzeng WN. 1985. Immigration timing and activity rhythms of the eel, *Anguilla japonica*, elvers in the estuary of northern Taiwan, with emphasis on environmental influences. Bull. Jpn. Soc. Fish. Oceanogr. 47/48: 11-28.
- Tzeng WN, YT Wang. 1992. Structure, composition and seasonal dynamics of larval and juvenile fish community in the mangrove estuary of Tanshui River, Taiwan. Mar. Biol. 113: 481-490.
- Tzeng WN, YT Wang. 1993. Hydrography and distribution dynamics of larval and juvenile fishes in the coastal waters of the Tanshui River estuary, Taiwan, with reference to estuarine larval transport. Mar. Biol. 116: 205-217.
- Wang SB, PP Hwang. 1992. Occurrence of fish larvae and juveniles in Tan-Shui estuary, northern Taiwan. J. Fish. Soc. Taiwan 19: 173-182.
- Wang YT, WN Tzeng, SC Lee. 1991. A preliminary study on species composition and seasonal abundance of fish eggs and larvae from the coastal waters adjacent to the Tanshui River estuary, Taiwan. J. Fish. Soc. Taiwan 18: 7-20.
- Weinstein MP, SL Weiss, RG Hodson, LR Gerry. 1980. Retention of three taxa of postlarval fishes in an intensely flushed tidal estuary. Fish. Bull. 78: 419-435.
- Weisberg SB, WH Burton. 1993. Spring distribution and abundance of ichthyoplankton in the tidal Delaware River. Fish. Bull. 91: 788-797.
- Werner EE, JF Gilliam, DJ Hall, GG Mittelbach. 1983. An experimental test of the effects of predation risk on habitat use in fish. Ecology 64: 1540-1548.

臺灣北部淡水河口仔魚之移動與潮汐週期之關係

曾萬年¹ 王友慈¹

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。

¹ 國立臺灣大學動物學系