Biogeography **12.**
133–139. Aug. 20, 2010

Occurrence and Habitats of the Giant Mottled Eel *Anguilla marmorata* (Anguilliformes, Anguillidae) in Rivers of Ehime Prefecture, Japan

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Abstract. Japan is the northernmost distributional area for the giant mottle eel *Anguilla marmorata* Quoy & Gaimard, 1824. A total of 45 giant mottled eels were collected with eel pots from July 1997 to March 2010 in the freshwater lower reach of the Renjoji River in Ehime Prefecture, Shikoku Island, Japan. The number of *A. marmorata* caught per year was up to 11 (mean 3.4), indicating that the species was in quite low abundance in this river. Most of the eels were captured from June to September. Some eels were also captured incidentally in three adjacent rivers. The eels caught in the Renjoji River were small (30.3–59.7 cm in total length), which was probably caused by the selectivity of fishing gear used. As the eels were mainly captured at sites covered with emergent plants and inhabited by decapod crustaceans and fishes, such environment may be suitable for the habitats of *A. marmorata*.

Key words: *Anguilla marmorata*, seasonal occurrence, body size, habitats

Introduction

The giant mottled eel *Anguilla marmorata* Quoy & Gaimard, 1824 is a tropical anguillid that grows up to almost 180 cm in total length and 28 kg in body weight (Williamson & Boetius, 1993). This species occurs in freshwater in a wide region of the Indo-Pacific region, ranging from South Africa and Madagascar through the coast of Southeast Asian countries to China, Taiwan, South Korea and Japan (Watanabe *et al*., 2009). It also occurs in oceanic islands, such as Palmyra Atoll and the Marquesas Islands in the central Pacific and the Galápagos Islands in the eastern Pacific (Williamson & Boëtius, 1993; Handler & James, 2006; Watanabe *et al*., 2009).

The biology of *A. marmorata* is very poorly known in Japan. Recently, based on the literature published from 1963 to 2009, Mizuno & Nagasawa (2009) compiled information on the current geographical distribution of the species in Japan and reported that it mainly occurs in the regions along the coasts facing the North Pacific and the East China Sea and in southern small islands, including the Ryukyu Islands and the Bonin (Ogasawara) Islands: this distributional pattern is strongly affected by the route of the Kuroshio. Yamamoto *et al*. (2001) found that the glass eels of *A. marmorata* migrated to waters around Yaku Island, southern Japan, with peaks in June and September. Arai *et al*. (2002) also estimated the timing and duration of metamorphosis of the glass eels and the age at their recruitment to waters of the nearby Tanegashima Island. Currently, Chino & Arai (2009) reported the migratory history of the species in the Bonin Islands by studying strontium and calcium concentrations in

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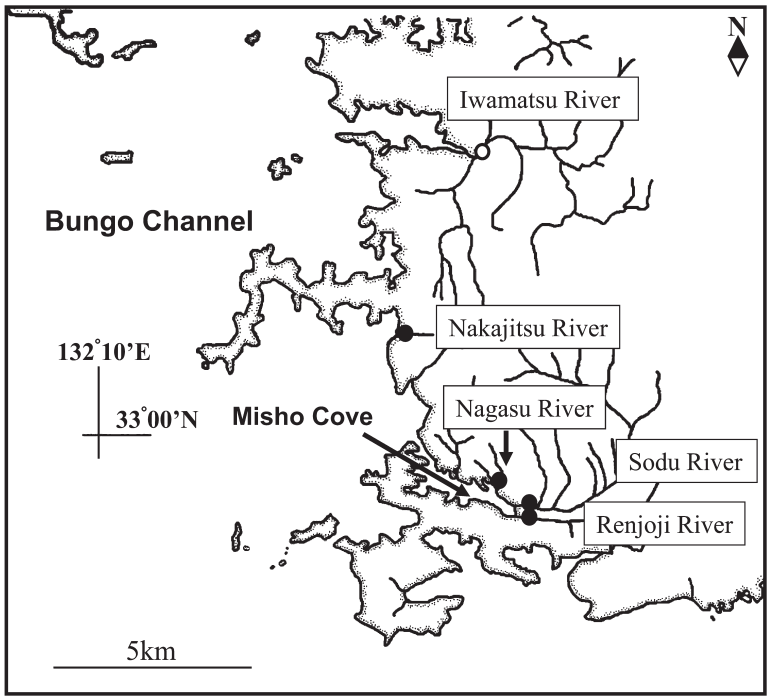

Fig. 1. A map of southwestern Ehime Prefecture, Shikoku Island, showing the sampling sites (closed circles) of *Anguilla marmorata* in the Renjoji, Sodu, Nagasu, and Nakajitsu rivers. The sampling location in the Iwamatsu River, where the species was collected by Ito & Mizuno (1978), is indicated by an open circle.

otoliths.

Since 1997, we have conducted research on the biology of two freshwater eels, *A. marmorata* and the Japanese eel *Anguilla japonica* Temminck & Schlegel, in Ehime Prefecture, Shikoku Island, Japan (Mizuno *et al*., 2000). In this prefecture, *A. marmorata* has been registered as a vulnerable species that is supposed to be facing a high risk of extinction in the wild (Mizuno, 2003). Our data are still quite limited but may be useful for understanding of the biology of *A. marmorata* for its conservation. We herein report that *A. marmorata* occurs in low abundance throughout the year at freshwater sites with emergent plants in the Renjoji River and adjacent rivers, Ehime Prefecture. Ecological aspects of *A. japonica* concurrently occurring with *A. marmorata* will be reported elsewhere.

Materials and Methods

Freshwater eel sampling was conducted with the assistance of a fisherman (Mr. Susumu Takamori) in the lower reach of the Renjoji River (32˚57′N, 132˚33′E at the mouth), Ainan, southern Ehime Prefecture, from July 1997 to March 2010 (Fig. 1). The river is short (3.8 km long), flowing into Misho Cove connected to the Bungo Channel (the western North Pacific Ocean). Two types of fishing gear, eel pots (locally called "unagi-jigoku", 65–80 cm long and 5.0–7.5 cm in diameter) and eel tubes ("korogashi", 100 cm long and 5.0 cm in diameter), were employed to catch eels. The eel pot is a polyvinyl-chloride (PVC) pipe and has a funnel-shaped bamboo cap and a plastic net (mesh size=10 [rarely 5] mm) at the anterior and posterior ends, respectively. The eel tube is also a PVC pipe but has no cover at both ends. Two eel tubes were usually set as a pair. Approximately 10 live freshwater shrimps,

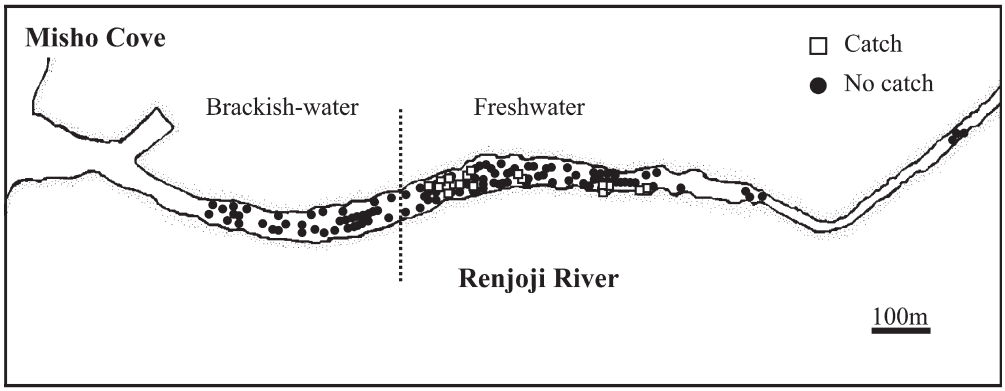

Fig. 2. A map of the lower reach of the Renjoji River, showing the sites where *Anguilla marmorata* was collected (open rectangles) and not collected (closed circles). As the collection sites were often overlapped, the number of open rectangles was fewer than the actual number of catch. Note no collection of *A. marmorata* in the brackish-water region.

such as *Macrobrachium japonicum* (De Haan) and *M. nipponense* (De Haan) (Decapoda, Palaemonidae), were placed in each eel pot, but no bait was used for the eel tubes. Although the number of eel pots used was different between seasons, up to 29 and 23 eel pots were widely set in the brackish-water (*ca* 350–630 m from the mouth) and freshwater regions (*ca* 630–1,650 m from the mouth), respectively (Fig. 2). Similarly, up to 19 and 33 pairs of eel tubes were set in each of these regions. The fishing gear was examined by Mr. S. Takamori for fish entrapment once a day or every two days in the warm-water season (from mid-May to late October) but once a week in other seasons. When *A. marmorata* was trapped, specimens were sent to the senior author (KM) to examine their morphology including total length (TL, cm) measurement. From July 2007 to October 2009, the senior author joined Mr. S. Takamori in fishing once to three times per month to record the number of both *A. marmorata* and *A. japonica* caught and also measured surface water temperature in the freshwater region. In addition, the presence of aquatic plants and animals as possible prey for *A. marmorata* was examined in the freshwater and brackish-water regions. Furthermore, incidental catches of *A. marmorata* in other rivers (Nagasu River, Sodu River, and Nakajitsu River, Fig. 1) adjacent to the Renjoji River were recorded, and the eels caught were measured for TL. Twelve specimens of *A. marmorata* have been deposited in the fish collection at the Tokushima Prefectural Museum, Tokushima, Japan (TKPM-P6359–6363, 13171, 13205, 13608, 13998–13999 from the Renjoji River; TKPM-P6364 from the Sodu River; TKPM-P13607 from the Nakajitsu River).

Results

Occurrence of *Anguilla marmorata* in the Renjoji River

Forty-five specimens of *A. marmorata* were collected in the Renjoji River during a period from July 1997 to March 2010. Of these, 44 fish were trapped with the eel pots and one fish was found dead on March 15, 2010. There was no catch by the eel tubes. The abundance of *A. marmorata* was very low: the number of fish caught per year (1997–2009) ranged from 0 to 11 (mean 3.4) (Table 1). In addition, from July 2007 to October 2009, a marked difference was found in abundance between *A. marmorata* (*N*=1) and *A. japonica* (*N*=74).

Specimens of *Anguilla marmorata* were taken only in the freshwater region (Fig. 2), while those of *A. japonica* were collected in the freshwater and brackish-water regions (*N*=32 and 42, respectively, from July 2007 to October 2009). The sites where *A. marmorata* was caught were mostly covered with emergent plants, such as *Phragmites australis* (Cav.) (Poales, Poaceae)

Table 1. Total length distribution of specimens of *Anguilla marmorata* caught in the Renjoji River, Ehime Prefecture, Japan.

	Total length (cm)									
Year	29 ≤	30–34	35–39	40–44	45–49	50–54	55–59	≥60	unmeasured	Total
1997*			1						10	11
1998*			2			2				4
1999		1	1	1		2				5
2000				1		1	1		1	4
2001										0
2002									1	1
2003									1	1
2004										0
2005									4	4
2006							1		2	3
2007				2	3	1				6
2008					1		1			2
2009						3				3
2010								1**		1
Total	−	1	4	4	4	9	3	1	19	45

* The data for 1997 and 1998 are from Mizuno *et al*. (2000).
** This fish was not trapped but found dead.

Table 2. Monthly changes in number of *Anguilla marmorata* caught with eel pots in the Renjoji River, Ehime Prefecture, Japan.

	Month												
Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1997*							3	3	5				11
1998*						3	1						4
1999							2	3					5
2000								2	2				4
2001													0
2002							1						1
2003								1					1
2004													0
2005						1	3						4
2006						3							3
2007						1	1		3			1	6
2008	2												2
2009						2	1						3
2010			1**										1
Total	2	0	1	0	0	10	12	9	10	0	0	1	45

* The data for 1997 and 1978 are from Mizuno *et al*. (2000).
** This fish was not trapped but found dead.

and *Sparganium japonicum* Rothert (Typhales, Sparganiaceae) (Fig. 3). Near these plants, springwater was also found, and shrimps (*Macrobrachium japonicum* and *M. nipponense*), crabs (*Chiromantes dehaani* (H. Milne Edwards) and *Eriocheir japonicus* (De Haan) [Decapoda, Grapsidae]) and fishes (*Nipponocypris temminckii* (Temminck & Schlegel), *Tribolodon hakonensis* (Günther) [Cypriniformes, Cyprinidae], *Oryzias latipes* (Temminck & Schlegel) [Beloniformes, Adrianichthyidae], *Eleotris oxycephala* Temminck & Schlegel [Perciformes, Eleotridae], *Luciogobius guttatus* Gill, and *Rhinogobius* spp. [Perciformes, Gobiidae]) were abundantly found. The bottom consisted of mud and small pebbles. By contrast, in the brackish-water region where *A. marmorata* was not captured, there were no emergent plants, and the bottom was mainly composed of fist-sized rocks. Some shrimps (*M. japonicum* and *M. nipponense*, and *Palaemon* spp. [Decapoda, Palaemonidae]), crabs (*C. dehaani*, *E. japonicus*, *Hemigrapsus penicillatus* (De Haan), and

Fig. 3. A picture of the lower reach of the Renjoji River, showing the emergent plants covering the sampling location. The picture was taken on April 29, 2009.

H. sanguineus (De Haan) [Decapoda, Grapsidae]), and fishes (*Redigobius bikolanus* (Herre), *Glossogobius olivaceus* (Temminck & Schlegel), *Acanthogobius flavimanus* (Temminck & Schlegel) [Perciformes, Gobiidae]) were less abundantly found.

Most specimens (*N*=41, 93.2%) of *A. marmorata* were trapped from June to September (Table 2). These fish were small, measuring 30.3 to 59.7 (mean 46.9, *N*=25) cm TL (Table 1), whereas one fish found dead on March 15, 2010 was much bigger (113.0 cm TL). There was a seasonal fluctuation in water temperature in the freshwater region of the river: the highest (25.7˚C) and lowest (13.9˚C) temperatures were recorded in July 2008 and March 2009, respectively (Fig. 4).

Occurrence of *Anguilla marmorata* in other rivers

Seven specimens of *A. marmorata* were incidentally captured in three rivers (Nagasu River, Sodu River, Nakajitsu River) near the Renjoji River. Five fish were caught in the Nagasu River (with eel pots): two (41.2 and 57.0 cm TL) and one (36.8 cm TL) were taken in June and July 2007, respectively, and two (38.3 and 54.5 cm TL) were collected in July 2009. Two fish (43.7 and 30.8 cm TL) were each captured in the Sodu River in July 1998 (with an eel pot) and in the Nakajitsu River in July 2001 (with a scoop net). All these fish were caught in the freshwater region (*ca* 500, 1000, and 500 m upstream from the mouth of the three rivers, respectively). The collection sites in the Nagasu and Sodu rivers were covered with emergent plants, like in the Renjoji River, whereas that in the Nakajitsu River was less thickly covered with those plants.

Discussion

Despite an over 14-year survey, only 45 specimens of *Anguilla marmorata* were collected in the Renjoji River: the mean number of eels trapped per year was as low as 3.4. This low abundance of the species can be explained by two possible reasons: small recruitment to the river, and selectivity of fishing gear used (see below). Since the study location is situated as the almost northern limit of the distribution for the species, the abundance of its recruitment is most likely to be low. The species so far has been regarded as being rare in Shikoku Island (Ochiai *et al*., 1979; Mizuno, 2003).

The specimens of *A. marmorata* were mainly caught from June to September in the Renjoji River. The species was also collected in June and July in three other rivers near the Renjoji River. Mizuno & Nagasawa

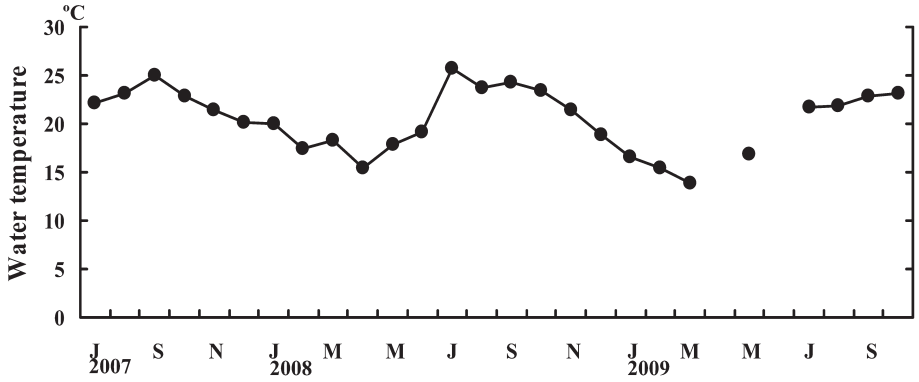

Fig. 4. Monthly changes in surface water temperature in the freshwater lower reach of the Renjoji River from July 2007 to October 2009.

(2009, table 1) reported a similar seasonal catch of the species, based on the data of catches in 10 prefectures in Japan including Ehime Prefecture. These seasonal variations in catch appear to be related to seasonal fluctuations in activity of the species. In the Renjoji River, water temperature was high (up to 25.7˚C) during the summer months, when the species can be more active than in other months. In addition, water temperature remained high (more than 13.9˚C) even in the winter months, which is most probably caused by the presence of springwater. This condition can allow the "tropical" anguillid *A. marmorata* to overwinter in the rivers in southern Shikoku which are located in the temperate region.

In this study, we collected *A. marmorata* in the freshwater region of the Renjoji River and the three adjacent rivers. A similar freshwater residence of the species has been reported from rivers in Taiwan and the Philippines (Shiao *et al*., 2003; Briones *et al*., 2007). We also confirmed that, in the Renjoji River, another anguillid species *A. japonica* was also present and more abundant than *A. marmorata*. Within this river, *A. japonica* was more abundant in the brackish-water region than in the freshwater region. Nishi & Imai (1969) reported that these species segregated their habitats in the Isso River, Yakushima Island, southern Japan. Shiao *et al*. (2003) also found that the two species used different habitats in the same river in Taiwan: *A. marmorata* and *A. japonica* are more abundant in the upper and lower reaches, respectively. From these observations, Shiao *et al*. (2003) suggested that both interspecific competition and adaptive radiation occur between the two species. While Japan is the northernmost distributional area for *A. marmorata*, it may be probable that similar habitat segregation exists between them even in rivers of this country. We need more information on the migratory behaviors, microhabitats, and feeding habits of these species in Japanese rivers.

The specimens of *A. marmorata* captured in the Renjoji River were all small (30.3–59.7 cm TL). This was probably caused by the use of eel pots with short length and small diameter (65–80 cm long and 5.0–7.5 cm wide). In addition, there was no catch of *A. marmorata* by the eel tubes, which may have been partly caused by the fact that no bait was placed in them. A dead specimen of *A. marmorata* measuring 113.0 cm TL was found in the river, which indicates that large-sized eels are present as well. More information on the distribution and abundance of such large eels is necessary based on catches using different types of fishing gear.

The sites where *A. marmorata* was collected in this study were commonly covered with the emergent plants. We think that such sites can provide the eels with excellent habitats for their feeding, because their possible prey (freshwater shrimps, crabs, and fishes) was abundantly found. Freshwater crabs are known to be one of the major prey animals eaten by *A. marmorata* (*e.g*.

Williamson & Boëtius, 1993). Since we have not yet examined the stomach contents of the species in the study area, we need clarify its feeding habits. Also, in order to keep the populations of *A. marmorata* stable in the rivers, it is important to conserve those areas that are covered with emergent plants and abundantly inhabited by decapod crustaceans and fishes.

Acknowledgements

We thank Mr. Susumu Takamori and his family, Ainan, Ehime Prefecture, and Mr. Hirotaka Katahira, Hiroshima University, for assistance in sampling. Thanks also go to Mr. Kiyokazu Hashigoe, Ehime Prefectural Ozu High School for useful information on the vegetation of the Renjoji River. We are grateful to an anonymous reviewer for constructive comments on the manuscript of the paper.

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(Accepted 20 July, 2010)