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Short Note

Age and growth of *Anguilla interioris* leptocephali collected in Indonesian waters

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Abstract—*Anguilla interiorisis* has been only known to be distributed in northern New Guinea, but recent sampling surveys for leptocephali and the development of species identification techniques using DNA analysis have discovered that this species also appears to occur off Sumatra in the eastern Indian Ocean, and may be present in other areas of the Indonesian Archipelago. To reveal the ages and early life histories of this species, the otolith microstructure of the leptocephali collected near the Sulawesi Island and off Sumatra of Indonesia were examined. The otolith microstructure of the *A. interioris* leptocephali was similar to other anguillid species and showed narrow increment widths (0.49–0.58 μm) near the core that increased (1.14–1.34 μm) before decreasing again until the otolith edge (0.51–0.83 μm), except in the smallest specimen (12.4 mm TL) collected off Sumatra, which had no peak. The range of Sr : Ca ratios in their otoliths were 8.37 to 14.01. Their ages were 19 d for the smallest specimen from off Sumatra, 85 d for the specimen (48.9 mm TL) from Tomini Bay, and 85 to 94 d for the three specimens (43.4–46.5 mm TL) from the Molucca Sea. The overall growth rate of the leptocephali was 0.48 mm/d, and this value was intermediate compared with the growth rates of the other anguillid species. The age of the smallest *A. interioris* leptocephalus collected off Sumatra and the geographic patterns of currents in the regions, suggest that it was spawned in the Indian Ocean and that it may belong to a different population than the New Guinea population.

Key words: eel, *Anguilla interioris*, leptocephali, otolith, age, growth, mtDNA

Introduction

Anguilla interioris is one of the most mysterious species of anguillid eels because of an almost complete lack of knowledge about its life history. Ege (1939) first described this species using only seven specimens from New Guinea. However, the morphological characters of his specimens of *A. interioris* heavily overlapped with other tropical species such as *A. celebesensis* and *A. megastoma*, and furthermore, there have been no ecological studies of this species. Aoyama et al. (2000) clearly distinguished 11 morphologically unidentified specimens of *Anguilla* that were collected in New Guinea and on Sulawesi Island as *A. interioris* or *A. celebesensis* using mitochondrial DNA analysis. This finding may contradict Ege's (1939) information on the geographic distribution of these species, because it suggested that *A. interioris* may be found all over New Guinea, while *A. celebesensis* may not be found there, but is distributed around north Sulawesi Island and in the Philippines. However, a new problem about the geographic distribution of *A. interioris* arose from the distribution of their leptocephali, because specimens were collected in the eastern Indian Ocean and Indonesian Archipelago of Sulawesi Island, far from their known habitat along the northern coast of New Guinea. In this paper, we examine the age and life history characteristics of these specimens using their otolith microstructure and microchemistry to collect basic life history information about *A. interioris*, and discuss the migration and geographic distribution of this species.

Materials and Methods

A total of five leptocephali were collected with a 3 m Isaacs Kidd Midwater Trawl during 3 cruises of the R/V Baruna Jaya VII of the Indonesian Institute of Science, in Indonesian waters around Sulawesi Island during May 2001 (BJ-01-1) and in October 2002 (BJ-02-4), and then off west Sumatra in June 2003 (BJ-03-2) (Fig. 1). After measuring their morphological characters, these leptocephali were identified using mtDNA analysis (Aoyama et al. in review). Their otoliths were extracted and ground to the core. The Sr and Ca contents were measured in two of the specimens (45.3 mm

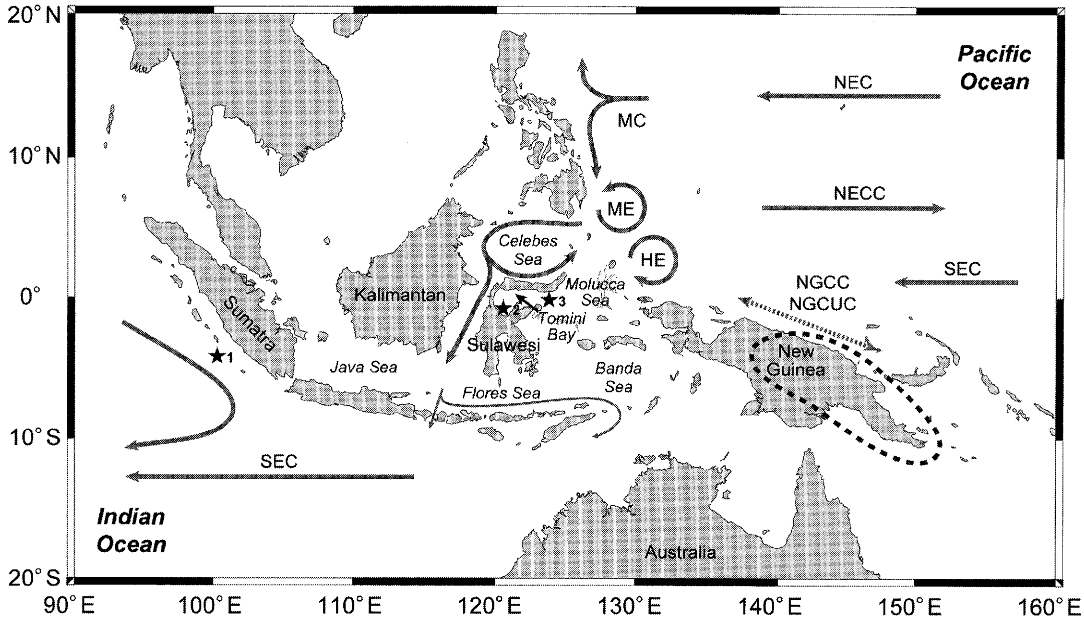

Fig. 1. Map showing the distribution of *Anguilla interioris* leptocephali collected in the eastern Indian Ocean (★$_1$), Tomini Bay (★$_2$) and Molucca Sea (★$_3$) during 3 cruises, and the estimated geographic distribution of *Anguilla interioris* in northeast New Guinea (broken line). The major current features of the region are the North Equatorial Current (NEC), North Equatorial Countercurrent (NECC), Mindanao Current (MC), Mindanao Eddy (ME), Halmahera Eddy (HE), South Equatorial Current (SEC), New Guinea Coastal Current (NGCC), and New Guinea Coastal Undercurrent (NGCUC).

and 46.5 mm TL) along the longest axis of each otolith using a wavelength dispersive X-ray electron microprobe (JXA-8900, JEOL), after Kuroki et al (2005). The averages of Sr and Ca concentrations pooled for every 10 successive growth increments were used for the life history transect analysis. The otoliths of all five specimens were analyzed with a scanning electron microscope (SEM, Hitachi S-4500) to observe the otolith microstructure, count growth increments, and measure increment widths. The average increment widths of every 10 successive rings from outside the core to the otolith edge were used for otolith growth analysis. The individual growth rates of leptocephali were calculated as (TL-3)/age, because a mean length of 3 mm TL at hatching was obtained for artificially fertilized *Anguilla japonica* (Yamamoto and Yamauchi 1974). Overall growth rates were calculated using the slope of regressions to compare with those of other species of the genus *Anguilla* reported in previous studies.

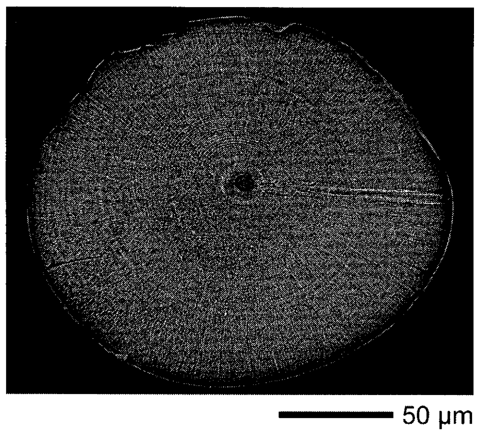

Fig. 2. SEM photograph showing the otolith growth increments of an *Anguilla interioris* leptocephalus (46.5 mm TL) collected in the Molucca Sea, Indonesia.

Results and Discussion

The fundamental otolith microstructure of *A. interioris* leptocephali (12.4–48.9 mm TL) was the same (Fig. 2) as that of the other species of anguillid leptocephali that have been studied (e.g. *A. japonica*, Tabeta et al. 1989; *A. anguilla*, Lecomte-Finiger 1994; *A. marmorata* and *A. bicolor pacifica*, Arai et al. 2001a; *A. celebesensis* and *A. borneensis*, Kuroki et al. 2006). Otolith diameter ranged from 26.57–149.60 μm in the five specimens of *A. interioris* leptocephali (Table 1). The mean diameter ($\pm$S.D.) of the hatch check (HC) was 8.88$\pm$2.70 μm, and the mean distance between the HC and first feeding check (FFC) was 0.54$\pm$0.04 μm (Table 1). The low values (0.49–0.58 μm) of otolith increment widths near the core increased in all specimens and then reached small peaks (1.14–1.34 μm) before decreasing again to the otolith edge (0.51–0.83 μm), except for the smallest specimen that had no peak (Fig. 3). Sr : Ca ratios of the two analyzed otoliths ranged from 8.37–14.01, and tended to increase gradually toward the otolith edge (Fig. 3).

The ages of the smallest leptocephalus (12.4 mm TL) collected off Sumatra was 19 d, the specimen from Tomini Bay (48.9 mm TL) was 85 d, and the three from the Molucca Sea (43.4–46.5 mm TL) were 85–94 d (Table 1). The mean individual growth rate of all five specimens was 0.49±0.03 mm/d (Table 1). Overall growth rates expressed as a coefficient of the regression line between age and TL ($y=0.48x+3.72$, $r^2=0.97$) indicated that the overall growth rate of these specimens was 0.48 mm/d (Table 2). The hatch dates of *A. interioris* leptocephali ranged from late February in Tomini Bay, to early June for the specimen from off west Sumatra, and to July for those in the Molucca Sea (Table 1). The hatching dates ranged over at least three months, which suggests that the spawning of this species may occur for a relatively long period like other tropical species (Arai et al. 2001b, Sugeha et al. 2001, Shiao et al. 2002).

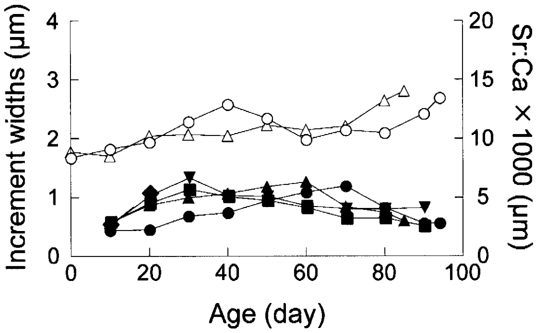

Fig. 3. Plots of the Sr : Ca ratios measured at 1 μm intervals (open symbols) and otolith increment widths averaged for every 10 increments (closed symbols) along transects from the core to the edge of the otoliths of *Anguilla interioris*.

The growth rate of these *A. interioris* leptocephali was intermediate among other leptocephali of the genus *Anguilla* (Table 2), because they were faster than those of temperate species (*A. anguilla*, *A. rostrata*, *A. japonica*) and slower than tropical species (*A. celebesensis*, *A. borneensis*). It is generally believed that temperate eels perform a large scale migration of thousands kilometers between their spawning areas and their freshwater growth habitats, while tropical eels show a local, small scale migration of from several tens to hundreds of kilometers (Aoyama et al. 2003). Recently, Kuroki et al. (2006) hypothesized that species such as *A. marmorata* and *A. bicolor pacifica* that appear to have mid scale spawning migrations also have intermediate growth rates during their leptocephalus stage, which can influence the distance of transportation from the spawning areas to the growth habitats. If this is true, *A. interioris*, a tropical species with an intermediate growth rate, may show a mid scale migration. If the maximum size of *A. interioris* leptocephali is the same as those of *A. marmorata* and *A. bicolor pacifica* (about 50 mm TL), this species may have a similar duration of oceanic mi-

Table 1. The collection date, sampling area, total length (TL), age, otolith diameter (OD), hatch check diameter (HC), the distance between HC and FFC (HC-FFC), hatching date, and individual growth rate (GR) of the *Anguilla interioris* leptocephali examined during this study.

Collection date	Sampling area	TL (mm)	Age (d)	OD (μm)	HC (μm)	HC-FFC (μm)	Hatching date	GR (mm/d)
24-May-01	Tomini Bay	48.9	85	145.99	8.82	0.54	28-Feb-01	0.54
06-Oct-02	Molucca Sea	46.5	94	149.60	6.24	0.49	04-Jul-02	0.46
06-Oct-02	Molucca Sea	43.4	88	126.38	12.59	0.58	10-Jul-02	0.46
06-Oct-02	Molucca Sea	45.3	85	144.88	7.85	0.56	13-Jul-02	0.50
20-Jun-03	Off Sumatra	12.4	19	26.57	—	0.55	01-Jun-03	0.49

Table 2. Summary of the growth rates (GR) of the leptocephali and the estimated spawning areas of each species of anguillid eels that has been studied.

Species	GR*[1] (mm/d)	Reference	Growth habitat	Spawning area	Reference
A. anguilla	0.38*[2]	Castonguay (1987)	Temperate	Offshore (Sargasso Sea)	Schmidt (1925)
A. rostrata	0.38*[2]	Castonguay (1987)	Temperate	Offshore (Sargasso Sea)	Schmidt (1925)
A. japonica	0.43	Shinoda (2004)	Temperate	Offshore (west of Mariana)	Tsukamoto (1992)
A. marmorata	0.42	Kuroki et al. (2006)	Tropics	Offshore (North Equatrial Current)	Kuroki et al. (2006)
A. bicolor pacifica	0.48	Kuroki et al. (2006)	Tropics	Offshore (western Pacific Ocean ?)	Kuroki et al. (2006)
A. interioris	**0.48**	**present study**	**Tropics**	**Offshore (off Sumatra)**	**present study**
A. celebesensis	0.55	Kuroki et al. (2006)	Tropics	Inshore (Celebes Sea, Tomini Bay)	Aoyama et al. (2003)
A. borneensis	0.61	Kuroki et al. (2006)	Tropics	Inshore (Celebes Sea)	Aoyama et al. (2003)

*[1] are obtained from the slope of linear regressions between age and total length of a wide range of sizes of leptocephali for each species. *2 are obtained for the two Atlantic species of *A. anguilla* and *A. rostrata* being combined.

gration.

Considering the growth rate, body size and the age of the leptocephali collected in Tomini Bay and the Molucca Sea (Table 1), they may have been large enough to begin metamorphosis in only about 4–13 d, assuming that *A. interioris* collected in this study also begin metamorphosis at around 50 mm like other tropical eels (Kuroki et al. 2006). Since they probably recruit to freshwater habitats close to the place of metamorphosis, they may not recruit to their known habitat along the northern coast of New Guinea, but instead to the places near the sampling localities (Fig. 1). If *A. interioris* has become established in these areas, the present understanding of the geographic distribution of this species may need to be corrected. However, since there are complex currents associated with the Asian-Australian monsoon seasons or intra-seasonal eddies in these areas (Wyrtki 1961, Lukas et al. 1996, Qiu et al. 1999, Luick and Cresswell 2001), the distribution of this species needs to be reexamined using a greater numbers of specimens and oceanographic information about the currents in the region.

If the molecular identification was correct, it is obvious that the leptocephalus collected off Sumatra would have been spawned near the sampling sites, because the specimen was too small and young to have been transported there from the northern Indonesian Seas. The prevailing currents are southward through the Indonesian Throughflow and to the southeast along west Sumatra. In addition, water flows offshore to the west to form the South Equatorial Current in the area between Sumatra and Java Islands (Wyrtki 1961), so few leptocephali from off west Sumatra are likely to be transported northward into the Indonesian Archipelago or to New Guinea (Fig. 1). Therefore, this specimen appears to have been spawned in the Indian Ocean and likely belongs to a different population of *A. interioris* than those recruiting to New Guinea in the western North Pacific. These considerations suggest that *A. interioris* may be distributed not only along the northern coast of New Guinea, but also more widely in the Indonesian Archipelago, and may have several spawning areas in this tropical region.

This study is the first description of the otolith microstructure and the early life history of *A. interioris* leptocephali that were identified using mtDNA sequence analysis. However, further ecological studies using a larger number of specimens of *A. interioris*, together with genetic and geographic distribution analyses are needed to gain a better understanding of this poorly known species of tropical anguillid eel.

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