Estuarine, Coastal and Shelf Science 86 (2010) 467–476

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

# Physical factors influencing immature-fish communities in the surf zones of sandy beaches in northwestern Kyushu Island, Japan

Ryutei Inui [a,*], Takashi Nishida [b], Norio Onikura [a], Katsuhisa Eguchi [c], Motoyoshi Kawagishi [a], Masaya Nakatani [a], Shin Oikawa [a]

[a] Fishery Research Laboratory, Graduate School of Bioresource and Bioenvironmental Science, Kyushu University, 2506 Tsuyazaki, Fukutsu, Fukuoka 811-3304, Japan
[b] Japan Pulp & Paper Research Institute, Inc., Tokodai 5-13-11, Tsukuba, Ibaraki 300-2635, Japan
[c] Saga Prefectural Fisheries Research and Development Center, 6966 Nagoya, Chinzei, Karatsu, Saga 847-0401, Japan

ARTICLE INFO

*Article history:*
Received 17 January 2009
Accepted 27 September 2009
Available online 30 October 2009

*Keywords:*
physical conditions
sandy beach
surf zone
fish assemblage
fish community

*Regional index terms:*
Japan
Kyushu Island
Japan Sea

ABSTRACT

We aim to understand the relationships between physical conditions and characteristics of the immature-fish community in surf zones of sandy beaches. Therefore, we obtained fish samples between March 2007 and February 2008 and analyzed certain physical conditions in the surf zones of 21 sandy beaches on the coastline of the northwestern Kyushu Island, Japan. We collected a total of 83 species and 6458 immature individuals. In a BIO-ENV analysis, the highest correlation was observed between fish assemblage and S20 (i.e., the slope from the shoreline to the sites where the depth was 20 m) and current velocity (CV) values. Stepwise multiple linear regression analyses revealed that the number of species and individuals decrease with an increase in the S20 and CV values. These results show that species richness and the abundance of immature-fish increase under shelving and calm conditions. Thus, immature-fish assemblages are strongly influenced by the prevailing physical conditions. Moreover, in six of the 10 dominant species, a negative correlation was observed between CV and abundance. On the other hand, S20 was found to be the explanatory variable only in the case of the most dominant species, i.e., *Gymnogobius breunigii*. Furthermore, a positive correlation was observed between S1 (i.e., the slope from the shoreline to the sites where the depth was 1.0 m at the mean tidal level) and median particle size (i.e., MPS of the sediments) and the abundances of *Sillago japonica* and *Favonigobius gymnauchen*, respectively, and a negative correlation with salinity, in the case of *Acanthogobius lactipes*. We conclude that the characteristics of the fish community in surf zones on sandy beaches are determined by not only the shelving and calm conditions, which influence fish assemblages and abundances, but also the habitat diversity, which influences the diversity of fish species.



## 1. Introduction

Surf zones of sandy beaches over the world play multiple roles such as functioning as transit routes and/or habitats for many fish species, particularly the immature individuals (McLachlan and Brown, 2006). In general, fish conservation and management strategies, such as habitat enhancement and fish stocking, require not only the evaluation of the ecological function of fish habitats but also the elucidation of the relationships between fish populations and the physical conditions in their habitats (Beger and Possingham, 2008; Valavanis et al., 2008). To ensure the overall development of fish conservation and management strategies, it is essential to investigate the relationship between fish populations and the physical conditions in surf zones.

Several studies have indicated the existence of relationships between physical conditions and the number of fish species and individuals (Romer, 1990; Kinoshita, 1993; Clark, 1997; Nakane, 2008), the composition of fish fauna or assemblages (Akazaki and Kimoto, 1989; Akazaki and Taki, 1989; Clark et al., 1996; Arayama et al., 2002), and the appearance patterns of the fishes of each lifestyle group (Gomes et al., 2003; Strydom, 2003; Strydom and D'Hotman, 2005). However, the potential relationships between the physical conditions and various features of the fish communities, such as abundance, diversity, and abundance of each lifestyle group need to be comprehensively analyzed to identify the physical conditions that affect the fish communities. To date, there have been no studies on these aspects.

Marine and estuarine fish communities are largely influenced by the distribution of the dominant fish species (Catalán et al., 2006; Franco et al., 2006; Nanami and Endo, 2007; Selleslagh and Amara, 2008; Shibuno et al., 2008). In particular, studies conducted at

* Corresponding author.
*E-mail addresses:* inuiryutei@yahoo.co.jp, ryutei@bun.bbiq.jp (R. Inui).

0272-7714/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecss.2009.09.034

various sites have reported that the larvae and juveniles of the dominant species are present in large amounts in the surf zones of sandy beaches (Clark et al., 1996; Harris and Cyrus, 1996; Layman, 2000; Pessanha and Araújo, 2003; Strydom and D'Hotman, 2005). Since the abundance of the dominant species influences the nature of the fish community at each site, it is necessary to investigate the existing physical conditions to identify the conditions that influence the dominant fish communities and thereby determine the relationships between the physical conditions and fish communities in the surf zones of sandy beaches.

In this study, we aim to clarify the relationships between the physical conditions and the immature-fish communities in the surf zones of sandy beaches. To this end, we conducted fish sampling; investigated the physical conditions in the surf zones of sandy beaches; analyzed the relationships between various physical conditions and fish assemblages to determine the physical conditions that correlated with the fish assemblages; and analyzed the relationships between various physical conditions and fish diversity, total abundance, abundance of each dominant species, and diversity and abundance of each lifestyle group to obtain detailed information on the physical conditions that correlated with the fish communities.

## 2. Materials and methods

### 2.1. Study area

We selected 21 sandy beaches on the 150-km coastline of northwestern Kyushu Island, Japan (Fig. 1). This area faces the south of the Japan Sea, and the Tsushima Current flows along its northern side. This area shows temperate-fish fauna with several tropical fishes (Nishida et al., 2007). Sampling sites were set up at each sandy beach in this area.

### 2.2. Sampling and identification

Between March 2007 and February 2008, fish sampling was conducted during the spring tide once a month, when the Japan Meteorological Agency forecasted a calm wave (lower than 2 m). To ensure that the tidal conditions were as uniform as possible, we conducted sampling for 2 h before and 2 h after the mean tide levels during the daytime at all the beaches. Therefore, we required a few days to complete the sampling procedures at all the beaches. The fishes were captured using a small seine net (width, 10 m; depth, 1 m; mesh size, 1.5 mm). The net was extended for 2 m perpendicular to the shoreline and then pulled for 35 m parallel to the shoreline. The area swept during each haul at each site was approximately 70 $m^2$. We conducted two replicate sweeps at a shallow site with depth less than or equal to 70 cm, and the seine covered an area of 140 $m^2$ at each sampling site.

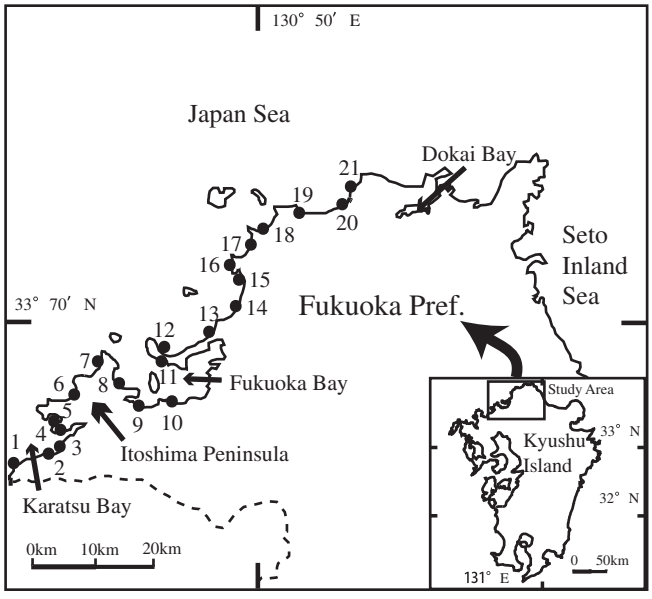


**Fig. 1.** Map of the survey sites in the sandy beaches in Fukuoka Prefecture, northern Kyushu Island, Japan.

The samples were preserved in 99% ethanol, identified to the species level (Okiyama, 1988; Nakabo, 2002), and counted; in addition, their standard lengths (SL) were measured. The captured fishes were categorized as larvae, juveniles, and adults according to the method proposed by Inoue et al. (2008); in this system, individuals in the developmental stages between hatching and attainment of a full set of external meristic characters are classified as larvae, and those in the immediately following stages until the attainment of sexual maturity are classified as juveniles. In addition, individuals were also classified into three lifestyle groups (marine species, estuarine species, and diadromous species) according to the criteria put forth by Okamura and Amaoka (1997), Kawanabe et al. (2001), Nakabo (2002), and Eguchi et al. (2008).

### 2.3. Physical conditions

At each beach, we measured the length of the sandy beach (LB; km), the distance from the river mouth to each sampling site (DRM; km), the slope from the shoreline to the sites where the depth was 20 m (slope over a large area, S20), the slope from the shoreline to the sites where the depth was 1 m at the mean tidal level (slope over a small area, S1), salinity (SAL), water temperature (WT; °C), median particle size of the sediments (MPS; mm), and the current velocity (CV; cm/s), which was used as an index of wave exposure.

S20, LB, and DRM were measured using a marine chart (Japan Coast Guard, Tokyo). To measure LB, we usually considered the lock headlands as the borders of the beaches. However, when there were large artificial structures such as fishing ports on the sandy beach or on the boundary of the beach and the lock headland, we considered the artificial structure as the border.

Before fish sampling at each beach every month, we measured SAL and WT at a depth of approximately 0.8 m by using YSI Model 30 (YSI/Nanotech Inc., Kanagawa).

CV was measured in June 2007, October 2007, and March 2008 by using plaster balls (Doris Japan Co., Ltd., Tokyo) during days with calm wave conditions during the neap tide. The plaster balls were set up at a depth of approximately 2 m (at the mean tidal level) for 25 h. CV was calculated on the basis of the reduction in the weight of the balls, and WT was determined according to the technique described by Yokoyama et al. (2004). MPS and S1 were measured at the mean tidal level. To determine the MPS, surface-sediment samples were obtained from the shoreline (at mean tidal level) of each beach in March 2008 by using a cylindrical corer (diameter, 12 cm; height, 5 cm). The collected sediments were sieved and separated into seven groups ($<$0.063 mm, 0.063–0.125 mm, 0.125–0.25 mm, 0.25–0.5 mm, 0.5–1 mm, 1–2 mm, and $>$2 mm) according to the method proposed by Matsumoto (1986). The sediment attributes were expressed in terms of the median particle size, which corresponded to the 50% ordinate value in the cumulative curve for this value (McLachlan and Brown, 2006). S1, which is the distance from the lateral line to the sites where the depth was 1 m, was measured at the mean tidal level on each beach. D1 was the average of SI values at three points that were set at 30-m intervals on a line parallel to the shoreline.