Chapter 21
Circulation

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Contents

The freshwater eel genus *Anguilla* consists of 19 species/subspecies that inhabit brackish and freshwater habitats worldwide. The distribution of the genus is mainly in the tropics, however its exact distribution range remains unclear. The freshwater eels have been often traded as living and cooked products for propagation and commercial use, which may negatively affect resource conservation and environmental protection. For example, the European eel had been frequently observed in natural waters in Japan and is suspected to have been released for stock enhancement despite the fact that this species does not naturally inhabit these waters and does not contribute to reproduction in the open ocean. In addition, in the mid-2010s, tropical species were imported to East Asian countries (mostly from the Philippines and Indonesia) as aquaculture seedlings, causing problems with species disguising due to high prices and difficulty in species identification. This chapter outlines (1) the obscurity in defining the distribution range of catadromous eels, which are born in the open ocean and grow in freshwater; (2) the occurrence of alien eel species in East Asian countries; (3) possible problems in utilizing tropical species for aquaculture; and (4) changes in the commercial use of the species in the Japanese market during the past decade.

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21.1 Distribution Range of Anguillid Species: A Case of the Japanese Eel

The 19 species/subspecies of the genus *Anguilla* are widely distributed throughout the world (see Chap. 1). Of these, 13 are found in tropical countries, mainly in Southeast Asia. In the temperate zone, 3 species are distributed in the Northern Hemisphere (Europe, North America, and East Asia) and 4 in the Southern Hemisphere (Oceania). Because of the high commercial value of freshwater eels, live adults, juveniles, and processed foods are traded internationally (see Chap. 23). However, imported live eels are sometimes released into rivers for propagation, resulting in the spread of non-native species.

To distinguish between native and non-native (exotic/alien) species, it is essential to have information on their natural distribution ranges. In the case of the freshwater fish that spend their entire lives in rivers, lakes, and ponds, they may move to neighboring rivers when the water rises, but they do not travel long distances. Therefore, it is possible to determine boundaries by examining whether fish live in each locality. However, catadromous freshwater eels that spawn in the open ocean and grow in freshwater are quite complicated. Here, we first considered the natural distribution range of the Japanese eel *A. japonica*, which is one of the most well-studied species in the genus. The Japanese eel is born in the western waters of the Mariana Islands and subsequently transported by the Kuroshio Current to the coastal areas of Taiwan, Korea, China, and Japan (Fig. 21.1). The southern limit of the distribution range of Japanese eel*s* is the Philippines. In fact, 60 out of 63,237 glass eels recruited from northern Luzon Island are Japanese eels (Tabeta et al. 1976; Yoshinaga et al. 2014, unpublished data). For example, on Mindanao Island in the southern Philippines, 2 out of 4745 glass eels were Japanese eels (Shirotori et al. 2016). These facts suggest that the Philippines are involved in the distribution range of the Japanese eel. However, the Japanese eel population is extremely small compared to other species; thus, it is reasonable to assume that the Japanese eel is not substantially distributed in the Philippines, despite coming to the shore due to occasional dispersal.

Next, we considered freshwater eel species that are naturally distributed in Japanese waters. In addition to the Japanese eel, 4 species/subspecies, the Indo-Pacific eel *A. marmorata*, Pacific bicolor eel *A. bicolor pacifica*, and Luzon eel *A. luzonensis* have been recorded from the Japanese coast. *A. marmorata* is found in rivers along the Pacific coast from Kyushu to the Kii Peninsula in the middle of Japan. In contrast, *A. bicolor pacifica* and *A. luzonensis* have been confirmed only in limited southern areas, such as Yakushima, Tanegashima, Iriomote, and Okinawa Islands (Inoue et al. 2021; Kita et al. 2021). Although it is not clear whether these individuals contribute to reproduction in the open ocean, it is reasonable to assume that *A. japonica* and *A. marmorata* are the 2 main species inhabiting Japan.

In Southeast Asian countries, such as Indonesia and the Philippines, where the number of anguillid species is much larger than that in temperate zones, the distribution range of each species is not well known. For example, the New Guinea

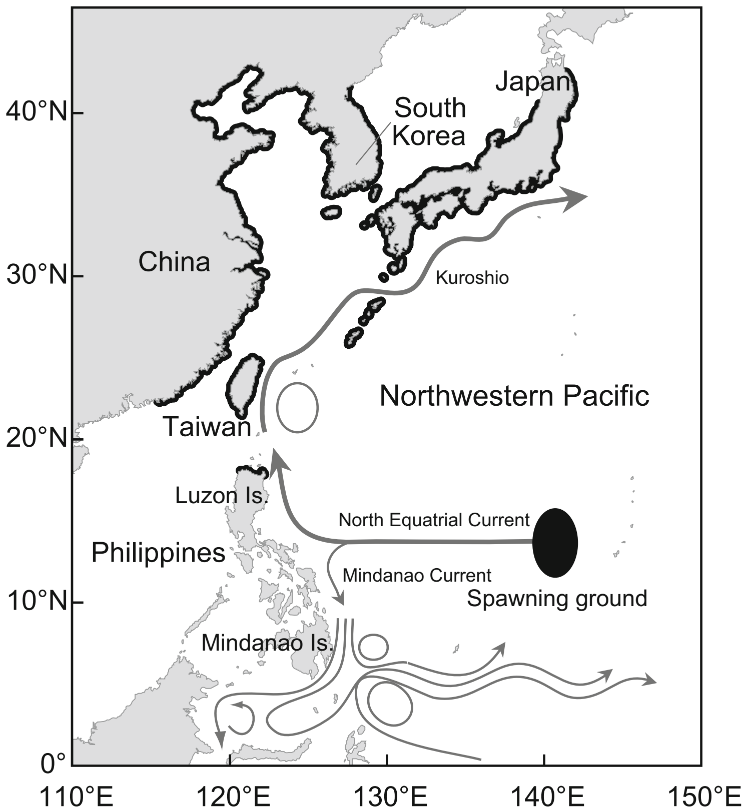

Fig. 21.1 Distribution range of the Japanese eel *Anguilla japonica* as shown by bold coastlines. The spawning area is denoted by a black oval, and the two major currents that transport the leptocephalus larvae, by thick arrows

eel *A. interioris*, which was originally thought to be from New Guinea Island, has also been found in southern Java in Indonesia facing the Indian Ocean as well as in the southern Philippines. However, the actual situation is completely unknown, and the distribution center of each tropical eel species has not been sufficiently clarified.

The existence of subspecies and genetically differentiated populations is also problematic when considering the distribution range of anguillid eels. *A. marmorata* is composed of at least 4 genetically differentiated populations (3 in the Pacific Ocean and 1 in the Indian Ocean (Minegishi et al. 2008), but is taxonomically recognized as a single species. In addition, there are 2 genetically differentiated subspecies of bicolor eels, *A. bicolor* in the Indian and Pacific Oceans, which are designated as *A. bicolor bicolor* and *A. bicolor pacifica*, respectively. Strictly speaking, *A. bicolor bicolor* and the Indian Ocean population of *A. marmorata* should be regarded as non-native species in the Pacific. However, spawning in the open ocean has limited migration barriers compared to inland waters, and thus, genetic exchange may continue among subspecies and populations. Therefore, it is difficult to define the boundary between the distribution areas of each subspecies or population of the genus *Anguilla*.

The purpose of this section is to introduce past cases of (1) exotic eel species in Japan and other countries; (2) alternative and counterfeiting in cultured eel species; and (3) changes in species used in processed foods to provide basic data for conservation.

21.2 Non-native Eel Species in Japan and Other East Asian Countries

Exotic or alien eel species (those that are not supposed to be naturally distributed in Japan) have been reported in many places within the past few decades. The most common species was the European eel *A. anguilla*. The European eel is widely distributed from northern Africa to Europe, but does not inhabit the Pacific Ocean. They were reported to be from the Uono River in Niigata Prefecture and Lake Shinji in Shimane Prefecture in 2000 (Zhang et al. 1999; Aoyama et al. 2000), but have also been found in schools of the Japanese eel migrating to spawning grounds in the East China Sea (Sasai et al. 2001). The European eel has also been observed in Mikawa Bay, Aichi Prefecture (Okamura et al. 2002), and more recently, in the upper reaches of the Tone River in 2015 (Arai et al. 2017). Because of their large size (total length: $>$ 100 cm) it is assumed that these individuals were left over from the previous release. In addition to the European eel, the American eel *A. rostrata* has also been found in Japan, probably originally cultured in China and subsequently imported to Japan. Indeed, there is no rule restricting the release to native species; thus, the species with the lower price per weight are selected for obligatory stocking of inland fisheries. European and American eels have also been found in the natural waters of Taiwan and Korea (Han et al. 2002; Honga et al. 2017). Furthermore, Korea has utilized 6 exotic species/subspecies for aquaculture (in addition to *A. rostrata* which has been intensively cultured): *A. bicolor bicolor*, *A. bicolor pacifica*, *A. anguilla*, Mozambique eel *A. mossambica*, and *A. marmorata* (Honga et al. 2017). Thus, they can be found in natural waters if escape occurs.

Species identification is a challenge in surveys of exotic eel species. Freshwater eels are classified into 4 morphological groups: (I) variegated marking of the body surface and undivided maxillary and mandibular bands of teeth (4 species); (II) variegated with a toothless longitudinal groove in the maxillary and mandibular bands of teeth (4 species); (III) not variegated with a long dorsal fin (6 species); and (IV) not variegate with a short dorsal fin (5 species/subspecies) (Watanabe et al. 2004, 2009). *Anguilla japonica* belongs to group III, which includes 6 species: *A. anguilla*, *A. rostrata*, Borneo eel *A. borneensis*, *A. mossambica*, and New Zealand longfin eel *A. dieffenbachii*. However, the European and American eels found in Japanese waters cannot be distinguished from the Japanese eel based on morphological traits; thus, their presence is confirmed by genetic analysis. Therefore, it is possible that these exotic species were released in areas in which no surveys were conducted. To precisely identify freshwater eel species with similar morphological traits, various genetic methods based on polymerase chain reaction (PCR) have been developed (Itoi et al. 2005; Minegishi et al. 2009; Tanaka et al. 2014; Yoshitake et al. 2019). These methods are considerably expensive, but are essential for species identification of morphologically indistinguishable anguillid eels. Genetic species identification of freshwater eels collected from various parts of Japan in the mid-2010s showed that most of them were *A. japonica* except for the 4 *A. anguilla* in the upper reaches of the Tone River mentioned above. Although it is not clear how *A. anguilla* interacts with native *A. japonica*, competition for resources and habitats may explain why these species occupy similar ecological niches.

The most serious problem with exotic eel species is the occurrence of diseases caused by parasites and bacteria (see Chap. 17). In the European eel, this has been caused by the parasitic nematode, *Anguillicola crassus*. This nematode parasitizes the swim bladder and causes no noticeable symptoms in small numbers; however, in large numbers, it causes inflammation by compressing internal organs (Ogawa 2006). Originally distributed in East Asia, this nematode was thought to have been introduced to Germany with the Japanese eel exported from Taiwan around 1980 (Koops and Hartmann 1989). Since then, it has rapidly spread to most parts of Europe. This nematode also parasitizes the Japanese eel, but no significant symptoms are observed. This is due to the difference in susceptibility of European and Japanese eels to the nematode. The Japanese eel, which has coexisted with the nematode for many years, has developed partial resistance to the parasite, which inhibits its excessive growth. However, the European eel has only recently been infected with the parasite, and thus has no means of defense, resulting in severe symptoms. Dermocystidiosis, a fungal disease, has been introduced in Japan by eels imported from Europe. This is not a serious case, but shows that parasites and pathogens are inevitably introduced when eels are imported as hosts. Anthropogenic movement of eels is expected to accelerate in the future, creating concern that pathogens may be introduced. Indeed, Eel virus European (EVE), Eel virus European X (EVEX), and Anguillid herpesvirus-1 (HVA) have been found in the distribution range of *A. anguilla* and potentially threaten the stock of the species (McConville et al. 2018). The spread of pathogens by the release of non-native species into natural waters may cause catastrophic damage to the natural populations of native species. Since it is almost impossible to eliminate the pathogen once it has spread, great care must be taken not only to control artificial releases but also to prevent its dispersal from aquaculture facilities.

21.3 Alternative Species for Aquaculture Seedlings

In East Asian countries, Japanese and European eels have been utilized for aquaculture for decades, and, more recently, the American eel. However, stocks of these species have been partly decreasing because of over-exploitation. Thus, to compensate for the shortage of these temperate species, tropical species have been utilized as alternative seedlings. Among the 13 tropical anguillid subspecies, *A. bicolor* is the most notable and has been utilized on a commercial scale. However, the recruitment of glass eels in temperate and tropical regions can be quite different. In Southeast Asian countries, several species simultaneously recruit at the same place, and dominant species differ monthly; therefore, it can be technically difficult to utilize only a specific species for aquaculture.

Based on the species composition of tropical eels that recruited four localities in the Philippines and Indonesia (northern Luzon, Mindanao, Sulawesi, and Java), we considered the possibility of collecting *A. bicolor* for aquaculture (Fig. 21.2; Table 21.1). Of the 2 subspecies of *A. bicolor*, *A. bicolor pacifica* is recruited in northern Luzon, Mindanao, and Sulawesi, and *A. bicolor bicolor* on Java Island. Semi-annual to annual sampling surveys confirmed the recruitment of 4–7 species/subspecies at each locality. In northern Luzon, 5 species/subspecies have been observed (Yoshinaga et al. 2014; Aoyama et al. 2015). In November and December 2011, *A. bicolor pacifica* occupied most of the recruitment; however, in the same months of the following year, less than half was observed. In Mindanao, the Philippines, *A. bicolor pacifica* accounted for almost half of the recruitment in

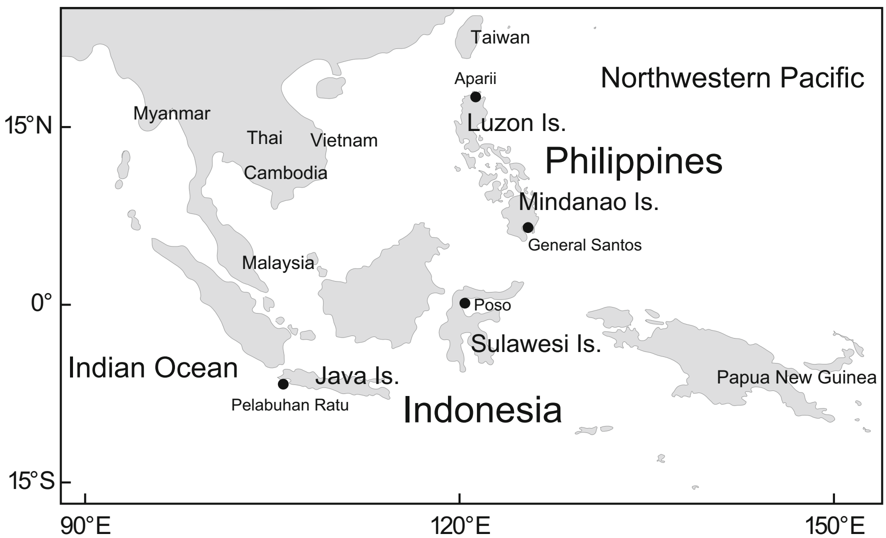

Fig. 21.2 Map showing the four localities—denoted by black dots—in the Philippines and Indonesia where the species composition of glass eels was investigated (Table 21.1)

Table 21.1 Recruitment of tropical anguillid species in East Asian Countries

					Year and month																
					2009			2011		2012											
Country	Locality	Species	Common name	Morphology group	Jan	Feb		Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Philippines	Northern Luzon	*A. luzonensis*	Luzon eel	1st				1.4	1.7				1.1	39.3	86.5	96.7	87.3	77.4	23.1	7.1	1.2
		A. celebesensis	Celebes eel	1st				0.1												0.3	
		A. marmorata	Indo-Pacific eel	2nd	73.1	43.0		3.5	2.5	68.4	93.1	97.9	98.7	59.9	11.2	2.1	2.9	9.0	35.9	51.5	54.6
		A. japonica	Japanese eel	3rd	16.8																
		A. bicolor pacifica	Pacific bicolor eel	4th	10.1	57.0		95.1	95.8	31.6	6.9	2.1	0.2	0.8	2.3	1.2	9.8	13.7	41.0	41.1	44.2
					2014									2015							
	Mindanao				Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar					
		A. celebesensis	Celebes eel	1st			1.4	11.9	1.1	2.0	1.2		9.1	2.2	2.8						
		A. interioris	New Guinea eel	1st		1.4	0.3			0.3	0.7	4.5	5.5	6.3	1.7						
		A. luzonensis	Luzon eel	1st		1.0		0.5	1.1												
		A. marmorata	Indo-Pacific eel	2nd	99.6	92.5	90.0	68.5	48.1	66.3	94.9	72.0	79.5	74.6	87.0	71.3					
		A. japonica	Japanese eel	3rd											0.3						
		A. borneensis	Borneo eel	3rd		0.5															
		A. bicolor pacifica	Pacific bicolor eel	4th	0.4	4.6	8.3	19.1	49.8	31.4	3.2	23.6	5.9	16.9	8.1	28.7					
Indonesia					2014		2015														
	Slawesi				Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep						
		A. celebesensis	Celebes eel	1st	9.5	–	–						2.0	3.4	2.0						
		A. interioris	New Guinea eel	1st	1.4	–	–														
		A. marmorata	Indo-Pacific eel	2nd	88.5	–	–	100.0	99.1	95.4	96.1	99.6	95.7	95.7	97.7						
		A. bicolor pacifica	Pacific bicolor eel	4th	0.7	–	–		0.9	4.6	3.9	0.4	2.3	0.9	0.3						

(continued)

Table 21.1 (continued)

Country	Locality	Species	Common name	Morphology group	Year and month																
					2009			2011		2012											
					Jan	Feb		Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					2015																
	Java				Feb	Mar	Apr	May	Jun	Jul	Aug	Sep									
		A. interioris	New Guinea eel	1st	0.0	–		0.7		7.1	3.9	4.0									
		A. bengalensis bengalensis	Indian Bengal eel	2nd	0.3	–		1.4		1.3		1.6									
		A. marmorata	Indo-Pacific eel	2nd	0.9	–	31.6			25.0	18.8	18.2									
		A. bicolor bicolor	Indian bicolor eel	4th	98.8	–	68.4	97.8	100.0	66.6	77.4	76.3									

Source: Aoyama et al. 2015; Shirotori et al. 2016; Yoshinaga et al. 2014, unpubl. Data

December 2011, but fewer in other months. On Sulawesi Island, *A. marmorata* has dominated for almost the entire year, and recruitment of *A. bicolor pacifica* was quite limited. However, even though the survey period was limited, *A. bicolor bicolor* was dominant on Java Island facing the Indian Ocean (Pelabuhan Ratu). Therefore, compared to the other 3 localities, a stable fishery catch of *A. bicolor* glass eels is possible. Glass eels collected at this site have been farmed and processed in Indonesia and have been sold in major Japanese supermarkets since 2013. However, since *A. bicolor bicolor* is widely distributed along the Indian Ocean coast (see Chap. 1), it is expected to be extremely difficult to implement, requiring coordinated monitoring among many countries that share resources of this species.

Around the mid-2010s, many eels caught in Southeast Asia were introduced into East Asian countries as a substitute species for Japanese eels. As mentioned earlier, >5 species of freshwater eels are distributed in the tropics and the distribution center of the genus, whereas Japanese eels are rare. However, tropical eels are not easily distinguished from Japanese eels, except for scientific observations, leading some eels imported from Southeast Asia to be incorrectly sold as Japanese eels. Although the number of eels brought from Southeast Asia is currently decreasing, this chapter introduces some cases of disguised species, and provides information on the challenges surrounding eels.

21.3.1 Case 1

End of March 2012: A non-specialized middleman sold 2 kg of glass eels of the Japanese eel imported from the Philippines to a trader in the Japanese central fish market, *Tsukiji Shijo*. The price was ~1/5 of the current price, and was accompanied by a DNA certificate stating: “This is to certify that the MARINE PRODUCT tested and presented in this laboratory is: A. JAPONICA 98%”. However, the authors confirmed by genetic analysis that these were actually *A. marmorata* and some other species, but not *A. japonica*. The author could not find any information about the researcher who signed the certificate, and most of the certificate was plagiarized by an abstract of a paper reporting the genetic analysis of the Japanese eels, not the content of the expert opinion.

21.3.2 Case 2

At the end of January 2015, a wholesaler purchased 3 kg of glass eels, which were indicated as Japanese eels, from 2 men who the wholesaler had never met. The wholesaler later asked the author to assess the species because of his suspicion, probably because of a slightly different morphology. Genetic analysis revealed that most of the eels were *A. bicolor*, and their species composition suggested that they originated from the northern Philippines. The men who disguised the glass eels were later prosecuted and the case was settled with monetary compensation.

21.3.3 Case 3

In March 2015, elvers of Japanese eels purporting to be from Vietnam were posted on an Internet bulletin board (now closed), claiming to have a DNA certificate, and selling for about half of the normal price. The author assessed the species and found them to be European eels. The process is unclear, but the company that imported eels from Vietnam was an IT company, and an antisocial organization was also involved.

21.3.4 Case 4

These cases are known by the author, but are just the tip of the iceberg, as there were many suspected cases of deception in 2015. It has become common for a price hike to be reported in newspapers and TV news at the end of the demand season (January to March). Non-specialized middlemen who are engaged in the business of importing and exporting marine products other than eels usually obtain eels of unknown species from Southeast Asian countries and sell them at a lower price than usual. However, as mentioned above, there are almost no Japanese eels in Southeast Asia, which results in disguising this species. Some claimed to have been accompanied by expert certificates, but they were often poorly fabricated. We do not know how many of them were brought into the country under false pretenses. However, if eels were released into natural rivers, it is feared that they may have introduced parasites. The demand for tropical eel species is similar to that for temperate species in East Asian countries, and thus it is extremely difficult to collect specific species for aquaculture. The bycatch of glass eel includes some species that are found in threatened categories on the Red List, such as the Luzon eel (Vulnerable), and attention must be paid to the conservation of such species.

21.4 Changes in the Species Used for Inexpensive Eel Products

In Japan, freshwater eels are consumed in a variety of ways, from high-end to inexpensive restaurants, and as precooked products sold in supermarkets. Freshwater eels were once a luxury food in Japan; however, in the 1990s, European eels farmed in China were imported and sold in large quantities, causing prices to drop dramatically and availability to increase, thereby making them a common household food.

Domestic traders were so exhausted by the price decline that they demanded the establishment of safeguards. In contrast, in Japan, the import of freshwater eels has declined since 2010 due to the detection of banned chemicals, the revelation of counterfeit products, and the ban on exports of the European eel from the European Union. The current annual consumption is ~4–50,000 tons, and ~1/2 of the eel products sold in Japan are domestically produced, with the remainder coming from China.

In Japanese supermarkets, “domestic” and “Chinese” eel products (*kabayaki* in Japanese) are sold, but there is no obligation to label the species. To understand the actual situation of eel species in circulation, we have been conducting genetic species identification on the *kabayaki* provided by supermarkets and relatively cheap restaurants since 2011. Although the number of samples examined is limited and it is not possible to grasp the entire distribution process, we have identified some factors such as the change in species after 10 years of survey.

In 2011, the first year of our survey, most of the identified samples were Japanese eels. However, the species of eel served at a conveyor-belt *sushi* restaurant changed from the European eel in July to the Japanese eel in October, even though it was served as an ingredient in the same product. They may have been using cheap European eels when the purchase price was high and Japanese eels when the price had settled. As for the *kabayaki* sold in supermarkets, the relatively cheap ones from China were usually European eels, and more recently, American eels have been observed.

Both the Japanese and European eels were served at a beef-bowl restaurant in 2013. In 2014, 3 species were detected in several eel bowls that were purchased from the same store. In this restaurant chain, 3 pieces of *kabayaki* are processed in China and vacuum-packed, then heated and served (we observed this by looking into the kitchen). Since there were 4 pieces of the European eel and 2 pieces of the American eel, the 2 species were already together when they were processed in China. In 2014, the European eel was used at other beef-bowl restaurants, lunch boxes, and conveyor-belt *sushi* restaurants. However, it is interesting to note that the number of restaurants serving the European eel has decreased since 2015. One reason for this is that the international trade of European eels has reduced as range states develop management and policy measures in line with the CITES listing, and also because of negative campaigns by conservation groups. In 2015, only one conveyor-belt *sushi* restaurant used European and American eels, as the staff in charge of the restaurant did not fully understand the CITES listing of the European eel, and switched to Japanese eel the following year.

In 2017, European eels were still sold in some supermarkets, but the distribution of European eels was almost nonexistent compared to previous years. However, European eels are still farmed in China, and some beef-bowl chain restaurants began to handle them again after 2018. It is unclear whether these eels are illegally exported from the EU or caught in North Africa, where they can be legally exported. Indeed, the European eel was found in almost half of the commercial products sold in Hong Kong supermarkets between 2017 and 2018 (Richards et al. 2020). In any case, in the consumption of eels, which depends on natural resources, the reality of international trade is constantly changing; thus, it is important to keep an eye on the actual situation of the species in circulation.

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