Occurrence of exotic eels in natural waters of South Korea

Yang-Ki Hong, Jung-Eun Kim, Jeong-Ho Lee, Mi-Young Song, Hee-Won Park and Wan-Ok Lee

Inland Fisheries Research Institute, National Institute of Fisheries Science, Gapyeong, Republic of Korea; Inland Aquaculture Research Center, National Institute of Fisheries Science, Changwon, Republic of Korea

ABSTRACT
We surveyed the proportion of anguillid eel species inhabiting South Korea natural waters. From September 2014 to August 2015, 429 eels were collected in various habitats for identification using morphological features and DNA-based molecular methods. We found 424 Japanese eels (Anguilla japonica, 98.8%), two European eels (A. anguilla, 0.5%), one American eel (A. rostrata, 0.23%), one tropical eel (A. marmorata, 0.23%), and one short-finned eel (A. bicolour pacifica, 0.23%). Three (A. anguilla, A. rostrata, and A. bicolour pacifica) are exotic species to the natural waters of South Korea; this study is the first record of their distribution in this region. Specifically, A. anguilla was found in the Lake Soyang and Cheongpyeong, while A. rostrata was found only in the Lake Cheongpyeong, and A. bicolour pacifica was found in the Geum River estuary.

ARTICLE HISTORY
Received 25 May 2016
Accepted 3 September 2017

KEYWORDS
Identification; Anguilla anguilla; A. rostrata; A. bicolour pacifica; exotic species

Introduction
The genus Anguilla has been recognized as comprising 16 species, three of which are further divided into two subspecies (Watanabe et al. 2009). All anguillid eels are distributed in the Indo-Pacific except the European eel (Anguilla anguilla Linnaeus 1758) and the American eel (A. rostrata Lesueur 1828), both found in the North Atlantic Ocean (Ege 1939; Tzeng and Tabeta 1983; Watanabe et al. 2004). Ege’s (1939) classification divided Anguilla into four groups based on color markings, geographic distribution, and morphological characteristics. The genus was also divided into two groups: long and short dorsal fin groups, based on the ratio of anus-dorsal fin origin length (AD) to total body length (TL), but this could not clearly divide the freshwater eels into two groups. Later classifications grouped the genus based on the ratio of predorsal (without head length) length to total length (PDH/TL) and AD/TL (Watanabe et al. 2004).

Only two species of anguillid eels have been reported in Korea: the Japanese eel (A. japonica Temminck and Schlegel 1846) and A. marmorata Quoy and Gaimard 1824 (Kim et al. 2005). The latter is rare species, and its habitats in Jeju Island – the northern limit of its distribution – are protected as part of a Natural Monument (Kim and Park 2007). In contrast, the Japanese eel is a commercially important aquaculture species in Korea and throughout in East Asia. There are over 500 eel ponds in Korea, with a total surface area of approximately 2,000,000 m² (Lee 2014). Eel culture is entirely dependent on wild glass eels because commercial production of glass eels has not yet been successful. Unfortunately, the wild A. japonica population has experienced a decline in Korea and, in other countries, a situation variously attributed to global climate change, overfishing, and river pollution, among other potential causes. Thus, it is now considered Endangered on the International Union for Conservation of Nature (IUCN) Red List (Jacoby and Gollock 2014). In addition to native eels, Korea, has imported glass eel species from 15 countries. Seven species comprise most of the imports from 2003 to 2015: A. japonica (70,100 Kg, 63.3%) A. bicolour bicolour McClelland 1844 or A. bicolour pacifica E.J. Schmidt 1928 (19,000 Kg, 17.2%), A. rostrata (10,200 Kg, 9.2%), A. anguilla (8500 Kg, 7.6%), A. mossambica Peters 1852 (2200 Kg, 2.0%), and A. marmorata (700 Kg, 0.7%) (NFQS 2015). Of these species, A. anguilla was listed in the Conservation on International Trade in Endangered Species of Wild Flora and Fauna (CITES) Appendix II in 2007 and is on the International Union for Conservation of Nature (IUCN) Red List as Critically Endangered (Crook 2011; Ahn et al. 2015). Thus A. anguilla and A. japonica has been strengthened by the recent international regulations. So imported glass eels, have facilitated the purchase with a relatively low value, from Southeast Asia (A. bicolour ssp.) and Africa (A. mossambica), raising the likelihood of exotic species escaping into natural waters.
Several exotic species (e.g. *A. anguilla*, *A. rostrata* and *A. australis*) have been found in Japanese water, and *A. rostrata* has been found in the Kaoping River of southwestern Taiwan (Tabeta et al. 1976; Zhang et al. 1999; Aoyama et al. 2000; Okamura et al. 2001; Han et al. 2002; Okamura et al. 2008). These exotic eels have had a measurable ecological impact on native eels in rivers and lakes of both regions (Aoyama et al. 2000; Han et al. 2002; Okamura et al. 2008). In particular, imported exotic species are believed to have escaped from Japanese aquaculture farms during 1968, as exotic eels began to emerge in Japan’s natural waters since that year. Their presence in river ecosystems raised the need to analyze the distribution, population shifts, and biological characters of exotic eels (Tabeta et al. 1976; Zhang et al. 1999; Aoyama et al. 2000; Okamura et al. 2008). In particular, imported exotic species are believed to have escaped from Japanese aquaculture farms during 1968, as exotic eels began to emerge in Japan’s natural waters since that year. Their presence in river ecosystems raised the need to analyze the distribution, population shifts, and biological characters of exotic eels (Tabeta et al. 1976; Zhang et al. 1999; Aoyama et al. 2000; Okamura et al. 2008). However, no studies have documented exotic eels in South Korea waters. The external morphologies of native and introduced eels are quite similar, complicating the identification of exotic eels (Han et al. 2002). Therefore, in this study, we combined molecular methods with morphological classification to identify exotic anguillid eels. This is the first formal record of three exotic species (*A. anguilla*, *A. rostrata*, and *A. bicolor pacifica*) in the natural waters of South Korea.

Materials and methods

Specimen sampling

From September 2014 to August 2015, we collected 429 eels from several habitat types in South Korea, including two streams and one river (128 eels), five Lakes (149), as well as two estuaries (152) (Table 1, Figure 1). Set nets and long-lines were used to capture the eels.

Morphometric identification

Specimens were first examined morphometrically. Body color was recorded and physical features were measured (Figure 2). The total length (TL), anus-dorsal length (AD) and pectoral-dorsal length (PDH) were measured to the nearest 0.1 mm using a Vernier caliper (Mitutoyo). Next, AD and PDH were calculated as ratios of total body length (Watanabe et al. 2004). The range of two morphological characters (AD and PDH) in each species were compared and combinations of either two of these characters were compared to identify of anguillid eels. Body weight (BW) was measured to the nearest 0.1 g using a digital scale (CAS). Sex was determined via visual inspection of gonad morphology, following Kuhlmann (1975). Eels in the silvering stage was recorded by examination of body color and pectoral fins, following Okamura et al. (2007).

Molecular identification

Genetic analysis was used to validate the identification of morphologically vague specimens. A piece of the pectoral fin per specimen was preserved in absolute ethanol and kept at −20°C until extraction. Genomic DNA (gDNA) was extracted with TNES- (Tris, NaCl, EDTA, SDS) urea buffer using the phenol-chloroform method (Asahida et al. 1996). gDNA quantity and quality were assessed using a NanoDrop ND-1000 spectrophotometer (Thermo Scientific) with extinction coefficients

| Table 1. Specimens numbers of *A. japonica*, *A. marmorata* and exotic species, grouped by sex and silvering stages. |
|---|---|---|---|---|
| Sampling sites | Stations | Sex | Total | Y1 | Y2 | S1 | S2 |
| Stream & River | Daecheon | Juvenile | 94 | 94 | | | |
| | | Female | 7 | 3 | 2 | 2 |
| | | Male | 18 | 16 | 1 | 1 |
| | Bongdang | Female | 8 | 5 | 1 | 2 |
| | | Male | | | | |
| Lakes | Yeongsan | Unknown | 1 | 1 | | | 1 |
| | Soyang | Juvenile | 5 | 4 | 1 | | |
| | | Female | 106 | 48 | 49 (1^a) | 6 | 2 |
| | | Male | 11 | 4 | 5 | 2 |
| | Ulam | Juvenile | 1 | 1 | | | |
| | | Female | 13 | 2 | 7 (1^b, 1^c) | | |
| | | Male | | | | 2 |
| | Cheongpyeong | Female | 6 | 5 | 1 | | |
| | | Male | | | | |
| | Namyang | Female | 1 | 1 | | | |
| | | Male | | | | |
| | Busa | Juvenile | 5 | 1 | 4 | | |
| | | Female | 1 | 1 | | | |
| | | Male | | | | |
| Estuary | Han river | Female | 41 | 2 | 8 | 29 | 2 |
| | | Male | 3 | 1 | 1 | 1 |
| | Geum river | Female | 99 | 40 | 37 | 19 | 3 |
| | | Male | 9 | 1 | 6 (1^d) | 1 |

^a* A. marmorata*, ^b* A. anguilla*, ^c* A. rostrata*, ^d* A. b. pacifica*. 

Y.-K. HONG ET AL.
We conducted a three-step analysis as it was the most cost-effective, rapid, and convenient method to obtain data. First, we performed a multiplex-PCR amplification for rapid molecular identification, using mitochondrial 16S ribosomal RNA (rRNA)-specific primers: AJ16S1L (forward primer: 5'-GCCTAGTTATAGCTGGTTGC-3'), J16S2H (reverse primer for amplifying Anguilla: 5'-ATGT TTGTGTAAACAGGC-3') and AF16SSH (A. japonica-
specific reverse primer: 5′-TCCGTGGATGGCAGTGGTC-3′) (Sezaki et al. 2005). A GeneAmp PCR System 9700 Thermal Cycler (Applied Biosystems) was used for amplification with the following 20 μL reaction mixture: template gDNA (50 ng/μL), 2 μL of 10 × Ampli Taq DNA polymerase buffer, 0.4 μL of 20 μm primers, 1.6 μL of 20 mM dNTP, one unit of Ampli Taq DNA polymerase, and sterilized water (as necessary to reach appropriate volume). The thermocycling protocol comprised 30 cycles of denaturation at 94°C for 1 min, annealing at 55°C for 1 min, and extension at 72°C for 1 min. PCR products were loaded on a QIAxcel (Qiagen, Hombrechtikon, Switzerland) with a QIAxcel DNA high resolution kit (Qiagen). Gel electrophoresis visualization revealed two bands (400 and 560 bp) for A. japonica and one (560 bp) for Anguilla sp. Next, PCR products of about ambiguous two bands for A. japonica and one band for Anguilla sp. amplified with a primer set of AJ1651L and AJ1652H were digested with Aпал enzyme. Gel electrophoresis showed three bands of 213, 200, and 147 bp specific to A. japonica. Finally, specimens that did not possess the three A. japonica-specific bands were identified through phylogenetic analysis (see next section) of the mitochondrial cytochrome b gene. Primers Cyt-b1 (5′-TGCTAAGAGCCCTAAGTCG-3′) and Cyt-b2 (5′-CTAGTCAACCTACTAATGGG-3′) were designed based on the conserved regions of Anguilla cytochrome b sequences deposited in GenBank/NCBI (Han et al. 2002).

Phylogenetic analysis

The cytochrome b gene sequences of six unknown individuals (AS1–AS6) and one A. japonica individual were aligned with those of 16 Anguilla species deposited in the GenBank/NCBI using Clustal W (version 1.81). A phylogenetic tree constructed using the neighbour-joining method with genetic distance calculated by Kimura’s two-parameter model using the programe MEGA 4.1 (Tamura et al. 2007).

Results

Morphometric identification

One of the 429 specimens (0.23%) had variegated markings and was therefore estimated as A. marmorata. Another specimen (0.23%) was estimated as A. bicolor ssp. through its possession of a short dorsal fin and an AD/TL of 0.4 (Table 2). The remaining 427 specimens were too similar to identify through their morphology.

Molecular identification

The PCR results successfully grouped all eel specimens into distinct species. We were able to identify 423 of 429 specimens (98.6%) as A. japonica (213, 200, and 147 bp); six individuals (AS1–AS6) exhibiting one or two bands remained unknown Anguilla sp., but were subsequently identified through sequencing analysis. AS1 and AS6 formed a clade with A. anguilla; AS2, with A. rostrata; AS3, with A. bicolor pacifica; AS4, with A. marmorata; and AS5, with A. japonica (Figure 3). Hence, A. rostrata, A. marmorata, and A. bicolor pacifica represented 0.7% of the total specimens (one eel each); 0.5% (two eels) were A. anguilla; while the majority (424, 98.8%) represented A. japonica.

Morphometric comparisons

Anguilla marmorata is the only species with variegated markings. In a comparative analysis with three characters, the combination of PDH/TL, AD/TL, and marking type (variegated vs. non-variegated) could distinguish eels with long or short dorsal fins. Respectively, AD/TL and PDH/TL were 14.6% and 14.9% for A. marmorata (n = 1), 0.4% and 25.7% for A. bicolor pacifica (n = 1), 8.4% and 21.4% for A. rostrata (n = 1), 12.1 ± 0.1% (mean ± SD; range = 12.0%–12.2%) and 18.8 ± 1.7% (17.6%–20.1%) for A. anguilla (n = 2), as well as 8.6 ± 1.2% (6.0%–13.6%) and 18.3 ± 1.2% (13.7%–22.3%) for A. japonica (n = 424) (Table 2, Figure 4). The relationship between AD/TL and PDH/TL divided the eels into two groups (Figure 5).

In A. japonica (n = 424), TL ranged 175.0–858.0 mm (494.8 ± 152.9 mm) and BW ranged 5.2–1417.3 g (252.9 ± 229.8) (Table 2, Figure 6(A)). The female to male sex ratio was 1:0.15, with 281 adult females and 42 adult males; juveniles (n = 101) were not sexed (Table 1). Eels were classified into four stages based on their SI

Table 2. Morphometric data of the five anguillid eels.

| Characters / Species       | A. japonica | A. anguilla | A. rostrata | A. marmorata | A. bicolor pacifica |
|---------------------------|-------------|-------------|-------------|--------------|---------------------|
| Number                    | 424         | 2           | 2           | 1            | 1                   |
| TL (mm)                   | 175–858     | 775–793     | 92–95       | 84           | 2                   |
| BW (g)                    | 5.2–1417.3  | 964.1–1043.0| 285         | 81.5         | 130.8               |
| AD (mm)                   | 12.0–107.0  | 92–95       | 44          | 80           | 2                   |
| AD/TL (%)                 | 6.0–13.6    | 12.0–12.2   | 8.4         | 14.6         | 0.4                 |
| PDH (mm)                  | 30.9–157.2  | 139.7–151.4 | 112.4       | 81.5         | 130.8               |
| PDH/TL (%)                | 13.7–22.3   | 17.6–20.1   | 21.4        | 14.9         | 25.7                |

Note: TL: total length, BW: body weight, AD: distance between the verticals through the anus and origin of the dorsal fin, PDH: distance between the origin of the pectoral fin and origin of the dorsal fin.
Discussion

We used morphological and molecular data to investigate the relative proportions of anguillid eel species inhabiting natural bodies of water in South Korea. We identified 429 eels collected from streams, rivers, Lakes, and estuaries. Three exotic species – the European eel (Anguilla anguilla), American eel (Anguilla rostrata), and the short-finned eel (Anguilla bicolor pacifica) – were found (Table 1). Anguilla anguilla was present at a very low proportion (n = 2, 0.5%) in the Lake Cheongpyeong and Soyang (Table 1). European glass eels were initially imported in 2005, but are now banned under CITES. No eel culture...
ponds were present near the Lakes. Thus, it seems very likely that the European eels were not released from culture ponds into nearby natural waters. Instead, *A. anguilla* may have been accidentally mixed with *A. japonica* fry imported from other regions, as the latter species is stocked annually to support the local economy (Byeon 2015). Future studies interested in the exact timing of entry could attempt to estimate the import year through otolith analysis, provided *A. anguilla* specimens are large enough. The two species resemble each other morphologically (Watanabe et al. 2004), so to avoid exotic eel entry into Korean natural waters, future eel stocks should be identified via morphology and genetics.

Next, *A. rostrata* was found in Lake Cheongpyeong (Table 1). American glass eels were imported into South Korea from 2004 to 2015, and as they are highly
unlikely to have migrated naturally from the North Atlantic to Asia (Tsukamoto and Aoyama 1998), these eels probably dispersed into natural waters via artificial releases, similar to *A. anguilla*.

*Anguilla bicolor pacifica* was found above the Geum River estuary (Table 1). Since 2008, short-finned eel imports have increased as a result of international trade restrictions on temperate eels. Because *A. bicolor pacifica* exhibits clear morphological differences in body color and shape from *A. japonica* (Watanabe et al. 2004), the eels escaping from culture ponds nearby river rather than artificial released. Currently, available data are insufficient to determine if *A. bicolor pacifica* is native to any region in Korea, although the species is known to be native to Taiwan and Japan (Tzeng and Tabeta 1983; Shen 1993; Tzeng et al. 1995; Yamamoto et al. 2000; Han et al. 2001). Future studies should therefore perform detailed surveys to verify if the distribution of *A. bicolor pacifica* extends to Korea.

*Anguilla marmorata* is known from Jeju Island, South Korea, the northernmost limit of its distribution. Although this species has been observed in several streams (Youngduk Ohsip, Guchon, Hwagae) of mainland South Korea, there have been no confirmed reports outside the island since 1990 (Choi et al. 1989; Kim et al. 2005; Kim and Park 2007). In this study, *A. marmorata* was captured above the Seungchon weir, Yongsan River (Table 1). Since 2012, the species has been imported as glass eels. This individual probably escaped from eel ponds connected to the river, but the mouth of the river should be carefully monitored at migration time to determine whether it is natural habitat for this species.

Anguillid eels belong to a long or short dorsal fin group (Ege 1939), which can be defined by the relationship between AD/TL and PDH/TL (Watanabe et al. 2004). AD and PDH ratios (Figure 5) confirmed *A. bicolor pacifica* as a short dorsal fin eel, while *A. japonica*, *A. anguilla*, *A. rostrata* and *A. marmorata* are long dorsal fin eels, in agreement with Watanabe et al. (2004). Furthermore, *A. marmorata* was distinguished from the other four species via its variegated marking.

The *A. anguilla* and *A. rostrata* specimens had were green or gray dorsal skin on the head and trunk, in addition to yellow or white ventral skin, indicating the Y2 silvering stage (Table 1). Thus, these two individuals were still sexually immature, but the *A. anguilla* specimen appeared have an eye index value with a 98% correspondence to those of mature *A. anguilla* from Japan’s Mikawa Bay. These eels may sexually mature in sea waters (Okamura et al. 2008), given that mature eels have been collected from the East China Sea (Aoyama et al. 2000). *A. anguilla* also progress silvering of sexual maturation proceeds that inhabit the natural waters, there is a need to further study about whether the migratory potential to spawn. In contrast, *A. bicolor pacifica* exhibited complete melanization at the tip of pectoral fins but without full pigmented belly (black or dark brown), indicating the S1 stage and thus, potential spawning ability. Our survey data suggests a strong possibility of genetic contamination with native eel populations as exotic eels disperse into East Asian waters (Okamura et al. 2008). Hence, future studies should focus internal, morphometric and gonadal characters of exotic eels in Korean natural waters.

Introduced exotic species can directly and negatively affect native species, potentially reducing or extirpating native populations (Taylor et al. 1984; Coblenz 1990; Lodge 1993). In South Korea, exotic species in inland fisheries have increased substantially, beginning with the common carp *Cyprinus carpio* (Linnaeus 1758) imported from Japan in 1929. Anguillid eels are important aquatic resources, and as of 2015, six kinds of glass eels are being imported into South Korea (Ahn et al. 2015; NFQS 2015). This study is the first to record three exotic species, (*A. anguilla*, *A. rostrata*, and *A. bicolor pacifica*) in South Korean natural waters. These exotic eels may compete with native eels for habitat and food resources, with repercussions that could adversely affect other aquatic animals (Aoyama et al. 2000; Han et al. 2002). Moreover, exotic eels may carry infectious pathogens and parasites against which native species have no resistance, or disrupt native gene pools through hybridization (Okamura et al. 2008). Therefore, ecological research of exotic eels is required to develop effective control measures and prevent negative consequences on domestic freshwater ecosystems.

In conclusion, we believe that the three exotic eel species sampled here may already inhabit natural bodies of water in South Korea. Hence, long-term monitoring surveys should focus on upstream migration in glass eel habitats to verify whether exotic eels are indeed present. National and local government agencies should strengthen regulations and management of eels imported for aquaculture. For example, connections between eel ponds and natural waters should be eliminated, and eels stocked for inland fisheries should not be released into the wild unless the species identity has been confirmed.

**Acknowledgements**

The authors are grateful to members of the NIFS Inland Fisheries Research Institute Fisheries Resources Laboratory for sample analysis and also thank Mr. Sung-Jang Cho for field assistance.
Disclosure statement
No potential conflict of interest was reported by the authors.

Funding
This study was supported by a grant from the National Institute of Fisheries Science [grant number R2017034].

References

Ahn JC, Chong WS, Na JH, Yun HB, Shin KJ, Lee KW, Park JT. 2015. An evaluation of major nutrients of four farmed freshwater eel species [Anguilla japonica, A. rostrata, A. bicolor pacifica and A. marmorata]. Kor J Fish Aquat Sci. 48:44–50. Korean.

Byeon HK. 2015. Fluctuation of introduced fish and characteristics of the fish community in Lake Soyang. Korean J Environ Ecol. 27:139–155.

Coblentz BE. 1990. Exotic organisms: a dilemma for conservation. Conserv Biol. 4:261–265.

Crook V. 2011. Trade in European eels: recent developments under CITES and the EU Wildlife Trade Regulations. TRAFFIC Bulletin, 23:71–74.

Ege V. 1939. A revision of the genus Anguilla Shaw, a systematic, phylogenetic and geographical study. Dana Rep. 16:1–256.

Han YS, Chang CW, He JT, Tzeng WN. 2001. Validation of the occurrence of short-finned eel Anguilla bicolor pacifica in natural waters of Taiwan. Acta Zool Taiwan. 12:9–19.

Han YS, Yu CH, Yu HT, Chang CW, Liao IC, Tzeng WN. 2002. The exotic American eel in Taiwan: ecological implications. J Fish Biol. 60:1608–1612.

Jacoby D, Gollock M. 2014. Anguilla japonica [Internet]. The IUCN Red List of Threatened Species. Version 2014.3. [accessed 2017 Mar 8]. www.iucnredlist.org.

Kim IS, Choi Y, Lee CL, Lee YJ, Kim BJ, Kim JM. 2005. Illustrated book of Korean fishes. Seoul: Kyohaksa, Korean.

Kim IS, Park JY. 2007. Freshwater fishes of Korea. Seoul: Kyohaksa. Korean.

Kuhlmann H. 1975. The influence of temperature, food, size, and origin on the sexual differentiation of elvers (Anguilla anguilla). Helgolander Wissenschaftliche Meeresuntersuchungen. 27:139–155.

Lee TW. 2014. Ecology and management of eel population in Korean water. In: proceedings of the international Eel symposium and the 2014 annual meeting of the east Asia Eel resource consortium; 2014 Sep 29–30; Gwangju, Korea.

Lodge DM. 1993. Biological invasions: lessons for ecology. Trends Ecol Evol. 8:133–137.

Okamura A, Yamada Y, Yokouchi K, Horig N, Mikawa N, Utow T, Tanaka S, Tsukamoto K. 2007. A silverying index for the Japanese eel Anguilla japonica. Environ Biol Fish. 80:77–89.

Okamura A, Zhang H, Mikawa N, Kotake A, Yamada Y, Utow T, Horig N, Tanaka S, Oka HP, Tsukamoto K. 2008. Decline in non-native freshwater eels in Japan: ecology and future perspectives. Environ Biol Fish. 81:347–358.

Okamura A, Zhang H, Yamada Y, Utow T, Mikawa N, Horig N, Tanaka S, Motonobu T. 2001. Identification of two eel species, Anguilla japonica and A. anguilla by discriminant function analysis. Nippon Suisan Gakkaishi. 67:1056–1060. Japanese.

Tzeng WN, Tabeta O. 1983. First record of the short-finned eel Anguilla bicolor pacifica from Taiwan. Bull Japan Soc Sci Fish. 49:351–363.

Tsukamoto K, Aoyama J. 1998. Evolution of freshwater eels of the genus Anguilla: a probable scenario. Environ Biol Fish. 52:139–148.

Tzeng WN, Cheng PW, Lin FY. 1995. Relative abundance, sex ratio and population structure of the Japanese eel Anguilla japonica in the Tahshui River system in northern Taiwan. J Fish Biol. 46:183–201.

Tzeng WN, Tabeta O. 1983. First record of the short-finned eel Anguilla bicolor pacifica elvers from Taiwan. Bull Japan Soc Sci Fish. 49:27–32.

Watanabe S, Aoyama J, Tsukamoto K. 2004. Re-examination of Ege’s (1939) use of taxonomic characters of the genus Anguilla. Mar Sci. 74:337–351.

Watanabe S, Aoyama J, Tsukamoto K. 2009. A new species of freshwater eel Anguilla luzonensis (Teleostei: Anguillidae) from Luzon Island of the Philippines. Fish Sci. 75:387–392.

Yamamoto T, Mochioka N, Nakazono A. 2000. Occurrence of the third Anguilla species, Anguilla bicolor pacifica glass-eels, from Japan. Suisanoshoukou. 48:579–580.

Zhang H, Mikawa N, Yamada Y, Horig N, Okamura A, Utow T, Tanaka S, Motonobu T. 1999. Foreign eel species in the natural waters of Japan detected by polymerase chain reaction of mitochondrial cytochrome b region. Fish Sci. 65:684–686.