I Chiu Liao[1], Chin-Lau Kuo[1], Wann-Nian Tzeng[2,3], Shih-Tsung Hwang[1], Chi-Lun Wu[1], Chia-Hui Wang and Yu-Tzu Wang

[1]Taiwan Fisheries Research Institute, Keelung 202, Taiwan.

[2]Department of Zoology, College of Science, National Taiwan University, Taipei 106, Taiwan.

[3]Corresponding Author: E-mail:wnt@ccms. ntu.edu.tw.

(Accepted 9 December 1996)

The First Time of Leptocephali of Japanese Eel *Anguilla japonica* Collected by Taiwanese Researchers

Abstract

Three leptocephali of Japanese eel *Anguilla japonica* were collected in the presumed spawning ground of 12°30′–14°30′N and 131°30′-140°30′E, on 16 to 23 August, 1995. It was the first time of such collection by Taiwanese researchers. Total lengths of the leptocephali were measured as 27.4, 28.8 and 31.4 mm, respectively. Their daily ages were estimated to be 46, 50 and 51 days by counting otolith growth increments, and growth rates be 0.577-0.658 mm·d^{-1}. The daily ages of these three leptocephali were back-calculated for birth dates be July 1 and 3, and the spawning dates were on June 2 and 4 of the lunar calendar which were in the period of new moon. This study confirms that Japanese eel spawns in summer. Based on the localities of collections and the westward direction of ocean current, the body lengths and the daily ages of these three leptocephali are difficult to depict the spawning ground as previously known. Spawning ground is probably rather widely spread.

Key words: Leptocephali, Japanese eel *Anguilla Japonica,* Taiwanese researcher, Spawning ground

The Japanese eel *Anguilla japonica* Temminck & Schlegel is a temperate catadromous fish, widely distributed in rivers of the northeastern Asian countries, i.e. Taiwan, China, Korea and Japan(1). Development stages of the eel including leptocephalus, glass eel, elver, yellow eel and silver eel, are similar to those of *Anguilla anguilla*(2). The eel was presumed to originate from the same panmictic population(3), and its spawning grounds were recently assumed to be in the North Equatorial Current west of the Mariana Islands, 15°N, 140°E(4). The leptocephali drift with the North Equatorial Current from their spawning grounds. When they approach the continental shelf of the Philippines, they turn northward into the Kuroshio Current conveyed by the mechanism of Ekman transport(5). After reaching a fully grown size, leptocephali metamorphose into the glass eel stage and leave the strong Kuroshio Current(6). The glass eels become elvers upon arrival at estuaries. The period for the fish migrated from spawning ground to the estuary takes approximately 5-6 months(6-11). Life history of Japanese eel is little known particularly in leptocephalus stage because

Liao, I C., C. L. Kuo, W. N. Tzeng, S. T. Hwang, C. L. Wu, C. H. Wang and Y. T. wang (1996) The first time of leptocephali of Japanese eel *Anguilla japonica* collected by Taiwanese researchers. J. Taiwan Fish. Res., **4**(2): 107-116.

of the difficulty in the collection of leptocephalus.

Leptocephalus exhibit diurnal vertical migration from deeper waters during the day to shallow waters at night[12-16]. It was seldomly collected in the daytime[17,18]. The Japanese eel leptocephalus has been abundantly collected in the assumed spawning ground in 1991[4]. Thereafter, there is no document to report the leptocephalus in the area.

Taiwan Fisheries Research Institute attempted to collect the leptocephalus in August 1995 and was the first time to have the sample collection. It is therefore recording such information concerning the ecology of the leptocephalus. The purpose of this paper is to describe the oceanic structure where the leptocephalus was collected and the related biological information.

Materials and methods

I. Sampling design

Leptocephalus was collected using three different sampling nets, ORI, IKPT and Bongo net, at 50 stations in the eastern Philippines during the period from 10 to 23 August 1995 (Fig. 1). The net structures were described in Table 1. The ORI was towed for the 50 stations in daytime or night time, while the IKPT was towed for 31 stations and Bongo net for 15 stations in the night time only. The towing depth was different among these nets (Table 1). The duration of sampling was approximately 10-20 minutes for both the ORI and Bongo nets and 30 minutes for the IKPT. During sampling, the oceanic structure of the stations from surface to 1000 m depth was also monitored by conductivity, temperature and depth measurement (CTD).

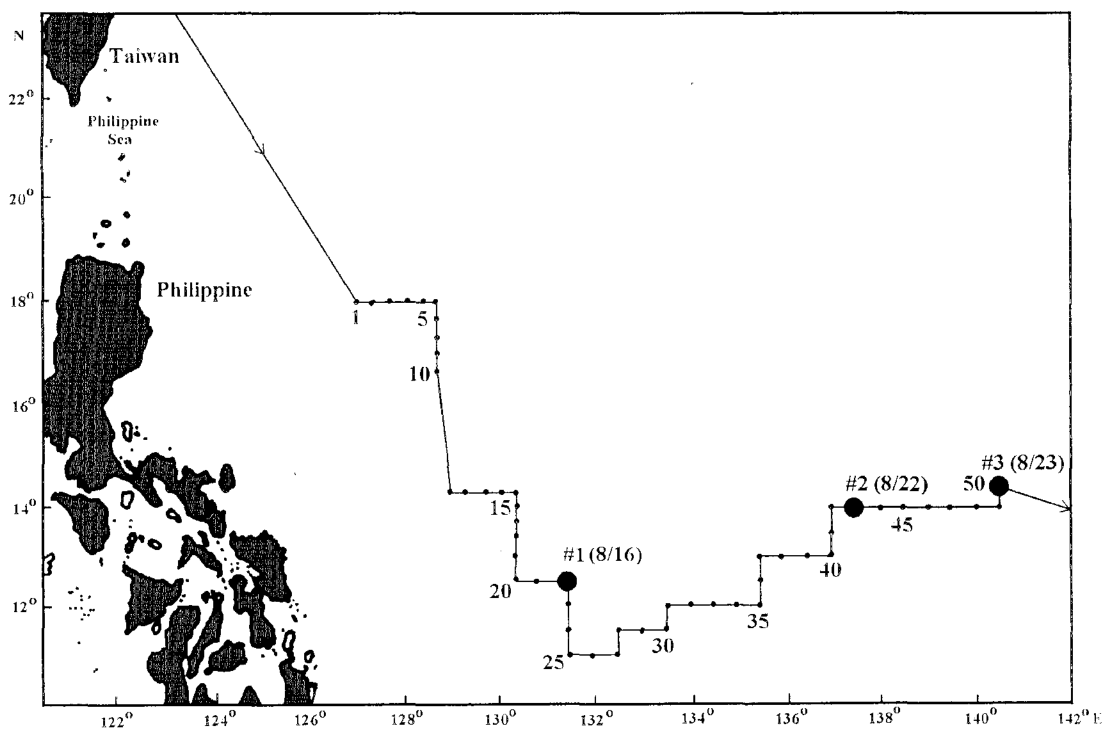


Fig. 1. Map showing the 50 sampling stations. Leptocephali were collected in station nos. 22, 43 and 50.

Table 1. Comparison of three sampling gears.

Gear	*Net length (cm)*	*Net mouth opening (m^2)*	*Mesh size (mm)*	*Sampling depth (m)*	*Sampling duration (min)*
IKPT	900	3	5 (Cover net 3 cm)	0-250	30
Bongo net	340	0.28	0.1 and 0.33	0-175	10-20
ORI-200	740	2	2	0-75	10-20

II. Data analysis

Species of leptocephalus were identified according to eye-type, digestive tract, pigmentation and myomeres[19-21]. Morphometric and meristic characters of *Anguilla japonica* leptocephalus were measured and compared with previous studies of Tabeta and Mochioka[20], and Ozawa et al.[21].

Otolith was polished from antisulcus to reveal primordium. Daily growth increment in the otolith was examined with SEM. Maximum diameter through primordium to hatching check and first feeding check were measured, respectively. The procedure of otolith preparation for daily growth increment examination was similar to Tzeng[9], and Tzeng and Tsai[10]. The age of leptocephalus was determined by the assumption of the growth increments in their otoliths being deposited in daily interval[22-24]. The birth date of leptocephalus was backcalculated from daily age and the date. Growth rate was calculated from total length and daily age of the fish at capture.

Results

I. Species identification

A total of 27 leptocephali was collected from the 50 stations. Three of them were identified to be *Anguilla japonica,* which were collected each from the stations Nos. 22, 43 and 50 (Fig. 1 and Table 2).

Table 2. Age, birth date and growth rate of the Japanese eel *Anguilla japonica* leptocephali collected in the spawning ground eastern Philippines.

Specimen no.	*Sampling station*	*Depth (m)*	*Location*	*Sampling date*	*Sampling time*	*Sampling gear*	*TL (mm)*	*No. DGI*	*Birth date*	*Growth rate ($mm \cdot d^{-1}$)*
1	ST22	5130	12°30'N 131°30'E	Aug 16	20:43 -21:14	IKPT	27.4	41	July 1	0.658
2	ST43	4120	14°00'N 137°30'E	Aug 22	5:05 -5:35	IKPT	28.8	45	July 3	0.577
3	ST50	4330	14°30'N 140°30'E	Aug 23	19:36 -19:54	ORI	31.4	46	July 3	0.617

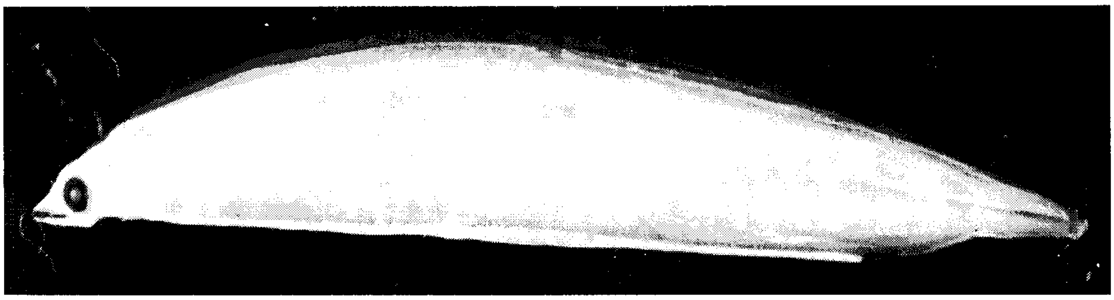
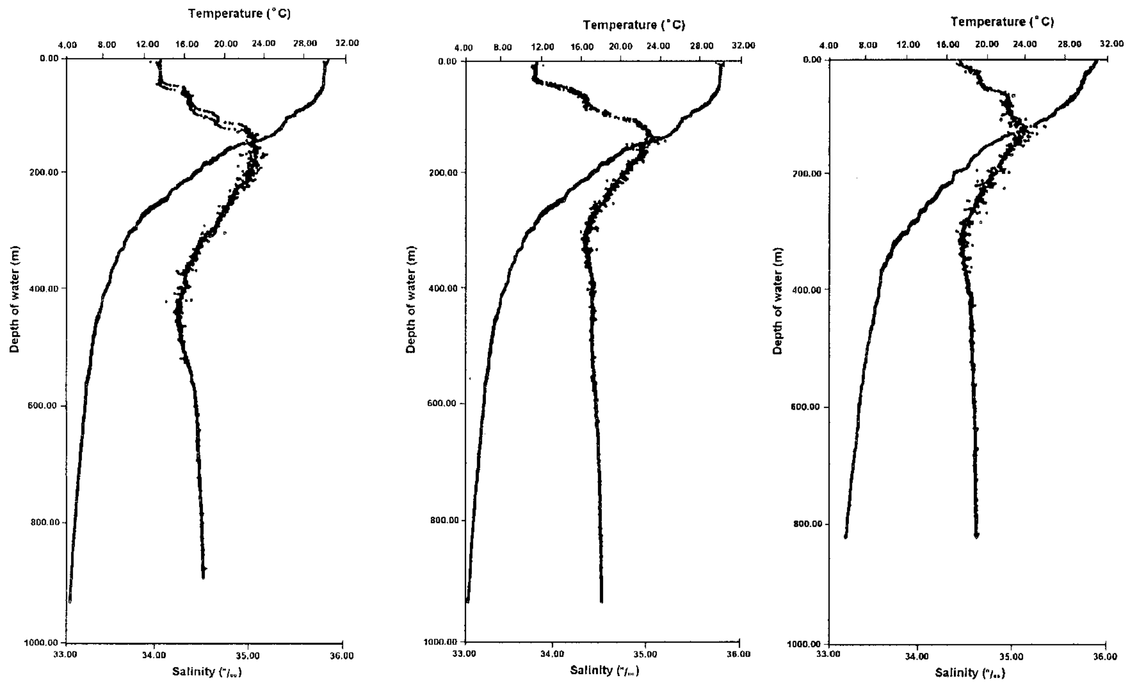


Fig. 2. External feature of the leptocephalus of Japanese eel *Anguilla japonica*, 27.4 mm TL.

Table 3. Comparisons of morphometric and meristic characters of the *Anguilla* leptocephali collected in the western Pacific Ocean.

Species		***A. japonica***	***A. japonica***	***A. japonica***	***A. marmorata***	***A. marmorata***	***A. bicolor pacifica***
Length (mm)	Total	27.4-31.4	33.9-47.0	24.0-31.8	32.5-47.3	33.5	47.8
	Standard	27.3-30.9	33.3-46.0	23.6-31.2	31.9-46.1	33.0	46.8
	Head	2.5-2.9	3.5-4.1	2.7-3.4	3.2-4.0	3.4	4.0
	Snout	0.7-0.8	1.0-1.3	0.7-0.9	0.9-1.1	0.8	1.0
	Eye	0.7-0.8	0.9-1.1	0.8-1.0	0.8-1.0	0.9	1.0
	Upper jaw	1.4-	1.5-1.9	1.3-1.6	1.5-1.9	1.6	1.7
	Postorbital	1.0-1.4	1.5-2.0	1.1-1.5	1.5-2.0	1.5	1.9
	Pectoral	0.8-	0.9-1.2	0.5-1.0	0.7-1.3	1.0	1.2
	Preanal	21.6-24.7	25.8-35.7	19.0-25.5	24.6-35.2	26.1	35.3
	Predorsal	19.2-21.6	23.0-32.4	19.0-22.0	20.8-30.1	24.8	33.5
	Ana-dorsal	1.5-3.1	2.2-4.0	2.2-2.4	3.2-5.1	1.3	1.8
Depth (mm)	Before eye	0.9-1.1	1.5-2.0	1.2-1.5	1.5-1.8	1.6	1.5
	At pectoral base	2.0-2.3	2.6-3.2	2.2-2.7	3.0-3.3	2.6	3.0
	At midpoint between pectoral and vent	4.2-5.2	6.3-8.3	4.2-5.9	7.5-9.3	6.4	8.2
	At vent	4.0-4.1	5.7-7.1	4.0-5.0	5.9-7.8	5.6	7.5
Myomeres	Total	114-118	113-118	112-117	103-1.6	105	108
	Predorsal	64-71	65-71	68-70	56-61	64	71
	Preanal	77-84	76-81	77-81	68-73	74	75
	Ana-dorsal	11-13	6-11	10-	8-14	9	4
	1st vertical blood vessel	18th-19th	15th-19th	16th-20th	15th-18th	17th	17th
	2nd vertical blood vessel	32nd-40th	37th-42nd	32nd-42nd	37th-39th	38th	41st
	3rd vertical blood vessel	46th-	44th-48th	44th-8th	42nd-45th	44th	46th
	Anterior margin of gall bladder	30th-45th	26th-29th	29th-34th	22nd-25th	28th	23rd
Teeth		0-1+1+2-4+2-4/1+2-4+3-4	0-1+4-6+7-12/1+5-7+3-7	1+1+3-6+3-5/1+3-6+3-4	0-1+1+5-6+8-12/1+3-7+7+4-9	1+1+5+7 /1+7+3	0+1+6+12 /1+3+9
Reference		this study	Tabeta and Mochioka 1988	Ozawa et al. 1989	Tabeta and Mochioka 1988	Ozawa et al. 1989	Tabeta and Mochioka 1988



(a) (b) (c)

Fig. 3. Vertical distribution of salinity and temperature in the stations nos. 22 (a), 43 (b) and 51 (c).

Total lengths of the three leptocephali were 27.4 mm, 28.8 mm and 31.4 mm, respectively. The leptocephalus of 27.4 mm was shown in Fig. 2. Morphometric and meristic characters of the leptocephali were similar to those identified by Tabeta and Mochioka[20], and Ozawa et al.[21]. There could have 4 species of *Anguilla* in this area[25-27]. Total myomeres of the leptocephalus was a key character to discriminate *A. japonica* from the other three species, *A. celebesensis, A. marmorata* and *A. bicolor pacifica* (Table 3).

II. Oceanographic structure in the spawning region

Oceanographic structure of the 3 stations where leptocephali were collected was shown in Fig. 3. Thermocline was obvious. Temperature was approximately 29.5°C in the surface layer, and decreased to 8°C at the depth of 400 m. Salinity was approximately 33.8 ‰ in the surface layer, increased with depth and reached a maximum (approximately 35.0 ‰) at the depth of 140-180 m, then decreased with depth and reached a minimum (34.3 ‰) at the depth of 300-420 m and then slightly increased to 34.5 ‰. The low salinity in the surface layer was due to precipitation, salinity maximum layer was the tropical water and minimum layer the north pacific intermediate water[5].

III. Age and birth date

Otolith microstructure of the Japanese eel leptocephali exhibited 4 distinct parts. Primordium in the center, is a deep EDTA-etched hole with a diameter of 5.29±0.31 mm, followed by a less $CaCO_3$ layer with a deep-etched hatching check, diameter 10.43 ±1.25 mm, the third layer was a radical crystalline structure with no discernible increments, diameter 19.05±1.26 mm. This layer was deposited in yolksac period. The outer layer exhibited discernible daily growth increments which was assumed to be deposited after the fish has begun external feeding (Fig. 4).

Daily growth increment in otolith of the three leptocephali collected on 16, 22 and 23 August was counted to have 41, 45 and 46 rings, respectively (Fig. 4). The fish was assumed to deposit their first increment 5 days after hatching[9]. In other words, their true ages were 46, 50 and 51 days old. The birth date back-calculated from the age was on 1 and 3 July. Growth rates of the fish were estimated to be 0.658, 0.577 and 0.617 mm·d^{-1}.

Discussion

The leptocephalus was collected by the ORI in

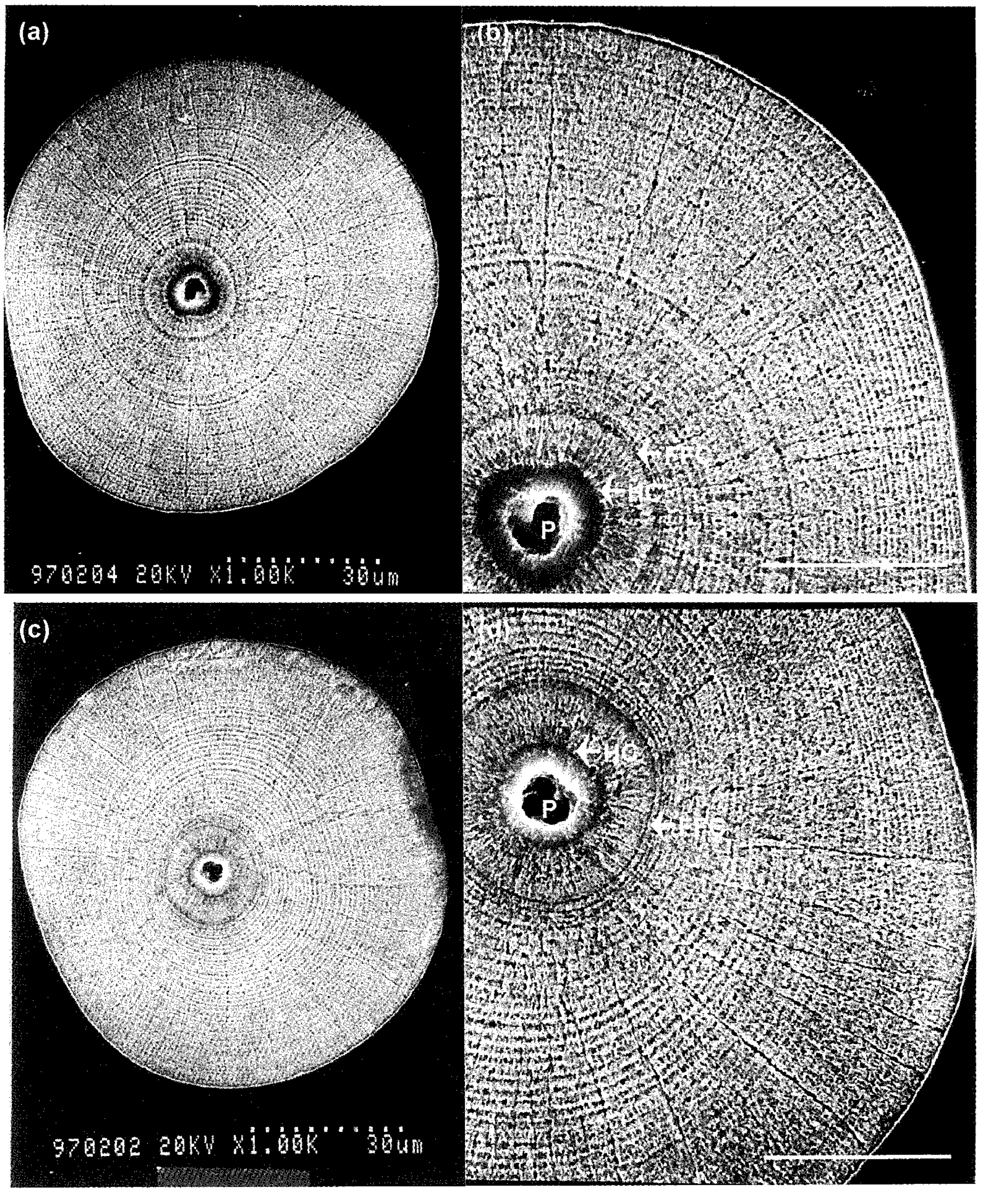


Fig. 4. Micro-photography showing daily growth increments in otoliths of two leptocephali collected in station 43 on 22 August 1995 (a and b, 28.8 mm TL), station 50 on August 1995 (c and d, 31.4 mm TL). b & d, magnified from a & c; P = primordium; HC = hatching check; FFC = first feeding check. Scale bar = 30 μ m (a, c), 15 μ m (b, d).

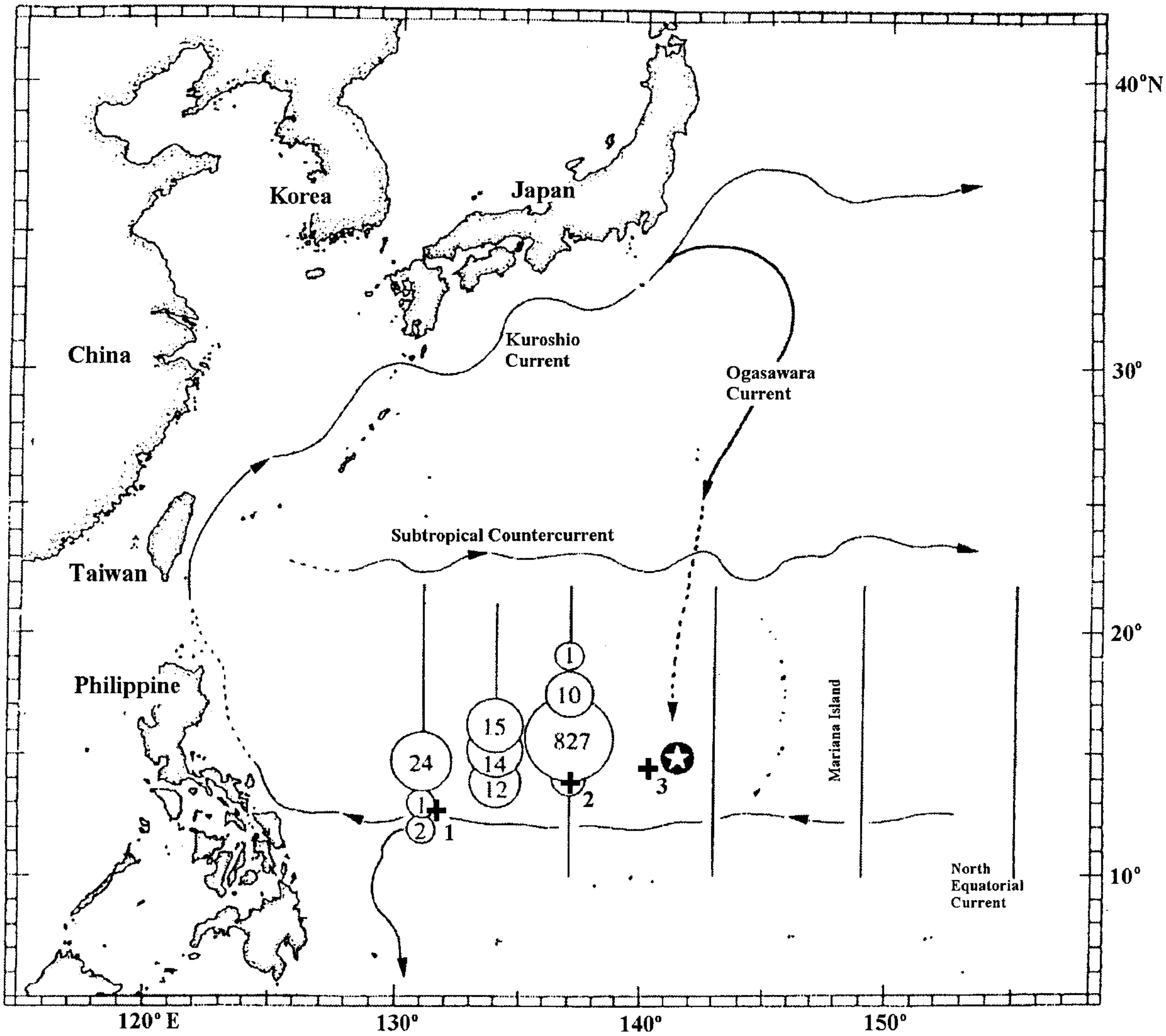


Fig. 5. Modifying from Tsukamoto (1996[6]), a comparison of locations where leptocephali were collected by this study (cross marks) and by Tsukamoto (circle marks). Numbers in circle indicated the number of leptocephali collected, and star mark indicates a possible spawning site.

the layer 0-75 m and by the IKPT, 0-250 m. This indicates that the leptocephalus may migrate vertically to the upper part of the thermocline at night in salinity maximum layer which originated from tropical water.

The birth date of the three leptocephali collected in this study was estimated to be on July 1 and 3, which was close to the estimation of Tsukamoto et al.[28] at July 13 ± 5.3. This indicates that Japanese eel spawns in summer which is striking in contrast to the common understanding that the *A. japonica* spawns in winter[29,30].

Furthermore, Yu et al.[31] showed that the fertilized eggs of *Anguilla japonica* in captivity hatched after 48 hours at the water temperature of 19.5°C and the salinity of 35 ppt. Accordingly, the eggs of these three leptocephali were probably layed two days before hatching, i.e. on June 2 and 4 of the lunar calander, in other words, the eel spawns in the period of new moon.

The presentation of Japanese eel leptocephali in the collections of this study is very meaningful because it is the first time for the research vessel of Taiwan to find the leptocephali of *Anguilla japonica*. The spawning ground of Japanese eel was first described in 1988[17,18], but it was waived later in a systematic investigation in 1991[4]. The location of leptocephalus found in this study was similar to that by Tsukamoto[4] (Fig. 5). Leptocephalus passively migrated westward with the North Equatorial Current from spawning ground at a speed of 20 $cm \cdot s^{-1}$[5]. Therefore, Tsukamoto[4] postulated that the spawning ground was in the eastern side of the location where the leptocephalus was collected (Fig. 5). Supposely the leptocephalus was transported westward from the spawning ground, the age of leptocephalus should be increased from east to west and the size increased as well[32], however, the age and size of the samples collected in this study increased from 46 days and 27.4 mm in the west to 51 days and 31.4 mm in the east. The age and size were positively correlated to the sampling date and increased from west to east. This might be indicated that the spawning ground was widely spread and might not be concentrated in the small area in 15°N and 140°E as indicated by Tsukamoto[6]. Otherwise, the leptocephali could drift with the eastward currents, which was opposited the normal westward transportation of larvae[17,32]. Those questions as above mentioned may be solved when more leptocephali are collected and the location of spawning ground is confirmed.

Acknowledgement

The authors wish to thank the crew of the R/V Fishery Researcher 1 of the Taiwan Fisheries Research Institute for collecting and sorting the samples.

References

1. Tesch, F. W. (1977) The eel-biology and management of *Anguilla* eel. Chapman and Hall press, London, 434pp.
2. Bertin, L. (1956) Eels - a biological study. Cleaver-Hume Press, London, 192pp.
3. Sang, T. K., H. Y. Chang, C. T. Chen and C. F. Hui. (1994) Population structure of the Japanese eel, *Anguilla japonica*. Col. Biol. Evol. **11**(2): 250-260.
4. Tsukamoto, K. (1992) Discovery of the spawning area for Japanese eel. Nature, **356**(6372): 789-791.
5. Kimura, S, K. Tsukamoto and T. Sugimoto (1994) A model for the larval migration of the Japanese eel: Roles of the trade winds and salinity front. Mar. Biol., **119**: 185-190.
6. Tsukamoto, K. (1996) Breeding places of freshwater eels. *In* Early life history and prospects of seed production of the Japanese eel *Anguilla japonica,* (O. Tabeta ed.). Koseisha Koseikaku, Japan. Suisan Gaku Ser., **107**: 11-21. (in Japanese)
7. Tabeta, O., K. Tanaka, J. Yamada and W. N. Tzeng (1987) Aspects of the early life history of the Japanese eel *Anguilla japonica* determined from otolith microstructure. Nippon Suisan Gakkaishi, **53**: 1727-1734.
8. Tsukamoto, K, A. Umezawa (1990) Early life history and oceanic migration of the eel *Anguilla japonica*. La Mer., **28**: 188-198
9. Tzeng, W. N. (1990) Relationship between growth rate and age at recruitment of *Anguilla japonica* elvers in a Taiwan estuary as inferred from otolith growth increments. Mar. Biol., **107**: 75-81.
10. Tzeng, W. N. and Y. C. Tsai (1992) Otolith microstructure and daily age of *Anguilla japonica* elvers from the estuaries of Taiwan with reference to unit stock and larval migration. J. Fish Biol., **40**: 845-857.
11. Cheng, P. W. and W. N. Tzeng (1996) Timing of metamorphosis and estuarine arrival across the dispersal range of the Japanese eel *Anguilla japonica*. Mar. Ecol. Prog. Ser., **131**: 87-96.
12. Schmidt, J. (1925) The breeding places of the eel. A. Rep. Smithsonian Inst., **1924**: 279-316.
13. Kleckner, R. C and J. D. McCleave (1982) Entry of migrating American eel leptocephali into the Gulf Stream system. Helgol. Meeresunters., **35**: 329-339.

14. Schoth, M. and F. W. Tesch (1982) Spatial distribution of the 0-group eel larvae (*Anguilla* sp.) 1979 in the Sargasso Sea. Helgol. Merresunters., **35**: 309-320.

15. Castonguay, M, J. D. McCleave (1987) Vertical distributions, diel and ontogenetic vertical migrations and net avoidance of leptocephali of *Anguilla* and other common species in the Sargasso Sea. J. Plankton Res., **9**: 195-214.

16. Kleckner, R. C., J. D. McCleave (1988) The northern limit of spawning by Atlantic eels (*Anguilla* spp.) in the Sargasso sea in relation to thermal fronts and surface water masses. J. Mar. Res., **46**: 647-667.

17. Kajihara, T. (1988) Distribution of *Anguilla japonica* leptocephali in western Pacific during September 1986 of the Japanese eel *Anguilla japonica* determined from otolith microstructure. Nippon Suisan Gakkaishi, **54**: 929-933.

18. Kajihara, T., K. Tsukamoto, T. Otake, N. Mochioka, H. Hasumoto, M. Oya and O. Tabeta. (1988) Sampling leptocephali with reference to the diel vertical migration and the gears. Nippon Suisan Gakkaishi, **54**: 941-946.

19. Jespersen, P. (1942) Indo-Pacific leptocephalids of the Genus *Anguilla*. Dana Rep., **22**: 1-128.

20. Tabeta, O. and N. Mochioka (1988) Anguillid leptocephali from the waters south of Okinawa and east of Taiwan and Luzon, Western North Pacific, in 1986. Nippon Suisan Gakkaishi, **54**: 935-940.

21. Ozawa, T, O. Tabeta and N. Mochioka. (1989) Anguillid leptocephali from the Western North Pacific east of Luzon. Nippon Suisan Gakkaishi, **55**: 627-632.

22. Pannella, G. (1971) Fish otolith: daily growth layers and periodical patterns. Science, **173**: 1124-1127.

23. Umezawa, A. and K. Tsukamoto (1991) Factors influencing otolith increment formation in Japanese eel, *Anguilla japonica* T. & S., elvers. J. Fish Biol., **39**: 211-223.

24. Martin, M. H. (1995) Validation of daily growth increments in otoliths of *Anguilla rostrata* (Lesueur) elvers. Can. J. Zool., **73**: 208-211.

25. Tzeng, W. N. (1982) Newly record of the elver, *Anguilla celebesensis* Kaup, from Taiwan. BioScience, **19**: 57-66. (in Chinese with English abstract)

26. Tzeng, W. N. (1983) Species identification and commercial catch of the anguillid elvers from Taiwan. China Fish. Mon., **366**: 16-23. (in Chinese with English abstract)

27. Tzeng, W. N. and O. Tabeta. (1983) First record of the short-finned eel *Anguilla bicolor pacifica* from Taiwan. Nippon Suisan Gakkaishi, **49**: 27-32.

28. Tsukamoto, K., A. Umezawa, O. Tabeta, N. Mochioka and T. Kajihara. (1989) Age and birth date of *Anguilla japonica* leptocephali collected in Western North Pacific in September 1986. Nippon Suisan Gakkaishi, **55**: 1023-1028.

29. Matsui, I. (1952) Morphology, ecology and culture of the Japanese eel. J. Shimonoseki Coll. Fish., **2**: 1-245.

30. Tabeta, O. (1981) On the early life history of Japanese eel with reference to the spawning ground. Kaiyo to Sebutsu (Aquabiology), **3**: 412-417. (in Japanese)

31. Yu, T. C., C. L. Tsai, Y. S. Tsai and J. Y. Lai (1993) Induced breeding of Japanese eels, *Anguilla japonica*. J. Taiwan Fish. Res., **1**(1): 27-34. (in Chinese with English abstract)

32. Ozawa, T., F. Kakizoe, O. Tabeta, T. Maeda and Y. Yuwaki (1992) Larval growth and drift of the Japanese eel *Anguilla japonica* estimated from leptocephali collection. Nippon Suisan Gakkaishi, **58**: 15-23.

廖一久 [1]，郭慶老 [1]，曾萬年 [2]，黃士宗 [1]，
吳繼倫 [1]，王佳惠 [2]，王友慈 [2]
[1] 台灣省水產試驗所
[2] 國立台灣大學 動物系
(1996 年 12 月 9 日)

台灣水產研究者首度捕獲日本鰻的柳葉形仔鰻之記錄

摘 要

1995 年 8 月 16 日至 23 日，台灣省水產試驗所「水試一號」試驗船於 12°30′N – 14°30′N 與 131°30′E - 140°30′E 之間，也就是菲律賓以東的海域，捕獲 27 尾柳葉形仔鰻，其中三尾是日本鰻。這是台灣有史以來，第一次捕獲日本鰻的柳葉形仔鰻，其意義非常重大。三尾柳葉形仔鰻的體長分別爲 27.4 ， 28.8 以及 31.4 mm ，由耳石日週輪數目研判，其日齡分別爲 46 ， 50 及 51 天，體成長率爲 0.577 – 0.658 $mm \cdot d^{-1}$ ，孵化日期爲 7 月 1 日及 3 日，產卵日期則爲農曆的 6 月 2 日及 6 月 4 日，因此，鰻魚可能在新月期間產卵。綜合以上各點，本研究再次證實日本鰻是在夏季產卵，惟根據採集地點與海流方向，這三尾柳葉形仔鰻之體長與日齡不足以肯定或說明目前所認知的產卵場，所以推測產卵場的分布範圍可能更爲分散。

關鍵詞： 柳葉形仔鰻，日本鰻，台灣研究人員，產卵場

廖一久, 郭慶老, 曾萬年, 黃士宗, 吳繼倫, 王佳惠, 王友慈 (1996) 台灣水產研究者首度捕獲日本鰻的柳葉形仔鰻之記錄. 水產研究, **4**(2): 107-116.