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Stock Status and Management Prospect of the Freshwater Eels *Anguilla* spp. in Taiwan

Abstract

To understand the population status of the anguillid eels in Taiwan, the species composition of eel caught by a bamboo trap in seven rivers of Taiwan was investigated and the catch data of both elver and adult eel in Taiwan Fisheries Yearbooks were analyzed by spectral analysis and cross correlation. *Anguilla japonica* was the most abundant among the four species identified, making up 89.8 % of the total catch, followed by *A. marmorata* (9.6 %), and *A. bicolor pacifica* (0.6 %). *A. celebesensis* were rare. *A. japonica* tended to be distributed downstream while *A. marmorata* upstream. The catch of both elvers and adults showed a cyclic change in the interval of 7 and 11 yrs. There is a close correlation between the catch of elvers and the adults. The reduction of elver catch in the estuary can increase the population of the adult eels in the river.

Key words: Stock status, Freshwater eels, *Anguilla* spp.

There are fifteen species and three subspecies of freshwater eels in the genus *Anguilla* Shaw of the family Anguillidae[1,2]. According to previous studies, there are four eel species, *A. japonica* Temminck & Schlegel, *A. marmorata* Quay & Gaimard, *A. bicolor pacifica* (Schmidt), and *A. celebesensis* Kaup, that could be found in Taiwan[3-5]. *A. japonica* is a temperate species; the other three species are tropical ones. Only *A. japonica* elvers are harvested for eel aquaculture in Taiwan. Due to the increasing demand of elvers for restocking, the elvers in the estuary of Taiwan were overexploited since the eel aquaculture industry was established in 1965.

Several aspects on the resources and ecology of the elver of *A. japonica*, including catch and the timing of estuarine immigration in relation to environmental cues[6,7], fishing exploitation rates[8] daily age and birth date[9], larval migration[10,11], stock identification[12,13], otolith microchemistry and migratory environmental history[14-16], were well investigated. However, little is known concerning the resources and ecology of the adult eel in the freshwater streams of Taiwan[17,18]. For the conservation of eel resources, a baseline study of the ecology of the eel is essential. This study attempts to understand the species composition, species-specific distribution and resources status of adult eels in the rivers of Taiwan.

Materials and Methods

Adult anguillid eels in the seven rivers of Taiwan were investigated (Fig. 1). In this study, we collected the adult eel by a trap in 1997-1998. The trap was made of bamboo in a dimension of 100 cm in length, 10-15 cm in diameter with earthworm as lure. The trap was set both upstream and

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downstream of the river to collect the eel. Species was identified from external morphology[3,4]. Species composition of the eels upstream and downstream of the river was compared to understand if the distribution of *A. japonica* and *A. marmorata* was separated because it has been believed that *A. marmorata* tended to distribute in the higher elevation of the stream.

The catches of elvers in each coastal prefecture of Taiwan recorded in the Taiwan Fisheries Yearbooks were mapped to understand the distribution of the elvers on the coast of Taiwan. Meanwhile, the annual catch of both elver and adult eels recorded in the same yearbook[19] was analyzed with spectral analysis respectively to understand their periodic fluctuation. The relationship between the catch of the elver and adult was analyzed by cross-correlation.

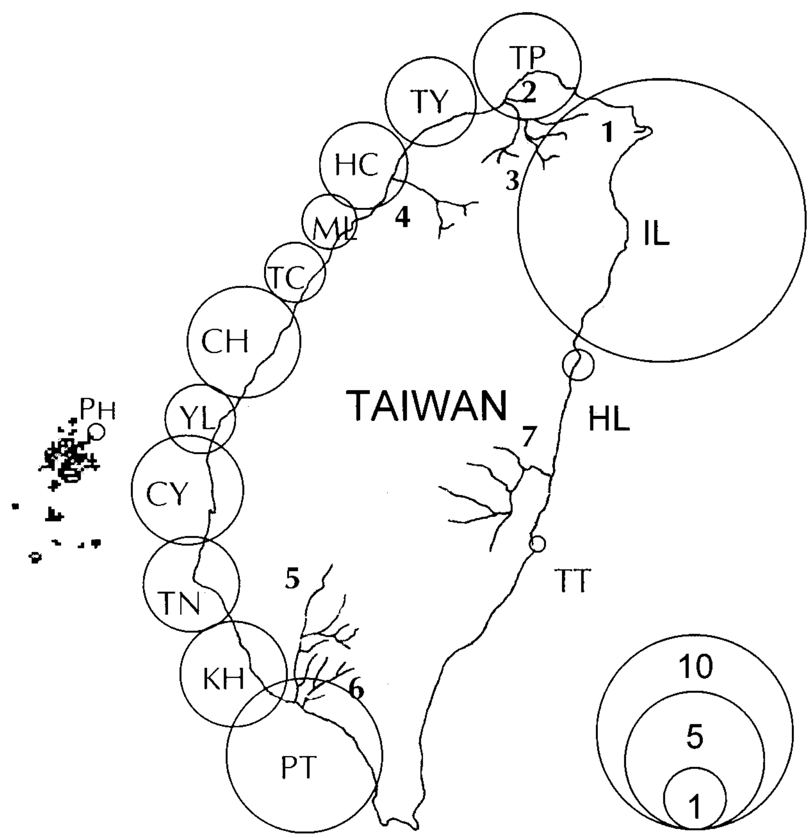

Fig. 1. Mean annual catch of elvers of *A. japonica* in each coastal prefecture of Taiwan,1967-1998. Abbreviation, prefecture name; circle, number in 10^6; bold number, sampling river of adult eels as in Table 1.

Results and Discussion

1. Distribution of elvers on the coast of Taiwan

There were four species of eels identified in the previous study. *A. japonica* was the most numerous species in the catch of elvers, making up 81.4 % of the total elver catch, followed by *A. marmorata* (16.2 %). The other two species were very rare[20-22]. The spatial distribution of mean annual catch indicated that elvers were more abundant on the north and western than eastern coasts of Taiwan

(Fig. 1). The distribution pattern of elvers closely correlated to the coastal current. The elvers were considered to be migrating with the cold China Coastal Current to the northern and western coasts of Taiwan because peak migration of the elvers coincided with the period of the lowest winter temperature, when the northeastern monsoon-driven China Coastal Current was strongest[7]. In addition, the freshwater discharge was comparatively abundant and the continental shelf area was wider on the west coast of Taiwan, which may also have the potential to attract the upstream migration of elvers. On the contrary, the two prefectures, HL and TT on the eastern coast of Taiwan where Kuroshio is almost close to the coast and salinity is higher and continental shelf is narrow, might have been less attractive for inshore migration of elvers. This may be the reason why elvers were more abundant on the western than eastern coast.

2. Species-specific distribution of the eels in the river

The species composition of adult eels both from upstream and downstream of the rivers was similar to that of elvers in the estuary[3,20,21,4]. *A. japonica* was the most dominant, making up 89.8 % of the total adult eel catch, followed by *A. marmorata* (9.6 %), and *A. bicolor pacifica* (0.6 %) (Table 1). *A. celebesensis* was not identified because its external features were similar to *A. marmorata.*

The species composition of the eels was different upstream and downstream of the rivers. *A. japonica* was relatively more abundant downstream (95.0 %) than upstream (8.3 %). On the contrary, *A. marmorata* was more abundant upstream (83.4 %) than downstream (4.4 %) (Table 1). This indicated that the territoriality of distribution was different between these two eel species.

Table 1. Species composition of the adult eels collected in the inland waters of Taiwan. *Aj, A. japonica; Am, A. marmorata; Abp, A. bicolor pacifica; Ac, A. celebesensis;* U, upstream; D, downstream.

Site	*Reach*	*Aj*	*Am*	*Abp*	*Ac*	*Total*	*Source*
1. Longlong R.	U+D	55	64	-	-	119	Shen *et al.* (1998)[27]
2. Gongshytyan R.	U+D	683	48	1	-	732	Tzeng *et al.* (1995)[17]
3. Tanshui R.	U	-	1	1	-	2	Tzeng *et al.* (1995)[17]
	D	633	21	-	-	654	Tzeng *et al.* (1995)[17]
4.Tocheng R.	U	-	-	-	-	-	present study
	D	19	6	-	-	25	present study
5. Kaoping R.	U	1	8	-	-	9	present study
	D	39	5	4	-	48	present study
6. Tongkang R.	U+D	9	-	3	-	12	present study
7. Hsuikuluan R.	U	-	1	-	-	1	present study
	D	-	-	-	-	-	present study
Total (%)	U	1 (8.3)	10 (83.4)	1 (8.3)	-	12	
	D	691 (95.0)	32 (4.4)	4 (0.6)	-	727	
	U+D	1439 (89.8)	154(9.6)	9 (0.6)	-	1602	

3. *Continuous decrease of the catch of A. marmorata*

Catches of the downstream-migratory adult *A. marmorata* collected by a set-net in the upper region of the Tanshui River in northern Taiwan in autumn obviously decreased from 1966 through 1986 (Dr. C. S. Tzeng unpublished data) (Fig. 2). Trend analysis also indicated that the catches significantly decreased annually since 1966 ($p<0.0001$). The decline was probably due to the recruitment failure resulting from overfishing of elvers in the river mouth and the pollution and dam construction obstructing the upstream migration of the eel.

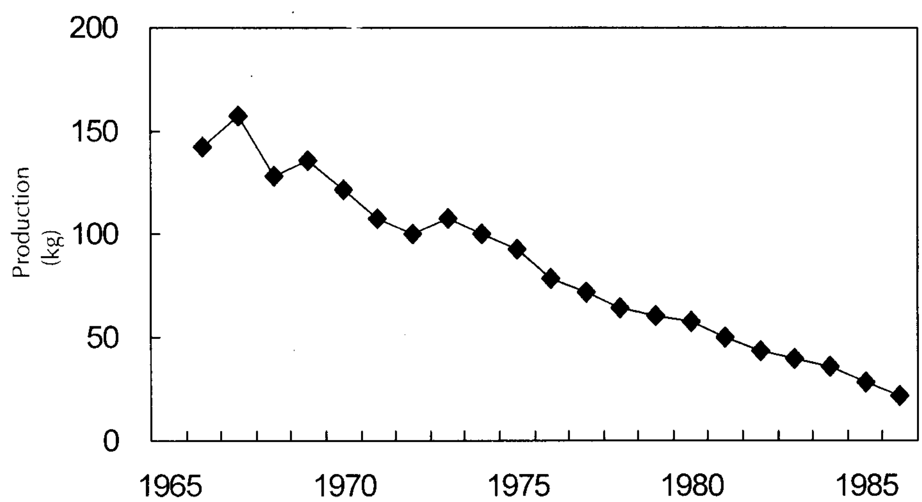

Fig. 2. Annual catches of the adult *A. marmorata* by a set-net in Penlin Town, Taipei County, 1966-1986.

4. *Periodic fluctuation of the catch of A. japonica*

Annual changes in catches of the adults and elvers of *A. japonica* in the inland waters of Taiwan from 1967 to 1998 were shown in Fig. 3. Periodic analysis indicated that the catches of the adult eel fluctuated in a cycle at an interval of approximately 7.3 yrs, 11 yrs and 22 yrs (Fig. 4a). The 22 yrs were neglected because of the data length. Similarly, those of elvers also fluctuated in a cycle at an interval of 7.5 yrs and 10 yrs (Fig. 4b). Cross correlation analysis indicated that the catches of elvers were positively correlated to that of the adults 1 yr and/or 7-8 yrs before and 5-6 yrs later. This implied that the recruitment of elvers depends on the amount of adults in the last year and/or 7-8 yrs before and the amount of elvers will contribute to the catch of adults 5-6 yrs later (Fig. 5).

The cyclic changes of the catch may correlate to environmental or biological cycles. The cycle of 10-11 yrs was synchronized with the cycle of sunspot. This phenomenon was also found in the Portuguese catch of *Sardina pilchardns*[23]. The other cycle may be due to the reproductive cycle of the eel. Adult eels were usually caught in the fall during their downstream spawning migration. The silver eel takes approximately 6 months to migrate from Taiwan to the spawning ground in the west Mariana Island[24] and spawning in the summer[9]. On the contrary, the eel larvae also take approximately 5-6 months to migrate from the spawning ground to the estuary[16]. Accordingly, the one-year delayed cross-correlation of the catch of elver to adult eel is reasonable if the abundance of elver is dependent on the density of spawner. On the other hand, the age at first maturity of *A. japonica* ranged 4-10 yrs with a mean of 6.4 yr (male) and 8.3 yr (female)[25]. This indicated that the abundance of elver will contribute to that of the adult 5-6 yrs or 7-8 yrs later.

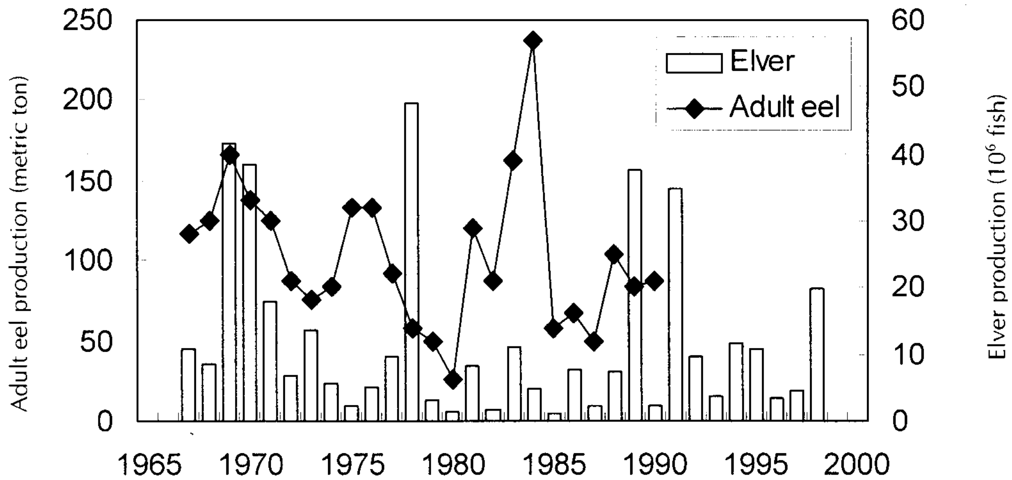

Fig. 3. Annual catches of *A. japonica* in the inland waters of Taiwan, 1967-1998.

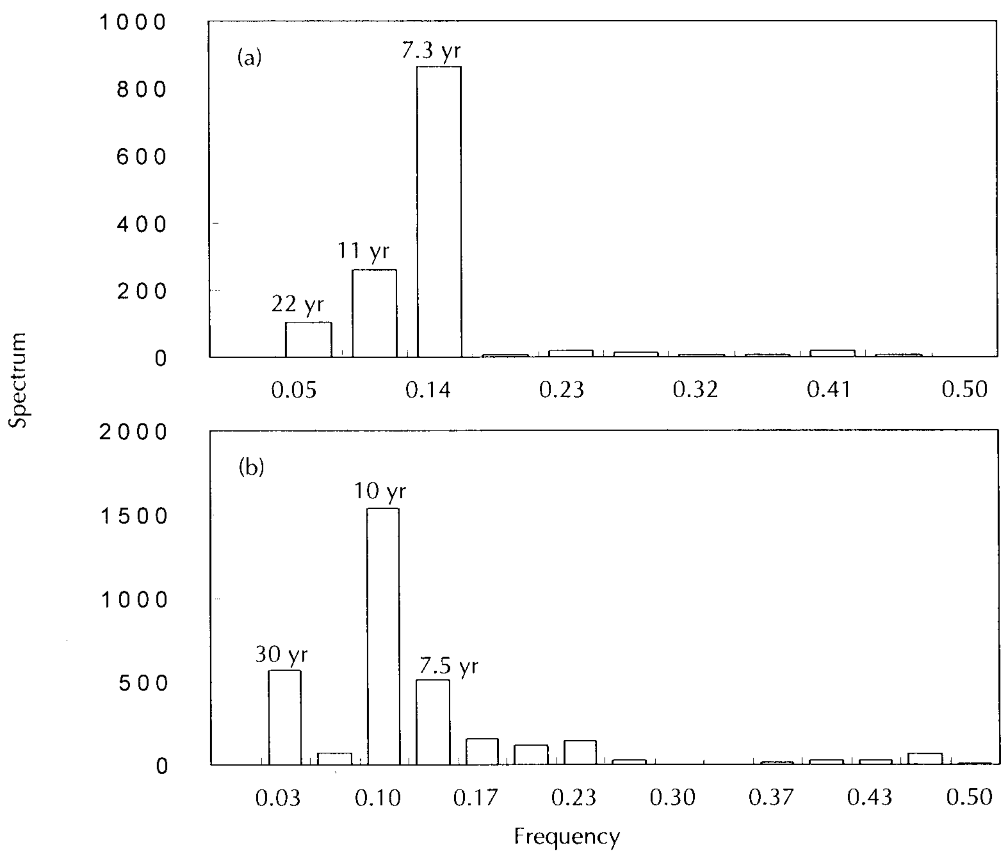

Fig. 4. Periodogram of the catch-time series of *A. japonica* in the inland waters of Taiwan. (a) adult eels, 1967-1990; (b) elvers, 1967-1998.

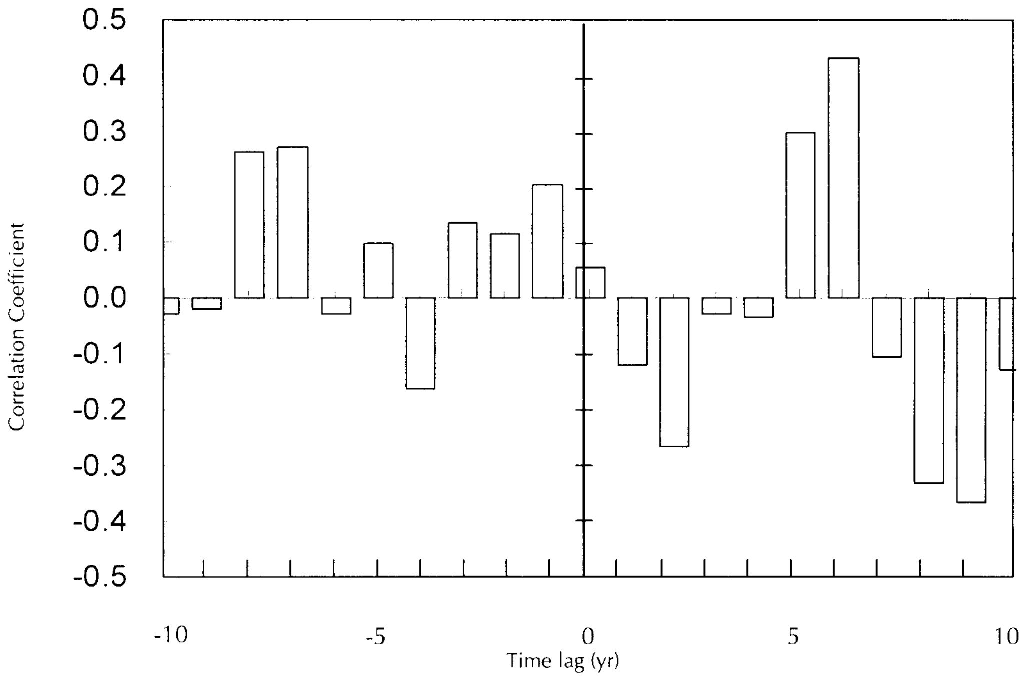

Fig. 5. Cross correlationt of the catches of elvers and adults of *A. japonica* from 1967-1990 in Taiwan.

5. Management prospect

The Japanese eel *A. japonica* was considered to be a panmictic population, which is distributed from Taiwan in the south through Mainland China, Korea to Japan in the north[12]. If this is true, the cyclic fluctuation of the catch of eel in Taiwan should also happen in other countries. However, time-series changes in the catch of both elvers and adults of *A. japonica* in Japan were not synchronous with those of Taiwan, but showed a continuous decrease since 1980[26]. This indicated that the fluctuation patterns of the catches of both elver and adult Japanese eels were different among countries. Suppose the Japanese eel is a panmictic population, and climate condition are also similar among countries, the periodic fluctuation of the catch of Japanese eel found in Taiwan should also exist in the other areas. However this is not the case. Whether different subpopulations exist in Japan or Taiwan, or pollution and habitat degradation influences the catch of the eel among countries needs further study.

The other interesting subject is the species-specific distribution of *A. japonica* and *A. marmorata*. The habitat partition can reduce their interspecific competition. *A. marmorata* is distributed mainly upstream and its population size was smaller than *A. japonica*. In general, the population size of a species depends on both food resources and carrying capacity. The volume of the river system in Taiwan was very small particularly the upstream region. The confinement of the carrying capacity of the habitat and the small area upstream may have resulted in the small population of *A. marmorata* in the rivers of Taiwan. On the other hand, dam construction was prevailing in the river, which may obstruct the upstream migration of *A. marmorata*. This may also lead to the decline of the population of *A. marmorata* in the river of Taiwan. Although, we did not investigate the eel in all of the rivers of Taiwan, dam construction prevailed elsewhere because of the increasing demand for freshwater use. For the conservation of *A. marmorata*, habitat conservation is most important.

On the other hand, *A. japonica* elvers in the estuary of Taiwan were overharvested for restocking. Previous investigation indicated that in a particular estuary more than half of the elvers were harvested before upstream migration[8], which has led to the population density of the eel in the river decreasing to a low level[17]. Probably due to the low density of the eel in the river, the sex ratio of the eel population was predominated by female, which are advantageous for reproductive success and can avoid the collapse of the eel population[17]. In addition, there is a close correlation between the adult and elver abundance (Fig. 5). In other words, if we reduce the catch of elver in the estuaries, we can guarantee to have more spawning migratory adult eel. For restocking, elvers in the estuaries of Taiwan have been overfished for many years. To recover the eel population, reducing the catch of elvers in the estuary is the most effective method.

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