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Temporal variations of fish assemblage in the surf zone of the Nakdong River Estuary, southeastern Korea

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To assess temporal variations in fish assemblages, fish samples were collected on a monthly basis in the surf zone of the Nakdong River Estuary in 2004. Surveys were conducted at two sites during day and night neap tides using a 10-m beach seine. In total, 2397 specimens (8146.0 g) comprising 27 species and 16 families were collected during the study period. The dominant fish species were *Mugil cephalus*, *Plecoglossus altivelis*, *Favonigobius gymnauchen*, *Opsariichthys uncirostris amurensis*, and *Hyporhamphus sajori*, which accounted for 84.6% of the total number of individuals. The fish sampled were primarily small species or the early juveniles of larger species. The species composition and abundance varied greatly, with a peak in the number of individuals in July (summer) and January (winter), and the peak in biomass during July (summer). The catch rate was low in the spring and autumn months due to the low abundance of the dominant species recorded. A cluster analysis revealed that the fish assemblages were characterized by distinct seasonal groups reflecting the reproductive habits of adult fishes. Fish abundance did not significantly differ between the two sites, although a significant difference in their abundance was detected between day and night, with more fish specimens collected at night than during the day at both sites. The Nakdong River Estuary is an important ecosystem for small and/or juvenile fishes, providing a habitat within the estuary suitable for their development and migration.

Keywords: Fish assemblage; *Mugil cephalus*; *Plecoglossus altivelis*; *Favonigobius gymnauchen*; *Opsariichthys uncirostris amurensis*; *Hyporhamphus sajori*; juvenile; surf zone; Nakdong River Estuary

ECOLOGY, POPULATION BIOLOGY & ANIMAL BEHAVIOR

Introduction

Surf zones, physically dynamic and complex environments with little habitat complexity, are physically determined by the total water and sediment movements (Komer 1998; McLachlan & Brown 2006). Sediment transportation by river currents is known to influence the topography of nearby surf zones (Komer 1998), and the importance of sandy beach surf zones as transit routes and/or habitats for the larvae and juveniles of many fish species is widely recognized in various parts of the world (McLachlan & Brown 2006). The high proportion of juvenile fishes in these environments indicates that sandy beaches provide important alternative nursery grounds for many estuarine species (Brown & McLachlan 1990). The utilization of surf zones by large numbers of juvenile fishes is almost certainly due to the presence of rich food resources in the form of zooplankton, as well as the protection from predation provided by the shallowness, turbidity, and turbulence of these areas (Lasiak 1986).

The Nakdong River, the second largest river in Korea, is located in the southeastern part of the country. The Nakdong River Estuary is an important spawning and nursery ground for many aquatic animals, and is a very productive fishery (Jeon 1987). In 1987, an estuary dyke was constructed to prevent the influx of salt water into the shallow freshwater in the estuary. These anthropogenic modifications of the river have diminished the freshwater flows that transport nutrients and sediments to estuaries, threatening the existence of estuarine habitats (Gillanders & Kingsford 2002; Flemer & Champ 2006). Environmental change has affected the estuary ecosystem, and in particular the population structure. Several studies have reported that animal community structures have been altered, with species composition and abundance changes occurring after the construction of the estuary dyke (Jang & Kim 1992; Hong et al. 1994; Kwak & Huh 2003). For example, Kwak and Huh (2003) reported that demersal species have become dominant due to changes in the sediment environment caused by the irregular discharge of freshwater and variations in the movement of seawater.

Although many studies have investigated the community structure of surf zone fishes worldwide, the seasonal variation in the species composition and the abundance of fishes in surf zones along the southern coast of Korea is unknown. Several previous studies have suggested that surf zones are important nursery grounds for larval and juvenile fishes, which have a relatively lower abundance in the western coastal surf zone habitats of Korea (Shin & Lee 1990; Lee et al. 1997). Seasonal variations in fish abundance are primarily the result of species-specific recruitment (Mariani 2001) and/or the interaction of species with environmental factors, especially water

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temperature (Shin & Lee 1990; Ayvazian & Hyndes 1995; Potter et al. 2001). Species-specific seasonal occurrence in a surf zone is also caused by ontogenetic shifts between inshore and onshore habitats (Gibson et al. 1993). However, the fish assemblage in the surf zone of the Nakdong River Estuary has not been studied, and the importance of the nursery habitats for marine residents and/or marine juveniles, including migrated species, has remained unknown.

Although sallow estuarine systems are important for juvenile and migratory species as their habitat and migration pathway, there is little information on faunal assemblage of these ecosystems in Korea. The objective of the present study was to examine the seasonal and diel variations in the species composition and abundance of fishes inhabiting the surf zone of the Nakdong River Estuary.

Materials and methods

Study area

The study area was a sandy beach ~1100 m wide, located at the eastern tip of the Nakdong River Estuary (35°04′N, 128° 96′ E; Figure 1). The mean tidal range is 1.2 m for the spring tide and 0.4 m for the neap tide. A sandbank with a length of ~800 m and a width of 200 m protects the study area from high wave action. Two sampling sites were established at each end of the beach to determine the ecological traits of fish assemblages in the study area (Figure 1). The two sites were separated by ~1 km, and environmental conditions, such as the degree of wave action, water temperature, salinity, and substrate grain size, were similar.

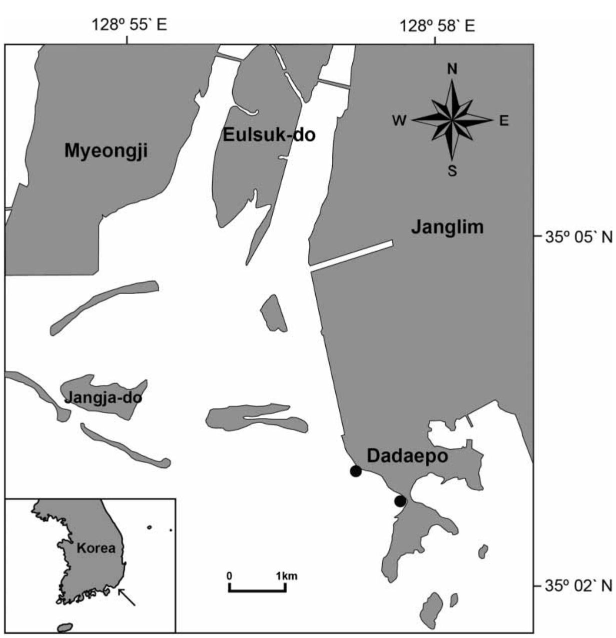

Figure 1. Map of the study area and the location of the two sampling sites in the surf zone of the Nakdong River Estuary.

Field sampling

The surveys were conducted monthly throughout 2004. The fish samples were collected by pulling a modified beach seine (10 m × 1.5 m; 10 mm mesh size) across 20 m of surf water parallel to the coast. Sampling was replicated three times. In total, a 60-m^2 tow was sampled on each occasion during both the day and night low tide in the surf zone of the estuary. The surface water temperature (using a thermometer) and salinity (via a salinometer) were also monitored during each sampling period. Specimens were preserved immediately in 10% formalin in seawater after capture and later transferred to 70% ethanol. These samples were identified according to Masuda et al. (1984) and Kim et al. (2005). For larval and early juvenile fishes, the criteria of Leis and Carson-Ewart (2000) and Okiyama (1989) were used for taxonomic identification. The size and weight of each fish specimen were recorded to the nearest millimeter in standard length and the nearest gram in wet weight, respectively. The guts were then separated for a later gut content analysis.

Developmental stages, and the ecological and feeding guilds of fishes

The fishes collected were categorized as larvae, juveniles, or adults, according to Kendall et al. (1984) and Leis and Carson-Ewart (2000), with larvae representing the developmental stages between hatching and the attainment of a full set of external meristic characteristics and juveniles being the stage immediately following until reaching sexual maturity. The five ecological guilds containing estuarine residents (ER), freshwater species (FW), marine adventitious (MA), marine juvenile (MJ), and diadromous (catadromous, anadromous, or amphidromous) migrants (DM) were categorized according to general descriptions of Korean fishes (Chyung 1977; Kim et al. 2005). In addition, by analyzing the gut contents, they were classified as zooplankton feeders (preying mostly on calanoid copepods, Z), benthic invertebrate feeders (mainly gammarid amphipods, B), fish feeders (F), or insect feeders (I).

Data analysis

The fish data were analyzed to obtain community variables. The diversity index (H′) was calculated using Shannon and Weaver's formula to compare monthly population diversity (Shannon & Weaver 1949). Logarithmic transformations ($\log 10(x+1)$) of both environmental variables and fish abundance (number and weight) data were performed to meet the assumptions of normality and homocedasticity for statistical tests and to reduce the bias of abundant species. A one-way analysis of variance (ANOVA) was applied to determine the significance of seasonal water temperature and salinity. A three-way ANOVA with an orthogonal design was used to analyze the spatial (two sites), seasonal (four seasons), and diel (day and night) effects on fish abundance.

A one-way analysis of similarity (ANOSIM) was used to compare the significant differences in the structure of the assemblages between the two sites, day and night, and among months. Hierarchical cluster analyses using Bray–Curtis similarity were used for the classification and ordination of each month based on the number of individuals of each species. The similarity index was subjected to an average linkage cluster analysis. To determine the species responsible for any seasonal variations in the structure of the assemblages, a similarity percentage (SIMPER) analysis was applied using the PRIMER software package (Clarke & Warwick 1994).

Results

Water temperature and salinity

Water temperature at the study site ranged from 9.9 to 31.3°C during the day and from 9.7 to 28.7°C at night. The peak water temperature was recorded in July for both day and night measurements, with a decline beginning in October and a minimum reached during January at night and February during daytime (Figure 2(a)). Water temperature varied significantly among the seasons ($F = 77.601$, $P < .001$), but did not vary significantly between two sites ($F = 0.069$, $P = 0.794$) or between day and night ($F = 1.591$, $P = 0.213$). Salinity ranged from 2.6 to 30.2‰ during the day and from 3.1 to 32.6‰ during the night. Salinity also changed significantly among seasons ($F = 25.391$, $P < .001$), but no significant variation was observed between two sites ($F = 1.938$, $P = 0.172$) or between day and night ($F = 0.094$, $P = 0.761$).

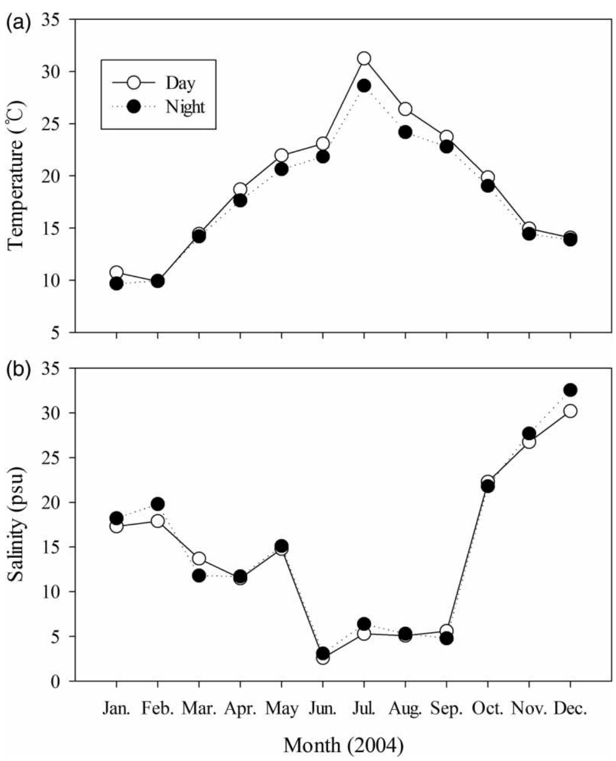

Figure 2. Monthly changes in the mean water temperature (a) and salinity (b) between day (black circle) and night (open circle) observations in the surf zone of the Nakdong River Estuary.

Fish species composition

In total, 2397 individuals (8146.0 g) belonging to 27 species, 17 families, and 9 orders were collected during the study period (Table 1), with Gobidae (5 species), Engraulidae (3 species), and Clupeidae (3 species) being the most widely represented families. Of these species, 2,202 individuals (91.9%) were juveniles and 195 (8.1%) were adults. The numerically dominant species were *Mugil cephalus* (26.2%), *Plecoglossus altivelis* (22.6%), *Favonigobius gymnauchen* (13.2%), *Opsariichthys uncirostris amurensis* (11.7%), and *Hyporhamphus sajori* (10.9%), which together accounted for 84.6% of the catch and 69.3% of the biomass. Most of the fish collected were small species or young juveniles. Only ~8% of the total number were adults and consisted of 136 *F. gymnauchen*, 34 *Leiognathus nuchalis*, 6 *Acanthogobius lactipes*, 5 *Acanthogobius flavimanus*, 4 *Coilia nasus*, 3 *Sardinella zunasi*, 1 *Engraulis japonicus*, and 1 *Takifugu niphobles*.

Fish assemblages differed significantly among months ($R = 0.602$, $P = 0.010$); however, no significant differences in the species composition was observed between the two sites ($R = –0.023$, $P = 0786$) or between day and night ($R = 0.046$, $P = 0.072$) according to the ANOSIM.

Seasonal variation in species composition

The number of fish species varied with season (1–11 species), with the highest number recorded in July during daytime and in September at night (Figure 3(a)). The number of individuals also varied by season, with a peak in summer and winter for both the day and night samples (Figure 3(b)). Large numbers of fishes were collected in winter and summer when *M. cephalus*, *P. altivelis*, *F. gymnauchen*, and *O. uncirostris amurensis* were abundant, while the number collected was lowest in March. The fish biomass differed substantially among the different seasons (Figure 3(c)). The highest biomass was recorded in July and August in both day and night samples when relatively large *M. cephalus* specimens were abundant. The range of the diversity index was 0.20–1.29 in the day and 0.27–1.76 at night, and higher values were recorded in spring and autumn (Figure 3(d)). The diversity indices were relatively low (<2.0) throughout the year.

Table 1. Species composition of fish caught using a beach seine in the surf zone of the Nakdong River Estuary on a monthly basis from January to December 2004 (developmental stage (DS): L, larvae; J, juvenile; A, adult), prey items (Cl, Cladocera; Co, Copepoda; Eu, Euphausiacea; Ga, Gammeridae Amphipoda; Ma, Macrura; My, Mysidacea; Pi, Pisces; Po, Polychaeta), ecological guild (EG), and feeding guild (FG)).

		Abundance		Biomass (g)						
Family	Species	*N*	*N*%	*W*	*W*%	Size range (cm, SL)	DS	Prey items	EG	FG
Congridae	*Conger myriaster*	2	0.1	1.6	0.0	9.1–10.3 (TL)	L	Co	MJ	Z
Engraulidae	*Coilia nasus*	7	0.3	166.0	2.0	6.6–23.9	J, A	Co	DM	Z
	Engraulis japonicus	2	0.1	3.6	0.0	5.4–6.2	J, A	Co	MA	Z
	Thryssa kammalensis	27	1.1	31.2	0.4	3.9–5.1	J	Co	MJ	Z
Clupeidae	*Clupea pallasii*	15	0.6	198.1	2.4	9.8–12.5	J	Co	MJ	Z
	Konosirus punctatus	43	1.8	172.8	2.1	3.8–10.6	J	Co, Cl	MJ	Z
	Sardinella zunasi	5	0.2	50.1	0.6	3.2–11.4	J, A	Co	MA	Z
Cyprinidae	*Hemibarbus labeo*	73	3.0	410.1	5.0	5.1–9.7	J	Ga, Po, Pi	FR	B, F
	Opsariichthys uncirostris amurensis	281	11.7	648.3	8.0	2.6–9.1	J	Ga, In, Po	FR	B, I
Osmeridae	*Plecoglossus altivelis*	541	22.6	311.9	3.8	3.2–5.1	J	Co	DM	Z
	Hypomesus niponensis	8	0.3	21.1	0.3	5.1–7.8	J	Co	DM	Z
Hemiramphidae	*Hyporhamphus sajori*	262	10.9	1635.4	20.1	2.8–16.7	J	Co	MJ	Z
Scorpaenidae	*Sebastes schlegeli*	5	0.2	5.1	0.1	3.4–3.8	J	Ma, Ga	MJ	B
Platycephalidae	*Platycephalus indicus*	11	0.5	28.4	0.3	4.7–8.1	J	Ga, Po	MJ	B
Moronidae	*Lateolabrax japonicus*	5	0.2	284.0	3.5	6.5–20.4	J	Ma, Pi	MJ	F
Carangidae	*Trachurus japonicus*	4	0.2	1.8	0.0	3.1–3.8	J	Cl	MJ	Z
Leiognathidae	*Leiognathus nuchalis*	38	1.6	605.3	7.4	2.0–10.7	J, A	My, Co, Ga	MA	Z
Mugilidae	*Mugil cephalus*	628	26.2	2251.8	27.6	2.5–18.5	J	Ga	MJ	B
Champsodontidae	*Champsodon snyderi*	4	0.2	1.9	0.0	3.1–3.6	J	Is	MJ	B
Gobiidae	*Acanthogobius flavimanus*	69	2.9	432.8	5.3	3.4–14.4	J, A	Ga, Po, Ma	ER	B
	Acanthogobius lactipes	16	0.7	37.1	0.5	4.7–6.2	J, A	Ga, Po	ER	B
	Favonigobius gymnauchen	316	13.2	796.4	9.8	2.6–6.9	J, A	Ga, Ma	ER	B
	Gymnogobius heptacanthus	1	0.0	1.2	0.0	4.6	J	Eu	ER	Z
	Tridentiger trigonocephalus	2	0.1	1.7	0.0	3.1	J	Ga	ER	B
Paralichthyidae	*Paralichthys olivaceus*	1	0.0	2.3	0.0	5.2	J	My, Ma	MJ	B
Pleuronectidae	*Kareius bicoloratus*	1	0.0	0.4	0.0	2.5	J	My	MJ	B
Tetraodontidae	*Takifugu niphobles*	30	1.3	45.7	0.6	1.6–9.4	J, A	Po, Ga, Ma	ER	B
	Total	2397		8146.0						

Temporal and spatial variations in the abundance of fishes

Temporal and spatial variations in fish abundance (determined from the average number of individuals collected per towing) were compared between the day and night samples, the two sites, and among four seasons. The mean number of individuals per haul varied between day and night, between stations 1 and 2, and among seasons, and was highest at station 2 during the night in summer and lowest at station 2 during the day in spring (Figure 4). The overall abundance was higher in summer than other seasons and during nighttime than daytime. Three-way ANOVA results revealed that the mean number of individuals varied significantly between day and night, and among seasons ($P < .05$). However, no significant differences were observed between sites, and no first- and second-order interactions were detected ($P > .05$; Table 2).

Cluster analysis

The dendrogram showed five clusters with a 50% level of similarity, which were characterized by samples from different months (Figure 5). Group A comprised samples collected during 3 months in winter (January, February, and December) characterized by high abundance, mainly juveniles of *P. altivelis*. Group B included March and April samples and was characterized by low fish abundance, although the samples had a high proportion of *M. cephalus*. Groups C (May and June samples) and D (July and August samples), which represented late spring and summer samples, respectively, were dominated by *F. gymnauchen* in group C, *O. uncirostris amurensis* in group D, and *M. cephalus* in both groups. Group E was composed of autumn samples (September–November). These months were characterized by juveniles of *H. sajori* and several other species.

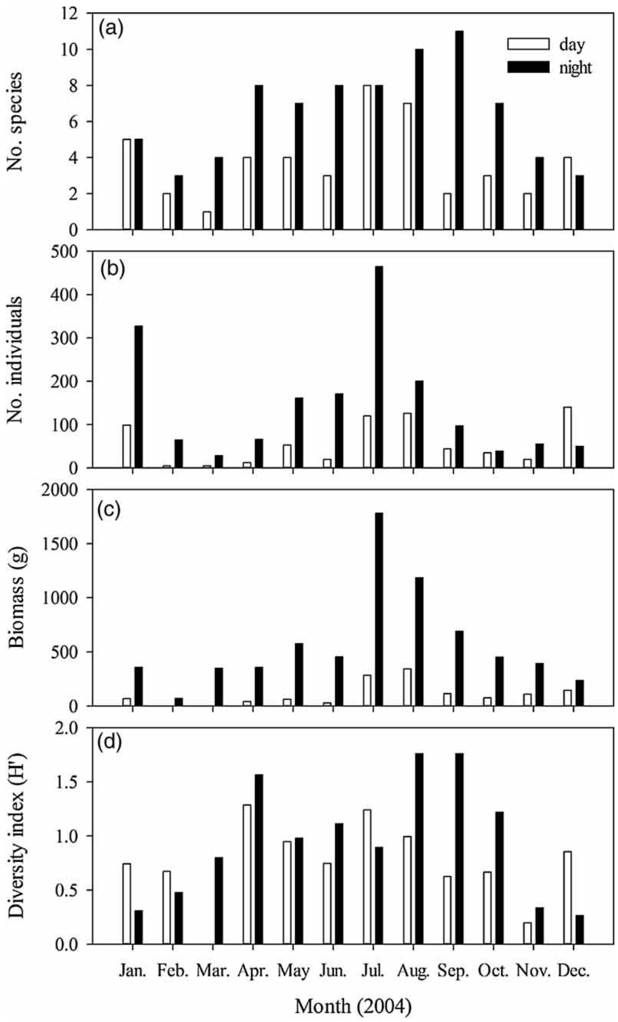

Figure 3. Monthly variations in the number of species (a), individuals (b), biomass (c), and diversity index (d) between day and night in the surf zone of the Nakdong River Estuary.

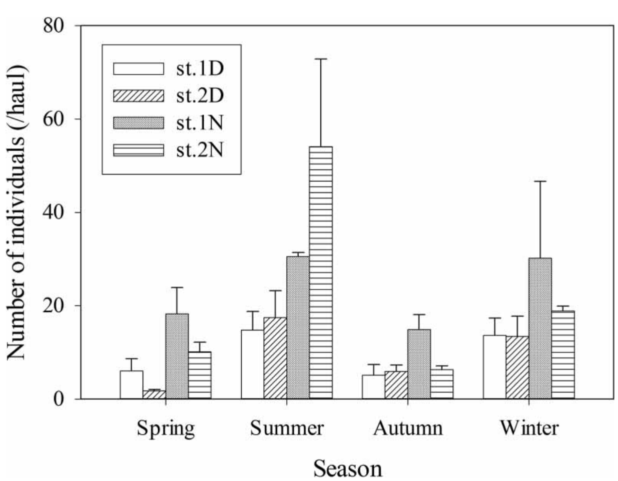

Figure 4. Seasonal variations in the mean number of individuals per haul (± standard error) in stations 1 and 2 between day and night in the surf zone of the Nakdong River Estuary.

Table 2. Results of a three-way ANOVA testing the effects of day and night, sampling site, and season on the abundance of fish.

Source	d.f.	MS	*F*	*p*-Value
Diel	1	1.825	9.536	0.004
Site	1	0.000	0.001	0.970
Season	3	0.661	3.453	0.028
diel × site	1	0.000	0.000	0.988
diel × season	3	0.113	0.590	0.626
site × season	3	0.085	0.444	0.724
diel × site × season	3	0.101	0.526	0.668

The SIMPER analysis revealed the species that contributed most to the similarity in each season (Table 3). Nine species contributed more than 90% of the similarity between the groups, two species (*M. cephalus* and *P. altivelis*) being dominant in group A, and four (*M. cephalus*, *P. altivelis*, *H. sajori*, and *K. punctatus*) in group B. Group C consisted primarily of four species (*M. cephalus*, *F. gymnauchen*, *H. sajori*, and *A. flavimanus*). Six species (*M. cephalus*, *F. gymnauchen*, *O. uncirostris amurensis*, *H. sajori*, *A. flavimanus*, and *L. nuchalis*) were dominant in group D, and four (*F. gymnauchen*, *H. sajori*, *A. flavimanus*, and *L. nuchalis*) dominated group E.

Ecological and feeding guild analysis

From the cluster analysis in Figure 5, five ecological guilds were identified in each of the selected groups (Figure 6(a)).

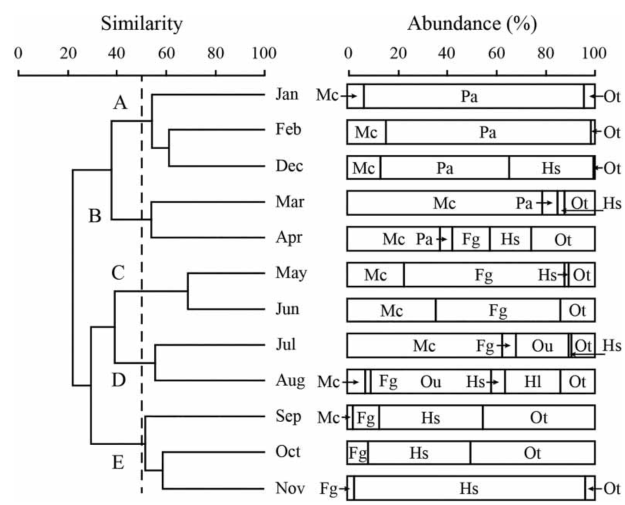

Figure 5. A dendrogram of the hierarchical cluster analysis based on the number of individuals of each fish species in each month of 2004 (left figure). Fish assemblages were divided into five groups (A–E) at 50% similarity. The percentage abundance of dominant fish species and other minor species for each month is shown (right figure). Fish abbreviations: Fg, *F. gymnauchen*; Hl, *H. labeo*; Hs, *H. sajori*; Mc, *M. cephalus*; Ou, *O. uncirostris amurensis*; Pa, *P. altivelis*; Ot, other species.

Table 3. Average similarity and percentage contribution (%) from a SIMPER analysis of the most common species contributing to >90% of each group by season (clusters in Figure 5).

	Group A	Group B	Group C	Group D	Group E
Average similarity	56.26	53.77	68.85	55.32	53.60
M. cephalus	30.50	53.60	33.66	17.85	
H. niponensis	66.79	14.87			
F. gymnauchen			47.11	9.64	15.24
O. uncirostris amurensis				40.41	
H. sajori		10.51	4.81	8.15	56.22
H. labeo					
A. flavimanus			4.81	11.52	10.02
K. punctatus		21.02			
L. nuchalis				5.15	12.87

By analyzing the ecological guilds by the number of species within each guild, of the 27 species identified in this study, six were estuarine residents (ER) (five goby species and *T. niphobles*), and they were abundant in groups C and D. Three diadromous migrant species were also identified, among which *P. altivelis* was abundant in winter (group A), and the other two species were occasionally present in spring and autumn. Thirteen marine juveniles (MJ) were abundant year-round, with most occurring occasionally in small numbers and for a short period; only *M. cephalus* (spring and summer) and *H. sajori* (autumn) were abundant in particular seasons. High numbers of two freshwater species (*Hemibarbus labeo* and *O. uncirostris amurensis*) occurred in summer (group D), while three marine adventitious (MA) fishes were minor species in all groups.

By analyzing the gut contents, four feeding guilds were identified (Table 1), and all of the guilds were represented only in group D (Figure 6(b)). Zooplankton feeders (Z) and benthic invertebrate feeders (B) occurred in all groups, with zooplankton feeders being more common in groups A and E, and benthic invertebrate feeders being more common in groups C and D. Two fish feeders (large-sized *H. labeo* and *L. japonicus*) accounted for a small proportion of the fish in groups D and E, and insect feeders (~40% of *O. uncirostris amurensis*) were represented only in the summer (group D).

Discussion

A broad range of water temperatures (9.7–31.3°C) and extremely low salinity (~2.0‰) were observed in the study area compared to other coastal areas. The large range in water temperature and low salinity in the study area are similar to the environmental characteristic of the surf zone on the midwestern coast of Korea (Lee et al. 1997) and also other estuarine systems (Pombo et al. 2005; Veiga et al. 2006; Plavan et al. 2010). In general, a shallow surf zone experiences a wide range of water temperatures throughout the year because these areas are readily influenced by the heating and cooling of the adjacent land. Extremely low salinity was found in the surf zone of the Nakdong River Estuary, especially in summer due to the heavy rainfall during the rainy season. These dramatic environmental variations might contribute to the formation of distinct biological communities.

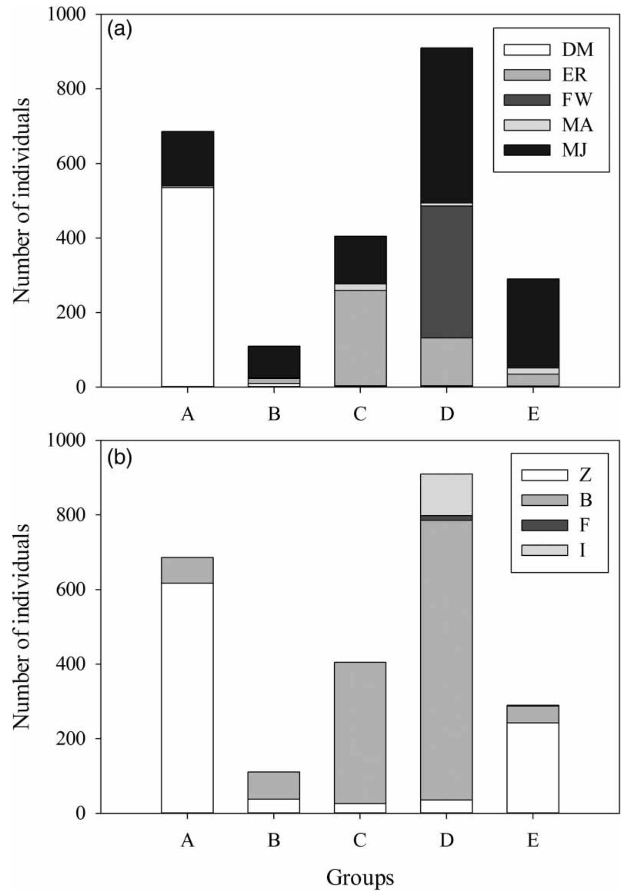

Figure 6. The number of individuals from each ecological (a) and feeding (b) guild in each group resulting from the cluster analysis in Figure 5. Ecological guilds: estuarine residents (ER), freshwater species (FW), marine adventitious (MA), marine juvenile (MJ), and diadromous (catadromous, anadromous, or amphidromous) migrants (DM). Feeding guilds: zooplankton feeder (Z), benthic invertebrate feeder (B), fish feeder (F), and insect feeder (I).

Twenty-seven fish species were recorded in the surf zone of the Nakdong River Estuary, with *M. cephalus*, *P. altivelis*, *F. gymnauchen*, *O. uncirostris amurensis*, and *H. sajori* being numerically dominant. The fishes collected in this study area were predominantly from small species and/or juveniles of marine fishes, indicating that the surf zone of the estuary functions as a nursery area. This conclusion is in general agreement with other studies on estuaries elsewhere in the world (Lee et al. 1997; Strydom 2003; Barreiros et al. 2004; Nanami & Endo 2007; Inoue et al. 2008; Plavan et al. 2010). The significantly greater abundance of juveniles than adults at our study site indicated that these species were likely to be dependent on the surf zone for shelter, survival, and refuge from predators during the early stages of their life cycle. Most of the marine species that use the estuary as a nursery ground have commercial and/or recreational value. For example, among the dominant species, *M. cephalus* is harvested as a food fish, and *P. altivelis* and *H. sajori* are valued in recreational fishing (NFRDI 2004; Kim et al. 2005). Several minor species, such as Clupeiformes fishes, also have commercial value in Korea.

Seasonal variation in both species composition and abundance was considerable for fish communities utilizing the surf zone. The dominant species had a distinct pattern of seasonal occurrence, and fish assemblages were consequently categorized into five seasonal groups by a cluster analysis. The seasonal abundance of many species can be attributed to their reproductive habits. For example, the increase in the abundance of *M. cephalus* (from late spring to summer), *H. sajori* (in autumn), and *P. altivelis* (in winter) occurred mainly after their respective spawning seasons (Nishida 1978; Novikov et al. 2002; Hsu et al. 2007). These species appear to use the surf zone as a nursery ground, whereas the consistent occurrence of *F. gymnauchen* and *A. flavimanus* in this area suggests that these species undergo their entire life cycle in this zone. However, *O. uncirostris amurensis*, a freshwater species, was predominant in the summer fish community. *O. uncirostris amurensis* and also *H. labeo* may be washed away to the tip of the Nakdong River Estuary by the increased freshwater discharge. Therefore, the species composition in summer was dominated by freshwater species and euryhaline marine species such as *M. cephalus*, *F. gymnauchen*, *A. flavimanus*, and *T. niphobles*.

In the Nakdong River Estuary, the number of individuals peaked in summer and winter. These peaks in abundance corresponded closely with the peak abundance of *M. cephalus* in July and *P. altivelis* in January. Seasonal variations in fish abundance are a common feature of dynamic ecosystems such as estuaries. The shifts in the abundance of some species were mainly due to their reproductive periods because most individuals sampled were young-of-the-year juveniles in the first year of their life cycle. The higher fish abundance in summer found in this study was similar to observations reported in the surf zone on the western coast of Korea (Shin & Lee 1990; Lee et al. 1997). Many studies worldwide have reported low fish abundance in the surf zone during winter due to the extremely low water temperature (Lasiak 1984; Strydom 2003; Veiga et al. 2006). However, in this study, a relatively high fish abundance was recorded during winter, especially in January, because of the strong dominance of juvenile *P. altivelis*, which migrated into the estuary during this period (Chyung 1977; Yamada et al. 1995). These seasonal changes in fish assemblages might be due to a resource partitioning strategy that reduces competition for food or may reflect species responses to suboptimal physical environmental conditions, or a combination of these two factors (Akin et al. 2003).

In terms of the diel changes in fish assemblages, the mean abundances were higher at night than in the daytime (Figure 4). Nagelkerken et al. (2002) reported that in general, the abundance of fishes living in shallow coastal areas, such as seagrass and intertidal habitats, is higher during the night. Gibson et al. (1996) recorded the highest abundance of such fish at night, indicating an onshore migration at dusk followed by an offshore migration at dawn, which may have been determined by their feeding activity and predator avoidance. Quinn and Kojis (1987) found more species, individuals, and biomass immediately after dusk, probably due to changes in illumination, gear efficiency, and/or the behavior of the animals. Despite the diel changes in the occurrence of some species in the Nakdong River Estuary, no strong evidence for the existence of distinct day and/or night communities was identified. The observed diel changes in abundance were likely to be caused by shifts in the abundance of a particular species rather than by their presence and/or absence.

In terms of ecological guilds, five ecological systems were identified. Marine juvenile species and estuary residents were the more diverse groups caught during our study. Similar results were reported in many other shallow estuarine systems (Veiga et al. 2006; Cardoso et al. 2011). In terms of abundance, marine juveniles dominated the community with 1008 individuals (42.4% of the total number of individuals), followed by diadromous migrant species (23.2%) and estuarine residents (18.1%). The guilds in the summer (group A) and winter (group D) fish communities were dominated by freshwater and diadromous migrant species, respectively. We found different guild proportions in the fish community collected by small trawls in the estuary (Kwak & Hun 2003; Lee et al. 2009). Marine stenohaline adult fishes were rare in this study, although they were the dominant guild in previous studies, which may be attributable to difficulties in approaching the surf zone for adult fishes due to the low salinity and shallow water depth. In addition, the low habitat diversity of the surf zone may lead to a different fish assemblage (Mathieson et al. 2000).

Freshwater species are reportedly a minor group in the surf zone occurring with variable intensity depending on the estuary (Pombo et al. 2005; Veiga et al. 2006; Inoue et al. 2008). However, two cyprinid species, *O. uncirostris amurensis* and *H. labeo*, were caught in large numbers in this study during summer when the salinity was low enough for their occurrence and survival, as both species can tolerate brackish waters (Kim et al. 2005). They will be swept away to the estuary by heavy rainfall in summer, although they are originally freshwater species. Also, three diadromous species were identified, which used the estuary as a stopover during migration. One species, *P. altivelis*, was common during winter both in terms of abundance and biomass, but two more diadromous species had low abundance. *P. altivelis* is a typical amphidromous fish, which is present nearshore in the Northwest Pacific from late autumn to spring during the early stages of its life cycle (Chyung 1977; Yamada et al. 1995). Only a few studies have reported the occurrence of *P. altivelis* in the Nakdong River Estuary (Kang et al. 2012) due to the blockage of their migration route to the upper river by the estuary dyke. Our results confirmed that large numbers of juvenile *P. altivelis* were present in the surf zone, which will contribute to the conservation and management of this species.

With respect to the feeding guilds, an overall dominance of taxa feeding on both benthic invertebrates and zooplanktons was observed. The dominant invertebrates, calanoid copepods, mysids, and amphipods, were important food resources for many fishes in the surf zone of the Nakdong River Estuary. Zooplankton and benthic invertebrate feeders, which were the most numerous fish in both species and individual numbers, primarily consumed these prey items. These food resources were also abundant in the diet of small-sized pelagic and benthic fishes such as *Thryssa kammalensis* (Baeck et al., 2014) and *Repomucenus lunatus* (Huh et al., 2013) which occurred in large numbers around the study area. The individual numbers of zooplankton and benthic invertebrate feeders displayed significant responses to seasonal differences in prey abundance, tending toward higher densities of calanoid copepods and mysids in groups A and E (early spring, autumn and winter), and gammarid amphipods and polychaetes in groups C and D (late spring and summer). For example, small zooplanktivorous juveniles of *P. altivelis* and *H. sajori* tended to accumulate in the low-temperature seasons (autumn and winter), when zooplankton densities tended to be higher (Jeong et al. 2004), while most of the benthic invertebrate feeders, which were mainly estuarine residents, were abundant during warm seasons (late spring and summer).

In conclusion, the Nakdong River Estuary is an important ecosystem for many fishes. Of the 27 species caught in this study, 18 have economic value. In addition, most of the species were exclusively represented by juveniles, emphasizing the importance of this ecosystem as a nursery ground providing suitable conditions for the development of fishes. However, as in many surf zones across the world, many of the species that occurred in the study site were occasional and were sampled only a few times. Seasonal variations in species composition were evident, with the summer and winter assemblages characterized by a clear dominance of marine juveniles, low diversity, and the presence of freshwater species.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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