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Climate Change and Its Importance to the Vertical Distribution of *Rhynchocypris kumgangensis* (Cypriniformes: *Cyprinidae*) in Deogyusan National Park

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Abstract: *Rhynchocypris kumgangensis*, endemic to Korea, is limited to the upper Hangang River and Gucheondongcheon Stream. As a key and climate-sensitive biological indicator species in Deogyusan National Park, it has a southern range limit in the Gucheondong Valley. Due to climate change, notable shifts in the activity, vertical distribution, and population of *R. kumgangensis* in the Gucheondongcheon Stream are expected. Owing to the rapidly changing climate, significant changes in the activity, vertical distribution, and population size of *R. kumgangensis* in the Gucheondongcheon Stream are anticipated, and continuous surveys of the distribution of *R. kumgangensis* in this river area have been conducted. This study assessed the habitat of *R. kumgangensis* at 13 sites, including five in the Gucheondongcheon Stream, from July to October 2020 and compared the results with historical data to evaluate the impacts of climate change. At the five Gucheondongcheon Stream sites, 102 individuals were recorded from April to October 2020, and 378 were recorded between June 2018 and July 2019. Additionally, the subdominant species shifted from *R. kumgangensis* (2014–2018) to *Zacco koreanus* (2020). In the two southernmost Gucheondongcheon Stream sites, only 18 *R. kumgangensis* were observed in 2020 compared to 82 in 2019, indicating a significant population decline.

Keywords: *Rhynchocypris kumgangensis*; Gucheondongcheon; climate change; southern range limit; Geumgang River

1. Introduction

Rhynchocypris kumgangensis is an endemic Korean species that belongs to the *Rhynchocypris* genus of the Cyprinidae family. As a cold-water freshwater fish species, *R. kumgangensis* inhabits mountain streams with clear water and low temperatures [1]. Members of the *Rhynchocypris* genus include six species distributed across South Korea and North Korea. Due to the similarity in morphological traits, among other things, many taxonomic discussions have been conducted [2–5]. Initially, *R. kumgangensis* was reported as an unidentified species named *Moroco sp.* by Uchida [6] in samples collected from the Amnokgang and Bukhangang rivers. Later, a researcher in North Korea renamed it *R. kumgangensis* and *Phoxinus kumgangensis* [7]. In South Korea, *R. kumgangensis* has been used to identify novel species [4] based on characteristics of the *genus Rhynchocypris* [8]. *Rhynchocypris kumgangensis*, the target fish species in the current study, showed limited distribution in the following regions: the Daedonggang and Amnokgang Rivers in North Korea, the uppermost waters of the Hangang River, the Muju Gucheondong Valley of the Geumgang River, the Bakdal Valley in Bonghwa-gun, Gyeongsangbuk-do, the Sobaeksan Valley in Danyang-gun, and Chungcheongbuk-do in South Korea [9].

R. kumgangensis is a representative Climate-sensitive Biological Indicator Species (CBIS) suggested by the Ministry of Environment (MOE) to analyze the effects of climate change on the

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habitat of stream-river ecosystems [9]. In particular, *R. kumgangensis* is sensitive to changes in water temperature; its highest water temperature does not exceed 20 °C throughout the year [9–11]. Thus, the investigation and analysis of the vertical distribution of *R. kumgangensis* can indirectly evaluate the impact of climate change on the ecosystems of organisms that are more sensitive to external factors, such as climate change, than humans.

This study investigated the accurate distribution of *R. kumgangensis* from the origin to the upper waters of the Geumgang River water system in Deogyusan National Park to provide details of the distribution and sympatric species of *R. kumgangensis* in Deogyusan National Park. In addition, this study can be used as important data for predicting environmental changes in stream-river ecosystems due to climate change and is vital in strategies for the protection of *R. kumgangensis* and the preservation of fish diversity.

2. Materials and Methods

2.1. Study Period and Location

The fish fauna and physicochemical properties of the streams in Deogyusan National Park were investigated during two periods: July 9, 2020, and October 8–16, 2020. The study locations included 13 sites in Deogyusan National Park, which joins the Geumgang River, including four sites adjacent to the Gucheondongcheon Stream, four sites adjacent to the Wondangcheon Stream, two sites adjacent to the Bukchangcheon Stream, and three sites adjacent to the Myeongcheon Stream. All study sites were in the Muju-gun Administration District (Figure 1).

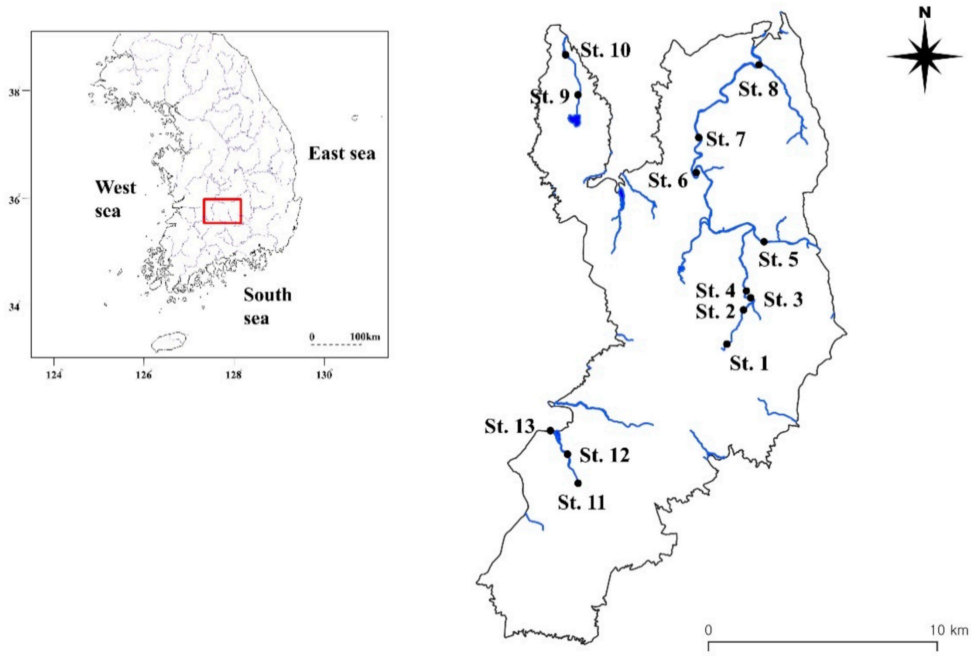

Figure 1. Map of the study location showing sampling sites in Deogyusan National Park, Jeollabuk-do, Korea.

st. 1: Isokdae, Seolcheon-myeon, Muju-gun, Jeollabuk-do
st. 2: Geumpotan Valley, Samggong-ri, Seolcheon-myeon, Muju-gun, Jeollabuk-do
st. 3: Bipadam, Samggong-ri, Seolcheon-myeon, Muju-gun, Jeollabuk-do
st. 4: Inwolahm Valley, Samggong-ri, Seolcheon-myeon, Muju-gun, Jeollabuk-do
st. 5: Samgong-ri 101-1, Seolcheon-myeon, Muju-gun, Jeollabuk-do
st. 6: Sushimdae, Shimgok-ri, Seolcheon-myeon, Muju-gun, Jeollabuk-do
st. 7: Dugil-ri, Seolcheon-myeon, Muju-gun, Jeollabuk-do
st. 8: Dugil Bridge, Dugil-ri, Seolcheon-myeon, Muju-gun, Jeollabuk-do
st. 9: Jeoksang-myeon, Muju-gun, Jeollabuk-do

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st. 10: Bukchang-ri, Jeoksang-myeon, Muju-gun, Jeollabuk-do
st. 11: Jukcheon-ri, Anseong-myeon, Muju-gun, Jeollabuk-do
st. 12: Jukcheon-ri, Anseong-myeon, Muju-gun, Jeollabuk-do
st. 13: Jukcheon-ri, Anseong-myeon, Muju-gun, Jeollabuk-do

2.2. Survey Method

The physicochemical properties of the study sites (water temperature, dissolved oxygen (DO), pH, and electrical conductivity) were measured using a water quality sensor (Pro Quatro, YSI Inc., OH, USA). The width and depth of the water in the environmental quality survey were measured using a tape measure, and the substrate structure was visually examined at each site [12]. Kick nets (4 × 4 mm mesh) and cast nets (7 × 7 mm mesh) were used for fish collection. The collected fish were identified to the species level and their numbers were recorded at the site [1] before being released into the water. For fish community analysis at each site, the following indices were measured: dominance [13], species diversity [14], evenness [15], and species richness [16]. The similarity in fish communities in each stream was estimated by drawing a similarity matrix [17] based on the square root transformation of the total number of fish species that appeared during the study period and the Bray-Curtis similarity index. The similarity between the two groups was analyzed using permutational multivariate analysis of variance (PERMANOVA) and one-way analysis of similarity (ANOSIM). Between-group variation was analyzed using non-metric multidimensional scaling (NMDS) and visualized in two dimensions [18]. The contributing species and percentage contributions were determined using a similarity percentage (SIMPER) analysis to determine the similarity of fish communities. Habitat variation between the Gucheondongcheon and Wondangcheon Streams was examined using comparative analyses of PERMANOVA and one-way ANOSIM tests for substrate, DO, and water temperature. PERMANOVA, SIMPER, and NMDS analyses were performed using the Primer v6 software (Primer-E Ltd. Plymouth, UK) and PERMANOVA+ add-on modules.

3. Results

3.1. Physicochemical Properties

The water temperature ranged from 11.0 to 20.0°C with seasonal and regional variations (Table 1). The regional variation in water temperature is thought to be due to the difference in water depth between mountain streams and upper river water. Dissolved oxygen (DO) was 10.93–12.04 mg/L in the first survey and 6.84–8.02 mg/L in the second survey, displaying seasonal variation (Figure 2). The estimated pH was 6.58–8.39 (Table 1). In the first survey, the pH at sites 1, 2, 3, and 4 of the Gucheondongcheon Stream was relatively low (6.58–6.74). The estimated salinity was 0.01–0.03‰, corresponding to freshwater (Table 1).

Table 1. Physical and chemical properties of study streams in Deogyusan National Park from April 2020 to October 2020 (mean ± standard deviation).

	Gucheondongcheon Stream	Wondangcheon Stream	Bukchangcheon Stream	Myeongcheon Stream
Water temperature (°C)	13.9 ± 2.74	16.1 ± 2.39	16.8 ± 1.06	14.9 ± 3.46
Dissolved oxygen (mg/L)	9.38 ± 2.45	9.33 ± 1.74	8.34 ± 3.32	9.15 ± 2.48
pH	6.98 ± 0.34	7.49 ± 1.28	7.49 ± 1.02	6.45 ± 0.51
Salinity (‰)	0.01	0.03	0.03	0.01

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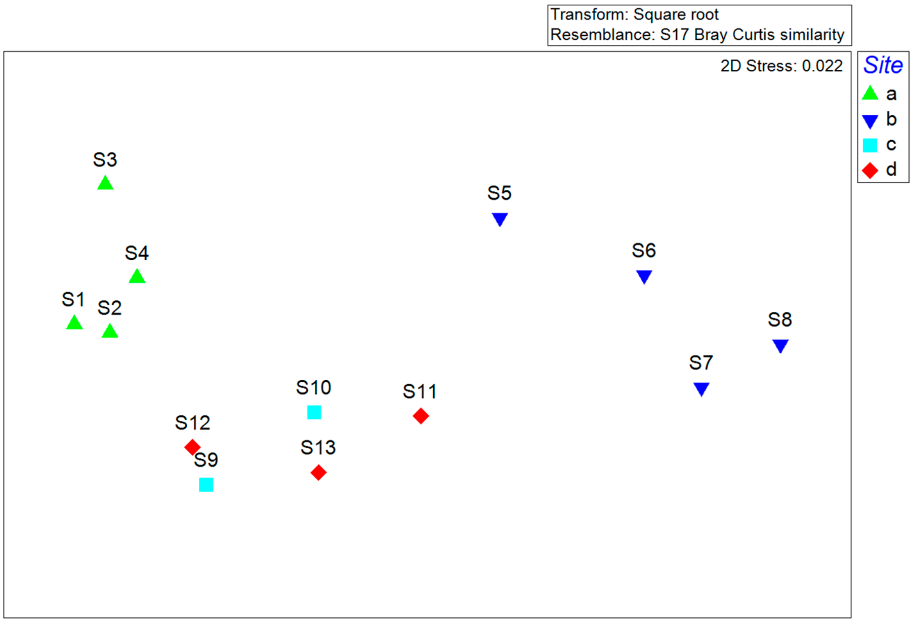

Figure 2. Non-metric multidimensional scaling of samples based on Bray-Curtis's similarities. Site a, Gucheondongcheon Stream; Site b, Wondangcheon Stream; Site c, Bukchangcheon Stream; Site d, Myeongcheon Stream.

The substrate structure at the study sites consists mainly of rocks, boulders, and pebbles. The upper mountain streams, the Gucheondongcheon and Myeongcheon Streams, showed an abundance of rocks, boulders (> 256 mm), and cobbles (64–256 mm), whereas the Wondangcheon and Bukchangcheon Streams were mainly comprised of cobbles and pebbles (16–64 mm) and gravel (2–16 mm). Site 8 in the area downstream of the Wondangcheon Stream and site 13 downstream of the Myeongcheon Stream were mainly composed of sand (Table 2).

Table 2. Environmental characteristics of the sampling sites in Deogyusan National Park in 2020.

Streams	**Site**	**Water width (m)**	Water depth (m)	Bottom structure (%)				
				B	C	P	G	S & M
Gucheondongcheon	**st. 1**	**5**	0.1–0.5	40	20	20	10	10
	st. 2	5–10	0.5–0.1	20	30	20	30	10
	st. 3	5–10	0.5–1.5	30	10	20	30	10
	st. 4	3–8	0.1–0.8	30	10	20	20	20
Wondang cheon	st. 5	10–20	0.1–1	-	30	20	30	10
	st. 6	10–20	0.1–1	10	20	30	30	10
	st. 7	10–20	0.1–1	10	10	30	30	20
	st. 8	20–30	0.1–2	-	20	20	20	40
Bukchang cheon	st. 9	2–5	0.1–1	-	30	30	30	10
	st. 10	1–2	0.1–1	-	40	20	20	20
Myeong cheon	st. 11	5	0.1–1	40	20	10	20	10
	st. 12	5	0.1–0.5	30	20	20	20	10
	st. 13	5	0.1–1	10	10	10	20	50

*B (boulder), > 256 mm; C (cobble), 64–256 mm; P (pebble), 16–64 mm; G (gravel), 2–16 mm; S & M (sand and mud), < 2 mm [12].

3.2. Fish Fauna

The investigation of the 13 sites in Deogyusan National Park indicated 17 species and 996 fish, of which the Cyprinidae family showed the highest frequency with 12 species and a 95.58% relative abundance (Table 3). Based on 337 fish and 37.85% relative abundance, *Rhynchocypris oxycephalus* was confirmed as the dominant species in the target national park, and *Zacco koreanus* (360 fish and 36.14% relative abundance) was confirmed as the subdominant species. *R. oxycephalus* showed the highest frequency, based on its appearance at 10 of the 13 investigated sites, followed by *Z. koreanus*, which appeared at seven sites. In addition, one fish each of *Pseudobagrus koreanus* and *Silurus microdorsalia* were found at sites 8 and 10, respectively. The target species in this study, *R. kumgangensis*, appeared only at sites in the Gucheondongcheon Stream. In the Deogyusan National Park, 11 endemic species were found: *Pseudopungtungia nigra*, *Coreoleuciscus splendidus*, *Hemibarbus mylodon*, *Microphysogobio yaluensis*, *R. kumgangensis*, *Z. koreanus*, *Iksookimia koreensis*, *Pseudobagrus koreanus*, *Silurus microdorsalia*, *Coreoperca herzi,* and *Odontobutis platycephala*, indicating endemic speciation of 64.71%. This level was higher than that across all the rivers in South Korea (25.9%) [19].

Table 3. List and individual numbers of fish collected at each site in the Deogyusan National Park from April to October 2020.

Species	st. 1	st. 2	st. 3	st. 4	st. 5	st. 6	st. 7	st. 8	st. 9	st. 10	st. 11	st. 12	st. 13	Total	RA
Cypriniformes															
Cyprinidae															
Pungtungia herzi						11	19	31			4			65	6.53
*Pseudopungtungia nigra** ※								17						17	1.71
*Coreoleuciscus splendidus**							3	4						7	0.70
Squalidus gracilis majimae											1			1	0.10
*Hemibarbus mylodon** ※							3	2						5	0.50
Pseudogobio esocinus					3			2						5	0.50
*Microphysogobio yaluensis**											10			10	1.00
Rhynchocypris oxycephalus	17	24	19	29	4				68	34	58	46	78	377	37.85
*Rhynchocypris kumgangensis**	8	10	65	19										102	10.24
Zacco platypus								3						3	0.30
*Zacco koreanus**					73	69	59	93		14	40		12	360	36.14
Cobitidae															
*Iksookimia koreensis**							2	1						3	0.30
Siluriformes															
Bagridae															
*Pseudobagrus koreanus**								1						1	0.10
Siluridae															
*Silurus microdorsalis**										1				1	0.10
Salmoniformes															
Salmonidae															
Oncorhynchus masou masou			12	4	1									17	1.71
Perciformes															
Centropomidae															
*Coreoperca herzi**							2	5						7	0.70
Odontobutidae															
*Odontobutis platycephala**						9	3	3						15	1.51
Number of individuals	25	34	96	52	81	89	91	162	68	49	113	46	90	996	
Number of species	2	2	3	3	4	3	7	11	1	3	5	1	2	17	

Total, total individuals; RA, relative abundance (%); *, Korean endemic species; ※, endangered species.

National parks tend to show higher levels of endemic speciation than other rivers and reservoirs [5]. In this study, Deogyusan National Park showed a higher level of endemic speciation than Odaesan National Park (30.77%) [20], Mudeungsan National Park (35%) [21], and Sokrisan National Park (53.8%) [22]. The Geumgang River exhibited approximately 26 endemic species [23]. Eleven of

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those species were found in Deogyusan National Park, indicating the richness of endemic species. This finding is thought to be due to the appropriate levels of fish habitat diversity and conservation in Deogyusan National Park, which facilitate the settlement of endemic species. *Pseudopungtungia nigra* (n = 17), a Class I endangered wildlife species, was found at Site 8, and *Hemibarbus mylodon* (n = 5), a natural heritage fish, was found at Sites 7 and 8 (Table 2).

Wondangcheon Stream had the highest species diversity and number of fish, with 13 species and 423 fish. The lowest species diversity was observed in the Bukchangcheon Stream, with only three species: *R. oxycephalus*, *Z. koreanus*, and *S. microdorsalis*. Mountain streams (Gucheondongcheon and Bukchangcheon) contained fewer species, whereas Wondangcheon and Myeongcheon Streams in the upper reaches of the river contained more species. In addition, fish communities varied across streams (PERMANOVA; Pseudo-F = 11.029, P = 0.001). Separate groups were observed in the Gucheondongcheon and Wondangcheon Streams, whereas fish converged into a single group in the Bukchangcheon and Myeongcheon Streams (Figure 2).

Table 4. Similarity percentage analysis for differences in fish assemblages in each stream.

Streams	Average similarity (%)	Species	Average abundance	Average similarity	Ratio similarity/ standard deviation	Species contribution (%)	Cumulative contribution (%)
Gucheondoncheon	74.94	*Rhynchocypris oxycephalus*	4.69	42.10	4.69	56.17	56.17
		Rhynchocypris kumgangensis	4.60	30.43	6.66	40.61	96.78
Wondangcheon	59.18	*Zacco koreanus*	8.54	42.18	4.06	71.28	71.28
		Pungtungia herzi	3.31	8.36	0.90	14.13	85.41
		Odontobutis platycephala	1.62	4.02	0.89	6.79	92.2
Bukchancheon	59.37	*Rhynchocypris oxycephalus*	7.23	51.24	4.21	86.30	86.30
		Zacco koreanus	3.36	8.13	0.58	13.70	100
Myeongcheon	71.10	*Rhynchocypris oxycephalus*	7.81	71.10	-	100	100

The dominant and subdominant species in most streams were *R. oxycephalus* and *Z. koreanus*. Still, the dominant species in the Gucheondongcheon Stream was *R. kumgangensis* (49.28% relative abundance), and the subdominant species in the Wondangcheon Stream was *P. herzi* (14.42% relative abundance) (Table 5).

Table 5. The most abundant species in each stream of Deogyusan National Park.

Streams	Dominant species (RA, %)	Sub-dominant species (RA, %)
Gucheondongcheon	*Rhynchocypris kumgangensis* (49.28)	*Rhynchocypris oxycephalus* (43.00)
Wondangcheon	*Zacco koreanus* (69.50)	*Pungtungia herzi* (14.42)
Bukchangcheon	*Rhynchocypris oxycephalus* (87.18)	*Zacco koreanus* (11.97)
Myeongcheon	*Rhynchocypris oxycephalus* (73.09)	*Zacco koreanus* (20.88)

RA, relative abundance.

3.3. Fish Community Indices

Among the investigated streams, the dominance indices ranged from 0.839 to 0.991. Bukchangcheon Stream exhibited the highest dominance index at 0.991, whereas Wondangcheon Stream had the lowest (0.839). This high dominance was presumed to be due to the greater number of fish of the dominant species collected. The diversity index was highest in Wondangcheon Stream

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(1.163) and lowest in Bukchangcheon Stream (0.414). This is presumably because the Bukchangcheon Stream is a mountain stream with a high flow rate and low water temperature. It is dominated by torrential species, which reduces species diversity.

In contrast, the Wondangcheon Stream has a low flow rate and more diverse habitats than mountain streams, facilitating habitation by a greater species diversity with a concomitantly higher diversity index. The evenness index was highest in the Gucheondongcheon Stream (0.828) and lowest in the Wondangcheon Stream (0.454). The species richness index was the highest in Wondangcheon (1.984) and lowest in Gucheondongcheon (0.375) (Table 6). The Gucheondongcheon, Bukchangcheon, and Myeongcheon mountain streams exhibited fewer inhabiting species with a higher level of dominance but lower levels of diversity and species richness. In contrast, the Wondangcheon Stream, which joins the Gucheondongcheon Stream, showed relatively low dominance but high species richness as an upstream river reach. This feature is common in the upstream (which has a lower number of fish species) and downstream reaches (which has an increased number of fish species) [24].

Table 6. Biological indices of fish communities in Deogyusan National Park.

	Gucheondongcheon	Wondangcheon	Bukchangcheon	Myeongcheon	Total
Dominance index	0.923	0.839	0.991	0.940	0.740
Diversity index	0.910	1.163	0.414	0.774	1.574
Evenness index	0.828	0.454	0.377	0.481	0.556
Species richness index	0.375	1.984	0.420	0.725	2.318

3.4. Distribution of R. Kumgangensis

This study investigated the distribution of *R. kumgangensis* in Deogyusan National Park. Sites 1–4, corresponding to the Gucheondongcheon Stream, were inhabited by this species (Figure 3). The *R. kumgangensis* habitat environment in the Hangang River water system has repeating riffle-pool sequences, and the substrate consists of large cobbles and pebbles with an average annual water temperature of 2.0–19.2℃ and an average dissolved oxygen of 9.2–14.0 mg/L [24]. The Gucheondong Valley of the Deogyusan National Park was found to have an annual water temperature of -0.1–18.4℃ and dissolved oxygen of 8.4–13.6 mg/L in the *R. kumgangensis* habitat [10], in contrast to the findings in the current study (water temperature, 11–16.5℃; DO, 6.84–12.04 mg/L). The results of this study were influenced by the timing of measurements during the summer months. onsequently, the water temperature readings were comparatively high, whereas the dissolved oxygen levels were relatively low.

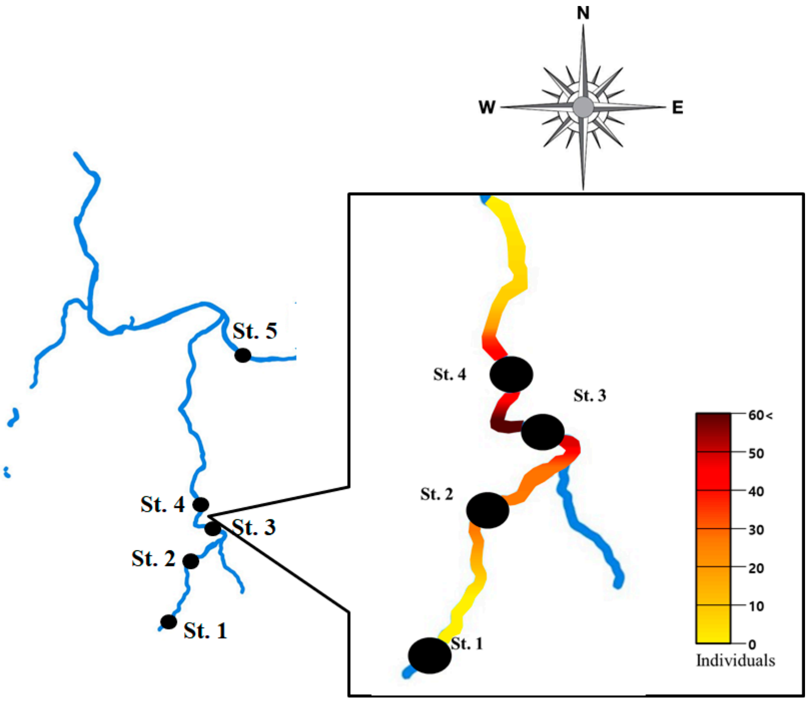

Figure 3. Vertical distribution of *Rhynchocypris kumgangensis* along the Gucheondongcheon Stream.

At site 1 (upstream reaches of the Gucheondongcheon Stream), 17 fish were detected. In contrast, at site 4 (downstream reaches), 29 fish were detected, indicating a larger distribution of fish in the lower parts of the Gucheondongcheon Stream with inhabitation throughout the stream. The highest number of *R. kumgangensis* was observed at site 3. This seems to be due to the collection of a greater number of fish at site 3, with increased water width and depth in the pools, compared with sites 1 and 2, with narrower water and a lack of areas with greater depth. At Site 4 in the Gucheondongcheon Stream, a small concrete weir did not serve its purpose. *R. kumgangensis* was not detected in the Wondangcheon Stream, which joins the Gucheondongcheon Stream, *R. kumgangensis* was not detected. Compared with the Gucheondongcheon Stream, the substrate structure in the Wondangcheon Stream had fewer parent rocks, although no statistical significance was found (PERMANOVA, Pseudo-F = 4.784, P = 0.055). Dissolved oxygen was similar (PERMANOVA, pseudo-F = 7.259, P = 0.069), but the water temperature was different (PERMANOVA, pseudo-F = 27.062, P = 0.027). Hence, the most critical factor influencing inhabitation by *R. kumgangensis* is likely to be the water temperature.

4. Discussion

R. kumgangensis and *R. oxycephalus* are characterized by their inhabitation of stream waters rich in dissolved oxygen and at low temperatures [1]. *Rhynchocypris kumgangensis* primarily inhabits the uppermost reaches of mountain streams, with a decrease in habitat density towards the lower reaches [25]. Similarly, *R. kumgangensis* habitats in Deogyusan National Park were limited to the Gucheondongcheon Stream, whereas *R. oxycephalus* inhabited the Gucheondongcheon and Wondangcheon Streams. Generally, species sharing similar ecological statuses separate their space and food to use limited resources [26–28] efficiently. *Rhynchocypris kumgangensis* and *R. oxycephalus* inhabiting the Bangdongcheon Stream in Inje-gun, Gangwon-do, were shown to inhabit different tributaries for spatial separation [10]. In the Gucheondong Valley, the main feed of *R. kumgangensis* is mayflies, and that of *R. oxycephalus* includes caddisflies and terrestrial insects to reduce competition for food [10]. Although the two species shared similar habitats, *R. kumgangensis* was not found in the Wondangcheon Stream, inhabited by *R. oxycephalus*.

R. kumgangensis has been declared an indicator species of climate change by the Ministry of Environment in South Korea, as it is considered to represent climate change significantly through alterations in its region of distribution and population size. This species was also reported to have the most significant influence on water temperature during spawning [9]. The reported spawning period of *R. kumgangensis* is April–May, with a required water temperature of 11–14 °C [25]. The spawning period of *R. oxycephalus* is similar to *that of R. kumgangensis* from May to June, but the mean water temperature is 19 ± 0.5°C [29]. Thus, the distribution of *R. kumgangensis* was conjectured to be limited to hydrospheres with water temperatures lower than *R. oxycephalus*.

Climate change could lead to a population decline in *R. kumgangensis*. The climate of the Korean Peninsula is projected to experience a significant increase in the maximum temperature (TMAX) with increasing warming levels, with a corresponding increase in precipitation reaching tropical temperatures. The SSP-8.5 scenario projects a further increase of 1.8°C by 2040 and 3.3°C by 2060 [30–32]. Therefore, an increase in water and air temperatures at Deogyusan National Park, the southern range limit of *R. kumgangensis*, is inevitable, and it is thought that *R. kumgangensis*, a cold-water fish species, is at risk of localized extinction. Therefore, it is necessary to observe and track changes in biota through long-term monitoring.

To assess the long-term changes in The Fish Assessment Index (FAI) values, the Stream/River Ecosystem Survey and Health Assessment data were checked [33]. We found that the FAI values of the six points corresponding to the Gucheondongcheon Stream near the survey site for 11 years (2013–2023) were A-grade in most years and B-grade in 2016, 17, 22, and 23. In recent years, there has been a trend towards declining health ratings. The results of this survey were also confirmed as A-B, depending on the location. The decreasing trend in FAI was influenced by decreases in sensitive species (SS), insectivorous species (I), and domestic species (D). Therefore, along with climate change, stream/river ecosystem survey results and health assessments should be monitored annually to monitor changes in population status.

In this study, *R. kumgangensis* was the dominant species in the Gucheondongcheon Stream. These findings indicate that their distribution is limited to the Gucheondongcheon Stream; as a species inhabiting mountain streams, it is likely to be sensitive to changes in the surrounding environment. The narrow distribution range also implies that this species requires protection. In South Korea, *R. kumgangensis* has been reported to inhabit certain regions of the Hangang and Geumgang river water systems. However, as their habitats are limited to the Gucheondongcheon Stream in the Geumgang River, extinction in this region is expected to prevent further detection of *R. kumgangensis* habitats in the Geumgang River water system. Thus, environmental fluctuations in *R. kumgangensis* habitats should be periodically monitored in preparation for climate change. The level of protection of the natural ecosystem of Deogyusan National Park should be increased to preserve biological species diversity in the Geumgang River water system.

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