Title

Discrimination and Distribution of Two Tropical Short-Finned Eels (Anguilla bicolor bicolor and Anguilla bicolor pacifica) in the Indonesian Waters

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Discrimination and Distribution of Two Tropical Short-Finned Eels
(Anguilla bicolor bicolor and Anguilla bicolor pacifica) in the Indonesian Waters

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Abstract A total of 272 glass eel specimens of the two tropical short-finned eels (Anguilla bicolor bicolor and Anguilla bicolor pacifica) were collected around Indonesian waters from 2004 to 2007. Field sampling was conducted in 11 estuaries (Krueng Aceh, Air Kertaun, Cibaliung, Citanduy, Pacitan, Palu, Dumoga, Poigar, Bone Bolango, Akelamo, and Pami River) that spread out from western to eastern Indonesian archipelagos. Objectives of the study were to understand subspecies discrimination and distribution as well as population study of the tropical short-finned eel species (Anguilla bicolor) in the Indonesian waters based on morphological analyses of body measurements and vertebrae counts. Although morphological key characters of ano-dorsal length as a percentage of total length (-2.13 ~ 3.92) and number of ano-dorsal vertebrae (-3 ~ 4) overlap between subspecies, specimens were assigned to one of two subspecies based on their reported range of distribution from the western Sumatera Island to the southern Jawa Island (A. bicolor bicolor) and from the western Sulawesi Island to the western Papua Island (A. bicolor pacifica). Cluster analyses based on Euclidean distance separated the tropical short-finned eel species into two major clades. The first clade consisted of subspecies of A. bicolor bicolor from Cibaliung, Air Kertaun, and Pacitan River estuaries. The second clade consisted of subspecies of A. bicolor pacifica from Palu, Dumoga, Poigar, Bone Bolango, and Akelamo River estuaries. Interestingly, A. bicolor bicolor from Citanduy River estuary (Jawa Island) nested in the second clade. The results suggested that a single tropical short-finned eel species, A. bicolor, inhabit in the Indonesian Waters. However the species was ecologically and biologically separated into two clade of subspecies, i.e. a Western Indonesian Clade of A. bicolor bicolor derived from Indian Ocean and an Eastern Indonesian Clade of A. bicolor pacifica derived from Pacific Ocean.

Key words: tropical short-finned eels, Anguilla bicolor bicolor, Anguilla bicolor pacifica, Western Indonesian Clade, Eastern Indonesian Clade

Introduction

About 16 species of anguillid eel were reported to inhabit the world, e.g Anguilla celebesensis, A. marmorata, A. borneensis, A. interioris, A. megastoma, A. obscura, A. bicolor, A. nebulosa, A. japonica, A. anguilla, A. rostrata, A. dieffenbachii, A. reinhardtii, A. australis, A. mossambica, and A. luzonensis (Ege, 1939; Jespersen, 1942; Tsukamoto and Aoyama, 1998; Arai et al., 1999a; Aoyama et al., 2001 and 2003; Minegishi et al., 2005; Sugetha et al., 2001a, b and 2008a, b, c; Watanabe et al., 2005a, b and 2009). Three species among them (A. bicolor, A. nebulosa, A. australis) consist of two subspecies, namely A. b. bicolor and A. b. pacifica (Ege, 1939; Aoyama et al., 2001 and 2003; Watanabe et al., 2005a, b; Minegishi et al., 2001 and 2005; Sugetha et al., 2008a, b, c), A. n. nebulosa and A. n. labiata (Ege, 1939; Aoyama et al., 2001; Watanabe et al., 2005a, b; Minegishi et al., 2001 and 2005), and A. a. australis and A. a. schmidtii (Aoyama et al., 2001; Watanabe et al., 2005a, b; Minegishi et al., 2005), respectively. The short-finned eel, A. australis, was reported to inhabit in subtropical region of the southern hemisphere especially in the waters around Australian continent and New Zealand (Ege, 1939; Jespersen, 1942; Jellyman, 1977; Todd, 1981; Sloane, 1984; Chisnall and Kalish, 1993; Arai et al., 1999d; Shiao et al., 2002; Aoyama et al., 2001; Watanabe et al., 2005a, b; Minegishi et al., 2005). The long-finned eel, A. nebulosa, was reported to inhabit the tropical region...
mostly in the islands around the Indian Ocean (Ege, 1939; Jespersen, 1942; Aoyama et al., 2001, 2003, and 2007; Watanabe et al., 2005a, b; Minegishi et al., 2005). The short-finned eel, *A. bicolor*, was reported to inhabit the sub tropical to the tropical region mostly in the waters around Indonesian archipelagos (Ege, 1939; Jespersen, 1942; Tzeng and Tabeta, 1983; Arai et al., 1999a, b, and c; Setiawan et al., 2001; Aoyama et al., 2001, 2003, and 2007; Watanabe et al., 2005a, b; Kuroki et al., 2006 and 2007; Sugeha et al., 2001a and 2008a, b, c).

Indonesian waters are known as the center of distribution of the tropical anguillid eels in the world. Some authors reported the occurrence of five to seven species and sub species of anguillid eels in the waters around Indonesian archipelagos, *e. g.*, *A. nebulosa nebulosa*, *A. celebesensis*, *A. marmorata*, *A. borneensis*, *A. interioris*, *A. bicolor bicolor*, and *A. bicolor pacifica* (Ege, 1939; Jespersen, 1942, Aoyama et al., 2001, 2003 and 2007; Watanabe et al., 2005a, b; Minegishi et al., 2005, Wouthuyzen et al., 2009). However the most recent study on the species diversity, geographic distribution, and abundance of tropical anguillid eels in the Indonesian waters suggested that nine species and subspecies inhabit the region, *e. g.* *A. celebesensis*, *A. marmorata*, *A. borneensis*, *A. interioris*, *A. obscura*, *A. bicolor bicolor*, *A. bicolor pacifica*, *A. nebulosa nebulosa*, and *A. megastoma* (Sugeha et al., 2008a, b, c). Those species and subspecies were distributed from the west, the central, to the east region of Indonesian waters in different timing and pattern of abundance that regulated by seasonal tropical monsoon (Sugeha et al., 2008a, b, c). In that study, the highest diversity occurred in central Indonesian waters where five species were found including four long-finned eel species (*A. marmorata*, *A. celebesensis*, *A. borneensis*, *A. interioris*) and one short-finned eel species (*A. bicolor pacifica*). The others species were mostly found in the western Indonesian waters (*A. nebulosa nebulosa* and *A. bicolor bicolor*) and in the eastern Indonesian waters (*A. obscura*, and *A. megastoma*) (Sugeha et al., 2008a).

The short-finned eel species, *A. bicolor*, could be separated from long-finned eel species based on a key morphological character of ano-dorsal length as a percentage of total length (ADL/TL) and number of ano-dorsal vertebrae (ADV) at juvenile stage (Tabeta et al., 1976; Tzeng & Tabeta, 1983; Sugeha et al., 2001a and 2008b, c). However, the two subspecies of *A. bicolor* (*A. bicolor bicolor* and *A. bicolor pacifica*) were present in the Indonesian waters based on their distribution range (Ege, 1939; Jespersen, 1942; Watanabe et al., 2005a,b; Aoyama et al., 2001, 2003 and 2007; Sugeha et al., 2008a, b, c) and genetic study (Minegishi et al., 2001; Watanabe et al., 2005b; Aoyama et al., 2001, 2003 and 2007; Jamandre et al., 2007; Sugeha et al., 2008b, a, c). Based on morphology, genetics, and geographic distribution, Sugeha et al. (2008a, b, c) recorded a simultaneous catch of *A. bicolor bicolor* in the western Indonesian waters (from Sumatera to the Jawa Islands) and *A. bicolor pacifica* in the central (Sulawesi Island) and east region of Indonesian waters (from Halmahera and Papua Islands). In that study the authors found that the *A. bicolor bicolor* dominated the catch in the western region while *A. bicolor pacifica* were dominated in the central region and were least dominant in the eastern regions, compared to the other anguillid eel species collected.

The study of Sugeha et al. (2008a, b, and c) validated the occurrence of the two subspecies in Indonesian waters and provided means for recognizing and separating the two subspecies of glass eels in the region. Sympatric distribution between and within Anguilla species (Aoyama et al., 2003 and 2007; Gagnaire et al., 2007; Sugeha et al., 2008a) and overlapped population structure within species (Minegishi et al., 2008) and or subspecies (Aoyama et al., 2007; Jamandre et al., 2007) are highly possible in the Indonesian waters and surrounding area. This is especially true in the central Indonesian Seas that are known as the most complicated bio-geographic region in the world due to the complex oceanography of Indonesian Through flow (Godfrey, 1996), thermocline (Ilahude and Gordon, 1996), tidal transport and mixing (Hatayama et al., 1996) and the unique bio-ecological conditions of Wallace Line (Barber et al., 2000, Tomascik et al., 1997) and Weber Line (Tomascik et
al., 1997). It is important to know whether subspecies of the tropical short-finned eel, *A. bicolor*, in the Indonesian waters consists of single or multiple populations, as was examined recently for *A. bicolor* in Indian Ocean (Watanabe et al., 2005b) and Philippine waters (Jamandre et al., 2007) and for *A. marmorata* in Indonesian waters (Minegishi et al., 2008).

Knowledge on the population structure of the anguillid mainly for temperate eel species, i.e. *A. japonica* (Ishikawa et al., 2004; Tseng et al., 2006; Maes et al., 2006), *A. rostrata* (Maes et al., 2006), and *A. anguilla* (Daemen et al., 2001; Wirth and Bernatchez, 2001; Maes et al., 2006). However, only few studies have been done on the population structure of the tropical eel species, i.e. *A. marmorata* (Robinet et al., 2002; Ishikawa et al., 2004; Maes et al., 2006; Minegishi et al., 2008) and *A. bicolor bicolor* (Watanabe et al., 2005). Therefore, we proposed to study the discrimination and distribution of the short-finned eel, *A. bicolor*, in the Indonesian waters. The objective of this study was to better understand subspecies discrimination and distribution as well as population study of the tropical short-finned eel species (*A. bicolor*) in the Indonesian waters based on morphological analyses of body measurements and vertebrae counts.

**Materials and methods**

**Sample collection**

Glass eels were collected at the mouth of 11 estuaries (Krueng Aceh, Air Kertaun, Cibaliung, Citanduy, Pacitan, Palu, Dumoga, Poigar, Bone Bolango, Akelamo, and Pami River Estuaries) covering western to eastern Indonesian archipelagos (Figure 1). Glass eel sampling was conducted on the three dates of new moon in 2004 (Citanduy, Pacitan, Dumoga, Poigar, Palu, Bone Bolango Estuaries), six dates of new moon in 2005 (Cibaliung, Palu, Poigar estuaries) and in 2006 (Krueng

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Fig. 1. Map of the sampling locations of tropical anguillid glass eels, *Anguilla bicolor*, in the Indonesian Waters.

Aceh, Air Kertaun, Palu, Akelamo, Pami Estuaries) and twelve dates of new moon from May 2006 to April 2007 (Palu Estuary). Method of line transects using triangular scoop nets was done in each location (see Sugeha et al., 2001a and 2008a, b, c). The glass eels were fixed in 10% formalin just after capture and transported to the laboratory for future analyses.

**Morphological analyses**

A total of 272 glass eel specimen of *A. bicolor* were collected. Total length (TL), pre-dorsal length (PDL), and ano-dorsal length (ADL) were measured to the nearest 0.1mm (Sugeha et al., 2001a, b and 2008b, c). Pigmentation stage was determined according to Bertin (1956). A part of samples then was stained with alizarin-red solution, and total vertebrae (TV), pre-dorsal vertebrae (PDV), pre-anal vertebrae (PAV), abdominal vertebrae (ABV), and ano-dorsal vertebrae (ADV) were counted according to Tabeta et al. (1976), Tzeng & Tabeta (1983), and Sugeha et al. (2001a, b and 2008b, c). Species identification based on the ano-dorsal length as a percentage of total length (ADL/%TL) and the number of ano-dorsal vertebrae (ADV) as reported by Tabeta et al. (1976), Tzeng & Tabeta (1983), and Sugeha et al. (2001a, b and 2008b, c).

**Population study analyses**

Population study of the tropical short-finned eels was analyzed using morphometric data. A dendogram of separated populations was constructed using Primer 6.0. We carried out cluster analysis based on Euclidean distance with a classification technique using Hierarchical Agglomerative by group average linking of the data of body length measurements.

**Results**

* Morphological characters of the tropical short-finned eel Anguilla bicolor

Glass eel specimens of short-finned eels were relatively smaller than the long-finned glass eels. The short-finned eels could be distinguished from the long finned eels by presence of melanophores that concentrated on the caudal only with none on the body (Tabeta et al., 1976; Tzeng & Tabeta, 1983, Sugeha et al., 2001a, b).

Pigmentation development of the tropical short-finned eels was in the earliest stage compared to the tropical long-finned glass eels. Based on observation of pigmentation development from 264 specimens of the tropical short-finned eels collected, it was found that pigmentation development was dominated by stage VA (93.18%) then stage VB (6.8%). Pigmentation stage VA was characterized by the appearance of pigment spots in the caudal region only while pigmentation stage VB is recognized by the appearance of pigment spots in the caudal and in the skull but none in the body (Bertin, 1956; Sugeha et al., 2001a). The results suggest that glass eel stage captured was just finishing metamorphosis, and just entering the freshwater area.

Total body weight of short-finned eels collected in the present study ranged from 0.06 to 0.19gr (0.12±0.02) (parenthetic values here and elsewhere are mean ± one standard deviation), total body length (TL) was 45 to 57mm (50.95±2.48), pre-dorsal length (PDL) was 13 to 22mm (19.02±1.03), and pre-anal length (PAL) was 14 to 23mm (19.50±1.07) (Figure 2). Total number of vertebrae (TV), pre-dorsal vertebrae (PDV), pre-anal vertebrae (PAV), ano-dorsal vertebrae (ADV), and abdominal vertebrae (ABV) of the short-finned eels specimens also shown a great range of distribution, e. g, 100 to 113 (106.5±4.82), 30 to 40 (35±3.32), 31 to 39 (35±2.74), and 40 to 45 (42.5±1.87), respectively (Figure 3). Beside the appearance of pigment melanin concentrated in the caudal region and not in the body, based on the characters of ADL/%TL and ADV, it was determined that all 272 specimens of tropical short-finned eels belong to the short-finned eel, *A. bicolor*, with a wide range of ADL/%TL and ADV from -2 to 3 and from -3 to 4, respectively (Sugeha et al., 2001a).
DISCRIMINATION and DISTRIBUTION of TWO TROPICAL SHORT-FINNED EELS
(ANGUILLA BICOLOR BICOLOR and ANGUILLA BICOLOR PACIFICA) in the INDONESIAN WATERS

Fig. 2.  Frequency distribution of body weight, total length, pre-dorsal length, and pre-anal length of the tropical short-finned eels, Anguilla bicolor, collected in the Indonesian Waters.
Fig. 3. Frequency distribution of total vertebrae, pre-dorsal vertebrae, pre-anal vertebrae, and abdominal vertebrae of the tropical short-finned eels, *Anguilla bicolor*, collected in the Indonesian Waters.
Table 1. Internal and external morphological characters of the two species and subspecies of tropical short-finned eels *A. bicolor bicolor* and *A. bicolor pacifica* collected in the Indonesian Waters

<table>
<thead>
<tr>
<th>Species and subspecies</th>
<th>Sampling location (N)</th>
<th>Character</th>
<th>TL</th>
<th>PDL</th>
<th>PAL</th>
<th>ADL</th>
<th>TV</th>
<th>PDV</th>
<th>PAV</th>
<th>ADV</th>
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<tr>
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<tr>
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<td>-0.50 ± 1.00</td>
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<td>0.27 ± 0.52</td>
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<td></td>
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<td>18.50 ± 22.00</td>
<td>-0.50 ± 2.00</td>
<td>105 ± 113</td>
<td>33 ± 39</td>
<td>33 ± 39</td>
<td>-3 ± 4</td>
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<td>53.12 ± 1.55</td>
<td>19.18 ± 0.85</td>
<td>20.09 ± 0.72</td>
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<td>109.08 ± 1.50</td>
<td>36.00 ± 1.17</td>
<td>36.25 ± 1.32</td>
<td>1.10 ± 1.26</td>
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<td>18.00 ± 21.50</td>
<td>0.00 ± 1.50</td>
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<tr>
<td><em>A. bicolor pacifica</em></td>
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<tr>
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<td>Range</td>
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<td>45.00 ± 52.00</td>
<td>17.00 ± 20.00</td>
<td>17.00 ± 21.00</td>
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<td>34 ± 39</td>
<td>34 ± 38</td>
<td>-3 ± 2</td>
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<td>0.23 ± 0.71</td>
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<td>18.00 ± 21.00</td>
<td>-1.00 ± 1.00</td>
<td>103 ± 109</td>
<td>34 ± 39</td>
<td>33 ± 39</td>
<td>-3 ± 3</td>
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<td>18.85 ± 0.86</td>
<td>18.92 ± 0.78</td>
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<td>105.77 ± 1.31</td>
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<td>36.65 ± 0.97</td>
<td>0.04 ± 1.05</td>
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<td>17.00 ± 21.00</td>
<td>17.00 ± 21.00</td>
<td>-1.00 ± 1.00</td>
<td>95 ± 108</td>
<td>21 ± 39</td>
<td>27 ± 39</td>
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<td>19.11 ± 0.95</td>
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<td>19.00 ± 20.50</td>
<td>-0.50 ± 1.00</td>
<td>101 ± 104</td>
<td>33 ± 38</td>
<td>33 ± 38</td>
<td>0 ± 1</td>
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<td>19.13 ± 0.85</td>
<td>19.50 ± 0.71</td>
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<td>13.00 ± 19.00</td>
<td>14.00 ± 20.00</td>
<td>-0.50 ± 1.00</td>
<td>105 ± 110</td>
<td>33 ± 37</td>
<td>34 ± 36</td>
<td>-3 ± 1</td>
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<td>17.30 ± 2.44</td>
<td>18.00 ± 2.35</td>
<td>0.70 ± 0.65</td>
<td>107.83 ± 1.94</td>
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</table>
Adjustment subspecies *Anguilla bicolor bicolor* and *Anguilla bicolor pacifica*

In the present study, subspecies discrimination of *A. bicolor* could not be done based on morphological analyses alone. The species had to show a wide range of ADL/%TL and ADV from -2 to 3 and -3 to 4, respectively. Therefore, sampling location is useful determining subspecies where their ranges do not overlap (Ege, 1939; Jespersen, 1942; Aoyama *et al.*, 2001, 2003, and 2007; Watanabe *et al.*, 2005a, b; Sugeha *et al.*, 2001a, b and 2008a, b, c). In the present study, all specimens of *A. bicolor* collected in the estuaries of Sumatera Island and Jawa Island were assigned to *A. bicolor bicolor* (N=119) while all specimens of collected in the estuaries of Sulawesi Island, Halmahera Island, and Papua Island were assigned to *A. bicolor pacifica* (N=153).

Total body length of *A. bicolor bicolor* glass eels ranged from 48 to 57mm (52.86 ± 1.67) while total body weight was ranged from 0.10 to 0.18gr (0.14 ± 0.02). Total body length of *A. bicolor pacifica* glass eels was 45 to 55mm (49.54 ± 1.99) while total body weight ranged from 0.6 to 0.19gr (0.11 ± 0.02). In general *A. bicolor bicolor* was bigger than *A. bicolor pacifica* in both total length and body weight. Complete morphological character of the body measurements and vertebrae counts of each subspecies in each sampling location was seen in Table 1.

*Ano-dorsal* length as a percentage of total length (ADL/%TL) overlapped between the two subspecies.

![Graph showing ADL/%TL distribution](image)

**Fig. 4.** Frequency distribution of *ano-dorsal* length as a percent of total length (ADL/%TL) of the two tropical short-finned eels species and subspecies (*A. bicolor bicolor* and *A. bicolor pacifica*) from Indonesian waters. Remarks: Negative and positive numbers expressed the dorsal fin origin located behind and in front of the anal fin origin, respectively. Zero (0) number expressed the dorsal fin origin and the anal fin origin located symmetrically.
Anguilla bicolor bicolor was about -1 to 3 (1.6 ± 1.15) while A. bicolor pacifica was about -2 to 2 (0.4 ± 1.13) (Figure 4). An overlap occurred from -1 to 2 of ADL/%TL. Number of ano-dorsal vertebrae (ADV) also overlapped between the two subspecies. Anguilla bicolor bicolor was about -3 to 4 (1.10 ± 1.26) while A. bicolor pacifica was about -3 to 2 (1.10 ± 1.26). An overlap occurred from -3 to 2 of ADV (Table 1).

Anguilla bicolor bicolor and A. bicolor pacifica were dominated by pigmentation development stage VA (95.45% and 95%, respectively) (Figure 5). They were in the early stage of pigmentation development.
development and near the end of metamorphosis when collected. It is suggested that the two subspecies experience similar physiological conditions of pigmentation development during their coastal migration before reaching the estuaries of Indonesian continents.

**Population structure of Anguilla bicolor**

Cluster analyses separated the tropical short-finned eels into two major clades (Figure 6). The first clade consists of *A. bicolor bicolor* from Cibaliung, Air Kertaun, and Pacitan River estuaries. The second clade consists of *A. bicolor pacifica* from Palu, Dumoga, Poigar, Bone Bolango, and Akelamo River estuaries. Interestingly, *A. bicolor bicolor* from Citanduy River estuary (Jawa Island) was nested into the second clade.

**Discussion**

**Species dan Subspecies discrimination and distribution**

This study is the first to study the discrimination of the two tropical short-finned eels, *A. bicolor bicolor* and *A. bicolor pacifica*, based on both morphology and geography data analyses of the glass eels from the bio-geographically complex of Indonesian waters. *Anguilla bicolor bicolor* and *A. bicolor pacifica* overlap morphologically. However, they could be recognized statistically supporting their reported range of distribution in Indonesian waters. Species and subspecies discrimination in the eel genus *Anguilla* has become one of the most interesting topics for study on eel biology this decade. Aoyama *et al.* (1999) concluded that morphological study could not discriminate between *A. celebesensis* and *A. interioris* and suggested that mitochondrial DNA sequences are required to solve the problem. Dijkstra and Jellyman (1999) also found a problem validating the subspecies classification of *A. australis* (*A. australis australis* and *A. a schmidtii*) in Australia and New Zealand and concluded that subspecies designation were justified. However, Watanabe *et al.* (2006) confirmed that considerable morphological differences exist between those two subspecies.

Those studies suggest that both morphological and genetic studies, as well as ecological study are required to identify *Anguilla* species and subspecies. The present study used both of morphological and ecological information to study the tropical short-finned eel, *A. bicolor*. However, in the future genetic study is required to validate our species and subspecies identifications. Previous study on the complete DNA mitochondrial genome of the species successfully discriminate the two subspecies, *A. bicolor bicolor* and *A. bicolor pacifica* (Minegishi *et al.*, 2001). However, those authors used specimens chiefly from outside the Indonesian waters, or from more subtropical area.

Following the study by Sugetha *et al.* (2008a b, c), this study is re-viewing geographic distribution of *A. bicolor* in the Indonesian waters since Ege (1939) and Jespersen (1942) for more than 50 years ago. In the present study it was found that *A. bicolor* were inhabit in the Sumatera Island (Krueng Aceh, Batang Antokan, and Air Kertaun Estuaries), Jawa Island (Cibaliung, Citanduy, Progo, and Pacitan Estuaries), Sulawesi Island (Palu, Poigar, Dumoga, and Bone Bolonago Estuaries), Halmahera Island (Akelamo Estuaries), and Papua Island (Pami Estuaries). *Anguilla bicolor pacifica* has been reported from Philippine waters (Jamandre *et al.*, 2007) and the western Pacific Ocean (Aoyama *et al.*, 1999). *Anguilla bicolor bicolor* was reported from South Africa and Myanmar (Watanabe *et al.*, 2005); Seychelles, Madras, and North Australian (Ege, 1939); Reunion (Ege, 1939; Watanabe *et al.*, 2005; Robinet *et al.*, 2002); Madagascar (Ege, 1939; Watanabe *et al.*, 2005), and Philippine Islands (Jamandre *et al.*, 2007). Those studies suggested that these two subspecies are mainly found in tropical waters. However, the present study strongly suggested that *A. bicolor* is mainly distributed in the tropical region of Indonesian waters. In detail, *A. bicolor bicolor* dominated in the western Indonesian waters while *A. bicolor pacifica* dominated in the center and eastern Indonesian waters. Moreover, it was proven that the Indonesian waters as the center of distribution and dispersal of many
anguillid eel species (Sugeha et al., 2008a, b, c).

Population study of A. bicolor and its implication to migratory history and spawning ecology of the species in the Indonesian Waters

In the present study, the two subspecies of A. bicolor was separated into two clade, i.e. western Indonesian clade of A. bicolor bicolor and eastern Indonesian clade of A. bicolor pacifica. However A. bicolor bicolor from Citanduy River of western Indonesia nested in the second clade of eastern Indonesia. There are two possible explanations. First, miss identification such that specimens from Citanduy River actually were A. bicolor pacifica. If the specimens from Citanduy River were A. bicolor pacifica, then morphological data and range of geographic distribution cannot be used for subspecies identification of A. bicolor from Indonesian waters and that genetic identification should be applied. The occurrence of gene flow of the species and subspecies in the Indonesian waters might be an appropriate reason for answering the problem.

Second, if the identification was correct there may be multiple populations of A. bicolor in central Indonesian waters where the two subspecies overlap. Multiple populations of tropical anguillid eels have been reported in the tropical giant mottled eel A. marmorata (Minegishi et al., 2008). The authors reported the occurrence of A. marmorata populations from the North and South Pacific in Ambon Island (Indonesia) based on genetic population study. In a recent study (Watanabe et al., 2005) on the population structure of A. bicolor bicolor based on morphology and genetic analyses of specimens from Indian Ocean, including the western Indonesian region, it was suggested that there is no population of A. bicolor bicolor in the eastern and western side Indian Ocean. However, a more recent study reported the occurrence of A. bicolor bicolor in Philippine waters that life sympatric with A. bicolor pacifica and A. marmorata (Jamandre et al., 2007). The phenomenon may be possible to occur in the Indonesian region since Philippine waters directly connected with the Sulawesi and Maluku Seas of Indonesian in conjunction with the Indonesian Trough flow. If this idea is correct then it might answer why A. bicolor bicolor from Citanduy estuary nested with eastern Indonesian clade of A. bicolor pacifica. Glass eels might be transported from western to eastern region of Indonesian waters via Indian Ocean tidal propagation (Tomascik et al., 1997) that is regulated by tropical monsoons in the Indonesian region. The Indian Ocean tidal propagation influences tidal condition in the western Indonesian region and might be affecting transport and mixing processes in the Inter-Tropical Convergence Zone (ITCZ) of the Indonesian region (Hatayama et al., 1996; Tomascki et al., 1997). If true, then A. bicolor pacifica may appear in the first clade of western Indonesian waters after transported by Indonesian Trough flow.

Interestingly, Sugeha et al. (2008c) reported dominance of A. bicolor pacifica glass eels among Anguilla species during inshore migration in the estuary of Palu River (western Sulawesi Island) located in front of Makassar Strait. This dominance is unusual because previous reports suggested that the species always was the least abundant of tropical eel species in north Sulawesi Island (Arai et al., 1999; Sugeha et al., 2001a and 2008b), in central Sulawesi Island (Sugeha et al., 2001b) and more eastern regions of Indonesian waters (Sugeha et al., 2008a). A greater catch of A. bicolor pacifica in western Sulawesi Island of central Indonesia waters might be evidence of isolated population there that is ecologically separated from eastern Indonesian population. Alternatively, central Indonesian A. bicolor pacifica may come from eastern Indonesian population during larvae migration through Indonesian Trough flow of the Makassar Strait. The migration of A. bicolor pacifica larvae from eastern to western Indonesian waters is worth considering since A. interioris that usually occur in eastern Papua New Guinea have been found in waters around North Sulawesi Island (Sugeha et al., 2008b) and west Sumatera Island (Aoyama et al., 2007; Sugeha et al., 2008a). Also A. obscura and A. megastoma that usually are found in western Papua Island but has been found in the waters around Halmahera and Sulawesi Islands (Sugeha et al., 2008a). Genetic study of population structure for the
tropical short-finned eels in the Indonesian waters is required to clarify the phenomenon.

Our results support previous studies that two A. bicolor subspecies were separated geographically and biologically, i.e. western Indonesian clade of A. bicolor bicolor which may be derived from the Indian Ocean and eastern Indonesian clade of A. bicolor pacifica which may be derived from the Pacific Ocean. If this idea is correct, then this study supports the hypothesis that A. bicolor bicolor may spawn in the Indian Ocean (Jespersen, 1942; Kuroki et al., 2006; Aoyama et al., 2007) and A. bicolor pacifica may spawn in the Pacific Ocean (Arai et al., 1999d; Aoyama et al., 1999). However, the anomaly of A. bicolor bicolor from Citanduy estuary and the dominancy of A. bicolor pacifica in Palu estuary might indicate relatively close spawning ground of the two subspecies from their recruitment area in the central Indonesian waters.

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