Ages at maturation of tropical freshwater eels, *Anguilla bicolor bicolor* and *A. bengalensis bengalensis*

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**ABSTRACT**

Freshwater eels are one of the world’s most valuable cultured fish species. However, there is little information available on the biological characteristics of tropical anguillid eels genus *Anguilla* in the silver (maturation) stage even though these tropical eels account for two-thirds of all species in the genus. In order to understand the life history of tropical anguillid eels, *Anguilla bicolor bicolor* and *A. bengalensis bengalensis* which are found in Malaysian natural waters, age at maturation was studied. Their total length, body weight and maturation were significantly increased and advanced as their age became older. The ages at maturation (stages IV and V) of *A. bicolor bicolor* and *A. bengalensis bengalensis* ranged from 5.5 to 8.5 years and from 6.5 to 10.5, respectively. Ages of maturation in the tropical eels were earlier than that of other temperate eels *A. anguilla*, *A. rostrata*, *A. australis* and *A. dieffenbachii*, reported previously, although it was similar to that of the temperate eel *A. japonica*. The higher growth rate found in the tropical eels associated with the tropical habitat environment might induce the earlier maturation than the temperate species.

**Key Words:** Anguillid eels; downstream migration; life history; maturity; tropical waters

**1. Introduction**

The freshwater eel of the genus *Anguilla*, being catadromous, migrate between fresh water growth habitats and offshore spawning areas. The freshwater eels are widely distributed throughout the world. Nineteen species/subspecies of *Anguilla* have been reported worldwide, 13 of which occur in tropical regions (Ege 1939; Arai 2016). Of the 13 species/subspecies found in tropical areas, 7 species/subspecies occur in the western Pacific around Indonesia and Malaysia, i.e. *A. celebesensis* (Kaup 1856), *A. interioris* (Whitley 1938), *A. bengalensis bengalensis* (Gray 1831), *A. marmorata* (Quoy & Gaimard 1824), *A. borneensis* (Popta 1924), *A. bicolor bicolor* (McClelland 1844) and *A. bicolor pacifica* (Schmidt 1928) (Ege 1939; Arai 2016). Recent molecular phylogenetic researches on freshwater eels have revealed that tropical eels are the most basal species originating in the Indonesian and Malaysian region and that freshwater eels radiated out from the tropics to colonize the temperate regions (Minegishi et al. 2005), suggesting that tropical freshwater eels must be more closely related to the ancestral form than their temperate counterparts. Thus, studying the biological aspects of tropical eels provides clues for understanding the nature of primitive forms of life history in freshwater eels.

Previous biological studies on tropical freshwater eels were mostly focused on their early life history such as ages at metamorphosis and recruitment, oceanic larval period and coastal migration (e.g., Arai, Aoyama et al. 1999; Arai, Limbong et al. 1999, 2001; Arai, Otake et al. 1999; Arai, Marui et al. 2002; Arai, Miller et al. 2003; Marui et al. 2001; Sugeha et al. 2001; Robinet et al. 2003). Consequently, knowledge about their early life history has accumulated during the last few decades. After their recruitment into the rivers and estuaries, studies about migratory histories of tropical eels were only intensively examined (Chino and Arai 2010a, 2010b, 2010c; Arai et al. 2013; Arai and Chino 2018). Some recent studies have been done on the downstream migration of tropical silver eels such as silvering season, maturation and spawning ground estimation (Arai and Chino 2013; Arai 2014b; Arai et al. 2016; Abdul Kadir et al. 2017; Arai and Abdul Kadir 2017a, 2017b). There is a general lack of knowledge about the basic biological information such as age, growth and maturation of the tropical silver eels compared to temperate freshwater eels.

The populations of the European and Japanese eels are considered to be outside safe biological limits, and current fisheries are not sustainable (Dekker 2003; Arai 2014c). Species other than European and Japanese eels, including several tropical species, seem to have replaced their eels on the international market (Arai 2014a). The tropical eels *Anguilla bicolor bicolor* and *A. bicolor pacifica* are the most target species for eel trading (Pethiyagoda 1991; Arai 2014a). Now, tropical eels are suggested to have begun to follow the same trends as the European and Japanese eels (Arai 2014a). This suggests that we cannot rule out overfishing in tropical countries. However, fewer studies are available on tropical eels than for temperate eels.

The objective of the present study was to investigate the basic biological characteristics of tropical eels *Anguilla bicolor bicolor* and *A. bengalensis bengalensis* in Peninsular Malaysia,
Malaysia. Their demographic attributes (age, size, growth and maturation) were obtained to provide important basic biological information about tropical eels.

2. Material and methods

A total of 46 specimens of *Anguilla bicolor bicolor* and that of 18 specimens of *A. bengalensis bengalensis* were collected by local fishermen primarily in the northwestern Peninsular Malaysia, Malaysia during May 2014 and January 2016 (Figure 1). The eels were collected by angling and bamboo trap at night. After eels were collected, biological parameters, such as total length (TL) and body weight (BW), were measured (Table 1). The sex of each eel was determined by visual and histological observations of the gonads. The sex and maturation stage of all eels were examined followed by Arai et al. (2016). Stages correspond to a growth phase (stages I and II), a pre-migrant phase (III) and two migrating phases (IV and V) (Table 1).

Figure 1. Map showing the collection sites of the tropical anguillid eels in the northwestern Peninsular Malaysia during May 2014 and January 2016. Black circles on the map indicate the sampling location. In Penang Island, eel specimens were collected from six rivers as shown in the map.
After the TL and BW measurements of each specimen were measured, scales were collected from various parts of the body for each eel. 5–15 scales were collected in each eel. Scales were cleaned and placed on the glass slide for the age determination. Scales were observed under dissecting microscope, photographed and the number of rings was recorded (Figure 2). Scale annuli were identified according to Pantulu (1957) and Jel-lyman (1979). The largest number of annual rings was used in each eel specimen. Thereafter, 1.5 years was added to the each of the age data as the age because scales were not generated in the early developmental stage for the period in *Anguilla bengalensis bengalensis* (Pantulu 1957).

Differences between data were analysed using the Mann–Whitney U-test (Sokal and Rohlf 1995). The results of linear regression analysis were tested by analysis of covariance (ANCOVA) (Sokal and Rohlf 1995).

### 3. Results

All specimens were determined as females in *Anguilla bicolor bicolor*. Seventeen females and one male were found in *A. bengalensis bengalensis*. We used female specimens only for further analyses (Table 1). All maturation stages from I to V were found in both species with the variation of a number of specimens in each stage (Table 1).

*Anguilla bengalensis bengalensis* were ranged from 411 to 720 mm, from 126 to 1110

| Table 1. Morphological characteristics in female specimens used in the present study. |
| Species | Maturation stage | Number of specimens | Total length (mm) | Body weight (g) | Age (years) |
|---------|-----------------|---------------------|------------------|----------------|-------------|
|         |                 |                     | Mean ± SD | Range | Mean ± SD | Range | Mean ± SD | Range |
| *A. bicolor bicolor* | I | 3 | 540 ± 9.5 | 534–551 | 316 ± 32.5 | 283–348 | 5.8 ± 1.2 | 4.5–6.5 |
|         | II | 6 | 588 ± 46.9 | 505–638 | 356 ± 65.3 | 270–466 | 5.5 ± 1.4 | 3.5–7.5 |
|         | III | 11 | 581 ± 96.6 | 411–685 | 390 ± 174 | 126–664 | 6.1 ± 1.0 | 4.5–7.5 |
|         | IV | 18 | 595 ± 78.0 | 455–711 | 437 ± 230 | 174–1125 | 6.7 ± 1.0 | 5.5–6.5 |
|         | V | 8 | 601 ± 77.9 | 455–720 | 410 ± 197 | 179–798 | 6.6 ± 0.8 | 5.5–7.5 |
| *A. bengalensis bengalensis* | I | 1 | 487 | 5.5 | | | |
|         | II | 6 | 807 ± 144 | 637–1011 | 1038 ± 512 | 421–1800 | 6.7 ± 0.8 | 5.5–7.5 |
|         | III | 3 | 851 ± 111 | 726–935 | 1367 ± 532 | 772–1800 | 7.2 ± 0.6 | 6.5–7.5 |
|         | IV | 4 | 1116 ± 141 | 991–1295 | 2436 ± 1544 | 2100–5100 | 7.8 ± 2.1 | 7.5–10.5 |
|         | V | 3 | 958 ± 86.3 | 899–1057 | 2160 ± 783 | 1579–3050 | 7.8 ± 1.5 | 6.5–9.5 |

2.5 mm

Figure 2. A scale from a 585 mm in TL *A. bicolor bicolor* showing five rings.

Figure 3. Relationships between age and total length (TL) and body weight (BW) in *A. bicolor bicolor* and *A. bengalensis bengalensis*. 
1125 g and from 3.5 years to 8.5 years and from 487 to 1295 mm, from 257 to 5100 g and from 5.5 years to 10.5 years, respectively (Table 1). Close linear relationships were found between age and TL and BW and between maturation stage and TL and BW in both species (Figures 3 and 4 ANCOVA, df = 16–45, F = 1.07–3.82, p < .01–.0001). There were also close linear relationships between maturation stage and age in both species (Figure 5, ANCOVA, df = 0.63–1.02, p < .05–.0001). The maturation stage advanced as eels became older in both species. In migrating phase of stages IV and V, there were no significant differences in age between the species (Mann Whitney U-test, p > 0.05). The age at maturation was similar between the two species. However, their morphological characteristics at the maturation were different between two species. TL and BW of A. bengalensis bengalensis in the sum of stages IV and V were averaging 1048 mm (±140 mm: SD) and 2889 g (±1365 g), respectively and the TL and BW were significantly larger than those of A. bicolor bicolor which were averaging 597 mm (±76 mm) and 429 g (±217 g), respectively (Mann Whitney U-test, p < .005–.0001).

4. Discussion

The knowledge on maturation and downstream migration of the tropical anguillid eels as they begin their spawning migration is scarcely studied. In the present study, ages at maturation were similar for both Anguilla bicolor bicolor and A. bengalensis bengalensis. Their maturation advanced as the eels became larger and older (Figures 3 and 4). However, their somatic growth at the timing of maturation was different. A. bengalensis bengalensis achieved a larger size than that of A. bicolor bicolor. Therefore, the growth rate of A. bengalensis bengalensis was faster than that of A. bicolor bicolor. These results suggest that the timing of maturation of these eels might be associated with age and growth to be ready for certain physiological conditions but somatic growth at the timing was species-specific. In the temperate eel A. japonica, age, TL and BW at maturation have been reported to be 470–970 mm, 129–1384 g, and 4–17 years, respectively (Kotake et al. 2007; Chino and Arai2009), which overlap the data for A. bicolor bicolor and A. bengalensis bengalensis (Table 1). However, in the temperate European eel A. anguilla, the size of female silver eels was estimated to be 540–610 mm and the age of silver eels ranged from 8–12 years (Tesch 1977). In the American eel A. rostrata, the size and age of female silver eels were 400–940 mm and 19.3 years, respectively (Jessop 1987). And finally, in the Australasian temperate eels A. australis and A. diefenbachii, the sizes and ages were 670–1040 mm and 15–33 years and 1100-1400 mm and 23–59 years, respectively (Arai et al. 2004). The body length at maturation in A. bicolor bicolor is almost the similar as those of the temperate eels A. anguilla, A. rostrata and A. japonica, while the age at maturation in A. bicolor bicolor is younger than those of temperate eels. In A. bengalensis bengalensis, the TL at the maturation was overlapped or larger than that of temperate eels A. japonica, A. anguilla, A. rostrata and A. australis, while the age at maturation is younger than those of temperate eels. In Malaysia like other topical region, there is a higher average temperature than temperate region having a constant high temperature, with an average temperature of 28°C all year round. Such tropical climate might affect the difference in somatic growth and maturation between tropical and temperate eels. These results all lead to the conclude that the maturation rates of tropical eels A. bicolor bicolor and A. bengalensis bengalensis are
faster than that of temperate eels. The higher growth rate found in tropical eels *A. bicolor* and *A. bengalensis* might bring about this earlier maturation.

Until recently, considerably less research has examined the spawning migration of tropical eels in comparison with that of temperate eel species. Recently, Arai et al. (2016) and Arai and Abdul Kadir (2017b) found that a spawning period of a tropical eel *Anguilla bicolor* that extends throughout the year. The findings described in this report indicate that tropical eels have life history characteristics that differ markedly from those of temperate eels. Temperate anguillid species make their spawning migration as silver eels during the fall and winter. The difference in spawning season duration and timing between tropical and temperate species could be attributed to differences in the seaward migration seasons of maturing adult eels. The year-round spawning migration of tropical species and constant larval growth extend the period of recruitment to estuarine habitats to year-round in tropical eels (Arai et al. 2001, 2016; Arai and Abdul Kadir 2017a). Faster growth and younger maturation found in the tropical eels *Anguilla bicolor* and *A. bengalensis* with constant tropical climate condition might promote their constant and non-seasonal spawning migration throughout the year.

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