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Predation risks for juvenile fishes in a mangrove estuary: A comparison of vegetated and unvegetated microhabitats by tethering experiments

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ABSTRACT

Predation rates for juveniles of three fish species, the resident cardinal fish *Apogon amboinensis*, vagile mojarra *Gerres erythrourus* and benthic resident sand goby *Favonigobius reichei*, were compared in a creek between a mangrove-root area (fringing area with submerged portions of mangrove roots) and a bare sand area (unvegetated central area) in the Urauchi River mangrove estuary, Iriomote island, southern Japan, by daytime tethering experiments. *A. amboinensis*, occurring restrictedly in the mangrove-root area, hovered inactively near mangrove roots during the day. The other two species, on the other hand, inhabited both mangrove-root and bare sand areas, *G. erythrourus* swimming actively and speedily in the water column and *F. reichei* resting immobile on the substratum, its body coloration similar to the later. The predation mortality rate of *A. amboinensis* was significantly lower in the mangrove-root area than the bare sand area, whereas no differences in the rates for *G. erythrourus* and *F. reichei* were found between the two microhabitats. In addition, species and individual densities of piscivorous fishes, determined from a visual census, were significantly higher in the mangrove-root area, suggesting that the potential predation risk was not necessarily lower. The lower mortality rate of *A. amboinensis* in such a predator-rich area may be due to their anti-predator tactic associated with mangrove structural complexity, sheltering behind mangrove roots when disturbed by predators. The similar mortality rates of the other two species between the microhabitats may have resulted from anti-predator tactics independent of mangrove vegetation structure, such as rapid flight and cryptic body coloration.

1. Introduction

Tropical and subtropical mangrove estuaries often support large numbers of fish species and individuals compared to nearby open-water mud- or sandflats, thereby suggesting that mangroves provide nursery habitats for juveniles of many species (Blaber, 2000; Kathiresan and Bingham, 2001; Nagelkerken, 2009; Nagelkerken et al., 2008; Robertson and Blaber, 1992). Hypotheses that have been proposed to explain the high abundance of small juvenile fishes in mangrove estuaries have been based mainly on the provision by mangroves of effective feeding and refuge areas from predators for juvenile fishes (Laegdsgaard and Johnson, 2001; Manson et al., 2005; Verweij et al., 2006). Among these hypotheses, the refuge value of mangrove habitats has been supported especially by the following: (1) shallow waters exclude large piscivorous fishes (Blaber and Blaber, 1980; Paterson and Whitfield, 2000; Rypel et al., 2007), (2) high turbidity decreases underwater visibility, thereby creating difficulties for visual predators in detecting and catching small prey (Blaber and Blaber, 1980; Cyrus and Blaber, 1987), and (3) the structural complexity of mangrove vegetation provides protection for small fishes in several ways, such as reducing prey visibility, and limiting the searching and catching ability of predators (Laegdsgaard and Johnson, 2001; Rönnbäck et al., 1999).

The potential refuge value of these factors for small fishes, however, has usually been inferred indirectly from habitat use patterns by juveniles and/or piscivores. For example, the sheltering effects of mangrove vegetation structures, such as prop roots, pneumatophores and tree trunks, are mainly supported by results showing higher densities of small fishes and juveniles and/or lower densities of larger carnivores in mangrove habitats than in unvegetated habitats (Blaber, 2000; Robertson and Blaber, 1992; Robertson and Duke, 1987; Shinnaka et al. 2007). Such differential densities, however, do not serve as direct evidence for the sheltering effects of mangrove vegetation structures, because the possibility remains that such patterns may reflect other factors, such as habitat preferences and/or prey availability.

In addition, the densities of small fishes are not always higher in complex vegetation microhabitats in mangrove estuaries (Smith and Hindell, 2005). Microhabitat use patterns of small fishes differ among species, some fishes occurring mainly in structurally complex areas

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with prop roots and/or pneumatophores while others include bare sand/mud substrata. The sheltering function of mangrove vegetation structures, therefore, may differ among fish species, as already pointed out for a seagrass system (e.g. Horinouchi, 2007a; Horinouchi et al., 2009; Nakamura and Sano, 2004). Accordingly, predation mortality patterns in mangrove systems should be examined in detail.

In the present study, the predation mortality patterns of small juvenile fishes, i.e. the cardinal fish *Apogon amboinensis*, mojarra *Gerres erythrourus* and sand goby *Favonigobius reichei*, which are abundant in the study site, were examined across microhabitats in the mangrove estuary by tethering experiments. The tethering technique, although having some deficiencies (e.g. Curran and Able, 1998; Manderson et al., 2004; Peterson and Black, 1994), is nevertheless an effective tool for quantifying relative predation pressures among habitats and has been employed in many earlier studies (e.g. Baker and Sheaves, 2007; Horinouchi, 2007b; Laegdsgaard and Johnson, 2001; Nakamura and Sano, 2004; Nakane et al., 2009). In this study, the following questions were addressed: (1) Does predation mortality differ between the mangrove-vegetated and unvegetated sand/mud areas? (2) Does the predation mortality pattern differ among the prey species?

2. Materials and methods

2.1. Study site

The study was conducted in a creek in the Urauchi River mangrove estuary (24°24′ N, 123°46′ E), situated on the northern side of Iriomote Island, Ryukyu Islands, Japan, in August and September 2009 (Fig. 1). The mangrove forest comprised dense, undisturbed mature trees, dominated especially by the red mangrove *Rhizophora stylosa*.

Two microhabitats in the study creek were chosen for the tethering experiments: (1) the fringing area with submerged portions of mangrove roots in the creek (hereafter called “mangrove-root area”) and (2) the unvegetated central area of the creek (hereafter called “bare sand area”). The mean density of prop roots in the former area was 63.3 ± 3.7 (standard error) m^{-2} ($n = 20$). The tidal range within the creek was approximately 1.5 m, prop roots being inundated at high tide and partially exposed at low tide. Mean water temperature and salinity were 30.1 ± 0.02 °C and 31.3 ± 0.1, respectively, during the study period. Mean water turbidity and clarity at high tide were 7.1 ± 0.7 NTU and 4–6 m, respectively, indicating that the study site could be classified as a “clear water” estuary (Blaber et al. 1997). These environmental factors remained constant between the two microhabitats.

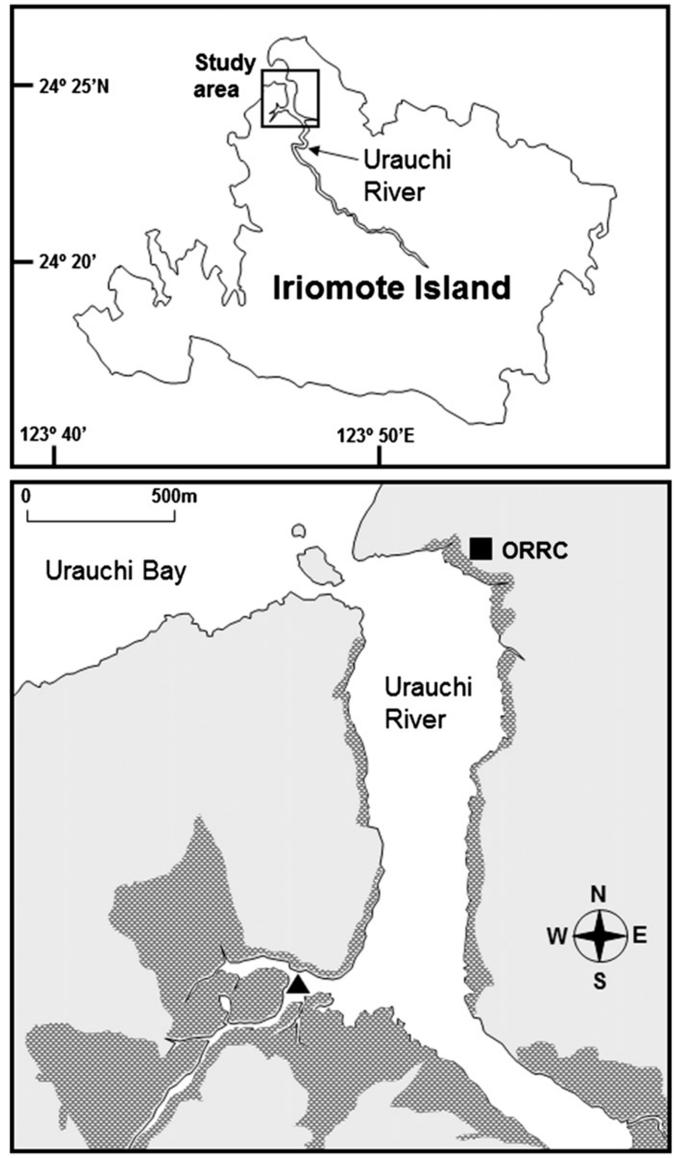

Fig. 1. Map of the Urauchi River mangrove estuary, Iriomote Island, Ryukyu Islands, Japan. Shaded areas indicate mangrove forests. ▲, experimental site; ■, Okinawa Regional Research Center, Tokai University (ORRC).

2.2. Tethering experiment

2.2.1. Experimental prey fish species

Juveniles of three species, the resident cardinal fish *A. amboinensis*, vagile mojarra *G. erythrourus* and benthic resident sand goby *F. reichei*, were employed as representatives of the common prey fish types in the mangrove estuary. They are relatively abundant during the summer season (June–September), being frequently preyed upon by piscivorous fishes (Nanjo et al., 2008). Adults of the former also occurred in the Urauchi River mangrove estuary. The occurrence of *A. amboinensis* was mostly restricted to the mangrove-root area (annual mean density 28.6/20 m^2) (Nanjo, unpublished data), juveniles hovering inactive, although sometimes forming a group, near roots during the day. In contrast, juveniles of *G. erythrourus* and *F. reichei* occurred in both mangrove-root and bare sand areas (annual mean densities 1.6/20 m^2 and 0.2/20 m^2 for *G. erythrourus*; 0.4/20 m^2 and 0.3/20 m^2 for *F. reichei*, respectively) (Nanjo, unpublished data). Juvenile *G. erythrourus*, often forming small aggregations of <10 individuals, swam actively in the water column during the daytime. Solitary *F. reichei* juveniles remained motionless on the substrate surface.

2.2.2. Tethering procedure

To compare relative predation rates for each fish species between the mangrove-root area and bare sand area, tethering experiments were conducted in the mangrove creek (Fig. 1). Tethering experiments can only measure relative predation rates rather than actual predation rates (Peterson and Black, 1994), because of potential artifacts, such as changes in behavior or escape responses of tethered fish, resulting in increased vulnerability to predators (Curran and Able, 1998; Peterson and Black, 1994). The effects of tethering on prey behavior and vulnerability should be assumed as remaining constant across treatments. When the physical nature of the habitats differs between treatments (e.g. vegetated and unvegetated habitats), interactions between experimental artifacts and treatments are most likely to be a problem, especially when tethered prey becomes entangled in vegetation (one treatment) and is less able to avoid predators (Peterson and Black 1994). In addition, it is possible that habitat differences in predator guilds, the predator's ability to detect and capture prey, and prey hiding ability, would interact with experimental artifacts. These inherent limitations must be considered when interpreting results. In order to overcome such deficiencies, we conducted field observations