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Movements and Home Ranges of an Endangered Freshwater Fish, *Pseudobagrus brevicorpus*, and the Impact of River Management

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Abstract: An ecological understanding of threatened species provides the basis for their protection and recovery. This information must be used to analyze threats in order to propose conservation strategies for target species. River management projects, such as the construction of dikes, revetments, and dredging, are often undertaken to prevent flooding, and these activities affect fish communities and population dynamics. The critically endangered *Pseudobagrus brevicorpus* is highly vulnerable, but the causes of its decline are poorly understood. In this study, we assess the movements and habitat selection of *P. brevicorpus* to better understand its ecological characteristics and analyse the causes of its decline. We used radio telemetry to track the movements of the species and compared the effects of river-maintenance projects with data from a long-term study of the distribution of this endangered species. Total movements and home ranges were quite limited, with an average total distance traveled of 107.58 ± 66.01 m over an approximately 8-week monitoring period. The average MCP (minimum convex polygon) was 341.91 ± 776.35 m^2, the KDE (kernel density estimation) 50 was 76.01 ± 30.98 m^2, and the KDE 95 was 144.41 ± 58.86 m^2. The species is nocturnal, and during the day, individuals primarily hide among rocks and aquatic roots. The movement and habitat selection of *P. brevicorpus* indicated that the species could be directly or indirectly affected by river management. Acute population declines have been anticipated due to a lack of avoidance during management, and post-management habitat loss appears to have contributed to long-term population declines. Therefore, a strategic approach that considers ecological consequences is urgently needed to prevent the extinction of this species.

Keywords: home range; movement; conservation; *Pseudobagrus brevicorpus*; radio telemetry

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1. Introduction

In order to protect, restore, and conserve a species, it is necessary to analyze the causes of its decline and propose mitigation measures [1]. The most fundamental and important aspect of this process is the obtaining of accurate information about the target species. In the case of most endangered species, the lack of such studies often leads to inadequate analysis of the causes and ineffective suggestions for restoration [1,2]. Fish, which inhabit unique aquatic environments, present greater challenges in data collection and study compared to other taxonomic groups. Furthermore, data on migration and habitat selection, which are crucial for conservation, remain limited.

Habitat selection and movement of fish are primarily driven by survival purposes, such as spawning, feeding, and predator avoidance [3,4]. The movement patterns of fish vary among species and are specific to their purpose, such as spawning or feeding [5]. Point-based surveys can provide information on the distribution and environment of fish, but they are limited in capturing data on movement and habitat selection. Although movement and habitat selection are key factors in the ecological study of fish, direct observation is not possible, due to the aquatic nature of fish habitats. Nevertheless, the ongoing need to understand the ecological characteristics of fish, in order to support scientific and policy decisions on their conservation and restoration, has gained importance worldwide [6–9]. Telemetry methods have been increasingly applied to monitor fish behavior. Among various telemetry methods, radio telemetry enables individual identification through transmitters and receivers by assigning species-specific frequencies. Its wide reception range allows for the accurate localization of fish [5,10]. Additionally, small-sized transmitters can now be manufactured, making radio telemetry highly applicable with respect to small fish in freshwater ecosystems.

Globally, the number of endangered species is increasing, due to factors such as development for human use, overfishing, and habitat destruction [11]. Freshwater fish, confined to water systems, are particularly vulnerable to disturbances within these ecosystems [12,13]. Freshwater fish are the second-most threatened taxon in the world, following amphibians and reptiles [14], and many countries, including those following IUCN guidelines, have designated certain species as endangered and in need of protection. In Korea, 29 freshwater fish species are listed as endangered, due to habitat loss and population decline [15]. Anthropogenic factors, including river development, water pollution, and the introduction of alien species, are the primary causes of this threat. In particular, in-stream activities supporting flood prevention, energy production, and irrigation have led to river modifications that degrade habitat quality by disrupting connectivity [16,17].

River maintenance refers to the development of rivers for management purposes, carried out to ensure the proper functioning of watercourses, so that human activities can continue safely [18]. Common river-maintenance works include the construction of dams or reservoirs for water supply, levees for flood prevention, and seawalls. The U.S. Global Water Strategy (2022–2027), Europe's Water Framework Directive (WFD), and Korea's 10-year river master plans are examples of ongoing initiatives aiming to manage rivers. Although recent river-maintenance plans increasingly emphasize nature-friendly approaches which consider the river's inhabitants, physical changes to rivers continue to negatively impact freshwater fish populations and communities [19–21]. Specifically, river management activities such as seawall construction and dredging to prevent floods are directly and indirectly threatening the survival of freshwater fish [9].

Pseudobagrus brevicorpus is a Korean endemic species of catfish belonging to the family Bagridae in the order Siluriformes. The species is known to occur only in the Nakdong River watershed in Korea, but it has recently been confirmed in independent streams in Pohang and Gyeongju city [22,23]. The species is protected as a Class I endangered wildlife species in Korea [15] and as Natural Monument No. 455 by the Cultural Heritage Administration [24] due to its population decline, which is primarily caused by the destruction of its natural habitat through water pollution, river development, and illegal capture. Previous studies on *P. brevicorpus* have focused on taxonomic identification [25], basic life history [26], growth and maturation [27], and population genetic structure analysis [28], extending from the time the species was first described by Mori (1936) [29]. However, there is a need for research on habitat use and selection, such as movement trends and behavioral patterns, through ongoing monitoring.

In this study, we used radio telemetry to monitor the movement characteristics of *P. brevicorpus*, an endangered species. Using location data obtained from monitoring, we analyzed the movement patterns and behavior of the species to understand its habitat utilization characteristics. Based on these findings, we discuss the conservation status and future prospects of the species.

2. Materials and Methods

2.1. Study Sites and Periods

The survey sites, Gokgang Stream and its tributary, Singwang Stream, flow into the East Sea of Korea (Figure 1). These areas were previously thought to be places where the *P. brevicorpus* did not occur, but its presence was first confirmed in 2005 [23]. It was introduced into the Gokgang Stream through unintentional means [23], and has since been consistently confirmed as occurring in the region. This area now contains the largest and most stable population of the species in Korea [30]. The monitoring area for the movement of *P. brevicorpus* spanned from Gokgang Stream to Singwang Stream, upstream of Yongyeon Reservoir. Field surveys were conducted from June to December 2020, excluding the spawning and wintering seasons. According to Kawk (2019) [31], *P. brevicorpus* is active from March to November and is inactive from December. Therefore, due to the protected species status, which requires a permit for research, the research was conducted during the most active period to maximise the results, and with a limited number of individuals. The survey area had undergone river-maintenance work, with the construction of gabion-type artificial embankments for flood control.

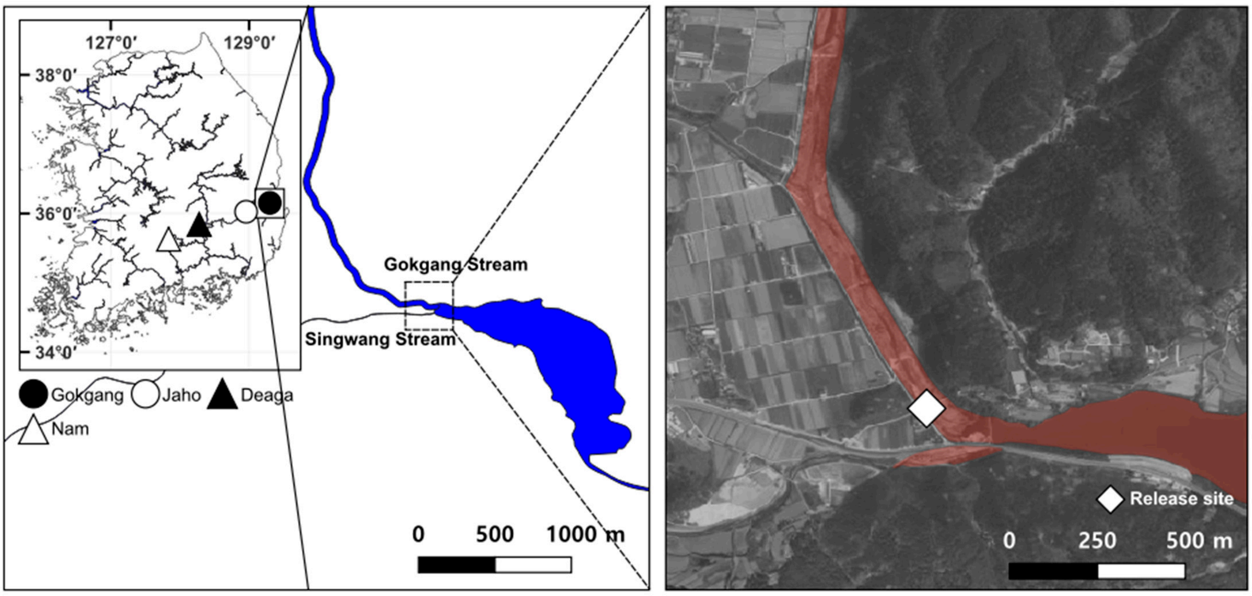

Figure 1. Map of study sites. The right panel's red color shading is the tracking area for the radio telemetry. Black and white symbols in the left panel indicate habitat-characteristics measurement sites. Black circle, Gokgang Stream; White circle, Jaho Stream; Black triangle, Daega Stream; White triangle, Nam River.

2.2. Physico-Chemical Characteristics of Streams

Dissolved oxygen (DO), conductivity, pH, velocity, depth, and substrate composition were measured to assess the chemistry of the river. Dissolved oxygen, conductivity, and pH were measured in the field using a YSI-proplus multiparameter instrument (YSI, Yellow Springs, OH, USA). Velocity was measured five times at each point using a digital velocimeter (Flowatch, JDC, Vaud, Switzerland), and water depth was recorded using a surveyor's staff at five random points. Substratum percentages were visually estimated in the field using the Wentworth (1922) [32] classification, dividing the substratum into five size categories: <2 mm, 2–16 mm, 16–64 mm, 64–256 mm, and >256 mm. For comparison of the introduced habitat, Gokgang Stream (36°7′44.3″ N, 129°17′3.48″ E), with natural habitats, similar measurements were taken from the Nam River (35°36′46.6″ N, 127°48′23.8″ E), Jaho Stream (36°3′3.6″ N, 129°0′82″ E), and Daega Stream (35°47′52.2″ N, 128°15′39″ E), where the species also occurs (Figure 1).

2.3. Radio Tagging

The study of *P. brevicorpus* as a Natural Monument and Endangered Species Class I was conducted with approval from Pohang City, Republic of Korea (Approval No. 2020-0061). Radio telemetry was used to determine the movement and home range of the *P. brevicorpus*. Fish utilized for tagging and tracking were captured using a stake net (mesh size: 4 mm) to minimize physical impact. Captured individuals were immediately transported to the laboratory in aerated tanks (550 × 380 × 300 mm). In the lab, the fish were placed in three holding tanks (900 × 400 × 550 mm) and acclimatized for 7 days. The *P. brevicorpus*, the smallest member of its family in Korea, was implanted with a Lotek nano tag (NTF-3-2: 11 × 5.2 × 5 mm, 180 mm whip antenna, 0.57 g in air, frequency 5 s, battery life 105 days; Lotek, Canada). A total of 14 individuals were tagged and released in the Gokgang Stream area: 2 on 12 June, 4 on 17 June, 3 on 7 July, and 5 on 28 September. The transmitter weighed 9% of the body weight of the smallest individual, minimizing the mechanism's impact on fish behavior [33,34] (Table 1). In this study, the transmitter was applied to 14 individuals; in general, a larger number of individuals may be beneficial for generalisation. However, there are a number of studies with 10–20 individuals in a limited area (within a few hundred metres), and this number is sufficient to understand their movement [35–37]. The procedure followed Yoon et al. (2015) [38]. Fish were anesthetized with 0.1 g L^{-1} ethyl 3-aminobenzoate methanesulfonate (Sigma-Aldrich, St. Louis, MO, USA) before measuring total length (TL), standard length (SL), and body weight (BW). During surgery, fish were placed on a V-shaped operating plate, and anesthetic was continuously supplied. A 1 cm incision was made near the pelvic girdle, the transmitter was inserted, and the antenna was passed through the body wall using a hypodermic needle. The incision was closed with silk sutures (SK442, Ailee Co., Busan, Republic of Korea), and sealed with Vetbond (3M, Maplewood, NJ, USA). An antibiotic (Ceftiofur Sodium, DaehanNupharm Co., Republic of Korea) was injected to prevent infection. Post-surgery, the fish were placed in aerated tanks for recovery. Surgical tools were sterilized with 70% ethanol to prevent infection. All animal experiments were approved by the National Institute of Ecology Institutional Animal Care and Use Committee (NIEIACUC-2020-006).

Table 1. Physico-chemical characteristics of current *P. brevicorpus* habitats. Gokgang Stream is the introduced habitat, and others are the original habitats. SD, standard deviation.

Physico-Chemical Factors		Nam River	Daega Stream	Jaho Stream	Gokgang Stream
Dissolved oxygen (mg/L)		8.35	8.47	8.22	6.83
Conductivity (μS/cm)		78.6	70.6	84.2	77.1
pH		8.54	8.33	8.8	9.5
Velocity (mean ± SD, m/s)		0.11 ± 0.1	0.4 ± 0.2	0.29 ± 0.2	0.24 ± 0.2
Depth (mean ± SD, cm)		69.8 ± 10.7	57.8 ± 12.3	61.8 ± 9.2	60.6 ± 23.9
Substrate composition (%)	<2 mm	30	10	10	20
	2–16 mm	10	10	10	30
	16–64 mm	10	20	20	30
	64–256 mm	20	30	30	10
	>256 mm	30	30	30	10

2.4. Fish Tracking and Movement Analysis

Fish implanted with transmitters were released near the capture site (Figure 1). Tracking was conducted using a 3-element Yagi antenna and IC-R30 receiver (ICOM, Osaka, Japan). If no signal was detected at the release site, the fish were tracked across the area extending from the Gokgang Stream estuary to an area 3 km upstream of the confluence of the Singwang and Gokgang Streams, based on prior data (www.nie.re.kr (accessed on 1 May 2020)) (Figure 1). GPS coordinates were recorded where the fish were detected, and the flow velocity, substrate structure, and water quality were measured. Regular tracking was performed every 7 days, until the last signal disappeared. An additional 24 h monitoring period was carried out on three occasions (23 June, 7 July, and 29 September) to observe diurnal and nocturnal movements. Daytime was defined as 06:00–18:00 and nighttime as 18:00–06:00.

Fish mobility for the 24 h monitoring individuals was analyzed by calculating spread distance from the release site, total distance traveled, and distance from the riparian line. The total distance was calculated as the sum of time-sequential displacements. Home ranges were identified using the minimum convex polygon (MCP) and kernel density estimation (KDE) methods. KDE was used to define the buffer zone (KDE 95%) and the core zone (KDE 50%) [39]. Analyses were conducted using QGIS 3.18 (QGIS.org (accessed on 19 February 2021)).

2.5. Data Analysis

Spearman correlation, a non-parametric analysis, was used to determine the relationships between TL, SL, BW, total distance, and home ranges (MCP, KDE 95%, KDE 50%) for each *P. brevicorpus*. The Wilcoxon signed-rank test was performed to assess differences in diurnal mobility (total distance and mean distance from the riparian line) between individuals. Statistical analysis was conducted using the R project (R version 4.3.1), with significance set at 0.05.

3. Results

3.1. Physico-Chemical Characteristics

The water-environment characteristics of the natural habitat and the Gokgang Stream, where the monitoring of *P. brevicorpus* was conducted, were found to be similar (Table 1). At the time of measurement, dissolved oxygen (DO) was 6.83 mg/L, slightly lower than measurements in other streams (8.22–8.35 mg/L), while the pH was found to be 9.5, slightly higher than those of other streams. Conductivity was recorded at 77.1 µS/cm, which was similar to other streams, and the flow velocity averaged 0.24 m/s, comparable to that of the original habitat. The water depth was consistent, ranging around 60 cm, and the substrate primarily consisted of gravel and pebbles in the 2–64 mm range.

3.2. Movement and Home Range

Radio-tracking of 14 *P. brevicorpus* revealed that none of the individuals were found in open water channels; instead, they were located in areas with riparian vegetation and gabions (Figure 2). The average total distance moved was 107.58 ± 66.01 m, with no.1 traveling the farthest, at 227.51 m, and no. 7 traveling the shortest distance, at 34.91 m (Table 2). The results from MCP and KDE used to identify home ranges showed that the average MCP was 341.91 ± 776.35 m^2, with no. 7 covering the smallest area (15.66 m^2), and no. 1 covering the largest (2985.61 m^2) (Figure 2). For KDE95 and KDE50, which represent the buffer and core habitat, respectively, the average values were 76.01 ± 30.98 m^2 for core and 144.41 ± 58.86 m^2 for buffer. The smallest areas were covered by no. 6, with 42.45 m^2 for core and 80.64 m^2 for buffer, and the largest by no. 12, with 137.40 m^2 for core and 261.06 m^2 for buffer.

Table 2. Individual size, movement, and home range information of monitored *P. brevicorpus*. MCP, Maximum convex polygon; KDE, Kernel density estimation. *, excluded from 24 h monitoring due to technical problem.

No.	Frequency	Release Date	Total Length (mm)	Standard Length (mm)	Body Weight (g)	Total Distance (m)	MCP (m^2)	KDE95 (m^2)	KDE50 (m^2)
1 *	151.449.20	2020.06.12	95	83	9.25	227.51	2985.61	133.19	70.11
2	151.889.30	2020.06.12	92	82	9.24	53.76	69.63	88.67	46.67
3	150.319.40	2020.06.17	84	73	7.89	84.50	145.46	123.81	65.16
4	149.339.30	2020.06.17	70	60	4.18	155.89	629.07	246.34	129.65
5	149.299.20	2020.06.17	74	66	5.03	102.43	109.35	141.12	74.27
6	149.399.20	2020.06.17	65	56	3.39	39.42	188.06	80.64	42.45

Table 2. *Cont.*

No.	Frequency	Release Date	Total Length (mm)	Standard Length (mm)	Body Weight (g)	Total Distance (m)	MCP (m^2)	KDE95 (m^2)	KDE50 (m^2)
7	149.439.80	2020.07.07	67	59	3.27	34.91	15.66	100.92	53.12
8	149.319.10	2020.07.07	84	73	7.46	78.91	28.24	102.23	53.81
9	148.339.00	2020.07.07	84	73	6.94	40.03	56.37	95.02	50.02
10	150.599.30	2020.09.28	90	77	9.18	105.91	40.33	133.97	70.52
11	151.379.30	2020.09.28	92	77	9.32	184.77	174.66	218.47	114.99
12	150.099.40	2020.09.28	82	69	6.45	205.29	127.32	261.06	137.40
13	149.359.20	2020.09.28	78	65	5.47	148.41	189.22	176.22	92.74
14	149.419.10	2020.09.28	72	58	4.12	44.15	27.75	120.08	63.20
Mean ± SD						107.58 ± 66.01	341.91 ± 776.35	144.41 ± 58.86	76.01 ± 30.98

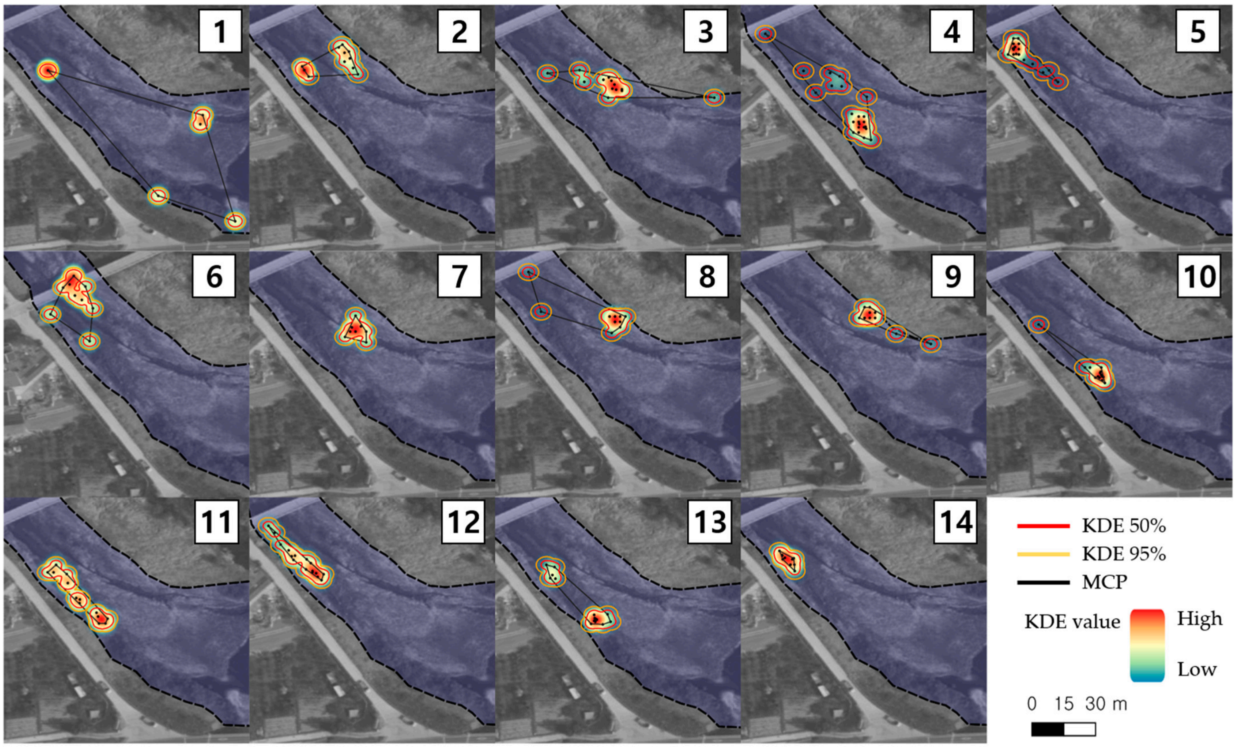

Figure 2. Estimations of MCP and home ranges of 14 *P. brevicorpus*. Blue shading indicates the water channels of the study sites, and the black dashed line is the riparian line. Black, yellow, and red solid lines denote MCP, KDE 95%, and KDE 50%, respectively.

Spearman correlation analysis of the size and movement of the *P. brevicorpus* showed no significant correlation between body size (TL, SL, or BW) and movement metrics (TD, MCP, KDE95, KDE50) ($p > 0.05$) (Table 3).

Table 3. Spearman correlation results for individual characteristics and movement data (*, $p < 0.05$).

	TL	SL	BW	TD	MCP	KDE95
SL	0.979 *	-				
BW	0.979 *	0.959 *	-			
TD	0.477	0.464	0.534	-		
MCP	0.126	0.126	0.226	0.635 *	-	
KDE95	0.086	0.075	0.160	0.846 *	0.42	-
KDE50	0.086	0.075	0.160	0.846 *	0.42	1.000 *

3.3. Diel Movement

The mean distances traveled during the day and night were 14.0 ± 7.7 m and 18.1 ± 11.5 m, respectively, with a larger range at night, though the difference was not statistically significant (Wilcoxon signed-rank test, $p > 0.05$) (Table 4, Figure 3). While some individuals exhibited more movement during the day, nighttime movements were more frequent overall (day > night in six cases; night > day in eight cases). The longest distance traveled during the day was 27.37 m, by no. 3, while the longest distance traveled at night was 37.12 m, by no. 13. Since the *P. brevicorpus* remained close to the riparian line during the day, the distance from the riparian line at night was also measured, to determine their actual movement. The results showed that, as the *P. brevicorpus* became more active at night, they tended to move farther from the riparian line, compared to their daytime movement. The average distance from the riparian line was 1.9 ± 0.8 m during the day and 2.4 ± 0.9 m at night, a statistically significant difference (Wilcoxon signed-rank test, $p < 0.05$). The nighttime movement showed more frequent distance away from the riparian line compared to daytime.

Table 4. Movement distance and distance from riparian line, identified by 24 h monitoring. No. 4 and no. 5 were tracked twice during the monitoring.

No	Movement Distance (m)		Distance from Riparian Line (m)	
	Day	Night	Day	Night
2	11.59	26.93	2.24	2.72
3	27.37	21.45	3.74	3.54
4-1	27.19	29.69	0.93	1.79
4-2	26.25	9.32	1.2	2.68
5-1	4.03	0	1.65	2.33
5-2	11.84	17.26	1.23	1.44
6	19.77	20.79	3.23	2.96
7	6.47	-	1.94	-
8	13.9	8.06	1.81	2.18
9	9.48	23.86	0.69	4.41
10	6.5	3.48	2.05	0.86
11	10.35	32.24	2.53	2.17
12	12.7	18.3	1.38	2.72
13	14.37	37.12	1.53	2.62
14	7.64	5.22	20.86	1.25
Mean ± SD	14.0 ± 7.7	18.1 ± 11.5	1.9 ± 0.8	2.4 ± 0.9

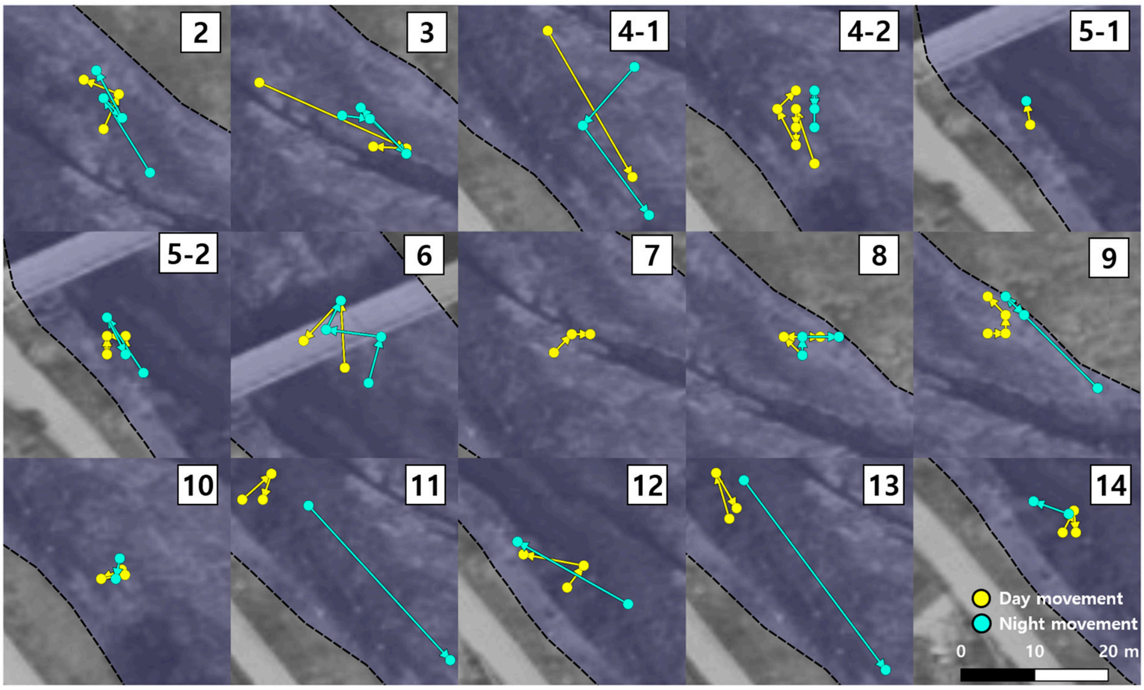

Figure 3. Diel movement of *P. brevicorpus*. No. 4 and No. 5 were tracked twice during the monitoring. Blue shading indicates the water channels of the study sites, and the black dashed line is the riparian line. Circles mean detection points and arrows indicate movement direction.

4. Discussion

During the monitoring period, *P. brevicorpus* exhibited limited movement, averaging approximately 100 m, although there are limitations in providing a full range of behaviors because the period from March to May is excluded from the main activity period. After the initial release, individuals made temporary movements before settling down in the same area. Despite the proximity of the study area to Singwang Stream, a tributary of Gokgang Stream, and the confirmed presence of *P. brevicorpus* in Singwang Stream and downstream areas, all individuals displayed high site fidelity, remaining within the vicinity of the study area. This characteristic has also been observed in a related species, *Pseudobagrus ichikawai*, in Japan [40].

The primary areas used by *P. brevicorpus* appear to be riparian zones adjacent to the revetment installation area. The availability of hiding places in these areas may have influenced their habitat selection. Bagrid catfish are known to hide in shelters such as crevices in riverbeds and banks [41]. These shelters are also used as breeding sites by some bagrid species (e.g., [42]). The *P. brevicorpus* has been mainly found in deep crevices and areas where the roots of aquatic plants (particularly *Phragmites japonica*) thrive. This habitat selection is likely related to the ecological characteristics and survival strategy of *P. brevicorpus*. A similar behavior has been observed in the Japanese endemic *P. ichikawai*, a behavior which is likely linked to predator avoidance [40]. In particular, hiding in crevices and among aquatic vegetation is thought to be a strategy to avoid predators, especially for *P. brevicorpus*, which inhabits relatively shallow and clear waters, compared to larger members of the family. Power (1984) [43] suggested that the depth selection of armoured catfish varies to avoid predatory birds. The areas occupied by *P. brevicorpus* are likely subject to constant feeding activity by birds such as herons and egrets, and hiding in these habitats may help avoid being detected by predators.

P. brevicorpus appears to be a nocturnal species with a wide range of nocturnal behaviors. Catfish (Siluriforms) are predominantly nocturnal, relying on non-visual sensory capabilities such as tactile, acoustic, chemical, or electrical organs [44]. Bagrid catfish, one of the largest families in the Siluriformes, are generally known to be nocturnal. Although the reasons for *P. brevicorpus*'s nocturnal activity are not fully understood, feeding behavior is thought to play a significant role. Catfish use their whiskers as mechanoreceptors to locate prey [45]. Foraging, in *P. brevicorpus*, occurs primarily at night, and most nocturnal movements, aside from during spawning, are believed to be related to feeding. Kwak et al. (2019) [46] reported that the volume of stomach contents in *P. brevicorpus* begins to increase at sunset and peaks before sunrise. The species predominantly feeds on aquatic insects, particularly Ephemeroptera, Diptera, Trichoptera, and Coleoptera [46]. Most aquatic insects are nocturnal [47], hiding during the day to avoid predation by mobile fish and emerging at night. This ecological trait may be a key factor in the nocturnal behavior of *P. brevicorpus*.

There are many reasons why species become endangered, but it is often due to their ecological and physiological traits being unable to adapt to environmental changes [6,48,49]. Various river disturbances caused by human activities can significantly alter freshwater ecosystems, affecting fish communities and populations [7,8,50]. The impacts of river development and environmental changes on freshwater fish have been well documented (e.g., [19–21]), and the effects of different types of construction (dredging, dam construction, straightening, etc.) are also well known. In Korea, common river improvement works such as dams, revetments, and dredging directly modify rivers through physical alterations. These activities have been found to contribute to the decline of *P. brevicorpus*, an association which is closely linked to their migration and ecological characteristics.

The limited movement, high site fidelity, and nocturnal nature of *P. brevicorpus* are likely major reasons for their inability to avoid the effects of river modifications. The riparian habitats preferred by *P. brevicorpus* are typically the first to be removed and managed during river modifications. Additionally, construction activities often occur during daylight hours, directly impacting *P. brevicorpus* when they are less mobile and less able to hide. Dredging [51,52] and the removal of in-channel vegetation [53] tend to directly affect fish, and significantly impact the survival of *P. brevicorpus*. Their limited mobility also makes it difficult for them to migrate to other areas, further threatening their populations. River modifications such as engineering works reduce the habitats favored by *P. brevicorpus*, leading to long-term population declines. Similar impacts have been observed in *P. ichikawai*, a related species in Japan, which has been threatened by habitat loss due to concrete retaining walls in streams [54,55]. Therefore, careful consideration and strategies are needed to manage the population of *P. brevicorpus* during river development works.

Restoration efforts such as stocking and population enhancement are important for the recovery of endangered species and can be highly effective when consistently applied (e.g., [56]). However, these efforts are more effective when considered in relation to the species' ecological characteristics (e.g., [7]). In the case of *P. brevicorpus*, restoration has been carried out in some streams where river restoration projects have been completed and the species had been detected until recently. Given the limited habitat of *P. brevicorpus*, dispersal releases are likely to be effective. Specifically, strategically considering linear releases along streams in targeted sections, rather than across large areas, would allow the species to spread more effectively.

In recent years, the effects of climate change have become more severe worldwide. The ecological traits of *P. brevicorpus*—limited migratory range, preference for watery areas, and nocturnal behavior—suggest that the species may be negatively affected by the increased dredging and dam construction in response to climate change. While it is essential to manage rivers in preparation for climate change, it is equally important to utilize NBS to maintain river ecosystems and allow coexistence between people and riverine species. Using threatened species like *P. brevicorpus* as flagship species could be highly effective in promoting conservation. Additionally, forming a citizen participation community with local residents would be beneficial in carrying out sustainable conservation activities for *P. brevicorpus* and its habitat. Furthermore, active conservation efforts should be undertaken to restore areas where river maintenance has been completed.

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References

1. Butchart, S.; Walpole, M.; Collen, B.; Van Strien, A.; Scharlemann, J.; Almond, R.; Baillie, J.; Bertzky, B.; Brown, C.; Bruno, J.; et al. Global Biodiversity: Indicators of Recent Declines. *Science* **2010**, *328*, 1164–1168. [CrossRef] [PubMed]
2. Joppa, L.; O'Connor, B.; Visconti, P.; Smith, C.; Geldmann, J.; Hoffmann, M.; Watson, J.; Butchart, S.; Virah-Sawmy, M.; Halpern, B.; et al. Filling in biodiversity threat gaps. *Science* **2016**, *352*, 416–418. [CrossRef] [PubMed]

3. Northcote, T.G. Migratory strategies and production in freshwater fishes. In *Ecology of Freshwater Production*; Gerking, S.D., Ed.; Blackwell: Oxford, UK, 1978; pp. 326–359.
4. Northcote, T.G. Mechanisms of fish migration in rivers. In *Mechanisms of Migration in Fishes*; McCleave, J.D., Dodson, J.J., Neill, W.H., Eds.; Plenum: New York, NY, USA, 1984; pp. 317–355.
5. Lucas, M.C.; Baras, E. *Migration of Freshwater Fishes*; Blackwell Science: Oxford, UK, 2001.
6. Cardinale, B.; Duffy, J.; Gonzalez, A.; Hooper, D.; Perrings, C.; Venail, P.; Narwani, A.; Tilman, D.; Wardle, D.; Kinzig, A.; et al. Biodiversity loss and its impact on humanity. *Nature* **2012**, *486*, 59–67. [CrossRef] [PubMed]
7. Dudgeon, D.; Arthington, A.; Gessner, M.; Kawabata, Z.-I.; Knowler, D.; Lévêque, C.; Naiman, R.; Prieur-Richard, A.-H.; Soto, D.; Stiassny, M.; et al. Freshwater Biodiversity: Importance, Threats, Status and Conservation Challenges. *Biol. Rev.* **2006**, *81*, 163–182. [CrossRef]
8. Pringle, C.M. Hydrologic connectivity and the management of biological reserves: A global perspective. *Ecol. Appl.* **2001**, *11*, 981–998. [CrossRef]
9. Song, M.-Y.; Jung, S.-Y.; Kim, K.-H.; Baek, J.-M.; Lee, W.-O. Characteristics of Fish Fauna and Community Structure in Daecheon Stream in Boryeong, Korea. *Korean J. Environ. Ecol.* **2013**, *27*, 437–448.
10. Kenward, R. *A Manual for Wildlife Radio Tagging*, 2nd ed.; Academic Press: London, UK, 2001.
11. IUCN Red List of Ecosystems (IUCN RLE). Available online: https://assessments.iucnrle.org/ (accessed on 3 March 2023).
12. Darwall, W.; Freyhof, J. Lost fishes, who is counting? The extent of the threat to freshwater fish biodiversity. In *Freshwater Fish Conservation: Options for the Future*; Closs, G.P., Krkosek, M., Olden, J.D., Eds.; Cambridge University Press: Cambridge, UK, 2016; pp. 1–36. [CrossRef]
13. Helfman, G. *Fish Conservation: A Guide to Understanding and Restoring Global Aquatic Biodiversity and Fishery Resources*; Island Press: Washington, DC, USA, 2007.
14. Sala, O.; Chapin, F.S., III; Armesto, J.J.; Berlow, E.; Bloomfield, J.; Dirzo, R.; Huber-Sannwald, E.; Huenneke, L.; Jackson, R.; Kinzig, A.P.; et al. Global biodiversity scenarios for the year 2100. *Science* **2000**, *287*, 1770–1774. [CrossRef]
15. Ministry of Environment (ME). *Conservation and Management Laws of Wildlife (Law No. 737)*; ME: Sejong City, Republic of Korea, 2023. (In Korean)
16. Belletti, B.; Garcia de Leaniz, C.; Jones, J.; Bizzi, S.; Börger, L.; Segura, G.; Castelletti, A.; van de Bund, W.; Aarestrup, K.; Barry, J.; et al. More than one million barriers fragment Europe's rivers. *Nature* **2020**, *588*, 436–441. [CrossRef]
17. Grift, R.E.; Buijse, A.D.; van Densen, W.L.T.; Breteler, J.G.P.K. Restoration of the river-floodplain interaction: Benefits for the fish community in the River Rhine. *Large Rivers* **2001**, *12*, 173–185. [CrossRef]
18. Water Resources Management Information System (WAMIS). Available online: http://wamis.go.kr/dic/dic_main.do (accessed on 3 March 2023).
19. Allan, J.D. Landscapes and Riverscapes: The Influence of Land Use on Stream Ecosystems. *Annu. Rev. Ecol. Evol. Syst.* **2004**, *35*, 257–284. [CrossRef]
20. Lau, J.; Lauer, T.; Weinman, M. Impacts of Channelization on Stream Habitats and Associated Fish Assemblages in East Central Indiana. *Am. Midl. Nat.* **2006**, *156*, 319–330. [CrossRef]
21. Sudduth, E.; Hassett, B.; Cada, P.; Bernhardt, E. Testing the Field of Dreams Hypothesis: Functional Responses to Urbanization and Restoration in Stream Ecosystems. *Ecol. Appl.* **2011**, *21*, 1972–1988. [CrossRef] [PubMed]
22. Kim, S.-K.; Kang, Y.-H.; Hong, G.-B.; Yoo, D.-U.; Suk, H.-Y.; Chae, B.-S.; Kim, H.-S.; Hwang, U.-W. Ichthyofauna and Community Structure from 21 Lakes in the Yeungnam Area including Gyeongsangbuk-do and Gyeongsangnam-do Provinces, Korea. *Korean J. Ichthyol.* **2011**, *23*, 288–299.
23. Yoo, D.-J.; Han, K.-H.; Lee, S.-H.; Yim, H.-S.; Hwang, J.-H.; Lee, J.; Kang, K.-W. Ichthyofauna collected from reservoirs in Pohang-si, Gyeongsangbuk-do. *J. Korean Fish. Soc.* **2008**, *41*, 363–370. [CrossRef]
24. Cultural Heritage Administration (CHA). *Report on State Designated Cultural Heritage Natural Monuments & Scenic Sites*; CHA: Daejeon, Republic of Korea, 2005; pp. 56–57. (In Korean)
25. Uchida, K. The fishes of Tyosen. Part 1. Nematognathi, Eventognathi. *Bull. Fish. Exp. Sta. Gov. Gener. Tyosen* **1939**, *6*, 1–458. (In Japanese)
26. Kang, E.J.; Hyun, Y.; Lee, H.H.; Chae, Y.C.; Kim, E.O.; Lee, S.G.; Bang, I.C. Ecology and Early Life History of Endangered Freshwater Fish, *Pseudobagrus brevicorpus* (Pisces: Bagridae). *Korean J. Environ. Biol.* **2007**, *25*, 114–121.
27. Yang, S.-G.; Kang, E.-J.; Kim, K.-S.; Bang, I.-C. Characteristics on Growth and Sexual Maturation of an Endangered Fish, Stumpy Bullhead (*Pseudobagrus brevicorpus*), from Korea by Artificial Rearing. *Korean J. Environ. Biol.* **2009**, *27*, 369–374.
28. Kim, K.S. Characterization of Polymorphic Microsatellite Markers and Population Structure Analysis in the Endangered Korean Stumpy Bullhead, *Pseudobagrus brevicorpus*. Master's Thesis, Soonchunhyang University, Asan, Republic of Korea, 2009. (In Korean).
29. Mori, T. Studies on the geographical distribution of fresh-water fishes in Korea. *Bull. Biogeogr. Soc. Jpn.* **1936**, *6*, 35–61. (In Japanese)
30. National Institute of Ecology (NIE). *National Survey on the Distribution of Endangered Species*; NIE: Seocheon, Republic of Korea, 2023.
31. Kwak, Y.H. Studies of the Conservation Biology of an Endangered Freshwater Fish, *Pseudobagrus brevicorpus*. Ph.D. Thesis, Soonchunhyang University, Asan, Republic of Korea, 2019; p. 218.
32. Wentworth, C.K. A Scale of Grade and Class Terms for Clastic Sediments. *J. Geol.* **1922**, *30*, 377–392. [CrossRef]

33. Jepsen, N.; Schreck, C.; Clements, S.; Thorstad, E. A brief discussion on the 2% tag/bodymass rule of thumb. In *Aquatic Telemetry: Advances and Applications*; Spedicato, M.T., Lembo, G., Marmulla, G., Eds.; FAO/COISPA: Rome, Italy, 2005; pp. 255–259.
34. Smircich, M.G.; Kelly, J.T. Extending the 2% rule: The effects of heavy internal tags on stress physiology, swimming performance, and growth in brook trout. *Anim. Biotelemetry* **2014**, *2*, 16. [CrossRef]
35. Horký, P.; Slavík, O.; Bartoš, L.; Kolářová, J.; Randák, T. Behavioural Pattern in Cyprinid Fish Below a Weir as Detected by Radio Telemetry. *J. Appl. Ichthyol.* **2007**, *23*, 679–683. [CrossRef]
36. Jellyman, D. A Review of Radio and Acoustic Telemetry Studies of Freshwater Fish in New Zealand. *Mar. Freshw. Res.* **2009**, *60*, 321–327. [CrossRef]
37. Hahn, L. The Application of Radio Telemetry to Fisheries Research in Brazil's Large Rivers. In *Telemetry Techniques: A User Guide for Fisheries Research*; Adams, N.S., Beeman, J.W., Eiler, J.H., Eds.; American Fisheries Society: Bethesda, MD, USA, 2012; pp. 237–252.
38. Yoon, J.D.; Kim, J.H.; Jo, H.B.; Park, J.M.; Jang, M.H.; Kim, J.D.; Park, S.; Joo, G.J. Seasonal habitat utilization and movement patterns of the threatened *Brachymystax lenok tsinlingensis* in a Korean river. *Environ. Biol. Fishes* **2015**, *98*, 225–236. [CrossRef]
39. Kauhala, K.; Auttila, M. Estimating habitat selection of badgers—A test between different methods. *Folia Zool.* **2010**, *59*, 16–25. [CrossRef]
40. Watanabe, K. Diel activity and reproductive territory of the Japanese bagrid catfish, *Pseudobagrus ichikawai*. *Environ. Biol. Fishes* **2008**, *81*, 77–86. [CrossRef]
41. Kawanabe, H.; Mizuno, N.; Hosoya, K. (Eds.) *Freshwater Fishes of Japan*; Yamatokeikokusha Press: Tokyo, Japan, 2001. (In Japanese)
42. Nikolskii, G.V. *Special Ichthyology (Chastnaya Ikhtiologiya)*; Lengy, J.I.; Krauthamer, Z., Translators; Israel Program for Scientific Translations; Sovetskaya Nauka: Moscow, Russia, 1961; (Original Work Published 1954).
43. Power, M.E. Depth distributions of armored catfish: Predator-induced resource avoidance? *Ecology* **1984**, *65*, 523–528. [CrossRef]
44. Helfman, G.S. Fish Behaviour by Day, Night and Twilight. In *The Behaviour of Teleost Fishes*; Pitcher, T.J., Ed.; Springer: Boston, MA, USA, 1986; pp. 366–387.
45. Biedenbach, M.A. Functional properties of barbel mechanoreceptors in catfish. *Brain Res.* **1971**, *27*, 360–364. [CrossRef]
46. Kwak, Y.H.; Kim, K.R.; Bang, I.C. Diel Activity and Feeding Habitat of *Pseudobagrus brevicorpus* (Pisces: Bagridae) in the Daegacheon Stream of Nakdonggang River, Korea. *Korean J. Ichthyol.* **2019**, *31*, 54–61, (In Korean with English abstract). [CrossRef]
47. Campos, R.; Rosa, J.; Higuti, J.; Buggenhagen, T.C.; Krawczyk, A.C.D.B. Diel variation of aquatic insect drift in streams of Southern Brazil. *Acta Sci. Biol. Sci.* **2021**, *43*, e54931. [CrossRef]
48. Chevin, L.-M.; Lande, R.; Mace, G.M. Adaptation, Plasticity, and Extinction in a Changing Environment: Towards a Predictive Theory. *PLoS Biol.* **2010**, *8*, e1000357. [CrossRef]
49. Chichorro, F.; Juslén, A.; Cardoso, P. A review of the relation between species traits and extinction risk. *Biol. Conserv.* **2019**, *237*, 220–229. [CrossRef]
50. Poff, N.L.; Zimmerman, J.K.H. Ecological responses to altered flow regimes: A literature review to inform the science and management of environmental flows. *Freshw. Biol.* **2010**, *55*, 194–205. [CrossRef]
51. Barletta, M.; Cysneiros, F.J.A.; Lima, A.R.A. Effects of dredging operations on the demersal fish fauna of a South American tropical–subtropical transition estuary: Dredging effects on fish assemblages. *J. Fish Biol.* **2016**, *89*, 1–22. [CrossRef]
52. Wenger, A.S.; Harvey, E.; Wilson, S.; Rawson, C.; Newman, S.J.; Clarke, D.; Saunders, B.J.; Browne, N.; Travers, M.J.; Mcilwain, J.L. A critical analysis of the direct effects of dredging on fish. *Fish Fish.* **2017**, *18*, 967–985. [CrossRef]
53. Beltrão, G.B.M.; Medeiros, E.S.F.; Ramos, R.T.C. Effects of riparian vegetation on the structure of the marginal aquatic habitat and the associated fish assemblage in a tropical Brazilian reservoir. *Biota Neotrop.* **2009**, *9*, 37–43. [CrossRef]
54. Watanabe, K. Pseudobagrus ichikawai. In *Circumstances in Endangered Japanese Freshwater Fishes and Their Protection*; Nagata, Y., Hosoya, K., Eds.; Midori Shobo: Tokyo, Japan, 1997; pp. 122–132. (In Japanese)
55. Kobayakawa, M. Pseudobagrus ichikawai. In *Threatened Wildlife of Japan—Red Data, Pisces—Blackish and Fresh Water Fishes*, 2nd ed.; Ministry of the Environment, Ed.; Japan Wildlife Research Center: Tokyo, Japan, 2003; Volume 4, pp. 110–111. (In Japanese)
56. Cooke, S.; Paukert, C.; Hogan, Z. Endangered river fish: Factors hindering conservation and restoration. *Endanger. Species Res.* **2012**, *17*, 179–191. [CrossRef]