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静岡県の小河川下流部で採集された黄ウナギ期のニホンウナギは、どのような筒を選択するか？

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Pipe choice by yellow eel stage of *Anguilla japonica* collected in the lower reaches of small rivers in Shizuoka Prefecture, Japan

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Abstract

Rearing experiments to investigate nest choice of yellow eel stage of *Anguilla japonica* collected in the lower reaches of the Shinkawa and Ohashi Rivers, Shizuoka, Japan, showed many individuals may prefer the longest available pipes. Most eels tried the several pipes and chose to stay with the head around the tip of the longer pipe than the individual length. The pipe length/eel total length was significantly larger in first chosen pipes than the second, and that of the second chosen pipe was significantly larger than no chosen pipes. A pipe diameter choice experiment showed that the individuals ＞20mm in body depth（＞*ca.*500mmTL）chose pipe diameters without tendency, while smaller individuals（＜20mm in body depth）never chose pipes larger than 3 times of their body depth, but chose pipes twice of body depth frequently. Nest diameter choice is thought to be essential for small individuals. It is suggested that nest preference thereafter might vary with growth due to competition and predation pressures changing. Artificial enhancement of microhabitat in the lower reaches, utilizing pipes of sufficient length and various diameters as shelters, should permit a free movement and residence of yellow eels, possibly resulting in an increase in individual numbers in suitable riverine systems for eel.

Keywords: *Anguilla japonica*; microhabitat choice; nest length; nest diameter; shelter

INTRODUCTION

Adaptation to different environments is a life history requirement for eels, which spawn and occupy their leptocephalus stage in the ocean, and subsequently metamorphose to glass eels when approaching the shore before attaining yellow eel in onshore or river habitats（*e.g.*, van Ginneken & Maes, 2005; Tsukamoto, 2006a, 2006b, 2009）. Commercial eel catches have progressively decreased in various parts of the world, eel populations currently being considered as severely damaged in Asia, America and Europe（Moriarty, 1990; Dekker, 2003; Geer, 2003; Han & Tzeng, 2006）. This has apparently resulted from chemical pollution, global climate change, overfishing, habitat degradation, or a combination of these（Knights, 2003; Åstrom & Dekker, 2007; Belpaire & Goemans, 2007; Bonhommeau *et al.*, 2008; McHugh *et al.*, 2010）. In particular, habitat conditions for yellow eel have drastically changed in recent years due to shallow sea reclamation, river improvements, and construction of hydro power generation complexes and dams（Machut *et al.*, 2007; McCarthy *et al.*, 2008）.

Studies on spawning areas, migration routes and aquaculture of the Japanese eel *Anguilla japonica* Temminck et Schlegel have revealed considerable information（Aida & Tsukamoto, 1999; Tsukamoto, 2006a, 2006b; Sekine, 2010）, although the ecology of the yellow eel stage has not been well studied in Japan because of the lower commercial value compared with the mass cultivation of glass eels. Tatsukawa & Matsumiya（1999）stated concerns about recent reductions in number of *A. japonica*, and the lack of ongoing and proposed future assessments, despite the importance of the species as a sustainable

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resource in Japan. Further ecological and behavioural studies on the Japanese yellow eel are clearly necessary for future resource conservation and environmental maintenance planning.

The yellow eel is known to hide itself in cracks or holes in riverbanks or mud during daytime and actively seek prey at night. The glass eel stage is also nocturnal (Dou & Tsukamoto, 2003). A diverse range of gear utilizing this habit has been developed for catching yellow eel in various districts in Japan. Uke, a pipe trap with a funnel-shaped, woven bamboo entrance, is commonly used. Angling of eel in cracks and holes is also popular and is, in fact, responsible for the greatest catches. Both methods have been used for generations. However, the relationship between ecology and eel behavior, and the gear and methods used for eel fishing has been hardly studied. During early studies of Japanese yellow eel microhabitat, Watanabe & Nishi (1969) and Watanabe *et al.*, (1969) observed and analyzed the usage of pipes, reporting an eel preference for coarse black pipes. More recently, Aoyama *et al.* (2005) reported on eel nest morphology in the mud substrate of tidal drainage channels, the maximum tunnel depths and diameters being from 17.8-30.0 cm and 1.2 to 7.9 cm, respectively. Clarification of artificial microhabitat choice, in addition to natural habitat nest morphology, should provide a sufficient understanding of microhabitat and nest preferences of yellow eel essential for continued environmental maintenance and resource conservation, especially in the face of human-induced river modifications.

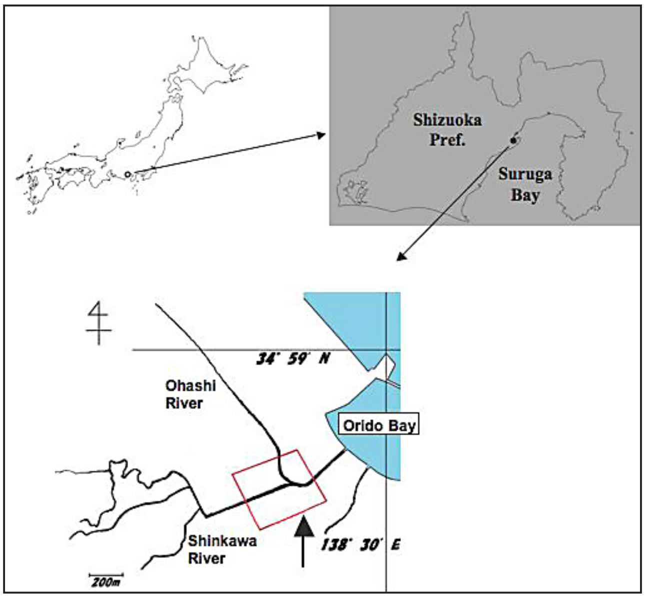

Fig. 1 Map showing sampling area in the Shinkawa and Ohashi Rivers, Shizuoka city, Japan.

MATERIALS AND METHODS

Individuals of Japanese yellow eel were collected from a sampling area including the junction of the Ohashi (total length 2.8km) and Shinkawa Rivers, Shimizu-ku, Shizuoka city, Shizuoka, Japan (Fig. 1). The Shinkawa River (3.3km long) originates at Nihondaira, becoming confluent with the Ohashi River 450m before the river mouth in Orido Bay. The salinity of the collecting site varied from 0 at low tide to *ca.*30 at high tide. The individuals were collected at low tide. The river width at the sampling site was ca. 8m, both banks (reinforced by concrete) being lined with houses, factories, farms and roads. The both sides of the river were strengthened by concrete and the river bottom was covered with sand, gravel and pebbles. There seems not many of nests or shelters for eel except some crevices between concrete walls and the bottom. Because there has been no established eel fishery and no record of deliberate eel releases in these rivers, only naturally-occurring upstreamers could be collected. Hollow bamboo (*Phyllostachys pubescens or P. bambusoides*) tubes (1200mm long, 32-63mm inside diameter), burned and soaked in water for one month according to a traditional method, were bound in pairs as traps, many being set in the sampling area.

Captured individuals were reared in a round polycarbonate tank (150cm in diameter, 70cm height, 40cm water depth), in fresh water being maintained at 24 ± 1℃ with two thermostatically-controlled heaters. The eel were fed with fishes (*Plecoglossus altivelis altivelis, Zakko platypus, Chaenogobius urotaenia, Rhinogobius spp., Mugil cephalus cephalus, Tribolodon hakonennsis, Phoxinus lagowskii steindachneri and Carassius gibelio langsdorfi*) and shrimps (*Macrobrachium nipponennse*) collected in the Sinkawa River, and with cultured earthworms.

Two laboratory experiments were conducted during daylight in a 300L acrylic aquarium (60 x 90 x 20cm water depth) with circulating filtrated fresh water; pipe length choice (experiment A-1, A-2) and pipe diameter choice (experiment B-1, B-2) , both being conducted for each individual eel. In a preliminary experiment, individuals were observed to enter and exit the pipes repeatedly for up to one hour, before settling in a chosen pipe. Accordingly, an acclimation time of one hour was set for each experiment and a pipe recorded as "chosen" and removed to finish the first choice if an eel remained inside for 30 min. In cases of less than 30 min settlement only observed during a 2-hour period, the experiment was recorded as "no choice made" .

Fourteen individuals captured in 2004 were used in

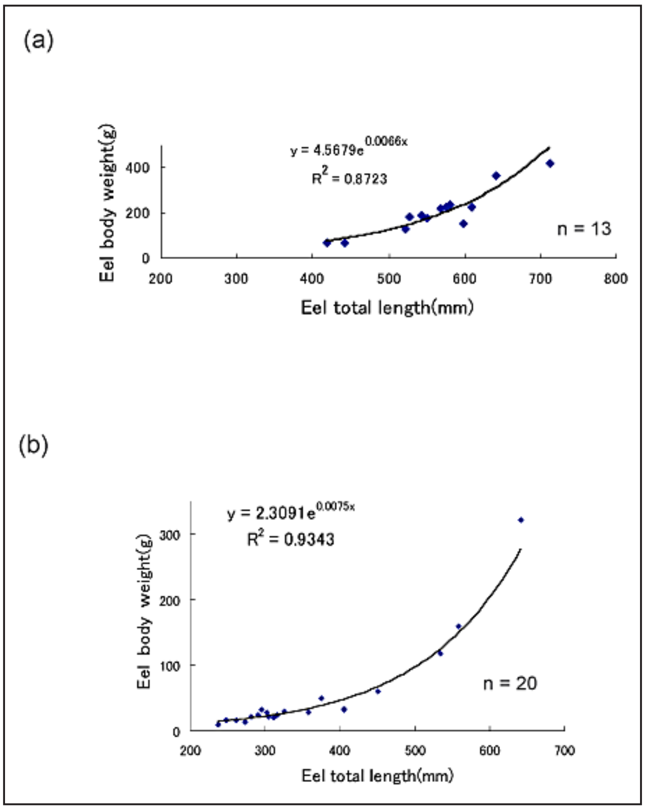

Fig. 2 a) Total length and body weight of *Anguilla japonica* collected in the Shinkawa and Ohashi Rivers in 2004 and used in Experiment A-1 (n=13, Y=4.5679e$^{0.0066x}$, R^2=0.87). b) Total length and body weight of *Anguilla japonica* collected in the Shinkawa and Ohashi Rivers in 2010 and used in Experiment A-2 (n=20, Y=2.3091e$^{0.0075x}$, R^2=0.93).

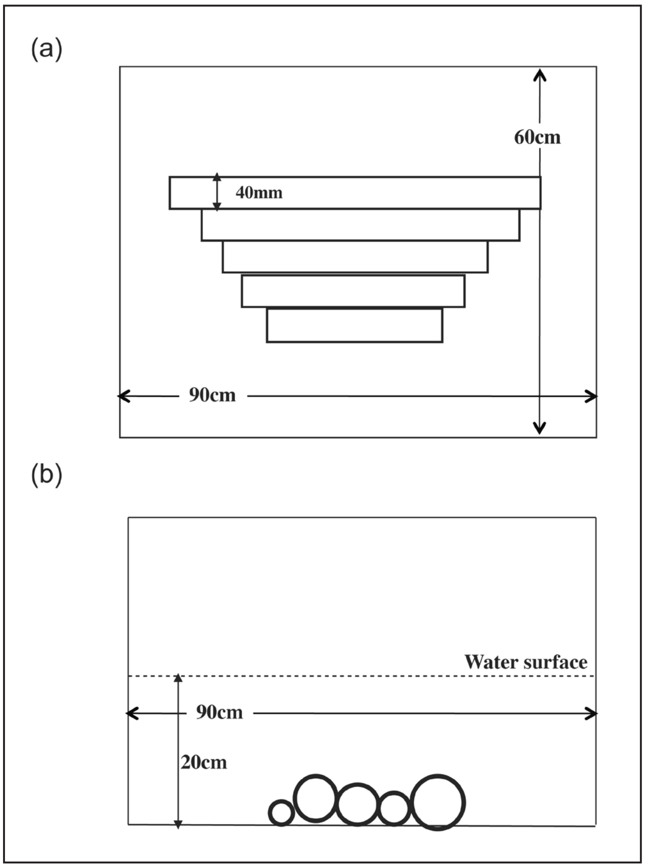

Fig. 3 a) Pipe arrangement plan in the aquarium of pipe length choice experiment A-1 (top view). b) Pipe arrangement plan in the aquarium of pipe diameter choice experiment B-1 (lateral view). Pipe arrangement was changed for each individual eel.

experiment A-1 and B-1, 12 small eel in 2005 in B-2, and 20 in 2009 and 2010 in A-2. Each was measured [total length (TL), body depth (BD)] to the nearest millimeter and body mass (BW) determined to 1g. The total length (419-712 mmTL) and body weight (66-422 gBW) of 14 individuals captured in 2004 are shown in Fig. 2.

Experiment A-1; 13 individuals were examined for pipe length choice in November and December 2004. Five polyvinyl chloride (pvc) pipes of inside diameter 40mm and lengths of 300, 400, 500, 600 and 700mm, respectively, were randomly placed parallel to each other in the center of the aquarium (Fig. 3a). Each eel was introduced to the aquarium one by one, and their pipe selection recorded as described above. After each trial, the pipe positions were changed randomly before the experiment was repeated with the next eel.

Experiment A-2; 20 individuals were examined in different three size groups in May and June 2010 for pipe length choice in the same procedure with different three diameter pipes; (a) Five pvc pipes of inside diameter 40mm and lengths of 300, 400, 500, 600 and 700mm, respectively, were tested for each of 5 individuals (405-642 mmTL). (b) Five pvc pipes of inside diameter 25mm and lengths of 200, 300, 400, 500 and 600mm were examined for each of 10 individuals (248-405 mmTL) including one eel used in (a) of no choice. (c) Five pvc pipes of inside diameter 15mm and lengths of 200, 250, 350, 450 and 550mm were tested for each of 7 individuals (237-320 mmTL) including one eel used in (b) of no choice. Thus total sample number is different from 20.

Experiment B-1; the same 13 individuals with used in A-1 were examined for pipe diameter choice in November and December 2004. Five pvc pipes of length 450mm and inside diameters of 25, 30, 40, 50 and 65mm, respectively, were randomly placed parallel to each other in the center of the aquarium (Fig. 3b). The first and second choices for each 14 individuals were recorded following the same procedure as in experiment A.

Experiment B-2; 12 smaller individuals (<20mm in body depth) captured in 2005 were examined for pipe diameter choice from September to November 2005 in the same procedure as B-1, utilizing five pvc pipes of length 450mm, inside diameters of 16, 20, 25, 30 and 40mm.

In statistic analysis, χ^2 test for goodness of fit was used to examine the significance of the choosiness on pipe length for eels. The pipe length/eel total length was calculated for the first, the second and no chosen pipes. Those were compared by *U* test.

RESULTS

PREFERRED NEST LENGTH

In experiment A-1, 11 (84.6%) of 13 large individuals (419-712 mmTL) chose the longest pipe (700mm), the remaining two (527, 609mmTL) choosing the second longest pipe (600mm), as first choice (Fig. 4). The choosiness for pipe length among five pipes was significant (χ^2 test for goodness of fit, $n = 13$, $df = 4$, $\chi^2 = 35.1$, $p < 0.001$). However, a significant relationship between eel total length and first choice pipe length was not found ($n = 13$, $R^2 = 0.0002$). Eight of 13 individuals initially chose the longest pipe and secondarily, the second longest pipe. Only two individuals (568, 581mmTL) chose the much shorter (400mm) pipe than eel body length as the second choice. The shortest (300mm) pipe was passed through but never chosen.

In experiment A-2a (inside diameter, 40mm), three of five large individuals chose the longest 700mm pipe initially and the second longest 600mm pipe secondly (Fig. 5a). The choosiness for the first choice pipe length was significant (χ^2 test for goodness of fit, $n = 3$, $df = 4$, $\chi^2 = 12.0$, $p < 0.05$). The remaining two (405mm, 534mmTL) showed no choice. The shortest (405mm) eel was also used for experiment A-2b (inside diameter, 25mm), choosing the 400mm pipe initially and the longest 600mm pipe secondly.

In A-2b experiment, six of 10 individuals (248-405 mmTL) chose the longest 600mm pipe and three chose 400mm pipe initially (Fig. 5b) . The choosiness for the first choice pipe length was significant (χ^2 test for goodness of fit, $n = 9$, $df = 4$, $\chi^2 = 16.0$, $p < 0.005$). Only one individual (311mmTL) chose the 200mm pipe (much shorter than eel body length) as the second choice. The shortest individual (248mmTL) showed no choice and was also used for experiment A-2c. It chose the longest pipe initially and the third longest pipe secondly.

In A-2c experiment, four of seven individuals chose the longest 550mm pipe and two chose 450mm pipe and one

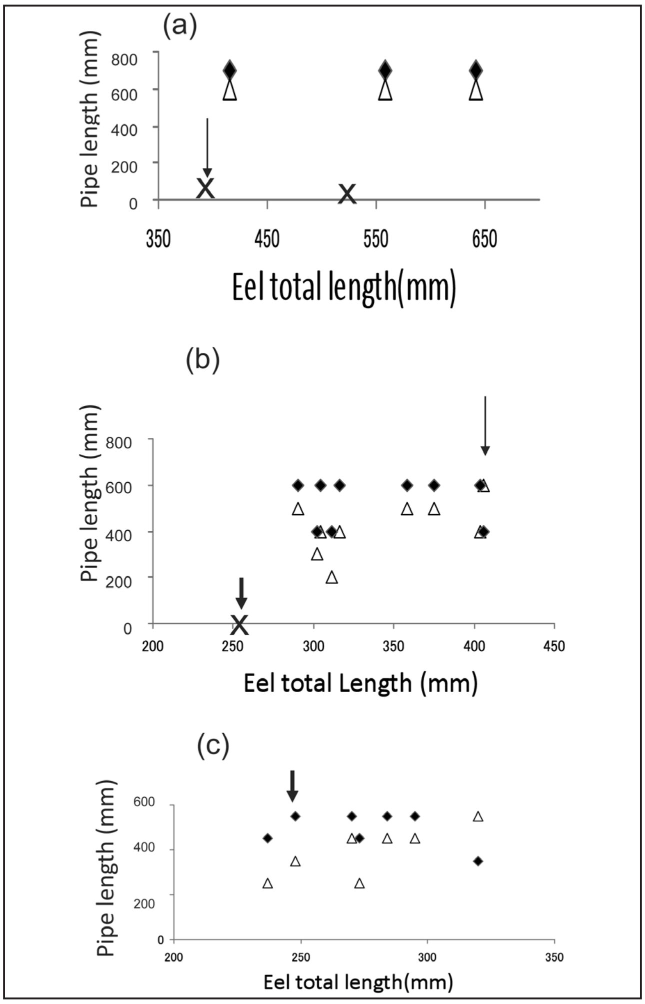

Fig. 5 Total length of *Anguilla japonica* and pipe lengths of first (◆) and second choices (△) in experiment A-2. X indicates an individual which showed no choice of pipes. a) $n = 5$ (two individuals, no choice), among 300, 400, 500, 600, 700mm long pipes of 40mm inside diameter, b) $n = 10$ (one individual, no choice) among 300, 400, 500, 600mm long pipes of 25mm inside diameter, c) $n = 7$ among 200, 250, 350, 450, 550 mm long pipes of 15mm inside diameter. A long arrow indicates the eel 405mmTL which showed no choice in experiment A-1a but chose the pipes in experiment A-2b. A short arrow indicates the eel 248mmTL which showed no choice in experiment A-2b but chose the pipes in experiment A-2c.

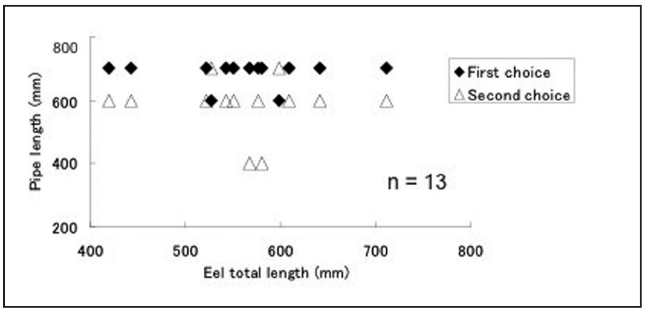

Fig. 4 Total length of *Anguilla japonica* and pipe lengths of first (◆) and second choices (△) among 300, 400, 500, 600, 700mm length pipes in experiment A-1 ($n = 13$).

chose 350mm initially (Fig. 5c). The choosiness for the first choice pipe length was not significant for small eels (χ^2 test for goodness of fit, $n=7$, $df=4$, $\chi^2=8.0$, $p>0.05$). One individual (273mmTL) chose the 250mm pipe (shorter than eel body length) as the second choice. All individuals made a definite choice among five pipes in this experiment.

Only one of 20 individuals chose the shorter pipe than itself as the first choice, and that pipe was 5mm shorter than the eel itself. Accordingly it is suggested that eel chooses the longer pipes than itself generally. In pipes, individual eel usually observed settling with the head at the tip of the pipe (body completely hidden) or occasionally with the anterior half of the head protruding.

The pipe length/eel total length (PL/TL ratio) was calculated for the first, second and no chosen pipes, respectively. PL/TL ratio ranges 0.98–1.67, mean ± SD = 1.24 ± 0.20 for the first choice (n = 13), 0.84–1.43, 1.06 ± 0.23 for the second choice (n = 13), 0.42–1.19, 0.74 ± 0.20 for no chosen pipes (n = 39) in A-1. PL/TL ratio of the first and second choice pipes were significantly larger than those of no chosen pipes ($U=12$ and 77, $P<0.05$). In A-2, PL/TL ratio ranges 0.92–2.22, 1.59 ± 0.41, n = 19 for the first choice, 0.64–1.72, 1.29 ± 0.31, n = 19 for the second choice, and 0.49–2.32, 1.03 ± 0.45, n = 57 for no chosen pipes. One individual showed no choice was excluded and three size classes were added. They were significantly different each other ($U=102.5$ between the first and the second, $U=300$ between the second and no chosen, $P<0.05$ in both).

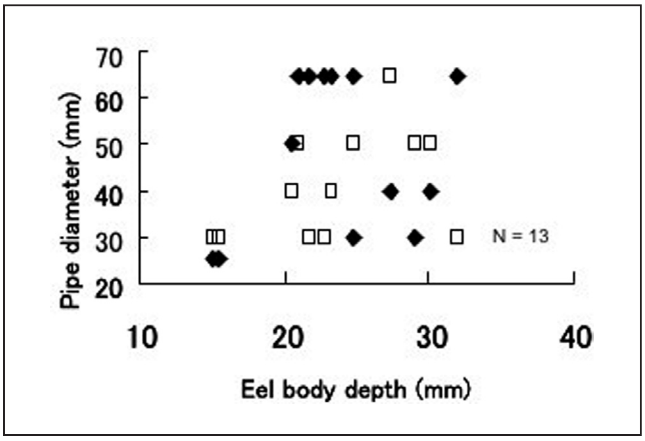

Fig. 6 Body depth of *Anguilla japonica* and pipe diameters of first (◆) and second choices (□) among pipes of 25, 30, 40, 50, 65mm inside diameter in experiment B-1 ($n=13$).

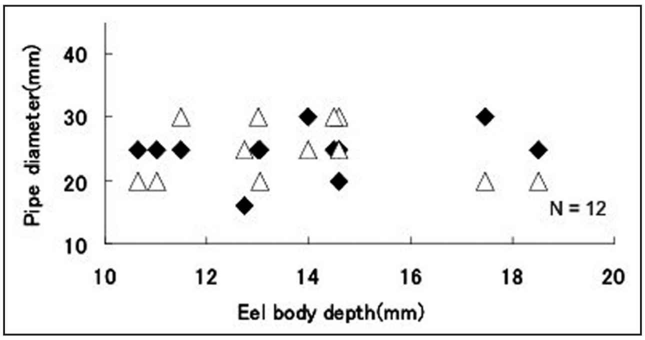

Fig. 7 Body depth of small *Anguilla japonica* (<20mm in body depth) and pipe diameters of first (◆) and second choices (△) among pipes of 16, 20, 25, 30, 40mm inside diameter in experiment B-2 ($n=12$).

PREFERRED NEST DIAMETER

In experiment B-1, 11 of 13 individuals greater than 20mm body depth chose a variety of pipes with no tendency for pipe diameter choice, there being no significant correlation between body depth and pipe diameter (Fig. 6). However, the two smallest eel (443mmTL, 15.5mmBD; 419mmTL, 15mmBD) chose the smallest pipe (25mm inside diameter) initially and the 30mm pipe secondly. They passed through the larger pipes repeatedly but never to settle in them.

In experiment B-2, 12 individuals less than 20mm in body depth never chose the largest pipe (40mm inside diameter), either as first or second choice (Fig. 7). However, they chose a variety of pipes (16, 20, 25 and 30mm inside diameter), regardless of their body depth.

DISCUSSION

Many individuals chose the longest pipe as their first or second choice, regardless of their total length (Fig. 3, 4). Watanabe & Nishi (1969) suggested that eel nests must necessarily be dark. However, in this study we noted that each eel positioned its head just under or slightly projecting from the tip of the pipe, even if the latter was much longer than the eel body. Such positioning has been suggested as readiness for both predatory and escaping behavior. Dou & Tsukamoto (2003) noted that glass eels buried themselves in the substrate or stayed in tubes immediately after sudden illumination. Yellow eels in this study also hid their entire body by choosing much larger pipes during daylight hours. The examination of nest burrows in a muddy substrate (Aoyama *et al.*, 2005) found the burrow distance to range between 44.5–98.5cm for 563 and 625mmTL eel, such burrow length almost completely guaranteeing full daytime shelter.

The mechanism of pipe diameter choice was not so simple as for pipe length choice. Comparatively large individuals (>20mmBD) chose 30–65 mm inside diameter pipes randomly (Fig. 6). It is of interest to note that a traditional Japanese eel trapping method which is called ‘Ishiguro’, involves a structure composed of flat stones on the riverbed, within which a number of eels congregate.

Similarly, commercially-sized yellow eels are also known to shelter in the interstices of aggregated stone structures. These may serve as resting places for conserving energy while swimming upstream, in addition to being shelters against predation.

The comparatively large individuals were observed to settle non-aggressively in the same large pipe in the aquarium, whereas smaller individuals stayed solitarily in each pipe or in the substrate, apparently to reduce competition against conspecifics. We often observed that smaller individuals initially competed for pipes. Similarly, young perch interact aggressively for shelters (Mikheev *et al.*, 2005), although the number of interactions between round goby shelter residents and intruders are most frequent when both are of large size (Stammler & Corkum, 2005). Such difference probably results from differential nest functions, providing shelter from predators or for parental care. Declining predation pressure with eel growth may be the reason for similarly declining intraspecific competition for shelters.

The 13 smaller individuals (＜20mmBD) chose pipes of 16-30mm inside diameter, approximately twice their own body depth. In experiments A-2a and A-2b, the shortest individuals (405mmTL, 12.5mmBD and 248mmTL, 8.5mmBD, respectively) chose pipes of 25mmϕ and 15mmϕ, respectively. Individuals less than 20mmBD did not choose pipes＞2.9 times their own body depth, preferring ca. twice body depth. It is likely that too large pipes would be too difficult to guard from larger conspecifics, small eel strategy being to monopolize a suitable diameter pipe as a refuge.

Possible predators of small eels include the river cormorant *Phalacrocorax carbo,* which was often observed feeding in the Shinkawa and Ohashi Rivers. Sato (1988) reported that a river cormorant could take prey less than 500g and shorter than 30cm. Because eel of 300mm TL weigh much less than 100g (Fig. 2b), it is likely that river cormorants can take individuals longer than 30cm. In this study, an eel body depth of 20mm (ca.500mmTL and 150g in body mass from Fig. 2) appeared to represent a threshold for microhabitat selection. Consequently, larger eels can most likely avoid predation from river cormorants, in addition to seagulls, and other birds and mammals considered to be predators of small eels. In small rivers, such as the Shinkawa and Ohashi Rivers, where few natural predators occur, individual eel larger than 20mmBD are likely to have low predation pressure. However, smaller eel would require a large number of suitable nests. Clearly, the addition of artificial microhabitat in the form of enough length and various caliber pipes in estuarine and lower river reach habitats would enable greater freedom of movement of smaller eels and may enhance eel population growth.

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要　旨

静岡県の新川・大橋川下流で採集された、黄ウナギ期のニホンウナギ *Anguilla japonica* による巣の選択について調べるために飼育実験を行った。多くの個体が、利用できるなかでも最長の筒を好んだ。大半の個体はいくつかの筒を試した後、自分の全長より長い筒を選んで入り、筒の端近くに頭部を置いて留まった。筒の内径選択実験では、体高が20mm より高い個体（全長約500mm より大）は内径選択がばらばらであったが、体高20mm 以下の個体では、体高の３倍より大きな内径の筒は選択せず、体高の２倍程度の内径の筒をよく選択した。このことから巣の内径選択は小型個体にとっては重要と示唆された。また、ニホンウナギの巣の選好性は、種内競争と捕食圧が変化することによって、成長とともに変わるのではないかと考えられた。シェルターとして十分な長さと様々な内径の筒を用いて、河川における黄ウナギに適したマイクロハビタットとして、特に下流部において人工的な巣穴などの充実を図れば、ウナギが自由に行き来したり滞在することができて、個体数の増加に繋がるかもしれない。