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Ages of the giant mottled eel *Anguilla marmorata* recruited at the northern Luzon Island, the Philippines between 2009 and 2011

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Abstract—To accumulate information on the larval transportation of the freshwater eels in the North Pacific, we examined the ages of the giant mottled eel *Anguilla marmorata* recruited at the northern Philippines. The glass eel specimens analyzed were collected at the river mouth of the Cagayan River in the Luzon Island in January 2009, November 2011 and November 2012, and the daily increment rings of the otoliths were observed to determine the ages at recruitment (n=14). There was no significant difference in the ages at recruitment among the 2009- (147.0±24.4 days; 126–182), 2011- (145.2±17.3; 122–161) and 2012-groups (136.0±11.1; 122–145), and were in the range of those in the previous studies at the same place. Further efforts to accumulate information on the ages at recruitment at various localities and timings will be important to comprehensively understand the early life history of *A. marmorata* in the North Pacific.

Key words: *Anguilla marmorata*, freshwater eel, giant mottled eel, glass eel, otolith, Philippines

Introduction

The freshwater eels, genus *Anguilla*, consist of 19 species/subspecies, and distribute in the Pacific, Atlantic and Indian Ocean (Ege 1939, Watanabe 2003, Watanabe et al. 2009). Among the genus, the giant mottled eel *Anguilla marmorata* distributes the most widely in the Pacific and Indian Ocean (Ege 1939), and is suggested to be consisted of at least four genetically-isolated populations in the North Pacific, South Pacific, Indian Ocean and Guam region (Minegishi et al. 2008).

In the North Pacific, the spawning grounds of *A. marmorata* and the Japanese eel *A. japonica* are known to be, at least partly, over-lapped (Kuroki et al. 2009). The spawning site of *A. japonica* is determined by certain landmarks such as salinity front and seamount ridge for latitude and longitude, respectively (Tsukamoto et al. 2011, Aoyama et al. 2014). The salinity front, the northern end of the low-salinity region, can be moved yearly, especially remarkable when global climatic changes such as El Niño occur (Kimura and Tsukamoto 2006). As a result, the spawning sites can be shifted yearly, or even monthly, and this may influence to the transportation of larvae, referred to as leptocephalus, in the North Equatorial Current and reproductive success (Zenimoto et al. 2009). Accordingly, the early life history of the freshwater eels is key to understand the recruitment of the stock in the genus.

The ages at recruitment of the anguillid eels in the North Pacific have been studied, mostly in *A. japonica*. The ages of *A. japonica* glass eels collected in early and end of May 1994 at western Japan were reported to be 172 days and 225 days in average, respectively (Kawakami et al. 1998). Such large variation in the ages at recruitment of *A. japonica* has been also observed at the other places in East Asian countries (Cheng and Tzeng 1996). At the northern Luzon Island of the Philippines, the ages at recruitment have been also reported in the five anguillid species (Arai et al. 1999, Leander et al. 2013, Yoshinaga et al. 2014, Shinoda et al. 2015). However, in comparison with temperate species of *A. japonica*, information in the tropical species is yet limited because of lesser feasibility for sample collection in the tropical area.

Recently, Aoyama et al. (2015) carried out a long-term monitoring of the recruitment of glass eels at the northern Philippines, where *A. japonica* was also reported to occur (Tabeta et al. 1976, Yoshinaga et al. 2014), and showed that four species including *A. marmorata* occurred with species-specific recruitment season. The long-term survey by Aoyama et al. (2015) had been carried out to fill in a major gap in the ecological information in the tropical anguillid species whose commercial demand has been rapidly increasing during recent years (Crook 2014), and their stock management is urgently required (Jacoby and Gollock 2014). The collection by Aoyama et al. (2015) has enabled the comparison of the recruitment of the tropical species at the northern Philippines, where is one of the most actively harvested areas. In this study, accordingly, we aimed to study the ages of *A. marmorata* recruited in different timings at the northern Philippines to complement the previous studies and contribute to the comprehensive understanding of the larval transportation in the North Pacific of the freshwater eels.

Materials and Methods

The *A. marmorata* specimens examined in this study were a part of the monthly-sampled collection of the glass eels at the river mouth of the Cagayan River in the northern Luzon Island, the Philippines in January and February 2009 (Yoshinaga et al. 2014) and between November 2011 and November 2012 (Period II in Aoyama et al. 2015). Among the total of 15-months collection, the three months were chosen in this study (1) to compare the ages at recruitment with the sympatrically spawning species of *A. japonica* which had been found only in January 2009 (2009-group) (Kuroki et al. 2009, Yoshinaga et al. 2014, Aoyama et al. 2015), and (2) to compare the ages of the specimens recruited in same month (November) of different years (2011- and 2012-groups) (Aoyama et al. 2015). The *A. marmorata* glass eel specimens, preserved in 99.5% *v/v* ethanol, were randomly chosen from the genetically identified samples (n=45 each), and total length and pigmentation stage were observed. For the otolith analysis, five specimens were randomly chosen from each group. The sample size in each group was determined to compare ranges in the ages at recruitment among different months with a small number of specimens, rather than to obtain representative value in a certain month with a larger sample size. One specimen in the 2009-group was omitted from the results due to a technical difficulty to obtain reliable count of rings. The methods for the genetic identification and otolith observation have been described elsewhere (Yoshinaga et al. 2014).

Results and Discussion

The total length of the 2009-group (mean±s.d., 46.6±1.7 mm; range, 43.3–51.8) was significantly smaller than those of the 2011- and 2012-groups (47.9±1.8; 42.0–52.7 and 48.5±2.0; 44.0–52.3, respectively) (n=45 each; one-way ANOVA, P<0.01; *post-hoc* PLSD test, P<0.01; Fig. 1, Table 1). The significant difference was found in the TL among the groups, but it could be due to the variation in the developmental stages. The newly-recruited glass eels is known to be negatively grow in the total length because the metamorphosing of the leptocephalus into the glass eel stage causes a shrinkage of the body (Okamura et al. 2012). According to the criteria developed in *A. japonica* (Fukuda et al. 2013), the pigmentation stages were V_A (100%) in the 2009-group, V_A (60%), V_{B1} (24%) and V_{B2} (16%) in the 2011-group, and V_A (5%), V_{B1} (82%) and V_{B2} (13%) in the 2012-group (n=45 each). However, the progress of the pigmentation at the glass eel stage can be varied among the species, and it was not possible to evaluate the total length of the specimens at various pigmentation stages, or even at same stage because the duration of each stage is not clear yet in *A. marmorata*. Recently, the pigmentation pattern at the glass eel stage has been partly reported in *A. borneensis* and *A. interioris* (Shirotori et al. submitted). These long-fin species have a tail pigmentation similar to that of the short-fin *A. bicolor*, and thus the pigmentation deposition at the glass eel stage is now recognized to be more complex than previously assumed (Shirotori et al. submitted). The comprehensive observation on the pigmentation development in the tropical species will be essential for the better understanding of the early life history traits in *Anguilla*.

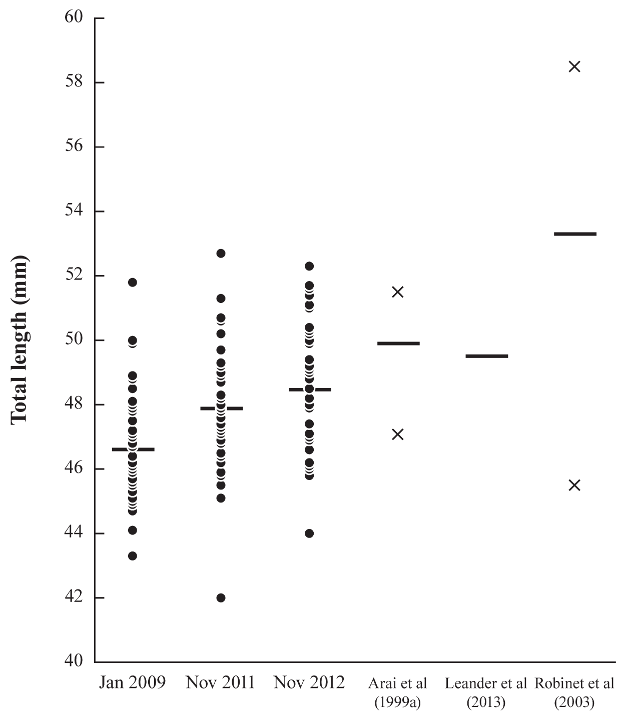

Fig. 1. The total lengths of the glass eels of *Anguilla marmorata* recruited at the northern Luzon Island, the Philippines in 2009, 2011 and 2012. Closed circles are values of each specimen with the averages shown by horizontal bars (n=45 each). The dotted bars are maximum and minimum values in the previous studies (not available in Leander et al. 2013). The specimens examined in Robinet et al. (2003) were the Indian Ocean population.

Table 1. Morphological characteristics and ages at recruitment of the *Anguilla marmorata* recruited at the northern Luzon Island, the Philippines between 2009 and 2012.

Collection date	TL (mm)	Pigmentation stage	Age at recruitment (days)	Hatching date
26 Jan 2009	45.0	V_A	137	11 Sep 2008
26 Jan 2009	45.5	V_A	182	28 Jul 2008
26 Jan 2009	44.1	V_A	126	22 Sep 2008
26 Jan 2009	44.9	V_A	143	5 Sep 2008
25 Nov 2011	52.7	V_{B2}	152	26 Jun 2011
25 Nov 2011	51.3	V_A	161	17 Jun 2011
25 Nov 2011	50.2	V_{B2}	122	26 Jul 2011
25 Nov 2011	47.3	V_A	159	19 Jun 2011
25 Nov 2011	46.9	V_{B1}	132	16 Jul 2011
14 Nov 2012	47.4	V_{B1}	144	23 Jun 2012
14 Nov 2012	46.6	V_{B1}	143	24 Jun 2012
14 Nov 2012	50.3	V_{B1}	145	22 Jun 2012
14 Nov 2012	46.9	V_{B1}	122	15 Jul 2012
14 Nov 2012	48.8	V_{B1}	126	11 Jul 2012

The validity of daily increment of the otolith ring has been confirmed in *A. marmorata* (Sugeha et al, 2001). The ages at recruitment were 147.0±24.4 days (126–182; n=4) in the 2009-group, 145.2±17.3 days (122–161; n=5) in the 2011-group, and 136.0±11.1 days (122–145; n=5) in the 2012-group (Fig. 2). There was no significant difference in the ages at recruitment among the three groups (ANOVA, P=0.61). The hatching months of the 2009-group were between July and September 2008 (Table 1). The 2011- and 2012-groups were both hatched in June and July in 2011 and 2012, respectively.

Two previous studies have reported the ages of *A. marmorata* recruited at the same place with this study: 154±13.5 days with a range between 136 and 178 days (Arai et al. 1999), and 144.8±14.2 days (Leander et al. 2013; range was not available). Even the numbers of specimens in each group were not large in this study, the ranges in the ages at recruitment were larger than that of Arai et al. (1999). This means that our data may be weaker to obtain reliable average and mode values than the previous studies, but are still capable to provide the variation in the ages at recruitment. Combining the results of this study and the previous ones, it was suggested that *A. marmorata* recruited at the northern Philippines had the oceanic larval period of about 140–160 days with a range between 120 and 180 days (Fig. 2).

We analyzed *A. marmorata* glass eels collected in January 2009 because *A. japonica* was observed only in this month during the long-term survey (Yoshinaga et al. 2014, Aoyama et al. 2015). The spawning grounds of *A. japonica* and *A. marmorata* are known to be, at least partly, overlapped (Kuroki et al. 2009), and thus they are likely to be transferred simultaneously in the North Equatorial Current. The ages at recruitment of *A. japonica* with 147.2±21.3 days with a range between 111 and 185 (Yoshinaga et al. 2014) was almost similar with those of *A. marmorata* in the 2009-

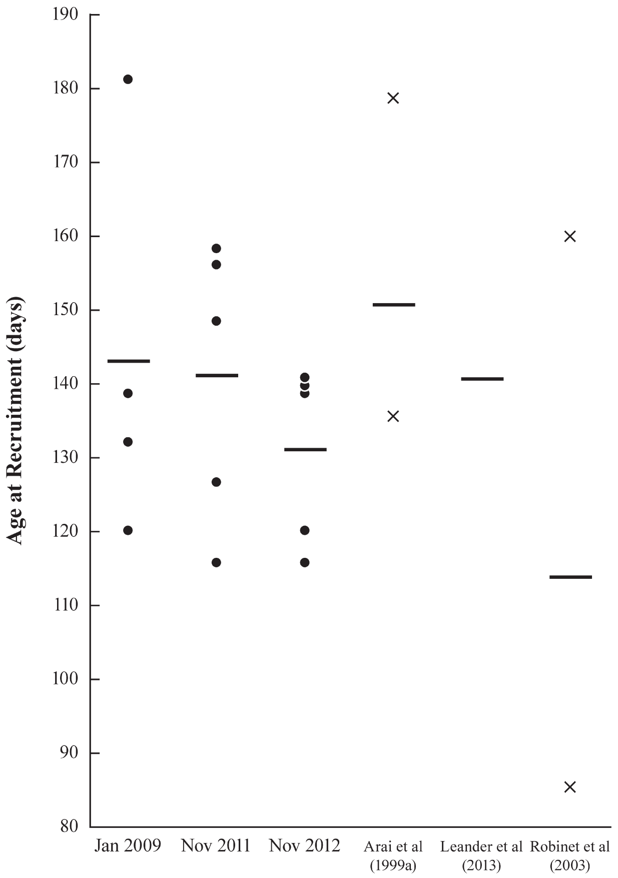

Fig. 2. The ages at recruitment *A. marmorata* at the northern Luzon Island inferred from the daily increment rings in the otolith. Closed circles are values of each specimen (n=4–5 each). The horizontal solid bars are the average, and the dotted bars are maximum and minimum values in the previous studies (not available in Leander et al. 2013). The specimens examined in Robinet et al. (2003) were the Indian Ocean population.

group of this study (Fig. 2). Even though the spawning ground of *A. marmorata* has not yet been enough understood, the two species might have been hatched at closed area and transported in the common environment.

In the Indian Ocean population of *A. marmorata*, the ages at recruitment at the east coast of Réunion Island has been reported to be 120.2±24.7 days with a range between 86 and 160 days (Robinet et al. 2003). A difference between the two genetically distinct populations of *A. marmorata* is the youngest recruitment of 122 and 86 days in the Pacific and Indian Ocean, respectively. There could be some possible mechanisms such as the ocean-specific transportation and the population-specific genetic traits, and further studies will be important to understand the variation in the early life history of multiple *A. marmorata* populations.

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