Ichthyol Res (2009) 56:92–95
DOI 10.1007/s10228-008-0056-z

SHORT REPORT

Semi-lunar spawning cycle and mating tactics in the marine goby *Asterropteryx semipunctata*

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Received: 25 April 2007 / Revised: 29 March 2008 / Accepted: 2 April 2008 / Published online: 2 May 2008

Abstract The reproductive behaviors of the marine goby *Asterropteryx semipunctata* were studied at Sakurajima, Kagoshima, Japan. Spawning occurred from late June to early October with a peak at 3–4 days after the full and new moon. This semi-lunar cycle might be advantageous to reducing nest-egg mortality but may not to larvae dispersion. Large males maintained spawning nests, and females spawned a whole clutch at a nest but with multiple males during a season. Females were less likely to be choosy due probably to a predation risk and/or nesting male shortage. Smaller males adopted sneaking tactics, and some of them became nesting males.

Keywords Gobiidae · Semi-lunar cycle · Reproductive behaviors · Alternative mating tactic · Polygamy

Introduction

Breeding habits of gobies have been studied in many species (reviewed by Breder and Rosen 1966; Miller 1984; Thresher 1984). According to these studies, gobies spawn demersal eggs that are guarded by males, and many gobies appear to be polygamous or promiscuous. However, in many cases the mating systems of gobies have been estimated depending on indirect evidence, e.g., from the number of egg masses at different developmental stages in a nest (e.g., Marconato et al. 1989), given that their inconspicuous spawning nest prevents direct observations of their reproductive behavior.

Asterropteryx semipunctata is a small goby that is common along rocky shores in the tropical and sub-tropical Indo-Pacific, ranging from Hawaii to the Red Sea (Randall et al. 1990). Dotu and Mito (1963) provided a brief note on the spawning season in southern Japan, and Cole (1990) reported that there was no evidence of hermaphroditism. Privitera (2001) examined clutch sizes, minimum spawning frequency, and egg, embryo and larva characteristics in aquaria. Privitera (2002) also determined the spawning season, spawning frequency and fecundity in the Hawaiian Islands based on ovary dissections. Instead of these studies of basic reproductive ecology, underwater observations on their reproductive behaviors have not been done. We found a study site at which mating behaviors of *A. semipunctata* could be easily observed. In this paper, we briefly describe some aspects of the reproductive tactics of *A. semipunctata* based on data from our field observations and their lunar cyclic spawning activity.

Materials and methods

Asterropteryx semipunctata spawns at various hours in the daytime, year-round, with a peak from May to July in the Hawaiian Islands (Privitera 2001, 2002), and from May to August in southern Japan (Dotu and Mito 1963). Eggs are laid on the underside of rock (Dotu and Mito 1963) or

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coral, and males attend eggs (Privitera 2001, 2002). Eggs hatch in aquaria shortly after lights are turned off, 4–6 nights after spawning (Privitera 2001).

We conducted underwater observations using SCUBA at Sakurajima, Kagoshima Prefecture, Japan (31°35′N, 130°36′E) in 1996, 2002 and 2005. Three study areas (4 × 8 m, 4 × 4 m and 2 × 2 m) were set on the bottom at a depth of 1–7 m, where *A. semipunctata* was abundant. The substrate consisted of volcanic rocks and sand, with scattered coral colonies. At the beginning of the spawning season of each study year, most individuals in and around the study areas were captured with a hand net and marked by subcutaneous injection of acrylic paint. Each marked fish was measured for total length (TL, mm), sexed and returned to the capture site. Sexes were distinguished by the structure of the urogenital papilla (see Privitera 2002): long, thin and pointed papilla in males, while it is short, broad and rounded in females.

To study courtship and spawning behavior, 5–80 min observations were conducted in various hours from July to September in 1996 and from May to October 2005. When courtship and spawning were observed, time and code number of the participants were recorded. To examine lunar cycle of spawning in this species, reproductive behaviors of males in the study area (2 × 2 m) were observed for 1 h at the same time within a day in 2005, and the number of males that conducted spawning behavior was recorded. In 2005, we observed 32 females to examine whether females prefer large males. Fish in the study area (2 × 2 m) were monitored around every full and new moon, when spawning behavior was frequently observed, and female mating behavior and the code number of the participants were recorded. To determine a territory or a home range of fish, 10–80-min observations were carried out from June to September 2002. Swimming routes and interactions with conspecifics were recorded. Since both nesting males and females aggressively interacted and excluded consexuals (see Results), the outermost range of their swimming routes was regarded as their territory. All observations were made between 0600 and 2000 hours. The total observation time was ca. 500 h.

Results

Fifty and 286 spawning of *Asterropteryx semipunctata* were recorded from 28 June to 22 September 1996 and from 23 June to 7 October 2005, respectively (Fig. 1). This spawning season is consistent with Dotu and Mito (1963). In both years, spawning occurred between 0715 and 1915 hours. The number of mating males peaked 3–4 days after the full and new moon in 2005 (Fig. 1), indicating a semi-lunar spawning cycle.

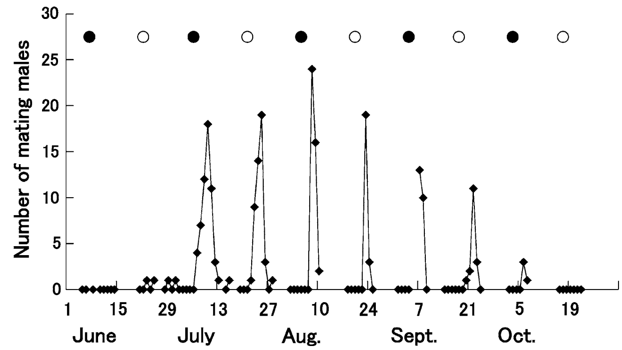

Fig. 1 Relationship between lunar phases and number of mating males of *Asterropteryx semipunctata* in the study area (2 × 2 m) in 2005. *Open circle* full moon, *closed circle* new moon

In 1996, 11 males (52–74 mm TL) maintained nests on the surface of rock crack, at which a total of 22 different mature females (42–64 mm TL) were observed to spawn. Before spawning, nesting males prepared nests by removing sand and stones. When a female approached a male nest, the male frequently exhibited courtship display, approaching the female and showing 'figure-8 swimming' with spreading of all fins. If the female entered the nest, the male pushed the female's body and oscillated around her as courtship. Subsequently, the female repeatedly released eggs on the surface of the nest. Just after a release of eggs, the male repeatedly shook its body right and left on the egg mass, presumably to fertilize the eggs. Mean duration of a whole spawning event was 79.5 min ± 58.4 SD ($n = 4$). After spawning, males attended and cared for the eggs until hatching (3 days, $n = 4$). Parental males chased out both conspecifics and other species such as wrasses and damselfishes, but these fishes (e.g., *Pomacentrus nagasakiensis*, *Pseudolabrus sieboldi* and *Thalassoma lutescens*) were observed to prey on eggs in 31 cases.

During spawning, small males (41–61 mm TL, $n = 7$) sometimes quickly entered the nest, suggesting that they may adopt sneaking tactics. Sneaking occurred in 10 of 50 spawning in 1996. Two of seven sneakers became nesting males in the spawning season. These were the largest sneakers (53 and 61 mm TL), and the sneaker of 53 mm became a nesting male after replacing a nest of which the nesting male disappeared.

Both nesting males and females aggressively interacted with other individuals of the same sex, defending territories against consexuals (Fig. 2). Female territories overlapped with those of multiple males and were not completely enclosed by one male territory. These male and female territories were retained during the study period of July–September in 2002. Home ranges of sneakers overlapped with the territories of nesting males.

Of six nesting males (67–70 mm TL) observed in 1996, three mated three females on different days. The other three

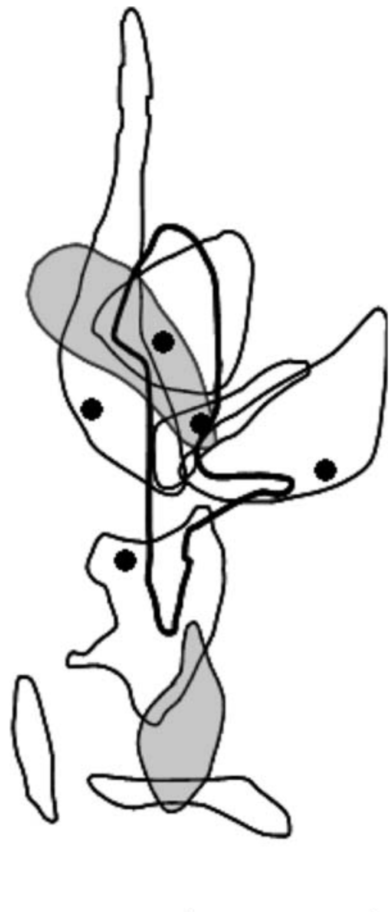

Fig. 2 Typical arrangement of territories and home ranges of *Asterropteryx semipunctata* during June 2002. *Open areas* male territories, *shaded areas* female territories, *thick line* a home range of a sneaker. *Solid circles* male nests, *bar* 1 m

males spawned with two females simultaneously. Of nine females (42–64 mm TL) observed in 1996, one spawned with three males on different days, three females spawned with two males on different days and the remaining five did with one male. Thus, mating with multiple mates was observed in both sexes during a spawning season. In 10 and 37 spawnings done by pairs of two marked fish in 1996 and 2005, males were 4–24 mm TL (mean = 9.4 ± 6.0 SD) and 0–34 (13.8 ± 8.4) larger than females, respectively. Sizes of the pair members were not correlated (Spearman rank correlation: $r_s = 0.48$, $P = 0.18$, $n = 10$ in 1996; $r_s = 0.30$, $P = 0.09$, $n = 37$ in 2005). Of the ten spawning in 1996, six (60.0%) occurred between individuals whose territories did not overlap, and the remaining four (40.0%) between individuals whose territories partially overlapped. The results indicate that the mating system of *A. semipunctata* is a male-territory-visiting polygamy (sensu Kuwamura 1996).

Of 32 females (31–66 mm TL) observed in 2005, 23, 8 and 1 spawned with one, two and three males, respectively (on different days in multiple mating). Seven (21.9%) of the 32 females visited a nesting male before mating a male at his nest. There was no size difference between visited males (65.1 ± 1.5 mm TL, 63–68) and mated males (65.6 ± 1.8 mm TL, 63–68; Wilcoxon signed rank test, $T = 8$, $P = 0.6$, $n = 7$).

Discussion

Spawning cycle. Our results clearly indicate that the goby *Asterropteryx semipunctata* exhibits a semi-lunar spawning cycle at Sakurajima. This spawning cycle is known in many gobies (e.g., Sunobe and Nakazono 1999; Takegaki 2000) and has been considered to contribute to dispersion and survival of hatching larvae (Thresher 1984; Robertson 1991). In *A. semipunctata*, spawning peaked 3–4 days after the full and new moon, and eggs hatched out 3–5 days after spawning (Privitera 2001; present study). Therefore, hatching does not correspond with the period when the tidal fluctuation became largest and when newly hatched larvae will be dispersed effectively.

It is suggested that synchronized spawning might reduce nest-egg mortality in species with paternal care (Robertson 1991). In the present study, eggs in nests were occasionally predated, and multiple clutches in a nest might reduce egg mortality because the presence of other eggs reduced the risk of a female's eggs being eaten, or created a 'delusion effect' in other words. Thus, synchronized spawning with a semi-lunar cycle in *A. semipunctata*, which might be triggered by a cue of the full and new moon, might be advantageous to reducing egg mortality.

Mating tactics. Our behavioral observations indicated that *A. semipunctata* males can sequentially and/or simultaneously fertilize eggs from multiple females, and this goby has a male-territory-visiting polygamy. The pattern of semi-lunar spawning of this goby (Fig. 1) suggests that a female will spawn once in a single spawning phase. In 1996, 18 males (11 nesting males and 7 sneaker males) and at least 22 females participated in reproduction. Of 18 males, only 11 males had nests probably because of the shortage of available nest sites. The sex ratio (nesting males vs. females) and synchronous spawning are likely to make the female-biased situation in the spawning phases, where nesting males tend to obtain multiple egg masses at the same time.

In most cases of sneaking in previous studies, small males attempt to fertilize eggs of females pair-spawning with large territorial males (Taborsky 1994). Although sneakers were smaller than nesting males in *A. semipunctata*, there was an overlap between their size distributions. One explanation is that nesting males act as both territorial males and sneakers at a same time (e.g., *Parapercis* *snyderi*; Ohnishi et al. 1997). However, we observed no sneaking by nesting males in spite of long-term observations, indicating that this possibility will be low. Another explanation is that the critical size of transition of a sneaker to a nesting male differs among local populations or mating groups. The largest sneakers became nesting males, one of which became a nesting male after disappearance of a nesting male. The results suggest that transition of a sneaker to a nesting male is a plastic response to the condition of a local mating group. Thus, the overlap in the size distribution between sneakers and nesting males might be the critical sizes of the transition difference among local mating groups.

Large size of males is important in female choice in many fish species with paternal care (Karino 1996). In the present study, females did not tend to spawn with larger males than those females visited previously, indicating that females do not base their choice on male size. We cannot exclude the possibility of mate choice depending on other unmeasured cues (e.g., courtship intensity, nest size, sexual dimorphisms). However, it is also possible that a predation risk leads to less scope for female choice, as has been shown in the sand goby, *Pomatoschistus minutus* (Forsgren 1992). In *A. semipunctata* at Sakurajima, only ca. 20% of females visited one male prior to spawning, and females did not visit more than one male before spawning, where individuals were sometimes attacked by a scorpionfish *Scorpaenopsis neglecta* (Hagiwara, personal observations). These observations suggest that costs of female-mate sampling behavior might be high in this population. Furthermore, synchronized spawning would induce a shortage of nesting males, which leads to less scope for female choice (e.g., Forsgren et al. 1996). Thus, females become less choosy due to some factors such as a predation risk and/or nesting male shortage in *A. semipunctata* at Sakurajima.

Acknowledgments We are grateful to H. Suzuki and other members of the Laboratory of Marine Biology, Kagoshima University, for their advice and encouragement during the study. We also thank T. Sunobe, M. Kohda and anonymous reviewers for their helpful suggestions and comments on the manuscript. G.N. Nishihara helped to correct the English. This research was carried out in accordance with Japanese law.

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