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Juvenile fish assemblages in the Jinju Bay region, Korea

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Abstract

Assemblages of juvenile fish and associated abiotic parameters were investigated inside and outside Jinju Bay in southern Korea, on a monthly basis from December 2014 to November 2015. Fluctuations in water temperature and salinity were larger inside than outside the bay. In total, 534,657 individuals per square kilometre from 81 fish species and 47 families were collected during the study period. The most dominant species was *Nuchequula nuchalis* both inside (25.6%) and outside (26.9%) the bay. The next dominant species were *Thryssa kammalensis* (17.9%) and *Zoarces gillii* (16.0%) inside the bay and *Liparis tanakae* (16.9%) and *T. kammalensis* (9.0%) outside the bay. Forty species (33% of total number of individuals) of young fish were recorded inside the bay and 47 species (52%) outside the bay. Therefore, it appears that a diversity of fish use nursery grounds inside and outside Jinju Bay. In particular, the following six species appeared: *Z. gillii*, *Pleuronichthys cornutus*, *L. tanakae*, *Hemitripterus villosus*, *Pennahia argentata*, and *Xenocephalus elongates*. Due to assemblage differences for fishes within Jinju Bay and outside the bay, management of both areas is required to maintain current diversity of species in the region.

Keywords: Bay ecology, Young fish, Teleost, Nursery, Jinju Bay, *Nuchequula nuchalis*, *Thryssa kammalensis*, *Liparis tanakae*

Introduction

Coastal bay environments are highly variable, particularly in terms of water temperature, salinity, oxygen, sea level, nutrient availability, and turbidity. These variabilities often create unfavourable conditions for marine organisms within bay ecosystems (Faria et al. 2006). Such variabilities, however, can also provide favourable conditions for early stages of fishes during ontogenesis, such as increased availability of nutrients from terrestrial discharge that can result in an abundant food supply (Selleslagh et al. 2009; Newton et al. 2014; Álvarez et al. 2015). Bays can also offer shelter and protection from predators for larval and juvenile stages of fishes (Allen 1982; Able and Fahay 2010; Song et al. 2012), as well as facilitating larval movement via protection from wave action (Swearer et al. 1999). As increases in shelter and food supply are generally positively correlated with rapid growth and high survival rates in the early stages of fishes, bays are generally considered as important spawning and nursery grounds worldwide (Vasconcelos et al. 2010; Grol et al. 2011; Newton et al. 2014; Lin et al. 2016). Many larvae and young fish (Has species characteristics, but sexually immature) inhabit these regions. Understanding the composition of the assemblages in these areas directs appropriate management of the species concerned.

Jinju Bay is located in the middle southern coast of Korea and is surrounded by Sacheon, Hadong, and Namhae provinces. The bay is semi-enclosed and highly influenced by the Nam River Dam, 9.5 km north from the tip of the estuary that feeds into the bay. During the monsoonal season in Korea (July to September), increases in freshwater significantly impact the associated coastal marine ecosystems (Yeo and Park 1997; Park 2005). The bay is also considered a spawning and nursery ground for various marine organisms including commercial and recreational species (Kurita et al. 2017;

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Yamane et al. 2019), and has long been used for shellfish farming because of its protection against wave action from the open sea. Approximately one quarter of the bay is comprised of intertidal habitat, which potentially accumulates organic pollutants derived from urban and human activities.

The influence of freshwater discharge from the Nam River Dam on the coastal environment and associated biological communities has previously been reported. Such impacts include stratification and destratification processes, which change the availability of nutrients and temperature gradients in the water column (Jung and Ro 2010; Kang et al. 2011), and circulation flows around the bay (Kim et al. 2010), all of which are documented to affect the distribution of phytoplankton (Oh et al. 2007) and polychaete (Kang et al. 2002) communities. Impacts of this freshwater discharge on the structure of fish populations have not been assessed.

This research investigates monthly changes in the species composition and community structure of juvenile fishes in Jinju Bay and just outside the bay in relation to the salinity gradient caused by the Nam River Dam. Such studies are pivotal in understanding the ecological function and optimizing sustainable management plans for the Jinju Bay area.

Materials and methods

Sampling and environmental observations

Samples were collected at two stations in waters inside and outside Jinju Bay, approximately 15 km apart (Fig. 1). Jinju Bay is shallow and heavily affected by coastal waters, while outside the bay the waters are deeper and less affected by coastal waters and freshwater flows from the Nam River Dam. The two sampling stations were classified according to adjacent geographic features and their distance from the Nam River (Kim et al. 2010; Kang et al. 2011). The inside station was located at the lower reaches of Nam River, surrounded by villages, inlands, islands, and reefs, while the outside station was exposed to open ocean from the southeastern inlet (Fig. 1).

Fish samples were collected using a small beam trawl (beam length 6 m; vertical net opening 1 m; mesh size 20 mm) monthly from December 2014 to November 2015 at both stations, with the exception of February 2015, where collection was not possible. The net was towed at a speed of 1.6–1.8 knots for 60 min (daytime). Immediately after capture, fish samples were snap frozen to − 20 °C then taken to the laboratory at Pukyong National University. Once at the laboratory, the total length (TL) of each fish was measured to the nearest millimetre. Bottom water temperature and salinity measurements were also taken monthly using a conductivity-temperature-depth (CTD) metre (SBE-19 plus, Sea-Bird Electronics, Inc.). The CTD metre was also used to measure the depth of the two stations.

Data analysis

All fish species were identified to the lowest possible taxonomic classification according to Kim et al. (2005) and Nakabo (2013). The scientific names and taxonomic classifications of fishes followed Nelson et al. (2016) and Kim and Ryu (2016). And the species collected according to Elliott and Dewailly (1995) were classified into six types according to purpose: estuarine residents (ER),

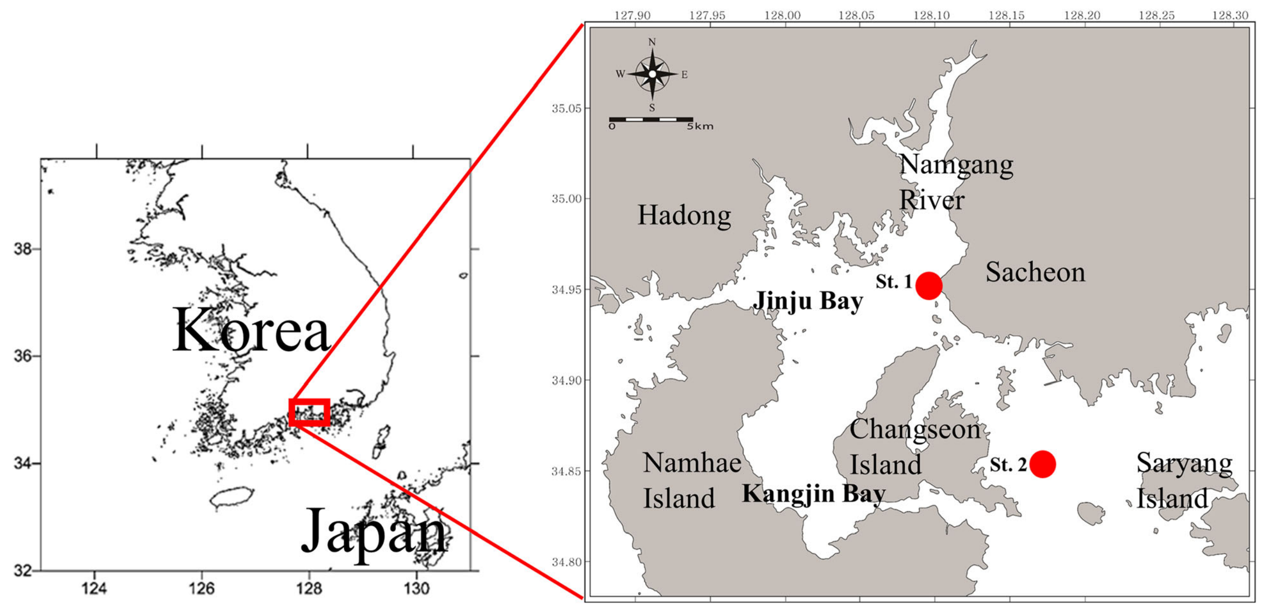

Fig. 1 Location of the stations inside and outside of Jinju Bay, Korea

marine adventitious visitors (MA), diadromous (catadromous/anadromous) migrants (CA), and marine seasonal. migrants (MS), marine juvenile migrants (nursery species) (MJ), or freshwater adventitious visitors (FW). The total length and wet body weight of each individual was measured to the nearest millimetre and gram, respectively. The abundance of each species was obtained using the swept area method (number of individuals per km^2). Species occurring more than six times (over 50%) during the survey period were considered resident species.

A one-way ANOVA followed by a post hoc Bonferroni's test, with sample site and season as fixed factors, was used to analyse the abundance data. All species were considered in the analyses, and abundances were $\log(x + 1)$ transformed. For the eight most numerically abundant species (comprising greater than 6.0% of the total population), variations in seasonal [spring (March–May), summer (June–August), autumn (September–November), and winter (December–February)] mean abundance were analysed.

A Mann-Whitney U test was used to examine differences in the number of fish species collected from inside and outside Jinju Bay. The community-level variable of fish assemblage was expressed as a species diversity index (H', Shannon and Weaver 1949) using the number of species and its abundance data. A Bray–Curtis similarity matrix was constructed based on the abundance of the fish species (Bray and Curtis 1957). Before calculation, a logarithmic transformation [$\log_{10}(x + 1)$] was applied to the data to decrease the effects of a few but extremely abundant species. Cluster analysis was carried out using the Bray–Curtis similarity. A similarity percentage (SIMPER) was then used to examine which species contributed most to the differences among samples. A non-metric multidimensional scaling (nMDS) ordination was further visualized to examine the cluster relationship on a two-dimensional plot. All multivariate analyses were performed using PRIMER statistical package version 6.0 (Clarke and Gorley 2006).

In addition, relationships between fish abundance and environmental factors (i.e. water temperature, salinity, depth, water transparency) were analyzed using canonical correspondence analysis (CCA). The relative contributions of environmental variables to the observed differences were assessed using correlation coefficients for relationships

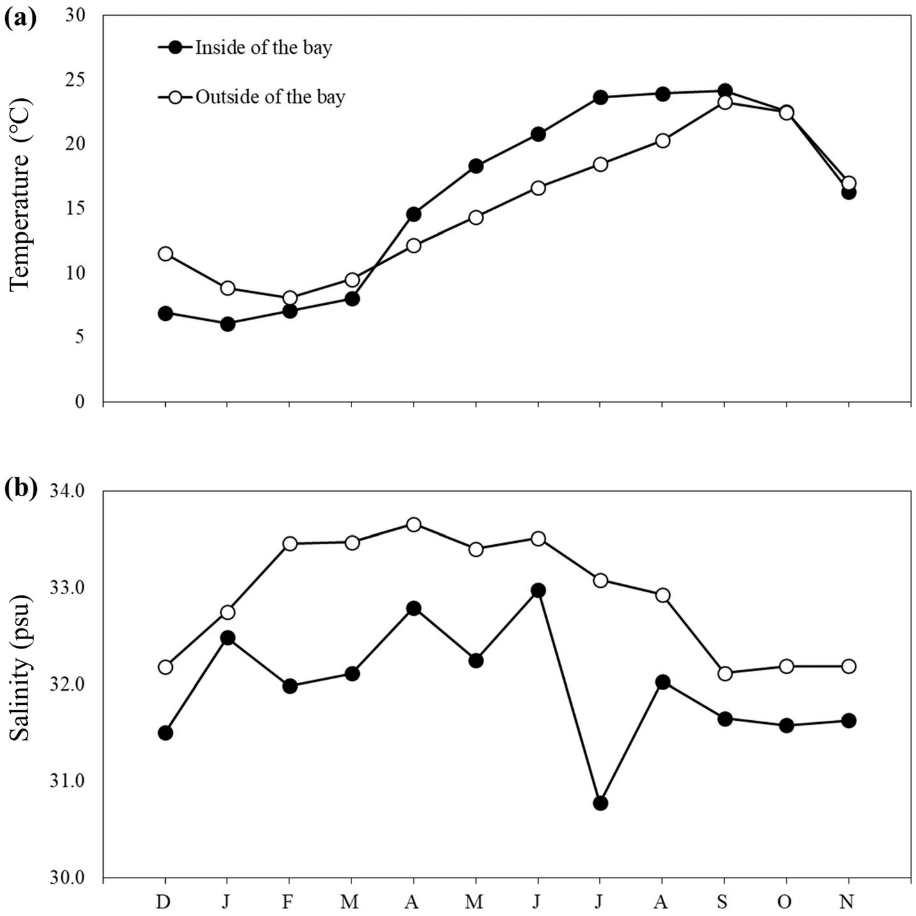

Fig. 2 Monthly variations in the bottom water temperature (**a**) and salinity (**b**) from inside (black circle) and outside (open circle) of Jinju Bay

between each fish assemblage of common fish species and the canonical axis. To avoid overestimation caused by less frequently occurring species, only those accounting for over 0.5% of the total percentage of abundance (resident fish) were used for this analysis. The test was performed using the package Excel XLSTAT V.7.5.2 (Add-in-software, http://www.xlstat.com). Data were log transformed $\log(x + 1)$ prior to analysis.

Results

Environmental variables

Depth between the stations differed, with depth inside Jinju Bay measured at 10.6 m and the outside at 18.6 m. Bottom water temperatures showed similar trends between the two stations, with a lower temperature measured during winter than during summer (Fig. 2). The extent of seasonal fluctuations in water temperature were greater at the station inside

Table 1 List of fish species and mean abundance of species (per km^2) in inside and outside of Jinju Bay, Korea, from December 2014 to November 2015

Family	Species	ER[a]	abundance		body length	
			inside	outside	inside	outside
Rajidae	*Okamejei kenojei*	MA	250	3200	9.8-31.3	9.2-37.6
Dasyatidae	*Dasyatis akajei*	MA	100		48.9-49	
Muraenesocidae	*Muraenesox cinereus*	MA	550	1000	34.1-53.8	29.6-51.4
Congridae	*Conger myriaster*	ER	2200	2950	22.5-54.5	11.5-41.3
Engraulidae	*Thryssa kammalensis*	MJ	33797	31297	7.0-13.5	4.4-13.3
	Thryssa adelae	MA	50	800	14.1	9.0-14.3
Clupeidae	*Sardinella zunasi*	MJ	50	50	12.1	9.4-9.4
	Konosirus punctatus	MJ		100		11.2-12.0
Synodontidae	*Saurida microlepis*	MA	100	300	27.6-41.7	7.6-39.4
Macrouridae	*Coelorinchus multispinulosus*	MA		100		18.2-19.4
Gadidae	*Gadus macrocephalus*	MJ	100		7.1-70.0	
Lophiidae	*Lophius litulon*	MA	50	100	32.1	6.1-12.3
Syngnathidae	*Hippocampus mohnikei*	ER	100		6.0-7.1	
Scorpaenidae	*Sebastes inermis*	MJ	50		7.4	
	Scorpaena neglecta	MJ	50		3.1	
	Inimicus japonicus	MJ	2000	1450	5.2-22.9	5.4-29.5
	Scorpaena onaria	MA	100		5.3-6.0	
	Sebastiscus marmoratus	MJ		50		19.5-19.5
	Minous monodactylus	MA		50		12.4-12.4
Aploactinidae	*Hypodytes rubripinnis*	MJ	500	1450	4.2-7.4	3.8-8.0
	Erisphex pottii	MA	150		7.3-8.9	
Triglidae	*Chelidonichthys spinosus*	MA	450	2400	16.4-30.6	15.5-26.0
Platycephalidae	*Cociella crocodila*	MJ	200		9.5-18.5	
	Platycephalus indicus	MJ	1200	2400	6.4-29.5	11.4-41.0
Hexagrammidae	*Hexagrammos agrammus*	MA	50		13.8	
	Hexagrammos otakii	MJ	500	50	9.9-24.7	21.4
Cottidae	*Pseudoblennius cottoides*	MJ	350		4.6-5.5	
	Alcichthys elongatus	MJ	350			
	Ricuzenius pinetorum	MJ	7649	12099	4.3-8.5	5.5-8.8
Hemitripteridae	*Hemitripterus villosus*	MJ	1700	1850	2.2-9.3	4.1-28.4
Liparidae	*Liparis tanakae*	MJ	5900	58445	4.3-55.4	5.2-52.6
Moronidae	*Lateolabrax maculatus*	MJ		50		20.9
Acropomatidae	*Malakichthys wakiyae*	MA		50		4.3
Apogonidae	*Apogon lineatus*	MA	1750	6799	5.6-9.0	3.4-9.7

[a] Ecological guilds: *ER* estuarine residents, *MA* marine adventitious visitors, *MJ* marine juvenile migrants (nursery species)

Table 2 Species composition of fishes collected by shrimp beam trawl inside of Jinju Bay, Korea, from December 2014 to November 2015 (unit: ind./km^2)

Scientific name	Dec.	Jan.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Total	%
Okamejei kenojei	0	0	50	50	50	0	50	50	0	0	0	250	0.1
Dasyatis akajei	0	0	0	0	50	0	0	0	0	50	0	100	0.1
Muraenesox cinereus	0	0	0	0	0	0	0	450	100	0	0	550	0.3
Conger myriaster	250	300	0	0	350	250	350	300	0	150	250	2,200	1.2
Thryssa kammalensis	0	0	0	0	0	0	6,100	27,548	100	0	50	33,797	17.9
Thryssa adelae	0	0	0	0	0	0	0	50	0	0	0	50	+
Sardinella zunasi	0	0	0	0	0	0	50	0	0	0	0	50	+
Saurida microlepis	0	0	0	0	0	0	50	0	0	0	50	100	0.1
Gadus macrocephalus	50	0	0	0	50	0	0	0	0	0	0	100	0.1
Lophius litulon	0	0	0	50	0	0	0	0	0	0	0	50	+
Hippocampus mohnikei	0	0	0	0	0	100	0	0	0	0	0	100	0.1
Sebastes inermis	50	0	0	0	0	0	0	0	0	0	0	50	+
Scorpaena neglecta	0	0	50	0	0	0	0	0	0	0	0	50	+
Inimicus japonicus	0	0	0	150	550	1,000	50	50	200	0	0	2,000	1.1
Scorpaena onaria	0	0	0	0	0	100	0	0	0	0	0	100	0.1
Hypodytes rubripinnis	350	100	0	50	0	0	0	0	0	0	0	500	0.3
Erisphex pottii	150	0	0	0	0	0	0	0	0	0	0	150	0.1
Chelidonichthys spinosus	100	0	0	0	100	100	0	0	100	0	50	450	0.2
Cociella crocodila	100	0	0	0	0	100	0	0	0	0	0	200	0.1
Platycephalus indicus	700	100	0	200	50	0	0	50	0	0	100	1,200	0.6
Hexagrammos agrammus	50	0	0	0	0	0	0	0	0	0	0	50	+
Hexagrammos otakii	250	50	50	50	100	0	0	0	0	0	0	500	0.3
Pseudoblennius cottoides	0	0	0	0	350	0	0	0	0	0	0	350	0.2
Cottidae sp.1	0	0	0	0	0	350	0	0	0	0	0	350	0.2
Ricuzenius pinetorum	5,400	1,350	750	150	0	0	0	0	0	0	0	7,649	4.1
Hemitripterus villosus	0	0	1,200	450	50	0	0	0	0	0	0	1,700	0.9
Liparis tanakae	50	100	2,350	3,300	100	0	0	0	0	0	0	5,900	3.1
Apogon lineatus	0	0	0	0	100	1,500	100	0	50	0	0	1,750	0.9
Sillago japonica	0	0	0	0	850	200	600	1,650	250	200	200	3,950	2.1
Trachurus japonicus	0	0	0	0	50	100	0	0	0	0	0	150	0.1
Nuchequula nuchalis	450	0	300	150	600	50	4,450	36,297	300	3,450	2,250	48,296	25.6
Acanthopagrus schlegelii	100	100	0	0	0	0	0	0	0	0	0	200	0.1
Johnius grypotus	0	0	0	0	0	0	0	250	0	0	0	250	0.1
Pennahia argentata	200	150	0	0	150	0	0	450	1,250	600	200	3,000	1.6
Upeneus japonicus	0	0	0	0	0	0	0	0	50	50	100	200	0.1
Ditrema temminckii temminckii	50	0	0	0	0	0	0	0	0	0	0	50	+
Zoarces gillii	250	700	50	16,549	11,749	750	0	0	0	50	0	30,098	16.0
Chirolophis wui	0	0	50	50	0	0	0	0	0	0	0	100	0.1
Pholis nebulosa	750	400	450	50	150	50	50	0	0	100	0	2,000	1.1
Pholis fangi	700	1,250	1,150	6,150	2,900	150	0	0	0	0	200	12,499	6.6
Champsodon snyderi	0	0	0	0	0	50	50	0	0	0	0	100	0.1
Parapercis sexfasciata	250	150	100	150	50	100	0	0	100	100	0	1,000	0.5
Repomucenus valenciennei	900	200	50	0	100	550	0	0	650	200	0	2,650	1.4

Table 2 Species composition of fishes collected by shrimp beam trawl inside of Jinju Bay, Korea, from December 2014 to November 2015 (unit: ind./km^2) *(Continued)*

Scientific name	Dec.	Jan.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Total	%
Amblychaeturichthys hexanema	550	100	50	0	0	0	0	0	0	50	0	750	0.4
Tridentiger trigonocephalus	100	600	200	350	0	50	0	0	0	0	0	1,300	0.7
Acanthogobius flavimanus	50	200	0	0	0	0	0	0	0	0	0	250	0.1
Cryptocentrus filifer	0	50	0	50	50	100	400	0	500	350	50	1,550	0.8
Acentrogobius pflaumi	100	0	100	100	50	0	50	0	750	100	50	1,300	0.7
Tridentiger nudicervicus	0	0	0	0	550	650	100	0	0	0	0	1,300	0.7
Trichiurus japonicus	0	0	0	0	0	0	0	100	0	0	0	100	0.1
Pleuronichthys cornutus	0	0	3,800	2,900	1,850	1,500	1,250	200	100	0	0	11,599	6.2
Kareius bicoloratus	0	100	0	0	50	50	50	0	0	0	0	250	0.1
Pseudopleuronectes yokohamae	100	150	50	50	100	150	100	100	150	50	50	1,050	0.6
Clidoderma asperrimum	0	0	0	50	0	100	0	0	0	0	0	150	0.1
Pseudaesopia japonica	0	0	50	0	0	0	0	0	0	0	0	50	+
Cynoglossus robustus	1,900	0	0	0	0	0	0	0	0	0	50	1,950	1.0
Cynoglossus semilaevis	150	0	0	0	0	0	0	0	0	0	0	150	0.1
Cynoglossus abbreviatus	0	100	50	0	50	0	100	0	0	0	0	300	0.2
Cynoglossus joyneri	50	400	0	0	0	0	0	300	0	0	0	750	0.4
Cynoglossus interruptus	0	0	0	50	0	50	300	0	150	0	0	550	0.3
Rudarius ercodes	50	0	0	0	0	0	0	0	0	0	0	50	+
Stephanolepis cirrhifer	0	0	0	0	0	0	0	0	0	0	50	50	+
Takifugu niphobles	100	0	0	0	50	150	0	0	0	0	0	300	0.2
No. of species	31	22	20	22	29	26	19	15	16	14	15	63	
Total	14,299	6,649	10,899	31,098	21,248	8,299	14,249	67,845	4,800	5,500	3,700	188,585	100

+: less than 0.1%

Jinju Bay (6.1–24.2 °C) than outside (8.1–23.3 °C). The difference in bottom water temperature between the stations was greatest in summer, and there was no significant difference in water temperature between stations in winter (Bonferroni's test, $P > 0.05$). Salinities were consistently lower at the station inside the bay than outside throughout the year, with the highest salinity occurring in April 2015 inside and the lowest during July 2015 outside (Fig. 2).

Fish species composition

A total of 534,657 individual fishes per square kilometre (ind./km^2), comprising of 81 species and 47 families, were collected at both stations. Of these, 188,585 ind./km^2 belonging to 63 species and 40 families were collected inside the bay, while 346,072 ind./km^2 from 65 species and 42 families were caught outside the bay (Table 1).

The number of species was similar between stations, but the number of individuals was considerably higher at the station outside than the one inside the bay. The most dominant species was *Nuchequula nuchalis*, which occurred at a frequency of 26% inside Jinju Bay and at 27% outside the bay. The next most dominant species inside the bay were *Thryssa kammalensis* (18%) and *Zoarces gillii* (16%), and *Liparis tanakae* (17%) and *T. kammalensis* (9%) outside the bay.

Forty species of young fishes were caught inside the bay, comprising approximately one third of the total number of individuals inside the bay. Forty-seven species of young fishes were caught outside the bay, comprising 52% of individuals caught, indicating that more various species grow outside of the bay. Juvenile *P. cornutus*, *Z. gillii*, and *Hemitripterus villosus* were commonly collected inside the bay from March to June, while at the station outside Jinju Bay, *L. tanakae* was commonly caught from March to May and *Pennahia argentata* from September to November (Tables 2 and 3).

Seasonal variation in species composition

While trends between seasons could not be empirically tested due to the lack of replication in seasonal data, monthly data binned into categories that matched particular seasons in Korea showed some interesting patterns. Difference between these binned data can be used to infer potential seasonal changes. The number of fish species varied from 14 to 31 between the four binned

Table 3 Species composition of fishes collected by shrimp beam trawl outside of Jinju Bay, Korea, from December 2014 to November 2015 (unit: ind./km^2)

Scientific name	Dec.	Jan.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Total	%
Okamejei kenojei	200	850	200	150	250	200	100	300	500	300	150	3,200	0.9
Muraenesox cinereus	0	0	0	0	0	0	0	150	300	400	150	1,000	0.3
Conger myriaster	400	250	600	350	100	250	200	0	350	200	250	2,950	0.9
Thryssa kammalensis	0	0	0	1,650	0	0	0	11,599	600	10,299	7,149	31,297	9.0
Thryssa adelae	0	0	800	0	0	0	0	0	0	0	0	800	0.2
Sardinella zunasi	0	0	0	0	0	0	0	0	0	50	0	50	+
Konosirus punctatus	50	0	50	0	0	0	0	0	0	0	0	100	+
Saurida microlepis	0	0	0	0	0	0	0	0	50	100	150	300	0.1
Coelorinchus multispinulosus	50	50	0	0	0	0	0	0	0	0	0	100	+
Lophius litulon	0	0	0	0	50	50	0	0	0	0	0	100	+
Sebastiscus marmoratus	50	0	0	0	0	0	0	0	0	0	0	50	+
Inimicus japonicus	0	0	250	600	250	50	100	0	0	0	200	1,450	0.4
Minous monodactylus	0	0	0	0	0	0	0	0	50	0	0	50	+
Hypodytes rubripinnis	500	250	700	0	0	0	0	0	0	0	0	1,450	0.4
Chelidonichthys spinosus	100	0	0	100	300	400	50	0	50	300	1,100	2,400	0.7
Platycephalus indicus	500	200	100	450	250	250	200	150	100	100	100	2,400	0.7
Hexagrammos otakii	0	50	0	0	0	0	0	0	0	0	0	50	+
Ricuzenius pinetorum	6,999	3,000	1,900	200	0	0	0	0	0	0	0	12,099	3.5
Hemitripterus villosus	0	50	1,650	150	0	0	0	0	0	0	0	1,850	0.5
Liparis tanakae	100	250	50,746	6,949	400	0	0	0	0	0	0	58,445	16.9
Lateolabrax maculatus	0	0	0	50	0	0	0	0	0	0	0	50	+
Malakichthys wakiyae	0	0	0	50	0	0	0	0	0	0	0	50	+
Apogon lineatus	0	0	0	0	1,000	3,150	450	0	0	1,150	1,050	6,799	2.0
Sillago japonica	0	50	0	1,300	450	550	600	2,600	1,300	200	250	7,299	2.1
Decapterus maruadsi	0	0	0	0	0	0	0	0	0	150	0	150	+
Trachurus japonicus	0	0	0	0	0	0	0	0	0	300	150	450	0.1
Nuchequula nuchalis	250	0	3,900	7,799	150	0	50	11,149	950	47,546	21,198	92,993	26.9
Hapalogenys mucronatus	0	0	0	50	0	0	0	0	0	0	0	50	+
Johnius grypotus	0	0	0	500	0	0	50	100	0	0	0	650	0.2
Pennahia argentata	0	0	0	50	1,150	2,100	750	8,299	1,150	6,549	2,500	22,548	6.5
Larimichthys polyactis	0	0	0	350	0	0	0	0	0	0	0	350	0.1
Upeneus japonicus	0	0	0	0	0	0	0	0	0	0	50	50	+
Halichoeres poecilopterus	0	50	0	0	0	0	0	0	0	0	0	50	+
Zoarces gillii	450	550	50	9,549	3,300	2,650	50	0	0	0	0	16,599	4.8
Chirolophis wui	0	50	0	0	0	0	0	0	50	0	0	100	+
Pholis nebulosa	1,350	50	50	100	150	150	0	0	0	0	50	1,900	0.5
Pholis fangi	50	150	500	2,700	1,050	2,000	50	0	0	0	100	6,599	1.9
Champsodon snyderi	0	0	0	0	0	0	0	0	0	0	200	200	0.1
Parapercis sexfasciata	1,450	450	150	100	250	150	0	0	100	0	50	2,700	0.8
Uranoscopus chinensis	0	0	0	0	0	0	0	0	0	0	50	50	+
Xenocephalus elongatus	0	0	0	0	0	0	0	0	0	800	150	950	0.3
Repomucenus valenciennei	250	100	0	0	1,100	1,650	850	1,000	700	4,000	3,950	13,599	3.9
Amblychaeturichthys hexanema	100	950	750	0	9,349	1,900	200	50	900	5,400	7,849	27,448	7.9

Table 3 Species composition of fishes collected by shrimp beam trawl outside of Jinju Bay, Korea, from December 2014 to November 2015 (unit: ind./km^2) *(Continued)*

Scientific name	Dec.	Jan.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Total	%
Tridentiger trigonocephalus	50	100	0	0	0	0	0	0	0	0	0	150	+
Acanthogobius flavimanus	300	50	100	0	0	0	0	0	0	0	0	450	0.1
Ctenotrypauchen microcephalus	50	0	0	0	0	0	0	0	0	0	0	50	+
Chaeturichthys stigmatias	0	0	0	150	0	0	0	0	0	0	0	150	+
Cryptocentrus filifer	0	0	0	0	100	200	0	0	0	0	0	300	0.1
Acentrogobius pflaumi	0	0	450	0	400	0	150	50	950	150	400	2,550	0.7
Trichiurus japonicus	0	0	0	0	0	0	0	200	0	0	50	250	0.1
Psenopsis anomala	0	0	0	0	0	0	0	0	0	150	0	150	+
Pseudorhombus pentophthalmus	0	0	0	0	0	0	0	0	0	100	1,550	1,650	0.5
Pleuronichthys cornutus	0	0	900	450	550	450	50	200	100	0	0	2,700	0.8
Kareius bicoloratus	50	100	0	0	50	0	0	0	0	0	0	200	0.1
Pseudopleuronectes yokohamae	100	500	250	50	300	100	50	0	200	0	0	1,550	0.4
Pseudaesopia japonica	50	300	150	200	250	150	0	0	0	0	0	1,100	0.3
Zebrias fasciatus	0	0	0	0	0	0	0	0	50	0	0	50	+
Cynoglossus robustus	50	0	0	0	0	50	0	0	0	0	0	100	+
Cynoglossus semilaevis	50	0	0	0	0	0	0	0	0	0	0	50	+
Cynoglossus abbreviatus	0	1,750	100	150	500	700	0	0	0	100	0	3,300	1.0
Cynoglossus joyneri	0	800	450	50	350	400	250	650	400	700	1,750	5,800	1.7
Cynoglossus interruptus	0	0	0	0	400	1,250	150	150	1,450	100	0	3,500	1.0
Stephanolepis cirrhifer	0	0	0	0	0	0	0	0	0	50	0	50	+
Takifugu niphobles	150	0	0	0	0	0	0	0	0	0	0	150	+
Lagocephalus wheeleri	0	0	0	0	0	0	0	0	0	50	0	50	+
No. of species	26	25	23	27	26	23	19	15	21	25	26	65	
Total	13,699	10,949	64,795	34,247	22,448	18,798	4,350	36,647	10,299	79,244	50,596	346,072	100

+: less than 0.1%

seasons, with the highest values recorded at both stations in winter (Fig. 3a). The mean number of species tended to be high during winter and spring at both stations and lowest during autumn (inside the bay) and summer (outside the bay). Fish abundance varied by temporally peaking in summer inside the bay and autumn outside the bay. Abundance was the lowest inside the bay in autumn and outside the bay in winter (Fig. 3b). Greater fish abundances corresponded with high occurrences of *N. nuchalis* and *T. kammalensis* during August (Tables 2 and 3). Diversity indices ranged from 0.98 to 2.63 inside the bay and 1.06 to 2.62 outside the bay. The highest diversities were recorded in winter inside the bay and summer outside the bay (Fig. 3c).

Multivariate analyses of fish assemblages

Cluster analysis of the 14 common species indicated that less than 1% of the total abundance of fishes were collected from inside the bay. Species were divided into five groups at a similarity level of 60% (Fig. 4a). Group A consisted of *L. tanakae*, *Z. gillii*, *Ricuzenius pinetorum*, *Pholis fangi*, *Repomucenus valenciennei*, and *Pholis nebulosi*, with a high emergence in spring and winter. Group B consisted of *N. nuchalis*, *P. argentata*, *Sillago japonica*, and *Conger myriaster* and were collected continuously during the survey period. *P. cornutus* and *Inimicus japonicus* collected in abundance in spring and summer formed Group C. *T. kammalensis* collected in summer comprised Group D, and *Cynoglossus robustus* collected in autumn comprised Group E (Fig. 4b).

Common fish species collected outside the bay were divided into four groups at a similarity level of 60% (Fig. 5a). *Amblychaeturichthys hexanema*, *P. argentata*, *R. valenciennei*, *S. japonica*, *Apogon lineatus*, *Cynoglossus joyneri*, and *C. interruptuss* were caught in high abundance in spring, summer, and autumn and clustered into Group A. *L. tanakae*, *Z. gillii*, *P. fangi*, and *Cynoglossus abbreviatus* collected in spring and winter formed Group B. Group C comprised of *N. nuchalis* and *T. kammalensis* that concentrated in spring and autumn. *R. pinetorum* collected in the winter formed Group D (Fig. 5b).

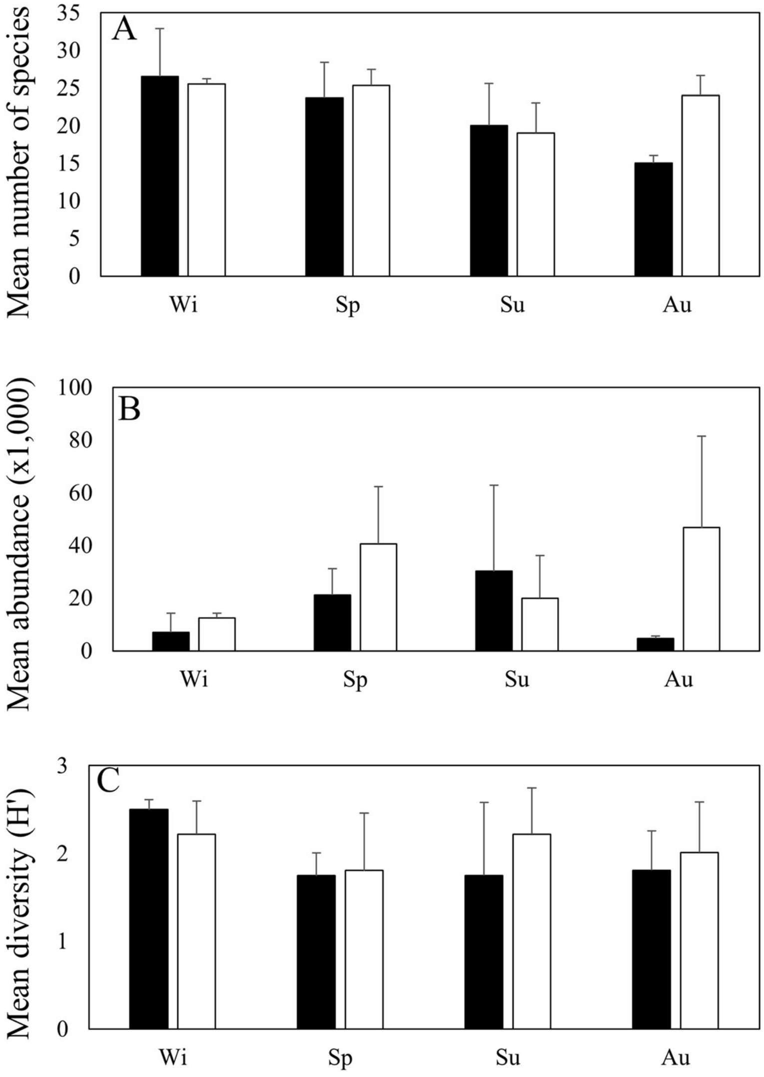

Fig. 3 Monthly variations in the number of species, number of individuals (ind./km^2), and diversity index (H') of fish collected inside (black) and outside (white) of Jinju Bay, Korea, from December 2014 to November 2015. Wi = winter, Sp = spring, Su = summer, Au = autumn

A canonical correspondence analysis revealed that three environmental factors contributed to fish assemblages between stations, and among common fish species in each of the four seasons (Fig. 6). Differences in fish assemblages between stations were linked to depth and salinity during winter, spring, and autumn, while temperature and depth contributed to differences in fish assemblages during summer (Fig. 6). Among the common fish species, *N. nuchalis* appeared negatively affected by salinity and depth in spring, summer, and autumn, but not in winter. *P. cornutus* appeared positively affected by water temperature in all seasons but autumn. *T. kammalensis* appeared positively affected by water temperature in summer and autumn, but was negatively affected by water temperature in spring.

Spatio-temporal variations in common fish species

In spring and autumn, the dominant species of fish at both stations were *Z. gillii* and *N. nuchalis*. However, the dominant species differed between stations in winter and summer. *Pleuronichthys cornutus* and *N. nuchalis* dominated inside the bay, while *L. tanakae* and *T. kammalensis* dominated outside the bay.

N. nuchalis occurred in low numbers at both stations in winter, but although the population increased rapidly inside the bay in the summer and outside the bay in autumn, there was no significant difference between the stations (ANOVA, P = 0.29; Fig. 7a). *T. kammalensis* showed a rapidly increasing trend inside the bay in the summer and was collected in large numbers in both summer and autumn outside the bay (Fig. 7b). *Z. gillii*

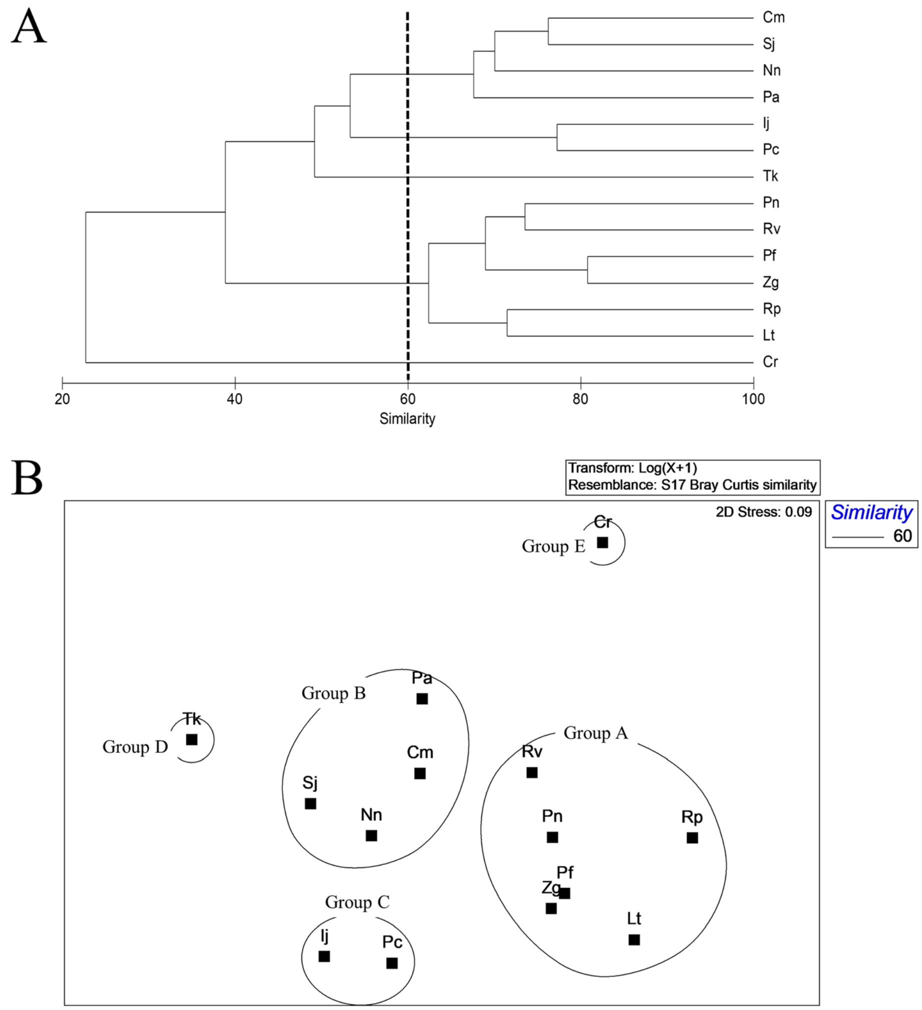

Fig. 4 A dendrogram (**a**) and non-metric multidimensional scaling (nMDS) (**b**) analysis of fish species collected by beam trawl inside of Jinju Bay, Korea (Nn, *Nuchequula nuchalis*; Tk, *Thryssa kammalensis*; Lt, *Liparis tanakae*; Zg, *Zoarces gillii*; Pa, *Pennahia argentata*; Rp, *Ricuzenius pinetorum*; Pf, *Pholis fangi*; Rv, *Repomucenus valenciennei*; Pc, *Pleuronichthys cornutus*; Sj, *Sillago japonica*; Cm, *Conger myriaster*; Cr, *Cynoglossus robustus*; Pn, *Pholis nebulosa*; Ij, *Inimicus japonicus*)

and *Pholis fangi* were intensively collected inside and outside the bay in the spring (Fig. 7c, d). *Pleuronichthys cornutus* was collected in significantly higher numbers inside of the bay in spring compared to the other seasons (Bonferroni's test, $P < 0.05$; Fig. 7e). *L. tanakae* was collected consistently outside the bay (ANOVA, $P = 0.34$; Fig. 7f). *Amblychaeturichthys hexanema* was collected in abundance inside the bay in winter and outside the bay in spring and autumn (ANOVA, $P = 0.20$; Fig. 7 g). *Pennahia argentata* was collected consistently outside the bay in summer and autumn (ANOVA, $P = 0.14$; Fig. 7h).

Size of juvenile fish

Juvenile *P. cornutus*, *Z. gillii*, *H. villosus*, *L. tanakae*, and *P. argentata* were collected inside and outside the bay (Fig. 8). *P. cornutus* occurred during seven of the monthly surveys (March–September) at both stations. These fish exhibited average lengths of 4.7 cm ± 0.5 cm (± SD) in March and 17.3 cm ± 1.1 cm in September. *Z. gillii* was collected over 3 months (April–June) inside the bay and over 4 months (April–July) outside the bay. *H. villosus* occurred over 3 months (March–May) inside the bay and for 2 months (March–April) outside the bay. These three species were collected more frequently from inside than from outside of the bay (Fig. 8). On the other hand, *L. tanakae* was found inside (6.2–18.5 cm TL) and outside (8.1–12.2 cm TL) of the bay over 3 months (March–May), but more individuals were collected at the station outside the bay than inside the bay. In addition, *P. argentata* (inside bay, 4.1–14.8 cm TL; outside of bay, 5.7–15.8 cm TL) were found more frequently outside the bay than inside, over 3 months (September–November). *Xenocephalus elongatus* occurred over 2 months (October–November), but only outside the bay.

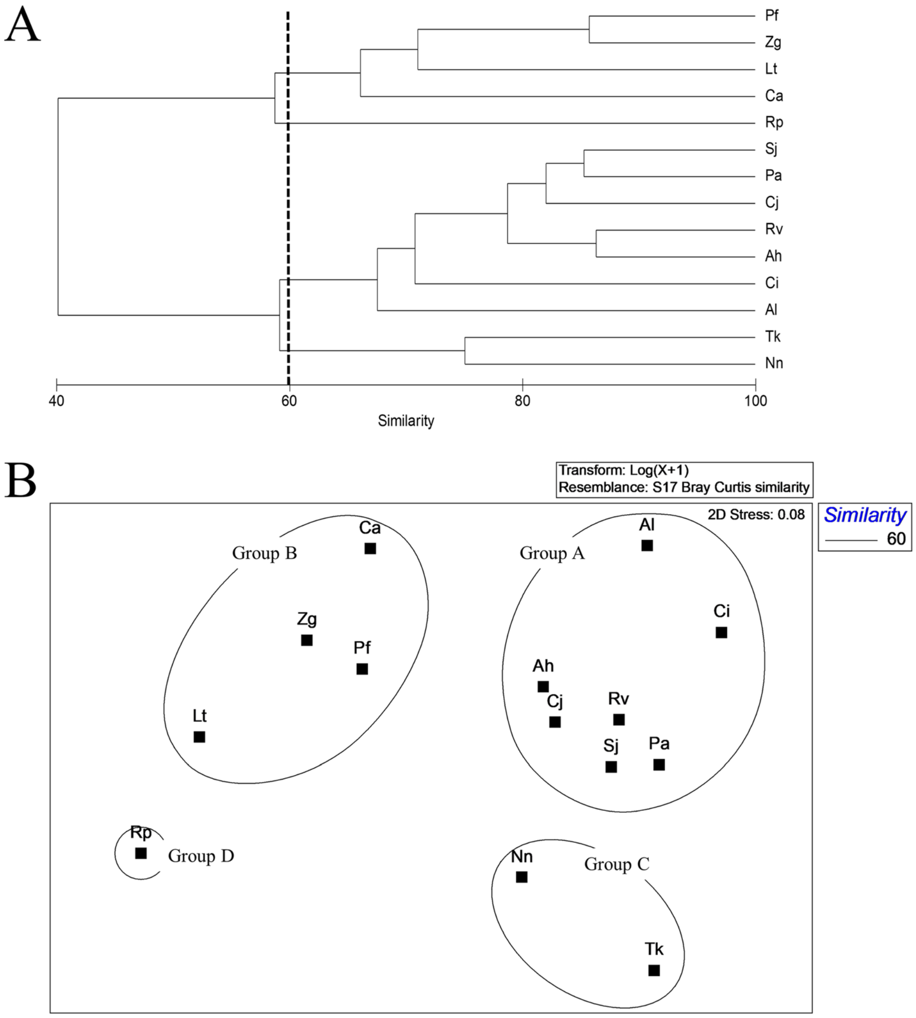

Fig. 5 A dendrogram (**a**) and non-metric multidimensional scaling (nMDS) (**b**) analysis of fish species collected by beam trawl outside of Jinju Bay, Korea (Nn, *Nuchequula nuchalis*; Tk, *Thryssa kammalensis*; Lt, *Liparis tanakae*; Zg, *Zoarces gillii*; Ah, *Amblychaeturichthys hexanema*; Pa, *Pennahia argentata*; Rp, *Ricuzenius pinetorum*; Pf, *Pholis fangi*; Rv, *Repomucenus valenciennei*; Sj, *Sillago japonica*; Al, *Apogon lineatus*; Cj, *Cynoglossus joyneri*; Ci, *Cynoglossus interruptus*; Ca, *Cynoglossus abbreviatus*)

All of these species were collected continuously throughout the study period, with TL increasing steadily over time, suggesting that these fish belonged to a single generation (Fig. 8).

Discussion

The consistent presence of juvenile fishes in the Jinju Bay region supports the concept that this broad area contains nursery grounds. The region appeared biodiverse in juvenile fishes, with 63 and 65 species collected inside and outside of the bay, respectively. Forty-seven of these species were collected simultaneously in both habitats. Of these, the most dominant species was *N. nuchalis* (26.4%), followed by *T. kammalensis* (12.2%), *L. tanakae* (12.0%), *Z. gillii* (8.9%), and *A. hexanema* (5.3%). *N. nuchalis* is a semi-benthic fish that occurs near the substratum and tends to move in conspecific groups (Kim et al. 2005). Although Kim and Kang (1991) reported that *N. nuchalis* occurs in relatively low abundance in coastal waters around Shinsudo in the southern Korean sea, they have consistently been documented as a dominant fish species in coastal fish assemblages in southern Korea, including the Nakdong river estuary (Kwak and Huh 2003), Gwangyang bay (Kwak et al. 2012), and coastal waters of Gadeok Island (Jeong et al. 2013). In addition, young larvae of this species have also been recorded in the coastal ecosystems of Gwangyang Bay (Cha and Park 1994) and Nakdong River estuary (Choi et al. 2015).

The neritic region of the Korean Peninsula is documented to have a high level of primary productivity and has been proposed as a spawning ground, a nursery ground,

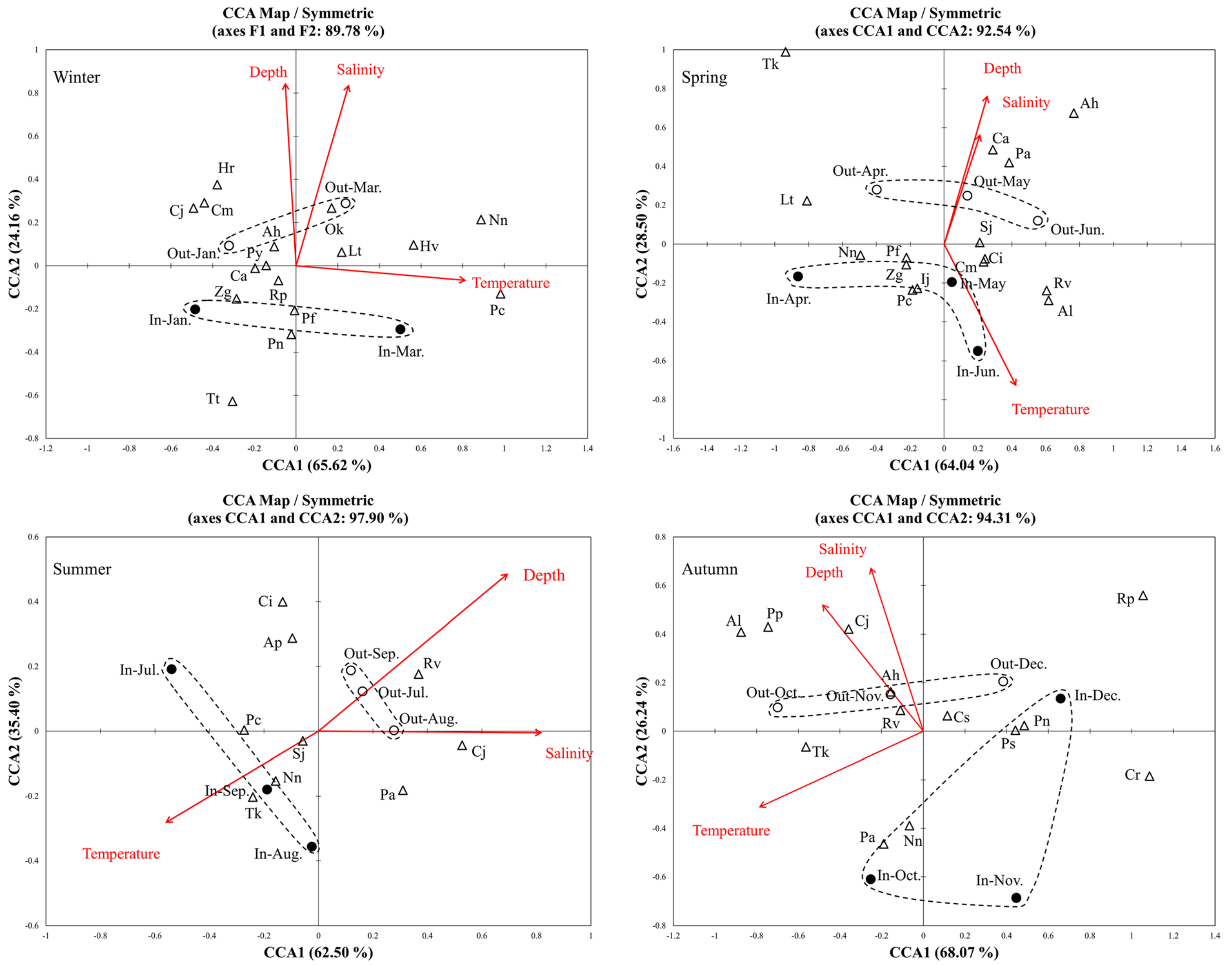

Fig. 6 Canonical correspondence analysis (CCA) ordination diagrams of stations in relation to environmental variables (temperature, salinity, depth) for young fish species inside (black circle) and outside (white circle) of Jinju Bay, Korea (Species codes are Ap, *Acentrogobius pflaumi*; Ah, *Amblychaeturichthys hexanema*; Al, *Apogon lineatus*; Cs, *Chelidonichthys spinosus*; Cm, *Conger myriaster*; Ca, *Cynoglossus abbreviatus*; Ci, *Cynoglossus interruptus*; Cj, *Cynoglossus joyneri*; Cr, *Cynoglossus robustus*; Hv, *Hemitripterus villosus*; Hr, *Hypodytes rubripinnis*; Ij, *Inimicus japonicus*; Nn, *Nuchequula nuchalis*; Lt, *Liparis tanakae*; Ok, *Okamejei kenojei*; Ps, *Parapercis sexfasciata*; Pa, *Pennahia argentata*; Pf, *Pholis fangi*; Pn, *Pholis nebulosa*; Py, *Pseudopleuronectes yokohamae*; Pc, *Pleuronichthys cornutus*; Pp, *Pseudorhombus pentophthalmus*; Rv, *Repomucenus valenciennei*; Rp, *Ricuzenius pinetorum*; Sj, *Sillago japonica*; Tk, *Thryssa kammalensis*; Tt, *Tridentiger trigonocephalus*; Zg, *Zoarces gillii*)

and a feeding site for many fish (Cha and Park, 1997). Song et al. (2019) collected young fish of *L. tanakae*, *Z. gillii*, *C. joyneri*, *P. argentata*, *P. cornutus*, and *P. yokohamae* around Jinju Bay and reported that they used Jinju Bay as a nursery ground and feeding site. In addition, most of the young fish individuals are collected in the estuary and bay, so it can be said to be a place for feeding site (Hwang et al. 2012). In addition, collected fish eggs and larvae to investigate fish that use Jinju Bay as a spawning and nursery ground. They found that 28 species use Jinju Bay as spawning grounds and 40 species use the area as a nursery ground. Most of the bays are rich in prey organisms under the influence of land, creating a favourable environment for young individuals (Newton et al. 2014; Álvarez et al. 2015).

In our study, *N. nuchalis* was the most dominant (inside the bay, 25.6%; outside the bay, 26.9%), followed by *T. kammalensis* (17.9%; 9.0%) and *Z. gillii* (16.0%; 4.8%). All other species of juvenile fishes were caught in much lower abundances (Table 1). As such, the fish assemblages were dominated by a few fish species, and such dominance by minority species is a common phenomenon in most of estuarine habitats worldwide (e.g. Maes et al. 2005; Elliott et al. 2007; Selleslagh and Amara 2008). *N. nuchalis* is commonly seen as a dominant species in many estuarine habitats in Korea (Kwak and Huh 2003; Yoon et al. 2011; Jeong et al. 2013). It is also a species known to have the capacity to inhabit polluted waters (Lee 1996; Lee et al. 2011; Jeong et al. 2013). It may, therefore, be indicative of pollution in the waters around Jinju Bay. Future research

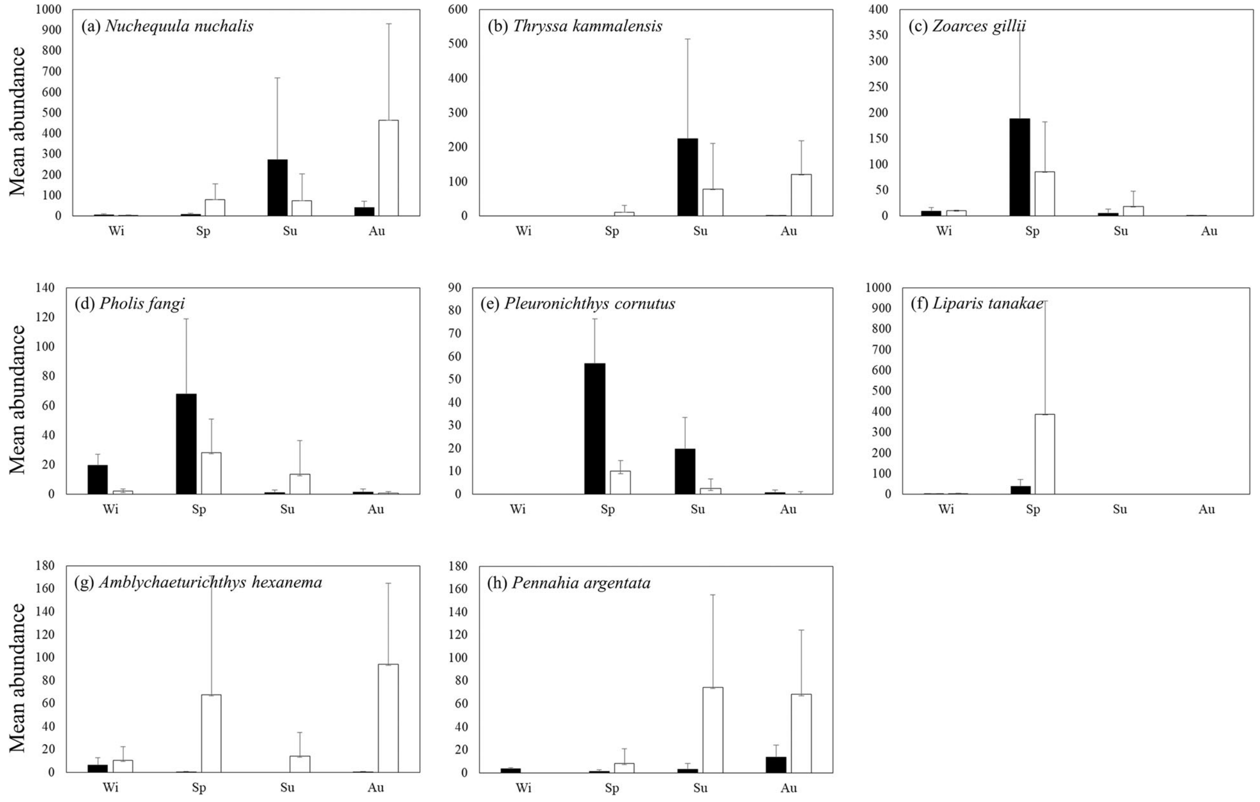

Fig. 7 Seasonal variations in mean abundance of 8 common fish species (**a–h**) between inside (black stick) and outside (white stick) of Jinju Bay, Korea, from December 2014 to November 2015

needs to be done to assess the relationship between pollution levels in Jinju Bay and the presence of *N. nuchalis.*

Sixteen species were collected within Jinju Bay only. *Tridentiger nudicervicus* (38.8%) and *Pseudoblennius cottoides* (10.4%) dominated the assemblage at this station whereas 18 species including *Pseudorhombus pentophthalmus* (40.2%) and *X. elongatus* (23.2%) dominated the assemblage outside the bay. These results revealed different fish assemblages inside and outside Jinju Bay, implying that different environment conditions, such as depth and salinity, may contribute towards optimizing habitat for each of the common species. During this study, salinities were lower inside Jinju Bay than at the station outside the bay. A substantial reduction in salinity was recorded in July within the bay that coincided with increased Nam River discharge derived from heavy rainfall at that time (Water Resources Management Information System WAMIS). This decrease in salinity has also been recorded at Gwangyang Bay (Kwak et al. 2012), Jinhae Bay (Hwang et al. 2011), and Masan Bay (Kwak and Park 2014). In addition, Nakdong River estuary (Park et al. 2015) located at the southern coast of Korea also indicated lowest salinity during the summer season. As with many rivers downstream in South Korea, Jinju Bay is an area that is heavily influenced by coastal water. According to a study by Chin et al. (2020), during the period of heavy rain in a similar estuary, salinity was reduced so substantially that anchovy spawning was stopped during this period. In addition, when there is substantial rain, photosynthesis of phytoplankton increases due to a decrease in salinity and an increase in organic matter (Park et al. 2013). After that, many phytoplankton die due to an anaerobic layer that forms on the surface of the water (Moon et al. 2006). The anoxic layer of the surface layer is also thought to have a substantial impact on pelagic eggs and larvae. During high rainfall, such as that experienced in Korea in July, the saline concentration decreases, thereby affecting the appearance or distribution of fish. Depth also differed between the stations, and this parameter may also influence the demography of species caught in this study (Muhling et al. 2007; Zhang et al. 2015). More research is required to understand the drivers behind the patterns observed in our research.

Estuaries provide spawning and nursery grounds for diversity of coastal fishes and estuarine residents (Hwang et al. 2005; Hwang and Rhow 2010; Lee et al. 2014; Park et al. 2015). In particular, juvenile *Z. gillii*, *P. cornutus*, *L. tanakae*, *H. villosus*, *P. argentata*, and *X. elongates* were collected continuously throughout the year, indicating the probability of fish nurseries inside and outside Jinju

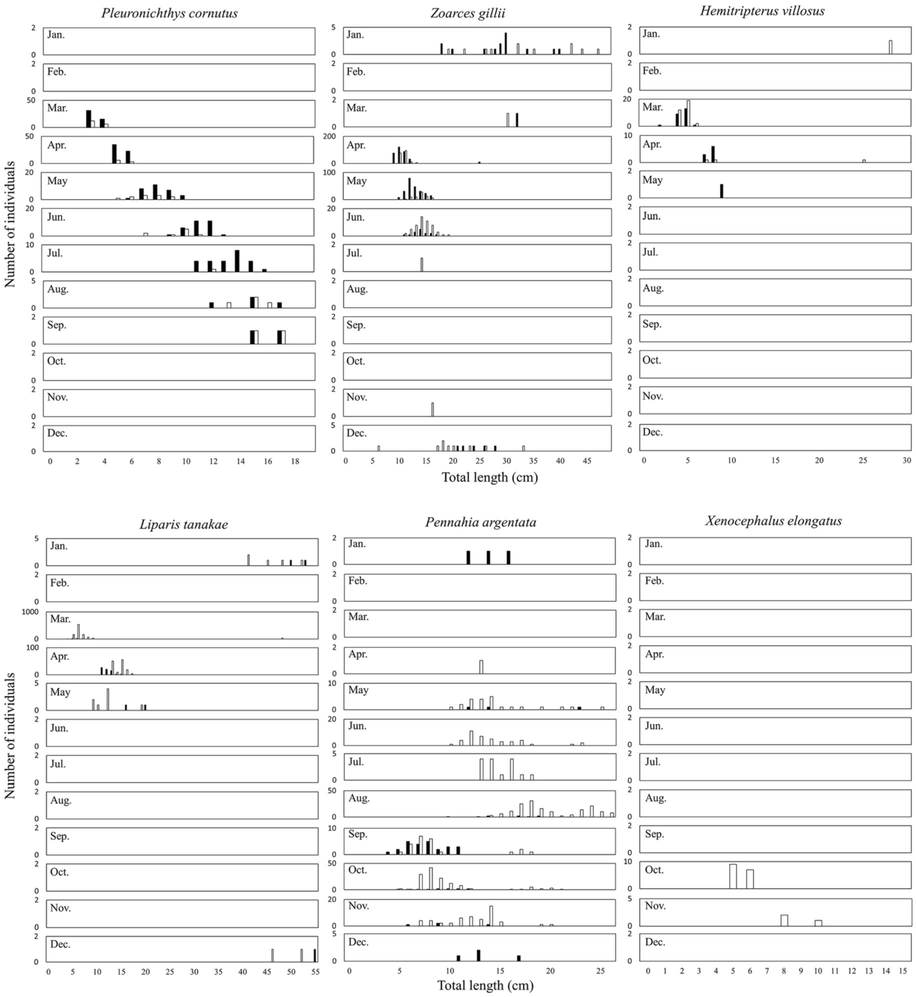

Fig. 8 Monthly change in length-frequency distribution of the six species caught with a beam trawl inside (black stick) and outside (white stick) of Jinju Bay, Korea, from December 2014 to November 2015

Bay due to the continued residency of these species. The location of the proposed nursery grounds differed depending on the species of fish. *Z. gillii*, *P. cornutus*, and *H. villosus* were resident species at the station inside Jinju Bay and are likely to use this areas as a nursery ground, whereas *L. tanakae*, *P. argentata*, and *X. elongates* were resident at the station outside the bay and potentially used this area as a separate nursery ground. In addition, the timing of residency differed from between species. Such difference temporal and spatial differences in occurrence may be a reflection of the spawning patterns of these species or may occur as avoidance of competition for food and habitat, as observed in other juvenile fish (Amara et al. 2001). If suchareas are acting as nursery grounds, food provisioning and refuge from predation for these juvenile fishes should be higher in these areas than in other regions (McLusky and Elliott 2004).

It is well known that offshore marine aquatic resources in the region are depleted due to overfishing and environmental pollution (Yoo et al. 1999; Zhang et al. 2003). For the conservation and management of aquatic biological resources in the region, various management regimes have been implemented, such as establishing a catch prohibition length and period (Cha and Jung 2012; Ji et al. 2015). Peterson et al. (2004) said that protecting spawning grounds during the spawning season is the most effective way to conserve such resources. Protection of the two proposed nursery grounds identified in this study should also be considered during spawning times of the relevant species.

Our research identified potential nursery grounds in Jinju Bay from collecting juvenile fishes over time. However, such functions are also verified throughout various methods, including analyses of single-nucleotide polymorphisms (SNPs) and trace elements (e.g. Sr, Ba, Cr) composition in fish body, because those methods have broadly been applied for estimating the sea areas of spawning grounds and migration routes during early life history

(Rooker et al. 2008; Nielsen et al. 2012; Bonanomi et al. 2016; Shiao et al. 2016). Thus, further studies are recommended via analysing trace elements of otoliths in both inside and outside Jinju Bay, and/or single-base polymorphism.

Conclusions

Jinju Bay is a semi-closed bay whose salinity is affected by freshwater discharge from the Nam River, particularly in summer. Nevertheless, 81 species were collected from inside and outside of Jinju Bay, and it was found that various fish were inhabited. Also, 40 species used inside of the bay as a nursery ground. Since outside of the bay has less environmental change than inside of the bay, more species (47 species) used inside of the bay as nursery ground. Especially *Pleuronichthys cornutus*, *Zoarces gillii*, and *Hemitripterus villosus* used inside of the bay as nursery ground. Meanwhile, *Liparis tanakae*, *Pennahia argentata*, and *Xenocephalus elongates* used outside of the bay.

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Authors' contributions
SHM and JKK contributed to the conceptualization and design of research. SHM, SNK, WCL, JBK, HCK, and JKK contributed to the investigations and experiments. SHM and JKK contributed to the data analysis. SHM and JKK contributed to the writing of the original draft. SHM, JEW, and JKK contributed to the writing including review and editing. The author(s) read and approved the final manuscript.

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Not applicable.

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Competing interests
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