Ichthyological Research
https://doi.org/10.1007/s10228-024-00986-w

SHORT REPORT

Rushing and spawning behavior of the Kidako moray *Gymnothorax kidako*

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Received: 26 April 2024 / Revised: 14 June 2024 / Accepted: 16 June 2024

Abstract
This study investigated the reproductive behavior of the Kidako moray *Gymnothorax kidako* in Tateyama, Chiba, Japan and Enoshima Aquarium. Field observations on reproductive behavior were conducted for 19 pairs from 24 July to 23 August 2017, at depths from 13 m to 18 m. Among these pairs, two instances were observed where the male gripped the female's snout in its mouth and rushed toward the water surface at 20:45 and 20:40. At Enoshima Aquarium on 8 August 2022, a male and a female spawned at 20:06 following similar behavior. These findings suggest that rushing is a pre-spawning behavior. Among the 19 pairs observed, males [80–100 cm in total length (TL)] were consistently larger than females (70–90 cm TL). However, a pair was interrupted when a small male, approximately 50 cm TL, rushed by gripping the female's snout. This suggests that smaller males unable to establish pairs may participate in reproduction through sneaking.

Keywords Anguilliformes · Muraenidae · Eel · Reproductive behavior · Sneaking

Introduction

The Muraenidae (moray eels) constitute the largest group within Anguilliformes, with a distribution spanning temperate and tropical waters of the Indo-Pacific and Atlantic oceans, comprising approximately 200 species across 16 genera (Nelson et al. 2016). Typically characterized by elongated bodies, moray eels lack pelvic and pectoral fins and are commonly found inhabiting cavities within rocky and coral reefs. Most species have large mouths with long, sharp canine-like teeth (Randall et al. 1990). Within coastal rocks or coral reefs, moray eels assume the role of resident top predators (Hixon and Beets 1993).

However, despite the considerable number of species, the reproductive biology of moray eels remains relatively understudied due to their nocturnal and cryptic habits (Matić-Skoko et al. 2011). Studies on spawning habits and maturation have primarily relied on monthly sampling and/or histological observations of gonads, focusing on species such as *Enchelycore pardalis*, *Enchelycore lichenosa* (Oomori et al. 2022a), *Gymnothorax equatorialis* (Lucano-Ramírez et al. 2008), *Gymnothorax javanicus* (Brock 1972), *Gymnothorax kidako* (Oomori et al. 2023), *Gymnothorax minor* (Oomori et al. 2022b), and *Muraena helena* (Matić-Skoko et al. 2011; Sallami and Ben Ibrahim 2021). These investigations indicate that the reproductive season of moray eels typically occurs during the summer months.

Regarding reproductive behavior, Moyer and Zaiser (1982) documented the spawning behavior of *G. kidako* on Miyake-jima Island. Loh and Chen (2018) elucidated the reproductive behavior of *Gymnothorax pictus* and *Gymnothorax thyrsoideus* through aquarium observations, noting behaviors such as rushing toward the water surface while the male grips the female's snout in its mouth (Loh and Chen 2018). On the other hand, *Gymnothorax herrei* exhibits group spawning, which a single female spawns with multiple males in a spawning aggregation (Ferraris 1985).

The Kidako moray, *G. kidako*, is found in temperate and subtropical waters surrounding Japan, the southern part of the Korean Peninsula, and Taiwan (Hatooka 2013). Spawning events in Tateyama, Chiba, Japan typically occur

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Published online: 13 July 2024

between July and August. The smallest mature individuals measure 47.4 cm and 62.1 cm in total length (TL) for males and females, respectively (Oomori et al. 2023). Based on otolith-increment counts, both males and females can live up to 34 years. Although there may be no significant difference in TL between males and females, males exhibit a greater growth rate compared to females (Oomori et al. 2023). This paper aims to describe the reproductive behavior of *G. kidako* observed in the field and aquarium settings and discuss reproductive behavior within the broader context of moray eels.

Materials and methods

Field observation. The spawning season of *Gymnothorax kidako* typically occurs between July and August. In this season, there appears a pair of *G. kidako*: the smaller individual within a pair, exhibiting a swollen abdomen, indicates a fully mature female just before spawning, and the larger is a male by the results of histological observation on gonads (Oomori et al. 2023). Given that Muraenidae are generally nocturnal (Matić-Skoko et al. 2011), we conducted night observations on spawning behavior for 19 pairs from 24 July to 23 August 2017, at depths from 13 m to 18 m, approximately 500 m off Banda Beach, Tateyama, Chiba, Japan (34°98' N, 139°77' E).

We surveyed pairs of *G. kidako*, identified by the presence of a female with a swollen abdomen, from 14:00 to 18:00 using SCUBA. Visual estimates of the TLs of males and females were made (Table 1). Subsequently, we recorded their behavior using two video cameras positioned approximately 2 m away from the pair for durations ranging from 12 to 20 h. The cameras were housed in an underwater case (SEA & SEA, Yokohama), including a video camera (MAX1, Muson, Guangdong) with a 64 GB micro SD card (MB-64DA/FFP, Samsung, Suwon) and a battery (PB-N36, Aukey, Guangdong), alongside a 4,000 lm underwater light (PELLOR4000, Pellor, Canton) with a corresponding battery (P2665C, KeepPower, Donggan). On the following day, the cameras were retrieved and inspected for recordings of reproductive behavior.

Observation in an aquarium. While we observed male and female pairs rushing together during field observations, we were unable to capture the moment of egg release due to it occurring outside the camera frame. Consequently, we conducted observations in an aquarium to confirm egg release or not after rushing.

On 7 August 2022, at approximately 11:00, about 500 m off Banda, Tateyama, we captured five females with swollen abdomens, indicative of imminent spawning (Oomori et al. 2023), using SCUBA and a hand net. Although distinguishing sexes of an individual without a visibly swollen abdomen is challenging, all individuals over 90 cm TL are male

Table 1 Date and time of observation, size in cm TL, frequency of agonistic behavior, and time of rushing on pairs of *Gymnothorax kidako* in 2017

Pair #	Date	Observation time	Size (cm TL)		Frequency of agonistic behavior	Time of rushing
			Male	Female		
1	Jul. 24–25	17:34–07:12	80	70		
2	Jul. 25–26	14:50–06:31	90	70		
3	Jul. 26–27	15:35–09:44	100	80	2	
4	Jul. 29–30	15:32–08:40	80	70	1	
5	Jul. 31–Aug. 1	16:50–06:52	90	70		
6	Aug. 1–2	15:48–07:16	80	80		
7	Aug. 2–3	17:02–09:46	80	80	1	
8	Aug. 4–5	16:58–07:20	80	70		
9	Aug. 5–6	17:21–08:06	80	70		
10	Aug. 6–7	17:32–09:52	80	70		20:45
11	Aug. 7–8	16:02–09:34	100	80		
12	Aug. 8–9	14:32–08:35	80	70	1	
13	Aug. 9–10	15:33–09:05	90	60		
14	Aug.13–14	17:20–09:04	90	90		
15	Aug. 15–16	17:10–07:56	80	70		
16	Aug. 20–21	17:30–09:21	100	70		
17	Aug. 21–22	17:34–09:30	80	80		20:40
18	Aug. 22–23	17:09–06:52	100	90	1	
19	Aug. 23–24	16:11–07:33	90	80		

(Oomori et al. 2023). Thus, we collected two such individuals. These specimens were then transferred to an FRP tank (150 × 80 × 80 cm) and transported to Enoshima Aquarium from 3:00 to 7:00 on 8 August. They were introduced into an exhibition aquarium (12 × 12 × 6.5 m), which ranged at a temperature and salinity of 22.0–22.5°C and 28–33 psu, respectively. This aquarium used a combination of circulating and natural filtered seawater with water exchange rate as 9 times/day (Itoh and Kan-oh 2020). During daylight hours, the tank was illuminated by natural and artificial light, transitioning to darkness after 18:00. The aquarium housed approximately 20,000 individuals, representing about 100 species of fish native to Sagami Bay.

Observations were conducted continuously for 24 h, with three individuals taking shifts until 7 September. Observations for rushing behavior were made visually. When rushing behavior occurred, video was taken with a video camera (TG-5, Olympus, Tokyo). After the observations, all individuals were collected, sacrificed with ice, measured for TL, and sexed using the methods of Oomori et al. (2023) as follows: males (96.3 and 93.6 mm TL) and females (82.6, 81.6, 77.3, 76.9, and 76.2 cm TL).

Results

Observation in Tateyama. The pairs remained positioned with half of their bodies protruding from the rock cave. Occasionally, the male would venture outside the cave, only to return later. When other individuals approached the pair, the male would forcefully drive them away by opening his mouth and biting, as observed in six instances (Table 1).

The first instance of rushing behavior was recorded on 6 August 2017 (Table 1). At 18:36, a small individual measuring approximately 50 cm intruded upon the cave of pair #10, interrupting their activities and remaining with the male and female. Surprisingly, the male did not exclude this intruder. At 20:45, the small individual gripped the female's snout in its mouth (Fig. 1a) and rushed toward the water surface (Fig. 1b), while the male remained stationary and did not pursue [Electronic Supplementary Material (ESM) 1].

The second rushing event was recorded on 21 August 2017 (Table 1). In pair #17, the male exhibited behaviors such as pushing its snout against the female's and shaking its dorsal fin from side to side. At 20:40, the male rubbed the tip of its mouth against the female's. Subsequently, as the female opened her mouth, the male gripped her snout in his mouth (Fig. 2a), and they rushed toward the water surface (Fig. 2b). However, the subsequent behavior after rushing could not be confirmed as it occurred outside the camera's frame (ESM 2).

Observation in the aquarium. Immediately after introduction at 7:00 on 8 August 2022, the individuals remained stationary at the bottom of the tank. However, by 8:00, the males began to move and occasionally visited the females. At 20:06, one of the males gripped the snout of a female in its mouth. They then rushed toward the top and attained to the water's surface by 4 s. At the surface, they spawned at once, and a gamete cloud was recognized. Subsequently, they returned to the bottom. No further spawning activity was observed until the end of the observation period.

Discussion

The rushing behavior toward the water surface while gripping the female's snout in the mouth, observed in Tateyama on 6 and 21 August 2017, was also noted in the aquarium observations following spawning on 8 August 2022. Therefore, the rushing behavior should be a pre-spawning behavior. The small individual, which exhibited rushing, should be male.

Similar reproductive behavior has been reported in *Gymnothorax pictus* aquarium observations: rushing toward the water surface while gripping the female's snout in the mouth and spawning. Although spawning has not been confirmed in *G. thyrsoideus*, the same pre-spawning behavior has also been described (Loh and Chen 2018). Although information is limited, these motor patterns are considered to be common in the pair spawning of *Gymnothorax*.

In their study on Miyake-jima Island, Moyer and Zaiser (1982) described the reproductive behavior of *G. kidako*, stating, "Two individuals were pressed laterally together with the posterior 1/3 of their bodies loosely entwined. Suddenly, they pressed abdomens together, and the eel closest to the pipe turned rapidly to the left, entering a hole in the pipe. Simultaneously, the other eel turned sharply to the right and dashed 60–80 cm away from the pipe. As their body separated, a large cloud of gametes appeared. There was no upward dash." In this case, spawning behavior without rushing is similar to those of garden eels *Gorgasia preclara* and *Heteroconger hassi* (Kakizaki et al. 2015). It is possible that there is variation in the spawning behavior of *G. kidako*. But we cannot rule out the possibility that Moyer and Zaiser (1982) made an error in their observations, as it is quite different from our results and a fully mature female with a swollen abdomen spilled eggs with the slightest movement, even if she did not intend to spawn (Oomori, unpublished data).

The smallest mature female was 62.1 cm TL, and the smallest male with sperm was 47.4 cm TL. Given that females typically establish pairs with larger males, males <62.1 cm TL are unlikely to form pairs (Oomori et al. 2023). In species where large males establish territories and monopolize spawning, smaller males are less likely to maintain territories and attract females. These males adopt

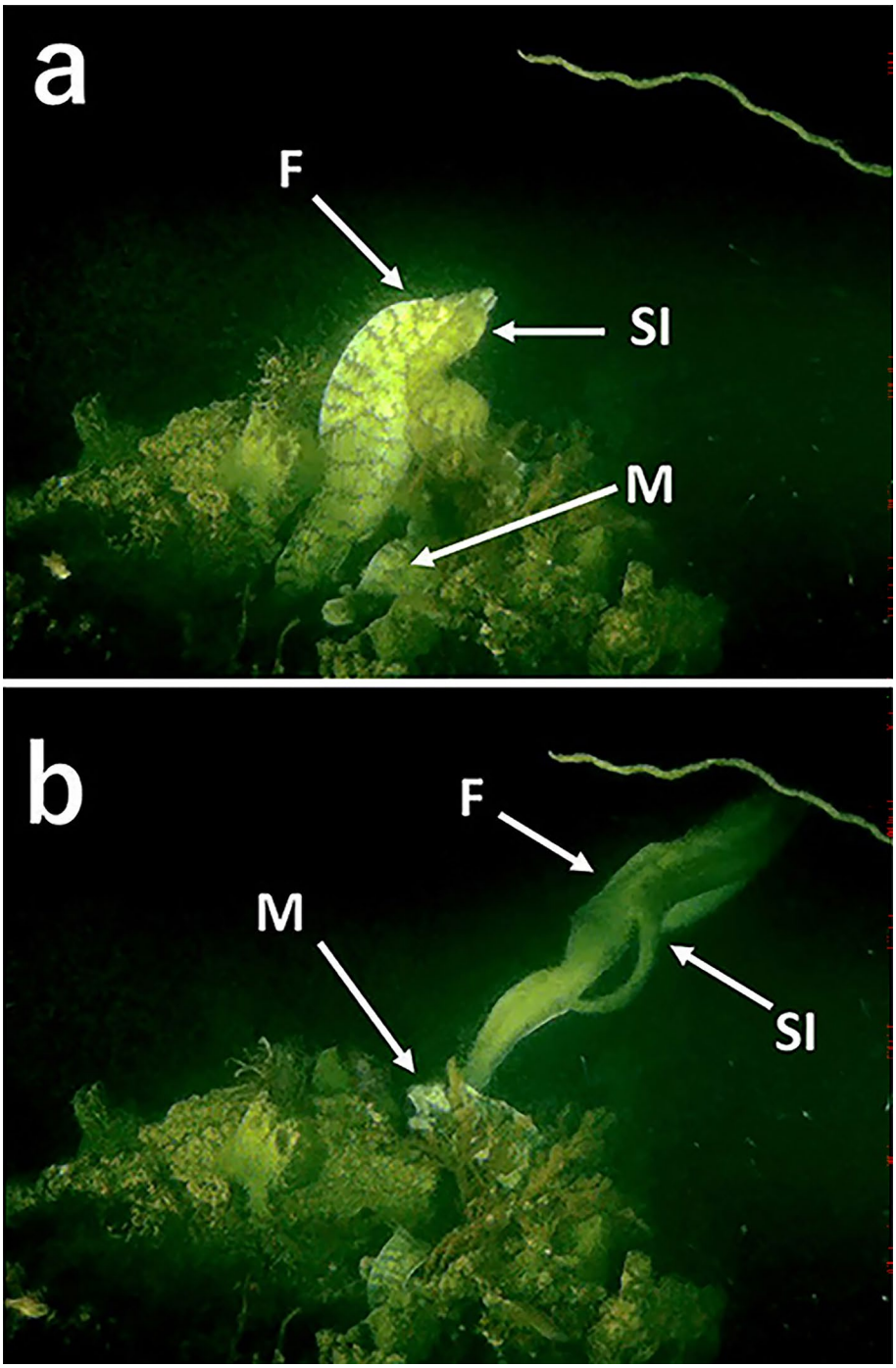

Fig. 1 Observation on 6 August 2017. **a** The small individual gripping the female's snout, **b** rushing toward the water surface. *M* male, *F* female, *SI* small individual (ESM 1)

alternative tactics and fertilize eggs through sneaking, which involves pair spawning by a female and subordinate male in the territory of a dominant male (Kuwamura 1987; Moyer 1991; Suzuki et al. 2008). The observation on 6 August 2017 indicates that a small male of *G. kidako* adopted alternative tactics and spawned by sneaking. These males may alternate tactics as they grow. The territorial male generally chases away small parasitic males from its territory (Taborsky 1994), and the larger males of *G. kidako* establishing a pair drove out the intruders. Although the small male *G. kidako* was able to remain in the cave and spawn in pair, it is unclear how this small male managed to do so. Additional studies are needed to clarify this point.

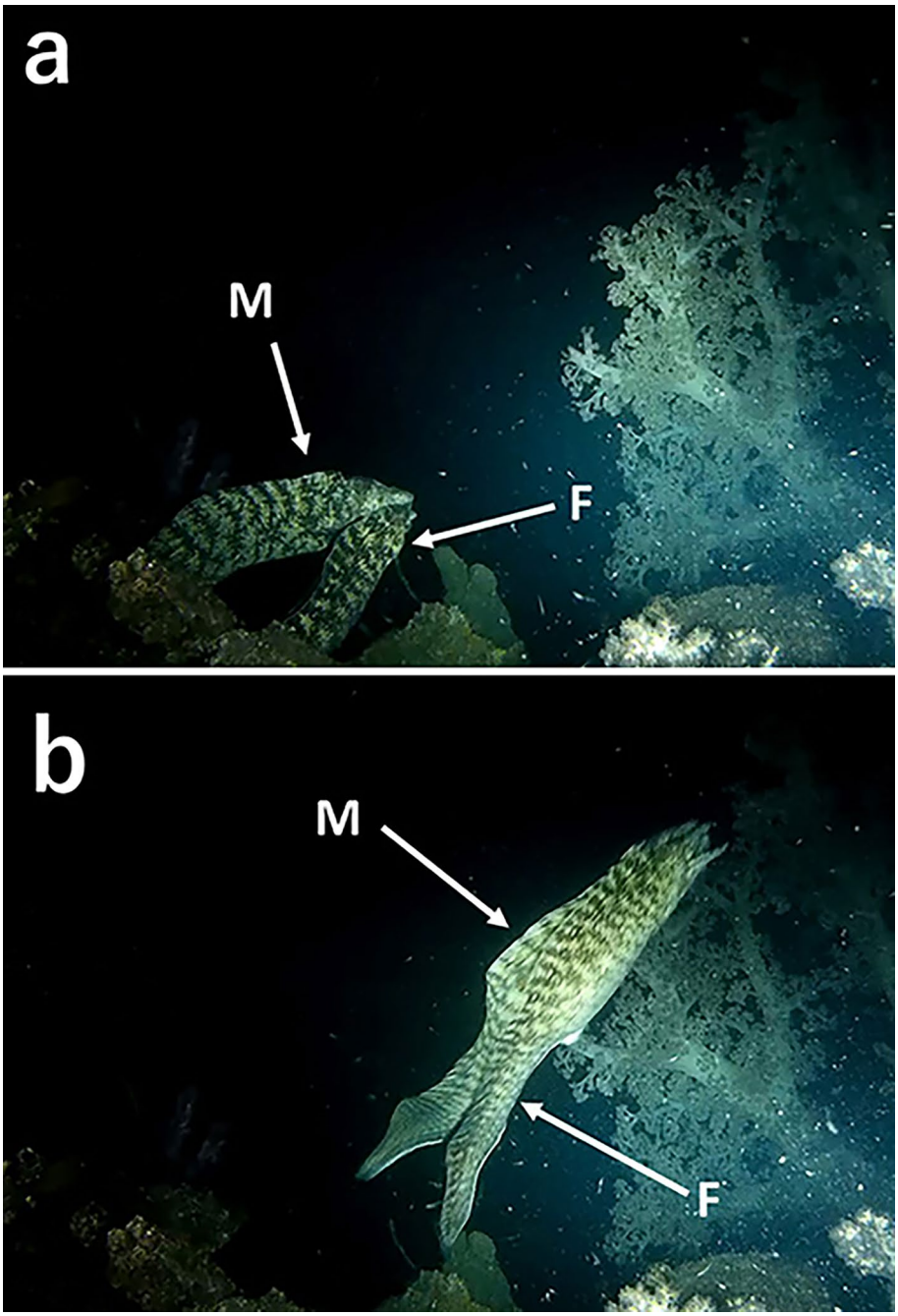

Fig. 2 Observation on 21 August 2017. **a** The male gripping the female's snout, **b** rushing toward the water surface. *M* male, *F* female (ESM 2)

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10228-024-00986-w.

Acknowledgments We are grateful to S. Shimizu, S. Ishibashi, H. Narita, S. Narita, and members of the laboratory of fish behavioral ecology for their assistance during this study.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval The experimental protocol in this study was approved by Tokyo University of Marine Science and Technology where the research was conducted, and all procedures were carried out in accordance with approved guidelines.

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