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Microhabitat Characteristics Determine Fish Community Structure in a Small Stream (Yudeung Stream, South Korea)

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ABSTRACT

Distribution of fish community depends largely on environmental disturbance such as habitat change. In this study, we evaluated the impact of environmental variables and microhabitat patch types on fish distribution in Yudeung Stream at 15 sites between early May and late June 2019. We used non-metric multidimensional scaling to examine the distribution patterns of fish in each site. *Gnathopogon strigatus*, *Squalidus gracilis majimae*, *Zacco koreanus*, and *Zacco platypus* were associated with riffle and boulder areas, whereas *Iksookimia koreensis*, *Acheilognathus koreensis*, *Coreoleuciscus splendidus*, *Sarcocheilichthys nigripinnis morii*, and *Odontobutis interrupta* were associated with large shallow areas. In contrast, *Cyprinus carpio*, *Carassius auratus*, *Lepomis macrochirus*, and *Micropterus salmoides* were found at downstream sites associated with large pool areas, sandy/clay-bottomed areas, and vegetated areas. On the basis of these results, we suggest that microhabitat patch types are important in determining the diversity and abundance of fish communities, since a mosaic of different microhabitats supports diverse fish species. As such, microhabitat patches are key components of freshwater stream ecosystem heterogeneity, and a suitable patch composition in stream construction or restoration schemes will support ecologically healthy food webs.

Keywords: Aquatic macrophytes, Microhabitat, Pool, Riffle, River continuum, *Zacco koreanus*

Introduction

Empirical studies have suggested that the relationship between the distribution of fish assemblages and environmental characteristics may be influenced by many variables, including body size (Knouft, 2002), habitat range (Willis *et al*., 2005), and life history traits (Mims & Olden, 2012). Ecological gradients related to the river continuum are closely associated with fish community composition in freshwater stream ecosystems (Curtis *et al*., 2018; Ratton *et al*., 2018), and can explain the common pattern of upstream-to-downstream replacement of congeneric species pairs that belong to the same environmental guild, exhibit similar life history strategies, and occupy similar trophic niches. Fish species differ in their habitat requirements and preferences, and therefore, their presence and abundance can be strongly influenced by habitat characteristics at different spatial scales from headwaters to downstream (Hoeinghaus *et al*., 2007; Mendonça *et al*., 2005). For example, large piscivorous fish are likely to have larger ranges compared with other fishes, but may

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be attracted to specific habitat spaces, such as a complex habitat rich in aquatic plants, due to prey abundance (Rilov *et al*., 2007). Fish assemblages can change substantially across habitats and spatial extents, even across tens of meters on reefs (Wedding *et al*., 2008). It is therefore important to consider spatial characteristics such as environmental variables and habitat patch types in each section of stream to better understand how habitat features spatially influence fish assemblages.

The ecological health of streams relies on linkages between physical habitat quality and species composition. Previous studies have described longitudinal mapping of habitat units in sequence, with dimensions of each unit and information based on riparian vegetation and microhabitat features (Stromberg, 2001; Thomson *et al*., 2001). Ecologically, pools and riffles are essential since many lotic species have evolved body morphology and behaviors to specifically occupy one unit or the other (Brooks & Brierley, 2002). Therefore, stream restoration projects commonly involve reach-scale channel reconfigurations, with pool-riffle sequences being a key morphological structure for restoration design (Kasahara & Hill, 2008). Despite various fish species' responses to habitat characteristics, available information regarding their distribution focuses mainly on the local scale (Buisson *et al*., 2008; Huang *et al*., 2016; Perkin & Gido, 2012). In particular, most studies in South Korea only explain the distribution of fish species in each section of the stream, but the impact of different microhabitat types as they relate to entire stream sections from headwaters to its mouth is unclear. South Korea has built weirs and dams in most stream sections to ensure continuous water resources, which has disturbed natural stream continua across many different sections, and may affect the spatial distribution of animal communities, including that of fish.

The primary objective of our study was to characterize the influence of environmental variables and habitat patch types on fish distribution within a continuous stream section. We hypothesized that the distribution of fish communities could be clearly distinguished according to habitat characteristics in each section of a stream. Habitat preference for each fish species lead to different spatial distribution in accordance with longitudinal section supported by different microhabitat types. We selected Yudeung Stream as a suitable study site because it reflects the continuous microhabitat types, with fewer weir and dam modifications compared with other streams in South Korea. The results of this study can be used as basic data for establishing stream restoration plans in management of stream health and fish species diversity.

Materials and Methods

Site description and monitoring strategy

Yudeung Stream, a major tributary of the Geum River in South Korea, is 44 km long and has an approximate drainage area of 289.14 km^2. Most sections, except for the upstream parts, run through downtown Daejeon City and are constantly disturbed by human activity. We selected 15 study sites that reflect diverse microhabitats from upstream to downstream sections (Fig. 1) and surveyed the stream from early May to late June 2019 over a period of eight weeks before the occurrence of summer monsoon (July to August; Choi & Kim, 2020a) to avoid physical disturbance of fish distributions caused by the monsoon. We randomly selected three sampling points per site based on virtual grids constructed over maps of each study site.

Environmental variables including water temperature, pH, dissolved oxygen (DO), conductivity, turbidity, and water velocity were measured in three quadrats at each of the study sites. We used a DO meter (YSI Model 58; YSI Incorporated, Yellow Springs, OH, USA) to measure temperature and DO, a Fisher Conductivity Meter (YSI model 152; YSI Incorporated) to measure conductivity, and an Orion Model 250A pH meter (Orion Research, Beverly, MA, USA) to measure pH. Turbidity was measured using a turbidimeter (Model 100B; HF Scientific Inc., Ft. Myers, FL, USA). Average water velocity was measured using a portable multi-parameter water checker (Hach Co., Loveland, CO, USA) at six sampling points for each site. Analysis of factors associated with regional variation of fish assemblages was performed using both environmental and

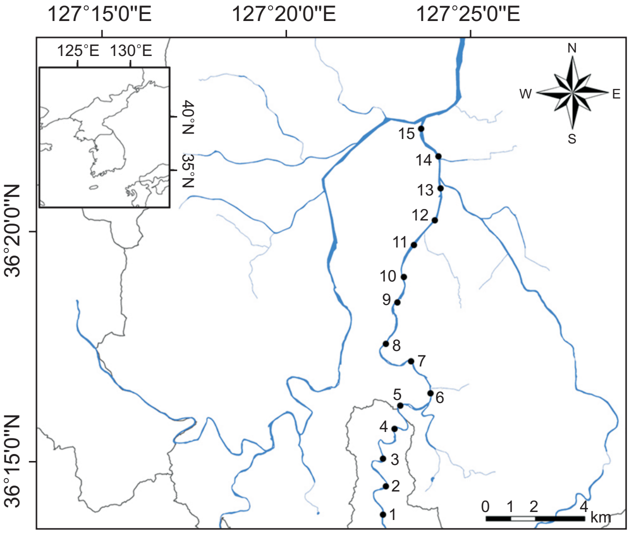

Fig. 1. Map of study sites in Yudeung Stream, as indicated by solid circles (●). The small map in the upper left corner indicates the Korean Peninsula.

spatial explanatory variables.

Fish were caught using a 3.5 m diameter cast net with 7×7 mm mesh size and a 5×5 mm mesh dip net (0.32 m^2 area). In cast net sampling, the same points along the 100 m riparian zone were sampled in the upper and lower part of the stream at all events. Cast net was cast 10 times at 10 m intervals to yield a total of 20 casts, covering a total water surface area of 61.2 m^2. Dip net sampling was conducted one hour later along the same stretch of water, with 20 samples covering 6.4 m^2 water surface area. In study sites dominated by aquatic macrophytes and boulders, we used only dip net sampling. All collected fish were preserved in methanol-formaldehyde solution and were identified to species level according to Kim and Park (2002) and Kim *et al*. (2005) based on the classification system of Nelson *et al*. (2016).

Identification of microhabitat patch types

We delineated the habitat and characterized the patches within 200 m upstream and downstream of each study site using a combination of remotely sensed and field-collected data (Kobayashi *et al*., 2012). Specifically, we used a combination of on-screen digitizing in ArcGIS 10.1 and Arc Pad 8.0 (Environmental Systems Research Institute, Redlands, CA, USA) on a desktop computer. Characterized patches of the study area were obtained from satellite images (Daum Kakao Map in June, 2019; https://map.kakao.com) with 50 cm resolution. Using this approach and guidelines adapted from Holmes and Goebel (2011) and Johansen *et al*. (2010), we identified and digitized six patch types in the riverine microhabitat as riffle, pool, shallow, boulder, sand/clay, and vegetated (Table 1). Several microhabitat patches that are difficult to distinguish from satellite images were additionally identified through field surveys. Riffles were classified as areas with a steep surface and shallow depth relative to up- and downstream areas, with swift flow and the surface usually broken (white-colored water). Pools were classified as areas with flat, smooth surfaces with greater depth relative to upstream and downstream areas. Shallows were classified as areas of less than 1 m depth, which could overlap with riffles and pools. Boulder classification was used to refer to patches with bottom structure larger than 256 mm. Sand/clay referred to areas with very fine particles of 0.125-0.004 mm. Vegetated areas included those occupied by aquatic macrophytes, namely emergent, floating, and submerged plants. We identified aquatic macrophytes species appearing at each study site.

Data analysis

Environmental variables and microhabitat patch types were log-transformed after assessing their degrees of normality based on the Shapiro-Wilk test. Also, Seventeen species were selected for further analysis. We then used

Table 1. Environmental variables and habitat patch types at study sites

Sites	Environmental variables						Habitat patch types (m^2)					
	WT	pH	DO	Cond.	Tur.	Vel.	Riffle	Pool	Shallow	Boulder	Sand/clay	Vegetation
1	16.3	7.6	102.1	98.3	1.8	1.4	532.5	324.2	868.2	528.3	0	223.1
2	16.4	7.4	115.3	101.5	2.4	1.1	694.2	220.1	442.7	647.3	0	415.3
3	16.2	7.8	111.2	106.2	2.1	1.8	846.3	262.4	410.5	785.1	0	284.3
4	17.3	7.3	95.3	84.3	2.0	1.0	651.2	286.3	604.2	452.2	105.2	214.3
5	17.5	7.8	92.7	125.3	1.5	1.1	781.21	215.3	485.3	562.3	95.5	252.6
6	17.2	7.1	84.6	128.5	1.8	1.2	684.6	318.7	325.4	408.4	108.3	254.3
7	17.3	7.6	74.5	108.4	2.1	1.5	612.3	268.2	226.2	485.2	156.2	212.5
8	16.9	7.6	95.3	116.2	2	0.6	552.3	125.3	274.3	528.3	112.3	205.2
9	17.1	7.7	86.3	113.2	1.5	0.2	216.2	0	538.9	582.4	0	146.2
10	16.8	7.5	84.3	208.4	2.5	0.5	265.3	523.5	214.3	282.3	0	542.3
11	17.2	7.2	68.3	198.3	1.8	0.3	285.3	610.5	426.4	151.2	528.2	652.1
12	17.9	7.5	82.5	207.3	3.2	0.6	265.3	471.3	325.8	256.3	405.2	568.2
13	17.8	7.4	74.3	215.3	5.6	0.2	185.2	721.3	445.2	151.2	451.3	571.2
14	17.5	6.8	68.3	235.2	11.6	0	0	1,065.2	652.3	54.2	584.3	584.3
15	16.7	7.1	47.3	254.2	19.2	0	0	879.3	548.2	0	684.2	625.3

WT, water temperature (°C); DO, dissolved oxygen (%); Cond., conductivity (μg/L); Tur., turbidity (NTU); Vel., water velocity (m/s). Shallow refers to depth not exceeding 1 m. Boulder refers to the bottom structure beyond 256 mm.

non-metric multidimensional scaling (NMDS) to examine species distribution patterns according to their abundance at each site. NMDS ordination plots were produced based on Euclidean distance, and goodness-of-fit was assessed in terms of loss of stress. Stress value for the two-dimensional solution was 0.186, lower than the generally accepted maximum stress value of <0.2 (Clarke, 1993). Environmental variables and microhabitat patch types were fitted to NMDS ordination axes scores. The significance of the fitted vectors was assessed using 3000 permutations, with *P*<0.05 considered significant. NMDS ordination was conducted with the R package 'vegan' (version 2.5-3; Oksanen *et al*., 2013).

We also clustered the 15 sites based on environmental variables and microhabitat patch types, allowing the generation of probability values for clusters using bootstrap resampling with 1000 runs. Clustering was carried out using R version 2.5-3 (R Core Team, 2019).

Results and Discussion

Environmental variables and microhabitat patch types

Environmental variables from each study site reflected the limnological characteristics of a temperate stream (Table 1). Among environmental variables, DO, conductivity, turbidity, and water velocity differed by site (one-way ANOVA, *P*<0.05). DO was generally highest in upstream regions, with sites 1-3 having <100% DO, and decreased downstream with a range of 47.3 to 95.3%. This reflects water velocity. In contrast, conductivity and turbidity increased downstream. Water temperature and pH did not differ notably among study sites (one-way ANOVA, *P*>0.05).

Microhabitat patch types differed markedly across study sites (Table 1). Greater areas of pool, sand/clay, and vegetation were present in the downstream regions, whereas riffle and boulder areas dominated in the upstream regions. In streams and rivers, the growth of aquatic macrophytes is closely related to water flow, and downstream areas with relatively lower flow are more suitable for macrophyte growth. The increase in sand/clay areas over boulders in the downstream also contributes to the development of aquatic macrophytes. Plant community composition varied similarly across the study sites. Most of the study sites were dominated by *Phragmites communis* Trin. and *Paspalum distichum* L., which were accompanied by a total of seven plant species: *Miscanthus sacchariflorus* (Maxim.) Hack, *Typha orientalis* C. Presl, *Typha angustifolia* L. sensu lato, *Paspalum distichum* var. *indutum* Shinners, *Ceratophyllum demersum* L., *Potamogeton malaianus* Miq. var. *latifolius* Nakai ex Mori, and *Potamogeton oxyphyllus* Miq.

Clustering of the study sites based on environmental similarity and microhabitat patch types yielded three groups with homogeneous native fauna (Fig. 2). These groups reflected the microhabitat characteristics of the studied aquatic ecosystems, implying an underlying biogeographical pattern. Group 1 included sites 14 and 15 as representative of downstream characteristics, and Group 2 comprised sites 10 to 13, representing the middle section. The remaining sites 1-9 in the upstream section constituted Group 3. Based on this, microhabitat characteristics of Yudeung Stream could be clearly distinguished by distinct environmental variables and microhabitat patch types in the upstream to downstream direction.

Effect of fish distribution on microhabitat structure

A total of 2042 individuals belonging to 24 fish species were collected at the 15 study sites (Table 2). Cyprinidae was the dominant family, represented by 14 species, with a relative abundance of 92.1%. They were followed by the Centrarchidae (3.0%), Gobiidae (1.7%), and Centropomidae (1.4%). The remaining families (Odontobutidae, Cobitidae, and Bagridae) represented less than 1%. These distribution characteristics are consistent which reported the dominance of Cyprinidae in freshwater streams (Kim & Park, 2002). On a species level, *Zacco platypus* dominated with 1015 individuals (ind.) (relative richness, 50%) across study sites, followed by *Zacco koreanus* (497 ind., 24.4%), *Pungtungia herzi* (105 ind., 5.2%), and *Coreoleuciscus splendidus* (80 ind., 3.9%) (Figs. 3, 4). The greatest abundance of fish was found at site 3 with 517 ind., followed by site 5 with 259 ind.

In this study, the fish community structure in Yudeung Stream was very similar to the previous results. Empirical studies suggested that the fish community in Yudeung Stream are dominated by Cyprinidae, and that higher relative richness of *Z. platypus*, *Carassius auratus*, and *P. herzi* (An *et al*., 2005; Lee, 2001). An *et al*. (2005) sug-

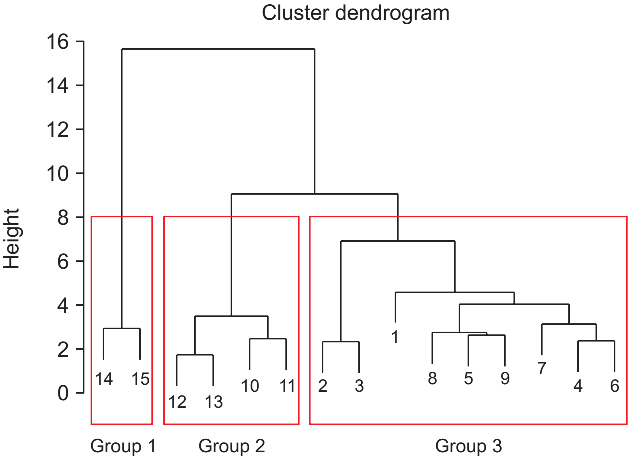

Fig. 2. Cluster analysis of environmental variables and microhabitat types among study sites indicated three groups.

Table 2. Fish species found at study sites in Yudeung Stream

Taxonomic groups	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cyprinidae															
Acheilognathus koreensis	6	3	5												
Acheilognathus lanceolata intermedia									4	3					
Carassius auratus													8	9	3
Coreoleuciscus splendidus	24	26	23		1				6						
Cyprinus carpio											4		4	2	8
Gnathopogon strigatus			9	10		3							7		
Pseudogobio esocinus			4				8	4							2
Pseudopungtungia nigra		2													
Pungtungia herzi		11	17	5	7		25	8		2	4	10	16		
Rhodeus uyekii									5						
Sarcocheilichthys nigripinnis morii		8	12						3						
Squalidus gracilis majimae		14					17	5							
Zacco koreanus		32	198	13	127	59	68								
Zacco platypus	19	86	234	89	124	90	74	55	66	34	21	48	58	5	12
Cobitidae															
Iksookimia koreensis	7	2	6												
Misgurnus anguillicaudatus	1	2	2												
Bagridae															
Pseudobagrus fulvidraco													1		
Centropomidae															
Coreoperca herzi			2	2			2	2	4	8	5				
Siniperca scherzeri											3				
Centrarchidae															
Lepomis macrochirus										4		5		7	3
Micropterus salmoides										10	6	12	2	10	1
Odontobutidae															
Odontobutis interrupta		8	5												
Odontobutis platycephala											1				
Gobiidae															
Rhinogobius brunneus						2	4	5	7		8		5		5
Number of species	5	11	12	5	4	4	7	6	7	6	8	4	8	5	7
Number of individuals	57	194	517	119	259	154	198	79	95	61	52	75	101	33	34

gested that tolerant species such as *Z. platypus* and C. *auratus* were frequently observed in most of streams because of their high resistance to water pollution. In this study, we found that *Z. platypus's* dominance was similar to the previous results, but *Z. koreanus* was more abundance than C. auratus. Although the Z. koreanus is a sensitive species, they were mainly distributed as high density at sampling points (site 2 to 7) located upstream section of Yudeung Stream. The prevous studies also suggested that sensitive fish species, such as *Rhynchocypris oxycephalus* and *Zacco temminckii*, were frequently observed in the upper parts than the downstream. In contrast, fish species, such as *Lepomis macrochirus* and *Micropterus salmoides*, can also be distributed in downstream because they are resistant to water pollution. From the different distribution characteristics of fish according to these types of sensitivity characteristics, we surmise that the environmental gradient (i.e. water quality and habitat environ-

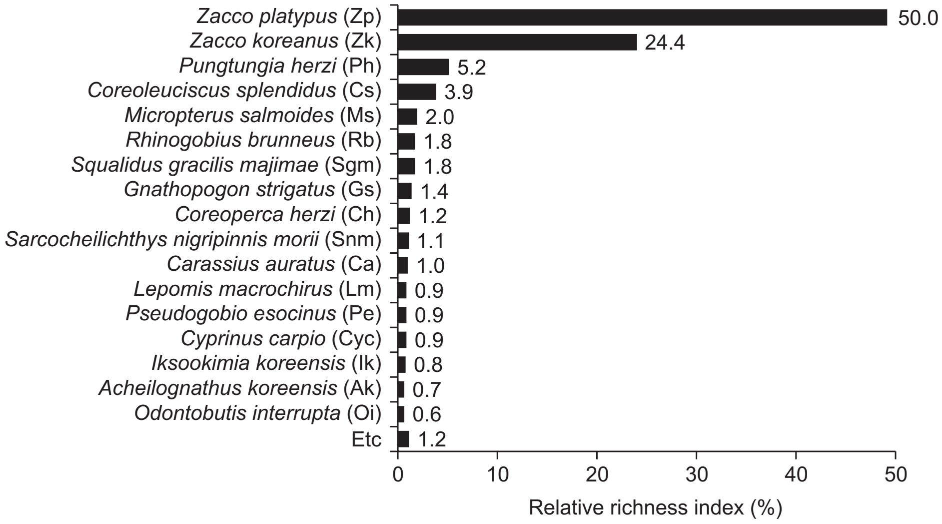

Fig. 3. Relative richness (%) of 16 species of fish in Yudeung Stream.

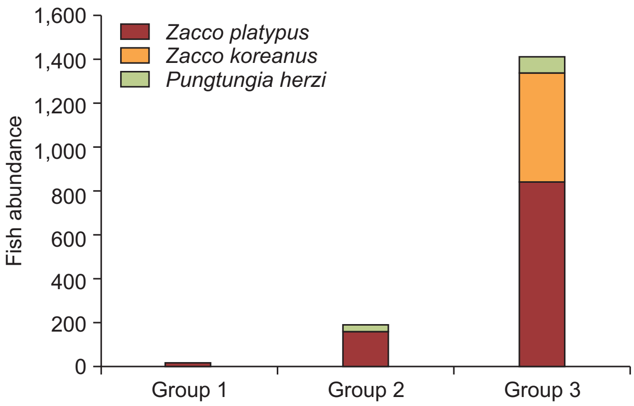

Fig. 4. Abundance of dominant fish species in three groups resolved by cluster analysis of study sites in Yudeung Stream.

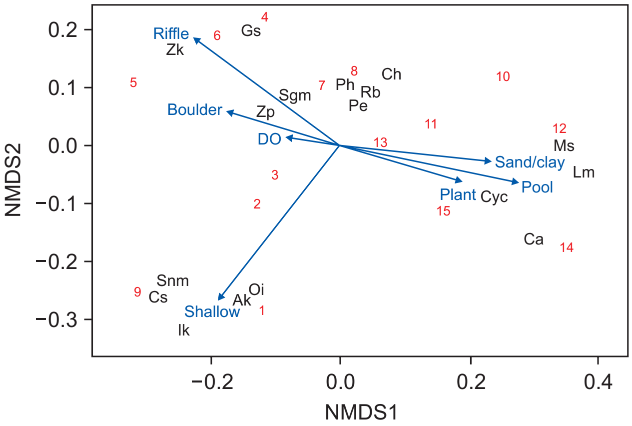

Fig. 5. Non-metric multidimensional scaling (NMDS) of 17 dominant fish species and 15 study sites. Blue arrows represent the associations with environmental variables and habitat patch types. Red numbers indicate site number (Fig. 4). The letters represent the abbreviations of scientific names for the 17 dominant fish species (Fig. 3). Ak, *Acheilognathus koreensis*; Ca, *Carassius auratus*; Cs, *Cyprinus carpio*; Ch, *Coreoperca herzi*; Cyc, *Cyprinus carpio*; Gs, *Gnathopogon strigatus*; Ik, *Iksookimia koreensis*; Lm, *Lepomis macrochirus*; Oi, *Odontobutis interrupta*; Ms, *Micropterus salmoides*; Pe, *Pseudogobio esocinus*; Ph, *Pungtungia herzi*; Rb, *Rhinogobius brunneus*; Sgm, *Squalidus gracilis majimae*; Snm, *Sarcocheilichthys nigripinnis morii*; Zk, *Zacco koreanus*; Zp, *Zacco platypus*.

ment) from upstream to downstream of Yudeung Stream has changed little from the past (the early 2000s) to the present.

We fitted the 17 dominant fish species to NMDS ordination axes and selected seven factors (one environmental variable and six microhabitat patch types) that were significantly correlated ($P<0.05$; Fig. 5). The results of NMSD analysis showed that *Gnathopogon strigatus*, *Squalidus gracilis majimae*, *Z. koreanus*, and *Z. platypus* were associated with riffle and boulder areas, but *Iksookimia koreensis*, *Acheilognathus koreensis*, *C. splendidus*, *Sarcocheilichthys nigripinnis morii*, and *Odontobutis interrupta* were more associated with shallow areas. These species were frequently found in the upstream sections of Yudeung Stream (sites 1-9), and the various microhabitat characteristics present in the upstream sections led to different spatial distribution of these fish species. We surmised that *Gnathopogon straggagatus*, *S. gracilis mazimae*, *Z. Koreanus*, *Z. platypus* are mainly distributed in riffle and boulder areas, because they generally prefer microhabitat with high water velocity and high concentration of DO (Fu *et al*., 2015; Jang *et al*., 2008). Rapidly flowing streams tend to have greater atmospheric gas exchange and therefore greater DO (Allan & Castillo, 2007).

Also, although fish species such as *A. koreensis*, *C. splendidus*, and *S. nigripinnis morii* have been found in shallow areas, these species do not avoid the habitat environment in riffle and boulder areas. The shallow area is distributed around the riffle and boulder areas, and supported by high concentrations of DO. Therefore, their distribution may be a transient distribution pattern due to the characteristics of fish with strong mobility and may also be related to feeding activity. The food items (e.g., invertebrates) were more abundant in shallow areas with lower water flow rates than riffle areas where water velocity are rapid (Meschiatti *et al*., 2000). In addition, shallow areas can be highly covered by aquatic macrophytes, which can be used as a habitat for various invertebrates (Williams *et al*., 2004).

In contrast, *Cyprinus carpio*, *C. auratus*, *L. macrochirus*, and *Mi. salmoides* were found in the downstream section (sites 14 and 15), associated with pool, sand/clay, and vegetated areas. *Cyprinus carpio* and *C. auratus* have relatively large bodies and poor swimming ability, and are not well-suited to rapidly flowing or shallow environments in upstream areas. They are mainly distributed in downstream sections, as well as in areas with limited flow such as wetlands and reservoirs (Hussain *et al*., 2015). Their distribution is broad due to strong environmental tolerances, such as resistance to drought and pollution (Koehn, 2004; Sun & Liang, 2004). *Lepomis macrochirus* and *M. salmoides* are introduced predators that prey indiscriminately on native fish species, zooplankton, and invertebrates (Weyl *et al*., 2010; Wilson *et al*., 2011), resulting in high density and exclusion of other species. Due to this, they are managed as ecological disturbance species in South Korea. Interestingly, adult *M. salmoides* prey on small *L. macrochirus*, which spends time in vegetated areas to avoid predation (Hossain *et al*., 2013). The leaves and stems of aquatic macrophytes increase the complexity of habitat structures in the water, and small fish utilize such refugia to avoid predators (Casatti, 2005; Sass *et al*., 2006). We observed both species at the same sites despite their predator–prey interactions; this suggests that aquatic macrophytes are indirect determinants of M. salmoides habitats. Other small species such as *C. carpio* and *C. auratus* also inhabit vegetated areas to avoid *M. salmoides* predation (Choi & Kim, 2020b; Jin *et al*., 2019). Therefore, we suggest that aquatic macrophytes are important habitats for fish distributed in downstream areas and their area determines the population size of prey species.

Rhinogobius brunneus, *Coreoperca herzi*, and *P. herzi* were mainly found at midstream sites with fluctuating environmental variables and habitat patch types, and their presence did not appear to be determined by key habitat characteristics. They have been previously reported as having a relatively wide range of distribution (Kim *et al*., 2016). From these points, we considered that these fish species have a broader distribution that does not rely on special habitat characteristics.

Stream management based on fish community distribution

Most of Korea's streams have been damaged or altered by weirs and embankments, and human activities have increased the inflow of pollutants (Woo *et al*., 2005). Structures built in the stream sections particularly affect variables such as water flow and slope of habitats, leading to increased nutrient concentration and reduced DO, thereby affecting various organisms (Allan & Castillo, 2007). Fishes respond rapidly to these environmental changes compared with other aquatic organisms and can be used as an 'indicator species' to determine the disturbance gradient in stream ecosystems. In particular, tolerant fish species are sensitive to disturbances such as changes in water quality, so they can continuously monitor the stream environment based on their spatial distribution.

Our results have not found much difference in comparison with the fish communty in Yudeung Stream, from the past data of about two decades ago. Yudeung Stream are supported by distinct gradient of water quality and fish community structre from upstream to downstream from the past to the present. We assumed that through the distribution of sensitive species such as Z. koreanus, the upstream area of Yudeung Stream was from site 1 to 7. The fish community structure changed rapidly after site 7 of Yudeung Stream. we considered that this change may be caused by physical and chemical disturbances by humans. From the site 7 of Yudeung Stream, the surrounding land cover mainly changes to the urbanized area. This means that not only water pollution caused by inflow of phosphorus and nitrogen, but also physical disturbances such as fishing will occure. From such finding, we speculate that the mid-lower reaches of Yudeung Stream have been continuously affected by human disturbance since the past. Therefore, we recommend minimizing the anthropogenic disturbance in the mid-lower of Yudeung Stream to maintain the typical environmental characteristics of mid-downstream.

Conflict of Interest

The authors declare that they have no competing interests.

Acknowledgments

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