Protecting eels protects freshwater biodiversity

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Figure 1: Left: the Japanese eel (Anguilla japonica). Right: the giant mottled eel (A. marmorata). Credit: Kobe University

An international research team has conducted a field survey on two species of eel native to Japan, and other organisms that share the same habitat, revealing for the first time in the world that these eels can act as comprehensive surrogate species for biodiversity conservation in freshwater rivers. It is hoped that conducting activities to restore and protect eel populations will contribute greatly to the recovery and conservation of freshwater ecosystems that have suffered a significant loss of biodiversity.

The team consisted of Researcher Itakura Hikaru (of Kobe University's

Graduate School of Science, and a JSPS Overseas Research Fellow at the University of Maryland), Specially Appointed Researcher Wakiya Ryoshiro (of The University of Tokyo), Dr. Matthew Gollock (of The Zoological Society of London) and Associate Professor KAIFU Kenzo (Chuo University).

The results of this research were published in the British scientific journal *Scientific Reports* on May 29.

Research Background

Although freshwater covers only 2.3% of the Earth's surface, it provides diverse habitats that support a far greater number of species per area than terrestrial or marine ecosystems. However, at the same time freshwater ecosystems have suffered significant deterioration and loss of biodiversity due to the human populations concentrated around them. As a result far more freshwater species are in danger of extinction than species belonging to other ecosystems. One third of freshwater species have been classified as 'Endangered' in the International Union for Conservation of Nature (IUCN)'s Red List of Threatened Species.

Figure 2: Conducting field sampling. Left: Sample collection using an electric

shocker. Right: Identifying and counting the sampled species. Credit: Kobe University

It is challenging to monitor and manage all the species that make up these ecosystems in order to protect biodiversity. For this reason, it is thought that by focusing conservation efforts on one or a few species, we can understand the functions, resource dynamics and structures of the biological communities to which they belong. This knowledge can be used to manage and conserve biodiversity. These surrogate species are classified as umbrella, indicator or flagship species according to conservation goals. So far some large mammal and bird species have been proposed as surrogate species.

The two kinds of eel that were the subject of this study are catadromous, meaning that they are migratory species that spawn in the ocean and grow in rivers and coastal waters. Anguillid eels can be found almost worldwide (except for the polar areas); in the varied aquatic environments of 150 countries, including inner bays, and all parts of rivers from the source to mouth.

In this study, the researchers focused on the eels' unique life cycle and confirmed that they can serve as umbrella, indicator and flagship species. They propose that eels are a comprehensive surrogate species for the conservation of freshwater biodiversity.

Region	Species	Common name	Migratory type	Coverage (%)
Mainland Japan	*Anguilla japonica*	Japanese eel	Diadromous	86.5 (59.6–100.0)
	Eriocheir japonica	Japanese mitten crab	Diadromous	84.2 (61.1–100.0)
	Macrobrachium japonicum	Freshwater prawn	Diadromous	69.2 (66.7–71.9)
	Gymnogobius petschiliensis	Floating goby	Diadromous	62.3 (52.6–77.8)
	Rhinogobius nagoyae	Freshwater goby	Diadromous	57.6 (38.9–89.9)
	Macrobracbium formosense	Freshwater prawn	Diadromous	55.6 (13.5–88.9)
	Plecoglossus altivelis altivelis	Ayu	Diadromous	52.8 (27.9–77.8)
	Tridentiger brevispinis	Dusky tripletooth goby	Diadromous	35.4 (23.3–58.3)
Amami-Oshima Island	*Anguilla marmorata*	Giant mottled eel	Diadromous	93.7 (93.8–95.7)
	Macrobrachium japonicum	Freshwater prawn	Diadromous	80.3 (66.3–100.0)
	Sicyopterus japonicus	Rock climbing goby	Diadromous	72.5 (51.1–100.0)
	Macrobracbium formosense	Freshwater prawn	Diadromous	60.1 (25.5–100.0)
	Tridentiger kuroiwae	Dusky tripletooth goby	Diadromous	53.1 (17.0–87.4)
	Plecoglossus altivelis ryukyuensis	Ayu	Diadromous	43.6 (17.0–81.8)
	Caridina multidentata	Japanese marsh shrimp	Diadromous	19.5 (6.2–39.6)
	Eleotris fusca	Sleeper gobies	Diadromous	6.5 (0.0–19.6)

Figure 3: The distribution range of freshwater species in rivers. Only the most numerous organisms are shown. Credit: Kobe University

Research Methodology

Eel and other freshwater organisms (fish and large crustaceans such as crab and shrimp) were collected from 78 sites spanning upstream to downstream regions in six rivers in Japan using an electric shocker (three mainland rivers in Kyushu and Honshu, and three rivers on Amami-Oshima island) (Figure 2). The Japanese eel is mostly found in the mainland rivers, whereas the giant mottled eel largely inhabits Amami-Oshima's rivers. In order to determine these two species' suitability as indicator and umbrella species for biodiversity conservation, the distribution of the sampled eels and freshwater organisms in the rivers was analyzed and their trophic levels in the food web were researched.

Furthermore, the researchers also investigated the quantitative relationship between the number of eels and the number of other migratory diadromous species (biodiversity), and the environmental factors affecting this. Japan is a mountainous country and there are many small, fast flowing rivers. It was predicted that the migratory species that travel between the sea and the rivers during their life cycles would be predominant in freshwater rivers' ecosystems. Therefore, a large number of migratory species was interpreted as an indicator of biodiversity.

The results from each of the field studies on Japanese eels and giant mottled eels showed that they were the most widely distributed of all freshwater species in river habitats. Japanese eels covered 87% of the study rivers in mainland Japan, whereas the giant mottled eel was found in 94% of the Amami Oshima rivers used in this study (Figure 3). Stable isotope analyses of the muscle tissue of eel and other freshwater organisms were carried out to estimate their trophic levels. The results showed that the mean trophic levels of eel species were greater than three which indicates that they are higher-order predators, and these values were significantly higher than those for other freshwater organisms (Figure 4). These results support the eels' potential as umbrella species and show that they require a diverse range of lower trophic level animals for food.

This study confirmed the presence of 48 species of freshwater organisms, including fish and crustaceans. As predicted, a total of 80% of these were migratory species (78% in Honshu/Kyushu and 91% on Amami Oshima island). Furthermore, there was a positive correlation between the number of Japanese eels or giant mottled eels and the number of other migratory species. A statistical model was used to investigate various environmental factors that may have an impact on both of these groups. The researchers found a strong negative correlation between the number of eels and other migratory species and the following two points; 'the distance of the study site from the sea' and the

'cumulative height of trans-river structures, such as dams or weirs, that species have to pass in order to get from the sea to the study site'. These factors have an impact on river-ocean connectivity for migratory species. In other words, these results imply that the positive correlation found between the number of eels and the number of other migratory species is probably an indirect relationship through river-ocean connectivity. In areas where river- ocean connectivity is high (i.e., it's easy for them to swim upstream), there will be greater numbers of eels and other migratory species. Conversely, if river- ocean connectivity is low, there will be fewer of these species. These results show that eels are an indicator of good river-ocean connectivity, and through this they are an indicator of biodiversity.

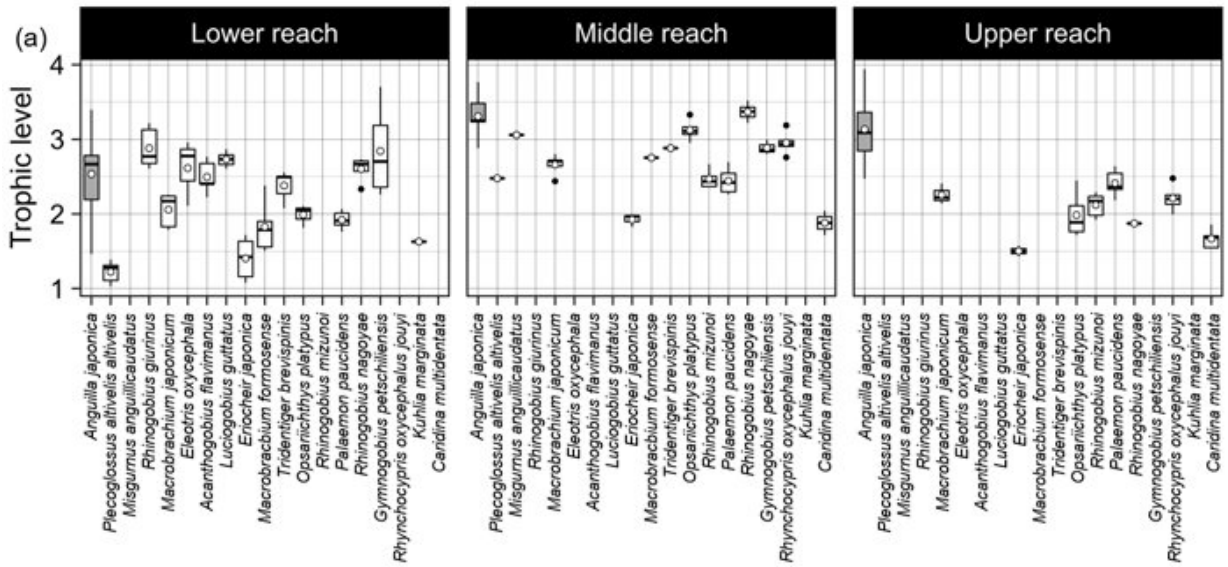

Figure 4: The trophic levels of freshwater organisms in the food web. Credit: Kobe University

This research showed that trans-river structures (Figure 5) have a

negative impact on eels and other migratory species. It has been indicated that eels can climb such structures vertically, if the structures are wet. However, trans-river structures inhibit eel movement, moreover they have been shown to cause a decline in the numbers of many eel species. In this study, it was shown that even barriers under 1m high could have a negative impact on eel distribution. Previous studies have indicated that the habitat loss caused by these trans-river structures is a leading factor in the decline in eel numbers. Many other studies have reported that the distribution of other migratory species is limited by these structures in a similar way to eels. Eels are an indicator of river-ocean connectivity. It is hoped that improving and maintaining this connectivity for eels will greatly boost the biodiversity of freshwater ecosystems.

In 2016, IUCN decided upon the 'Promotion of Anguillid eels as flagship species for aquatic conservation'. This designation was based on the widespread decline of eel numbers, the effects of habitat deterioration and destruction, as well as eels' global distribution and their unique catadromous migration. As shown in this study, eels have the following important aspects that make them suitable as a flagship species; they are widely distributed, higher-order predators that are generally larger than other freshwater organisms, and are easily identifiable.

Looking at eels in terms of their importance ecologically, commercially and culturally, we can conclude that they have provided a diverse ecological service worldwide since ancient times. Eels are found almost all over the world, and have served as a source of food in various lands and eras. They have played roles in food cultures, in literature and art, in legends and belief systems. Therefore, the researchers concluded that eels have the ability to stir up great public awareness worldwide about environmental issues, which is connected to their value as a flagship species.

In conclusion, eels can serve as indicator, umbrella and flagship species, making them a comprehensive surrogate for the conservation of freshwater biodiversity.

Figure 5: Examples of trans-river structures in the rivers covered by the survey (left: a 25m high dam, right: a spillway of less than 1m in height.). Credit: Kobe University

Further Developments

This study confirmed the possibility that eels could be used as a surrogate species by using Japanese rivers as a model. These results could be applied to regions where, like in Japan, migratory species dominate freshwater ecosystems, such as islands that are relatively new geologically. On the other hand, continental freshwater ecosystems, for example, have a higher diversity of primary freshwater species that spend their entire lives in freshwater compared to Japan, therefore it is predicted that the impact of river-ocean connectivity on biodiversity would be lower than in the results of this study. However, trans-river structures also inhibit the mobility of primary freshwater species, such as

upriver migrations for egg laying.

Sixteen species of eel have been discovered so far and they are globally distributed. Consequently, eels have the potential to be a surrogate species for freshwater biodiversity conservation worldwide, due to their importance in ecosystems as widely distributed higher-order predators, in addition to their commercial and cultural importance. It is hoped that further research could investigate this possibility in continental rivers and elsewhere.

More information: Hikaru Itakura et al. Anguillid eels as a surrogate species for conservation of freshwater biodiversity in Japan, *Scientific Reports* (2020). DOI: 10.1038/s41598-020-65883-4

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