

Fish-egg predation by the small clingfish *Pherallodichthys meshimaensis* (Gobiesocidae) on the shallow reefs of Kuchierabu-jima Island, southern Japan

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Synopsis

We observed predation of demersal fish eggs by the clingfish *Pherallodichthys meshimaensis* on the shallow reefs of Kuchierabu-jima Island, southern Japan. The processes of egg predation varied with the target species. For targeting of eggs of the combtooth blenny *Istiblennius edentulus*, up to 65 individuals of the clingfish gathered around the *I. edentulus* nest hole. Some individuals succeeded in intruding into the hole and fed on eggs while the egg-guarding male of *I. edentulus* temporarily left the nest. For targeting of eggs of the triplefin blenny *Helcogramma obtusirostris*, solitary clingfish individuals closely approached spawning females of *H. obtusirostris* at nests on open surfaces of rocks. Most clingfish contained only fish eggs in their diets, and these fish-egg eaters had larger body sizes than individuals that mainly fed on harpacticoid crustacea. Thus, *P. meshimaensis* may change its feeding habits when growing to an obligate fish-egg eater targeting demersal egg spawners.

Introduction

Clingfishes (Gobiesocidae) occur widely in temperate and tropical waters of the Atlantic, Indian and Pacific Oceans, and include 36 genera with 120 species (Briggs 1955, Nelson 1994). Almost all species are less than 100 mm, and often inhabit intertidal or subtidal reefs (Gonçalves et al. 1996, 2002, Patzner 1999, Hofrichter & Patzner 2000). Clingfishes have a sucking disk modified from pelvic fins that enables them to adhere to the reef substrate, even in turbulent waters (Hofrichter & Patzner 2000). Most species have been reported to feed on zooplankton or benthic animals (Gould 1965, Wells 1979, Sakashita 1992, Prochazka 1998).

Pherallodichthys meshimaensis is a small clingfish (maximum 30 mm in total length, TL) that

occurs in shallow waters over boulders and rocky areas and on the coral reefs of southern Japan (Shiogaki & Dotsu 1983). During our preliminary observations in coastal waters around Kuchierabu-jima Island, *P. meshimaensis* often occurred on reefs below 10 m, which are sympatrically inhabited by blenniid and tripterygiid fishes, as has been widely reported for many other clingfishes (Wells 1979, Willis & Roberts 1996, Prochazka 1998). We observed that *P. meshimaensis* fed on the eggs of these fishes.

Fish eggs are potentially nutritious food resources. However, obligate fish-egg eaters have been reported to be restricted to fishes of freshwater habitats, e.g., African cichlids and spiny eels (Wilhelm 1980, McKaye & Kocher 1983, Ochi et al. 1999). There have been no descriptions of obligate fish-egg eaters among reef fishes, although

fish eggs have been confirmed in the diets of planktivorous or omnivorous fishes (i.e. facultative fish-egg eaters) (e.g., Hiatt & Strasburg 1960, Randall 1967, Hobson 1974, Sano et al. 1984, Ochi 1985, Moyer 1987, Sakai & Kohda 1995). In the present study, we report the unique feeding habits of *P. meshimaensis* as an obligate fish-egg eater using data from diet analyses and observation of the foraging behavior on the shallow reefs of Kuchierabu-jima Island.

Materials and methods

We conducted a field study on the reefs of Kuchierabu-jima Island (30°28' N, 130°11' E), southward of Kyushu Island, Japan. The Island fronts onto the Kuroshio Current, is situated within a subtropical region and maintains over 200 fish species on its reefs (Gushima & Murakami 1976).

On the reefs of Kuchierabu-jima Island, *P. meshimaensis* were usually found on the surfaces of rocks or dead corals covered with algal mats, or inside narrow spaces between boulders. We set up behavioral observation areas at two large rocks on reefs in Nishiura Bay (rock I, 5 m width and 2.5 m height; rock II, 4 m width and 3.0 m height). These rocks were situated ca. 10 m from the beach, and were ca. 120 m apart from each other. The surfaces of these rocks were mostly covered with algal mats, and many cracks were present on the tops. Holes abraded by sea urchins and *Barbatia* clam colonies were present around the lateral sides of the rocks.

We focally observed the feeding behavior of *P. meshimaensis* at a nest hole (nest A) of *Istiblennius edentulus* (Blenniidae) on rock I during September 2002. Underwater observation was maintained for 1–3 h during the daytime (08:00–18:00) each day using a snorkel (960 min total observation). The sex of *I. edentulus* was distinguished using the sexually dimorphic body colors described in Aizawa (2002). A male of *I. edentulus* (120 mm in TL) guarded the eggs inside the nest hole (entrance diameter 3 cm × 11 cm, inside length 8 cm), located in the middle of rock I. The eggs of *I. edentulus* were laid in dense layers on the inner rocky surface of the nest as reported for congeneric species (Sunobe et al. 1995). We recorded the behavioral patterns of both *P. meshimaensis* and

I. edentulus over time, during the process of egg predation. To analyze the diurnal patterns of the predatory behavior, we counted the number of *P. meshimaensis* individuals near nest A every 30 min during the daytime in August 2001 (n = 76, random sampling data over 13 days), and compared the data between the morning (5:30–11:30) and afternoon (12:00–18:30) periods. We counted the number of *P. meshimaensis* individuals gathering in front of nest A and four other neighboring nests of *I. edentulus* during August–September 2001 (random sampling data, n = 10–76 at each hole).

We also observed the egg predation by *P. meshimaensis* at mating nests of *Helcogramma obtusirostris* (Tripterygiidae) on rock II. The sex of the triplefin blenny was distinguished using the sexual dimorphism in body colors described in Hayashi (2002). Males of *H. obtusirostris* establish mating nests on the algal turf of open rocky surfaces where females visit to spawn demersal eggs during the morning (H. Takeda, personal communication). The eggs of *H. obtusirostris* were attached with twiny algae. We observed 13 nests (males of 19–27 mm in TL) during the morning period (7:30–10:30) from September to October 2002, using a snorkel. When we found *P. meshimaensis* around the nest, we recorded the behavior of *P. meshimaensis* and *H. obtusirostris* over time (n = 36 individual appearances in 19 days).

To analyze the diets of *P. meshimaensis*, we randomly sampled 99 individuals of *P. meshimaensis* on reefs at a depth of 0.1–2.8 m in Nishiura Bay and Honmura Bay (ca. 16 km from Nishiura Bay along the shoreline), using hand nets and anesthesia (1% quinaldine dilution) during the daytime (7:00–19:30) from May to October 2002. We conducted focal sampling of 26 other individuals just after confirmation of their feeding behavior on rock I. These samples were immediately fixed by immersion in and abdomen injection of 10% formalin dilution. We measured the TL and mouth width of each individual. We identified food items in the gut and counted the number of each item using a microscope. The occurrence ratio (%) of clingfish individuals that fed on the food item was then calculated.

Pherallodichthys meshimaensis spawns eggs on rock surfaces or the shell surface of colonial *Barbatia* clams within cracks, crevices or holes (S. Hirayama, unpublished data). We collected

Table 1. Comparisons of gut contents between two body size categories of *Pherallodichthys meshimaensis* on the reefs of Kuchierabujima Island. Empty diet individuals were omitted from the data (n = 41).

Food items	All sizes (n = 84)		Smaller half (9.3–17.3 mm in TL; n = 42)		Larger half (17.3–24.8 mm in TL; n = 42)	
	Occurrence (% fishes)	Item no.	Occurrence (% fishes)	Item no.	Occurrence (% fishes)	Item no.
Harpacticoid copepoda	42.9	541	76.2	535	9.5	6
Amphipoda	4.8	4	7.1	4	0.0	0
Ostracoda	3.6	4	9.5	4	0.0	0
Gastropoda	1.2	1	2.4	1	0.0	0
Fish demersal eggs	66.7	2201	35.7	364	97.6	1837
Fish larvae	1.2	5	0.0	0	2.4	5

spawned eggs of *P. meshimaensis* from nests for comparison with the diameters of eggs appearing in the diets of sampled *P. meshimaensis* to determine whether the eaten eggs were those of other fishes.

The results are presented as the mean \pm SD except where indicated.

Results

Diet components

The gut contents of *P. meshimaensis* were mainly composed of fish eggs and harpacticoid copepods (Table 1). The occurrence ratio of fish eggs in individuals in the larger half of the sample was significantly higher than that in the smaller half (Fisher's exact probability, $p < 0.001$; Table 1). The occurrence ratio of harpacticoid copepods in individuals in the smaller half of the sample was significantly higher than that in the larger half (Fisher's exact probability, $p < 0.001$; Table 1). There were 27 individuals (32%) that fed only on benthic animals and not on fish eggs. Their body sizes (13.2 ± 2.1 mm in TL, $n = 27$) were significantly smaller than those of individuals whose guts were occupied only by fish eggs (18.6 ± 2.3 mm in TL, $n = 49$; unpaired t -test, $t = 9.9$, $df = 74$, two-tailed $p = 0.0001$; Figure 1). Eight other individuals that fed on both fish eggs and benthic animals had intermediate body sizes (15.8 ± 2.3 mm in TL, $n = 8$; unpaired t -test, vs. the former category, $t = 2.9$, $df = 33$, two-tailed $p = 0.006$; vs. the latter category, $t = -3.15$, $df = 55$, two-tailed $p = 0.003$; Figure 1).

Fish eggs were found in the guts of *P. meshimaensis* throughout all the sampling months of May to October. Each gut contained 38.7 ± 33.0 eggs ($n = 57$ individuals). The fish eggs appearing in the guts had a significantly shorter major axis (0.78 ± 0.03 mm, $n = 147$) and wider minor axis (0.62 ± 0.06 mm, $n = 147$) than the eggs of *P. meshimaensis* (major and minor axis, 0.82 ± 0.13 mm and 0.41 ± 0.10 mm, respectively, $n = 5$; unpaired t -test for the major axis, $t = 3$, $df = 150$, two-tailed $p = 0.003$; unpaired

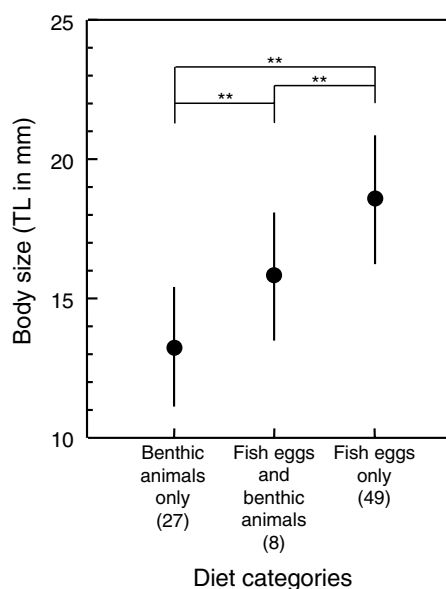


Figure 1. Differences in the individual body sizes of *Pherallodichthys meshimaensis* among the three diet categories. The mean TL \pm SD are shown. The sample sizes are indicated in parentheses. Empty diet individuals ($n = 41$) were omitted from the data. $**p < 0.01$ by unpaired t -test.

t-test for the minor axis, $t = 7.7$, $df = 150$, two-tailed $p = 0.0001$). The mouth width of *P. meshimaensis* ranged from 0.74 to 2.95 mm ($n = 125$), and was significantly correlated with the TL (Pearson's correlation coefficient, $r = 0.84$, two-tailed $p < 0.001$).

Benthic feeding behavior

Small individuals of *P. meshimaensis* (range 7–13 mm TL) were often observed to feed on benthic animals inside abraded holes created by sea urchins. They performed repeated brief stop-and-go movements, frequently moved their heads and eyes and showed picking behavior to the substrate while they remained stationary using their sucker disk. In 10 individuals collected just after performing this feeding behavior, nine actually contained only benthic animals within their guts (16.3 ± 11.6 copepods, $n = 9$), and one individual was empty.

Egg-predatory behavior

During the daytime, some individuals of the clingfish remained stationary inside the abraded holes or within gaps between *Barbatia* clams colonizing cracks in the rocks. At the same time, there were individuals that aggregated around the nest holes of *I. edentulus* (within ca. 10 cm from the hole entrance). The numbers did not differ significantly between the morning (18.0 ± 12.0 individuals, $n = 53$ surveys) and afternoon periods (16.8 ± 16.5 individuals, $n = 23$ surveys; unpaired *t*-test, $t = 0.36$, $df = 74$, two-tailed $p = 0.7$). The number varied among nests of *I. edentulus*, and there was a positive correlation between the number of individuals and the entrance hole size (Pearson's correlation coefficient, $r = 0.99$, two-tailed $p < 0.05$, $n = 5$; Figure 2). Up to 65 individuals of the clingfish gathered near the entrance to nest A, which had the largest entrance hole (33 cm^2). The nest-guarding males of *I. edentulus* often showed aggressive approaches to the aggregating *P. meshimaensis*. Among the 22 individual *P. meshimaensis* collected from aggregations, 14 (64%) were confirmed to have ingested fish eggs within their guts.

The intrusion attempts by the clingfish occurred throughout the daytime, from sunrise to 40 min

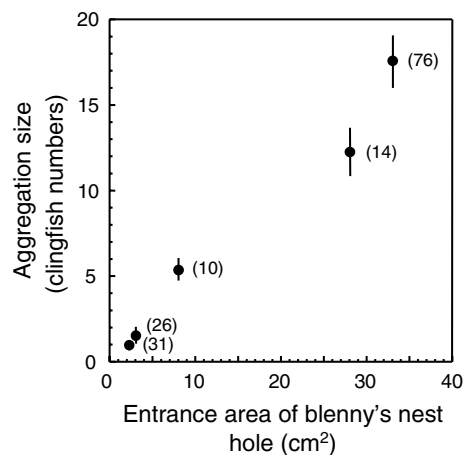


Figure 2. Relationship between the nest size (hole entrance area) of *Istiblennius edentulus* and the aggregation size of *Pherallodichthys meshimaensis* near the nest. The mean \pm SE are shown. The number beside each plot indicates the sample size of each hole.

before sunset (05:30–18:30). The guarding male of *I. edentulus* sometimes left the nest for several seconds (7.6 ± 5.3 s, maximum 20, $n = 23$) for feeding behavior or intraspecific social behavior (chasing conspecific males and performing courtships to females). Of 353 intrusion attempts by the clingfish, 273 (77%) occurred when the guarding male of *I. edentulus* was absent from the nest. The clingfish intrusion was successful in 224 cases (success ratio 82%). The remaining 80 intrusion cases were performed when the guarding male was present within the nest hole. Seventy-two of these intrusion attempts failed due to attacks by the guarding male of *I. edentulus*. This success ratio (8 of 80; 10%) was significantly lower than the former intrusion cases (Fisher's exact probability, $p < 0.0001$).

At each intrusion attempt, 2.9 ± 2.8 individual *P. meshimaensis* simultaneously swam toward the hole entrance from the aggregation (maximum 25, $n = 353$). Inside the nest hole of *I. edentulus*, the clingfish mouthed an egg by wholly enveloping it with its body fixed on the substrate using the sucker disk. The clingfish then wiggled its body rapidly to dislodge the egg from the substrate, and swallowed it. Clingfish individuals immediately left the hole after the blenny came in. Of 16 individual clingfish collected just after performing these behavioral patterns inside the nest of *I. edentulus*, 15 (94%) contained fish eggs within their guts.

In contrast, at the mating nests of the triplefin blenny *H. obtusirostris*, we observed that one or two individuals of the clingfish slowly approached mating pairs of *H. obtusirostris* (1.1 ± 0.4 clingfish, maximum 3, $n = 38$), and daringly remained stationary close to the females of the triplefin blenny. *P. meshimaensis* never formed any large aggregations near the target nests. Of 39 individual approaches by *P. meshimaensis* toward the mating nests of *H. obtusirostris*, six (15%) were chased by the nest-guarding males of *H. obtusirostris*. The clingfish dug its head under the abdomen of a spawning female of *H. obtusirostris*, and fed on the eggs by swallowing them in time with the egg release by the female ($n = 8$). Once spawning behavior were started, pairs of *H. obtusirostris* were never observed to attack *P. meshimaensis*. We did not observe any predatory behavior on eggs that had already been spawned within the algal mat, unlike the case with *I. edentulus*.

Discussion

Many individuals of *P. meshimaensis*, especially large ones, ingested only fish eggs. In diet analysis studies focusing on Pacific reef fishes, at least 86 fish species of 17 families have been confirmed as fish-egg eaters, e.g., damselfishes, wrasses, butterflyfishes and goatfishes (Hiatt & Strasburg 1960, Hobson 1974, Gushima 1981, Sano et al. 1984). However, none of these species has been reported to ingest fish-eggs to more than 25% of their diet volume, and they principally feed on plankton and benthic animals, i.e. they are facultative fish-egg eaters. Thus, the clingfish in the present study is a rare example of an obligate fish-egg eater among reef fishes.

The guts of small individuals of *P. meshimaensis* tended to contain benthic animals, rather than fish eggs. This feeding habit may change with growth. Such a dietary change is known to occur in fishes with unique feeding habits, e.g., scale-eating fishes (Nshombo et al. 1985), and the clingfish *Chorisochismus dentex* that feeds on rock-attached limpets on intertidal reefs (Stobbs 1980). Smaller individuals of these fishes ingest zooplanktons or benthic small animals (Stobbs 1980, Nshombo et al. 1985), similar to small individuals of *P. meshimaensis*. In the case of *P. meshimaensis* targeting eggs of *I. edentulus*, the swimming ability seemed to severely

affect the success of the egg predation attempts in the contexts of eluding attacks from the egg-guarding male or making a successful flash intrusion into the nest hole. Moreover, the mouth width increased with the body size of *P. meshimaensis*, although even the smallest value for the mouth width was nearly equal to the diameters of the predated eggs. Thus, smaller individuals may be potentially unsuitable for egg predation probably due to a restriction of feeding opportunities and/or the presence of considerable costs in conducting special feeding techniques.

The clingfish showed different behavioral patterns in egg predatory attempts according to the two targeted fishes. By forming aggregations, each individual clingfish may obtain benefits for the moderate risk of attacks from the nest-guarding male of *I. edentulus*, i.e. dilution or confusion effects (Pitcher & Parrish 1993). The aggregation size may be simply affect the ease of intrusion, since the aggregation size of *P. meshimaensis* was positively correlated with the nest hole size of *I. edentulus* (Figure 2). Contrastingly, in cases of targeting *H. obtusirostris*, the clingfish did not form large aggregations around the nest. The clingfish did not show any predatory behavior on eggs of *H. obtusirostris* that had already released on twiny algae. Considerable differences in the costs of searching and handling eggs between the two target fishes may force the clingfish to develop varieties of egg-predatory behavior as described above.

Some clingfishes are known to have mucus with toxic components (Hori et al. 1979). When *P. meshimaensis* are captured, they produce a considerable amount of mucus from the body skin (S. Hirayama unpublished data). For *H. obtusirostris*, mating pairs of the triplefin that were far smaller than the *I. edentulus* did not show any attacks against closely approaching *P. meshimaensis* in the present study. This may be due to the effects of the mucus, although the details of the mucus components are unknown at present. Further studies on the clingfish are required to clarify the predatory strategy and to estimate the impacts of egg predation.

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