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Surface Seawater Temperature as A Potential Cause of Delayed Arrival of the Japanese Eel *Anguilla japonica* Elvers on the Coast of Taiwan

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ABSTRACT

The Japanese eel *Anguilla japonica* is one of the most important food fish in Taiwan. For cultivation, elvers of the eel are caught from the wild population in estuaries during their upstream migration. The relationship between recruitment timing of elvers and surface seawater temperature was analyzed based on the daily catch data of elvers in an estuary of northeastern Taiwan since 1980. It was found that most elvers recruited to the estuary during the period from December to January, with a rhythmic activity that follows the lunar cycle. However, the peak recruitment period in the years of 1986-87, 1990-91 and 1995-96 occurred in March, delayed approximately two months. This delay coincided with low temperature years. The low surface seawater temperature, in winter, in the continental shelf area of Taiwan may influence the recruitment period of the elvers in estuaries.

***Key words**: Japanese eel, Elver, Catch, Water temperature, Otolith.*

INTRODUCTION

The Japanese eel, *Anguilla japonica* Temminck and Schlegel, is a catadromous fish. It spawns in the middle Pacific Ocean west of the Mariana Islands, 14-16°N 134-143°E (Tsukamoto, 1992), during June and July (Tsukamoto, 1990; Tzeng, 1990; Tzeng and Tsai, 1994). Its leaf-like larva (leptocephalus) drifts on the North Equatorial Current and Kuroshio Current and metamorphoses to a glass eel in the continental shelf areas of Taiwan, Mainland China, Korea and Japan. Glass eels become pigmented elvers at entry of the estuaries. Elvers are harvested for cultivation or restocking at estuaries in winter during their upstream migration (Tzeng, 1983, 1985, 1986). Eel migration from the oceanic spawning grounds to the estuaries takes 4 to 5 months (Cheng and Tzeng, 1996). The eel lives in rivers for 5 to 12 years (Tzeng *et al*., 2000a). During late autumn when eels become premature, they migrate downstream to the ocean to spawn and die (Tesch, 1977).

The catch of elvers was influenced by many environmental factors in estuaries (such as temperature, salinity, turbidity, pH, stream-water odor, and tidal cycle) as well as by moon phase and rainfall. These factors may act alone or in combination to influence the migration of elvers (Sloane, 1984; Tzeng, 1985; Sorensen and Bianchini, 1986; Tosi *et al*., 1990; Chen Lee *et al*., 1994). Previous research is primarily associated with the upstream behavior of elvers in estuaries. No documents have referred to the environmental factors in the offshore area which may influence the timing of peak recruitment of elvers at estuaries. For successfully harvesting elvers for aquaculture, it is necessary to predict the time of their estuarine arrival.

The transportation of eel larvae from the spawning ground to estuaries involves two development stages, which live in two different current systems. The two stages

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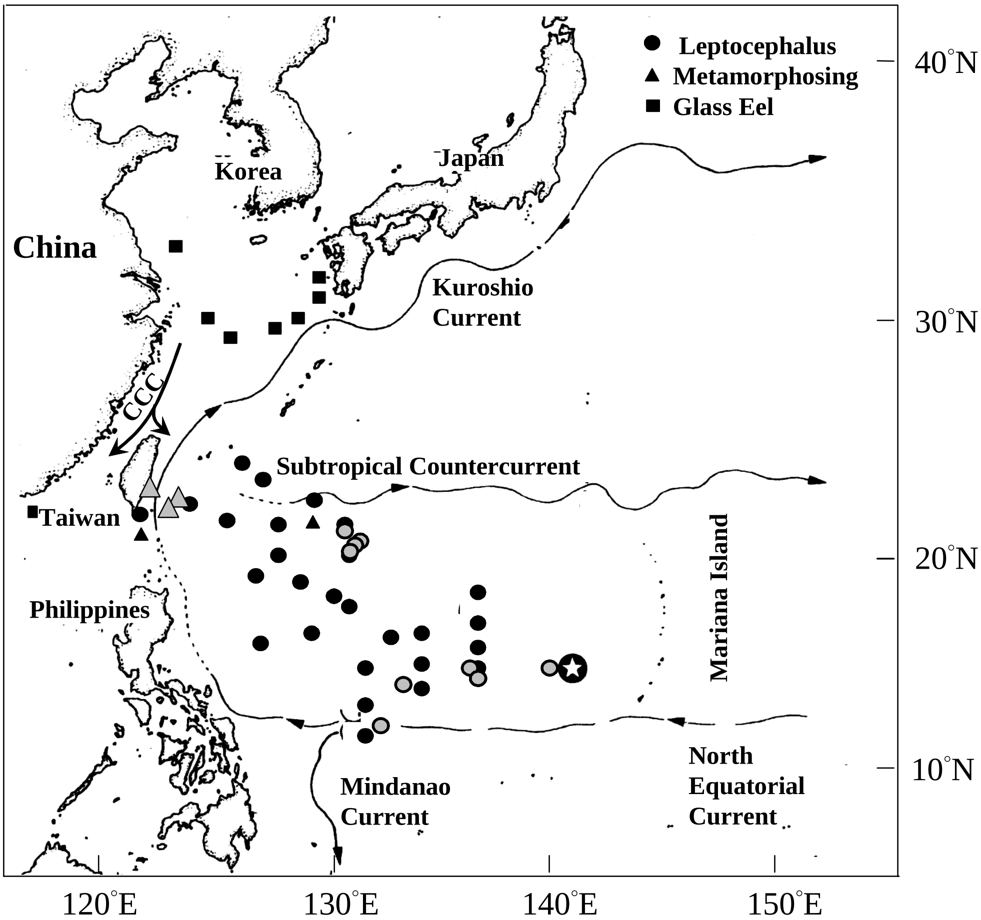

Fig. 1. Oceanic current and dispersal of leptocephali (circle), metamorphosing leptocephali (triangle), and marine glass eels (square) of the Japanese eel *Anguilla japonica* (CCC: China Coastal Current; Star: the presumed spawning ground; Solid symbols: data from Tsukamoto and Umezawa 1990, Tsukamoto 1992; Gray symbols: data from Liao *et al*. 1999 and unpublished) (modified from Tzeng, 2002).

transportation processes are shown in Figure 1. The lepotocephalus stage is transported by the warm North Equatorial Current and the Kuroshio Current from spawning ground to continental shelf. Glass eel stage is transported by the cold coastal current from coastal waters to the estuaries (Tzeng, 1996; Cheng and Tzeng, 1996). The fluctuation of these currents may influence the transportation of eel larvae, and the fluctuation will be reflective of the seawater temperature.

Recently we found that estuarine arrival of elvers was delayed in particular years when surface seawater temperature was lower than other years. This study attempts to clarify the cause and effect of the delayed arrival of elvers in estuaries of Taiwan.

MATERIALS AND METHODS

The daily catches of Japanese eel elvers used in this study was collected in the coastal waters off Shuang-Chi River in the north-eastern Taiwan from 1980 to 1998 (sampling sites refer to Figure 1 of Tzeng (1985)). The elvers are caught daily by a hand trawling net on the coast through out the fishing season (Tzeng, 1985). The catch data collected on the coast are more suitable than those collected in the river mouth and inner river to study whether or not the arrival of elvers is delayed because the elvers collected on the coast are newly recruited (Tzeng, 1985). The catch data were reported from approximately 70 fishermen covering approximately 80% of all the total effort in the studied area.

Eels in the coastal waters of Taiwan include four species, i.e.; *Anguilla japonica*, *A. marmorata*, *A. bicolor pacifica* and *A. celebesensis* (Tzeng, 1982; Tzeng and Tabeta, 1983). The fishermen classify these elvers into white- and black-type according to the pigmentation on the tail (Tzeng, 1983). The white-type which belongs to the elvers of *A. japonica* is sold for eel culture, whereas the black-type which includes the elvers of *A. marmorata*, *A. bicolor pacifica* and *A. celebesensis* has not been cultured in Taiwan. Only the catch data of the white-type were used in this study.

To understand the relationship between delayed arrival of elvers and seawater temperature, annual mean surface seawater temperature in the offshore of the elver's sampling areas, 121-124°E 25-26°N, was calculated from the data of the Integrated Global Ocean Service System Products Bulletin (http://ingrid.ldgo.columbia.edu/SOURCES/.IGOSS/nmc/)

In addition, the hatching date and growth rate of elvers were compared between a delayed year (1996) and a non-delayed year (1998) by examining daily growth increments in otoliths. The procedure of otolith preparation for daily growth increment examination and age determination is the same as previous studies (Tzeng, 1990; Tzeng and Tsai, 1994; Cheng and Tzeng, 1996).

RESULTS

1. Daily changes of elver catch

Daily catch of the Japanese eel elvers in the coastal waters off Shuang-Chi River in the years of 1985-88, 1989-1992 and 1994-1997 was selected for analysis because surface sea water temperature decreased abnormally in these years (Figures 2a, b, and c). It was found that maximal daily catches of elvers were delayed in the years of 1986-87, 1990-91, and 1995-96. In normal years, the maximal daily catch of elvers occurred around December and January, but around March in the delayed years. This difference is approximately 2 months.

On the other hand, regardless of regular or delayed years, the catch of elvers reached a peak with an interval approximately one month. This was due to the rhythmic activity of elvers in the coastal waters that follows the lunar cycle of new moon. This phenomenon was similar to the previous study (Tzeng, 1985).

2. Delayed arrival of elvers and surface seawater temperature

Monthly change of surface seawater temperature off northeastern Taiwan (121-124°E 25-26°N) for the above mentioned years were shown in Figure 3. In comparison with the seasonal change of the elver catch (Figure 2), it was found that elvers recruited to the estuary in the low surface seawater temperature winter. Furthermore, it was found that the years of delayed arrival always occurred in the low water temperature years, e.g. in 1986, 1990 and 1995 (Figure 4). This indicates that the delayed arrival of elvers was related to surface seawater temperature.

3. Comparison of hatching dates and growth rate of elvers between years

Of elvers which arrived at estuaries in January, daily ages, hatching dates, and growth rates were all similar between 1996, a delayed arrival year, and 1998, a non-delayed arrival year (Figures 5-8). This indicates that elvers that hatched at the same time will arrive at the estuary simultaneously.

DISCUSSION AND CONCLUSION

The phenomenon of delayed arrival of elvers on the coast of Taiwan was found also in Japan (Yanagizawa, 1999; personal communication). The causes of the dely may stem from both biotic and abiotic factors. Biotic factors may involve the changes of spawning location and time. Abiotic factors

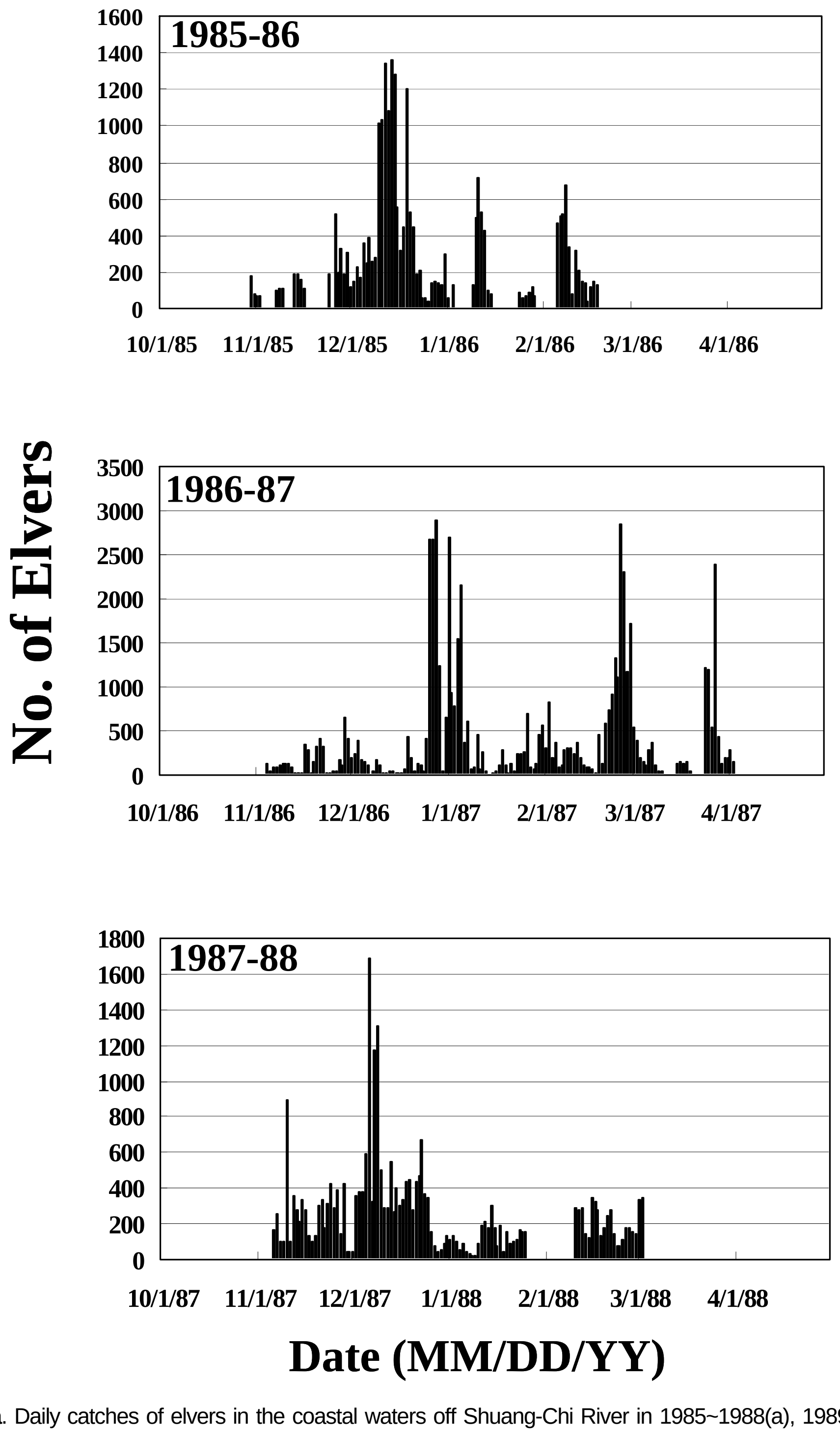

Fig. 2a. Daily catches of elvers in the coastal waters off Shuang-Chi River in 1985~1988(a), 1989~1992(b), and 1994~1998(c).

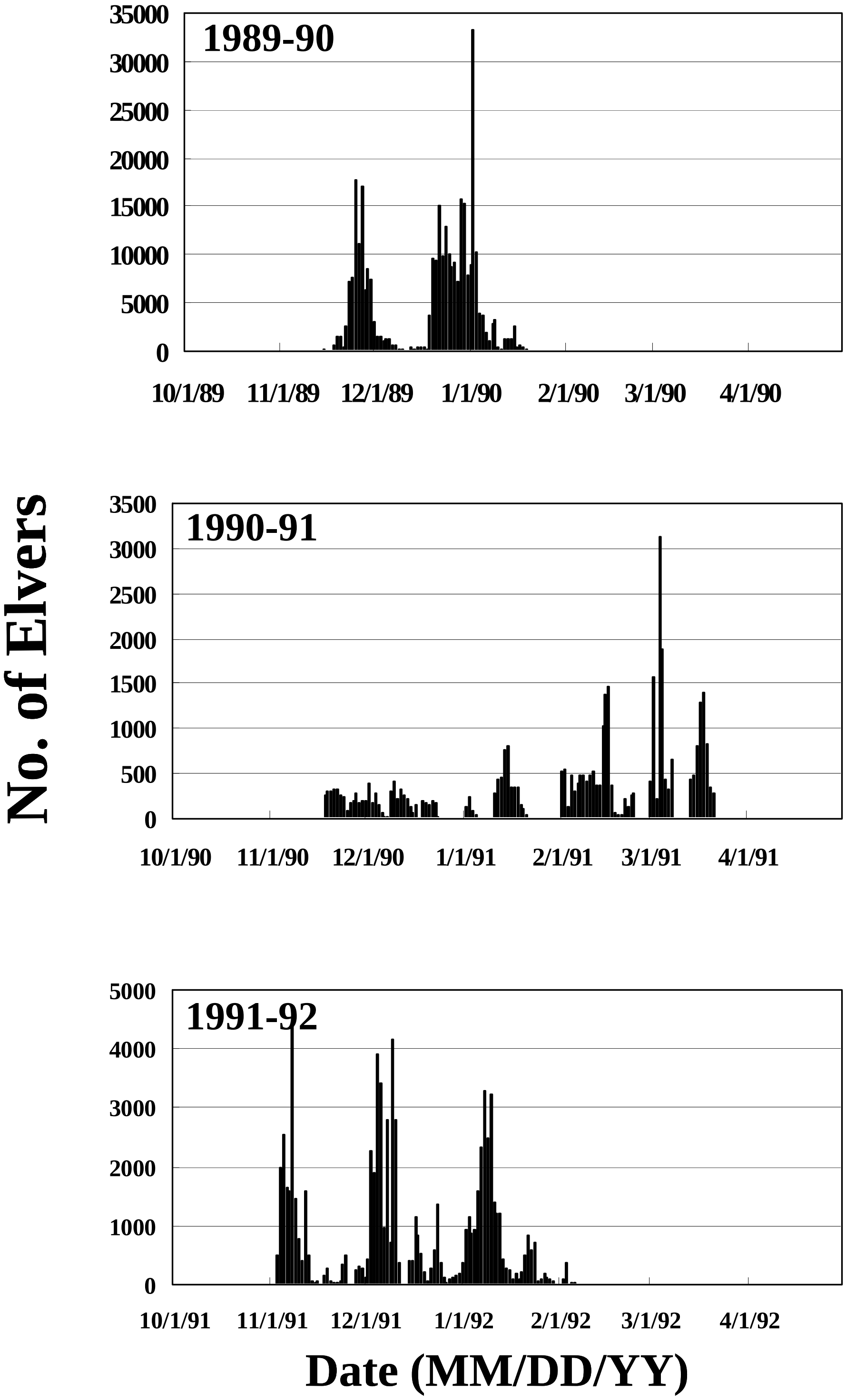

Fig. 2b. Daily catches of elvers in the coastal waters off Shuang-Chi River in 1985~1988(a), 1989~1992(b), and 1994~1998(c).

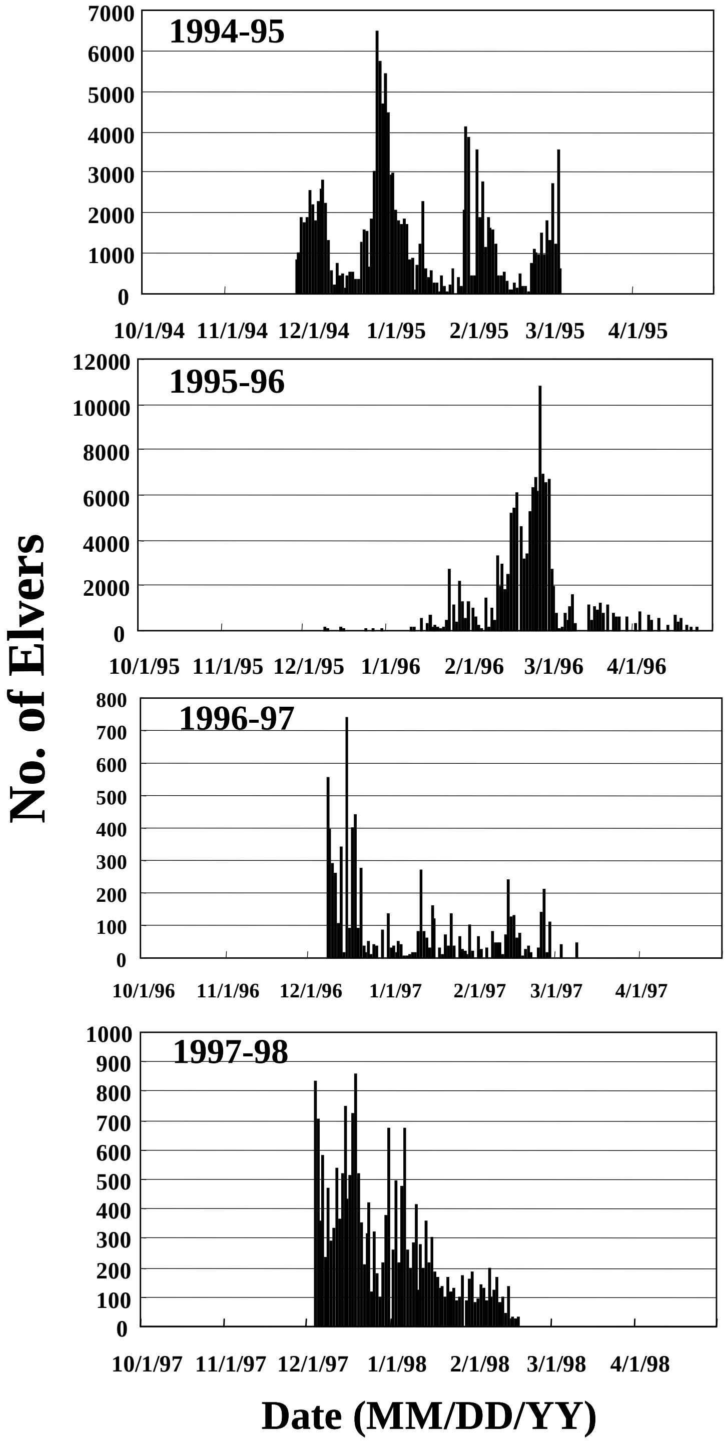

Fig. 2c. Daily catches of elvers in the coastal waters off Shuang-Chi River in 1985~1988(a), 1989~1992(b), and 1994~1998(c).

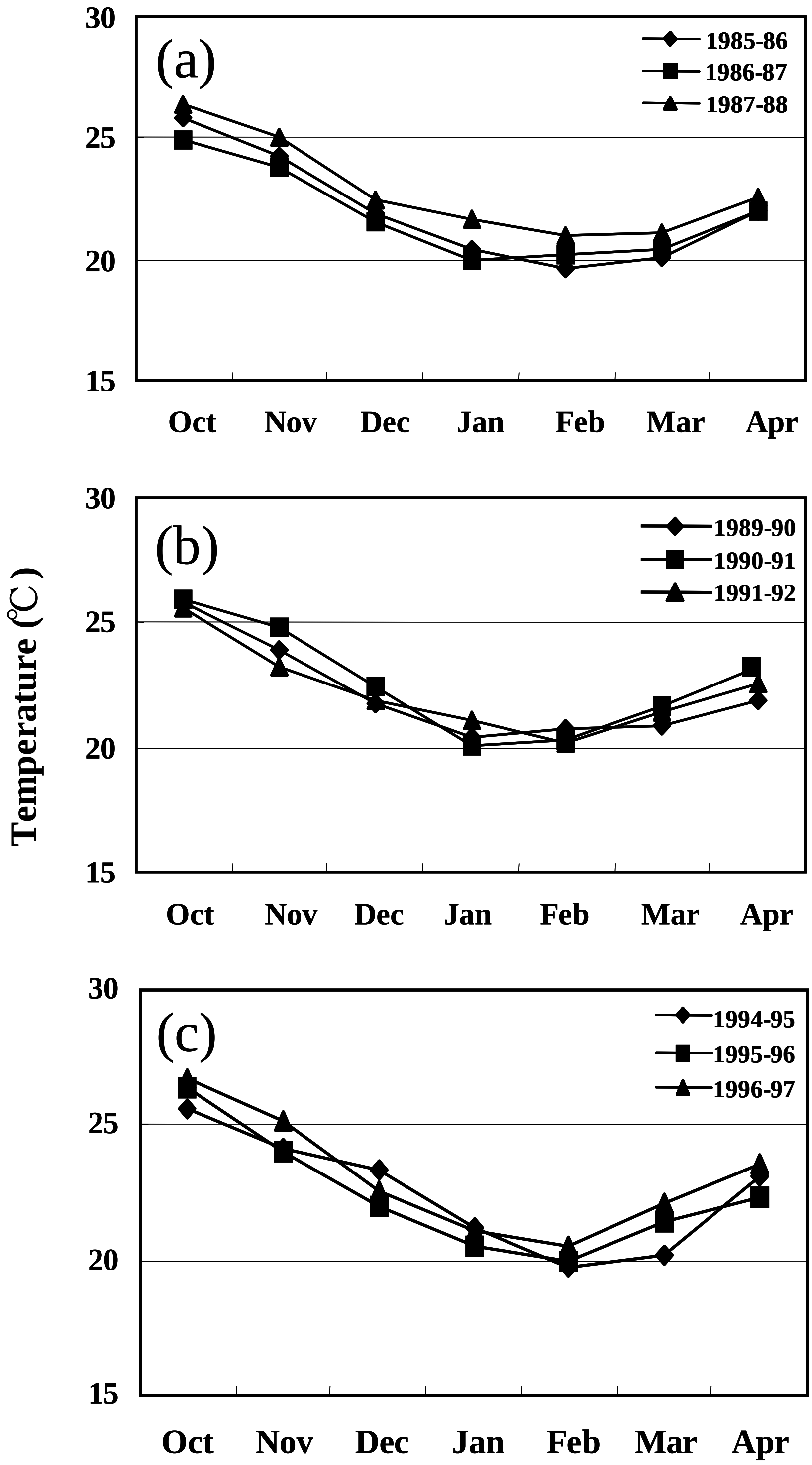

Fig. 3. Mean monthly surface seawater temperature in the offshore area of northeastern Taiwan in 1985~1988(a), 1989~1992(b) and 1994~1997 (c).

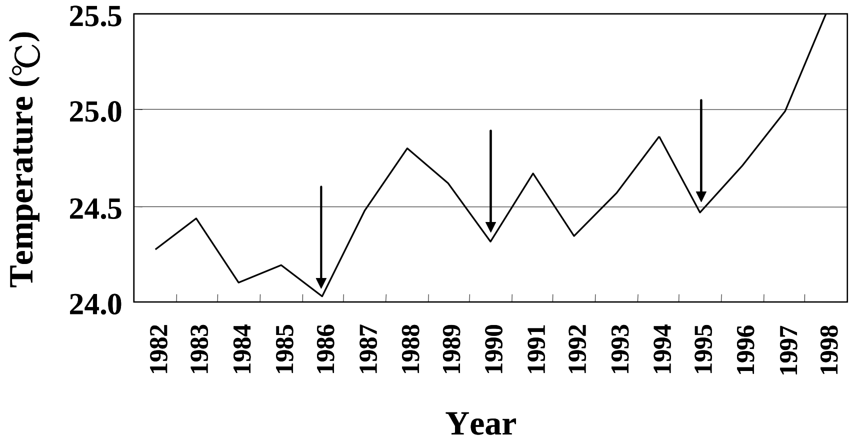

Fig. 4. Mean annual surface seawater temperature in the offshore area of northeastern Taiwan, 1982~1998. Arrows indicate the delayed arrival years of elvers.

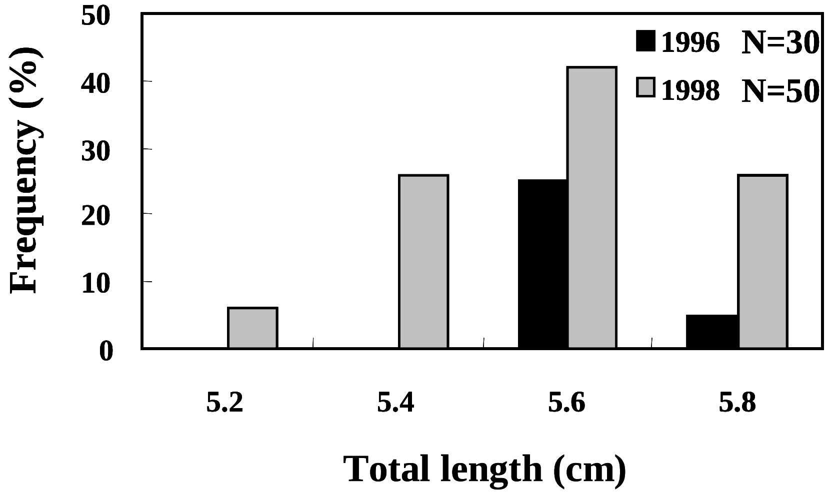

Fig. 5. Frequency distribution of total lengths of elvers collected in the January of 1996 and 1998.

may involve advection of the current that transported the leptocephalus from the spawning ground to the continental shelf, and those that transported glass eel from coastal waters to the estuary.

The Japanese eel spawns in the waters west of Mariana Islands (Tsukamoto, 1992) and its larva (leptocephalus) drifts on the North Equatorial Current to the west and then turns northwards to connect to the Kuroshio Current by Ekman transport (Kimura *et al*., 1994). A recent study indicated that Ekman transport might change from northward to southward during El Niño years (Kimura *et al*., 1999). Meanwhile, the salinity front where the eel spawns may also shift southward during El Niño. These changes in abiotic factors may influence the movement of leptocephalus from the spawning ground to the continental shelf. Both the North Equatorial and Kuroshio Current are warm and highly saline. The decrease of surface seawater temperature in the waters off northeastern Taiwan may be a result of the weakening of the current that transported the leptocephalus and, thus, lead to the delayed arrival of leptocephalus off the

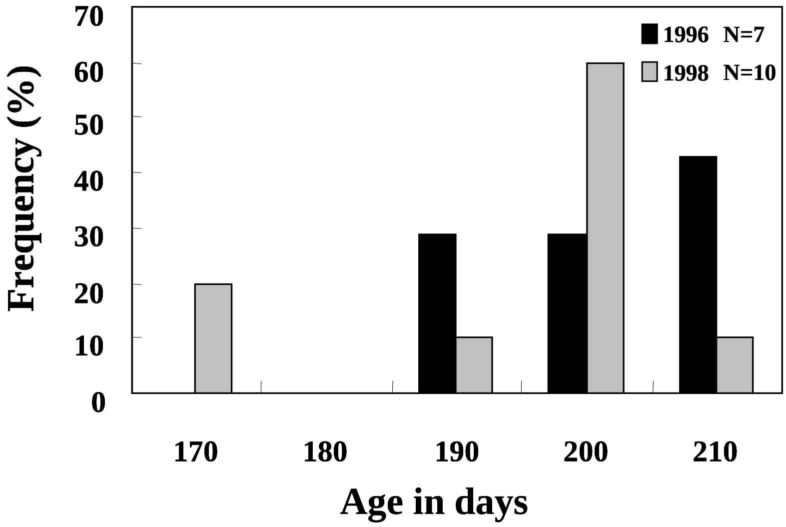

Fig. 6. Frequency distribution of daily ages of elvers at estuarine arrival in January of 1996 and 1998.

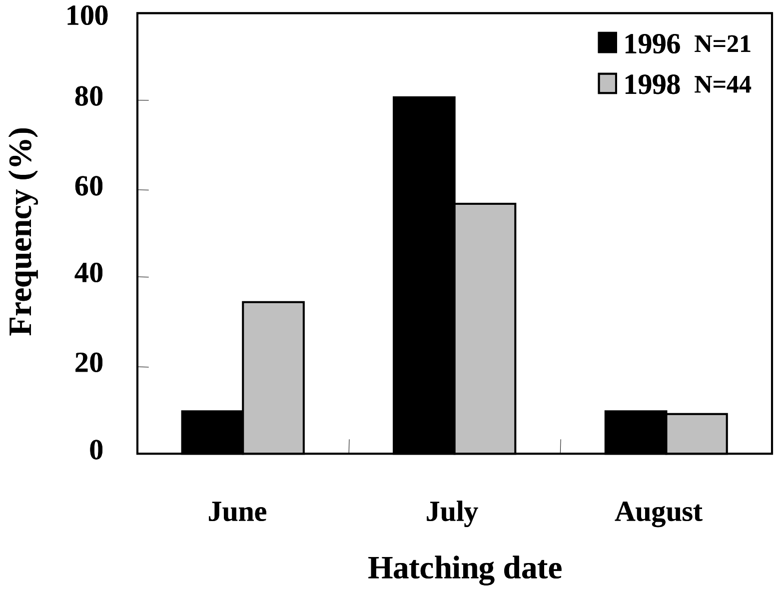

Fig. 7. Frequency distribution of hatching dates of elvers collected in January of 1996 and 1998.

continental shelf of Taiwan.

On the other hand, glass eels were transported by the cold China Coastal Current from the continental shelf to the coast of Taiwan (Tzeng, 1996). The lower mean surface seawater temperature may indicate that the duration of the cold China Coastal Current in the waters off Taiwan was longer due to the weakening of the Kuroshio, allowing thus the fishing season of elvers to be extended. A previous study indicated that the date of peak catch matched the date of lowest water temperature (Tzeng, 1985). Accordingly, the delayed arrival of elvers on

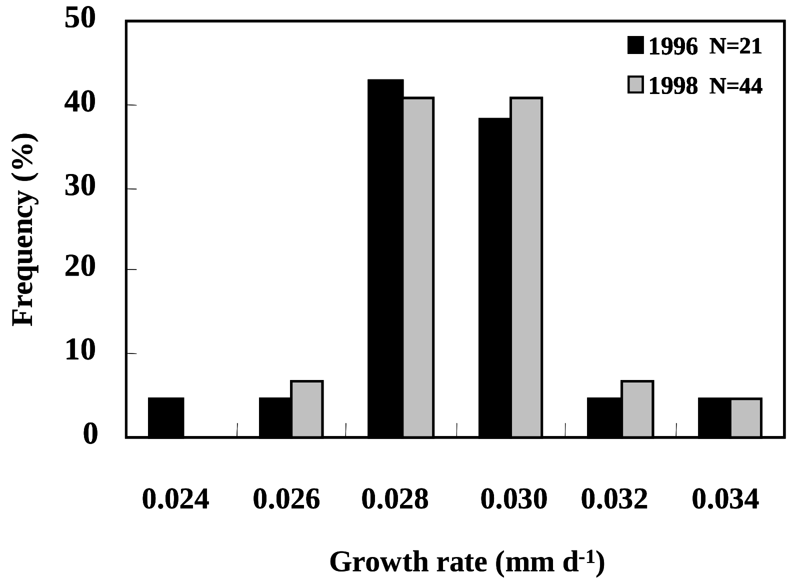

Fig. 8. Frequency distribution of growth rates of elvers collected in January of 1996 and 1998.

the coast of Taiwan was related to the change of current.

A previous study indicated that the early-hatched and fast-growing larvae recruited to the estuary earlier than those that were late-hatched and slow-growing (Tzeng, 1990; Cheng and Tzeng, 1996). To understand if the spawning season and growth rate of eel larvae influence the delayed arrival of elvers, the hatching date distribution and growth rate of the elvers were compared. However, they are similar between delayed (e.g. 1996) and non-delayed arrival years (e.g. 1998). In addition, the age and size of leptocephalus investigated in August of 1995, between their spawning ground and the Philippines, increased from west to east. This indicates that the leptocephalus could drift with the eastward currents, which opposes the normal westward transportation of larvae (Kajihara, 1988; Ozawa *et al*., 1992; Liao *et al*., 1996). These results indicate that abiotic factors are the principal cause of delayed arrival of elvers on the coast of Taiwan.

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海水表層溫度是導致日本鰻鰻線延遲到達台灣沿岸之可能原因

曾萬年

(2006 年 3 月 8 日收件；2006 年 4 月 23 日修正；2006 年 4 月 25 日接受)

日本鰻為台灣最重要的食用魚類之一。為了養殖的目的，漁民於河口域捕獲即將溯河的野生鰻線族群。本研究根據 1980 年以來，台灣東北部雙溪河口的每日漁獲量資料，分析鰻線入添的時機與海水表層溫度之關係。結果發現鰻線於每年的十二月至隔年的一月大量入添至河口域，漁獲量呈現月週期的律動現象。1986-87、1990-91 及 1995-96 三個漁期，鰻線的漁獲量高峰出現在三月，較正常年延遲約二個月。鰻線的延遲入添，發生在低水温的年度，表示冬季台灣沿岸陸棚區的低水温可能是影響河口域鰻線之入添時期的主要原因。

關鍵詞：日本鰻，鰻線，漁獲量，水温，耳石。

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