



Developing habitat suitability index for habitat evaluation of *Nannophya koreana* Bae (Odonata: Libellulidae)

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Background: The Korean scarlet dwarf, *Nannophya koreana* Bae (Odonata: Libellulidae), is an endangered dragonfly with an increasing risk of extinction owing to rapid climate changes and human activities. To prevent extinction, the *N. koreana* population and their habitat should be protected. Therefore, suitable habitat evaluation is important to build the *N. koreana* restoration project. The habitat suitability index model (HSI) has been widely used for habitat evaluation in diverse organisms.

Results: To build a suitable HSI model for *N. koreana*, 16 factors were examined by seven experienced researchers. A field survey for *N. koreana* observed sites and spatial analysis were conducted to improve the model. Five factors were finally selected by this procedure (crown density, open water surface, water depth, pioneer plant cover, and type of water source). Finally, the *N. koreana* HSI model was generated with the five adjusted factors based on interview, field survey, and spatial analysis. This model was validated by a current *N. koreana* habitat in 2021. With this model, 46 sites in Uljin-gun, Korea, were surveyed for *N. koreana* habitats; five sites were identified as core habitats and seven as potential core habitats.

Conclusions: This model will serve as a strong foundation for the *N. koreana* restoration project and as a reference for future studies on *N. koreana* and other endangered insect populations. Further analysis and long-term data will improve the efficacy of this model and restore endangered wildlife.

Keywords: endangered species, habitat suitability index, endemic species, *Nannophya koreana*, Libellulidae

Introduction

Nannophya koreana Bae is a small dragonfly recently described based on morphology and mitochondrial cytochrome oxidase C subunit I (COI) gene sequences (Bae et al. 2020). A total of seven dragonflies in the Genus *Nannophya* (Pygmyflies), including *N. koreana*, are reported worldwide. Of these, four species in Australia, one in the Himalayas, and *N. pygmaea* have been reported worldwide (Steinmann 1997; Theischinger and Fleck 2003). *N. pygmaea* is distributed in Australia, tropical and subtropical areas of Southeast Asia, China, Japan, and India (Bae et al. 2020; Kim et al. 2010; Kim 2020; Steinmann 1997; Theischinger and Fleck 2003). Based on morphological and molecular studies, the Korean population of *N. pygmaea* was recently described as *N. koreana* in 2020 because it was distinguished from other populations of *N. pygmaea*

originally described in Indonesia and China (Bae et al. 2020; Kirby 1889). *N. koreana* is distributed throughout South Korea except Jeju Island. However, its habitat is very limited as it prefers small wetlands located in flat areas on the mountains or hills. They often fly near water surfaces with their small body sizes, increasing the risk of local extinction caused by predators and human activities including changes of fallow paddies (Bae et al. 1999). Therefore, *N. koreana* has been categorized by the Ministry of Environment of South Korea since 1998 as one of the 26 endangered insect species to protect its population and habitat. Because *N. koreana* is enlisted as an endangered species, suitable habitat is critical for its survival at the risk of climate change and to restore its population size.

N. koreana is known as the smallest dragonfly. The nymph of *N. koreana* is approximately 7.3 mm long, and the adult body length is ca. 11 mm; thus, it is known as the



smallest dragonfly (Bae et al. 1999). After emerging as adults, the male keeps its territory and copulates with the females that enter the territory. After copulation, the female oviposits on the surface of open water (Yabu and Nakashima 1997). After most of the *N. koreana* eggs have hatched during late spring and early summer, the nymphs stay underwater until they emerge as adults in late spring (Kim et al. 2010).

The habitat suitability index (HSI) was developed to evaluate the habitat environment for designated organisms in the 1980s; this index could be used to develop expectation models for organisms (U.S. Fish and Wildlife Service 1980). HSI can evaluate and predict the environmental factors that affect habitat status with quantified values to exclude any possible bias from different researchers or invalid assumptions (Gibson 2004). HSI has been applied to evaluate wildlife habitats and prevent wildfire (Brach and Kaczmarowski 2014) and landslides (Moayedi et al. 2019).

A total of 11 previous publications on the *Nannophya koreana* population in South Korea were retrieved by online bibliographic databases such as Google Scholar (Google) and Research Information Sharing Service with the keywords '*Nannophya pygmaea*' and '*Nannophya koreana*'. From the previous studies, the distribution of *N. koreana* was reported throughout most of South Korea. *N. koreana* populations were observed from small mountainous wetlands and fallow paddies; their territory was comparably small (approximately 500 m²), and the home range was also small. Previous *N. koreana* habitats in Munkyeong and Buyeo have been reported as destroyed as well as *N. koreana* was observed at only five habitats in 2021 among 23 confirmed *N. koreana* habitats in 2017 (Oh et al. 2017). Moreover, previous *N. koreana* studies were limited to genetics (Bae et al. 2020), egg hatching temperature (Kim et al. 2006; Moayedi 2019), and habitat characteristics description (Cho et al. 2012; Kim et al. 2009a, 2009b; Lee et al. 2008; Kim et al. 2010; Kim et al. 2011; Kim et al. 2016; Ministry of Environment [MOE] 2009; Oh et al. 2017), because it resides and oviposits on few limited wetlands and it has been protected by government with small population size. Therefore, there is limited information available to build a model for habitat or species restoration projects.

This study developed an HSI model based on the current status of the *N. koreana* habitat, literature review, and interview with experienced *N. koreana* researchers. The developed HSI model was validated with known *N. koreana* habitats. In addition, 46 potential *N. koreana* habitats in Uljin-gun, Korea, were evaluated based on the developed HSI model. This *N. koreana* HSI model will serve as a primary foundation for habitat evaluation and restoration projects for endangered *N. koreana* in South Korea.

Materials and Methods

Research sites

Five research sites were selected to analyze habitat characteristics. *Nannophya koreana* was observed at these sites, and the distance between each site was at least ca. 20 km. The five research sites were located in Incheon-si (Site 1), Jincheon-gun (Site 2), Chungju-si (Site 3), Daejeon-si (Site 4), and Gokseong-gun (Site 5) (Fig. 1). *N. koreana* population was confirmed at all the research sites in 2021. In addition, 46 sites (30 mountainous wetlands, 5 previously observed *N. koreana* sites, and 11 recently fallow paddies) without current *N. koreana* population in Uljin-gun, Korea, were evaluated by the HSI model as potential *N. koreana* habitats for restoration projects. However, detailed information on the study sites is not disclosed to protect the endangered insect population.

Selection of environmental variables

The *N. koreana* habitat characteristics were selected based on previous studies provided in Table 1. A total of 11 factors were identified by experienced researchers (Table 1). The experienced researchers were selected based on three criteria: individuals with a Ph.D. in insect science or related areas and at least five years of research experience in insect biology. Based on these criteria, seven experienced researchers were selected. The first round of interview was focused on the overall adequacy and importance of the selected variables as well as checking for missed variables. The second round of interview was conducted for checking the adequacy for selected habitat variable from field survey and the first round of interview. In both interviews, the priority of each variable was checked by each interviewee.

The 11 factors were categorized into two groups; one for field survey data and the other to retrieved from spatial information. The detailed datasets for the spatial information were retrieved from the following institutes: weather information (Korea Meteorological Administration and WorldClim), soil information (Korea Soil Information system), continuous digital topographic map (National Geographic Information Institute), forest type map (Forest Geographic Information System), and vegetation index (Environment Bigdata Platform). The Aeronautical Reconnaissance Coverage Geographic Information System was used to analyze spatial information.

Field survey

The habitat characteristics were investigated from the current *N. koreana* observed sites to develop the HSI model. The field survey was conducted seven times from May to August 2021. Diverse factors (open water surface, crown density, water depth, pioneer crown density, floating-leaved plant cover, water source type, and others) that can affect the *N. koreana* habitat were examined. Water depth was

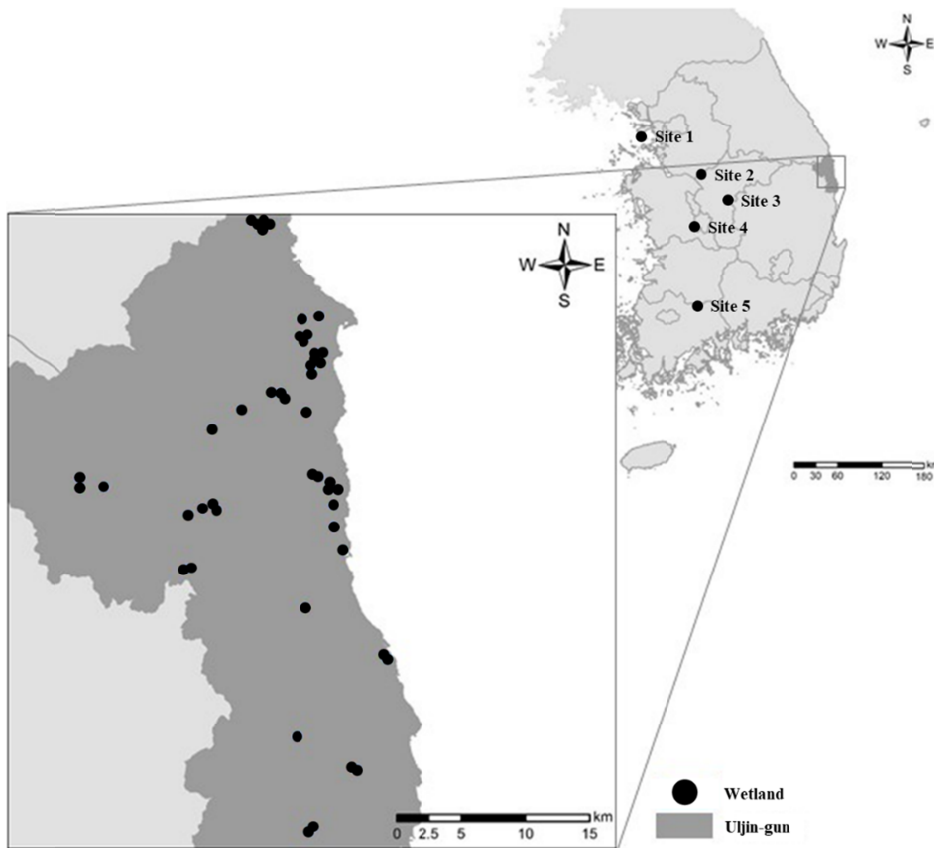


Fig. 1 Study sites of *N. koreana* Bae.

Table 1 Environmental variables for *N. koreana* habitat characteristics analysis

Factor	Contents	Acquisition
Distribution	More than 23 habitats have been reported, but only five sites were recently confirmed.	Retrieved
Habitat type	Mountainous wetlands and fallow paddies.	Retrieved
Habitat area	113.4–1,153.1 m ² . The average area was 500 m ² , which is relatively small.	Retrieved
Home range	Recently emerged adults stay at the emerging site. Adults have a relatively small area of activity; thus, the density of adults is high in a small area.	Retrieved
Air temperature	Relatively wide range between 16–27°C	Retrieved
Vegetation	Open area without shade and tall trees. Early transitional vegetation structures include <i>Juncus decipiens</i> , <i>Murdannia keisak</i> , <i>Pericaria thunbergii</i> , <i>Typha laxmannii</i> , and <i>Cyperaceae</i> . Vegetation types for the oligotrophic state, which is the early stage of eutrophication.	Measured
Water temperature	Above 14.3°C during the hatching period. Optimal growth temperature is 30–35°C, which is higher than that for other dragonflies.	Measured
Open water surface	Open wetland with direct sunlight for water touching ovipositing.	Measured
Water depth	General water depth is 0–10 cm, and ca. 20 cm is also possible. The water depth has limited fluctuation throughout the year.	Measured
Water quality	The water quality might not affect the survival of <i>N. koreana</i> .	Measured
Risk factors	Wetland reduction because of drought. Predation by natural enemies during nymphal stages with deep water depth. Reduction of open water surface because of high crown density or tall vegetation. Conversion of wetland to dry land caused by ecological succession. Developing pressure because of private land.	Measured

measured by ruler at three different points. Open water surface was estimated with a tape measure by two different researchers. The height of plant was measured by a tape measure by two researchers at the three points on the each study site. Other factors were retrieved from spatial information.

Developing habitat suitability index model

The major habitat factors were selected based on interview with seven experienced researchers who were provided with basic environmental information from the current *N. koreana* habitat. In the second round of interview, each major habitat factor was weighted to develop a suitable in-

dex and prioritized to calculate the HSI (Table S1). The weighted value for each variable was divided by the summation of the all the weighted values for all the variables. The calculated suitability index (SI) was used for building HSI for *N. koreana*.

Results

Habitat analysis

Literature review

N. koreana preferred open spaces without tall trees at the beginning of the ecological succession. Therefore, various grasses, including *Juncus decipiens* (Buchenau) Nakai, *Murdannia keisak* (Hassk.) Hand.-Mazz., and *Persicaria thunbergii* (Siebold & Zucc.) H. Gross were identified as the dominant plant species in these habitats.

The air temperature was in the range of 16–27°C during egg hatching period. The egg hatching threshold temperature of *N. koreana* was 14.3°C, which is relatively warmer than that of other dragonflies. The water level for the *N. koreana* habitat was 0–20 cm, with minimal fluctuation. Moreover, minimal water level fluctuation is required for *N. koreana* survival because ovipositing occurs on water surfaces. However, the water quality was not the major factor in the *N. koreana* habitat. The risk factors for *N. koreana* habitat includes wetland reduction caused by drought and deep-water level, as well as open water reduction caused by tall plants, wetland reduction, and anthropogenic activities.

Field survey

The *N. koreana* habitats were measured as water depth

(12.20 ± 8.04 cm [mean ± standard deviation {S.D.}], open water ratio (60.00 ± 14.14% [mean ± S.D.]), average plant height (16.00 ± 8.22 cm [mean ± S.D.]), and percentage of pioneer crown density (2.00 ± 2.74% [mean ± S.D.]). For spatial analysis, the *N. koreana* habitats were summarized as altitude (163.00 ± 108.57 m [mean ± S.D.]), annual average temperature (11.40 ± 1.07°C [mean ± S.D.]), the average temperature in June (21.81 ± 0.60°C [mean ± S.D.]), the average temperature in July (21.85 ± 0.90°C [mean ± S.D.]), annual precipitation (1,662.40 ± 249.83 mm [mean ± S.D.]), precipitation in the driest month (26.80 ± 3.19 mm [mean ± S.D.]), heat index (92.27 ± 9.05 [mean ± S.D.]), and vegetation index (0.76 ± 0.03 [mean ± S.D.]) (Table 2). Based on these analyses, the *N. koreana* habitat was confirmed as a shallow wetland with a wide-open water surface originating from surface runoff and precipitation where Poaceae and Cyperaceae were the dominant vegetation.

Developing *N. koreana* HSI

Generating major factors for HSI

Based on the literature review and field survey, 16 habitat factors for *N. koreana* were presented to seven researchers. After the second round of in-depth interview, five factors: forest density, open water surface, water depth, percentage of pioneer crown density, and water source type were selected as major habitat factors (Table 3). Although fallow paddy was an important *N. koreana* habitat, it is a subtype of mountainous wetlands and is not an official term in the wetland classification system (Kim et al. 2013); therefore, wetland types were excluded from the major habitat factors. The vegetation height was excluded because it was highly related to the open water surface determined by crown density rate. The annual average temperature was

Table 2 Analysis for *N. koreana* habitat characteristics

Habitat variables	Site 1	Site 2	Site 3	Site 4	Site 5	Data source
Wetland type	MW	FP	FP	FP	FP	FS
Water depth (cm)	3	10	10	13	25	FS
Open water surface (%)	50	50	70	50	80	FS
Vegetation height (cm)	15	10	10	15	30	FS
Forest type	UFL	UFL	UFL	UFL	UFL	FS
Dominant vegetation	FD	PT	PT	EU	PJ	FS
Pioneer crown density (%)	0	5	0	5	0	FS
Water source	SR, P	SR, P	SR, P	SR, P	SR, P	FS
Altitude (m)	28	234	306	136	111	FS
Annual average temperature (°C)	12.54	10.12	10.41	12.11	11.84	KMA
June average temperature (°C)	21.88	21.21	21.34	22.72	21.92	KMA
July average temperature (°C)	23.09	20.76	21.3	22.32	21.8	KMA
Annual precipitation (mm)	1,405.07	1,698.75	1,505.96	1,643.23	2,058.98	KMA
Warmth index	102.28	81.39	84.38	98.68	94.62	KMA
The driest month's precipitation (mm)	23	26	25	29	31	WC
Normalized difference vegetation index	-	0.80	0.76	0.73	0.73	KIGAM

MW: mountainous wetland; FP: fallow paddy; FS: field survey; UFL: unstocked forest land; FD: *Fimbristylis dichotoma*; PT: *Persicaria thunbergii*; EU: *Eleocharis ussuriensis*; PJ: *Phragmites japonica*; SR: surface runoff; P: precipitation; KMA: Korea Meteorological Administration; WC: WorldClim; KIGAM: Korea Institute of Geoscience and Mineral Resources.

Table 3 Selecting major variables for *N. koreana* habitat analysis

Variables	Result of in-depth interview with experienced researchers	
	Contents	Results
Crown density	Major factor for light reflection	Appropriate
Open water surface	Major factor for water touching oviposition	Appropriate
Water depth	Major factor for natural enemy	Appropriate
Pioneer crown density	Major factor for ecological succession and wetland conversion	Appropriate
Water source	Major factor for temperature	Appropriate
Wetland type	Not suitable for wetland classification system	Inappropriate
Vegetation height	Open water surface is more important vegetation height	Inappropriate
Annual average temperature	Not important because of nationwide distribution	Inappropriate
Monthly average temperature in June or July	Too big annual fluctuation and lack of studies	Lack of research
Annual precipitation	Too big annual fluctuation and lack of studies	Lack of research
Precipitation in the driest month (mm)	Draught might be important but need more studies	Lack of research

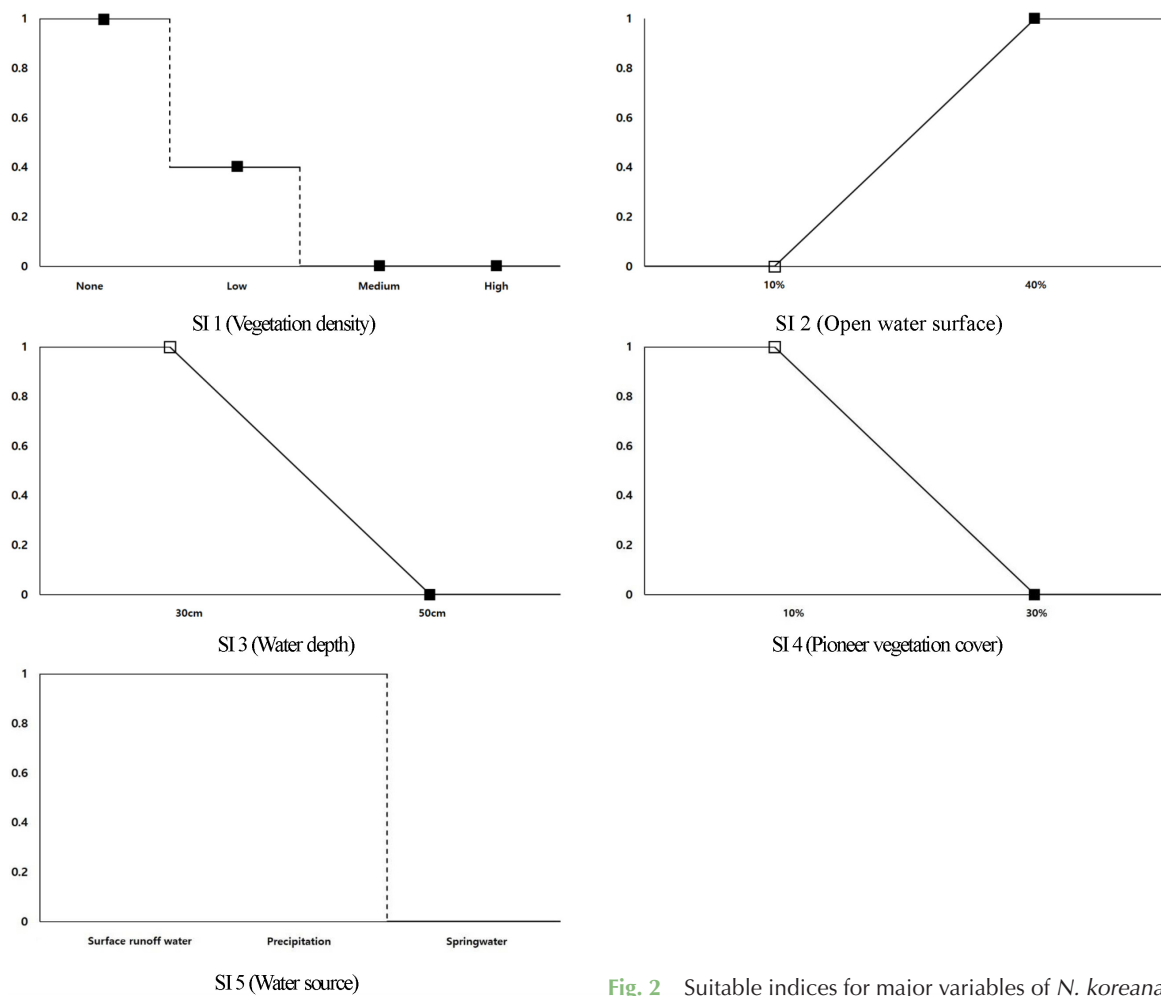


Fig. 2 Suitable indices for major variables of *N. koreana* habitat.

also excluded based on comments made by the experienced researchers. In addition, the monthly average temperature for June and July (*N. koreana* egg hatching period), annual precipitation, and precipitation in the driest month were not selected as major habitat factors because of large annual fluctuation and insufficient research to support these factors.

Developing suitable indices for major habitat factors

The suitable indices for major habitat factors were generated by in-depth interview based on the literature review and field survey (Fig. 2).

(1) Crown density (SI 1)

Based on literature review and expert interview, *N. koreana* habitat was concluded to be found in wetlands without shade from trees. Moreover, the habitat was open to sun-

light without vegetation from the past to the present. Therefore, the suitable *N. koreana* habitat was selected as a wetland open to sunlight (Table 4). The index was determined considering mountainous wetlands with low crown density where sunlight could reach the water surface.

(2) Open water surface (SI 2)

During the *N. koreana* emerging period, the temperature was relatively high, and the adults oviposited while touching the water surface. Therefore, the exposure to open water surface was selected as the major habitat factor rather than crown density because adults also oviposited among the Poaceae and Cyperaceae stem, which did not completely cover the water surface. Based on the field survey on the five *N. koreana* observed sites, the exposure to open water surface was more than 50% for *N. koreana* habitat. Therefore, it seems that the suitable habitat should have exposure to open water surface of at least 40% during the dry season conditions.

(3) Water depth (SI 3)

Based on the literature review, the water depth of the *N. koreana* habitat was confirmed as less than 20 cm. The water depth is an important factor because the water temperature is closely related to the water depth during oviposition period and the possibility of fish appearance (one of the major threats to *N. koreana* survival). Based on field survey, the deepest water depth was confirmed as 25 cm at the Wolbongjae in Gokseong-gun, Korea. Water depth could be changed due to diverse factors, including drought, heavy rainfall, and seasonal fluctuation; therefore, the suitable water depth was presented as 30 cm and confirmed by experienced researchers.

(4) Pioneer crown density (SI 4)

Based on literature review, most of the *N. koreana* habitats were found in fallow rice paddies, and *N. koreana* preferred the early stage of the vegetation succession. Annual grasses are first introduced and followed by perennial grasses such as Juncaceae and Typhaceae at the early stage of vegetation succession in fallow rice paddies. From the field survey, perennial grasses, including Lamp rush (*Juncus decipiens* [Buchenau] Nakai) and Japanese moor grass (*Molinia japonica* Hack.), were dominant species near the flooded area, whereas short plants, including Korean persicary (*Persicaria thunbergii* [Siebold & Zucc.] H. Gross) and *Ussuri spikerush* (*Eleocharis ussuriensis* G. Zinserl), were located near the *N. koreana* habitats. The transition of fallow rice paddies to land was considered one of the major threats to *N. koreana* protection in previous studies; therefore, pioneer vegetation (willows and alders) cover serving as an indirect indicator for the transition of fallow rice paddy was selected as a major factor and it was examined for suitability by experienced researchers.

(5) Water source (SI 5)

Among diverse water sources, surface runoff, including runoff from spring water, was selected as a suitable water source for the *N. koreana* habitat, and it was examined by experienced researchers. From the literature review, *N. koreana* could be a tropical dragonfly, so the optimum growth temperature and low and high-temperature threshold for *N. koreana* were higher than that for other dragonflies. Moreover, *N. koreana* showed high density in a limited area with slow movement and small activity. In addition, the newly emerged adults often stay where they emerged. Therefore, the water temperature is one of the major factors for the *N. koreana* habitat. However, wetlands with spring water are generally low in temperature, so they are unsuitable for *N. koreana*. Therefore, surface runoff was suggested as a suitable water source for the *N. koreana* habitat.

Developing HSI model

The importance of each factor for the selected SI model was examined by experienced researchers (Table 5), and their relationship with the HSI model was established by weighting them (Equation 1).

Table 4 Categories for crown densities

Class	Crown density
Low	Stands where trees occupy less than 50% of the canopy area
Medium	Stands where trees occupy 51%–71% of the canopy area
High	Stands where trees occupy more than 71% of the canopy area
None	Non forest

Data from Forest Geospatial Information System of Korea Forest Service.

Table 5 Weighting on the major habitat variables based on the interview with experienced researchers

No.	Habitat variables	Expert assessment score							Weight factor
		1	2	3	4	5	6	7	
1	SI 1 (Crown density)	1	1	3	4	5	3	3	2.85
2	SI 2 (Open water surface)	4	3	5	3	4	3	2	3.42
3	SI 3 (Water depth)	5	5	4	3	4	5	4	4.28
4	SI 4 (Pioneer crown density)	3	1	2	2	5	4	3	2.85
5	SI 5 (Water source)	5	5	4	4	2	2	4	3.71

HSI = 0.17 (SI 1) + 0.2 (SI 2) + 0.25 (SI 3) + 0.17 (SI 4) + 0.21 (SI 5) [Equation 1]
 HSI: habitat suitability index; SI 1: crown density; SI 2: open water surface; SI 3: water depth; SI 4: pioneer crown density; SI 5: type of water source.

Habitat suitability assessment and key habitat selection

The potential 46 habitats in Uljin-gun, Korea, were evaluated based on the developed HSI. Only one potential hab-

itat (Bongpyeong-ri (3) wetland) was evaluated as HSI point 1. Two potential habitats (Mt. Chunjuk (3) and Hwaseong-ri (2) wetlands) were confirmed as HSI point 0.9. Seven potential habitats, including Sillim-ri and Ssangjeon-ri wetlands, had the lowest HSI point of 0.38, except for nine habitats where the wetland was disturbed by human activities (Table 6).

Table 6 HSI analysis for potential sites of *N. koreana* habitat in Uljin-gun

	Location	SI 1	SI 2	SI 3	SI 4	SI 5	HSI
1	Eumnam-ri wetland	0	0	0.25	0.17	0.21	0.63
2	Mt. Cheonchuk (1) wetland	0	0.1	0.25	0.17	0.21	0.73
3	Mt. Cheonchuk (2) wetland	0.17	0	0.25	0.17	0.21	0.8
4	Mt. Cheonchuk (3) wetland	0.17	0.1	0.25	0.17	0.21	0.9
5	Mt. Cheonchuk (4) wetland	0.17	0	0.25	0.17	0.21	0.8
6	Osan-ri (1) wetland	0.17	0	0	0.17	0.21	0.55
7	Osan-ri (2) wetland	0.068	0	0.25	0.17	0.21	0.698
8	Osan wetland (Uljin)	0	0	0	0.17	0.21	0.38
9	Jinbok-ri (2) wetland	0	0	0	0.17	0.21	0.38
10	Goseong-ri (2) wetland	0.17	0	0.25	0.17	0.21	0.8
11	Daeheung-ri wetland	0.17	0	0.25	0.17	0.21	0.8
12	Sillim-ri (1) wetland	0	0	0	0	0	-
13	Ssangjeon-ri (1) wetland	0	0	0.25	0.17	0.21	0.63
14	Ssangjeon-ri (2) wetland	0	0.2	0	0.17	0.21	0.58
15	Ssangjeon-ri (3) wetland	0	0	0	0	0	-
16	Wangpi-ri (1) wetland	0	0.2	0.25	0	0.21	0.66
17	Wangpi-ri (2) wetland	0	0	0	0.17	0.21	0.38
18	Sanpo-ri (2) wetland-1	0	0.1	0.25	0.17	0.21	0.73
19	Sanpo-ri (2) wetland-2	0.068	0.1	0.25	0.17	0.21	0.798
20	Jinbok-ri (1) wetland	0.068	0.2	0	0.17	0.21	0.648
21	Sanpo-ri (1) wetland	0	0	0.25	0	0.21	0.46
22	Nagok-ri (1) wetland	0	0	0	0	0	-
23	Nagok-ri (2) wetland	0	0	0.25	0	0.21	0.46
24	Hujeong-ri wetland	0	0	0.25	0.17	0.21	0.63
25	Yongjang wetland (Uljin)	0.17	0	0.25	0.17	0.21	0.8
26	Hwaseong-ri (2) wetland	0.17	0.1	0.25	0.17	0.21	0.9
27	Bongpyeong-ri (1) wetland	0	0	0	0.17	0.21	0.38
28	Bongpyeong-ri (2) wetland	0.17	0	0.25	0.17	0.21	0.8
29	Bongpyeong-ri (3) wetland	0.17	0.2	0.25	0.17	0.21	1
30	Samsan-ri wetland	0	0	0	0.17	0.21	0.38
31	Sadong-ri wetland	0	0	0	0	0	-
32	Ogok-ri (2) wetland	0.17	0	0.25	0.17	0.21	0.8
33	Deogin-ri (2) wetland-1	0.068	0.2	0.25	0.17	0.21	0.898
34	Deogin-ri (2) wetland-2	0	0.1	0.25	0.17	0.21	0.73
35	Seongu-ri wetland	0	0	0	0	0	-
36	Seongu-ri (1) wetland	0	0	0	0.17	0.21	0.38
37	Myeongdo-ri (1) wetland-1	0	0	0	0	0	-
38	Myeongdo-ri (1) wetland-2	0	0	0.25	0.17	0.21	0.63
39	Myeongdo-ri (1) wetland-3	0.068	0.1	0.25	0.17	0.21	0.798
40	Myeongdo-ri (2) wetland	0	0.2	0.25	0.17	0.21	0.83
41	Goseong-ri (1) wetland	0	0	0	0	0	-
42	Sillim-ri (2) wetland-1	0	0	0	0	0	-
43	Sillim-ri (2) wetland-2	0	0.1	0.25	0.17	0.21	0.73
44	Myeongdo-ri (3)	0	0	0	0	0	-
45	Hwaseong-ri (1) wetland	0	0	0.25	0	0.21	0.46
46	Ogok-ri (1) wetland	0	0	0	0.17	0.21	0.38

HSI: habitat suitability index; SI 1: crown density; SI 2: open water surface; SI 3: water depth; SI 4: pioneer crown density; SI 5: type of water source.

Table 7 HSI analysis for the six recent *N. koreana* observed sites

No.	Location	SI 1	SI 2	SI 3	SI 4	SI 5	HSI
1	Uljin, Myeongdo-ri (2) wetland	0	0.2	0.25	0.17	0.21	0.83
2	Daejeon	0.17	0.2	0.25	0.17	0.21	1
3	Cheongju	0.17	0.2	0.25	0.17	0.21	1
4	Jincheon	0.17	0.2	0.25	0.17	0.21	1
5	Incheon	0	0.2	0.25	0.17	0.21	0.83
6	Gokseong	0.17	0.2	0.25	0.17	0.21	1

HSI: habitat suitability index; SI 1: crown density; SI 2: open water surface; SI 3: water depth; SI 4: pioneer crown density; SI 5: type of water source.

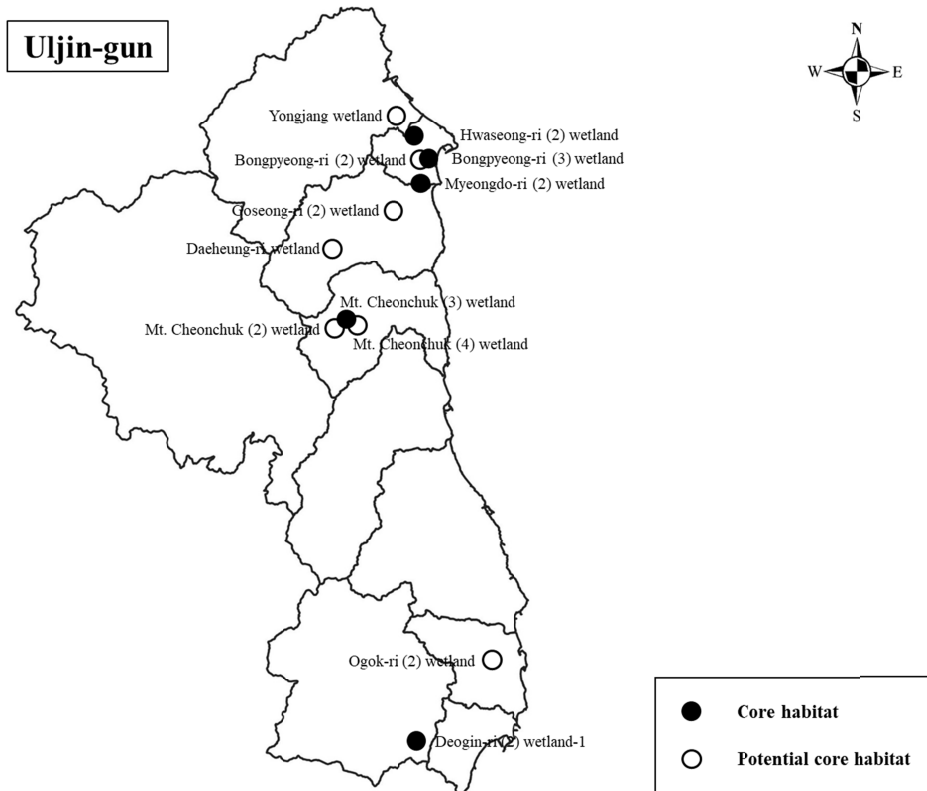


Fig. 3 Five core habitats and seven potential core habitats of *N. koreana* in Uljin-gun.

Discussion

With rigorous habitat analysis, four habitats among the five *N. koreana* habitats observed in 2021 were evaluated as HSI point 1 (Table 7). The HSI for potential habitat in Incheon-si was evaluated as 0.83 because of the wrong scale of crown density data. Based on the field survey, the crown density was zero; thus, the HSI should be corrected.

In Uljin-gun, four *N. koreana* potential habitats among the five observed *N. koreana* habitats were disturbed by human activities, including construction and cultivation. However, the HSI point for Myeongdo-ri 2 wetland (a previously confirmed habitat) where *N. koreana* was not observed in 2021 was 0.83. Therefore, potential habitats with an HSI point of more than 0.83 was categorized as core habitats for *N. koreana*. In addition, potential habitats in Uljin-gun with an HSI point of more than 0.8 were selected as potential core habitats for *N. koreana* (Fig. 3).

Conclusions

This study developed an HSI model for endangered insects through literature review, field survey, and interview with experienced researchers to evaluate the core habitats of *Nannophya koreana*. Based on previous studies, the primary habitat factors were selected. Among the selected primary factors, crown density, open water surface exposure, water depth, pioneer crown density, and water source type were selected as habitat factors by experienced researchers and GIS data generation. The SI model was developed with these five habitat factors. Based on the SI model, the HSI model for *N. koreana* was developed. The developed HSI model for *N. koreana* was applied to the 46 potential *N. koreana* habitats in Uljin-gun. Five core habitats and seven potential core habitats were established based on the HSI model for *N. koreana*. Most of these selected sites were located in the middle and northern part of Uljin-gun, Korea, where the altitude is generally high, and new fallow pad-

dies are increased because of the reduction of the human population.

Among 46 potential habitats for *N. koreana* in Uljin-gun, the HSI value was 1 for Bongpyeong-ri (3) wetland and the value was 0.9 for Mt. Cheonchuk (3) wetland and Hwaseong-ri (2) wetland. In addition, as the HSI value was 0.83 for Myeongdo-ri (2) wetland in Uljin-gun, where *N. koreana* was observed in the past, five potential habitats (Bongpyeong-ri (3) wetland, Mt. Cheonchuk (3) wetland, Hwaseong-ri (2) wetland, Deogin-ri (2) wetland-1, and Myeongdo-ri (2) wetland) with HSI value of 0.83 or higher were selected as the core habitat for *N. koreana* in Uljin-gun.

However, we determined seven potential habitats (Yongjang wetland, Bongpyeong-ri (2) wetland, Goseong-ri (2) wetland, Daeheung-ri wetland, Mt. Cheonchuk (4) wetland, and Ogok-ri (2) wetland) for *N. koreana* with the HSI value more than 0.8 because of the error range from the field survey as well as spatial data scale.

Based on this study, the potential and surrogate habitats for *N. koreana* could be more effectively evaluated with scientific evidence to protect this endangered insect population. However, the available habitat information on *N. koreana* habitats was insufficient to improve the quality of the HSI model because of the limited previous studies and possible study sites. Therefore, a long-term study on the current habitat and scouting for unknown populations will improve the efficacy of the current model. In addition, a verification study on the current model and development of restoration strategies for *N. koreana* should be followed to preserve vulnerable dragonflies in the ecosystem.

Supplementary Information

Supplementary Information accompanies this paper at <https://doi.org/10.5141/jee.22.068>.

Table S1. Example of the second round of interview with experienced researchers.

Abbreviations

Not applicable.

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Not applicable.

Authors' contributions

HGK did writing-original draft, review & editing, RHJ did investigation, data curation, writing-review. SK did investigation and data curation. JHT did methodology and writing review, JWJ did investigation and data curation. SC did conceptualization and writing-review & editing. YJY did conceptualization, investigation, and writing-review & editing.

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Competing interests

The author declares that they have no competing interests.

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