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Assessing the Habitat Potential of Eurasian Otter (*Lutra lutra*) in Cheonggye Stream Utilizing the Habitat Suitability Index[1a]

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서식지 적합성 지수를 이용한 청계천 수달의 서식지 평가[1a]

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ABSTRACT

The Eurasian otter (*Lutra lutra*) is an apex predator of the riparian ecosystem. It is a keystone and an indicator species; consequently, its presence suggests a sustainable water environment. Otter is a keystone species as a predator at the top of the food web in the aquatic environment and an indicator species representing the health of the aquatic environment. Although Eurasian otters disappeared from the Han River urban water system because of anthropogenic activities like habitat destruction, poaching, and environmental pollution in the 1980s, the species were sighted in the Cheonggye Stream, Jungrang Stream, and Seongnae Stream, which are urban sections of the Han River, in 2016 and 2021. Therefore, it is pertinent to assess the habitat potential in the area for conservation and management measures to ensure its permanent presence. However, existing studies on otter habitats focused on natural rivers and reservoirs, and there is a limit to applying them to habitats artificially confined habitats in narrow spaces such as tributaries in urban areas of the Han River. This study selected the Cheonggye Stream, an artificially restored urban stream, to evaluate its potential as a habitat for Eurasian otters in urban water environments using the habitat suitability index (HSI). The HSI was calculated with selected environment attributes, such as the cover, food, and threat, that best describe the *L. lutra* habitat. According to the results, the confluence area of Seongbuk Stream and Cheonggye Stream and the confluence area of Cheonggye Stream and Jungnang Stream were suitable otter habitats, requiring appropriate conservation efforts. The HSI model suggests a valuable method to assess the habitat quality of Eurasian otters in urban water environments. The study is crucial as it can help rehabilitate the species' populations by identifying and managing potential Eurasian otter habitats in highly urbanized areas of the Han River basin and its tributaries.

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KEY WORDS: CONSERVATION STRATEGY, ENVIRONMENTAL ATTRIBUTES, KEYSTONE SPECIES, REINTRODUCTION, URBAN STREAM

요 약

수달(Eurasian otter, *Lutra lutra*)은 식육목 족제비과에 속하는 동물이다. 수달은 수계환경 먹이그물의 최상위에 존재하는 포식자로 핵심종(keystone species)이자 건강한 수계환경을 대변하는 지표종(Indicator species)이다. 현대에 이르면서 남획과 서식지 파괴, 환경 오염 등에 의하여 한강 도심 수계에서 사라졌지만, 2016년 다시 발견된 이후 2021년 1월에도 한강의 지류인 청계천, 중랑천과 성내천에서 서식함을 확인하였다. 수달의 서식지 보호와 관리 방안 수립을 위하여 잠재 서식지 평가가 시급하나, 기존의 수달 서식지 관련 연구는 자연형 하천과 저수지 위주로 이루어져 한강 도심 지류와 같이 좁은 공간에 인위적으로 한정된 서식지에 적용하기에는 한계가 있다. 본 연구에서는 인공하천인 청계천이 수달의 잠재 서식지로 적합한지를 서식지 적합성 지수(Habitat Suitability Index, HSI)를 활용하여 평가하였다. 서식지 적합성 지수는 수달의 서식 환경을 나타내는 지표, 먹이자원, 위협 요소 환경 특성을 종합하여 추정하였다. 그 결과 성북천과 청계천의 합류 지점과 청계천과 중랑천의 합류 지점이 적합한 서식지로 나타났다. 본 연구에서 추정한 HSI는 도심 하천의 수달 서식지 평가가 가능하였으며, 따라서 청계천을 포함한 한강 도심 지류에서의 효과적인 수달 모니터링과 수달 인공 서식지 장소 선정을 위한 기반 자료가 될 수 있을 것으로 판단된다.

주요어: 보전 방안, 환경 특성, 지표종, 재유입, 도심 하천

INTRODUCTION

Eurasian otter (*Lutra lutra*) is a semiaquatic mammal inhabiting the riparian ecosystem. As a keystone species and an apex predator, *L. lutra* plays a vital role in regulating the riparian ecosystem by controlling multiple prey species (Foster-Turlet *et al*., 1990). Recently, anthropogenic activities such as urbanization and river projects that replaced natural riparian structures with artificial ones dramatically destroyed and reduced their critical habitats (National Institute of Ecology, 2019). According to the International Union for Conservation of Nature Red List of Threatened species, *L. lutra* is now listed as near-threatened species (Roos *et al*., 2015). The species` high public interest, economic value, sensitivity to specific land use actions, and critical role in the environment make habitat restoration and protection efforts essential (US Fish and Wildlife Service, 1980; Kruuk, 2006; Stevens *et al*., 2012).

In South Korea, *L. lutra* was common in the riparian ecosystems until the mid-20th century, which quickly disappeared by anthropogenic activities such as poaching and habitat destruction caused by rapid industrialization and urbanization (Jo *et al*., 2006). Nevertheless, recent stream restoration projects have improved water quality by altering various artificially canalized rivers and streams back to near-natural environmental conditions (Ahn and Lee, 2020). Such changes may have played a vital role in the restoration of the *L. lutra* populations in the Han River, as confirmed by its sightings through trap cameras in the highly urbanized tributaries in 2016 and 2021 (Ministry of Environment, 2016; Social Cooperative Hangang, 2021).

Previously, studies have used the habitat suitability index (HSI) to identify the preferred habitat characteristics and the spatial distribution of *L. lutra* in South Korea. HSI assesses the suitability of a specific area as a habitat for a target species based on the preference of a species to different environmental attributes. Many species distribution models require occurrence data. But the data is hard to achieve as *L. lutra* is an elusive nocturnal animal hard to sight, especially in a newly established area. HSI can be easily applied to map habitat preferences based on documented criteria and experts' opinions (Brooks, 1997). Also, HSI is flexible in adjusting habitat variables to the characteristics of the study site. For example, Shin *et al*.(2020a) focused on the riparian type used by Eurasian otters in the Daecheong dam reservoir area and suggested the importance of the wetland cover. Another study was conducted in the Daecheong dam and Banbyeon stream, where commercial fishing is taking place; the distribution of fishery and fishing nets (Shim *et al*., 2020) and the distance from the aquaculture farm were used to evaluate the threat requirement of the habitat (Shin *et al*., 2020b).

Nevertheless, most previous studies focused on rural and periurban areas, whereas few studies focused on urbanized streams (Hong *et al*., 2017). As Morrison *et al*.(2006) highlighted, environmental characteristics that determine habitat quality are different between rural and urban areas. The urban stream does not meet the ideal conditions of otter habitat because they are usually straightened and channelized, are susceptible to multiple pollutants that degrade water quality and prey within, and are highly disturbed by human activities (Forman, 2014). Human activities affect wildlife behavior, and the influence is more significant in urban areas as the distance between humans and animals is closer (Miller *et al*., 2001; George and Crooks, 2006). Despite these problems of the urban stream environment, *Lutra* spp. has been reappearing in numerous urban areas worldwide due to conservation efforts (Khoo and Lee, 2020).

Cheonggye Stream, located at the center of Seoul, Korea, is one of the urban streams where *L. lutra* is newly discovered (Social Cooperative Hangang, 2021). The stream is rehabilitated to near-natural environmental conditions and overcame some of the past limitations of urban streams. However, since the stream is heavily used as an urban park, drawbacks and advantages coexist. The present study identifies potential *L. lutra* habitats and evaluates their suitability in a stream that flows through the highly urbanized district of Seoul. Specifically, a) the environmental characteristics that determine *L. lutra* territory are identified, b) the habitat suitability of the areas is evaluated using the HSI, and c) potential otter habitats that require conservation efforts are prioritized.

MATERIALS AND METHODS

1. Study Site

The Cheonggye Stream is an artificial restored urban stream flowing through the central part of Seoul, the capital of the Republic of Korea (Figure 1). Cheonggye

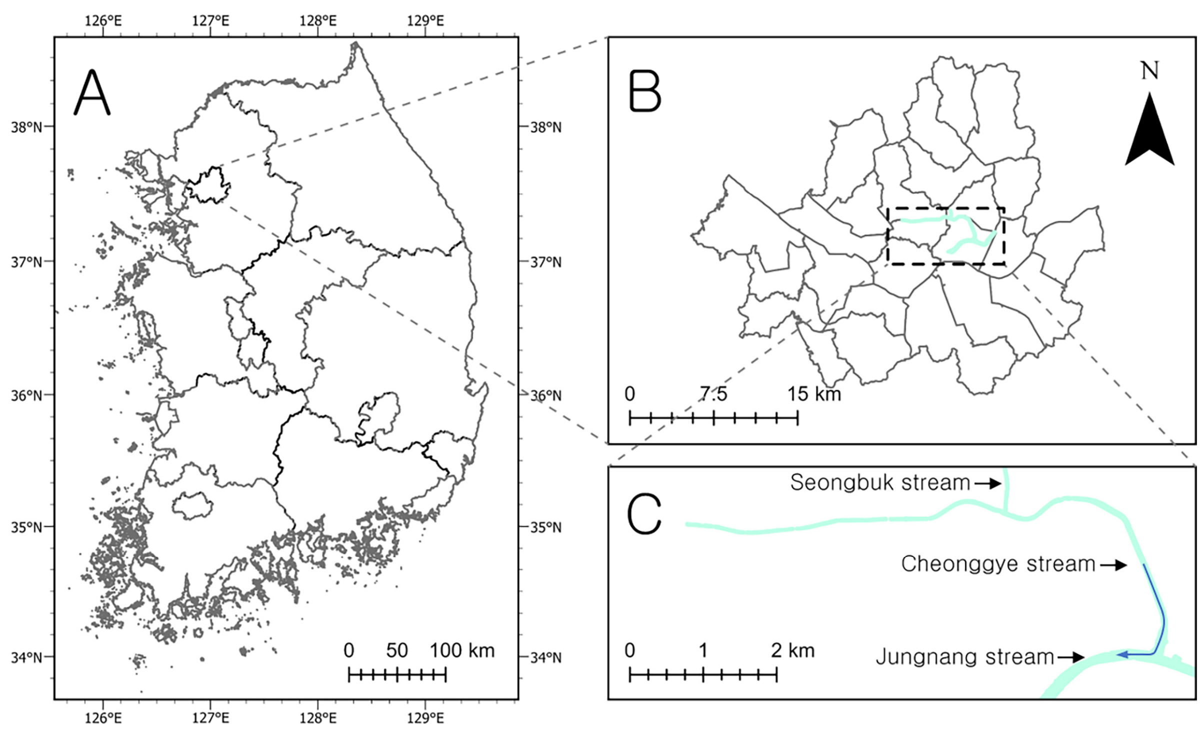

Figure 1. Location of the study site, Republic of Korea (A), Seoul (B), Cheonggye Stream (C).

Stream is 8.48 ㎞ long, originating from the Baekundong valley in the west, joining the Jungnang Stream, and finally, from the Han River in the east. Its upstream flows through Seoul's highly urbanized central business district (CBD), but its downstream is joined by more green space and parks before joining the Han River. In 1955, the stream was mostly buried under roads and urban highways. The Seoul metropolitan government decided to restore the Cheonggye Stream by daylighting its course in 2013. Nevertheless, the resulting stream possessed a highly artificial character in its flow regime and surrounding environment (Kim and Shin, 2014). Despite the unnatural quality, the Cheonggye Stream became a shelter and a refuge for various urban wildlife (eight genera, 27 species of fish, and 31 bird species) (The Seoul Institute, 2014).

2. Methods

HSI

HSI is calculated in consideration of numerous environmental characteristics that affect a species' inhabitance. Each environmental attribute is represented as the suitability index (SI), the relative preference of a target species to each ecological characteristic. Documented criteria and experts' opinions explain the SIs (US Fish and Wildlife Service, 1980). Arithmetic and geometric means are used to aggregate the SIs and create the HSI formula depending on the response of the target species to environmental attributes (Draugelis-Dale, 2007). The simplest yet most common way to create the formula is an arithmetic mean. Nonetheless, the geometric mean is used to reflect some critical habitat attributes that can lower the suitability value significantly since one 0 value of SI will lead to a 0 HSI value (Shim *et al*., 2020).

SI for Eurasian otter habitat

Understanding the ecology and life characteristics of the target species is pertinent to set criteria and evaluating habitat suitability (Jung, 2016). Thus, cover, food, and threat were selected as habitat attributes based on previous studies (Foster-Turlet *et al*., 1990; Shim *et al*., 2020; Shin *et al*., 2020a; Shin *et al*., 2020b). Land cover types were used to calculate the cover (SI 1) and presence of alluvial islands (SI 2), food with the biomass of fish species (SI 3), and the number of fish individuals (SI 4), a threat with the presence of artificial riverside (SI 5) (Table 1). The

Table 1. Suitability index variable and valuation criteria of L. lutra in Cheonggye Stream

Habitat attribute	SI variable	Class	Score	Source data
Cover: Land cover types	SI 1	Body of water Natural grassland Artificial grassland and Natural bare land Artificial bare lands Roads and urban district	5 4 3 2 1	2019 LULC map (1) 2021 Maxar satellite image (2)
Cover: Alluvial island	SI 2	Presence of alluvial island Absence of alluvial island	5 1	
Food: Biomass of fish species	SI 3	Biomass > 80% 60% < Biomass ≤80% 40% < Biomass ≤60% 20% < Biomass ≤40% Biomass ≤ 20%	5 4 3 2 1	2015 Cheonggye Stream fish monitoring survey (3)
Food: Number of fish individual	SI 4	Individuals > 550 400 < Individuals ≤ 550 250 < Individuals ≤ 400 100 < Individuals ≤ 250 Individuals ≤ 100	5 4 3 2 1	
Threats: Artificial riverside	SI 5	None Only one riverside Both riversides	5 3 1	2019 LULC map 2021 Maxar satellite image

(1) Ministry of Environment 2019; (2) Esri, Inc; (3) National Institute of Fisheries Science 2015

data used to evaluate cover and threat were derived from subdivided land cover maps provided by the Ministry of environment 2019. Moreover, Maxar satellite images (Esri, Inc) were used as a reference to identify the land cover types, and a field survey through Cheonggye Stream was taken in July 2021 to confirm. Food was calculated on the basis of the 2015 Cheonggye Stream fish monitoring survey (National Institute of Fisheries Science, 2015). The SIs and HSI values were evaluated from 1 (unsuitable) to 5 (most suitable). The spatial boundaries of the study area are confined to the riparian ecosystems of the Cheonggye Stream, assuming that otters cannot pass through highly urbanized areas surrounding the Cheonggye Stream.

Two SIs represented the cover; the land cover types (SI 1) and the presence of the alluvial island (SI 2). *L. lutra* demand a large territory with diverse and undisturbed land cover, using tree holes, boulder gap, and reed beds for shelter and nurseries (Foster-Turlet *et al*., 1990). Alluvial island is selected as a key habitat because the presence of structure not only ensures the stream width but serves as a resting area where they dry their fur, and the island happens to be one of the places where the species are most commonly found (Kruuk, 2006). The relative score for each land cover type (SI 1) was set on the basis of the criteria used in the previous studies (Shim *et al*., 2020; Shin *et al*., 2020b). The land cover types ranged from 5 to 1. First, with the highest values for the inland wetland and inland water (5, most suitable), followed by the natural grassland (4, suitable), artificial grassland and natural bare land (3, moderate), artificial bare lands (2, marginal), and roads and urban districts (1, unsuitable). Since the alluvial island is not classified in the land cover map used, we manually digitized and classified it as a new category on the basis of Maxar satellite images and field survey. Thus, the value of SI 2 was based on the presence (5) or absence (1) of alluvial islands.

Cheonggye Stream fish monitoring survey data were used to calculate the biomass of fish species (SI 3) and the number of fish individuals (SI 4). The fish comprises 80% of *L. lutra* diet, and the population is strongly correlated with fish density in a stream (Kruuk *et al*., 1991). They are an opportunistic hunter preferring abundant, easy-to-catch, and bottom-feeding fish with adequate biomass (Carss *et al*., 1998). The survey data provided the number of species, the number of individuals, and species average size and weight at six monitoring sites throughout the stream (Figure 2). Additionally, the data from the monitoring sites were extrapolated downstream until the next monitoring site, as it shares a similar river structure and environmental characteristics.

For determining SI 3, the otters' preference for fish species was considered. Three fish species are prey items most commonly found in the spraints of Eurasian otters in Korea; these are (i) common carp (*Cyprinus carpio*), (ii) crucian carp (*Carassius auratus*), and (iii) pale chub (*Zacco platypus*) (Han, 2004; Choi and Yoon, 2012). Also, they are the species with the highest biomass in the

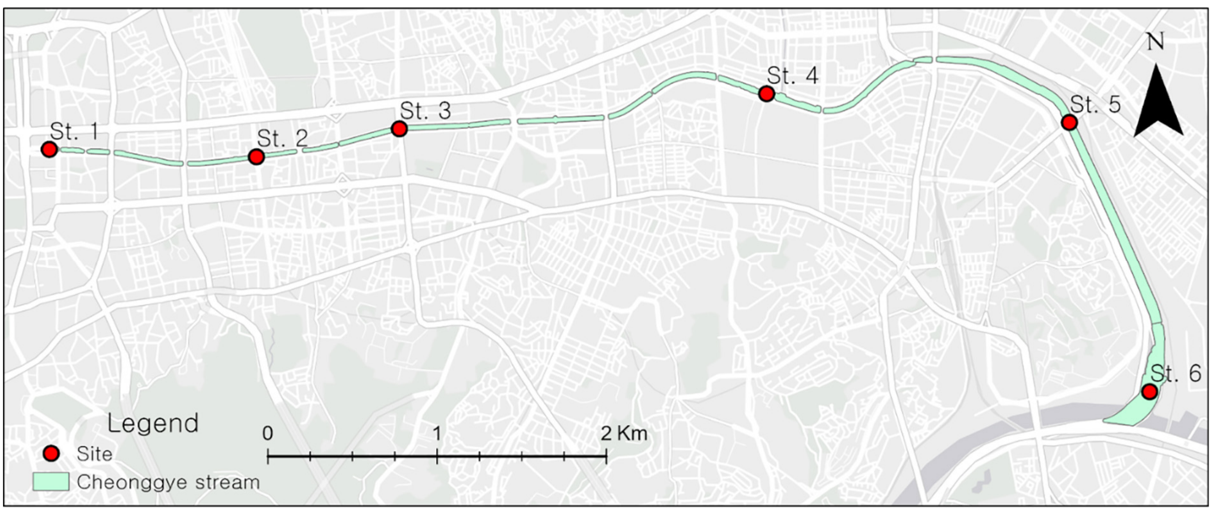

Figure 2. Cheonggye Stream with six survey sites from 2015 Cheonggye Stream fish monitoring survey.

Table 2. Number of fish species and an individual from 2015 Cheonggye Stream fish monitoring survey

Scientific name	Sites						Total	Individual ratio (%)	Biomass
	1	2	3	4	5	6			
Cyprinus carpio		3	8	2	4	2	19	0.71	40.35
Carassius auratus		2	16	16	49	12	95	3.53	22.63
Zacco platypus	373	324	162	393	203	76	1531	56.96	16.37
Other species	185	293	165	271	108	21	1043	38.8	20.65
N of individual	558	622	351	682	364	111	2688	100	100
N of species	12	14	14	13	14	7	24		

Cheonggye Stream. The species' biomass is scaled to 100 to the total biomass of all fish. Common carp, crucian carp, and pale chub had the highest biomass of 40.35, 22.63, and 16.37, respectively. Other 21 minor species were assigned equally, with the remaining 20.65 (0.98 each) (Table 2). The biomass of fish species found in each survey site was calculated to determine SI 3 from 5 to 1 (Table 1).

In previous studies, an otter is known to consume 12-15% of its body weight per day in conservative estimation (Wayre, 1979; Carss *et al*., 1998; Kruuk, 2006; Melissen, 2000). The average biomass of each fish individual was approximately 23.32 g regardless of fish species, and the average male *L. lutra* weighs 10 kg. Hence, 550 fish individuals is considered adequate to fulfill the food demand. The number of fish individuals (SI 4) based on the number of fish in the area was set (Table 1).

The threat was considered to be strongly affected by the presence of an artificial riverside because of human disturbance and its effect on predation (SI 5). *L. lutra* are vulnerable to anthropogenic threats as cover and food requirements are directly affected by canalization and concrete-built artificial structures (Han, 2004). Thus, all artificial riversides and any natural buffer zone were identified by analyzing land cover maps, satellite images, and field surveys. SI 5 was scored from 5 to 1: the area with no artificial riverside as 5, artificial riverside on one streamside as 3, and artificial riverside on both streamside as 1.

HSI formula

The HSI was calculated, and results were mapped on the basis of the five SIs created in this study (Formula 1). A geometric mean was applied to calculate each habitat SI (cover, food, and threat), considering that the habitat components were complementary to each other (Shim *et al*., 2020), and not to overestimate the habitat attribute because it tends to have a lower value than the arithmetic mean (Draugelis-Dale, 2007). The overall HSI was calculated using an arithmetic mean on the basis of each habitat SI.

$$HSI = \frac{\sqrt{SI1 \times SI2} + \sqrt{SI3 \times SI4} + SI5}{3} \quad (1)$$

RESULTS AND DISCUSSION

1. Results

Based on the environmental attributes of the cover, food, and threat, HSI values were calculated and expressed as a map (Figure 3). The cover value increased toward the downstream. The proportion of the stream that was classified as unsuitable based on the cover was 68.9%, whereas a moderate value was shown by the downstream and confluence areas (Table 3). Artificial bare land, extremely narrow stream width, and the lack of alluvial islands brought about the low cover value of the upstream. Food resource value was moderate to high over 84.3% of the stream due to abundant fish resources. Nevertheless, the upstream area close to CBD was shown to be unsuitable due to a low fish population and a lack of species with a high biomass, such as common carp and crucian carp. Threat value showed a similar pattern with cover; the value increases upstream to downstream.

Most of the stream had a moderate HSI value of 3: abundant food resources made up for the lack of cover

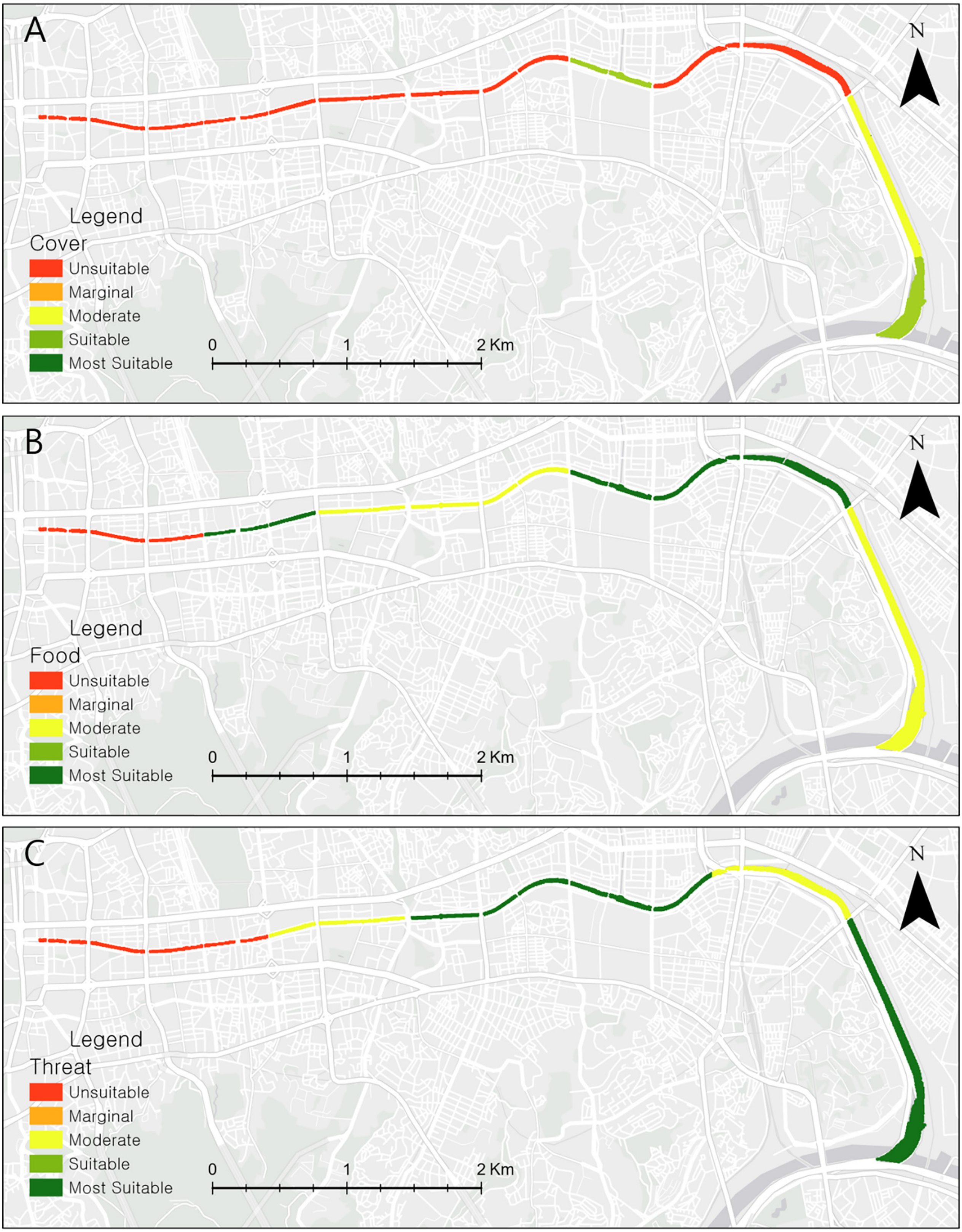

Figure 3. Map of Cover (A), Food (B), and Threats (C) habitat attribute.

Table 3. Length and percentage of HSI and suitability index value

Value	Cover		Food		Threat		HSI	
	Length (㎞)	%	Length	%	Length	%	Length	%
1 (Unsuitable)	5.84	68.9	1.33	15.7	1.82	21.5	1.33	15.7
2 (Marginal)	1.31	15.4					1.17	13.8
3 (Moderate)			3.22	38.0	2.21	26.1	4.65	54.8
4 (Suitable)	1.33	15.7					1.33	15.7
5 (Most suitable)			3.93	46.3	4.45	52.5		
Total	8.48	100	8.48	100	8.48	100	8.48	100

throughout the stream where artificial structures were prevalent (Figure 4). The highest HSI value of 4 was observed along 1.33 ㎞ of the stream. Higher HSI values were observed at the confluences with alluvial islands, where the Seongbuk Stream joins Cheonggye Stream, and Cheonggye Stream enters the Jungnang Stream. By contrast, the lower HSI values (1 and 2) were observed over 1.33 and 0.49 ㎞, respectively. Such low HSI values resulted from the high portion of paved streamside and relatively low food resources. It was found that no part of the stream had the highest possible HSI value of 5.

2. Discussion

Environmental attributes for otter habitat

Two areas with the highest HSI value were confluences where the Seongbuk stream joins Cheonggye stream and the Cheonggye stream joins Jungnang stream. Confluences generally have relatively wide space and stream width with alluvial islands. Stream width and water surface area are proportional to food resources and are commonly used to represent food habitat attributes (Shim *et al*., 2020). Two confluence areas were also selected as an ecological hotspots to conserve in the Cheonggye Stream restoration project (The Seoul Institute, 2014). A complex riverine structure attracts plants and animals and acts as a passageway to urban wildlife (Kim and Shin, 2014)

Throughout the Cheonggye Stream, food value reflects the abundant fish resources. Availability of food determines the population structure and distribution of any faunal species; as food shortage is one of the leading causes of Eurasian otter mortality, fish biomass is the most crucial factor determining its presence and territory size (Kruuk, 2006). Although Cheonggye Stream is 8.48 ㎞

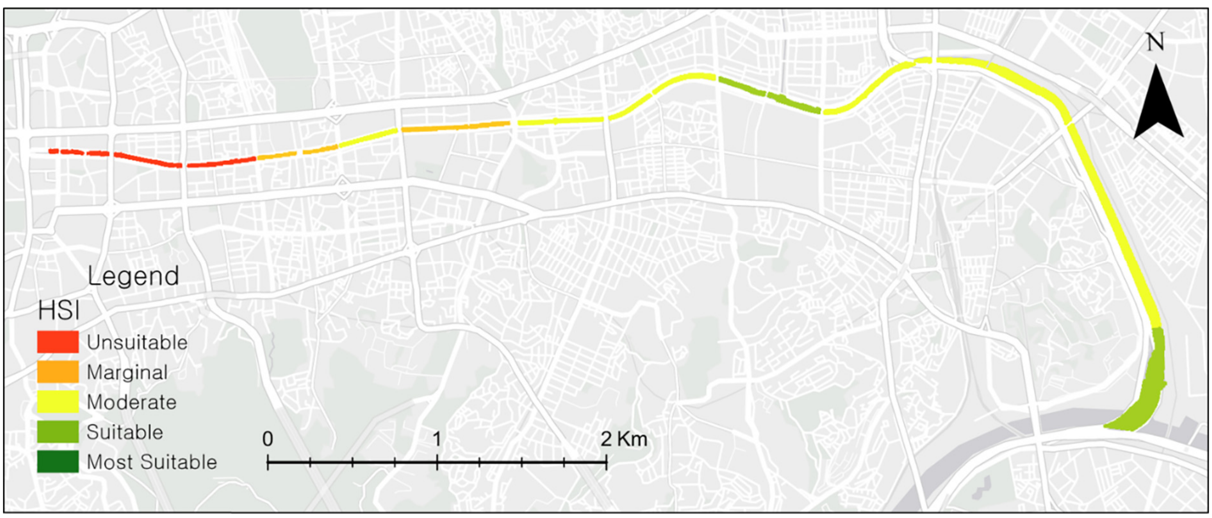

Figure 4. Map of Eurasian otter HSI.

long and barely fits the size of a single female *L. lutra* territory, they tend to share the territory when food resources are plentiful. *L. lutra* prefers shallow and narrow streams because the fish biomass per area is higher than in large water bodies, and less hunting effort is needed (Durbin, 1998; Ha *et al*., 2020). Small tributaries are important since female otters use them for breeding and nurturing sites to hide the cubs from aggressive males (Kruuk, 2006).

The presence of an artificial riverside (SI 5) was used to evaluate the threat. Citizens heavily use the trail, and anthropogenic activities affect wildlife behavior (Miller *et al*., 2001). Although artificial structures and trails are prevalent throughout the Cheonggye Stream, the areas with a threat value of 5 had a natural buffer zone between the stream and trail to reduce human disturbance (George and Crooks, 2006). Distance from the road is a common SI to evaluate the threat to Eurasian otter habitat (Shim *et al*., 2020; Shin *et al*., 2020b; Kim and Mo, 2021). Nevertheless, the conventional SI will not show the difference between the areas, which is not an ideal variable in the HSI, as urban streams are surrounded by roads (Brooks, 1997).

HSI and potential otter habitats

Presently, a single observation of *L. lutra* was made at Cheonggye Stream in 2021 at the confluence where it joins the Jungnang Stream. A single observation cannot determine whether the location is suitable for habitats or not. Brooks(1997) highlighted the importance of validating and verifying HSI with independent population data. Also, if the data are unavailable, it is vital to inform potential users of the model's stage of model development. Our model passed the calibration stage successfully, showing the region of interest with adjusted SIs to the urban stream environment (Van Horne and Weins, 1991). Nevertheless, it was not validated and verified because of a lack of field survey data considering the highly urbanized areas' newly and scarcely found *L. lutra*. The resulting value of the model will only show relative habitat suitability between the cells without randomly analyzed population data (Merow *et al*., 2013). Although such models still can be valuable to provide insights for management to facilitate the establishment of a returning species.

Previously, studies on the HSI of musteline species highlighted the importance of food resources, and model prediction often focused on whether the food habitat attributes were successfully mapped or not (Loukmas and Halbrook, 2001). Thus, we assume the essential factor that strengthens our results is the detailed fish survey data. In decision making for the sustainable management of wildlife and their habitats, especially when they are in their early stage of reintroduction or comeback, this simple assessment used in our study can be valuable (Brooks, 1997). Moreover, the model is mainly composed of data easily accessible, and the method is readily applicable to other urban streams, which can suggest how urban stream development alters the habitat quality of the otter or locate the areas with a high possibility of future habitat.

Optimal efforts for a sustainable coexistence

Despite the weakness of urban streams as *L. lutra* habitats, the species populations are rebounding in urban areas worldwide (White *et al*., 2013). For example, smooth-coated otters (*Lutrogale perspicillata*) are found in Singapore's highly urbanized city center, suggesting that otters adapt to urban environments with flexible behavior and increase human tolerance (Khoo and Lee, 2020). While many studies show a negative correlation between artificial structure and signs of otter presence (Jo *et al*., 2006), it is also known that otters are experienced in using artificial structures, concrete gaps, stairs, and bridges as passage (Kruuk *et al*., 1998). Moreover, it is possible that recreational activities by humans do not affect the populations of Eurasian otters, primarily because of their nocturnal behavior (Jo *et al*., 2017).

Nonetheless, it is pertinent to enforce conservation strategies to keep a proper distance from pedestrians (Dettori *et al*., 2021). Recently, the trap camera footage in the Han River showed Eurasian otters with scars, and spraints were mixed with plastic and styrofoam (Social Cooperative Hangang, 2021). Although the potential threat to otters is yet unknown, ingestion of plastics is most likely via fish prey (Smiroldo *et al*., 2019). Furthermore, the accumulation of plastic is expected to worsen since *L. lutra* are climax predators of the freshwater environment (Mahon *et al*., 2017).

In urban areas, natural habitat conditions that reflect the ecological characteristics of *L. lutra* should be maintained and enhanced in urban streams. For example, rehabilitation of reedbeds is important since they create abundant food resources and refuges from human and domestic animal disturbances (Liles, 2003). Hence, urban riverside management in Seoul should refrain from clearing all vegetation but rather conserve permanent patches of riparian and wetland vegetation (River Culture Research Society, 2020). We hope our approach will help conserve otters in highly urbanized areas and plan future monitoring strategies.

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