Short Note
Length-Weight Relationship and Associations between Otolith Dimension, Age and Somatic Growth of *Anguilla bicolor bicolor* (McClelland, 1844) from Northwest of Peninsular Malaysia

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Received: 29 October 2016; Accepted: 24 February 2017

The eels from the genus *Anguilla* (Garsault, 1764) are widely distributed throughout the world. Currently, a total of 19 species of *Anguilla* have been reported worldwide, where 11 of the species are from tropical regions[1, 2]. There are seven species and subspecies of *Anguilla* reported in the Pacific western region around Malaysia and Indonesia including *A. celebesensis* (Kaup, 1856), *A. interioris* (Whitely, 1938), *A. nebulosa nebulosa* (McClelland, 1844), *A. marmorata* (Quoy & Gaimard, 1824), *A. borneensis* (Popta, 1824), *A. bicolor bicolor* (McClelland, 1844) and *A. bicolor pacifica* (Schmidt, 1928)[3].

The length-weight relationship (LWR) is an important tool in fish biology, ecology and fisheries management[4]. The LWR is very valuable in determining weight and biomass when only length or weight measurement is available. LWR was also used as indications of ecological health condition and to allow for comparisons of species growth between different geographical regions[4, 5].

Otoliths are paired crystalline structures located in the inner ear of all bony fishes, used for sound reception, maintaining equilibrium and processing directional cues[6]. Other functions of otolith are to determine the age, growth rate and also the migration pattern of the eel itself[7]. Besides that, valuable information about stock structure and also mixing pattern caused by environmental differences can be determined using otolith microchemistry[8].

Information on anguillid biology and ecology in Peninsular Malaysia are still scarce[3,9]. Understandings on these aspects are very important for future studies on population dynamics, stock assessment and conservation of this species. Thus, this study was conducted to determine the LWR and associations between otolith dimension, age and somatic growth of *A. b. bicolor* from northwest of Peninsular Malaysia.

Samples of *A. b. bicolor* were collected from a few locations, namely Kuala Perlis River, Perlis (6° 24' N; 100° 8' E), Batu Pahat River, Perlis (6° 30' N; 100° 10' E), downstream of Pinang River, Balik Pulau, Penang (5° 23' N; 100° 11' E) and upper stream of Pinang River, Balik Pulau, Penang (5° 23' N; 100° 12' E), in the northwest of Peninsular Malaysia, Malaysia. All samples were obtained either by angling method or the traditional fish traps. Total lengths (TL) and body weights (BW) were recorded to

the nearest 0.1 cm and 0.1 g, respectively. The eye index was also calculated in order to determine the maturity of the eels[10].

The right sagittal otolith was extracted by carefully sliced the top of the head to expose the brain case without cutting through the otolith. Then, using the forceps, the brain was pushed out of the way and the two largest otoliths, sagittal otolith, was extracted from near the bottom of the brain case. The right sagittal otoliths were weighted using analytical balance (Kern & Sohn, Germany), while the length and width of the otolith were measured using Vernier caliper (Techno, Malaysia). The otolith length (OL) was measured as the horizontal distance between the anterior and posterior tips, whereas the otolith width (OW) was measured as the vertical distance from dorsal to ventral of the otolith edge (Fig. 1).

For age determination, the right otoliths were embedded in epoxy resin (Struers,

Epofix) and mounted on glass slides. The otoliths were then ground and polished using different size sand papers as described by previous study[11]. They were also cleaned in an ultrasonic bath (Copens Scientific, Malaysia) and rinsed with deionized water prior to being examined. The age was determined by counting the number of transparent zones under compound microscope (Nikon, Japan) and photos were recorded using image analyzer (Nikon Instruments Inc., USA)[11].

The LWR of the eels were calculated by using the equation of log W = log a + b log L, whereby W is the weight of fish in grams (g) and L is the total length of eel measured in centimeters (cm), a is the intercept (coefficient related to body form), and b the slope of the regression line[12]. Additionally, 95% confidence limits (CL) of a and b were estimated. The 95% confidence limits were estimated based on the values obtained from
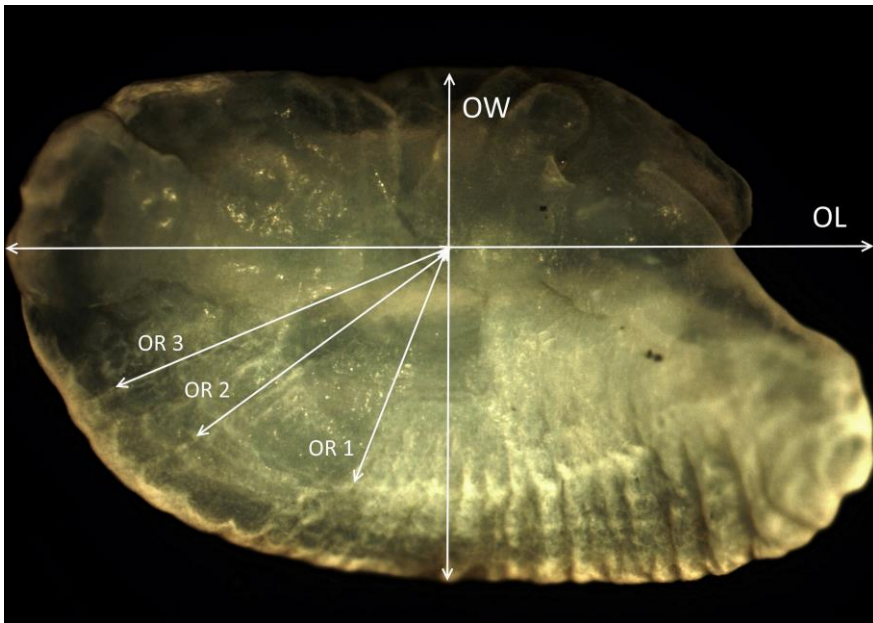

FIGURE 1. Measurement on the otolith ring of *Anguilla bicolor bicolor*. OW, otolith width; OL, otolith length; OR, otolith ring.

TABLE 1. Biological measurements of collected *Anguilla bicolor bicolor* from northwest of Peninsular Malaysia.

Develop-mental stages	Sample size	Total length (cm)		Body weight (g)		Age (year)	
		Mean ± standard deviation	Range	Mean ± standard deviation	Range	Mean ± standard deviation	Range
Silver	3	42.3 ± 1.1	27.5 - 51.0	145.0 ± 54.5	85.0 - 159.0	1.3 ± 0.6	1 - 2
Yellow	40	54.7 ± 7.9	39.2 - 70.0	308.9 ± 145.5	74.2 - 665.0	2.0 ± 1.0	1 - 4

the regression analysis. The value of *a* was determined from $10^{(constant)}$ which was $10^{-3.936}$ = 0.0001. Therefore, *b* = 3.659 and the upper and lower bound limits were 3.37 – 3.95. The lower and upper bound of the confidence limit was based on the lower and upper bound of the constant which are $10^{-4.434}$, $10^{-3.439}$ = 0.0000, 0.0004. The model fit to the data was measured by the coefficient of determination, R-squared (R^2). Outliers were identified based on the log–log plots and excluded from the regression analysis.

The relationships between otolith dimension, age and somatic growth were described using a simple linear least squares regression (R^2)[13, 14]. The model is A = β_0 + β_1 * B, where A is either BW, age, OL or OW, β_0 is the intercept, β_1 is the slope and B is either BW, TL, OW or OL. Significance of the linear regression was determined at $P < 0.05$. The test for significance of regression was carried out using analysis of variance (ANOVA), while the *t* test was used to check the significance of individual regression coefficients in the linear

regression model.

A total of 43 *A. b. bicolor* were collected in this study, with the age ranged from 1 to 4 years old. Three of the collected eels were in silver developmental stages while 40 were in yellow developmental stages. The range of TL and BW of collected eels were ranged from 27.5 cm to 70.0 cm and 85.0 g to 665.0 g, respectively. The biological measurements on the mean ± SD and range of the TL, BW and age of the eels are presented in Table 1. The LWR of *A. b. bicolor* is log W = log 0.0001 + 3.659 log L or W = $0.0001L^{3.659}$; R^2: 0.946 (Table 2). The significant ($P < 0.05$) linear regression relationships between otolith dimension, age and somatic growth of the eels are presented in Table 3.

In the present study, the TL, BW and age of the yellow eels were generally higher than silver eels. These suggest that the timing of maturation of this eel might be associated not with age or growth, but rather with the need to be prepared for certain physiological changes[11]. The derived *a* and

TABLE 2. The length-weight relationship of *Anguilla bicolor bicolor* collected from northwest of Peninsular Malaysia.

Species	Sample size	Length range (cm)	Weight range (g)	*a*	95% CL a	*b*	95% Cl b	R^2
A. b. bicolor	43	39.2-70.0	74.2-665.0	0.0001	0.0000-0.0004	3.659	3.37-3.95	0.946

TABLE 3. Linear regression relationship between otolith dimension, age and somatic growth of *Anguilla bicolor bicolor* collected from northwest of Peninsular Malaysia.

Parameters	Equation	R^2
Age-BW	Age = 0.005573 BW + 0.25	0.7339
Age-TL	Age = 0.1 TL – 3.38	0.5380
Age-OW	Age = 238 OW + 0.28	0.3260
Age-OL	Age = 8.39 OL – 0.7	0.2510
OL-BW	OL = 0.000225 BW + 0.25	0.3380
OL-TL	OL = 0.00497 TL + 0.04	0.4050
OW-BW	OW = 0.0000101 BW + 0.00389	0.4210
OW-TL	OW = 0.000207 TL – 0.00454	0.4350

R^2 : Coefficient of determination.
Significant linear regression at $P < 0.05$ was recorded for all equation.
BW, body weight; TL, total length; OW, otolith weight; OL, otolith length.

R^2 in the LWR indicates the eel-like body shape and strong correlation between the length and weight of the *A. b. bicolor* population, respectively[12]. However, the *b* value showed that the population of *A. b. bicolor* has increased in height or width more than in length, or positive allometric growth[12]. The values of *b* < 2.5 or >3.5 are often derived from samples with narrow size ranges, while the *b* values also can be affected by many factors, such as the length ranges of the specimens used and the area-season effect[15, 16]. Moreover, the *b* value recorded in this study was also higher compared to the *b* value reported previously in several geographic locations[17, 18].

There were significant relationships (P < 0.05) between all of the equations established between otolith dimensions, age and somatic growth of *A. b. bicolor* in this study. The established relationship may provide important information for the back calculations regarding eel size, age and otolith measurement of the eels[20]. Due to lack of biological data of *A. b. bicolor* in Malaysia, no comparison to previous studies could be made from this country. However, a study from Central Java, Indonesia,

showed positive relationship was found between eye index (EI), BW and TL of the species in each sexual development, but no correlation between gonadosomatic index (GSI), BW and TL, except for female *A. b. bicolor*[21]. In the present study, the coefficient of determination was low to moderate in strength for relationship between otolith dimensions with age and somatic growth, as contrary observed in other fish species[19]. We believed this was due to low number of samples collected. However, studies on these relationships in different species of *Anguilla* and other fish species have been extensively conducted[4, 13, 14, 17, 18, 19, 20]. The linear relationship between otolith dimension, age and somatic growth as observed in this study may depend on the growth rate and different between each fish species or become curvilinear in some larval or juvenile fishes[22, 23]. Moreover, the linear relations may change at intervals relative to fish size or ontogenetic stage in some species[24, 25].

In conclusion, even the total number of *A. b. bicolor* in this study quiet small, the equation derived from this study may help in current and future studies on population

dynamics, stock assessment and conservation of this species. This is the first study to demonstrate the associations between otolith dimensions, age and somatic growth of *A. b. bicolor* and their LWR in Malaysia.

ACKNOWLEDGEMENTS

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