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Effects of mangrove structure on fish distribution patterns and predation risks

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ABSTRACT

This study examined the effects of mangrove structure on fish distribution patterns and predation risks in southern Japan, utilizing field experiments in which artificial units mimicked mangrove root structure and canopy shade in a mangrove estuary. Fishes responded strongly to the different levels of root structure complexity but not to canopy shade, fish species richness and abundance being consistently higher in the units with roots than in those without roots, regardless of shade presence/absence. With increasing root density, fish abundance increased considerably, although with decreasing fish body size. A tethering experiment, employing the above units and the most abundant local fish *Apogon amboinensis* as representative of small fishes, revealed that the predation mortality rates of small fishes decrease with increasing root density. The results suggested that the sheltering effects provided by root structure against predators may be one of the most important factors determining the distribution patterns of mangrove-associated fishes, and at least partly explain the greater abundance of small-sized fishes in microhabitats with greater root densities.

1. Introduction

It is generally believed that tropical mangrove estuaries often support large numbers of fish species and individuals compared to nearby unvegetated bare substrata, which are usually characterized by fewer species and individuals (Blaber, 2000; Kathiresan and Bingham, 2001; Nagelkerken et al., 2008; Robertson and Blaber, 1992; Shinnaka et al., 2007). Habitat complexity structured by mangrove vegetation has been recognized as one of the major factors responsible for this, due to the greater habitat complexity providing shelter from predation, increased microhabitat availability and abundant food (Blaber, 2000; Manson et al., 2005).

Mangrove vegetation is characterized by several structural aspects, such as the complex structure of prop-roots, and canopy shade provided by a roof of branches and leaves above the water surface, such structures combining to form potential refuge sites from predators (Ellis and Bell, 2004; Laegdsgaard and Johnson, 2001; Nanjo et al., 2011). However, to date, only a few experimental studies have been conducted to examine the relationships of mangrove habitat structure and possible refuge function with fish distribution patterns. In addition, most of these studies were conducted in non-estuarine mangrove areas in the Caribbean region, where the mangrove root areas are continuously inundated due to small tidal ranges (Cocheret de la Moriniere et al., 2004; Nagelkerken et al., 2010; Verweij et al., 2006). However, the majority of mangroves world-wide, especially in the Indo-Pacific region (FAO, 2007), are found primarily in river–estuarine systems where the tidal range is relatively greater than in the Caribbean region, mangrove root areas therefore being more likely to be exposed at low tide. In addition, Indo-Pacific riverine mangroves differ in some habitat features from Caribbean mangroves (e.g. prop-roots of the former reach to the substratum, whereas those of the latter do not). Therefore, the findings of studies in the Caribbean region may not always be applicable to the majority of mangrove estuaries. Accordingly, further studies, especially in the Indo-Pacific region, are necessary for a more widespread understanding of the relationship between mangrove habitat complexity and fish distribution patterns.

Several studies conducted in coral reefs and seagrass beds have demonstrated that increased habitat complexity significantly reduces predation risks for small prey (Almany, 2004; Beukers and Jones, 1997; Gotceitas et al., 1997). Because of their vulnerability to predation (Sogard, 1997), this is especially important for small-sized fishes, such as juveniles, which sometimes actively select structurally complex habitats so as to reduce predation risks (e.g., Gotceitas et al., 1997; Lindholm et al., 1999; Nakamura et al., 2012). However, thus far no experimental studies have been conducted to examine whether or not increasing habitat complexity reduces the predation risks for small fishes in mangrove systems. Accordingly, little information exists on

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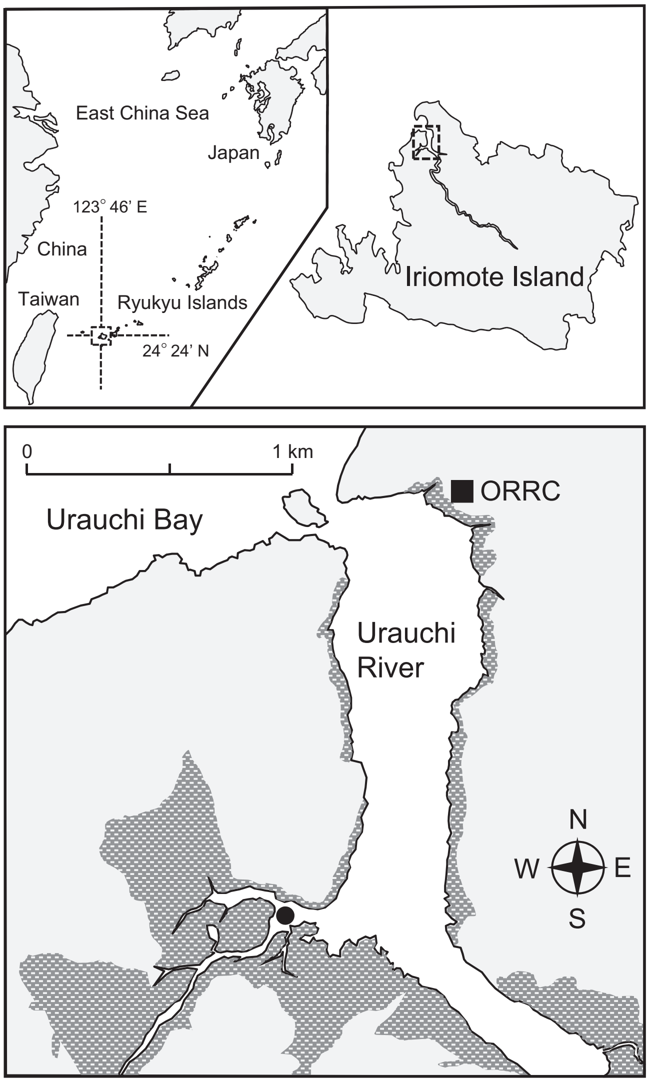

Fig. 1. Map of the Urauchi River mangrove estuary, Iriomote Island, Ryukyu Islands, Japan. Shaded areas indicate mangrove forests. Black circle shows the experimental site. Black square, Okinawa Regional Research Center, Tokai University (ORRC).

the effects of differential habitat complexity on the distribution patterns of and predation risks for small fishes in mangrove systems, particularly in the Indo-Pacific region.

The present study examined the effects of mangrove structure on fish distribution patterns and predation risks, utilizing field experiments in which artificial units mimicked mangrove structural properties, such as root complexity and canopy shade, in a mangrove system in southern Japan. Initially, the effects of root structure, canopy shade, and differences in root density on fish distribution patterns were investigated. Subsequently, we examined predation risk patterns for small fishes across several representative root density levels in the artificial units, using a tethering technique and the most dominant resident cardinal fish *Apogon amboinensis* as representative of the small fishes in the present mangrove system.

2. Materials and methods

2.1. Study site

The study was conducted in a creek of the Urauchi River (24°24′ N, 123°46′ E), situated on the northern side of Iriomote Island, Ryukyu Islands, Japan (Fig. 1), in July and August 2009 and July 2010 (summer), since juveniles of many fishes and some predatory fishes were most abundant in summer (Nanjo et al., 2011, 2014). Detailed information for the study site is given in Nanjo et al. (2014). The field experiments were conducted in the lower regions (0–250 m from the creek mouth) of the creek (Fig. 1), which were fringed by dense undisturbed mature mangrove forest, comprising predominantly red mangrove *Rhizophora stylosa*. The mean density, height and diameter of prop-roots in the fringing area of the mangrove forest were 63.3 ± 3.7 (standard error) m^{-2} (n = 20), 62.2 ± 2.9 cm (n = 100) and 3.3 ± 0.1 cm (n = 100), respectively, the physical properties of the roots being mimicked in the field experiments (see below). The tidal range within the creek was approximately 1.5 m with two tidal cycles per day, prop roots being inundated at high tide and partially exposed at low tide. Mean water temperature and salinity, measured by a small data logger (Compact-CT, JFE Advantech Co, Ltd.) anchored to a prop-root at the creek mouth, were 29.6 ± 0.02 °C and 31.0 ± 0.04, respectively, during the study period. Mean water turbidity, measured by a portable water quality analyzer (Model U-20XD, Horiba Ltd.), and clarity (horizontal visibility measured by a Secchi disk) at high tide were 2.0 ± 1.0 NTU and 4–6 m, respectively.

2.2. Study design

2.2.1. Experiment 1: the effects of root structure and canopy shade on fish distribution patterns

A field experiment using artificial units was conducted in July and August 2009 to examine whether or not the presence of roots and/or shade was important determinants of fish distribution patterns. Four treatments were undertaken: (1) both root structure and canopy shade present (STSH), (2) structure present and shade absent (ST), (3) structure absent and shade present (SH) and (4) both structure and shade absent (BS) (Fig. 2a). Five experimental units were employed for each treatment. The units for treatments with root structure (i.e. STSH and ST) comprised a concrete base (50 cm wide × 50 cm long × 3 cm deep) and polyvinyl chloride (PVC) pipes (60 cm in length, 3 cm in diameter) set vertically in the base at 10 cm intervals (i.e. 16 roots/0.25 m^2), so as to mimic the prop-roots of *R. stylosa* (hereinafter, PVC pipes referred to as artificial roots). The pipe density, length and diameter were in accordance with the average values of natural *R. stylosa* prop-roots at the study site. Bare sand areas (50 cm × 50 cm) chosen randomly in the area adjacent to the natural mangrove area served for the treatments of root structure absent (i.e. SH and BS). Canopy shade for the STSH and SH treatments was provided by 60 cm × 60 cm black shading fabric (polyethylene monofilament). After the establishment of a unit for each treatment with canopy-shade present (see below), the shading fabric was set 120 cm above the substratum surface, each corner being attached to a PVC pole support (2 cm diameter) (see Fig. 2a). The fabric was positioned so as to provide complete shading of the unit, at least during each census. Light intensity within the unit, measured by a small light intensity recorder (MDS-MkV/L, JFE Advantech Co, Ltd.) at ten randomly-established points, matched that measured under natural canopy conditions at midday (361.9 ± 25.1 μmol photons/m^2/s for artificial canopy shade, 343.1 ± 25.0 μmol photons/m^2/s for natural canopy shade; *t*-test, t = −0.496, P = 0.626).

As a preliminary precaution, the experimental units were immersed in water near the study creek for more than four days before the trial, in order to remove any effects of lye derived from the concrete base.

Twenty points were randomly established at low tide in the creek along the mangrove forest fringe, adjacent points being separated from each other by at least 3 m. Each point was assigned randomly to a single treatment and the corresponding unit. The concrete bases were buried completely in the substratum one day prior to starting the census.

Visual censuses were conducted once per day at high tide (ca. water depth 1.2 m) between 09:00 and 17:00 h for six consecutive days. Fishes occurring in each unit were counted and their total lengths (TL)