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

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## 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

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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.

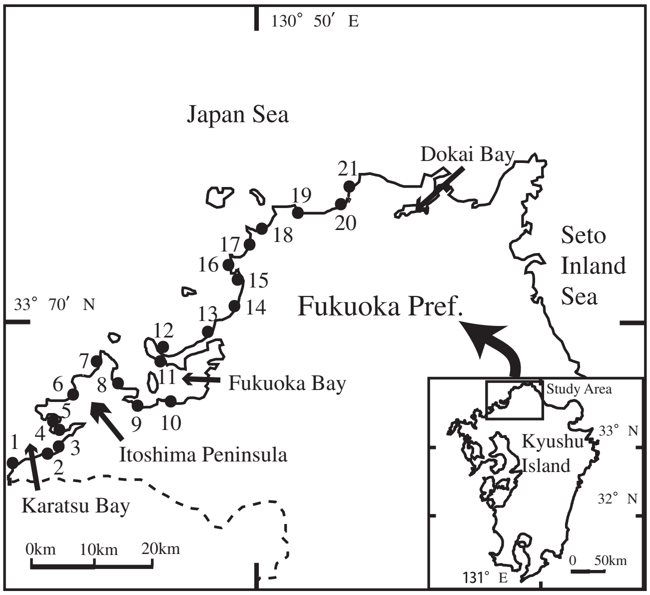

**Fig. 1.** Map of the survey sites in the sandy beaches in Fukuoka Prefecture, northern Kyushu Island, Japan.

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.

### 2.4. Data analyses

In this study, we used the data for immature-fish (larvae and juveniles), since very few adult individuals were collected. The similarity between the fish assemblages at the different sites was calculated by using the Bray–Curtis similarity coefficient on the basis of the number of individuals of each species, and the sampling sites were classified into several groups. Before the analyses, the abundance data were transformed to the corresponding log $(x+1)$ values. The resultant similarity matrix was subjected to cluster analysis (Ward's method) and non-metric multidimensional scaling (MDS). The average values for all the physical conditions, number of species (NS), number of individuals (NI), number of marine individuals (NMI), number of estuarine individuals (NEI), number of diadromous individuals (NDI), and abundance of each dominant species were compared by performing the Mann–Whitney *U*-test for the groups divided according to the cluster and MDS analyses.

BIO-ENV analysis (Clarke and Ainsworth, 1993) was performed to determine the subset of the physical conditions that showed the best correlation with the number of fish species in the fish community. Before the analysis, one-way ANOVA was performed to screen the physical conditions measured two or more times, and only the conditions that showed significant differences were used for the BIO-ENV analysis. The average values of the physical conditions were used for these analyses, and the fish abundance data and physical condition values were transformed to the corresponding log $(x+1)$ and log $(x)$ values, respectively (Zar, 1999).

The relationships between the physical conditions and the total fish diversity and abundances for each lifestyle group and for each dominant species were investigated by using stepwise multiple regression analysis. The average values of the physical conditions were used for these investigations; the data for the physical conditions were transformed to log $(x)$ values and those for fish diversity (NS), abundance (NI), and lifestyle types (NMI, NEI, NDI) were transformed to log $(x+1)$ values (Zar, 1999). These analyses were performed using the software SPSS 15.0 for Windows.

## 3. Results

### 3.1. Physical conditions

The types of borders and beaches and the average values for the physical conditions at each site are summarized in Table 1. One-way analysis of variance (ANOVA) was performed as a preliminary analysis, and the respective explanatory variables indicated that there were significant differences for S1 ($F = 19.994$, $p < 0.01$), SAL ($F = 5.895$, $p < 0.01$), and CV ($F = 12.240$, $p < 0.01$) and no differences for WT ($F = 6.475$, $p = 1.000$) among the survey sites.

### 3.2. Fish fauna

All the types of immature-fishes captured at the study sites are listed in Table 2. A total of 6597 individuals belonging to 83 species were collected, and most of these individuals were in the larval (20.3%) and juvenile (77.6%) stages. All the species consisted of at least some juvenile or larval individuals. These fish species were divided into marine species (67 species, 3282 immature individuals), estuarine species (nine species, 2825 immature individuals), diadromous species (five species, 327 immature individuals), and others (two species, 24 immature individuals). When the analysis was limited to immature-fish, the 11 dominant species were

**Table 1**

The types of borders (LH, rocky headlands; AS, artificial structures) and beaches (dissipative, intermediate, and reflective), and the average values (mean ± SD) for the physical conditions at each site, namely, the length of the sandy beach (LB), distance from the river mouth to each sampling site (DRM), slope from the shoreline to the sites where the depth was 20 m (S20), slope from the shoreline to the sites where the depth was 1 m at the mean tidal level (S1), salinity (SAL), water temperature (WT), median particle size of the sediments (MPS), and current velocity (CV).

| | St. 1 | St. 2 | St. 3 | St. 4 | St. 5 | St. 6 | St. 7 |
|---|---|---|---|---|---|---|---|
| LB (km) | 1.36 | 1.36 | 0.12 | 1.05 | 1.61 | 4.72 | 0.74 |
| DRM (km) | 1.54 | 0.50 | 0.69 | 3.30 | 7.75 | 1.18 | 7.59 |
| S20 | 1/189 | 1/318 | 1/285 | 1/338 | 1/226 | 1/147 | 1/70 |
| S1.0 | 1/43 ± 1/210 | 1/43 ± 1/882 | 1/9 ± 1/80 | 1/9 ± 1/80 | 1/20 ± 1/192 | 1/18 ± 1/30 | 1/29 ± 1/418 |
| SAL (ppt) | 32.9 ± 1.0 | 28.1 ± 5.2 | 32.2 ± 1.9 | 32.3 ± 1.3 | 32.7 ± 1.0 | 33.6 ± 0.8 | 33.0 ± 0.6 |
| WT (°C) | 20.7 ± 5.6 | 20.5 ± 5.9 | 20.8 ± 6.1 | 20.1 ± 5.9 | 20.4 ± 5.9 | 20.4 ± 5.5 | 20.6 ± 5.6 |
| MPS (mm) | 0.11 | 0.23 | 0.28 | 0.38 | 0.10 | 0.11 | 0.13 |
| CV (cm/s) | 9.84 ± 2.00 | 8.57 ± 0.76 | 4.13 ± 1.23 | 5.37 ± 0.93 | 3.31 ± 1.91 | 14.7 ± 3.16 | 11.7 ± 2.19 |
| Border of beach | LH, AS | LH, AS | LH | LH | LH, AS | LH | LH, AS |
| Beach types | Dissipative | Intermediate | Reflective | Reflective | Intermediate | Intermediate | Intermediate |
| | St. 8 | St. 9 | St. 10 | St. 11 | St. 12 | St. 13 | St. 14 |
| LB (km) | 3.22 | 2.21 | 1.08 | 1.90 | 3.61 | 5.65 | 3.71 |
| DRM (km) | 6.70 | 1.16 | 0.58 | 7.09 | 11.62 | 4.29 | 0.36 |
| S20 | 1/188 | 1/337 | 1/287 | 1/124 | 1/138 | 1/127 | 1/197 |
| S1.0 | 1/46 ± 1/1194 | 1/7 ± 1/97 | 1/9 ± 1/58 | 1/15 ± 1/109 | 1/21 ± 1/440 | 1/46 ± 1/435 | 1/24 ± 1/575 |
| SAL (ppt) | 32.6 ± 0.9 | 31.2 ± 2.3 | 30.8 ± 4.1 | 32.2 ± 1.4 | 33.7 ± 0.9 | 33.4 ± 0.8 | 31.9 ± 2.9 |
| WT (°C) | 20.8 ± 6.3 | 20.2 ± 7.0 | 20.4 ± 7.2 | 19.6 ± 6.8 | 20.9 ± 6.5 | 20.8 ± 6.5 | 20.6 ± 6.0 |
| MPS (mm) | 0.10 | 0.29 | 0.51 | 0.16 | 0.18 | 0.16 | 0.19 |
| CV (cm/s) | 11.2 ± 2.14 | 8.56 ± 2.24 | 6.68 ± 1.94 | 8.26 ± 1.26 | 17.8 ± 3.46 | 12.9 ± 2.43 | 14.5 ± 2.42 |
| Border of beach | LH | LH, AS | AS | LH, AS | LH, AS | LH, AS | LH, AS |
| Beach types | Dissipative | Reflective | Reflective | Reflective | Intermediate | Dissipative | Intermediate |
| | St. 15 | St. 16 | St. 17 | St. 18 | St. 19 | St. 20 | St. 21 |
| LB (km) | 2.74 | 0.57 | 5.26 | 3.90 | 8.84 | 8.84 | 0.26 |
| DRM (km) | 1.29 | 4.15 | 4.29 | 0.52 | 2.56 | 1.51 | 0.68 |
| S20 | 1/209 | 1/92 | 1/146 | 1/226 | 1/129 | 1/132 | 1/117 |
| S1.0 | 1/39 ± 1/311 | 1/41 ± 1/646 | 1/38 ± 1/135 | 1/52 ± 1/1808 | 1/22 ± 1/121 | 1/48 ± 1/269 | 1/34 ± 1/109 |
| SAL (ppt) | 32.4 ± 1.5 | 33.3 ± 0.7 | 33.3 ± 0.9 | 32.9 ± 1.3 | 33.2 ± 0.9 | 33.3 ± 0.9 | 28.9 ± 3.8 |
| WT (°C) | 19.9 ± 6.7 | 20.4 ± 5.8 | 19.9 ± 6.0 | 20.1 ± 6.1 | 20.3 ± 5.9 | 19.9 ± 5.3 | 19.7 ± 5.8 |
| MPS (mm) | 0.16 | 0.18 | 0.12 | 0.14 | 0.10 | 0.11 | 0.11 |
| CV (cm/s) | 7.77 ± 0.49 | 14 ± 1.2 | 13.3 ± 1.93 | 17.3 ± 1.12 | 10.3 ± 2.79 | 9.44 ± 1.29 | 9.94 ± 1.15 |
| Border of beach | AS | LH | LH, AS | AS | LH, AS | LH, AS | LH, AS |
| Beach types | Intermediate | Intermediate | Intermediate | Intermediate | Intermediate | Dissipative | Intermediate |

**Table 2**
Number of immature individuals of each species collected from each site during the survey; the individuals were captured using a small seine net. The size ranges (standard length, SL), and lifestyles (M, marine species; E, estuarine species; D, diadromous species; U, unknown species) are indicated for each species.

| Family | Species | Life style | Number of immature individuals captured in each sampling site | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | St. 1 | St. 2 | St. 3 | St. 4 | St. 5 | St. 6 | St. 7 | St. 8 | St. 9 | St. 10 | St. 11 |
| Ophichthidae | *Myrophinae* sp.2 | M | | | | | | 1 | | | | | |
| Congridae | *Ariosoma* sp. | M | | 1 | | | | 2 | | | | | |
| | *Gnathophis nystromi nystromi* | M | | | | | | 1 | | | | | |
| Clupeidae | *Etrumeus teres* | M | | | | | | | | | | | 1 |
| | *Spratelloides gracilis* | M | | | 3 | | | | | | | | |
| | *Konosirus punctatus* | M | 5 | 24 | 20 | | | | | | | | |
| Engraulidae | *Engraulis japonicus* | M | 120 | 2 | 4 | | | | 2 | 84 | | | 1 |
| Plecoglossidae | *Plecoglossus altivelis altivelis* | D | 1 | 3 | 6 | 2 | | 120 | | | 43 | 4 | 10 |
| Salangidae | *Salangichthys microdon* | E | | | 1 | | | | | | | | |
| Synodontidae | *Trachinocephalus myops* | M | | | | 2 | | | | | | | |
| | *Synodus macrops* | M | | | | | | | | | | | |
| Syngnathidae | *Urocampus nanus* | M | | | | | 1 | | | | 1 | 1 | |
| | *Syngnathus schlegeli* | M | 1 | 1 | 1 | 1 | 1 | | | | | | |
| Mugilidae | *Mugil cephalus cephalus* | M | | | | 1 | 1 | 1 | 3 | 5 | 1 | | |
| | *Chelon affinis* | M | | | 2 | | 4 | | | | | | |
| Atherinidae | *Hypoatherina valenciennei* | M | 1 | 24 | | | 1 | | | 1 | | 2 | 5 |
| Notocheiridae | *Iso flosmaris* | M | | | | | | 1 | | | | | |
| Belonidae | *Strongylura anastomella* | M | | 1 | | | | | | | | | |
| Scorpaenidae | *Sebastes inermis* | M | | | | | | | | | | 1 | |
| Triglidae | *Chelidonichthys spinosus* | M | 2 | | 1 | | 1 | 1 | | | | | |
| Platycephalidae | *Platycephalus* sp.2 | M | | 3 | | | | | | | | 1 | |
| Hexagrammidae | *Hexagrammos agrammus* | M | | | | 1 | | | | | | | |
| Family | Species | Number of immature individuals captured in each sampling site | | | | | | | | | | Total | SL (mm) |
| | | St. 12 | St. 13 | St. 1 4 | St. 15 | St. 16 | St. 17 | St. 18 | St. 1 9 | St. 20 | St. 21 | | |
| Ophichthidae | *Myrophinae* sp.2 | | | | | | | | | | | 1 | 39.1 |
| Congridae | *Ariosoma* sp. | | | | | | | | | | | 3 | 20.7–36.8 |
| | *Gnathophis nystromi nystromi* | | | | | | 1 | | | | | 2 | 27.8–29.7 |
| Clupeidae | *Etrumeus teres* | | | | | | | | | | | 1 | 54.7 |
| | *Spratelloides gracilis* | | | | 1 | | | | | | | 4 | 8.9–18.4 |
| | *Konosirus punctatus* | | 2 | | | | | | | | | 51 | 7.7–15.6 |
| Engraulidae | *Engraulis japonicus* | | 1 | | | | | | | | 1 | 215 | 8.7–60.6 |
| Plecoglossidae | *Plecoglossus altivelis altivelis* | | | | | | 70 | | | | | 259 | 13.5–48.9 |
| Salangidae | *Salangichthys microdon* | | | | | | | | | | | 1 | 22.4 |
| Synodontidae | *Trachinocephalus myops* | | | | | | | | | | | 2 | 35.7–70.6 |
| | *Synodus macrops* | | 1 | | | | | | | 1 | | 2 | 33.2–35.7 |
| Syngnathidae | *Urocampus nanus* | | | | | | | | | | | 3 | 33.2–86.3 |
| | *Syngnathus schlegeli* | | | | | | | | | | | 5 | 14.6–145.6 |
| Mugilidae | *Mugil cephalus cephalus* | | | | 3 | | 3 | 3 | | | 1 | 22 | 15.9–41.0 |
| | *Chelon affinis* | | | | | | | | | | | 6 | 30.9–45.6 |
| Atherinidae | *Hypoatherina valenciennei* | | | 1 | 79 | | | 3 | | 2 | | 119 | 7.6–86.9 |
| Notocheiridae | *Iso flosmaris* | | | | | | | | | | | 1 | 18.6 |
| Belonidae | *Strongylura anastomella* | | | | | | | | | | | 1 | 17.6 |
| Scorpaenidae | *Sebastes inermis* | | | | | | | | | | | 1 | 28.4 |
| Triglidae | *Chelidonichthys spinosus* | | | | | | | | | | | 5 | 17.4–77.8 |
| Platycephalidae | *Platycephalus* sp.2 | | | | | | | | | | | 4 | 8.0–120.1 |
| Hexagrammidae | *Hexagrammos agrammus* | | | | | | | | | | | 1 | 41.5 |
| Family | Species | Life style | Number of immature individuals captured in each sampling site | | | | | | | | | | |
| | | | St. 1 | St. 2 | St. 3 | St. 4 | St. 5 | St. 6 | St. 7 | St. 8 | St. 9 | St. 10 | St. 11 |
| Cottidae | *Furcina osimae* | M | | | | | | | | | | | |
| | *Pseudoblennius cottoides* | M | | | 1 | | | | | | 1 | 2 | |
| | *Pseudoblennius percoides* | M | | | | | 2 | | | | | | 1 |
| Moronidae | *Lateolabrax* spp. | M | 2 | 2 | 4 | | 24 | 5 | 1 | | 13 | 8 | 5 |
| Carangidae | *Decapterus maruadsi* | M | | | 1 | | | | | | 1 | | |
| Leiognathidae | *Leiognathus nuchalis* | M | | 1 | | 1 | 8 | | | | 6 | | |
| Gerreidae | *Gerres equulus* | M | 5 | 3 | 217 | | 15 | 5 | 5 | | 11 | 1 | 2 |
| Haemulidae | *Plectorhinchus cinctus* | M | | | 1 | | | | | | | | |
| Sparidae | *Sparus sarba* | M | 1 | 4 | 12 | 4 | 4 | | | | | 7 | 6 |
| | *Acanthopagrus schlegelii* | M | 3 | 3 | 18 | | 1 | | | | | 1 | |
| | *Acanthopagrus latus* | M | 2 | 6 | 2 | | 2 | | | | 3 | 2 | 1 |
| | *Pagrus major* | M | | | 1 | | 1 | | | | | | 1 |
| Sillaginidae | *Sillago japonica* | M | 3 | 5 | 119 | 36 | 51 | 1 | | | 271 | 30 | 111 |
| Mullidae | *Upeneus japonicus* | M | | | | | | | | 1 | | | |
| Embiotocidae | *Ditrema temmincki* | M | | | | | 1 | | | 3 | | | |
| Teraponidae | *Rhyncopelates oxyrhynchus* | M | | 1 | 1 | | | | | | | | |
| Microcanthidae | *Microcanthus strigatus* | M | | | 1 | 1 | | | | | | | |
| Girellidae | *Girella* spp. | M | 1 | | 2 | 27 | 15 | | | | 1 | | |
| Zoarcidae | *Zoarchias major* | M | | | | | 1 | | | | | | |
| Stichaeidae | *Dictyosoma burgeri* | M | | | | | | | | | | | 9 |
| Pholidae | *Pholis nebulosa* | M | | | | | | | | | 1 | 1 | |
| | *Pholis crassispina* | M | | | | 1 | | | | | | | |
| Family | Species | Number of immature individuals captured in each sampling site | | | | | | | | | | Total | SL (mm) |
| | | St. 12 | St. 13 | St. 14 | St. 15 | St. 16 | St. 17 | St. 18 | St. 19 | St. 20 | St. 21 | | |

**Table 2** (*continued* )

| Family | Species | Life style | Number of immature individuals captured in each sampling site | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | St. 1 | St. 2 | St. 3 | St. 4 | St. 5 | St. 6 | St. 7 | St. 8 | St. 9 | St. 10 | St. 11 |
| Cottidae | *Furcina osimae* | | | | | 1 | 1 | | | | | 2 | 13.2–47.9 |
| | *Pseudoblennius cottoides* | | | | | | | | | | | 4 | 7.9–47.4 |
| | *Pseudoblennius percoides* | | | | | | | | | | | 3 | 10.2–65.8 |
| Moronidae | *Lateolabrax* spp. | | 6 | 6 | 23 | | 14 | 2 | | 1 | 3 | 119 | 11.2–58.7 |
| Carangidae | *Decapterus maruadsi* | | | | | | | | | | | 2 | 10.7–11.4 |
| Leiognathidae | *Leiognathus nuchalis* | | | | | | | | | | | 16 | 7.7–50.1 |
| Gerreidae | *Gerres equulus* | | | 1 | 1 | | 1 | | 2 | 5 | 1 | 275 | 6.4–20.2 |
| Haemulidae | *Plectorhinchus cinctus* | | | | | | | | | | | 1 | 34.9 |
| Sparidae | *Sparus sarba* | | | | 2 | | | 1 | | | | 41 | 9.9–37.7 |
| | *Acanthopagrus schlegelii* | | | | | | | 1 | | | | 27 | 8.5–15.9 |
| | *Acanthopagrus latus* | | | 1 | | | | | 2 | 1 | 2 | 24 | 9.6–18.1 |
| | *Pagrus major* | | | | | | | | | | | 2 | 27.6–47.7 |
| Sillaginidae | *Sillago japonica* | | | 1 | | | 1 | 1 | | 1 | 1 | 632 | 10.1–72.5 |
| Mullidae | *Upeneus japonicus* | | | | | | | | | | | 1 | 28.8 |
| Embiotocidae | *Ditrema temmincki* | | | | | | | | | | | 4 | 45.9–51.6 |
| Teraponidae | *Rhyncopelates oxyrhynchus* | | | | | | | 2 | | | | 4 | 8.0–12.6 |
| Microcanthidae | *Microcanthus strigatus* | | | | | 1 | | 3 | | 1 | | 7 | 11.5–16.1 |
| Girellidae | *Girella* spp. | 3 | 1 | 1 | | 6 | | 1 | 8 | | 2 | 68 | 17.4–94.3 |
| Zoarcidae | *Zoarchias major* | | | | | | | | | | | 1 | 19.7 |
| Stichaeidae | *Dictyosoma burgeri* | 1 | | | 1 | | | | | | | 11 | 11.1–37.2 |
| Pholidae | *Pholis nebulosa* | 1 | | | | | | | | | | 3 | 18.0–101.6 |
| | *Pholis crassispina* | | | | | | | | | | | 1 | 66.4 |
| Family | Species | Life style | Number of immature individuals captured in each sampling site | | | | | | | | | | |
| | | | St. 1 | St. 2 | St. 3 | St. 4 | St. 5 | St. 6 | St. 7 | St. 8 | St. 9 | St. 10 | St. 11 |
| Percophidae | *Spinapsaron* sp. | M | 1 | | | | | | | | | | |
| Ammodytidae | *Ammodytes personatus* | M | | | | | | 1 | | | 5 | | |
| Chaenopsidae | *Neoclinus bryope* | M | | | | | | | | | | | 8 |
| Blenniidae | *Parablennius yatabei* | M | | | 2 | 1 | | | | | | | |
| | *Petroscirtes breviceps* | M | | | 1 | | | | | | | | |
| Callionymidae | *Repomucenus curvicornis* | M | | 1 | | 1 | | | | | | | |
| Gobiidae | *Taenioides cirratus* | E | | | | | | | | | | | |
| | *Leucopsarion petersii* | D | | 1 | 1 | | 1 | | | | 1 | | |
| | *Luciogobius* sp. | U | | 1 | | | | | | | 1 | 1 | 1 |
| | *Eutaeniichthys gilli* | E | | | | | | | | | | | |
| | *Chaenogobius annularis* | M | | | | | | | | | | | |
| | *Gymnogobius petschiliensis* | D | | | | 1 | | | | | | | |
| | *Gymnogobius urotaenia* | D | 1 | | | | | | | | | | |
| | *Gymnogobius heptacanthus* | M | | | 31 | | 156 | | | | | | 1 |
| | *Gymnogobius macrognathos* | E | | 3 | | | | | | | | | |
| | *Gymnogobius uchidai* | E | | 26 | 61 | | | | | | | | |
| | *Gymnogobius breunigii* | E | 21 | 188 | 498 | 12 | 157 | 1 | | | 727 | 335 | 1 |
| | *Acanthogobius lactipes* | E | | 432 | | | | | | | | | |
| | *Istigobius campbelli* | M | | | | | | | 1 | | | | |
| | *Cryptocentrus filifer* | M | | 5 | | | | | | | | | |
| | *Favonigobius gymnauchen* | M | | 1 | 151 | 58 | 65 | | | 2 | 14 | 68 | |
| | *Redigobius bikolanus* | E | | | | | | | | | | | |
| Family | Species | Number of immature individuals captured in each sampling site | | | | | | | | | | Total | SL (mm) |
| | | St. 12 | St. 13 | St. 14 | St. 15 | St. 16 | St. 17 | St. 18 | St. 19 | St. 20 | St. 21 | | |
| Percophidae | *Spinapsaron* sp. | | | 1 | | | | | | 3 | | 5 | 6.9–10.7 |
| Ammodytidae | *Ammodytes personatus* | | | | | | | | | | | 6 | 21.4–35.5 |
| Chaenopsidae | *Neoclinus bryope* | | | | | | | | | | | 8 | 8.4–12.6 |
| Blenniidae | *Parablennius yatabei* | | | 1 | | | | 1 | | | | 5 | 11.4–16.6 |
| | *Petroscirtes breviceps* | | | | | | | | | | | 1 | 16.6 |
| Callionymidae | *Repomucenus curvicornis* | | | | | | | | | | | 2 | 84.6–93.1 |
| Gobiidae | *Taenioides cirratus* | | | | | | | | | | 1 | 1 | 12.3 |
| | *Leucopsarion petersii* | | | | | | | 1 | | | | 5 | 17.5–42.8 |
| | *Luciogobius* sp. | | | | 2 | | | | | | | 6 | 11.3–16.4 |
| | *Eutaeniichthys gilli* | | | | 2 | | | | | 2 | | 4 | 8.9–10.6 |
| | *Chaenogobius annularis* | | 1 | | | 26 | | | | | | 27 | 11.2–16.5 |
| | *Gymnogobius petschiliensis* | | | | | | 4 | | 2 | | | 7 | 19.6–27.1 |
| | *Gymnogobius urotaenia* | | | | 1 | | | | | | | 2 | 17.5–25.0 |
| | *Gymnogobius heptacanthus* | | | | | | | | | | | 188 | 18.3–31.3 |
| | *Gymnogobius macrognathos* | | | | | | | | | | | 3 | 10.5–11.3 |
| | *Gymnogobius uchidai* | | | | | | | | | | | 87 | 11.0–18.4 |
| | *Gymnogobius breunigii* | | | | 344 | | | 4 | | | 1 | 2289 | 10.3–43.8 |
| | *Acanthogobius lactipes* | | | | | | | 1 | | | | 433 | 7.6–10.6 |
| | *Istigobius campbelli* | | | | | | | | | | | 1 | 5.3 |
| | *Cryptocentrus filifer* | | | | | | | | | 1 | | 6 | 9.8–12.2 |
| | *Favonigobius gymnauchen* | | | | 1 | | | 1 | | | 1 | 362 | 7.5–64.7 |
| | *Redigobius bikolanus* | | | | | | | | | | 3 | 3 | 5.8–6.3 |
| Family | Species | Life style | Number of immature individuals captured in each sampling site | | | | | | | | | | |
| | | | St. 1 | St. 2 | St. 3 | St. 4 | St. 5 | St. 6 | St. 7 | St. 8 | St. 9 | St. 10 | St. 11 |
| Gobiidae | *Acentrogobius* sp. B | M | | | | | 3 | | | | | | |

(*continued on next page*)

**Table 2** (*continued*)

| Family | Species | Life style | Number of immature individuals captured in each sampling site | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | St. 1 | St. 2 | St. 3 | St. 4 | St. 5 | St. 6 | St. 7 | St. 8 | St. 9 | St. 10 | St. 11 |
| | *Acentrogobius* sp. | U | 1 | 17 | | | | | | | | | |
| | *Rhinogobius* spp. | D | | 48 | | | | | | | 2 | | |
| | *Tridentiger trigonocephalus* | M | 1 | | | | 1 | | | 12 | 1 | | |
| | *Tridentiger obscurus* | E | | 1 | | | | | | | | | |
| Siganidae | *Siganus fuscescens* | M | | | | | | | | | | | |
| Paralichthyidae | *Paralichthys olivaceus* | M | 4 | 4 | 2 | 1 | 1 | | | 1 | | | |
| Bothidae | *Bothidae* sp. | M | | | | | | | | | | | |
| Soleidae | *Heteromycteris japonica* | M | 1 | | | | | | | 1 | | | 2 |
| Cynoglossidae | *Paraplagusia japonica* | M | | | | | | | | 5 | 1 | | 4 |
| Monacanthidae | *Rudarius ercodes* | M | 1 | | 1 | 1 | 2 | | | | 22 | | |
| | *Stephanolepis cirrhifer* | M | | | 3 | | | | | 1 | | | |
| | *Paramonacanthus japonicus* | M | | | 2 | | 1 | | | | | | |
| Tetraodontidae | *Takifugu pardalis* | M | | 1 | | | | | | | | | |
| | *Takifugu poecilonotus* | M | | 1 | | | | | | | 1 | | |
| | *Takifugu niphobles* | M | 542 | 100 | 110 | 16 | 7 | | | | 3 | 10 | 55 |
| | *Takifugu rubripes* | M | | | | | | | | | | | |
| Total number of species (NS) | | | 22 | 32 | 33 | 19 | 28 | 12 | 5 | 11 | 23 | 17 | 18 |
| Total number of immature individuals (NI) | | | 720 | 914 | 1281 | 168 | 528 | 140 | 12 | 116 | 1131 | 475 | 224 |
| Number of individuals: Marine species (NMI) | | | 696 | 194 | 714 | 153 | 370 | 19 | 12 | 116 | 357 | 135 | 212 |
| Estuarine species (NEI) | | | 21 | 650 | 560 | 12 | 157 | 1 | | | 727 | 335 | 1 |
| Diadromous species (NDI) | | | 2 | 52 | 7 | 3 | 1 | 120 | | | 46 | 4 | 10 |
| Family | Species | Number of immature individuals captured in each sampling site | | | | | | | | | | Total | SL (mm) |
| | | St. 12 | St. 13 | St. 14 | St. 15 | St. 16 | St. 17 | St. 18 | St. 19 | St. 20 | St. 21 | | |
| Gobiidae | *Acentrogobius* sp. B | | | | | | | | | | | 3 | 34.8–42.9 |
| | *Acentrogobius* sp. | | | | | | | | | | | 18 | 7.2–11.8 |
| | *Rhinogobius* spp. | | | | 3 | | | | | | 1 | 54 | 8.4–15.3 |
| | *Tridentiger trigonocephalus* | | | | | | | | | | | 15 | 13.7–46.5 |
| | *Tridentiger obscurus* | | | | | | | | | | 3 | 4 | 9.3–10.7 |
| Siganidae | *Siganus fuscescens* | | | | | | | 4 | | | | 4 | 15.9–19.6 |
| Paralichthyidae | *Paralichthys olivaceus* | | | | 1 | | | | | | | 14 | 15.2–94.6 |
| Bothidae | *Bothidae* sp. | 1 | | | | | | | | | | 1 | 15.6 |
| Soleidae | *Heteromycteris japonica* | | | | | | | | | | | 4 | 36.2–57.1 |
| Cynoglossidae | *Paraplagusia japonica* | | | 1 | | | | 2 | 1 | | 1 | 15 | 51.6–145.0 |
| Monacanthidae | *Rudarius ercodes* | | | | | | | 1 | | | | 28 | 4.1–28.9 |
| | *Stephanolepis cirrhifer* | 2 | | | | | | | | | | 6 | 8.2–28.9 |
| | *Paramonacanthus japonicus* | | | | | | | | | | | 3 | 21.7–34.5 |
| Tetraodontidae | *Takifugu pardalis* | | | | | | | | | | | 1 | 43.5 |
| | *Takifugu poecilonotus* | | | | 1 | | | | | | | 3 | 10.0–120.5 |
| | *Takifugu niphobles* | 1 | | | 27 | 1 | 2 | 1 | | 1 | | 876 | 4.0–105.6 |
| | *Takifugu rubripes* | | | | | | | 1 | | | | 1 | 42.8 |
| Total number of species (NS) | | 6 | 6 | 9 | 16 | 5 | 9 | 19 | 5 | 11 | 14 | 83 | |
| Total number of immature individuals (NI) | | 9 | 12 | 14 | 492 | 35 | 97 | 34 | 15 | 19 | 22 | 6458 | |
| Number of individuals: Marine species (NMI) | | 9 | 12 | 14 | 140 | 35 | 23 | 28 | 13 | 17 | 13 | 3282 | |
| Estuarine species (NEI) | | | | | 346 | | | 5 | | 2 | 8 | 2825 | |
| Diadromous species (NDI) | | | | | 4 | | 74 | 1 | 2 | | 1 | 327 | |

*Gymnogobius breunigii* (35.4%), *Takifugu niphobles* (13.6%), *Sillago japonica* (9.8%), *Acanthogobius lactipes* (6.7%), *Favonigobius gymnauchen* (5.6%), *Gerres equulus* (4.3%), *Plecoglossus altivelis altivelis* (4.0%), *Engraulis japonicus* (3.3%), *Gymnogobius heptacanthus* (2.9%), *Hypoatherina valenciennei* (1.8%), and *Lateolabrax* spp. (1.8%). These dominant species accounted for 89.3% of the immature individuals.

### 3.3. Classification of the fish community

Fig. 2 shows the results of the cluster analyses that were performed using the data for the numbers of individuals collected from each site. In addition, the similarities among the members of the fish communities, which were determined by performing the MDS analysis, are shown in Fig. 3. Fence lines are drawn according to the two groups (Groups A and B) classified by the cluster analysis, as shown in Fig. 2. The cluster analyses and the MDS analysis showed similar results.

The values for NS, NI, NMI, and NEI in Group A were higher than those in Group B (Table 3), and the average numbers of the individuals of several dominant fish species, such as *Gymnogobius breunigii*, *Takifugu niphobles*, *Sillago japonica*, and *Favonigobius gymnauchen*, in Group A were higher than the corresponding values in Group B (Table 3); these findings indicated that the fish communities in Group A were richer and showed a larger abundance than those in Group B. In addition, we noted significant differences between the LB, S1, S20, and CV values of the two groups (Table 3).

### 3.4. Effect of physical conditions on fish communities and dominant species

In the BIO-ENV analysis, the highest correlation was observed between the fish assemblage and the S20 and CV values ($R_S = 0.266$, $p < 0.01$). Fig. 4 shows the MDS ordination of 21 sites on the basis of the S20 and CV values. Fence lines are drawn on the basis of the two groups (Groups A and B) classified by the cluster analysis, as shown in Fig. 2.

The results of stepwise multiple linear regression analyses are shown in Fig. 5. The path coefficient shows the standard partial regression coefficient ($\beta$) and the direction and scale of the influence that each independent variable exerts on the dependent variable.

For the NS, NI, NMI, and NEI values, the best models were obtained for two physical conditions, namely, S20 and CV, and increasing S20 and CV values corresponded to a clear decrease in

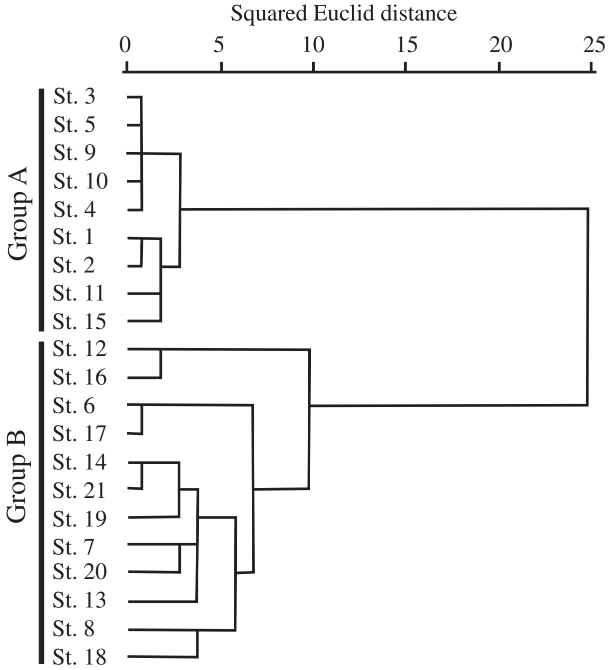

**Fig. 2.** Similarity among the members of the fish communities in the 21 sandy beaches, which was determined by cluster analysis performed using the abundances of 83 species.

the NS, NI, NMI, and NEI values. We did not obtain any models for NDI in the analysis. The analysis of the dominant species (Table 3) revealed that six species, namely, *Gerres equulus*, *Sillago japonica*, *Gymnogobius heptacanthus*, *Gymnogobius breunigii*, *Favonigobius gymnauchen*, and *Takifugu niphobles* showed negative correlations with the CV values. The S20 value was shown to be an explanatory variable only in the case of *G. breunigii*, which was ranked as the most dominant species. Furthermore, S1 showed positive correlation with *S. japonica*, and MPS showed positive correlation with *F. gymnauchen*; SAL showed negative correlation with *Acanthogobius lactipes*.

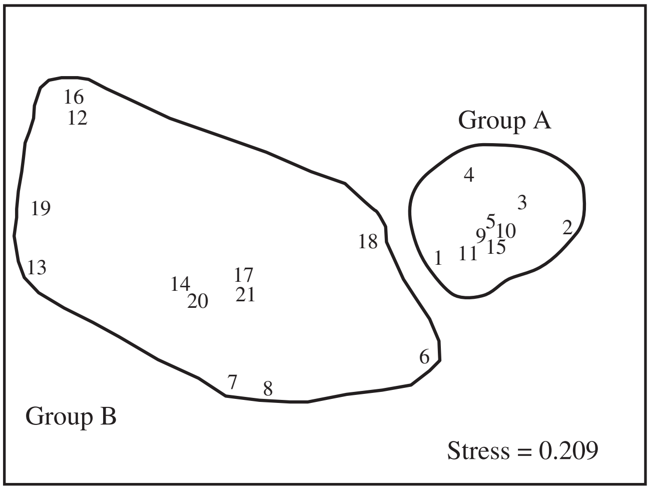

**Fig. 3.** Non-metric multidimentional scaling (MDS) ordination of the 21 sites on the basis of the abundances of 83 species.

**Table 3**
The average values of the physical condition parameters; the total number of species (NS) and individuals (NI); the number of marine (NMI), estuarine (NEI), and diadromous fish individuals (NDI); and the number of individuals of *Gymnogobius breunigii* (Gb), *Takifugu niphobles* (Tn), *Sillago japonica* (Sj), *Acanthogobius lactipes* (Al), *Favonigobius gymnauchen* (Fg), *Gerres equulus* (Ge), *Plecoglossus altivelis altivelis* (Paa), *Engraulis japonicus* (Ej), *Gymnogobius heptacanthus* (Gh), *Hypoatherina valenciennei* (Hv), and *Lateolabrax* spp. (Ls), in each group classified by using cluster analysis. The brevity codes of the physical condition parameters are listed in the legend for Table 1. Mann–Whitney *U*-test was used for statistical analyses between Group A and Group B. The values for statistical significance are also listed (ns, no significance).

| Abbreviations | Average values of physical condition parameters | | Statistical significance |
|---|---|---|---|
| | Group A | Group B | |
| LB (km) | 1.49 ± 0.75 | 4.11 ± 2.84 | $p < 0.05$ |
| DRM (km) | 2.66 ± 2.83 | 3.79 ± 3.44 | ns |
| S20 | 1/233 ± 1/609 | 1/130 ± 1/373 | $p < 0.01$ |
| S1 | 1/14 ± 1/22 | 1/33 ± 1/96 | $p < 0.05$ |
| SAL (ppt) | 31.6 ± 1.5 | 32.8 ± 1.3 | $p < 0.01$ |
| WT (°C) | 20.3 ± 0.4 | 20.4 ± 0.4 | ns |
| MPS (mm) | 0.24 ± 0.13 | 0.13 ± 0.03 | ns |
| CV (cm/s) | 6.94 ± 2.23 | 13.09 ± 2.73 | $p < 0.01$ |
| NS | 23.1 ± 6.5 | 9.3 ± 4.3 | $p < 0.01$ |
| NI | 659.2 ± 385.3 | 43.8 ± 46.2 | $p < 0.01$ |
| NMI | 330.1 ± 229.6 | 25.9 ± 29.4 | $p < 0.01$ |
| NEI | 312.1 ± 284.0 | 1.3 ± 2.6 | $p < 0.01$ |
| NDI | 14.3 ± 19.9 | 16.5 ± 38.9 | $p < 0.05$ |
| Gb | 253.7 ± 247.1 | 0.5 ± 1.2 | $p < 0.01$ |
| Tn | 96.7 ± 171.7 | 0.5 ± 0.7 | $p < 0.01$ |
| Sj | 69.6 ± 87.5 | 0.5 ± 0.5 | $p < 0.01$ |
| Al | 48.0 ± 144.0 | 0.1 ± 0.3 | $p < 0.05$ |
| Fg | 39.8 ± 51.2 | 0.3 ± 0.7 | ns |
| Ge | 28.3 ± 70.9 | 1.7 ± 2.1 | ns |
| Paa | 7.7 ± 13.6 | 15.8 ± 38.5 | ns |
| Ej | 4.1 ± 39.7 | 7.3 ± 24.2 | ns |
| Gh | 20.9 ± 51.7 | 0 | ns |
| Hv | 12.4 ± 26.1 | 0.6 ± 1.0 | ns |
| Ls | 9.0 ± 9.1 | 3.2 ± 4.1 | ns |

## 4. Discussion

### 4.1. Fish communities formed in surf zones

Immature-fishes accounted for 98% of the total number of individuals captured in this investigation, and the predominant species in the fish assemblages investigated in this study were primarily represented by larval and juvenile individuals. Moreover, all the species captured in this study showed at least some larval or juvenile individuals. These results are in agreement with the findings of previous studies conducted in the surf zones in various parts of the world (Robertson and Lenanton, 1984; Gibson et al., 1993; Suda et al., 2002; Inoue et al., 2008). This study indicates that the surf zones of sandy beaches in the northern coast of Kyushu Island are important for the larvae and juveniles, and the previous studies indicate that the surf zones play multiple roles in the development of the fish by functioning as transit routes, habitats, nurseries and/or feeding sites etc. (Robertson and Lenanton, 1984; Layman, 2000; McLachlan and Brown, 2006; Nissling et al., 2007).

### 4.2. Effect of physical conditions on fish communities

Although several studies have investigated the effects of physical conditions on the fish communities in surf zones (Akazaki and Kimoto, 1989; Akazaki and Taki, 1989; Romer, 1990; Kinoshita, 1993; Arayama et al., 2002; Nakane, 2008), very few studies have analyzed the relationships between fish assemblages and physical conditions (Clark et al., 1996; Granda et al., 2004). In this study, we

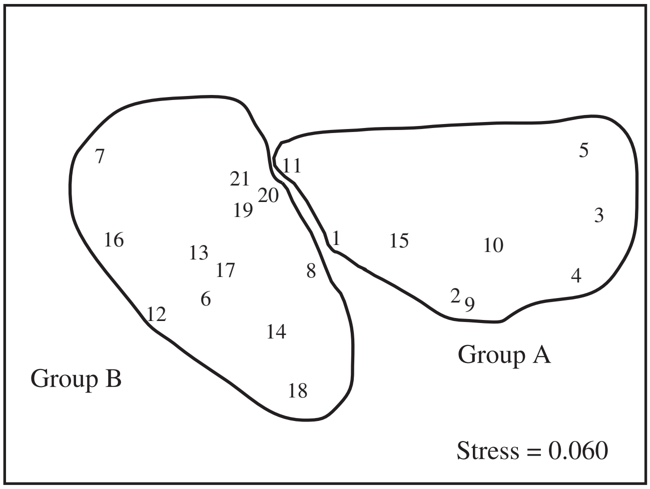

**Fig. 4.** Non-metric multidimentional scaling (MDS) ordination of the 21 sites on the basis of the S20 and CV values.

used cluster analysis to show that the immature-fish assemblages could be segregated into two groups on the basis of the prevailing physical conditions, and we used the BIO-ENV analysis to reveal that the characteristics of the immature-fish assemblages highly correlated with the S20 and CV values; these findings indicate that immature-fish assemblages inhabiting the surf zones of sandy beaches are influenced by the prevailing physical conditions. These findings are supported by the results of the MDS analysis performed using the S20 and CV values (Fig. 4) and the results of the cluster (Fig. 2) and MDS analyses (Fig. 3) performed using the immature-fish assemblages.

Romer (1990) and Clark (1997) reported that the number of individuals increased with a decrease in the wave exposure, which was estimated on the basis of the wave height. In this study, wave exposure was evaluated on the basis of the CV values, and the CV values negatively correlated with the species richness, total abundance, and abundances of several dominant fishes. This finding suggests that fish diversity and abundance increases with decreasing wave exposure. Our study and the abovementioned two studies share the view that the fish populations in surf zones are influenced by wave exposure.

The shallow areas of the surf zones are known to be used as nursery habitats for the larval and juvenile individuals of many fish species (Robertson and Lenanton, 1984; Ruple, 1984; Ross et al., 1987; Santos and Nash, 1995). However, to date, there has been no study on the statistical relationships between fish assemblages and the characteristics of the shelving bottom of the sea in sandy beaches. Although there have been a few reports on the statistical relationships between a few physical conditions and fish assemblages, fauna, abundance, and/or appearances (Clark et al., 1996; Clark, 1997), these reports do not pertain to the statistical relationship between fish assemblages and shallow conditions. This is the first report on the correlation between fish assemblages and the characteristics of the shelving bottom, such as the S20 values. However, after we analyzed the correlations for each species, only one species, which also was the most dominant species in this study, was found to show a negative correlation with the S20 values; this finding suggested that the negative influence of S20 on the most dominant species was extremely significant in establishing the total fish abundance. In addition, we noted that species richness was negatively influenced by S20, suggesting that fish diversity in surf zones is influenced by the characteristics of the shelving bottom.

### 4.3. *Effect of physical conditions on fishes in each lifestyle group*

In this study, we analyzed the regressions between the physical conditions and the immature-fish abundance and richness of each lifestyle group, i.e., the marine, estuarine, and diadromous groups; the fish abundances of the marine and estuarine species

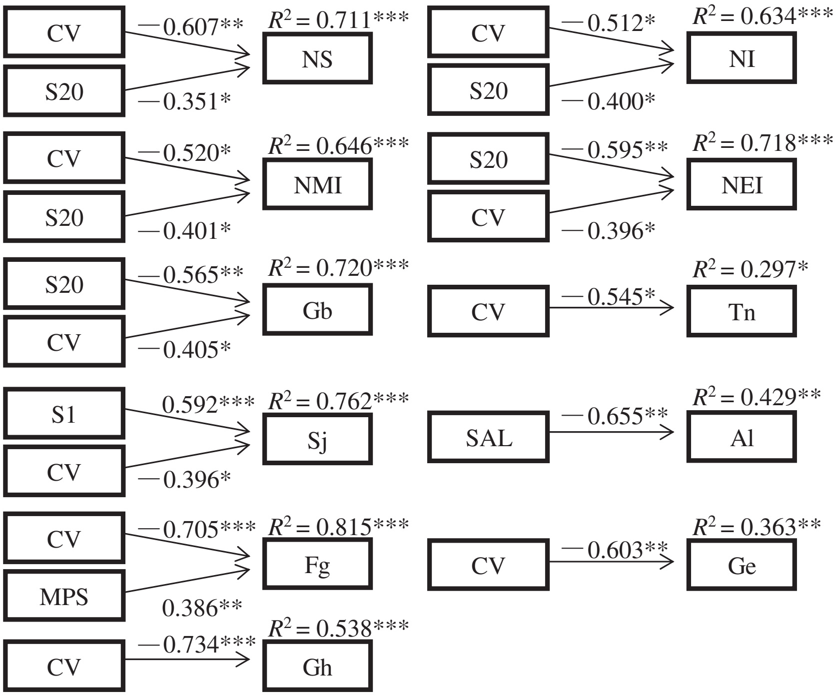

**Fig. 5.** The best models for studying regressions between the physical conditions and the individuals of each fish species, which were developed by stepwise multiple regression analysis ($n = 21$; *, $p < 0.05$; **, $p < 0.005$; ***, $p < 0.001$).

demonstrated an increase with a decrease in the S20 and CV values. These results correspond with the tendency observed in the analysis of the total fish species data with regard to the fish community structure: marine and estuarine species account for 90% or more of the total number of individuals.

SAL did not show any effect on the composition of the fish community, species richness, and fish abundances, except in the case of the abundance of *Acanthogobius lactipes*. Kinoshita (1993) has reported the existence of a correlation between the number of individuals and salinity and indicated that the fish abundance in the surf zone of a sandy beach in Japan increased with a decrease in salinity. However, in this study, we did not find any significant correlation between salinity and fish species richness and abundance, and only one species showed an increase in the number of individuals with decreasing salinity. In the aforementioned study (Kinoshita, 1993), the number of individuals in each fish species has been reported; therefore, we determined the number of individuals in each lifestyle group in that study. On analyzing these values, we observed that the percentage of diadromous individuals in the previous study (39.8%) was higher than that obtained in this study (5.1%). Since diadromous fishes migrate between fresh and marine waters (McDowall, 1988), they are believed to appear near a river mouth or a site with low salinity. Therefore, the differences in the effects of salinity can be attributed to the differences in the amounts of diadromous fishes in the fish communities examined.

Why do the abundances of diadromous fish differ between the surf zones of sandy beaches in the Japanese coastline? Several independent small rivers flow into the coastal area that was examined in this study (Nakajima et al., 2006), while a large river flows into the study sites of the previous study (Kinoshita, 1993). It is believed that the diadromous fish abundance may vary according to the size of the river flowing into the investigation site. Therefore, researchers must analyze the total fish species richness and abundance as well as the species richness and abundance of each lifestyle group. The specific characteristics of each coastal area may be determined by a comprehensive evaluation of the results of several studies, including previous reports; therefore, in each study, the analysis should be performed on the basis of the various physical conditions and biological factors prevalent in the study area, as has been done in this report.

### 4.4. Diversity of the physical conditions

We conclude that the species richness and abundance of immature-fishes in the surf zones of sandy beaches increase under shelving and calm conditions. Consequently, immature-fish assemblages are strongly influenced by the prevailing physical conditions. In addition, the size of the river flowing into the sandy beach is found to influence the composition of the fish community in sandy beaches and change the physical conditions that the fishes live in. However, it would be interesting to know whether these are the only physical conditions that affect the composition and characteristics of the fish community in the surf zones of sandy beaches.

In this study, S20 was found to be negatively correlated with fish species richness and abundance, suggesting that a gently shelving bottom has a positive effect on fish abundance in surf zones. In contrast, we found a positive correlation between S1 and the abundances of *Sillago japonica*, suggesting that a steep slope near the water edge had a positive effect on the abundance of this species. While these findings appear to be contradictory, they indicate that each fish species prefers a specific habitat and that the habitats determine the distribution of the different species. Habitat diversity largely contributes to the species diversity of fishes such as those belonging to Gobiidae (Begon et al., 1996), and the habitats in the surf zones of sandy beaches may be similar. Therefore, we conclude that the compositions of fish communities in the surf zones of sandy beaches are not only influenced by the characteristics of the shelving bottom, which influence fish assemblages and abundances, but also the habitat diversity, which influences fish species diversity.

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