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Predation pressure for a juvenile fish on an exposed sandy beach : comparison among beach types using tethering experiments

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Abstract: To determine whether or not predation pressure differed among beach types characterized by exposed sandy conditions for juvenile *Sillago japonica,* tethering experiments were conducted at three sites (reflective type, dissipative type, and a runnel of intermediate type) at Fukiagehama Beach, southern Japan, in August 2007. Predation pressure was considered to be lowest at the runnel site, since large piscivorous fishes may be unable to move across offshore, shallow sand ridges into runnels. The species and individual densities of piscivorous fishes were examined at each site plus an offshore site below the runnel by visual census. The mean survival rate of tethered prey per replicate did not differ significantly among the three sites. In addition, no significant differences in species or individual densities of piscivorous fishes were apparent among the three tethering experimental sites, although both densities were significantly lower at the offshore site than the runnel site. These results suggested that predation pressure was similar among the beach types, runnel habitats not providing small juvenile fishes with the level of protection from predators as previously believed.

Keywords: *tethering experiment, beach type, juvenile fish, predation refuge*

1. Introduction

Sandy beaches have been widely recognized as an important habitat type for juveniles of many fish species (*e.g.* MODDE and ROSS, 1981; LAYMAN, 2000; GIBSON *et al.,* 1993; SUDA *et al.,* 2002; MCLACHLAN and BROWN, 2006; INOUE *et al.,* 2008). Although they have long been considered as structurally monotonous environments, recent studies have demonstrated that sandy beaches are dynamic and complex environments, physically determined by the totality of water and sediment movements (KOMAR, 1998; SHORT, 1999). The resulting complexity, therefore, may enhance the value of sandy beaches as habitats providing food and refuge from predators for juvenile fishes.

Ridge-runnel systems are common topographic features of sandy beaches worldwide (KOMAR, 1998; SHORT, 1999). Ridges are elevated, elongated areas of sand that extend along the beach roughly parallel to the shore. Ebbing tides expose the ridges, and water is trapped behind them in troughs (runnels) (HARVEY, 1998). HARVEY (1998) and LAYMAN (2000) found that small and juvenile fishes were more abundant in runnel areas than in outer areas, suggesting that runnels serve as refuges from predation for small juvenile fishes, since large piscivorous fishes are probably less able to move across the shallow ridges into runnels. Other factors, such as increased

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food availability, may also contribute to heightened concentrations of juvenile fishes in runnels (HARVEY, 1998).

According to a morphodynamic scheme considering the spatial and temporal variability of coasts, sandy beaches can be classified into three major types: dissipative, reflective, and intermediate (WRIGHT and SHORT, 1984; SHORT, 1999). Dissipative beaches are characterized by wide, low gradient surf zones across which breaking waves gradually dissipate their force. In contrast, reflective beaches have relatively steep slopes and no surf zone, waves breaking abruptly near the shoreline. Intermediate beaches (intermediate between the dissipative and reflective types) exhibit a wide range of morphodynamic characteristics, accordingly being subdivided into several states, including ridge-runnel systems. Because dissipative and reflective beaches lack the ridge-runnel systems, it seemed likely that predation pressure on juvenile fishes in runnels on intermediate beaches may be lower than in the other two beach types. However, no studies have attempted to compare predation pressures among the three beach types.

A number of studies have indicated shortcomings of tethering experiments. Changes in the behavior or escape responses of tethered fish, for example, may result in increased vulnerability to predators (CURRAN and ABLE, 1998). Notwithstanding such artifacts, however, "tethering" has been recognized as useful for evaluating relative predation pressures between habitats (ARONSON and HECK, 1995; PETERSON *et al.,* 2001; BAKER and SHEAVES, 2007; HORINOUCHI, 2007). To date, tethering has been used on a wide variety of organisms, including invertebrates (*e.g.* PETERSON and BLACK, 1994; KNEIB and SCHEELE, 2000) and fishes (*e.g.* CURRAN and ABLE, 1998; LAEGDSGAARD and JOHNSON, 2001; MANDERSON *et al.,* 2004; NAKAMURA and SANO, 2004; BAKER and SHEAVES, 2007).

The aim of the present study was to determine whether or not predation pressure on juvenile (bottom dwelling) *Sillago japonica* differed among the three beach types (reflective, dissipative, and intermediate with a ridge-runnel system) on an exposed sandy beach in southern Japan, using tethering experiments. Species richness and total abundance of piscivorous fishes were also investigated by visual census and compared among the three beach types.

2. Materials and Methods

2.1. Study site

The study was carried out at Fukiagehama Beach (31°28′N, 130°18′E), situated on the southern coast of Kyushu Island, Japan, and opening broadly to the northern part of the East China Sea (Fig. 1). The beach was approximately 45 km long, with three distinct coastal segments represented by different beach types. The northernmost segment was dominated by a reflective beach, and the middle and southernmost segments, by an intermediate beach with ridges and runnels, and a

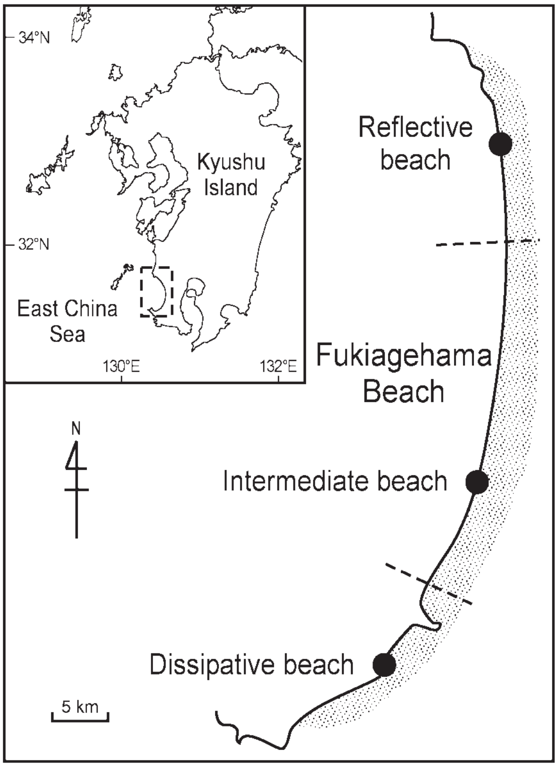

Fig. 1. Map of the study area at Fukiagehama Beach, Kyushu Island, southern Japan, showing experimental sites (●) in three coastal segments representing different beach types (reflective, intermediate with ridge-runnel systems, and dissipative).

Table 1. Beach profiles (dimensionless fall velocity, and intertidal slope and width) and wave height of each segment at Fukiagehama Beach. Definition and measuring methods of the dimensionless fall velocity (Ω) followed WRIGHT and SHORT (1984). Ω values < 2 and > 5 indicate reflective and dissipative beach states, respectively, and Ω values between 2 and 5 an intermediate beach state (MCLACHLAN and BROWN, 2006). The intertidal slope and width were examined by levelling, and wave height by visual observations. Three replicate measurements were conducted at each segment in August 2007. Values indicate mean ± standard error (n=3).

Segment	Beach type	Ω	Intertidal slope	Intertidal width (m)	Wave height (m)
Northern	Reflective	1.3±0.2	1/7.1±0.1	15.5±0.1	0.9±0.1
Southern	Dissipative	9.6±0.3	1/83.8±1.1	272.0±0.1	0.8±0.1
Central	Intermediate with ridges and runnels	4.3±0.4	1/41.7±2.2	140.3±1.5	0.9±0.1

dissipative beach, respectively (Fig. 1). Fukiagehama Beach is meso-tidal, with an average range of approximately 2 m. Some beach profiles and the wave heights of each segment are given in Table 1.

2.2. Tethering experiments

Tethering experiments were conducted at each of the three beach types in August 2007, when the wave conditions along Fukiagehama Beach were relatively calm. Similar experimentation was not possible in other seasons due to heavy wave action.

Newly-recruited juvenile sillaginids (*Sillago japonica*) were chosen as prey, since they were the most abundant component of the fish assemblage at the study beach during the summer season (NAKANE *et al.,* 2005), swimming actively over the bottom during the daytime, and feeding mainly on calanoid copepods and mysids (INOUE *et al.,* 2005). Juveniles of this species were captured at each experimental site with a 16 m pocket beach seine net and maintained in a tank for less than one hour prior to each experimental trial. Before tethering, the total lengths of the collected juveniles were measured to the nearest 0.1 mm. Similarly-sized juveniles were tethered to minimize the effects of prey size on predation (mean ± standard error = 34.1 ± 0.1 mm). A transparent monofilament line was attached to the muscle tissue of the anal fin base with a small fishing hook (5 mm long). The other end of the line was tied to a small lead weight (0.5 kg). Each tether was 1.0 m in length (0.128 mm in diameter), which allowed the fish sufficient mobility to avoid predators.

Five tethering stations (four replicates plus one control), parallel to the shore and separated from each other by more than 20 m, were established randomly at each site within the reflective and dissipative beaches, and in a runnel on the intermediate beach (Fig. 1). Within each station, four tethered fish were deployed on the sandy substratum at a (low tide) depth of ca. 0.5 m (between 10:00 and 13:00 h). Individual fish of each station were placed at least 15 m apart to ensure the independence of each predation event. Controls were carried out to determine whether or not prey fish could tear loose from hooks due to factors other than predator attacks. All control tethers were surrounded by a 4 mm mesh net to exclude predators. These experiments were performed at one site per day on three consecutive days. In the present study, an offshore tethering experiment below the intermediate beach runnels was not conducted because of relatively high wave action.

Immediately after all tethered juveniles had been observed swimming normally, each experiment trial was run over a 10 min period, the presence or absence of tethered juveniles being recorded at the end of each. The percentage of juveniles present was used as the survival rate for each station at each beach site. A one-way analysis of variance (ANOVA) was used to examine differences in survival rates among the three beach sites. Prior to the analysis, the homogeneity of variances was improved by arcsine transformation for proportional data.

2.3. Visual censuses

On completion of the tethering experiments, visual censuses were made at each experimental site (0.5 m deep), in order to estimate local species and individual densities of piscivorous fishes. In addition, a similar census was conducted at the offshore site (1.5 m deep) below the runnel on the intermediate beach. At each site, five 50 × 2 m belt transects, parallel to the shore and separated from each other by at least 25 m, were established randomly using a scaled rope. The rope was laid 5 min prior to census taking to reduce biases due to disturbance. After the recovery period, each transect was approached slowly by a diver using a snorkel and all fishes within the transect area counted for 10 min. Each census was made at low tide between 11:00 and 14:00 h, and each transect was censused once. Identification of fishes as piscivorous was based on dietary data from a preliminary study conducted at the study beach (unpublished). Species richness and abundance of piscivores at each site are expressed as the mean numbers of species and individuals per transect (100 m^2, five replicates per site), respectively. Fish classification follows NAKABO (2002).

In the present study, it was considered that avian and large invertebrate predators, such as herons (CROWDER *et al.,* 1997; MANDERSON *et al.,* 2004) and crabs (HAYWOOD *et al.,* 2003), respectively, contributed little to measured predation events in the tethering experiment, because such predators were not observed at each study site.

A one-way ANOVA was used to examine differences in species and individual densities of piscivorous fishes among the four sites. Tukey's honestly significant difference (HSD) test was performed when significant differences appeared in ANOVA. Before the analyses, data were log transformed to standardize variances.

3. Results

3.1. Tethering experiments

The mean survival rate of tethered prey per replicate did not differ significantly among the three beach sites (one-way ANOVA, $F_{2,11}=2.08$, $P=0.181$) (Fig. 2). At the end of the experimental period, the control trials included all of the tethered fish at each site, none having broken free from their hooks.

3.2. Visual censuses

A total of 39 piscivorous fishes, representing 7 species, were observed at the four beach sites during the study period (Table 2). There were significant differences in the species and individual densities of piscivores among the four sites (one-way ANOVA, species density, $F_{3,19}=3.71$, $P=0.034$; individual density, $F_{3,19}=4.29$, $P=0.021$). Tukey's HSD tests showed that the species number was significantly lower at the offshore site compared with the runnel site on the intermediate beach ($P=0.034$), although no significant differences were found among the three sites on the reflective beach, dissipative beach, and intermediate beach (runnel) ($P>0.10$). Similarly, no significant differences in individual numbers were apparent among the above three inshore sites ($P>0.05$), whereas a significantly lower number was obtained at the offshore site compared with the intermediate (runnel) and reflective beach sites ($P<0.05$) (Table 2).

4. Discussion

The most serious problem of tethering experiments lies in the potential artifacts that may vary among treatments (*e.g.* across habitats) (PETERSON and BLACK, 1994; KNEIB and SCHEELE, 2000; HAYWOOD *et al.,* 2003; BAKER and SHEAVES, 2007). If the physical structure of the habitats or composition of the predator assemblages differs considerably among experimental habitats, the effects of tethering on

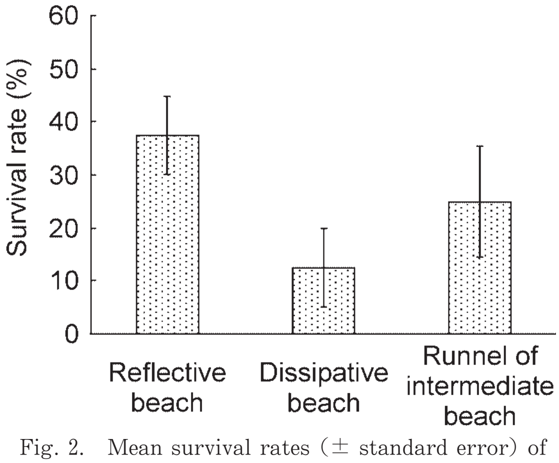

Fig. 2. Mean survival rates (± standard error) of tethered prey per replicate (n = 4) at each beach site.

Table 2. Mean number of individuals (± standard error) of each piscivorous fish species per transect ($100m^2$, n = 5) observed at each site.

Family	Species	Reflective	Dissipative	Intermediate	
				Runnel	Offshore
Belonidae	*Strongylura anastomella*	0	0	0.2±0.2	0
Platycephalidae	*Platycephalus sp.*	0.2±0.2	0.4±0.2	0.8±0.4	0
Moronidae	*Lateolabrax japonicus*	1.6±0.8	0	1.2±0.8	0.2±0.2
Carangidae	*Caranx sexfasciatus*	0.8±0.5	0	0	0
Sparidae	*Acanthopagrus latus*	0	0.2±0.2	0	0
Terapontidae	*Terapon jarbua*	0	1.4±1.0	0	0
Paralichthyidae	*Paralichthys olivaceus*	0	0.4±0.4	0.4±0.4	0
Mean number of species		1.2±0.4	1.2±0.4	1.4±0.2	0.2±0.2
Mean number of individuals		2.6±0.7	2.4±0.9	2.6±0.5	0.2±0.2

prey behavior and vulnerability may vary substantially among those habitats, leading to meaningless interpretations. In spite of this, the potential for significant interactions was minimal in the present study. The dominant habitat characteristic in each of the three experimental beach sites was the featureless sandy bottom, and the predator assemblage composition was similar among the sites (Table 2). We consider, therefore, that tethering in this study was a valid approach for quantifying relative predation pressures at the different beach sites.

In the control trials, none of the prey fish broke free from their tethers, demonstrating that consumption by predators most likely accounted for all prey missing from the experimental sites.

The results provided little evidence that the survival rate of juvenile *Sillago japonica* in the runnel on the intermediate beach was significantly lower than those on the reflective and dissipative beaches. Furthermore, no significant differences in the species and individual densities of piscivorous fishes were apparent among the three beach types, suggesting that the similar survival rates among the beach types reflected the similar densities of piscivorous fishes at each (Aronson, 1989; Kneib and Scheele, 2000; Nilsson, 2001).

Although the tethering experiment was not conducted at the deeper offshore site on the intermediate beach, the species and individual numbers of piscivorous fishes were significantly lower at that site than at the runnel site, evidence contrary to the hypothesis that runnels serve as refuges from predation for small juvenile fishes due to the low abundance of piscivores and hence reduced predation mortality, compared with adjacent deeper areas (Layman, 2000; Harvey, 1998). Furthermore, many piscivorous fishes may be able to move over shallow ridges into runnels and remain there during the ebb tide to feed. Some recent studies have similarly suggested that shallow estuarine sandy habitats in tropical Australia do not provide juvenile fishes with the level of protection from predators as previously assumed (Rountree and Able, 1997; Baker and Sheaves, 2006, 2007), although opposite findings have been reported from studies of temperate shallow sandy beaches in Scotland and North America (Linehan *et al.,* 2001; Gibson *et al.,* 2002; Manderson *et al.,* 2004). This indicates that the relative importance of shallow sandy habitats, including runnels, as predator refuges may vary among geographical locations. Further studies are therefore required to determine whether or not runnel habitats in other locations serve as refuges.

In this study, *S. japonica* was used as prey in tethering experiments. However, the escape behavior of tethered fish from predators may vary among fish species, resulting in different predation pressure among fishes. Further tethering experiments using other species are therefore necessary to understand the predation pressure for fishes on sandy beaches.

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References

ARONSON, R. B. (1989): Brittlestar beds: low-predation anachronisms in the British Isles. Ecology, **70**, 856–865.

ARONSON, R. B. and HECK, K. L., Jr. (1995): Tethering experiments and hypothesis testing in ecology. Mar. Ecol. Prog. Ser., **121**, 307–309.

BAKER, R. and SHEAVES, M. (2006): Visual surveys reveal high densities of large piscivores in shallow estuarine nurseries. Mar. Ecol. Prog. Ser., **323**, 75–82.

BAKER, R. and SHEAVES, M. (2007): Shallow-water refuge paradigm: conflicting evidence from tethering experiments in a tropical estuary. Mar. Ecol. Prog. Ser., **349**, 13–22.

CROWDER, L. B., SQUIRES, D. D. and RICE, J. A. (1997): Nonadditive effects of terrestrial and aquatic predators on juvenile estuarine fish. Ecology, **78**, 1796–1804.

CURRAN, M. C. and ABLE, K. W. (1998): The value of tethering fishes (winter flounder and tautog) as a tool for assessing predation rates. Mar. Ecol. Prog. Ser., **163**, 45–51.

GIBSON, R. N., ANSELL, A. D. and ROBB, L. (1993): Seasonal and annual variations in abundance and species composition of fish and macrocrustacean communities on a Scottish sandy beach. Mar. Ecol. Prog. Ser., **98**, 89–105.

GIBSON, R. N., ROBB, L., WENNHAGE, H. and BURROWS, M. T. (2002): Ontogenetic changes in depth distribution of juvenile flatfishes in relation to predation risk and temperature on a shallow-water nursery ground. Mar. Ecol. Prog. Ser., **229**, 233–244.

HARVEY, C. J. (1998): Use of sand beach habitat by *Fundulus majalis,* a surf-zone fish. Mar. Ecol. Prog. Ser., **164**, 307–310.

HAYWOOD, M. D. E., MANSON, F. J., LONERAGAN, N. R. and TOSCAS, P. J. (2003): Investigation of artifacts from chronographic tethering experiments-interactions between tethers and predators. J. Exp. Mar. Biol. Ecol., **290**, 271–292.

HORINOUCHI, M. (2007): Distribution patterns of benthic juvenile gobies in and around seagrass habitats: effectiveness of seagrass shelter against predators, Estuar. Coast. Shelf Sci., **72**, 757–664.

INOUE, T., SUDA, Y. and SANO, M. (2005): Food habits of fishes in the surf zone of a sandy beach at Sanrimatsubara, Fukuoka Prefecture, Japan. Ichthyol. Res., **52**, 9–14.

INOUE, T., SUDA, Y. and SANO, M. (2008): Surf zone fishes in an exposed sandy beach at Sanrimatsubara, Japan: does fish assemblage structure differ among microhabitats? Estuar. Coast. Shelf Sci., **77**, 1–11.

KNEIB, R. T. and SCHEELE, C. E. H. (2000): Does tethering of mobile prey measure relative predation potential? An empirical test using mummichogs and grass shrimp. Mar. Ecol. Prog. Ser., **198**, 181–190.

KOMAR, P. D. (1998): Beach Processes and Sedimentation, second ed., Upper Saddle River, NJ: Prentice Hall. 544pp.

LAEGDSGAARD, P. and JOHNSON, C. (2001): Why do juvenile fish utilise mangrove habitats? J. Exp. Mar. Biol. Ecol., **257**, 229–253.

LAYMAN, C. A. (2000): Fish assemblage structure of the shallow ocean surf-zone on the eastern shore of Virginia barrier islands. Estuar. Coast. Shelf Sci., **51**, 201–213.

LINEHAN, J. E., GREGORY, R. S. and SCHNEIDER, D. C. (2001): Predation risk of age–0 cod (*Gadus*) relative to depth and substrate in coastal waters. J. Exp. Mar. Biol. Ecol., **263**, 25–44.

MANDERSON, J. P., PESSUTTI, J., HILBERT, J. G. and JUANES, F. (2004): Shallow water predation risk for a juvenile flatfish (winter flounder; *Pseudopleuronectes americanus,* Walbaum) in a northwest Atlantic estuary. J. Exp. Mar. Biol. Ecol., **304**, 137–157.

MCLACHLAN, A. and BROWN, A. C. (2006): The Ecology of Sandy Shore, second ed., Burlington, MA: Academic Press. 340pp.

MODDE, T. and ROSS, S. T. (1981): Seasonality of fishes occupying a surf zone habitat in the northern Gulf of Mexico. Fish. Bull., **78**, 911–922.

NAKABO, T., (Ed.) (2002): Fishes of Japan with Pictorial Keys to the Species, English ed., Shibuya-ku, Tokyo: Tokai University Press. 1800pp.

NAKAMURA, Y. and SANO, M. (2004): Is there really lower predation risk for juvenile fishes in a seagrass bed compared with an adjacent coral area? Bull. Mar. Sci., **74**, 477–482.

NAKANE, Y., SUDA, Y., OHTOMI, J., HAYAKAWA, Y. and MURAI, T. (2005): Nearshore ichthyofauna in the intermediate sandy beach, Fukiagehama Beach, Kagoshima Prefecture, Japan. J. Natl. Fish. Univ., **53**, 57–70 (in Japanese with English abstract).

NILSSON, P. A. (2001): Predator behaviour and prey density: evaluating density-dependent intraspecific interactions on predator functional responses. J. Anim. Ecol., **70**, 14–19.

Peterson, C. H. and Black, R. (1994): An experimentalist's challenge: when artifacts of intervention interact with treatments. Mar. Ecol. Prog. Ser., **111**, 289–297.

Peterson, B. J., Thompson, K. R., Cowan, J. H., Jr. and Heck, K. L., Jr. (2001): Comparison of predation pressure in temperate and subtropical seagrass habitats based on chronographic tethering. Mar. Ecol. Prog. Ser., **224**, 77–85.

Rountree, R. A. and Able, K. W. (1997): Nocturnal fish use of New Jersey marsh creek and adjacent bay shoal habitats. Estuar. Coast. Shelf Sci., **44**, 703–711.

Short, A. D. (1999): Handbook of Beach and Shoreface Morphodynamics, Chichester, UK: John Wiley and Sons. 392pp.

Suda, Y., Inoue, T. and Uchida, H. (2002): Fish communities in the surf zone of a protected sandy beach at Doigahama, Yamaguchi Prefecture, Japan. Estuar. Coast. Shelf Sci., **55**, 81–96.

Wright, L. D. and Short, A. D. (1984): Morphodynamic variability of surf zones and beaches: a synthesis. Mar. Geol., **56**, 93–118.

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