

Feeding preference of threadsail filefish *Stephanolepis cirrhifer* on moon jellyfish and lobworm in the laboratory

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Abstract: We examined feeding preference in the threadsail filefish *Stephanolepis cirrhifer* on jellyfish and lobworm. Juvenile filefish were fed moon jellyfish *Aurelia* sp. and/or lobworm *Perinereis nuntia vallata* for 30 min in tanks with or without sand substrate, and the onset of foraging behavior, response latency (RL) and time spent foraging (total time spent searching for food and feeding) were analyzed using video recordings and measurements of food consumption. Organic matter consumption per unit of foraging time was also estimated for each prey item. In tanks with a sand substrate, RL was significantly shorter, foraging time was significantly longer, and organic matter consumption per unit foraging time was higher for jellyfish than for lobworm; however, the opposite trend was observed in tanks without a sand substrate. Filefish in all treatments consumed an average of $99 \pm 25\%$ of their body weight in jellyfish in 30 min. This study revealed that although filefish prefer lobworm to jellyfish when both are readily available, filefish will select jellyfish when only jellyfish are visible. These findings imply that frequent jellyfish blooms increase the feeding opportunities of filefish on jellyfish.

Key words: *Aurelia* sp., feeding strategy, food selectivity, gelatinous plankton, polychaete

Introduction

Jellyfish blooms, including blooms of planktonic cnidarians and ctenophores, have a markedly negative impact on local fisheries and other coastal industries (Graham 2001). Since jellyfish are voracious predators of copepods and fish larvae, these blooms may also have a major impact on the populations of commercially important fisheries resources (Brodeur et al. 2002, Purcell et al. 2007, Purcell 2003).

On the other hand, jellyfish are preyed upon by more than 69 fish species in 34 families (Arai 2005). Among these are monacanthids, such as the threadsail filefish *Stephanolepis cirrhifer* (Temminck and Schlegel) and the filefish *Thamnaconus modestus* (Günther) (Masuda et al. 2008), as well as several stromateids, scorpaenids and scombrids (Purcell & Arai, 2001). Except for several members of the Centrolophoidae and Stromateidae which feed almost exclusively on jellyfish, most of the fish species that include gelatinous prey in their diets are generalists (Arai 2005). Mianzan (1996) examined the stomach contents of 69 fish species from Argentine coastal waters and reported that 15–23% contained ctenophores, which accounted for

7–17% of the diet of these fish species throughout the year. However, the passage time of gelatinous prey through the fish gut is relatively quick; Arai et al. (2003) showed that the digestion speed for the ctenophore *Pleurobrachia bachei* Agassiz preyed upon by chum salmon *Oncorhynchus keta* (Walbaum) is more than 20 times faster than the passage time for shrimp. Consequently, this means that stomach content data collected in the field can underestimate feeding rates, and implies that the importance of jellyfish as prey in nature is still unknown.

The threadsail filefish is an omnivorous coastal species. Suyehiro (1934) demonstrated that threadsail filefish (body weight (BW): 6.1–20.7 g) feed on fish, epifauna such as amphipods, isopods, cirripeds, infauna such as polychaetes, pelecypods, and seaweeds such as *Sargassum* spp. Threadsail filefish also feed on gelatinous plankton, such as the moon jellyfish *Aurelia* sp. and the giant jellyfish *Nemopilema nomurai* Kishinouye (Masuda et al. 2008). However, it appears that no information currently exists regarding whether filefish feed on jellyfish when other prey is available.

In this study, we examined the feeding behavior and food preferences of threadsail filefish presented with moon jellyfish and lobworm *Perinereis nuntia vallata* (Grube). Polychaetes are often one of the most dominant infauna in

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coastal and estuarine environments (Fujii 2007). Among polychaetes, lobworms form a major component of demersal fish diets and are widely cultured as bait for recreational fishing. In recent years, jellyfish blooms have become common in coastal areas (Arai 2001, Mills 2001), and the likelihood of filefish encountering moon jellyfish has probably increased. We therefore examined whether filefish feed on jellyfish when other prey items are also available. Observations were conducted in tanks without substrate, when both prey items were readily accessible, and in tanks with a sand substrate, when the jellyfish would be more accessible than lobworm which live in the sand.

Materials and Methods

Hatchery-reared, juvenile threadsail filefish were used in this experiment because of the relative ease with which similarly-sized individuals could be obtained. While at the hatchery (Nisshin Marine Tech, Aichi, Japan), filefish were reared on a diet of rotifers, *Artemia* and commercial pellets. After being transported to the Maizuru Fisheries Research Station (MFRS) at Kyoto University, the juveniles were immediately stocked into a 500 L black polycarbonate tank where they were maintained on a diet of pellets (Otohime S2, Marubeni Nissin Feed Co. Ltd., Tokyo, Japan) for ca. 10 months in ambient filtered seawater without direct sunlight.

The experiments were conducted from 16 May to 6 June 2009 in glass fish tanks using the following four treatments: 1) jellyfish with a sandy bottom (JS), 2) lobworms with a sandy bottom (LS), 3) jellyfish and lobworms with a sandy bottom (MS), and 4) jellyfish and lobworms on a glass bottom (MG). A sandy bottom was provided in treatments JS, LS and MS to simulate natural conditions, whereas the MG treatment (no sand) was designed to test prey preference. We conducted 10 trials per treatment, with each trial consisting of a single fish that was not reused. In treatments JS, MS and MG, a jellyfish was suspended from a length of fishing line to prevent it from sinking and to allow it to swim freely in the upper 11 cm of the tank. Preliminary experiments revealed that the consumption of intact (i.e. free swimming) jellyfish by fish in the JS treatment was 57% of that observed for the tethered jellyfish. Nonetheless, we decided to use a tethered jellyfish to ensure that the jellyfish would always be visible in the video footage. In the LS, MS and MG treatments, a lobworm was released into each tank. There were no significant differences in fish standard length (SL: 76.2 ± 6.3 mm, mean \pm SD), wet body weight (BW: 13.3 ± 3.0 g), and the weight of either the jellyfish (wet weight: 56.9 ± 16.0 g; bell diameter: 9.3 ± 1.3 cm, mean \pm SD) or the lobworm (wet weight: 1.0 ± 0.2 g) among treatments ($p > 0.05$, one-way ANOVA). No measurable difference was observed in the progress of gonadogenesis among jellyfish in each trial. Jellyfish were collected from a pontoon adjacent to the MFRS and were transferred to a holding tank with a continuous supply of filtered seawater

without feeding. All of the jellyfish were collected within 24 h prior to the experimental trials and none had food items in their stomachs when they were presented to the filefish. Lobworms were purchased from a local fishing shop (Anglers Group, Osaka, Japan), transported to the MFRS, and stocked in a tank with a continuous supply of filtered seawater also without feeding. All lobworms were presented to filefish within 48 h of purchase. For substrate treatments, the white bottoms of the experimental glass tanks (W×D×H: 90×30×30 cm) were covered to a depth of 2 cm with bright cream-colored sand collected from lobworm habitat near the MFRS. The water depth was 22 cm from the surface to the sandy bottom. The amount of prey consumed in each tank was estimated by calculating the difference between the weight of the prey presented to the fish and the weight of the prey remaining 30 min after the fish started feeding.

The experiment was conducted in filtered seawater at an ambient temperature of $18.2 \pm 1.2^\circ\text{C}$ (mean \pm SD); there was no significant difference in temperature among treatments ($p = 0.66$, one-way ANOVA) and the water of the tank was not exchanged. Immediately prior to the initiation of each trial, each tank was divided into two compartments by inserting a 1-cm mesh polycarbonate divider into the tank to form an acclimatization compartment (compartment B+C), half of which was covered with a black vinyl sheet to minimize disturbance, and an experimental compartment (compartment A+B) (Fig. 1). After measuring SL and BW, fish were transferred to the acclimatization compartment of the experimental tanks and were left undisturbed for 12 h. Acclimatization and feeding motivation were confirmed by feeding fish 2–3 pellets before placing the jellyfish and/or lobworm into the acclimatization compartment of the tank. Once the lobworm had completely burrowed into the sand, the divider X was removed and the divider Y was inserted so that the fish was able to enter the experimental compartment and the experiment was started. Each experiment was

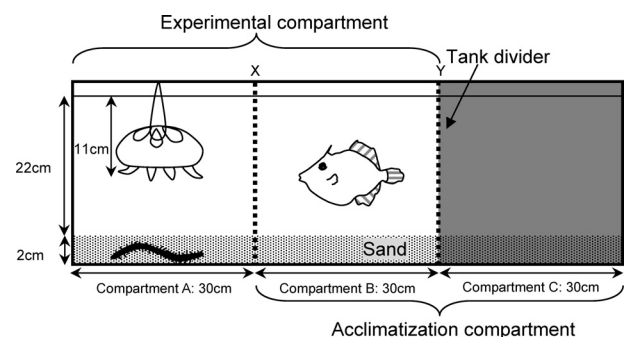


Fig. 1. Schematic drawing of an experimental tank used in the mixed prey and sand bottom (MS) treatment. The tank divider was moved from X to Y after the lobworm had completely buried itself in the sand. Except for the front of the experimental compartment (compartment A+B), the tank was covered with a black vinyl sheet.

conducted for 30 min and feeding behavior was recorded using a digital video recorder (DCR-PC100, Sony, Japan).

In the video analysis, response latency was defined as the time required for a filefish to start pecking at the jellyfish or at the tank sediment in JS, LS and MS treatments, or at the jellyfish or lobworm in the MG treatment. Bottom pecking was considered to indicate lobworm searching behavior in treatments with sediments. If no pecking behavior was observed during the experiment, then RL was taken as 1800 sec (=30 min). Search time was calculated by summing all of the periods when the intervals between pecking the sand bottom occurred within 30 sec of each other. A period of 30 sec was used because, when presented with a jellyfish, filefish usually pecked the jellyfish for a maximum of 30 sec. Feeding time was calculated by summing the times when the intervals between feeding on the jellyfish or lobworm occurred within 30 sec of each other, or when the jellyfish or lobworm was held in the mouth. Foraging time was defined as the total time spent searching for and/or eating food. Organic matter consumption per unit foraging time was calculated to estimate foraging efficiency. The organic content of jellyfish was calculated as in Lucas (1994) to be 0.003% of total wet weight (average bell diameter: 81–90 and 100 < mm). Lobworm organic content was estimated by combustion at 550°C for 2 h after drying at 110°C for 13 h.

The initial food weight, consumption of jellyfish, and consumption of jellyfish organic matter per unit foraging time were compared among treatments using one-way ANOVA. RL was compared using the log-rank test with Bonferroni correction (adjusted $\alpha=0.0083$), and the Steel-Dwass test was used to compare differences in foraging time among treatments. The Mann-Whitney U test was used to compare RL, foraging time and organic matter consumption per unit foraging time obtained for the two prey items. Values were considered significant at $p<0.05$.

Results

Filefish responded to the jellyfish first when the tank bottom was covered by sand (JS, MS), whereas they started to feed on the lobworm first in the glass bottom treatment (MG). The RL for jellyfish was significantly less than that for the tank bottom in the JS and MS treatments (Fig. 2a). Although not significant, the RL for lobworms was only 25% of the RL obtained for jellyfish in the MG treatment ($p=0.10$, Mann-Whitney U test). The RL for lobworm or bottom was shortest in the MG treatment, followed by the MS, LS and JS treatments; a significant difference was observed between the MG and JS treatments (log-rank test). The RL for jellyfish was shortest in the MS treatment, followed by the JS and MG treatments, and a significant difference was observed in the RL for jellyfish between MS and MG treatments (log-rank test).

When feeding on jellyfish, filefish started on the tentacles and moved onto the gastric cavity, gonads and oral arms

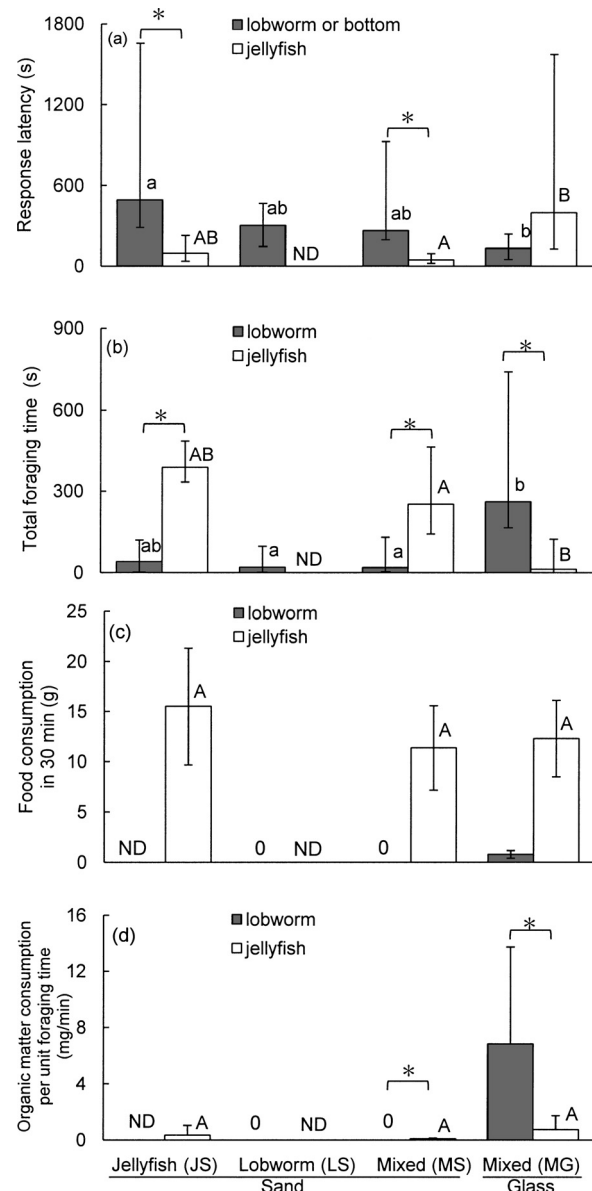


Fig. 2. (a) Response latency of filefish associated with lobworm (or bottom) and jellyfish expressed as median \pm interquartile range. (b) Total foraging time of filefish on lobworm and jellyfish (median \pm interquartile range). (c) Food consumption of filefish on lobworm and jellyfish (mean \pm SD). (d) Organic matter consumption per unit foraging time of filefish on lobworm and jellyfish (mean \pm SD). Different lower case and uppercase letters indicate significant differences among treatments ((a): $p<0.05$, log-rank test with Bonferroni correction, adjusted $\alpha=0.0083$; (b): $p<0.05$, Steel-Dwass test; (c) $p=0.14$, one-way ANOVA; (d) $p=0.16$, one-way ANOVA). Asterisks (*) in parentheses indicate a significant difference between prey items ($p<0.05$, Mann-Whitney U test). ND indicates that no data were available.

while leaving most of the umbrella. When feeding on lobworms, filefish held the worms in their mouths and swam for most of the foraging time before feeding. In the MS

treatments, the time spent foraging for jellyfish was significantly longer than that for lobworm (Mann–Whitney *U* test) and none of the fish were able to find a lobworm within 30 min. However, the foraging time for lobworm was significantly longer than it was for jellyfish in the MG treatment (Mann–Whitney *U* test), and it was also significantly longer than that in the LS and MS treatments (Fig. 2b, Steel–Dwass test). Foraging time for jellyfish was longest in the JS treatment, followed by the MS and MG treatments, with a significant difference observed between MS and MG treatments (Steel–Dwass test).

During the 30 min trial period, an average of 0.8 ± 0.4 g, or $5.5 \pm 3.0\%$ of fish BW, of lobworm were consumed in the MG treatment (Fig. 2c). Filefish in most trials of the MG treatment foraged on jellyfish after eating the lobworm. An average of 13.1 ± 4.9 g, or $98.9 \pm 25.1\%$ of fish BW, of jellyfish was consumed in the JS, MS and MG treatments; there was no significant difference in the consumption of jellyfish among treatments ($p=0.14$, one-way ANOVA). Fish in the JS, MS and MG treatments consumed $23.7 \pm 8.5\%$ of the jellyfish provided, whereas those in the MG treatment consumed $86.4 \pm 8.8\%$ of the lobworm. Seventy percent of the filefish in the MG treatment ate the whole lobworm, while the remaining 30% did not; there was no tendency to leave a particular part of the lobworm.

The organic content of the lobworms was 2.97% of wet weight. Jellyfish organic matter consumption per foraging time was significantly higher than that of lobworm in the MS treatment (Fig. 2d, Mann–Whitney *U* test). In the MG treatment, however, lobworm consumption per unit foraging time was significantly higher (9.1 times) than that of jellyfish (Mann–Whitney *U* test). Consumption of lobworm organic matter per unit foraging time was 6.84 ± 6.89 mg/min (mean \pm SD) in the MG treatment. Consumption of jellyfish organic matter per unit foraging time was 0.75 ± 0.10 mg/min in the MG treatment, 0.34 ± 0.70 mg/min in the JS and 0.09 ± 0.05 mg/min in the MS treatment, with no significant difference observed between treatments ($p=0.16$, one-way ANOVA).

Discussion

When both prey species were readily available, filefish exhibit a preference for lobworms. However, if only jellyfish are visible, then the filefish will feed on the jellyfish as indicated by the RL. The differences observed in the RLs between treatments with different substrates are considered to be related to lobworm accessibility. Filefish were capable of consuming large amounts of jellyfish within a limited time (=30 min), with the foraging efficiency of filefish feeding on jellyfish being slightly higher when the jellyfish was visible and the lobworm was not. However, when both potential prey items were visible, the foraging efficiency of filefish was markedly higher for lobworm than it was for jellyfish.

Although moon jellyfish are composed of 96% liquid and

lipid composes only 4–12% of the solid (Lucas 1994), Fukuda & Naganuma (2001) reported that they are rich in highly-unsaturated fatty acids (24.1–24.3% total fatty acids), such as docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA) and arachidonic acid (AA). Therefore, if filefish have the ability to remove the water and ash components of jellyfish, they would be able to obtain a considerable amount of nutrients from a jellyfish diet. Conversely, the moisture content of lobworm *P. nuntia vallata* is 78% of wet weight (Miyajima unpubl.) and the lipid content is only 1.0% (Saito et al. 2006). Olive et al. (2009) reported the EPA content of the lugworm *Arenicola marina* (Linne), another polychaete, to be 11.5% of the total fatty acid content. Arai (2005) reported that the calorimetric value of jellyfish per unit mass (wet basis) was less than 20% that of arthropods, implying that jellyfish contains fewer nutrients than other common prey item. In addition, several species of jellyfish, including the moon jellyfish, contain neurotoxins that need to be metabolized or neutralized. It is therefore not surprising that filefish exhibit a preference for lobworms when both prey items are readily available.

In treatments with sandy bottoms where jellyfish were visible and lobworms were not, filefish showed a preference for jellyfish and took little time to search for lobworms. This apparent preference may be explained by the costs associated with searching for prey. Lobworms generally remain buried in benthic substrates or under rocks in nature and are likely to be difficult to detect using visual cues. Filefish often search for their prey by forcefully expelling water through their mouths to expose objects buried beneath the sand (Meysman et al. 2005), or they may “peck” at rock surfaces. This type of searching behavior is relatively energy intensive compared to locating jellyfish which are larger in size and planktonic. Filefish can thus save energy if they feed on jellyfish.

The present findings also suggest that relatively large amounts of jellyfish are consumed. Jellyfish are usually larger than other prey items; the wet weight of one moon jellyfish is approximately 60 times that of one lobworm. In addition, as has been demonstrated for other gelatinous prey items, jellyfish are relatively easy to digest (Arai et al. 2003). Since filefish are pecking feeders, neither the size nor the texture of jellyfish is likely to reduce the feeding efficiency (Suyehiro 1934). Interestingly, this also means that once a filefish finds a jellyfish, it can consume large quantities at a time, which compensates slightly for the relatively low nutritional value of jellyfish. In previous experiments, we showed that filefish juveniles fed a diet of only moon jellyfish for 16 days not only survived, but increased in size by consuming as much as 24 times their body weight per day (Miyajima et al. unpubl.). The consumption of jellyfish in the present study is thus likely to have provided sufficient energy for sustaining the metabolism of the fish had which had free access to the jellyfish for an entire day.

Further, in addition to the jellyfish itself, filefish in the wild may consume the small zooplankton collected by jel-

lyfish. Parasites of jellyfish have also been found in the gut contents of jellyfish predators, such as juveniles of chinook salmon *Oncorhynchus tshawytscha* (Walbaum) and coho salmon *O. kisutch* (Walbaum) (Schabetsberger, 2003). However, in contrast to jack mackerel *Trachurus japonicus* (Temminck & Schlegel,) juveniles which feed on jellyfish stomach contents (Masuda et al., 2008), filefish appear to feed directly on the body of the jellyfish.

In our experiments, filefish did not locate any of the lobworms hiding in sand during the 30 min period allocated for foraging. Possible reasons for this are that the searching ability of hatchery reared fish is inferior to that of wild fish, or that lobworms in a 1800 cm² area (5.6 indiv. m⁻²) are difficult for filefish to find within a 30 min period. However, based on observations of wild filefish, it is unlikely that filefish would be able to locate find lobworms in 30 min under MS conditions (Miyajima unpubl.). Further research involving changes in lobworm density are required in order to quantitatively assess the foraging behavior of filefish.

The mobility of prey is also an important consideration in prey selection. Peterka & Matena (2009) demonstrated that prey selection in young-of-the-year roach *Rutilus rutilus* (Linne) was determined by prey evasiveness. In our study, the movement of jellyfish was restricted because they were tethered by a string. This may have resulted in some over-estimation of jellyfish consumption as our preliminary experiments revealed that, compared to the tethered jellyfish, filefish consumed only 57% of the free-swimming jellyfish. In the natural environment, jellyfish often drift with the current (Albert 2007). Since filefish are both demersal and territorial, they may not chase after jellyfish that drift away from their habitat. Rather, given the increasing frequency of jellyfish blooms, filefish are more likely to feed on jellyfish as they drift by. Further laboratory experiments simulating various fish-jellyfish interactions and based on field surveys are required.

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