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The First Tracking Studies on Yellow and Silver Eels *Anguilla japonica* in the Estuarine Habitat

Abstract

The behaviour and movements of yellow and silver phase Japanese eels were firstly studied using acoustic telemetry in the Fukui River estuary and the adjacent waters of Tachibana bay, Tokushima prefecture, Japan, in August and November, 1999. All four yellow eels released at the river mouth in August returned to the river, and moved further upstream making several stops at the same places, or refuges. Each refuge appeared to be repeatedly utilized by all eels examined in the study. The yellow eels spent most of their time in these refuges during daytime and moved predominantly at night. In contrast, a silver eel released in November demonstrated rapid movement towards the sea without stopping after release, while another silver eel showed sedentary behaviour hiding at one of the same refuges used by some of the yellow eels. This study suggested the need to investigate factors to establish the refuge as a hint for effective management of the eel stock. Different behavioural traits observed in the similarly matured silver eels suggested that empirically assumed external sign for spawning migration not strictly represents the spawning migratory phase of the eel.

Key words: Biotelemetry, Estuary, Behaviour, Refuge area, Japanese eel

Behavioural traits of the eels, moving essentially at night and exhibiting cryptic habits during daytime, make them difficult to observe in the wild[1]. Numerous biotelemetric studies on the Atlantic eels, *A. anguilla* and *A. rostrata*, have described their movements in rivers, lakes and tidal creeks[2-6], their time and space utilization in freshwater habitats[2-7] and their movements in coastal areas[8-13]. However, biotelemetric studies on the Japanese eel have been limited to silver eels released in the ocean[14,15]. As a result, knowledge about the movements of Japanese eel in freshwater or estuarine habitats and at the beginning of their spawning migration is very limited, in comparison with the Atlantic anguillid species.

Therefore, we carried out the first tracking experiment on the Japanese eel (yellow and silver phase) in an estuary using ultrasonic telemetry. In this

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paper we present the first data on the estuarine movements of yellow phase Japanese eels, and describe the first observations of silver phase eels released in estuarine habitat.

Materials and Methods

Tracking experiments with yellow eels and silver eels were conducted in the river mouth of the Fukui River and the adjacent waters of Tachibana Bay, Tokushima, Japan, separately in August and November 1999, respectively. The yellow eels used in the present study were captured at the river mouth using eel pots in August 1999, and held for about one week before release (Table 1). The silver eels were collected in October in the Tone river, Chiba prefecture, Japan, at a commercial weir and then transported to the Fukui River after intramuscular injection with a salmon pituitary extract (40 - 80 mg/kg body weight) to further enhance their sexual maturation during the two weeks prior to release (Table 1). All eels collected in the Tone river clearly showed a metallic silver body coloration at the time of capture, which is characteristic of migrating silver eel.

Table 1. The eels used in the study and the tracking duration.

Fish No.	*TL (cm)*	*Sampling date &locality*	*Stage*	*Release date*	*Tracking duration (hours)*
Y1	61.7	Aug.1999 in Fukui River	yellow	24-Aug-99	24
Y2	59.0	Aug. 1999 in Fukui River	yellow	24-Aug-99	38
Y3	64.5	Aug.1999 in Fukui River	yellow	25-Aug-99	60
Y4	58.5	Aug.1999 in Fukui River	yellow	25-Aug-99	53
S2	93.0	Nov. 1999 in Tone River	silver	10-Nov-99	98
S3	89.7	Nov. 1999 in Tone River	silver	11-Nov-99	8
S4	89.5	Nov. 1999 in Tone River	silver	13-Nov-99	1

Activated transmitters were attached surgically using nylon string to the back of the eel in front of the dorsal fin. Release took place about 12 hours later to allow tagged eels to recover from handling stress. The tracking system (VEMCO/Canada) included a depth-decoding ultrasonic receiver, a hydrophone and pressure-sensing acoustic transmitters (9 g weight in air, 16 x 62 mm, frequencies 50.0, 54.5, 60.0, 65.5 kHz, pressure limit 1000 PSI, life capacity 12 days). All eels were released at the same position, about 300 m off the river mouth in an area that is 5 m deep at flood tide (Fig. 1) The tagged eels were followed from an inflatable boat equipped with outboard engine. Swimming depth of the fish and boat's position were manually recorded at intervals of 0.1-4 hours as possible. Only the areas below the second bridge from the mouth of the river were checked for the presence of tagged eels.

Results

Movement patterns of yellow eels

All eels followed in the present study showed the same pattern of movement back to the river. They all then moved further upstream making several stops at the same exact places, even though they were released at different times (Fig. 1). These areas, or refuges, were very limited in size (less than 10 m) and were adjacent to a series of concrete blocks on the shore (100-300 m). The refuges were each utilized by 2-3 of the four individuals that were tracked. The eels generally spent most of their time in these refuges during day time (mostly >10 hours, Fig. 1). Even at night, the eels traveled in a range of only few hundred meters between the refuges, demonstrating predominantly sedentary behaviour (Fig. 2). The activity patterns of the eels showed no relation to tidal rhythms. All eels presumably swam near the bottom, although the transmitters used in the present study were not sensitive enough to detect their swimming depths in shallow waters. Assuming that the eels did not move during the intervals between various position plots, it was clear that the eels only move at night except immediately after release, and exhibit sedentary habits in the refuge areas during daytime (Table 2).

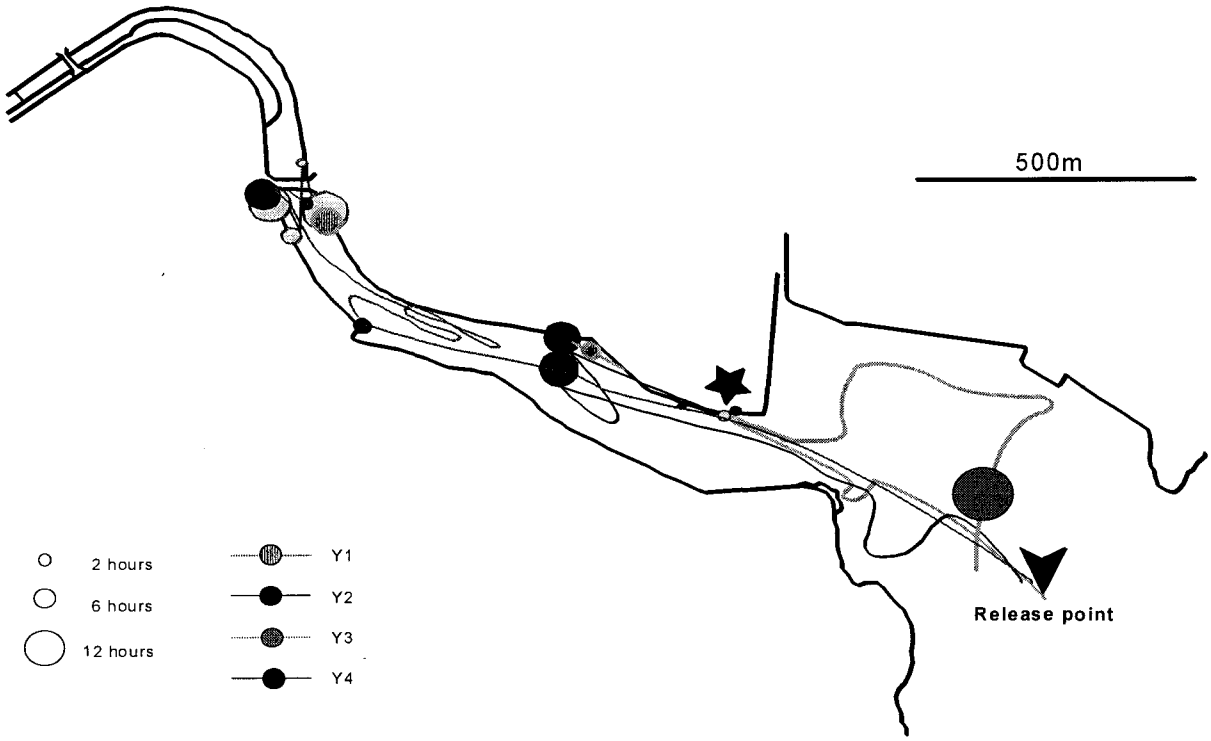

Fig. 1. Horizontal movements of the four yellow eels followed in the present study. Proportion of the circles correspond to the duration that the eel settled.

Table 2. Diel movements of the eels observed in the present study.

	Eel1		*Eel2*			*Eel3*				*Eel4*			
Date&Time	***24***	***25***	***24***	***25***	***26***	***25***	***26***	***27***	***28***	***25***	***26***	***27***	***28***
0:00				*			*					*	
1:00				*			*					*	E
2:00		*		*	*		*	*					
3:00					*			*					
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16:00	*					R				R			
17:00	*		*			*				*			
18:00	*	E	*			*				*			
19:00			*			*				*			
20:00			*			*	*			*	*	*	
21:00			*			*				*	*		
22:00			*			*					*		
23:00			*			*					*		

R: indicates the release, and E the end of experiment.

*: showed hour which apparent movement of the eel was observed.

Movement patterns of silver eels

The silver eel (S2) released on 10 November, initially swam around in the bay near release point, and then went into the river in the same way as the yellow eels in August. This silver eel eventually hid in one of the exact same refuges used briefly by yellow eels (★ in Fig. 1), and remained there until the end of study (the presence of the tagged eel was visually confirmed at the end of the study on 14 November).

The silver eel (S3) that was released on 11 November showed a completely different behaviour from the other silver eel (S2) and the yellow eels in August, and showed a fast movement directly towards the sea without stopping after being released (Fig. 2). In spite of the complicated topography in

the bay as result of construction associated with thermal power stations, the eel swam almost directly towards the mouth of the bay. After moving through the estuary in a northeasterly direction for about three hours after release, the eel suddenly turned south at about 3 km from the release point, despite the fact that continuing on the same direction was the most direct route to the sea (Fig. 2). The eel exhibited back and forth movement in the water between thermal power station and Takashima Island, and took almost three hours to pass about 1.5 km of this area. Then, the eel swam rapidly straight toward the ocean and reached about 13 km off the river mouth (30-35 m in depth) at 23 : 30, only seven and half hours from the release (Fig. 2). Tracking of this eel was abandoned at 23 : 40 due to severe weather conditions. The swimming depth of the eel appeared to be mostly near the bottom (2-35 m).

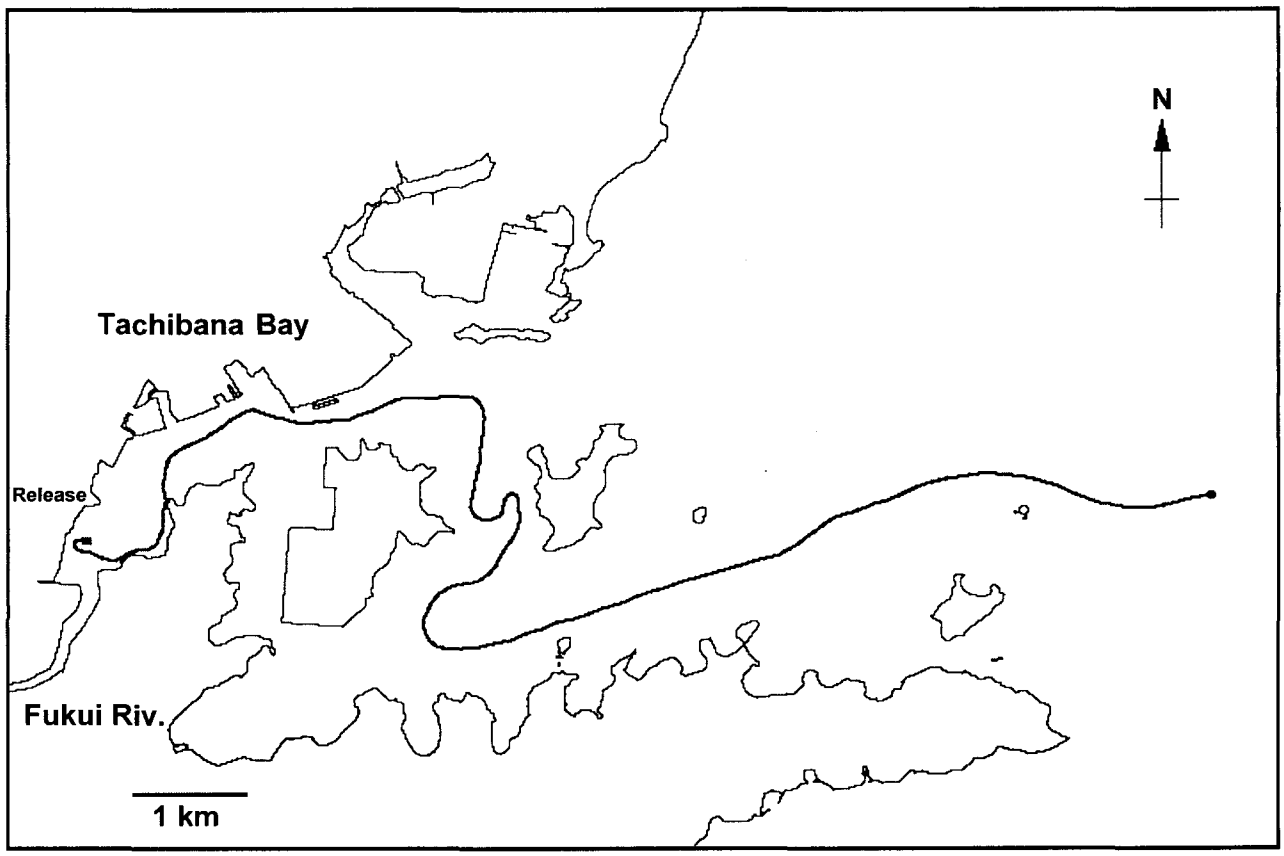

Fig. 2. Horizontal movements of the silver eel (S3).

A third silver eel (S4) was released at 13 : 33 on 13 November, and demonstrated a similar seaward movement to that shown by the silver eel S3. However, the signal was lost after one hour from release and was not subsequently detected in the estuary (not shown).

Discussion

The present study is the first to observe the patterns of movements of yellow phase Japanese eels using telemetry. Even though these yellow eels were presumably highly stressed initially as a result of tagging[2], after the first day of release they showed a similar diel activity pattern to that observed in American and European eels in a variety of freshwater and estuarine habitats[1-3,6-7]. They moved only at night for the most part, and they showed strong tendency to use the same refuge areas during the day. The concept of home range and refuge are often applied to anguillid eels [1-2, 4, 7, 16-18], although the home ranges of the eels during the short tracking duration in the present study were not clearly determined because some of the eels may have moved above of the second bridge, the four narrow areas along the continuous uniform shore protection were clearly suggested to be repeatedly utilized as refuges for the yellow eels after they returned to the river mouth. It is also interesting that the silver eel transported from the Tone river, hid one of the same refuges used by some of the yellow eels collected in the Fukui River. Although characteristics of these areas that attracted the eels was not determined during the present study, it is possible that there is structural habitat such as rocks or debris that provide shelter for hiding, or that these area shave soft mud substrate suitable for burrowing that make these locations good refuges for sedentary eels. In addition, there may be a tendency of eels to congregate in suitable refuge areas due to tactile contact with other eels, because several eels have been observed to squeeze into the same tube even when several tubes are available simultaneously[19]. Detailed behavioral and environmental data is needed to determine what makes these areas preferred habitats for eels.

The yellow eels tracked during this study generally exhibited cryptic habits in the refuge areas during daytime, and then moved to another refuge at night. This suggested that these refuge areas are essential for providing shelter during the day to the eels in this particular estuary and that they may forage during their movements at night. As a result of the recent decline of the eel stock in Japan there is an urgent need for efficient eel fishery management, and information about the habitat use of eels is critical to this effort. Additional information about what factors determine a preferred refuge for eels may enable significant ways to protect or enhance eel stocks to be developed by protecting or constructing suitable refuge habitats for eels.

This is the first report of behaviour of a sexually matured silver phase Japanese eel from the estuary to the open ocean, observed using continuous tracking with ultrasonic telemetry. Silver phase American and European eels have been tracked in various estuarine and marine habitats[1,6,8-9], but the silver phase Japanese eels have only been tracked after being released directly into coastal or open ocean environments[14-15]. The S3 sliver eel during this study showed a strong migratory motivation and moved out of the estuary and bay in a period of less than eight hours, indicating it was probably initiating its marine spawning migration. Some American silver eels have also been tracked from tidal freshwater estuarine habitats and out into the bay over period of several days[1,6], but the track of silver eel S3 that was released in estuarine habitat near the mouth of the river was the first observation of a silver eel that migrated immediately from estuarine habitat and swam out of the bay without stopping.

In tracking studies of silver phase European eels in the Mediterranean, Tesch[10] suggested that the eels swam toward deeper water until about 280 m, which may help explain the route that the S3 sliver eel showed during the present study. Although we could not determine the exact swimming depth of the eel during its seaward migration, the partial depth information obtained from the transmitter suggested

that the eel might have been swimming mostly near the bottom (data not shown) and the course it followed may have been influenced by the location of a shipping channel. The eel made a sudden turn to the south despite the fact that continuing to swim in an eastward direction was the most direct route out of the estuary. The waters between the thermal power station and Takashima Island, where the eel turned irregularly and the area to the south of Takashima Island are sometimes artificially dredged to enable large container ships to reach the pier of the power plant (Kusaka unpubl.). It is possible that the eel swam along the bottom from the releasing point searching for deeper water, and found the deeper dredged area at the mouth of the bay and then turned and followed the general path of the shipping channel out into the bay after some exploratory movements around the channel. One of the other silver eels tracked during this study showed a similar pattern of apparent migratory motivation, but it was lost after one hour of swimming towards the mouth of the estuary.

In contrast, the S2 silver eel demonstrated a pattern more similar to the four yellow eels and swam back into the estuary and settled one of the refuges used by the yellow eels. It is unclear why this particular silver eel behaved differently than the other two, but all the silver eels used in the present study were treated similarly after being collected in the Tone River and had been injected with hormones to artificially induce sexual maturation (GSI 3.9 obtained from other specimens processed similarly). However, it is possible that the eel that did not migrate was at an earlier stage of maturation that was not reflected by its silver coloration or it was more affected by the stress of the tagging procedure, or from the osmotic stress of being transferred from freshwater to partial seawater at the estuarine release site. Although it moved to one of the refuges used by some of the yellow eels, it did not show additional movement to any of the other refuges as did the yellow eels.

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