Save Our Eels: Protection or Extinction?

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Freshwater eels of Genus *Anguilla* are important aquatic species not only because of their unique catadromous life history, *i.e.* after being hatched in marine habitats, the fish migrate to freshwater areas where they spend the majority of their lives growing and maturing after which the adult fish return to the sea to spawn, but also for their value as food resource. Populations of the European, American and Japanese eels are now considered to be beyond safe biological limits and are seriously threatened with extinction. For such reason, the European eel has recently been categorized as critically endangered by the European Union and the United Nations. The drastic decline in eel populations due to overfishing, has led to increasing demand for cultured eels. As with many other aquatic species, aquaculture of eels still completely depends on wild juveniles since artificial propagation of eels has not yet been successful. Therefore, commercial eel industries are now considering tropical eels as possible replacement for the European and Japanese eels to compensate for the declining stocks. However, useful scientific research and information on the biology and stock assessments of tropical eels are inadequate, a situation which is quite different from that for other temperate freshwater eels, which have been well studied for several decades with trends and recruitment patterns being on record. Nevertheless, the present tropical eel catch has been reported as being less than half that of 20 years ago. The present trends in eel stocks and utilization for human consumption suggest that eel populations will decline to numbers that fall outside safe biological limits and will be seriously threatened with extinction without protection and conservation with strict enforcement of local and international laws. These insights are discussed in the article, where most of the contents were cited and refereed from the latest review regarding the present status of the biology and stocks of freshwater eels by Arai (2014a).

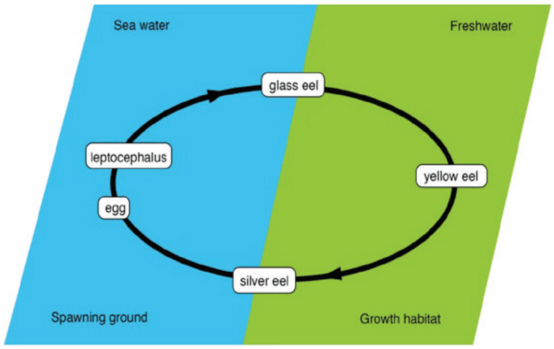

Fig. 1. Typical life history of freshwater eels of Genus *Anguilla*

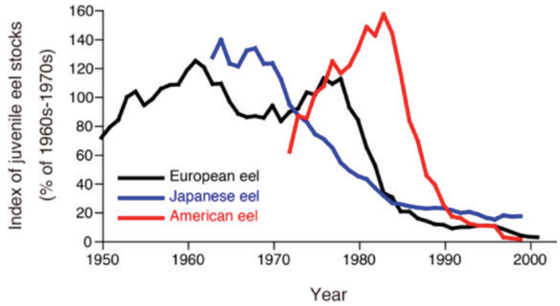

Fig. 2. Trends in juvenile stocks of the European, American and Japanese eels

Note: Data for European and Japanese eels are shown as landings of juveniles in each area and for the American eel as recruitment data from Lake Ontario at the northern limit of its distribution, the abundance of juvenile eels shows sharp decline after peaks, *i.e.* the European eel by 99%, the Japanese eel by 80%, and recruitment of the American eel has virtually ceased

Source: *Figure reference materials came from Dekker* et al. *(2003) and was drawn using original data provided by Dr. Willem Dekker (Arai, 2014a)*

Current Status and Concerns on Eel Stocks in the World

Freshwater eels are exotic animals and despite a huge number of scientific studies conducted on eels, the crucial aspects of their biology remain a mystery. No one has yet observed eels spawning in the natural environment, as spawning areas are located in the open ocean. This distinctly contrasts with other animals, such as the anadromous salmon fish whose biology is well studied and better understood because localized spawning stocks are relatively easy to survey when the adults return to freshwater to spawn. Freshwater eels are the most important of the eel families from a conservation standpoint because they have a unique catadromous life history (**Fig. 1**) and are utilized as food resources. Recently, however, juvenile abundance (**Fig. 2**) has declined dramatically by 99% for the European eel and by 80% for the Japanese eel (Dekker *et al*., 2003), while recruitment of the American eel near the species' northern limit has virtually ceased (Dekker *et al*., 2003). Other eel species, including the Australian and New Zealand eels (*Anguilla dieffenbachii* and *A. australis*) also show indications of decline (Dekker *et al*., 2003). The main problem is that all young eels used in aquaculture are wild juveniles (glass eels and elvers) captured in estuaries. Since almost all (90%) of the total world eel supply comes from aquaculture (FAO, 2010), therefore, the supply of eel resources for human consumption is completely dependent on wild catch.

The population size of wild juveniles has linearly decreased from over 200 metric tons in the early 1960s to 20 metric tons at present, and in Japanese eels, shortage of fry has become a serious problem for fish culture in recent years (Arai, 2014b). Eel stocks throughout Europe are also declining (Dekker, 2003a), and eel fishery yields have decreased in most European countries. Populations of the European, American and Japanese eels are considered to be outside safe biological limits, and current fisheries are not sustainable (Dekker, 2003b; Dekker *et al*., 2003; Arai, 2014b). Under such circumstance, the European eel was recently categorized as critically endangered by the European Union (EU) and the United Nations (CITES, 2007), although other eel species have not yet been seriously considered for protection. Since the early 1980s, juvenile recruitment has decreased, dropping to 1.0% that of the levels in 1970s.

Nonetheless, the causes of decline in stock and recruitment are not well understood, although overfishing, habitat loss and migration barriers, increased natural predation, parasitism, ocean climate variations, and pollution might have some impacts (Knights, 2003; Marcogliese and Casselman, 2009; Bonhommeau *et al*., 2008; Friedland *et al*., 2007). Since the European eel was listed by CITES under Appendix II and came under protection in March 2009, and considering that export/import ban was already issued by the EU in 2010, the international trade of juvenile eels has changed.

Species other than the European and Japanese eels, such as several tropical species, seem to have replaced the European eel on the international market. In addition, countries including Canada, the USA, Dominican Republic, Morocco, Madagascar, Philippines, and Indonesia have now entered the market by supplying juvenile eels for the farming industry in China, Japan, Taiwan, and South Korea (Crook, 2013; Anonymous, 2013a and 2014). Since fewer studies had been conducted on tropical eels than those of the European, American, Japanese, Australian, and New Zealand eels, the unavailability of information on basic life history, stock and population of tropical eels could lead to further serious declines in such eel resources. Therefore, before tropical eel juveniles are used to replace and augment the European and Japanese eels stocks, stock assessments and recruitment studies of source stocks are necessary to determine the sustainability of tropical eels. However, consumers in the East Asian countries do not pay much attention to protection, conservation and enhancement of tropical eel populations, concentrating instead on having a stable eel supply and trade as they did with European and Japanese eels. If such *ad hoc* eel resource utilization would continue, eels around the world would become extinct in the near future, considering that artificially induced breeding techniques for eel species are not yet firmly established, unlike for salmon, blue fin tuna and livestock. This situation could accelerate the status of wild eel stocks from threatened to declining. The inadequacy of scientific research, assessment and protection would lead to the collapse of tropical eel populations and affect the sustainability of the European, American, Japanese, Australian, and New Zealand eel resources. Therefore, rapid stock assessment and continuous monitoring of recruitment in tropical eels are necessary before fully utilizing this resource to avoid eel extinctions around the world.

History and Status of Eel Aquaculture

The global demand for eels has been met largely through the aquaculture production of essentially two eel species, the Japanese eel and the European eel (**Fig. 3**). Consumers in East Asia and Europe value the nutritional properties of these eels, making it a high-value aquaculture commodity. In fact, FAO (2010) mentioned that almost all (90%) of the world's eel supply comes from aquaculture.

Aquaculture of eels has been pioneered by countries where eels are a delicacy. Eel culture in Japan began in 1879 (Matsui, 1952) and at approximately the same time in Italy and France (Gousset, 1990; Heinsbroek, 1991; Ciccotti and Frontennelle, 2000). Initially, eel was raised in polyculture systems (Gousset, 1992), but large-scale commercial production started in the early 1960s when formulated feeds became available (Liao *et al*., 2002). Eel farming depends completely on the collection from the wild of juvenile stages such as the glass eel and elvers (**Fig. 4**). Therefore, the annual recruitment of the glass eel is very important to the eel aquaculture industry. However, recent recruitments of the glass eel stage of the Japanese eel have fallen to 10% that of the early 1960s rate (Ijiri *et al*., 2011).

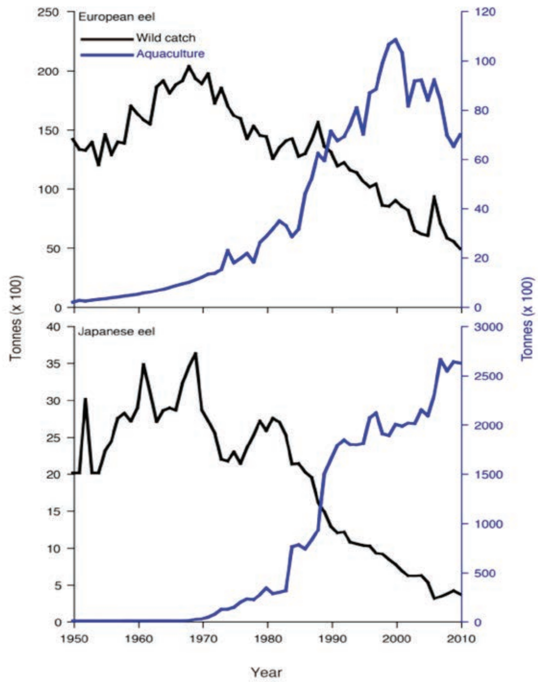

Fig. 3. Trends in global capture and aquaculture production between 1950 and 2010 for the European eel (top) and Japanese eel (bottom)

Note: Sharp declines in wild European and Japanese eel populations correspond to drastically increasing aquaculture demands for these eels after the 1970s, where peak capture of Japanese eels is less than the lowest captures of European eels, indicating a relatively low virgin biomass of Japanese eels

Source: *Arai 2014a, figure was drawn using the FAO FishFinder of the Food and Agriculture Organization of the United Nations (http://www.fao.org/fishery/fishfinder/contacts/en)*

Fig. 4. Newly recruited glass eels to Indonesian coasts (approximately 50 mm in total length), the complete dependence of eel aquaculture on wild glass eels could lead to serious declines in eel stocks

For the European eel, recruitment has also fallen, on average to <5% of the peak levels of the late 1970s and early 1980s (Dekker *et al*., 2007) as shown in **Fig. 2**, and the ICES continues to advise that the stock is outside safe biological limits and that current fisheries are not sustainable (ICES, 2006). The unstable supplies and prices for glass eels are serious concerns that confront the eel aquaculture industry. Therefore, the development of eel artificial breeding techniques is urgently necessary. In Japan, attempts to induce the artificial maturation of the Japanese eel started in the 1960s (Tanaka *et al*., 2003).

Yamamoto and Yamauchi (1974) were the first to successfully obtain fertilized eggs and larvae from the Japanese eel using hormone treatments, and after a two-week rearing period the preleptocephalus larvae reached 7 mm TL (Yamauchi *et al*., 1976). However, the larvae did not feed, and the transition into leptocephalus larvae did not occur. Although many researchers have henceforth succeeded in obtaining eel preleptocephali (Satoh, 1979; Wang *et al*., 1980), larval feeding and the production of leptocephali were not successful until 2001 (Tanaka *et al*., 2001).

For other eel species, such as the European eel (Prokhorchik, 1986) and the New Zealand short- and long-finned eels (*A. australis* and *A. dieffenbachii*, Anguillidae), experimentally produced larvae had only survived for few days (Lokman and Young, 2000), and as with the Japanese eel, did not develop into leptocephali. After much trial and error, Tanaka *et al*. (2001) found that preleptocephali were strongly attracted to and actively fed on shark egg powder. Thereafter, leptocephali have been successfully reared in aquaria using this diet for 100 days and have been raised to 22.8 mm TL, and the morphological characteristics and age of the reared leptocephali overlap with those of wild leptocephali (Tanaka *et al*., 2001). Soon after this study was performed, Tanaka *et al*. (2003) reported further progress in rearing larvae to the glass eel stage and even further to the yellow eel stage in 2003 (Ijiri *et al*., 2011).

After succeeding in rearing the eels to the leptocephalus stage (Tanaka *et al*., 2001), their diet was improved by supplementation with krill hydrolysate, soybean peptide, vitamins and minerals (Tanaka *et al*., 2003). The leptocephali that fed on this new diet grew to 50 to 60 mm TL and had begun to metamorphosis into glass eels approximately 250 days after hatching (Tanaka *et al*., 2003). The artificially produced glass eels could be grown and were artificially matured (Ijiri *et al*., 2011). Thereafter, a second generation of larvae was produced in 2010 (Ijiri *et al*., 2011). However, the techniques for producing glass eels are not yet firmly established (Tanaka *et al*., 2003). The egg quality is unstable, and the survival rates of the larvae are usually extremely low. In addition, the growth of the larvae is slower in captivity than in the wild by approximately 100 days (Arai *et al*., 1997). Under such conditions, the mass production of glass eels for use in aquaculture has not succeeded until recently.

Present Status of Trading and Biological Studies of Tropical Freshwater Eels

The present target tropical eel species is a tropical eel, *Anguilla bicolor* (*A. bicolor bicolor* and *A. bicolor pacifica*) from Indonesia and the Philippines (Anonymous, 2013a, 2014). China, Japan, Taiwan and South Korea have been importing cultured eel and selling it to consumers, using it to replace and compensate for the declining European and Japanese eel supply. Although Indonesia and the Philippines prohibit the export of juvenile eels, *i.e.* less than 150 g in weight from Indonesia and less than 15 cm in length from the Philippines to protect their resources, no regulations are enforced for juvenile fisheries in these countries (Anonymous, 2013a and 2014). All marked eels are either wild-caught eels or cultured eels from wild juveniles. Since there are no historical stock or juvenile recruitment data for eels available in these countries, fluctuation in the abundance of eels could not be well understood. The only available data in tropical eels show the three-year trend for recruitment from 1997 to 1999 based on quantitative sampling from an estuary in Indonesia (Arai *et al*., 1999; Sugeha *et al*., 2001), where juveniles were found to occur throughout each year (**Fig. 5**) with the highest recruitment occurring at the time of the new moon (Sugeha *et al*., 2001). More than 30,000 glass eels were collected

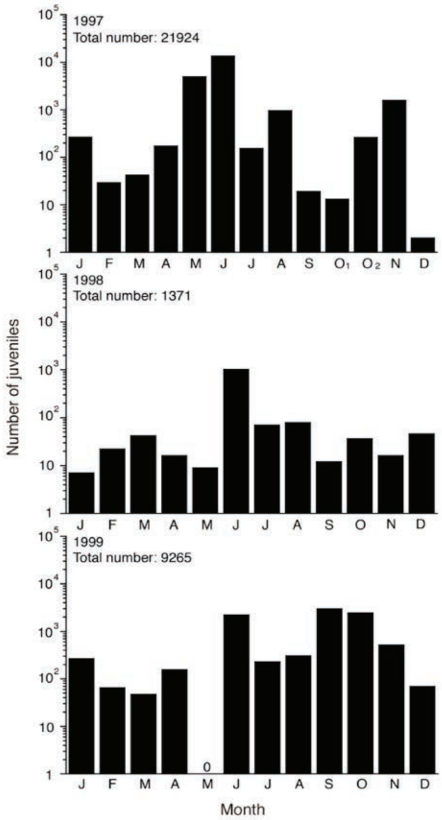

Fig. 5. Fluctuations of recruitment in tropical juvenile eels in Indonesia between 1997 and 1999

Notes: Monthly abundance of 3 tropical juvenile eels collected at the new moon in the Poigar River estuary, North Sulawesi Island of Indonesia from 1997 to 1999, where for October 1997 samples: 1 = early, 2 = late (Arai *et al.*, 1999; Sugeha *et al.*, 2001)

Juvenile eels were collected at the mouth of the tropical river, and were caught along a 10 m transect at the beach within 1.5 m from shore using 2 triangular scoop nets (mouth 0.3 m^2, 1 mm mesh), where the nets were fished simultaneously at depths of 25 to 50 cm in 10 replicate passes at hourly intervals (Arai *et al.*, 1999; Sugeha *et al.*, 2001); where the temporal patterns of juvenile catches suggest tropical juveniles recruit to the estuary throughout the year with considerable inter-annual variation in the recruitment patterns, such recruitment patterns are clearly different from those of European, American, Japanese, Australian and New Zealand eels, which have much shorter seasonal ranges in recruitment period during about half the year or less (Matsui, 1952; Haro & Krueger, 1988; Gandolfi *et al.*, 1984; Sloane, 1984; Jellyman, 1977)

This figure was drawn using the original data from Arai et al. *(1999) and Sugeha* et al. *(2001)*

quantitatively in the Poigar River estuary on north Sulawesi Island, Indonesia, with monthly collections from 1997 to 1999 (Arai *et al*., 1999; Sugeha *et al*., 2001).

The specimens identified were of three species, *Anguilla celebesensis*, *A. marmorata*, and *A. bicolor pacifica*, and were found each year in fluctuating abundances (**Fig. 6**). *A. celebesensis* was the most abundant species and comprised 73.5 %, 79.5 %, and 81.9 % of all glass eels recruiting to the estuary of the Poigar River in 1997, 1998, and 1999, respectively (**Fig. 6**) (Arai *et al*., 1999; Sugeha *et al*. 2001). This species was relatively abundant in all three years with peaks during June in 1997 and 1998 and during September in 1999 (**Fig. 6**). *A. marmorata* was the second most abundant species and comprised 23.8 %, 18.8 %, and 17.7 % of the yearly catches, respectively, and the peaks in abundance were reached during June in 1997 and 1998, and during January in 1999 (**Fig. 6**). *A. bicolor pacifica* comprised only 2.7 %, 1.7 %, and 0.3 % of the yearly catches respectively, with peak catches in June in 1997, January in 1998, and January and February in 1999 (**Fig. 6**). *A. celebesensis* and *A. marmorata* were collected almost throughout the year in 1997, 1998, and 1999, suggesting that in contrast to the temperate eels that recruit during half the year from winter to spring, these tropical eel species recruit to some degree throughout the year.

The temporal patterns of glass eel catches near the mouth of the Poigar River differed among species and years suggesting that there was considerable inter-annual variation in the recruitment patterns of glass eels in the region. However, such systematic surveys for tropical glass eels have never been conducted in other tropical regions. Further long-term surveys should be urgently needed to understand the natural (*e.g.* ambient environments such as global climate change and oceanic transportation systems) and anthropogenic impacts (*e.g.* over exploitation, habitat degradation and pollution) on the recruitment of glass eels in tropical regions. The natural reproductive ecology and spawning patterns of both tropical and temperate eel species remain a mystery, and it is thus extremely difficult to determine the nature of the migrations of freshwater eels (Arai, 2016).

Recently, Arai (2014c) found that tropical freshwater eels in Lake Poso, located in Central Sulawesi, Indonesia, had higher gonadosomatic index values than did temperate eels that were collected in coastal waters preparing for spawning migration and showed histologically fully developed gonads (**Fig. 7**). The results suggested that, in contrast to the long-distance migrations made by the Atlantic and Japanese eels, freshwater eels originally migrated only short distances, perhaps less than 100 km to local spawning areas adjacent to their freshwater growth habitats (Arai, 2014c).

Present Status of Stocks in Temperate Freshwater Eels

In contrast to the tropical eels, historical stock data for wild eels are available for European, American, Japanese, Australian, and New Zealand eels. For European and Japanese eels, wild catches fell gradually after the peak levels of the late 1970s and early 1980s in accordance with the increasing demand for eels in aquaculture (**Fig. 3**). Trends in juvenile abundance of the major eel stocks for European, American and Japanese eels also suggest that juvenile populations have declined dramatically and clearly lie outside of safe biological limits (**Fig. 2**). Moreover, the recruitment of European and Japanese eels in each distribution range declined by 99% and 80%, respectively, while recruitment of American eel at the northern limit of its distribution has ceased (**Fig. 2**).

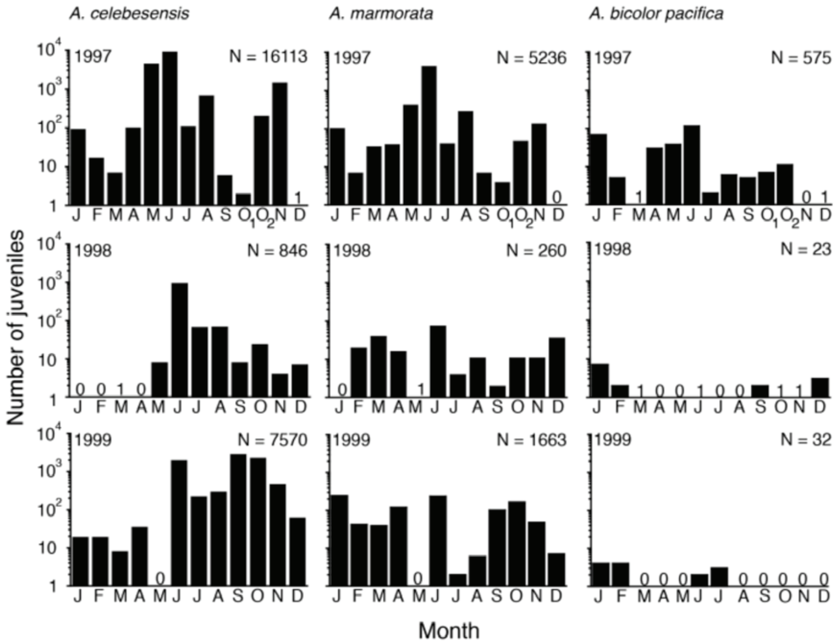

Fig. 6. Fluctuations of recruitment in tropical eels *Anguilla celebesensis*, *A. marmorata* and *A. bicolor pacifica* in Indonesia between 1997 and 1999 (Arai, 2014a)
Note: Monthly abundance of glass eels of each species collected at new moon in the Poigar River estuary from 1997 to 1999 (for October 1997 samples: O_1 = first new moon, O_2 = second new moon)

This figure was drawn using the original data from Arai et al. *(1999) and Sugeha* et al. *(2001)*

Worldwide Decline of Freshwater Eel Populations

The worldwide decline of freshwater eel populations is a major concern for animal conservation and diversity. European, American and Japanese eels have experienced sharp declines across their ranges over the last 30–40 years (ICES, 2006; Aprahamian *et al.*, 2007; Castonguay *et al.*, 1994; Dekker *et al.*, 2003, 2007) as shown in **Fig. 2** and **Fig. 3**. In spite of the seriousness of the situation for juvenile eel recruitment, eel consumption is still increasing. To continue to supply large amounts of eels to consumers, the replacement and compensation have started to import eels from foreign countries, mainly the Philippines, Indonesia and Madagascar (Anonymous, 2013a, 2013b, 2014). The main problem with consumption of this animal is that artificial propagation has not yet succeeded as it has with other common animals, such as salmon, blue fin tuna and livestock; therefore, juvenile eels are high-value aquaculture commodities that put high fishing pressure on a natural environment. Almost all (90 %) of the world's eel supply comes from aquaculture (FAO, 2010), and the present eel aquaculture completely (100 %) depends on wild juveniles. More than 90 % of the world production of eels is cultured in East Asia, primarily Japan, Taiwan and China (Ringuet *et al.*, 2002). Thus, wild juvenile eel catch will be needed in the future for these countries due to the increasing demands of aquaculture (**Fig. 3**). To enhance natural eel stocks and continue their commercial usage for human consumption, studies related to the establishment of commercial juvenile production are urgently required and should focus on this goal as a means of protecting wild eel stocks.

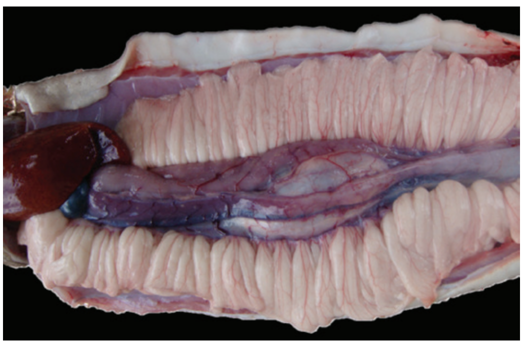

Fig. 7. Gonadal morphology of a spawning-condition tropical freshwater eel *Anguilla celebesensis* (754 mm in TL) that was collected from Lake Poso, Central Sulawesi, Indonesia

Concerns on Lack of Stock Assessment and Enhancement in Freshwater Eels

For the European eel, as a consequence of these concerns, the European Commission has agreed to an eel recovery plan, the aim of which is to return the European eel stock to sustainable levels of adult abundance and juvenile recruitment (Svedäng and Gipperth, 2012). In 2007, the European eel was listed in Appendix II of CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora) and Appendix II "includes species not necessarily threatened with extinction, but in which trade must be controlled to avoid utilization incompatible with their survival" (CITES, 2007). Although stock assessment and management of the European eel have received increasing attention from both the scientific community and fisheries agencies in recent years (ICES, 2006), such assessment and management of the Japanese eel have not yet been well studied. Such studies would help with the development of a concrete conservation policy and management applications for stock enhancement.

Despite the high demand for the product, the peak capture of Japanese eels (**Fig. 3**) is less than the lowest captures of European eels (Halpin, 2007). This fact indicates a relatively low virgin biomass of Japanese eels. To make matters worse, trade in tropical eels started with no scientific assessment and management before usage in spite of our experience with severely declining stocks in European, American, Japanese, Australian and New Zealand eels. Until now, there has been no information available on historical fishing records in tropical eels and only limited biological information compared with European, American, Japanese, Australian and New Zealand eels.

Do We Allow Freshwater Eels to Extinction?

Although European, American, Japanese, Australian and New Zealand eels appeared to have much shorter seasonal ranges during the recruitment period for about half of the year or less (Matsui, 1952; Haro and Krueger, 1988; Gandolfi *et al*., 1984; Sloane, 1984; Jellyman, 1977), at least a few juveniles of the tropical eels recruited year-round. The temporal pattern of tropical juvenile recruitment (**Fig. 5** and **Fig. 6**) was found to have considerable inter-annual variation (Arai *et al*., 1999; Sugeha *et al*., 2001). Thus, continuous long-term research is needed to determine the causes of the variation. Such year-round recruitment in tropical eels might be more convenient in aquaculture, which would be able to culture eels throughout year. In fact, 70 tons of eels were exported to Japan from one eel farm in Indonesia in 2013, and this amount is estimated to double in 2014 (Anonymous, 2014). Because the present market price of juvenile eels is 150 times higher than 20 years ago, a number of village people near juvenile eel fishing grounds in Indonesia tend to concentrate on eel fishing only, whereas they used to focus on farming and fishing (Anonymous, 2014). However, the juvenile eel catch is now reported to be half that of 20 years ago (Anonymous, 2014), although the estimated decline has never been evaluated based on scientific research. The causes of decline in eel stocks and recruitment are not well understood. One of the main reasons must be overfishing, as sharp declines in wild European and Japanese eel populations correspond to drastically increased aquaculture demands for these eels since the 1970s (**Fig. 3**). Now, tropical eels may have begun to follow the same trends as the European and Japanese eels. This suggests that we cannot rule out overfishing in tropical countries. Thus, if the wild juvenile eel catch of tropical eels continues to increase without assessment and protection of the stock and regulation of the catchment, all eel populations will decline to numbers outside safe biological limits. Currently, European, American and Japanese eels are seriously threatened with extinction due to eel consumption, and demand is still increasing. After the stocks and recruitment collapse in the present target eel species and areas, we will have to seek other targets for replacement and compensation to continue eel consumption. We may not be able to see such a unique animal on earth in the near future.

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