Coastal Marine Science 30(2): 453–458, 2006

Evidence for migration of metamorphosing larvae of *Anguilla japonica* in the Kuroshio

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Received 27 February 2006; Accepted 4 April 2006

Abstract—Two sampling surveys of the R/V Tansei Maru were conducted in the Kuroshio region south of Kyushu Island of Japan and to the south in the western North Pacific, to study the distribution patterns of the larval stages of the Japanese eel *Anguilla japonica* as they approach their recruitment areas in East Asia. Nine fully-grown premetamorphic leptocephali (49.5–58.3 mm TL) were collected during November 1996 to the east of Taiwan. During November and December 2000, nine early stage glass eels (51.3–57.0 mm TL, pigmentation stage II–IV) that were still in the late metamorphosis stages were collected in the Kuroshio. These findings suggest that metamorphosing Japanese eel leptocephali that recruit to the northern part of their species range migrate in the Kuroshio. They may detrain from the Kuroshio at the pigmentation stage IV–VA and begin their coastal migration.

Key words: *Anguilla japonica*, leptocephalus, glass eel, Kuroshio, metamorphosis, larval migration

Introduction

Considerable information on the early life history of the Japanese eel, *Anguilla japonica*, has been accumulated in the last decade due to the establishment of sampling methods for the leptocephali (Kajihara et al. 1988) and the determination of the spawning area (Tsukamoto 1992). Additional progress in understanding the life history has been made using the otolith microstructure and microchemistry of the leptocephali and glass eels (Tabeta et al. 1987, Umezawa et al. 1989, Tsukamoto and Umezawa 1990, Tzeng and Tsai 1992, 1994, Otake et al. 1994, Arai et al. 1997, Ishikawa et al. 2001, Tsukamoto et al. 2003). The Japanese eel leptocephali drift in the North Equatorial Current westward from the spawning area (Kimura et al. 1994), and are suggested to be subsequently transported in the Kuroshio to the coastal waters of East Asia including China, Taiwan, Korea and Japan (Tsukamoto and Umezawa 1990). It has been also suggested that they begin to metamorphose in the Kuroshio and may complete metamorphosis there or in the marginal waters over the continental shelf (Tabeta and Takai 1973, Tabeta and Konishi 1986, Tsukamoto 1990, Sakakura et al. 1996).

Some information has been gained from the fully grown stage or early metamorphosing leptocephali reported from several sampling surveys in the waters to the south of the Ryukyu Islands and close to Taiwan around the origin of the Kuroshio (Tsukamoto and Umezawa 1990, Tanaka 1975, Kajihara 1988). In addition, Arai et al. (1997) reported on the ages of five of the leptocephali that are described here, which were collected in the same general region. There also have been a total of ten glass eels collected offshore in the Kuroshio region, with eight being caught in the East China Sea (Tsukamoto and Umezawa 1990, Shojima 1966, 1967, 1990, Tabeta 1981), one in the South China Sea (Tabeta and Takai 1973), and one in the Kuroshio off Cape Ashizuri of Shikoku Island, Japan (Sakura et al. 1996) (Fig. 1a).

Despite these collections, there has been no direct evidence for determining the migration route and location of metamorphosis of Japanese eel leptocephali in the Kuroshio because neither metamorphosing leptocephali or glass eels have been collected in the region between the area east of Taiwan and the East China Sea and southern Japan, or off Shikoku Island. Therefore, the objectives of this study were to examine the distribution of the late stage leptocephali and metamorphosing early transition stage glass eels that have been collected during two cruises in the Kuroshio region to provide new information about the migration route of eel larvae from their spawning area to their estuarine and freshwater growth habitats.

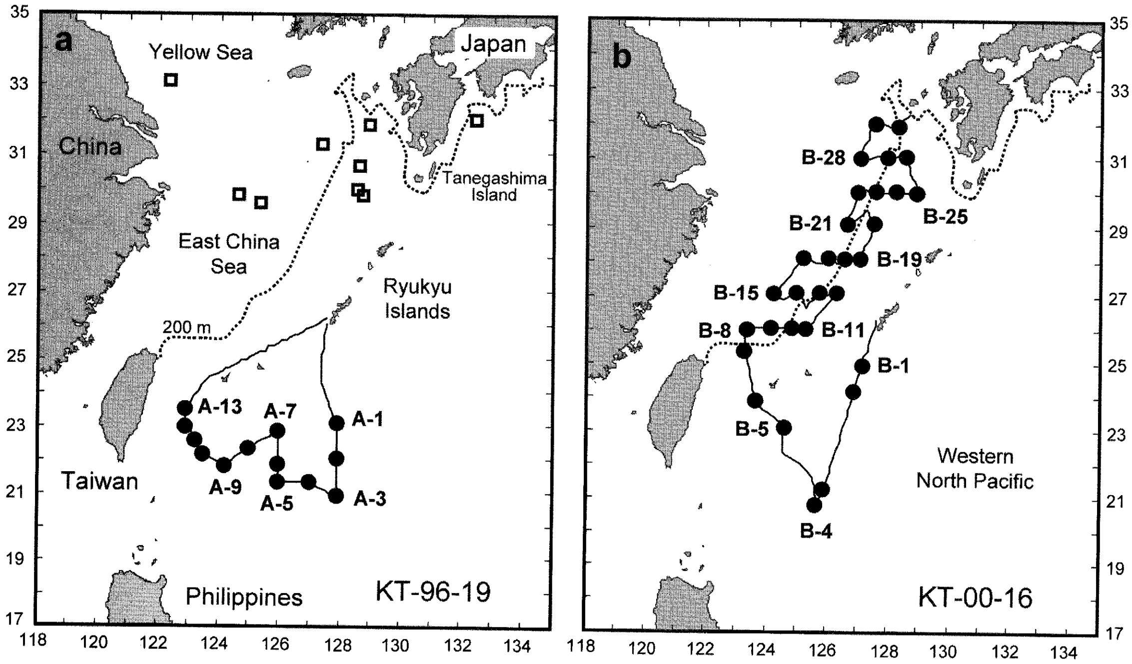

Fig. 1. Maps of the study area showing the cruise tracks and the location of sampling stations of the KT-96-19 (a) and the KT-00-16 (b) cruises. Some station numbers are shown to indicate the sequence of sampling in each cruise. The previous collection sites of the offshore glass eels (□), except for one caught in the South China Sea (21°56.5′N, 116°42.0′E), are also shown in (a). The dotted lines shows the 200 m depth contour.

Materials and Methods

Sampling for leptocephali and glass eels was carried out during the KT-96-19 and KT-00-16 cruises of the R/V Tansei Maru of the Ocean Research Institute of the University of Tokyo from 20 to 28 November 1996, and 27 November to 8 December 2000, respectively. The first cruise was conducted entirely over deep water in the western Pacific Ocean to the east of Taiwan and the latter was in the Kuroshio region of the East China Sea, with some stations in the same area as the former cruise (Fig. 1a, b). During the KT-00-16 cruise, the sampling stations in the Kuroshio region were located in transects from within the Kuroshio over the deep water of the Okinawa Trench, across the shelf break and over the shallow water of the East China Sea. Samples were collected with 3 m Issacs Kidd Midwater Trawls (IKMT) that had 8.7 m^2 mouth openings with either 1.0 or 0.5 mm mesh during both cruises. During the KT-96-19 cruise oblique tows were made in the upper 300 m, and during the KT-00-16 cruise both oblique tows from the surface to 500 m or to within 20 m of the bottom and horizontal step tows within the upper 200 m that targeted the strongest scattering layer observed using hydroacoustics were made.

Conductivity, temperature, depth profiles (CTD) were made at some stations depending on the sea state. The surface water temperature and salinity of the sampling area ranged from 25.9 to 27.5°C and from 34.0 to 34.5 psu in the KT-96-19 cruise, and 21.0 to 26.3°C and from 34.1 to 35.0 psu in the KT-00-16 cruise. Fig. 2 (Miller et al. 2002) shows the distribution of sea surface temperature in the Kuroshio and East China Sea region at the time of the KT-00-16 cruise. Ship-mounted Acoustic Doppler Current Profiler (ADCP) data were collected during each cruise for confirming the surface currents in the region. Reliable ADCP data were collected from only the upper 10 m surface layer in the water column due to the rough sea state during the two cruises.

Results

Nine leptocephali of the Japanese eel, *Anguilla japonica*, were collected in the western North Pacific to the east of Taiwan during the KT-96-19 cruise from 20°59.7–23°30.1N and 128°1.0–123°0.1E (St. A-3, 4, 6, 13) (Fig. 1a, 2). The total length (TL), preanal length (PAL) and predorsal length (PDL) ranged from 49.5–58.3 mm, 37.6–44.2 mm and 33.3–38.2 mm, respectively (Table 1). The total myomeres (TM), preanal myomeres (PAM) and predorsal myomeres (PDM) ranged 112–116, 77–80, and 67–71, respectively, and these were all within the typical range of *A. japonica* leptocephali (Table 1). All nine leptocephali were classified as fully-grown leptocephali (just prior to metamorphosis) based on their total lengths and preanal and predorsal myomeres. The otolith daily increments of five of these nine leptocephali were examined and described by Arai et al. (1997), and their ages ranged from 94–134 days after hatching.

Table 1. Leptocephali and glass eels collected during the KT-96-19 and KT-00-16 cruises. TL: total length, BL: body length, HL: head length, PAL: preanal length, PDL: predorsal length, BH: body hight, TM: total myomere, PAM: preanal myomere, PDM: predorsal myomere.

Fish no.		Cruise	Station	Location		TL (mm)	BL (mm)	HL (mm)	PAL (mm)	PDL (mm)	BH (mm)	TM	PAM	PDM	Pigmentation stage
				Latitude	Longitude										
1	Leptocephalus	KH-96-19	St.A-3	20°59.7N	128°01.0E	52.1	—	—	38.7	34.2	—	114	77	67	—
2	Leptocephalus		St.A-4	21°27.1N	126°59.8E	56.4	—	—	41.8	37.0	—	114	78	69	—
3	Leptocephalus		St.A-4	21°27.1N	126°59.8E	54.8	—	—	40.5	35.8	—	115	80	71	—
4	Leptocephalus		St.A-4	21°27.1N	126°59.8E	56.0	—	—	41.2	37.0	—	112	78	70	—
5	Leptocephalus		St.A-4	21°27.1N	126°59.9E	55.8	—	—	41.5	36.8	—	116	79	69	—
6	Leptocephalus		St.A-4	21°27.1N	126°59.9E	49.8	—	—	37.6	33.3	—	116	80	69	—
7	Leptocephalus		St.A-4	21°27.1N	126°59.9E	49.5	—	—	37.7	33.9	—	114	77	67	—
8	Leptocephalus		St.A-6	22°00.0N	126°00.0E	55.7	—	—	41.6	36.0	—	114	79	67	—
9	Leptocephalus		St.A-13	23°30.1N	123°00.1E	58.3	—	—	44.2	38.2	—	113	79	68	—
10	Glass eel	KH-00-16	St.B-11	26°01.9N	125°12.5E	54.8	53.8	5.2	19.3	15.2	—	116	—	—	II
11	Glass eel		St.B-11	26°01.9N	125°12.5E	57.0	56.1	7.2	21.0	16.9	2.4	114	38	—	—
12	Glass eel		St.B-11	26°01.9N	125°12.5E	52.5	50.3	6.0	19.2	14.0	2.8	—	—	—	II
13	Glass eel		St.B-19	28°04.3N	127°00.3E	56.1	—	5.7	21.0	16.0	2.0	114	39	30	III
14	Glass eel		St.B-20	29°07.5N	127°34.7E	54.4	53.5	5.9	20.0	14.8	2.0	113	38	38	III–IV
15	Glass eel		St.B-20	29°07.5N	127°34.7E	51.8	50.8	5.2	18.0	13.3	2.3	114	38	28	III–IV
16	Glass eel		St.B-20	29°07.5N	127°34.7E	56.5	55.6	6.2	20.0	15.5	2.3	116	36	27	III–IV
17	Glass eel		St.B-23	30°01.0N	127°36.2E	56.2	55.3	6.5	21.0	16.2	2.0	115	38	28	III–IV
18	Glass eel		St.B-25	30°00.2N	129°00.4E	51.3	50.0	6.3	18.5	15.0	2.0	116	38	30	III–IV

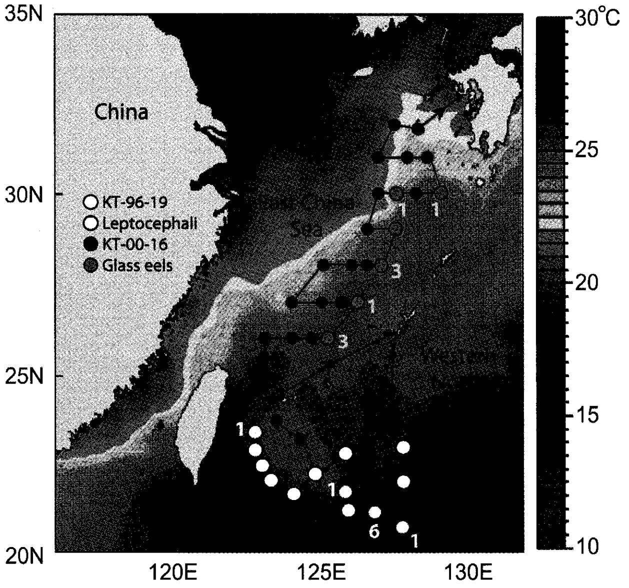

Fig. 2. A map of study area showing the approximate sea surface temperature (SST) on 30 November 2000, the cruise tracks (lines) and sampling stations (black and white circles), and the stations where *Anguilla japonica* leptocephali were collected during the KT-96-19 cruise (yellow circles) and metamorphosing glass eels were collected during the KT-00-16 cruise (blue circles). Numbers of leptocephali and glass eels collected in each catch station are also shown. The SST map was modified from Miller et al (2002).[23]

Ship-mounted Acoustic Doppler Current Profiler (ADCP) data (Fig. 3a) showed that the water currents in the 10 m surface layer at the three stations (St. A-3, 4, 6) where *A. japonica* leptocephali were collected was westward and it was north-eastward at the other positive station (St. A-13).

During the KT-00-16 cruise, nine early stage glass eels of *A. japonica* that were still in the late stages of the process of metamorphosing from the leptocephalus into the glass eel stage were collected in the Kuroshio region of the East China Sea. But there were no premetamorphic leptocephali collected during the cruise. The total length (TL), body length (BL), preanal length (PAL), predorsal length (PDL), head length (HL), and body depth (BD) of these specimens ranged from 51.3–57.0 mm, 50.0–56.1 mm, 18.0–21.0 mm, 14.0–16.9 mm, 5.2–7.2 mm and 2.0–2.8 mm, respectively (Table 1). Pigment was present only on the vertebrae and some caudal fins in four specimens from the southern two stations, indicating that they belonged to the pigmentation stage II to III (Fig. 4). The other five specimens were classified to the stage III to IV because of the presence of pigment on the vertebrae and caudal fins. The pigmentation stages of specimens from the northern three stations were more advanced than those from the southern stations.

The collection sites during the KT-00-16 cruise were 26°1.9N, 125°12.5E (St. B-11), 28°4.3N, 127°0.3E (St. B-19), 29°7.5N, 127°34.7E (St. B-20), 30°1.0N, 127°36.2E (St. B-23), 30°0.2N, 129°0.4E (St. B-25), all of which, except for St. B-25, were located along the 200 m depth contour at the edge of the continental shelf (Fig. 1b, 2). There was no apparent geographic cline in the total length of the specimens.

ADCP data showed that water current of the surface 10 m layer at the three southern stations where *A. japonica* glass

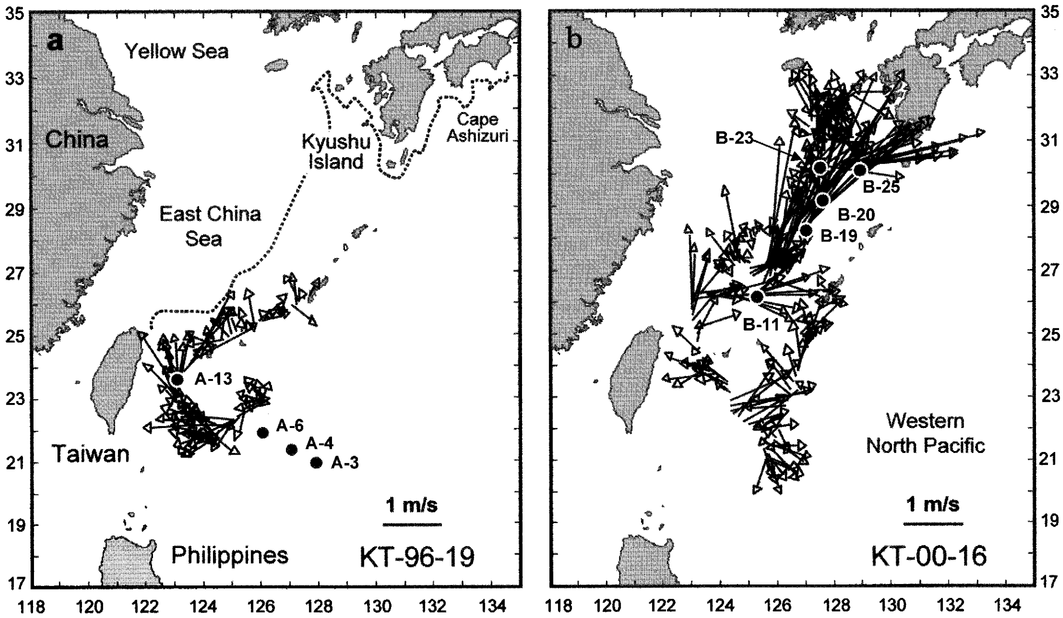

Fig. 3. Maps showing the surface current direction and velocities derived from ship-mounted Acoustic Doppler Current Profiler data during the KT-96-19 (a) and the KT-00-16 (b) cruises. The vectors of the catch stations are shown as white arrows. The dotted lines show the 200 m depth contour.

Fig. 4. A photograph of an *Anguilla japonica* glass eel (TL: 52.5 mm) collected from the most southern catch station (St. B-11) during the KT-00-16 cruise.

eels were collected (St. B-11, B-19, B-20) was northeast to north-north-eastward at a speed of 1.5 m sec^{-1} (Fig. 3b). Farther north, it was northward at a speed of 1.3 m sec^{-1} at St. B-23, and was eastward at 1.0 m sec^{-1} at St. B-25. The water temperature at the depth of 200 m at Station B-19 and B-20 (the only positive stations where CTD profiles were made), was 19.7 and 16.5°C, respectively, which were within the temperature range indicative of the main stream of the Kuroshio (Nitani 1972). This suggests that the positive stations, excepting for St. B-23, were located in the the main stream of the Kuroshio. Station B-23 was located in the Kuroshio Branch Current west of Kyushu as described by Ichikawa and Beardsley (2002). The maximum depths reached by the net at each of the collection sites ranged from 130 to 330 m, indicating that each of these net tows filtered water in the high velocity region of the Kuroshio, which extended down to about 500–600 m deep in the fall (Ichikawa and Beardsley 2002, Kaneko et al. 1990, Yuan et al. 1994).

Discussion

The collection sites of the Japanese eel leptocephali during the KT-96-19 cruise were located in the region to the south of the Ryukyu Islands and to the east of Taiwan, which appears to have complex circulation patterns. The circulation in this region appears to be dominated by eddies because there have been indications that it is often the general location of a relatively large eddy or small subgyre of the Kuroshio (Nitani 1972, Yang et al. 1999), as was suggested in September 1986 (Kajihara 1988). The ADCP data of this study indicated a complex eddy structure in that area. However, the stations where the Japanese eel leptocephali were collected during the KT-96-19 cruise appeared to be located in predominantly westward flow (St. A-3, 4, 6) or in northeast flow closer to the base of the Kuroshio (St. A-13), suggesting that these leptocephali may still have had the potential to be entrained into the Kuroshio (Fig. 2, 3a).

Before the present study, only one glass eel was reported from the main stream of the Kuroshio near Cape Ashizuri of Shikoku Island, Japan (Sakakura et al. 1996), and the other eight from the northern part of the species range were collected over the continental shelf of the East China Sea to the west of the Kuroshio region (Fig. 1a) (Shojima 1966, 1967, 1990, Tabeta 1981). The missing link in the migration route had remained in the period of time between those glass eels and the fully-grown or early metamorphosing leptocephali in the North Equatorial Current east of Taiwan. The nine early stage glass eels collected during the KT-00-16 cruise were included in the size range of those previously collected offshore glass eels (53.0–61.2 mm TL) and were of slightly earlier or the same pigmentation stages as previous ones. The present glass eels fill in the gap between those glass eels and leptocephali, providing the first direct evidence for the migration of metamorphosing leptocephali and glass eels through the Kuroshio. Furthermore, the collection of fully-grown leptocephali to the east of Taiwan during the KT-96-19 cruise and the glass eels within the Kuroshio region that were near the completion of metamorphosis (pigmentation stage II to IV), suggests that the metamorphosis from leptocephalus to glass eel may typically occur during the transportation within the Kuroshio for individuals recruiting to the northern part of the species range.

The recruitment area of glass eels may be determined by the locations where the individual glass eels detrain from the transporting currents and start their inshore migration (Tsukamoto and Umezawa 1994, Otake 2003). The detrainment from currents has been suggested to be coupled with the completion of metamorphosis in the Japanese eel (Tabeta and Takai 1973, Tabeta and Konishi 1986, Tsukamoto 1990, Tsukamoto and Umezawa 1994, Otake 2003). The glass eel collection site of St. B-23 was located just inside the 200 m depth contour near the likely northwest edge of the Kuroshio (Fig. 1b, 2). The glass eel from the station may have had the potential to enter the Kuroshio Branch Current west of Kyushu. This would have enabled it to eventually recruit to the western or northern part of Kyushu Island, Korea, or the Japan Sea coast of Japan, because the Kuroshio Branch Current is a main source of the Tsushima Warm Current that flows into the Japan Sea through the Tsushima Strait in winter (Lie and Cho 1994, Lie et al. 1998). The glass eel collected at St. B-25 where the ADCP detected strong eastward flow (Fig. 3b) would have been more likely to be transported to the east and then northeast by the main stream of the Kuroshio and to have eventually recruited to the Pacific coast of Japan. The other six glass eels from the southern region of the Kuroshio were in the Kuroshio main stream based on previous studies (Yuan et al. 1994) and the ADCP data collected during the cruise (Fig. 3b), and may have had three possibilities for the locations of their recruitment. If they were to quickly detrain from the Kuroshio or to become trapped in an eddy at the western edge of the current, they may have had the potential to recruit to the coasts of China and Korea by migrating across the East China Sea. If they continued north in the Kuroshio, they would have had the potential to be transported toward Korea or the Japan Sea by the Tsushima Warm Current, or to be transported to the Pacific coast of Japan by the Kuroshio.

The early stage glass eels that were collected in the Kuroshio region may provide a valuable first step towards answering some important questions about the development and migration associated with the recruitment of the Japanese eel by comparing their characteristics to those of the more extensively studied glass eels collected when they recruit to estuaries. The specimens from the Kuroshio region during the KT-00-16 cruise were at the pigmentation stages of II to IV, which is in contrast to the pigmentation stages of glass eels recruiting to estuaries of Taiwan, China and Japan that were reported to belong to the stages VA–VIA3 (Arai et al. 1997, Cheng and Tzeng 1996). This suggests that the inshore migration of glass eels begins at the pigmentation stage between IV and VA.

Marked increase in otolith increment width has been proposed to relate to the onset of the metamorphosis, with the width reaching a maximum before the completion of metamorphosis (Otake et al. 1994, Arai et al. 1997, Otake et al. 1997). Arai et al. (1997) suggested that some glass eels at pigmentation stage VB recruited to an estuary in Tanegashima Island, Japan, 56 km away from the main stream of the Kuroshio, apparently only 0 to 2 days after the otolith width maximum. Further examination is needed to confirm the relationship among the changes in otolith microstructure and the completion of the metamorphosis or the onset of inshore migration.

Because the timing of the beginning the inshore migration is a significant for determining the location of recruitment of each individual (Tsukamoto and Umezawa 1994, Otake 2003), research on this aspect is essential for understanding the recruitment mechanisms in anguillid eels. Therefore, future comparisons of the otolith microstructure between the early stage oceanic glass eels in the Kuroshio region described here and glass eels that recruit to estuaries may provide a breakthrough in determining the timing and duration of the inshore migration and fully understanding the recruitment mechanism of the Japanese eel.

Acknowledgments

We thank the other members of the cruises who helped the net sampling and plankton sorting and we express our gratitude to the captain and crew of the R/V Tansei Maru, Ocean Research Institute, The University of Tokyo for their assistance throughout the KT-96-19 and KT-00-16 cruises. Partial funding for this research was provided by grants from the Ministry of Education, Science and Culture of Japan (Grant-in-aid No. 08456094, 08041139, 10460081, 11460089 and 14360109), "Research for the Future" Program No. JSPS-RFTF 97L00901 from the Japan Society for the Promotion of Science, Touwa Shokuhin Shinkoukai, and the Eel Research Foundation from Nobori-kai.

References

Arai, T., Otake, T., Tsukamoto, K. 1997. Drastic changes in otolith microstructure and microchemistry accompanying the onset of metamorphosis in the Japanese eel *Anguilla japonica*. Mar. Ecol. Prog. Ser. 161: 17–22.

Cheng, PW., Tzeng, WN. 1996. Timing of metamorphosis and estuarine arrival across the dispersal range of the Japanese eel *Anguilla japonica*. Mar. Ecol. Prog. Ser. 131: 87–96.

Ichikawa, H., Beardsley, RC. 2002. The current system in the Yellow and East China Seas. J. Oceanogr. 58: 77–92.

Ishikawa, S., Suzuki, K., Inagaki, T., Watanabe, S., Kimura, Y., Okamura, A., Otake, T., Mochioka, N., Suzuki, Y., Hasumoto, H., Oya, M., Miller, MJ., Lee, TW., Fricke, H., Tsukamoto, K. 2001. Spawning time and place of the Japanese eel *Anguilla japonica* in the North Equatorial Current of the western North Pacific Ocean. Fish. Sci. 67: 1097–1103.

Kajihara, T. 1988. Distribution of *Anguilla japonica* leptocephali in western Pacific during September 1986. Nippon Suisan Gakkaishi 54: 929–933.

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

Kaneko, A., Koterayama, W., Honjo, H., Mizuno, S., Kawatate, K., Gordon, RL. 1990. Cross-stream survey of the upper 400 m of the Kuroshio by an ADCP on a towed fish. Deep-Sea Res. 37: 875–889.

Kimura, S., Tsukamoto, K., Sugimoto, T. 1994. A model for the larval migration of the Japanese eel: role of the trade winds and salinity front. Mar. Biol. 119: 185–190.

Lie, H., Cho, C. 1994. On the origin of the Tsushima Warm Current. J. Geophys. Res. 99: 25081–25091.

Lie, H., Cho, C., Lee, J., Niiler, P., Hu, J. 1998. Separation of the Kuroshio water and its penetration onto the continental shelf west of Kyushu. J. Geophys. Res. 103: 2963–2976.

Miller, MJ., Otake, T., Minagawa, G., Inagaki, T., Tsukamoto, K. 2002. Distribution of leptocephali in the Kuroshio Current and East China Sea. Mar. Ecol. Prog. Ser. 235: 279–238.

Nitani, H. 1972. Beginning of the Kuroshio. In: Stommel, H., Yoshida, K., (eds). Kuroshio: Its Physical Aspects. University of Tokyo Press, Tokyo. 129–163.

Otake, T., Ishii, T., Nakahara, M., Nakamura, R. 1994. Drastic changes in otolith strontium:calcium ratios in leptocephali and glass eels of Japanese eel *Anguilla japonica*. Mar. Ecol. Prog. Ser. 112: 189–193.

Otake, T. 2003. Metamorphosis. In: Aida, K., Tsukamoto, K., Yamauchi, K. (eds). Eel Biology. Springer-Verlag, Tokyo. 61–74.

Otake, T., Ishii, T., Ishii, T., Nakahara, M., Nakamura, R. 1997. Changes in otolith strontium:calcium ratios in metamorphosing *Conger myriaster* leptocephali. Mar. Biol. 128: 565–572.

Sakakura, Y., Tsukamoto, Y., Tsukamoto, K., Okiyama, M. 1996. First record of *Anguilla japonica* glass eel collected in the Kuroshio Current. Fisheries Sci. 62: 496–497.

Shojima, Y. 1966. Report on a capture of an elver of Japanese eel, *Anguilla japonica* T. et S. in the East China Sea. Bull. Japan. Soc. Sci. Fish. 32: 41–44.

Shojima, Y. 1967. Record of Japanese eel found in the offshore waters of the East China Sea for the second time. Zool. Mag. 76: 167–171 (in Japanese).

Shojima, Y. 1990. The glass eel collected in the East China Sea. Suisan Gijyutsu to Keiei 3: 18–28 (in Japanese).

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

Tabeta, O., Konishi, Y. 1986. An anguillid leptocephalus *Anguilla japonica* from the waters of Miyako Island, Okinawa, Japan. Bull. Japan. Soc. Sci. Fish. 52: 1935–1937.

Tabeta, O., Takai, T. 1973. An elver of *Anguilla japonica* found in the northern part of the South China Sea. J. Shimonoseki Univ. Fisheries. 22: 1–5.

Tabeta, O., Tanaka, K., Yamada, J., Tzeng, WN. 1987. Aspects of the early life history of the Japanese eel *Anguilla japonica* determined from otolith microstructure. Bull. Japan. Soc. Sci. Fish. 53: 1727–1734.

Tanaka, S. 1975. Collection of leptocephali of the Japanese eel in waters south of the Okinawa Islands. Bull. Japan. Soc. Sci. Fish. 41: 129–136.

Tsukamoto, K. 1990. Recruitment mechanism of the eel *Anguilla japonica* to the Japanese coast. J. Fish Biol. 36: 659–671.

Tsukamoto, K. 1992. Discovery of the spawning area for Japanese eel. Nature. 356: 789–791.

Tsukamoto, K., Otake, T., Mochioka, N., Lee, TW., Fricke, H., Inagaki, T., Aoyama, J., Ishikawa, K., Miller, MJ., Hasumoto, H., Oya, M., Suzuki, Y. 2003. Seamounts, new moon and eel spawning: the search for the spawning site of the Japanese eel. Env. Biol. Fish. 66: 221–229.

Tsukamoto, K., Umezawa, A. 1990. Early life history and oceanic migration of the eel, *Anguilla japonica*. La mer 28: 188–198.

Tsukamoto, K., Umezawa, A. 1994. Metamorphosis: A key factor of larval migration determining geographic distribution and speciation of eels. Proc. 4th Indo–Pacific Fish Conf. Bangkok, Thailand. 231–248.

Tzeng, WN., Tsai, YC. 1992. Otolith microstructure and daily age of the *Anguilla japonica*, Temminck & Schlegel elvers from the estuaries of Taiwan with reference to unit stock and larval migration. J. Fish Biol. 40: 845–857.

Tzeng, WN., Tsai, YC. 1994. Changes in otolith microchemistry of the eel, *Anguilla japonica*, during its migration from the ocean to the rivers of Taiwan. J. Fish Biol. 45: 671–683.

Umezawa, A., Tsukamoto, K., Tabeta, O., Yamakawa, H. 1 989. Daily growth increments in the larval otolith of the Japanese eel, *Anguilla japonica*. Japan. J. Ichthyol. 35: 440–444.

Yang, Y., Liu, C-T., Hu, J-H., Koga, M. 1999. Taiwan Current (Kuroshio) and impinging eddies. J. Oceanogr. 55: 609–617.

Yuan, Y., Takano, K., Pan, Z., Su, J., Kawatate, K., Imawaki, S., Yu, H., Chen, H., Ichikawa, H., Umatani, S. 1994. The Kuroshio in the East China Sea and the currents east of the Ryukyu Islands during autumn 1991. La mer 32: 235–244.