

Resource and Ecology of Elvers of the Japanese Eel *Anguilla japonica* in Taiwan

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Japanese eel, Anguilla japonica, is one of the most important cultured species in Taiwan. For cultivation, elvers found in estuaries are overfished and, thus, the eel population in inland waters has consequently decreased. This study reviews (1) the status of the eel elver resources in Taiwan, (2) the distribution of elvers on the coast of Taiwan in relation to current system, (3) biological rhythms of the elvers at upstream migration and the zeitgeber, and (4) the possible mechanism of the worldwide decrease in elver catch. These basic studies on the ecology of elvers are useful in the management of eel resources.

Key words: Japanese eel, Elver resources, Taiwan.

INTRODUCTION

The Japanese eel, *Anguilla japonica* Temminck and Schlegel, is distributed from the Philippines through Taiwan, mainland China, Korea, and north to Japan (Tesch 1977). It is a commercially important cultured species in Asian countries (Tzeng 1985). The eel spawns in the middle of the Pacific Ocean west of the Mariana Islands (14-16°N, 134-143°E) (Tsukamoto 1992) in June and July (Tsukamoto 1990; Tzeng 1990). Its leaf-like larva (leptocephalus) drifts with the North Equatorial and Kuroshio currents, metamorphoses to a glass eel as it approaches the continental shelf, and becomes an elver upon entering estuaries. Migration from the oceanic spawning grounds to estuaries takes 4 to 5 months (Tzeng and Tsai 1992, 1994). Eels remain in rivers for 4 to 10 yrs (Tzeng *et al.* 2000). During late autumn, when eels become premature, they migrate downstream to the ocean to spawn (Tesch 1977). Recently, it has been found that some elvers do not undergo an upstream migration; instead, they may remain in brackishwater until the silver eel stage (Tsukamoto *et al.* 1998; Tzeng *et al.* 1998; 2000).

Numerous studies on the Japanese eel have been conducted to determine spawning period and timing of metamorphosis and estuarine arrival (Tabeta *et al.* 1987; Tzeng 1990; Umezawa and Tsukamoto 1990; Cheng and Tzeng 1996), population structure (Tzeng and Tsai 1992; 1994; Liu and Liao 1995; Sang *et al.* 1994), timing of estuarine immigration in relation to environmental conditions

(Tzeng 1984a; 1985; Chen *et al.* 1994), fishing exploitation rates (Tzeng 1984b), and otolith microchemistry and migratory history (Otake *et al.* 1994; Tzeng 1994, 1995; Tzeng 1996a).

For cultivation and restocking, elvers are harvested in estuaries during their upstream migration (Tzeng 1983b, 1985, 1986); thus, elvers are overharvested by many overlapping cross-river nets fixed at river mouths. In the rivers of Taiwan, the Japanese eel population has significantly decreased (Tzeng *et al.* 1994). For conservation of eel resources, a base line study of elver ecology is essential. This paper reviews 1) the species composition of the anguillid eels in Taiwan, 2) the catch and demand of elvers in Taiwan, 3) the distribution of elvers in relation to the coastal current, 4) upstream behavior of elvers, and 5) global changes in catch of elvers of the Japanese, European, and American eel.

SPECIES AND SIZE COMPOSITION

There are four species of anguillid eel in Taiwan (Tzeng 1982, 1983a, b; Tzeng and Tabeta 1983); *Anguilla japonica* Temminck and Schlegel, *A. marmorata* Quay and Gaimard, *A. bicolor pacifica* (Schmidt) and *A. celebesensis* Kaup. *A. japonica* is the major species, making up 93-99% of the total elver catch, followed by *A. marmorata* (1-7%). The other two species are very rarely caught (Tzeng *et al.* 1995). *A. japonica* is a temperate species, while the other three species are tropical (Tesch 1977). This indicates that eels in the

rivers of Taiwan are primarily composed of the temperate species, *A. japonica*.

The size of elvers differs among species. The size of *A. japonica* at estuarine arrival is approximately 56 mm, which is significantly greater than those of the remaining anguillids (46-52 mm) (Fig. 1).

DISTRIBUTION OF ELVERS IN RELATION TO COASTAL CURRENT

The oceanic current systems are different between the east and west coasts of Taiwan. Elvers are most abundant in the north and west coastal waters than in coastal waters of the east, indicating that glass eels migrate to Taiwan with the cold

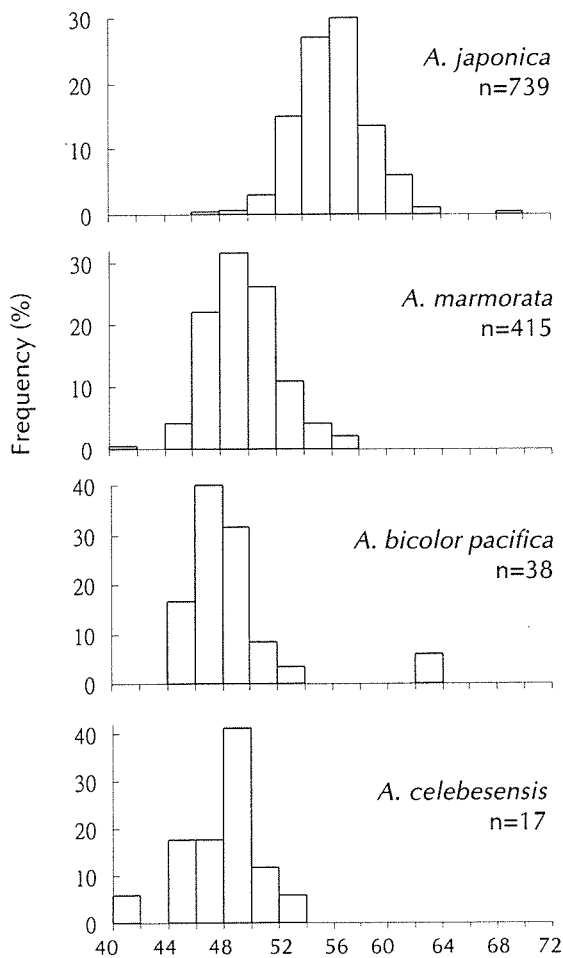


Fig. 1. Frequency distribution of total length of *Anguilla japonica*, *A. marmorata*, *A. bicolor pacifica*, and *A. celebesensis* (n = sample size).

China Coastal Current (Fig. 2). This is also validated by immigration of elvers in the coastal waters which reaches a peak during the period of lowest winter water temperature (Tzeng 1985), and that the daily age of elvers at estuarine arrival, along the west coast, is older in the south than in the north (Cheng and Tzeng 1996).

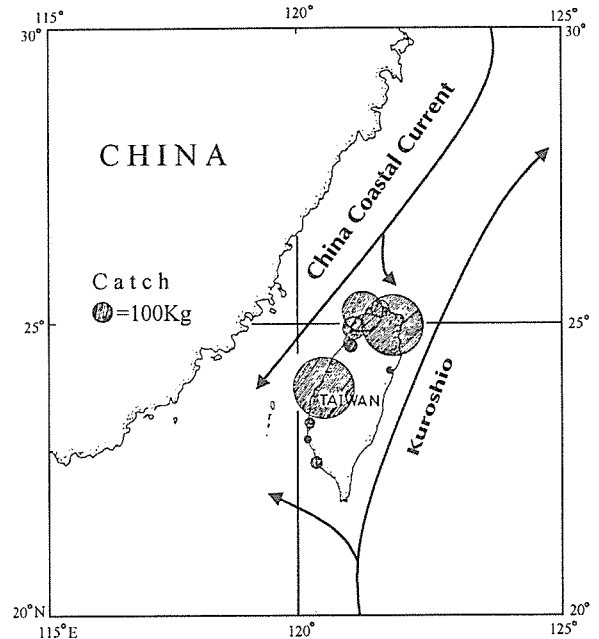


Fig. 2. Relationship between oceanic current and distribution of elvers on the coast of Taiwan during the month of January (after Chu 1963 and Chen 1975).

TIMING AND ACTIVITY RHYTHMS OF UPSTREAM-MIGRATION OF ELVERS IN THE ESTUARY

The maximum catch of elvers in coastal waters appears to be correlated with water temperature and often occurs on or several days after the lowest daily seawater temperature has been reached in the winter. The minimum water temperature was recorded at 15-16°C (Tzeng 1985).

The activity rhythm of elvers in coastal waters follows the lunar cycle. The peak catch occurs only once a month, around the time of the new moon phase. In contrast, a semilunar rhythm of elvers in the rivers has been observed; two peak catches occur in each lunar cycle, one around full moon and the other around new moon. The semilunar rhythm in rivers corresponds to the spring tide. However,

moonlight seemed to play a role in superimposing the tidal effect by inhibiting elver activity in coastal waters during the full moon period (Tzeng 1985).

The difference in activity rhythms of elvers in coastal waters and in inland rivers may be explained by the pigmentation of the elver. Most elvers in coastal waters are at stage VA, without pigments on the top of the head. Thus, elvers are sensitive to moonlight and in turn, during full moon, remain at the bottom of coastal waters where they were inaccessible to fishing gears. Thereafter, elvers advance to the VB stage, with pigments on the head. Since river water is turbid and elvers at this stage are not sensitive to moonlight, there is an upstream migration following the spring tide. Accordingly, the activity rhythm of elvers in river systems follows a semilunar cycle.

CATCH AND DEMAND OF ELVERS

The demand of elvers for eel farming in Taiwan has increased since the eel aquaculture industry was developed in 1965 (Fig. 3). Regression coefficient (b) of demand (y) on year (t) by the trend analysis of $y = a + bt$ was highly significant ($p < 0.0001$), but that of catch on year was not significant ($p > 0.8$). The correlation coefficient (r) between catch and demand was also not significant ($r = 0.04$, $F = 0.045$, $p > 0.05$). These statistics indicate that the fluctuation in elver catches is a natural phenomenon and is not related to the increasing demand. The supply of elvers for farming has been

seriously insufficient to meet the demand since 1971 (Fig. 3).

On the other hand, the catches of elvers in Taiwan showed a periodic fluctuation from 1967 to 1997 with peak catches in 1969-70, 1978-79, and 1990-91 (Fig. 3). The periodogram shows that catch fluctuated in cycles of approximately 10, 4.3, 2.7, and 2.1 years (Fig. 4). The period of the 30-year cycle is negligible since the time series is 30 years long. The periods of 10, 4.3, and 2-3 years correspond to the periods of increased sunspot activity, Kuroshio and ENSO (El Niño – Southern Oscillation).

GLOBAL CHANGE IN THE CATCH OF ELVERS

The elver resources of the Japanese eel are used by Taiwan, mainland China, Korea and Japan. Among these countries, Japan has the longest history of eel fisheries and an overwhelmingly higher catch than that of the other countries (Tzeng 1996b). The catch data from Japan was considered appropriate for evaluating the long-term fluctuations of elver resources.

In the years of 1972 to 1997, the catch of Japanese eel elvers in Japan reached a peak in 1979, and thereafter, gradually decreased until recent years. Catches of American eel and European eel also declined since 1979 (Castonguay *et al.* 1994a, b). This indicated that the fluctuation of elver catches was synchronous in both the Pacific and Atlantic Oceans (Fig. 5).

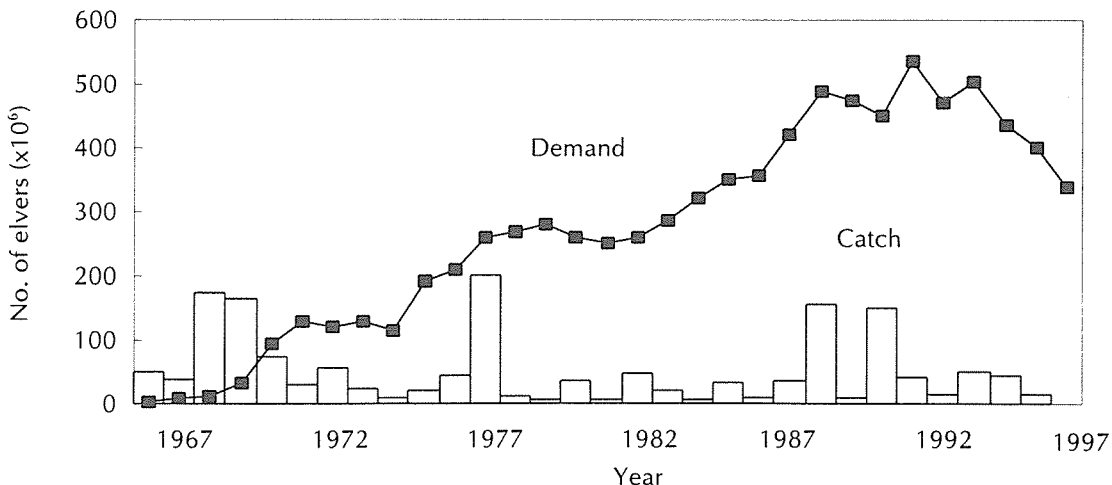


Fig. 3. Catch and demand of elvers in Taiwan from 1967 to 1997.

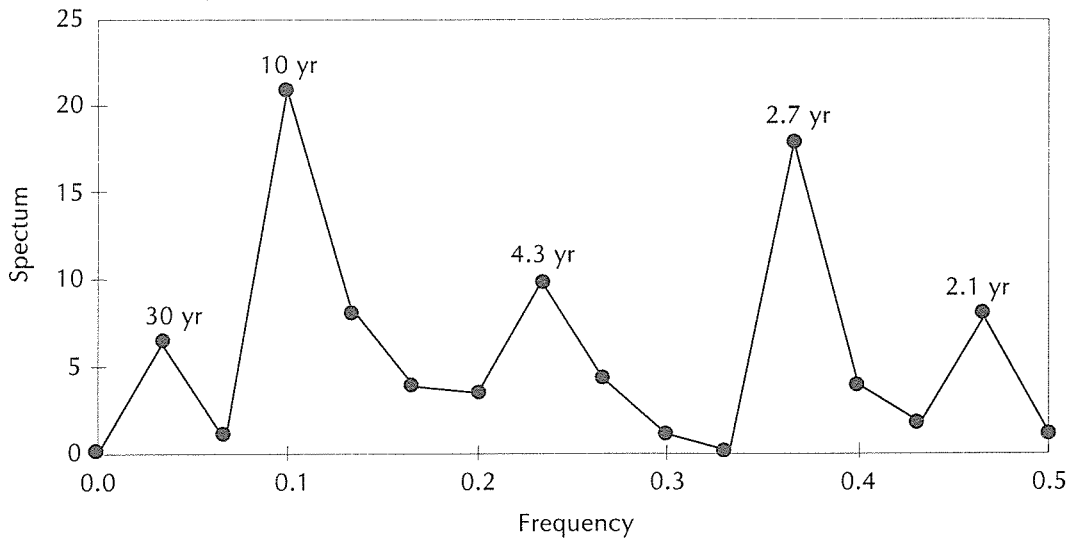


Fig. 4. Periodogram of the catch-time series of elvers in Taiwan. Data of the catch is as in Fig. 3.

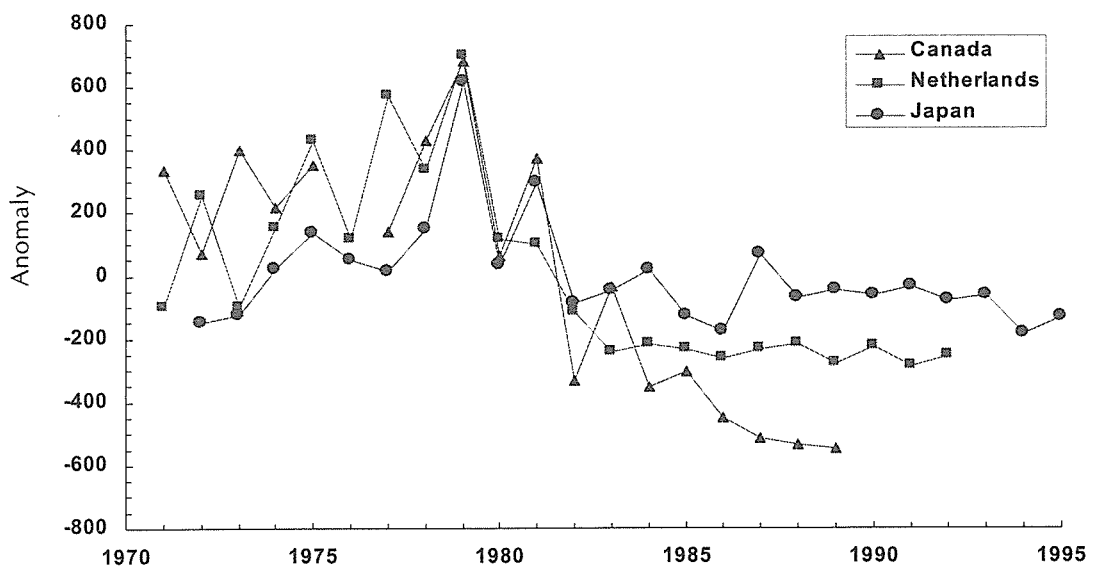


Fig. 5. Anomaly (Δx_i) of the annual catch of elvers for the Japanese eel in Japan, American eel in Canada, and European eel in the Netherlands (Castonguay et al. 1994b; Tzeng 1997). $\Delta x_i = x_i - \bar{x}$, x_i is the catch in the i th year, and \bar{x} the overall mean

DISCUSSION

According to eel farming areas and restocking density, the demand of elvers in Taiwan is estimated to be approximately 50 mt per year. However, the catch of elvers in Taiwan averages 10 mt only per year (Fig. 3). The catch is insufficient to meet the demand. The exploitation rate of elvers in Taiwan is very high, approximately 47.15% (Tzeng 1984b). Accordingly, increasing the catch can not

meet the demand either. For restocking, elvers are imported from other countries. However, elver catch has decreased worldwide. Recently, mainland China expanded their scale of eel aquaculture. This has led to increased difficulties of elver imports to Taiwan. The eel restocking areas in Taiwan have been reduced in recent years. To solve the deficiency of elvers of Japanese eel, the cultivation of other temperate eels, e.g. European eel, American eel and Australian eel, is suggested.

Among Asian countries, Japan has the highest eel elver catch, which reached a peak in 1979, but has drastically decreased since then (Fig. 5). The long term rise and fall of catch statistics corresponded with those of the American and European eels (Castonguay *et al.* 1994b). It has been hypothesized that the decrease in the catch of elvers of American and European eels is a result of a weakened Gulf Stream, which transports larvae from the spawning grounds in the Sargasso Sea to the Atlantic coasts of North America and Europe (Castonguay *et al.* 1994a, b). The Kuroshio, which transports Japanese eel larvae in the western Pacific, was reported to fluctuate at a cycle of 4 to 5 years. The catch of elvers in Taiwan fluctuated in cycles of 10, 4.3 and 2-3 years, which correspond to the activity period of sunspots, Kuroshio, and El Niño southern oscillation, respectively. This indicates that the fluctuation of the catch of elvers of Japanese, American, and European eels may be due to the fluctuation of oceanic currents, which are linked to global climatic changes.

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