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Dispersal and Upstream Migration of Marked Anguillid Eel, *Anguilla japonica*, Elvers in the Estuary of the Shuang River, Taiwan*

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Abstract

The elvers collected from the coastal waters off the Shuang River in northeastern Taiwan were marked by fluorescent red dye and released at the captured site. Out of the 4225 marked elvers released in four experiments during the period from December 1982 to March 1983, 1992 (47.15%) were recaptured. Based on the temporal and spatial variations of CPUE of the recaptures, it was found that most of the marked elvers aggregated at the river mouth in the first night after release. They began to migrate upstream slightly afterward. Upstream migration of elvers may be related with the developmental stages and they seemed to undergo physiological change during this short lag time.

1. Introduction

The term "elvers" is herein refered to young eels from the end of metamorphosis in the leptocephalus, which are drifted toward coastal waters and concentrated on estuary. Recently, aquaculture industry of eel was developed. Supply of elvers is insufficient to meet the growing demand. In order to increase the catch of elvers, a lot of researches and studies on the mechanism of elvers migration have been conducted (TESCH, 1977).

There are many hypotheses about the mechanism of upstream migration of the elvers. It has been considered that the elvers do not immediately go upstream when they meet fresh water. They must stay a period of time, until physiological acclimation is completed (DEELDER, 1958). Others believe that the elvers are passively transported by flood tides (CREUTZBERG, 1961). It has also been suggested that recruitment of elvers into freshwater can be distinguished into two behavioural phases, i.e. an initial entrance from the sea, and an upstream migration (JELLYMAN, 1977). In fact, there is distinct difference in developmental stage of elvers collected from coastal waters and river. The good fishing days in coastal waters and in rivers are associated with tidal periodicity (TZENG, 1982). In other words, the elvers have to undergo certain physical and behavioural transitions and to wait for an advantageous environmental condition to go upstream. These inferences are grounded only on the catch statistics and indirect biological measurement. There are no direct evidence, however, to prove them.

Marking experiments of elvers are expected to provide valuable information on their migration route and the process of upstream migration. However, elvers are too small and traditional methods of marking or tagging are difficult to apply. Fortunately, a new technique of marking with fluorescent dye has been developed in Japan (SAKURAI *et al.*, 1979). The dye is effective in marking elvers for about one month. So, I use this new dye to trace the dispersal and upstream migration of elvers.

2. Materials and methods

Among the four kinds of elvers, *Anguilla japonica*, is the most abundant species in Taiwan. A total of 4225 individuals of this species were marked with FX fluorescent dye in four mark-recapture experiments. They were released in the coastal waters off the Shuang River—a traditional fishing grounds of elvers in northeastern Taiwan (Fig. 1) during the season of

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upstream migration from December 1982 to March 1983.

In order to avoid changes of physiological and ecological conditions due to long time stocking, we bought enough number of elvers at one time on a good fishing day in the coastal waters. First, the elvers were stocked in sea water over night, then those active and at primary developmental stage (VA or VB) were selected and marked with saturated solution (0.5 g/liter of sea water) of FX fluorescent dye (SAKURAI *et al.*, 1979). Density of elvers stocked in FX solution is 20 per liter of FX solution and they were placed in the dark for 48 hours. After treatment of FX solution, body color of elvers changed from transparency into red (Plate 1). After the treatment, marked elvers were transfered to sea water and were ready for releasing.

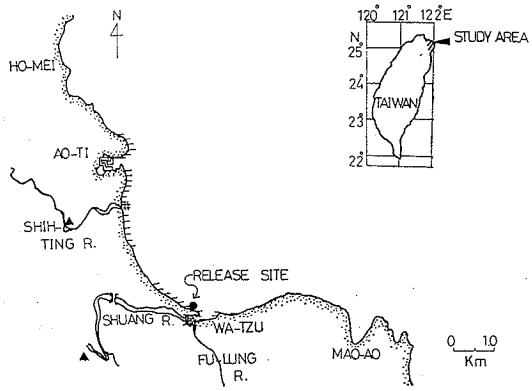


Fig. 1. Map showing the release site and the monitoring stations for the marked elvers. The fishing grounds of elvers are classified in three categories, namely coastal waters (''''''), river mouth (♯) and inner river (♯～▲). ▲ indicates the upper limit of tide influx.

In general, if animals for a mark-recapture experiment have significant diurnal rhythm, releases in their inactive time intervals are considered desirable (SOUTHWOOD, 1965). It is apparent that elvers are active at night. Therefore we released the elvers at about noon. From the night of releasing date, we asked fishermen to record the time of recapture, fishing ground, catch amount and fishing method for the marked elvers. Monitoring area extended to north to Ho-Mei, Ao-Ti, and south to Mao-Ao, and covered major rivers including Shuang River, Fu-Lung River and Shih-Ting River (Fig. 1). The body color of marked elvers was red in the first 2 weeks and was very easy to distinguish (Plate 1). When the color of marked elvers began to fade, we used UV lamp (3600 Å) as an auxiliary to detect them. Under UV radiation, fish bodies of marked elvers were orange colored, and easy to distinguish from unmarked ones.

The catch data of marked elvers were divided into three areas, i.e. coastal waters, river mouth and inner river (Fig. 1) and their CPUE were calculated. Because the fishing gears used in three areas were different, the units of CPUE were also different. The fishing gear used in the coastal waters, river mouth and inner river were man pulling-trawler, set net and dip net respectively. Based on the change of daily CPUE, the movements of marked elvers were studied. In addition, to understand the physical transition during upstream migration, the body length and pigmentation stage (STRUBBERG, 1913) of the recaptured elvers and natural ones were recorded.

Table 1. Release and recapture data for anguillid elvers marked in 1982/1983 season off Shuang River. Locations are given in Fig. 1.

Release date	Release time	Number released	Observation period for recapture	Recaptured in Coastal waters		River mouth		Inner river		Total	
				No.	%	No.	%	No.	%	No.	%
Dec. 17, 1982	12:30 AM	1275	Dec. 17–Jan. 11	497	38.98	16	1.25	75	5.88	588	46.12
Jan. 12, 1983	12:40 AM	1076	Jan. 12–Feb. 11	95	8.83	312	29.00	234	21.75	641	59.57
Feb. 12, 1983	12:00 AM	1100	Feb. 12–Mar. 18	605	55.00	15	1.36	11	1.00	631	57.36
Mar. 19, 1983	8:30 AM	774	Mar. 19–Apr. 1	72	9.30	59	7.62	1	0.13	132	17.05
Total		4225		1269	30.04	402	9.51	321	7.59	1992	47.15

3. Results

(1) Recapture rate

The recapture rate of marked elvers was very high. Out of 4225 elvers released in four experiments 1992 were recoveried (47.15%; Table 1). The recapture rates were very similar in the first three experiments being 46.12%, 59.57% and 57.36% respectively. However, the rate was only 17.05% for the 4th experiment. This drop in the rate may be due to the condition that time of the experiment was near the end of fishing season. Fishermen ceased fishing operation and the returns became few.

The recapture rates also changed with areas. In the first, third and fourth experiments recapture rates were higher in the coastal waters than those in the river mouth and inner river. For the second investigation, recapture rate in the coastal waters was lower than the other two. For the total recoveries from the four experiments, the percentage recapture was higher in the coastal waters than in the river mouth and inner river. The percentage reached 30.04% in the coastal waters, but only 9.51% in the river mouth and 7.59% in inner river (Table 1). It indicated that most of the marked elvers were fished before upstream migration.

(2) Size composition and pigmentation stages

The length frequency distributions of natural elvers collected from the catch in coastal waters, river mouth and inner river through whole fishing season and of the marked ones recaptured from these areas were shown according to area and release time (Fig. 2). The modes of body length of the unmarked natural elvers from different areas were in the same interval of 56–58 mm. It showed that they did not undergo a reduction in body length during upstream migration. The length frequency of the recaptures was very similar to that of the natural ones in each experiment.

The pigmentation stages were measured for unmarked elvers and also for recaptured ones from the same areas mentioned above. Most of the unmarked individuals were in stage VA in coastal waters and river mouth. The pigmentation stage was more advanced in the inner river, ranging from stage VA to VIA. Stage VB was most numerous (Fig. 3). It indicated that developmental stage was similar for the elvers from coastal waters and river mouth, but was more advanced in the inner river. Comparing with that of natural ones from the same area, the pigmentation stages of the recaptures had a similar trend of changes during upstream migration from coastal waters to inner river. Most of the elvers from coastal waters and river mouth were at stage VB, but the stage advanced to VIA_1, VIA_2 for those in the inner river (Fig. 3). In addition, the stages of marked elvers were generally more advanced than that of natural ones from the same area.

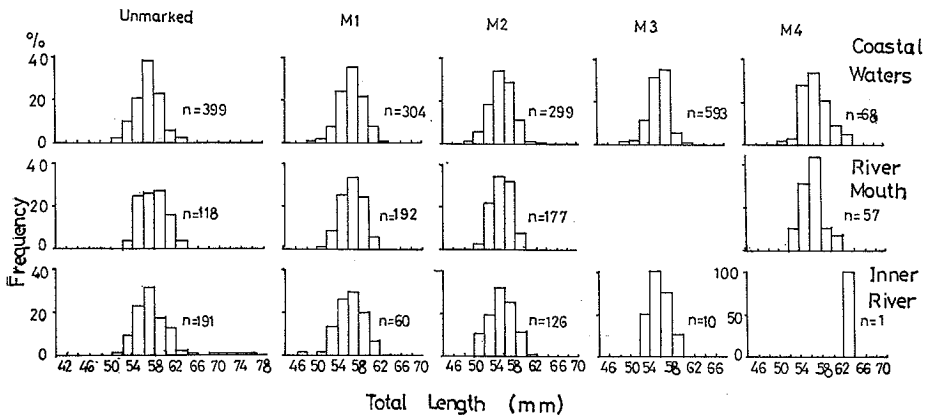


Fig. 2. Comparison of length-frequency distributions of natural (unmarked) and marked elvers (M_1~M_4) caught from coastal waters, river mouth and inner river. M_1~M_4 indicate the marked elvers released off the Shuang River on Dec. 17, 1982, Jan. 12, Feb. 12 and Mar. 19, 1983 respectively. n: sample size.

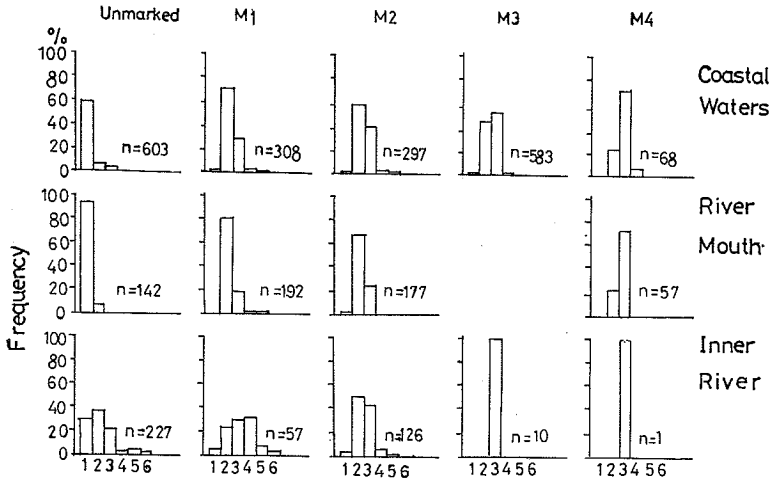


Fig. 3. Changes of frequency distribution of pigmentation stages of natural (unmarked) and marked (M_1~M_4) elvers caught from coastal waters, river mouth and inner river. M_1~M_4 refer to the note in Fig. 2. Pigmentation stages 1-6 indicate stages VA, VB, VIA_1 VIA_2, VIA_3, VIA_4 of STRUBBERG (1913), respectively. n: sample size.

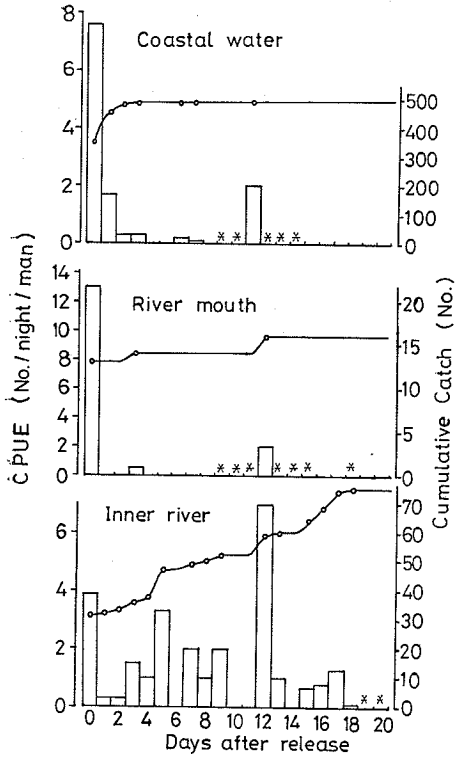


Fig. 4. Changes of CPUE and cumulative catch in the coastal waters, river mouth and inner river for the marked elvers released off the Shuang River at 12:30 AM, Dec. 17, 1982. *: no fishing operation.

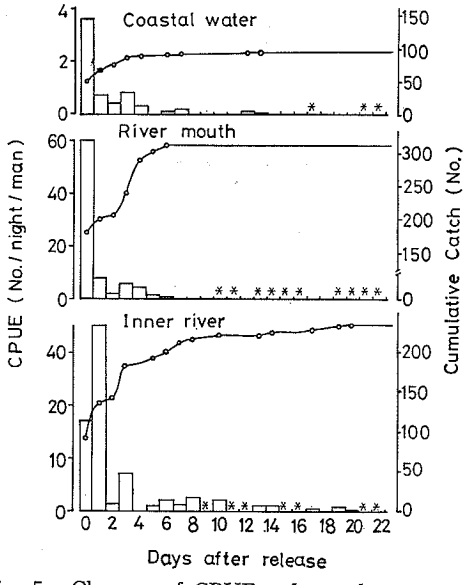


Fig. 5. Changes of CPUE and cumulative catch in the coastal waters, river mouth and inner river for the marked elvers released off the Shuang River at 12:40 AM, Jan. 12, 1983. *: no fishing operation.

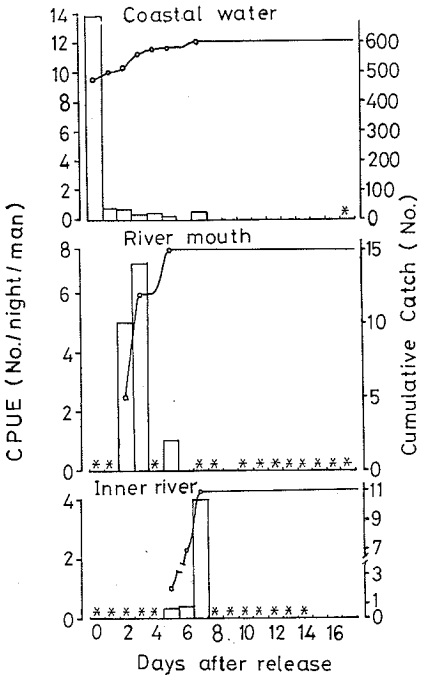


Fig. 6. Changes of CPUE and cumulative catch in the coastal waters, river mouth and inner river for the marked elvers released off the Shuang River at 12:00 AM, Feb. 12, 1983. *: no fishing operation.

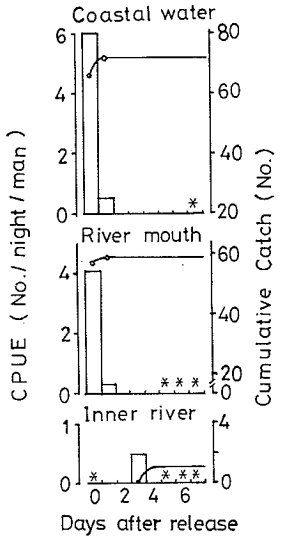


Fig. 7. Changes of CPUE and cumulative catch in the coastal waters, river mouth and inner river for the marked elvers released off the Shuang River at 8:30 AM, Mar. 19, 1983. *: no fishing operation.

Comparing the changes of the length frequency and the pigmentation stages of unmarked elvers with those of recaptured ones, it was suggested that the development of the elvers during their upstream migration are not retarded by marking of fluorescent dye.

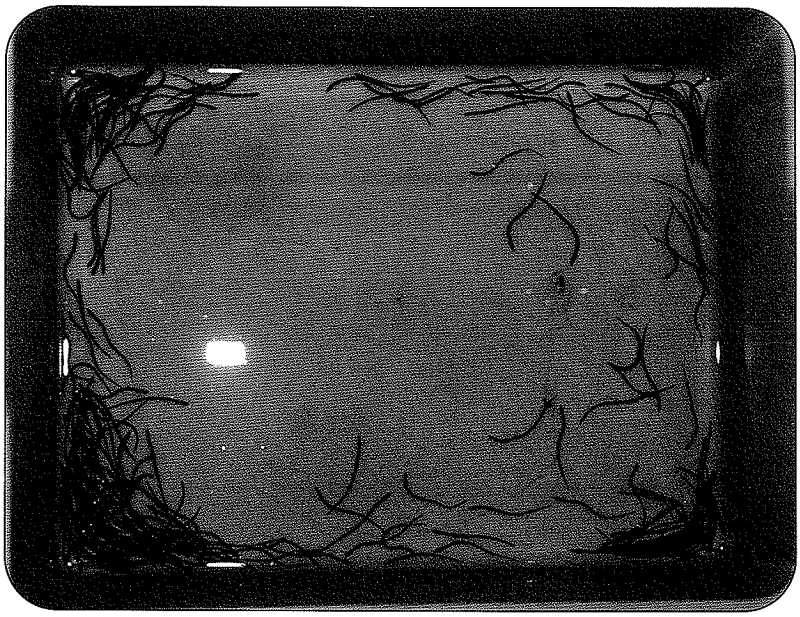
(3) Stay and upstream migration

The stay of the marked elvers in the coastal waters and their speed of upstream migration will be estimated by the daily changes of catch per unit effort (CPUE) and cumulative catch of marked elvers in the coastal waters, river mouth and inner river.

Daily changes of CPUE in the four experiments were similar. In the coastal waters CPUE was high during the night of the release, but decreased abruptly in the following day and continued to decrease in the following week. Beyond one week, there were few elvers found in the coastal waters. Cumulative catch indicated the same trend reaching asymptote at about one week after release (Figs. 4-7; upper panel). Therefore, it was suggested that most of the marked elvers stayed only one day, and very few stayed more than one week in coastal areas.

Daily changes of CPUE of recapture in river mouth were very similar to that in coastal waters (Figs. 4-7; middle panel). Except the 3rd experiment in which no fishing was operated in the first two days after release, CPUE was high at the night of release. It showed that marked elvers aggregated in river mouth during the day of release.

On the other hand, the changes of daily CPUE and cumulative catch in the inner river were significantly different from those in the coastal waters and in the river mouth (Figs. 4-7; lower panel). The catches were delayed and increased gradually. The maximum CPUE did not occur in the first night after release, but on the 12th day in the first experiment and on the 2nd day in the 2nd experiment. For other two experiments, maximum CPUE was not clearly observed because the recaptures were so scarce, but similar trend was suggested. It may be concluded that the marked elvers did not immediately migrate upstream when they aggregated in river mouth.



(Photo 1)

(Photo 2)

Plate 1. Photographs showing the lively marked elvers before releasing (Photo 1) and recaptured elvers (Red) and natural ones (White) fixed in 10 % formaline solution (Photo 2).

(4) Distribution and moving distance

To understand the dispersal of the marked elvers, time of recaptures was grouped into 1st day of releasing and then 5 day intervals for the remaining days and positions of recaptures were plotted on the map. Dispersal of the marked elvers released on December 17, 1982, was shown in Fig. 8. Most of the marked elvers were found in the coastal waters and a few of them migrated upstream into the Shuang River and Fu-Lung River on the day of release. On the 1st–5th days, elvers in the coastal waters apparently decreased but increased in the rivers. Some moved northward to the Shih-Ting River. On the 6th–10th days they moved as far north as to Ao-Ti Harbor and south as to Mao-Ao Bay. On the 11th–15th days, they extended even further to Ho-Mei in the north, and found again from Mao-Ao Bay in the south. After 16 days, elvers were caught continuously at Ho-Mei. It is clear that elvers were widely dispersed from the release site, but most of them migrated upstream to the river located near the releasing site.

For those released on January 12, 1983, the pattern of dispersal and upstream migration was a little different from that of the first experiment on December 17, 1982 (Fig. 9). Most of them entered the Shuang River and Fu-Lung River and only a few were recaptured in the coastal waters during the releasing day. Northern limit of the range was found in the Shih-Ting River. In the period from the 1st to 5th days, most of them were distributed around the Shuang River. Few of them migrated north to Ao-Ti Harbor. For the third (February 12, 1983) and fourth (March 17, 1983) experiments, the patterns of dispersal were similar to that of the second one. Most of them were found around the Shuang River. The distribution was rather limited to the areas around the river mouth (Figs. 10, 11).

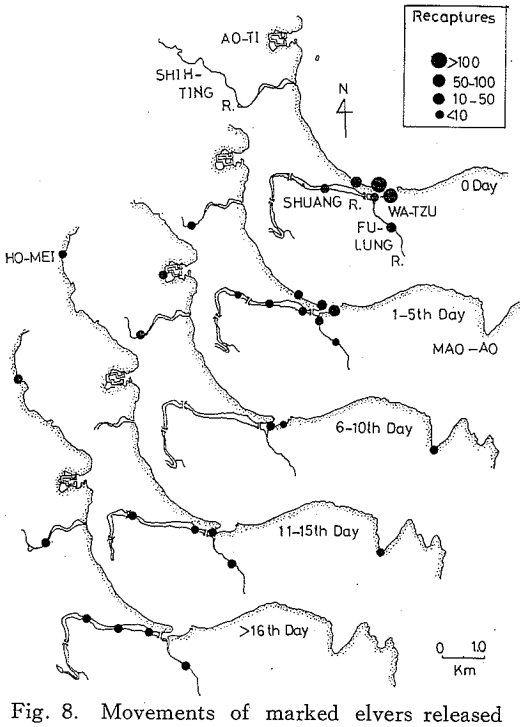


Fig. 8. Movements of marked elvers released in the coastal waters off the Shuang River on Dec. 17, 1982. Black circle: position and the number of marked elvers recaptured.

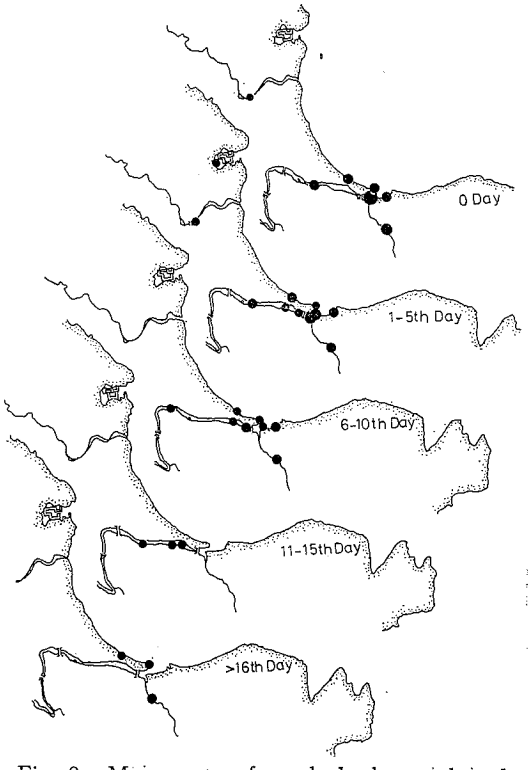


Fig. 9. Movements of marked elvers released in the coastal waters off the Shuang River on Jan. 12, 1983. Black circle: position and the number of marked elvers recaptured.

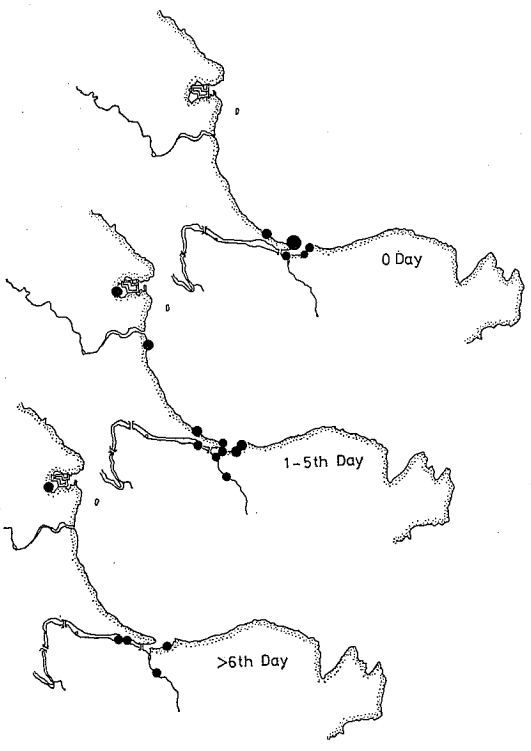


Fig. 10. Movements of marked elvers released in the coastal waters off the Shuang River on Feb. 12, 1983. Black circle: position and the number of marked elvers recaptured.

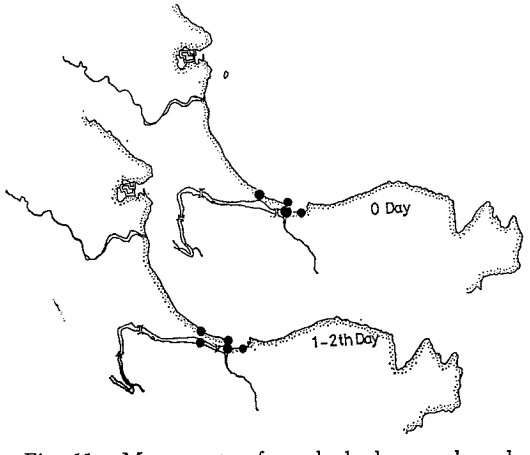


Fig. 11. Movements of marked elvers released in the coastal waters off the Shuang River on Mar. 19, 1983. Black circle: position and the number of marked elvers recaptured.

Table 2. Distances between sites of release and recapture of marked elvers.

Release date	Recaptured				
	Distance (km)			Position	Total
	0-1	1-5	>5	Unknown	
Dec. 17, 1982	561	19	7	1	588
Jan. 12, 1983	611	8	0	22	641
Feb. 12, 1983	522	54	0	55	631
Mar. 19, 1983	132	0	0	0	132
Total number	1826	81	7	78	1992
%	91.67	4.07	0.35	3.91	

The moving distances of the marked elvers were estimated. A total of 1992 elvers were recovered in the four experiments and 91.67 % of them were caught within 1 km from the releasing site, 4.07 % between 1-5 km and only 0.35 % moved more than 5 km (Table 2).

From the above mentioned analyses, it is clear that most of the elvers migrated upstream in the nearmost river, but some of them dispersed to a wide range.

4. Discussion

This was the first field investigation in Taiwan for studying upstream migration elvers by marking technique. The elvers are too small to carry a tag. On the contrary FX fluorescent red dye is a good biological staining for marking elvers and did not cause any observable damage to elvers. Furthermore, the marked elvers could be detected for one month (SAKURAI *et al.*, 1979). In the present investigation, it was found that few of the elvers died and some became slightly inactive during the marking process. After returning to normal sea water, however, they recovered shortly. In addition, the size composition of the recaptured elvers was similar to that of the natural ones, and the pigmentation of the marked elvers continued to develop after releasing (Figs. 2, 3). Therefore, I believe that the recapture data were reasonably representative of the behavior of the elvers during upstream migration.

Data on daily recaptures indicated that elvers dispersed widely in the coastal waters around the releasing site but most of them formed aggregation in mouth area of nearmost river

even at the night of release. However, migration upstream the river was delayed. The stage composition of pigmentation showed corresponding change for the elvers recaptured from different areas. The stage compositions of those recaptured from coastal waters and river mouth were similar, but the stage was advanced for those from inner river. Therefore, it was infered that the elvers underwent physiological change prior to upstream migration as had been reported elsewhere (DEELDER, 1958; JELLYMAN, 1979).

In many cases the marking experiments are carried out *in situ* and the animals are released immediately. In this study, however, it took 2-3 days to prepare the marked elvers (SAKURAI *et al.*, 1979). Since the preparing time was not short enough, pigmentation stage in some of marked elvers was changed from stage VA to VB. Also, during the period of 2-3 days of marking, the tidal condition in the estuary of experimental area was changed. Previous study (TZENG, 1982) indicated that the timing of upstream migration of the elvers was related to tidal periodicity. DEELDER (1958) and JELLYMAN (1979) also demonstrated that the onset of upstream migration was associated with their physiological conditions. Therefore, the changes in physiological stage and tidal level might have some influence on the speed of upstream migration of marked elvers. To avoid these sources of error, development of an instantaneous biological staining technique for marking elvers is necessary in the future study.

Acknowledgements

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Wann-Nian TZENG

雙溪の河口域における標識シラスウナギの拡散と遡河廻游について

曾　萬　年*

河口域におけるシラスウナギの移動状態を明らかにするため，1982年12月から1983年3月まで，4回にわたって，台湾の東北部にある雙溪の沿岸域で捕られた4225個体のシラスウナギを新しい蛍光染色剤で標識して，同地点に放流した。そのうち，1992個体（47.15％）が再捕された。再捕魚の CPUE の時間・空間の変化によって，その移動と遡河廻游が検討された。

標識されたシラスウナギはほとんどが放流当日に河口に集中する傾向を示し，翌日から次第に遡河する傾向が見られた。色素の発達状態の観察から，シラスウナギの遡河には発育段階が関係しており，河口域への集中から遡河までの時間おくれの間に発育段階の変化が進行するように思われた。

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