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Assessing a Reptile Species Protection Index for the Republic of Korea under Climate Change

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ABSTRACT

This study assessed changes in the Species Protection Index (SPI) for reptiles in the Republic of Korea under climate change. We integrated nationwide survey data to build species distribution models (SDM) for 18 reptile species and assessed their potential habitats under current and future climate scenarios (Shared Socioeconomic Pathway [SSP]: SSP2-4.5 and SSP5-8.5). The SDM performed well, with a mean area under the curve of 0.965 (range 0.869-0.999). By overlaying the predicted potential habitats with protected areas, we calculated Species Protection Scores for individual species and a taxon-level SPI for reptiles. The current SPI was 26.74 when all species were included, and 28.16 when ecosystem-disturbing (invasive) species were excluded. When the Species Conservation Target was adjusted to reflect the Republic of Korea context, these increased to 36.62 and 38.53, respectively. Under both future scenarios, SPI values declined through the mid-century (~2050) and then increased again in the late century (2060-2090). Ecosystem-disturbing (invasive) species initially exhibited lower SPI values but tended to overtake non-invasive species in the long term, underscoring the need to manage their incursions within protected areas. Overall, the findings support designating additional climate-informed protected areas alongside national and global 30% expansion targets.

Keywords: Biodiversity, Climate change scenarios, Conservation policy, Protected areas, Species distribution model

Introduction

The World Economic Forum identified climate change and biodiversity loss as risks threatening humanity over the next decade in its "Global Risks 2023" report, which outlines threats facing the world (World Economic Forum, 2023). Habitat changes for Earth's species due to climate change are progressing very rapidly (Chen *et al.*, 2011). Due to differing response speeds among individual species, interactions between species may cease, and new interactions may emerge (Pecl *et al.*, 2017). Within this climate-changing environment, effective conservation, restoration, and enhanced habitat connectivity are essential to boost species adaptability (Intergovernmental Panel on Climate Change [IPCC], 2022). In particular, there is a need to redefine priority areas for protected regions considering future climate conditions (Jones *et al.*, 2016).

Approximately 20% of the world's reptiles are currently estimated to be threatened with extinction (Böhm *et al.*, 2016), with habitat loss due to excessive development being the primary cause (Böhm *et al.*, 2016). Furthermore, future climate scenarios predict declines in reptile species diversity across many regions, making climate change an emerging threat (Biber *et al.*, 2023). Most terrestrial ectotherms lack sufficient tolerance for environments ex-

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ceeding their survival temperatures. Therefore, to adapt to climate warming, they need increased access to diverse habitats that allow escape from extreme high temperatures (Sunday *et al.*, 2014).

The Species Protection Index (SPI) is an indicator that can assess the conservation status of species, not just the area of protected areas, and can play a crucial role in assessing species conservation status at the national and global levels (Jetz *et al.*, 2022; Kim *et al.*, 2024). SPI was adopted as a component indicator for Target 3 of the 2022 Kunming-Montreal Global Biodiversity Framework (GBF; UNEP-WCMC, 2022). The SPI is assessed annually at the national level worldwide through the Map of Life (Map of Life, 2024). The SPI calculation can be performed independently at the national level, and the species or protected area information currently used in Map of Life may be updated or replaced. The SPI information currently provided by Map of Life is not based on data held by domestic public institutions and has limitations in that it does not reflect the latest data. Therefore, the interpretation of SPI values and results can vary due to differences in species habitat area assessment methods, weighting for endemic species, and the incorporation of the latest species survey data (Kim *et al.*, 2024).

In the Republic of Korea, research on current and climate change-induced reptile habitats is underway (Do *et al.*, 2022; Shin *et al.*, 2024), but studies assessing reptile SPI results linked to climate scenarios are not being conducted. Therefore, this study predicted current and future potential habitats for the Republic of Korea reptiles, analyzed overlapping areas with protected sites, and calculated the SPI. Furthermore, we compared SPI values between ecologically disruptive species and general species. We also adapted the selection of Species Conservation Targets (SCT) for SPI value determination to the Republic of Korea context and compared these with existing assessment values. The results of this study suggest the necessity not only for additional quantitative expansion of protected areas but also for selecting new protected areas considering climate change. Furthermore, it enables a quantitative examination of the risk of invasive species penetrating protected areas due to climate change.

Materials and Methods

Research target species

The number of biological species (native species) in the Republic of Korea is estimated to be approximately 100,000 (Ministry of Environment, 2012), and as of 2023, 60,010 species are recorded and managed in the National Species List (National Biodiversity Center, 2023). Among these, 36 reptile species are recorded (National Institute of Biological Resources, 2024). Out of these 36 species, 32 species were selected as research subjects, excluding four endangered wild species. The excluded endangered species are one Class I species (black headed snake [*Sibynophis chinensis*]) and three Class II species (Korean rat snake [*Elaphe schrenckii*], Korean tiger lizard [*Eremias argus*], and Reeves's pond turtle [*Mauremys reevesii*]). As ectotherms, reptiles are highly susceptible to the impacts of global warming, and habitats exceeding the physiological optimal temperatures for some reptile species have already been observed (Biber *et al.*, 2023). This suggests reptiles may be more vulnerable to global warming than other taxonomic groups adapted to colder environments (Diele-Viegas & Rocha, 2018). Therefore, research to develop reptile conservation strategies under climate change impacts is urgently needed. The target species for this study were selected as reptile species for which location survey points from at least 50 points were available for applying species distribution models (SDM) (Coudun & Gégout, 2007; Franklin, 2009). Furthermore, all marine reptile species were excluded.

Predicting potential habitats under climate change

The most critical element in species conservation index assessment is identifying the species' habitat. To predict the potential habitat of reptiles under climate change, SDM were utilized. SDM is a tool that analyzes the relationship between species survey location data and environmental variables such as climate, topography, and soil to predict the potential habitat of the species (Schimper, 1903; Grinnell, 1904; Franklin, 2009). SDM is applied in diverse fields including biodiversity assessment, species resource and habitat management/restoration, protected area selection, and impact assessments of invasive alien species and climate change (Miller *et al.*, 2004; Peters & Herrick, 2004; Franklin, 2009; Thorn *et al.*, 2009; Shin *et al.*, 2015).

Environmental variables for predicting future potential habitats of reptiles were constructed by categorizing them into climatic and geographic factors (Shin *et al.*, 2024). Climatic variables utilized current (2000-2019) and future (2021-2100) data from the Korea Meteorological Administration (Korea Meteorological Administration, 2023). 19 bioclimate variables (Bioclim) were generated using current and future maximum temperature, minimum temperature, and precipitation data. Bioclim is known to be a key variable determining the distribution and habitat of animals, plants, and ecosystems (Araújo *et al.*, 2005; Attorre *et al.*, 2007). The Korea Meteorological Administration selected four types of Shared Socioeconomic Pathways (SSP) (SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5) as the national climate change standard scenarios (Korea Meteorological Administration, 2023). This study selected the intermediate pathway (SSP2-4.5) and the most severe pathway (SSP5-8.5). Geographic variables included elevation (Digital Elevation Model), slope, Topographic Wetness Index, and distance from inland water bodies (Shin *et al.*, 2024). Variables for the final SDM were selected by excluding highly correlated variables through Pearson's r correlation analysis and referencing prior studies (Koo *et al.*, 2015; Park *et al.*, 2017; Shin *et al.*, 2018).

Reptile locations for SDM were identified through 8 survey projects conducted by the National Institute of Ecology from 2013 to 2021: ("The National Ecosystem Survey," "Basic Survey on Inland Wetlands," "Ecosystem survey of Baekdudaegan Protected Area," "Natural Environment Survey of Specific Areas," "Ecological and Landscape Conservation Area Detailed Survey," "Specific Island Discovery Survey," "Specific Island Detailed Survey," "National Coastal Sand Dune Natural Environment Survey"), and data from the Korea National Park Service's "National Park Biological Resources Status Survey" conducted from 2002 to 2022 (Shin *et al.*, 2024).

To reduce the uncertainty of SDM, an ensemble model was applied in this study. Recently, ensemble models, which combine multiple model algorithms, have been utilized to mitigate the uncertainty arising from a single SDM approach (Thuiller *et al.*, 2009; Kwon, 2014; Shin *et al.* 2018). 10 SDM algorithms (Generalized Linear Model [GLM], Generalized Boosted Model [GBM], Generalized Additive Model [GAM], Classification Tree Model [CTA], Artificial Neural Network [ANN], Surface Range Envelope [SRE], Flexible Discriminant Analysis [FDA], Random Forest [RF], Multivariable Adaptive Regression Splines [MARS], Maximum Entropy [MaxEnt]) were used to predict the distribution of individual reptile species using an ensemble model approach, where the model validation values were weighted and combined (Allouche *et al.*, 2006; Koo *et al.*, 2017; Shin *et al.* 2018).

SDM accuracy was measured using the area under the curve (AUC) value of the receiver operating characteristic curve via 10-fold cross-validation (Shin *et al.*, 2018). The AUC value ranges from 0.5 to 1.0, and prediction accuracy is classified as follows: AUC 0.9-1.0, excellent; 0.8-0.9, good; 0.7-0.8, fair; 0.6-0.7, poor; 0.5-0.6, fail (Swets, 1988; Parker-Allie *et al.*, 2009). The potential habitat for individual reptile species predicted via SDM is estimated as a probability value. The predicted probability values for individual reptile species were classified into occupied areas (presence) and unoccupied areas (absence) (Shin *et al.*, 2018). The cutoff value for habitat/non-habitat classification was set at the point where the sum of the model's sensitivity and specificity was maximized (Liu *et al.*, 2005).

Assessment of the Species Protection Index

The SPI is an indicator developed by Group on Earth Observations Biodiversity Observation Network (GEO BON) in 2016, focusing on assessing how protected areas contribute to biodiversity conservation (Kim *et al.*, 2024). SPI is a tool that can promote the designation of protected areas for species' actual habitats and measure the resulting conservation outcomes (Jetz *et al.*, 2022). SPI can be assessed in six steps as follows (Jetz *et al.*, 2022; Kim *et al.*, 2024). (Step 1) Calculate the habitat area for each species within the target taxon or group, (Step 2) Calculate the overlap area between individual species habitats and protected areas, (Step 3) Calculate the SCT, (Step 4) Calculate the Species Protection Score (SPS) for each species, (Step 5) Assign weights to each species, (Step 6) Sum the weighted SPS to evaluate the final SPI.

This study conducted the following six steps to evalu-

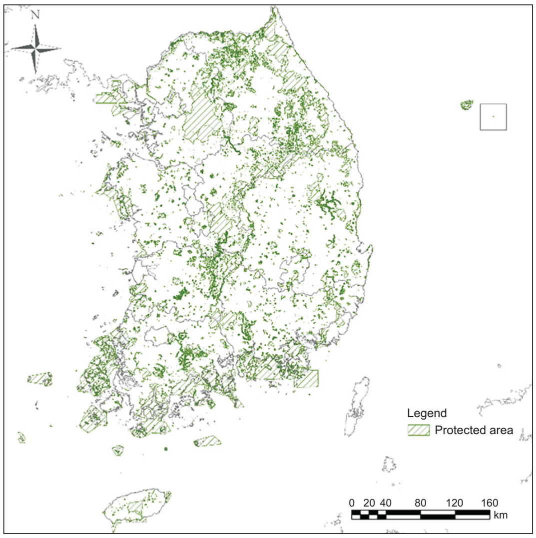

Fig. 1. Current status of protected areas in the Republic of Korea. Adapted from Korea Database on Protected Areas; 2024.

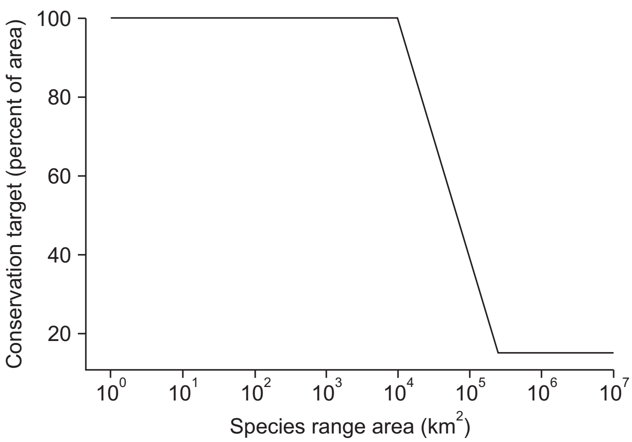

Fig. 2. The relationship between range of species and area-based conservation targets. Data from the article of Kim *et al.* (*Korean Journal of Ecology and Environment*, 57, 189-197).

ate the SPI. (Step 1) The habitat area for each reptile species (both current and future) was predicted using SDM. (Step 2) The overlapping area between the predicted individual reptile habitats and protected areas was calculated. Protected area data were obtained from the Korea Database on Protected Areas (Fig. 1; Korea Database on Protected Areas, 2024). (Step 3) The SCT value is determined based on the calculated individual habitat area of the reptile species. SCT represents the proportion of a species' habitat area within a country that should be protected. SCT is set at 100% for species with a habitat area under 10,000 km^2, and at 15% for species with a habitat area of 250,000 km^2 or more. Values in between are determined using a log-linear function (Fig. 2; Kim *et al.*, 2024). To maintain international comparability, we report SPI using the global SCT rule (100% at <10,000 km^2 to 15% at ≥250,000 km^2). In addition, we provide a country-specific sensitivity analysis (SCT-KR) that sets the 100% lower bound at 1,000 km^2 to reflect the Republic of Korea's small national extent and the prevalence of small-range species at national scales. (Step 4) SPS is calculated as the ratio of the species' habitat protection rate (the overlap between protected areas and the species' habitat) to the SCT value (Eq. 1). (Step 5) This study did not assign weights. However, weights could be assigned to species requiring urgent protection, such as endemic or endangered species within the country (Environmental Performance Index, 2024). (Step 6) This study averaged the SPS values of individual reptile species to derive the final SPI value.

$$Species\ Protection\ Score\ (SPS) = \frac{Area\ of\ habitat\ protected\ \left(\frac{Intersection\ area\ between\ protected\ areas\ and\ habitats}{Species\ habitat\ range}\right)}{Species\ consevation\ target\ (SCT)} \times 100 \quad \text{(Eq.1)}$$

To aid interpretation of SPI changes under climate scenarios, we additionally computed, for each species and time slice, (1) the total habitat area predicted by the

Table 1. Results of reptile Species Protection Index (SPI) assessment using species distribution models (current)

Scientific name	Habitat area (km^2)	Intersection area (km^2)	Species conservation target (%)		Protected area (%)	Species Protection Score	
			Original baseline	Revised baseline		Original baseline	Revised baseline
	(A)	(B)	(C)	(D)	(E)	{(E)/(C)}×100	{(E)/(D)}×100
Amphiesma vibakari	10,768.48	3,369.69	97.92	63.37	31.29	31.96	49.38
Dinodon rufozonatum	19,383.96	3,237.17	82.40	54.33	16.70	20.27	30.74
Elaphe dione	25,172.08	4,831.65	75.49	50.31	19.19	25.43	38.16
Hierophis spinalis	4,013.51	1,018.21	100.00	78.56	25.37	25.37	32.29
Oocatochus rufodorsatus	21,008.52	2,755.05	80.27	53.09	13.11	16.34	24.70
Rhabdophis tigrinus	37,487.76	5,416.87	64.98	44.18	14.45	22.24	32.71
Takydromus amurensis	26,281.18	6,723.26	74.36	49.64	25.58	34.40	51.53
Takydromus wolteri	22,687.81	3,022.77	78.24	51.90	13.32	17.03	25.67
Scincella huanrenensis	1,000.02	445.56	100.00	99.95	44.56	44.56	44.58
Scincella vandenburghi	23,387.13	4,381.49	77.44	51.44	18.73	24.19	36.42
Gloydius brevicaudus	16,578.15	3,170.20	86.52	56.73	19.12	22.10	33.71
Gloydius saxatilis	6,093.94	2,446.69	100.00	72.14	40.15	40.15	55.66
Gloydius ussuriensis	30,336.19	6,674.83	70.57	47.43	22.00	31.18	46.39
Pseudemys concinna	11,434.76	1,401.02	96.33	62.45	12.25	12.72	19.62
Pseudemys nelsoni	6,441.49	719.28	100.00	71.28	11.17	11.17	15.67
Trachemys scripta	15,920.42	1,513.49	87.59	57.36	9.51	10.85	16.57
Pelodiscus maackii	11,607.66	1,725.47	95.94	62.22	14.86	15.49	23.89
Pelodiscus sinensis	5,745.09	626.28	100.00	73.04	10.90	10.90	14.92
SPI (Overall mean across all species)						26.74	36.62
SPI (Overall mean across all species excluding ecosystem-disturbing [invasive] species)						28.16	38.53

*Ecosystem-disturbing (invasive) species.

SDMs and (2) the fraction of that area overlapping protected areas. These summaries are provided in Tables 1-4 to show how habitat-area trajectories and protected-area (PA)-overlap trajectories jointly determine SPS and, in turn, aggregate to the national SPI under each scenario.

Results

Selection of study species

Location data were collected for 32 reptile species inhabiting the Republic of Korea, excluding endangered species (four species). Among these 32 species, 18 species suitable for application to SDM were finally selected as study subjects (Table 5). The selected 18 species include three species designated as ecosystem-disturbing (invasive) species in the Republic of Korea. The three included species are the river cooter (*Pseudemys concinna*), Florida red-bellied cooter (*Pseudemys nelsoni*), and red-eared slider turtle (*Trachemys scripta*). The final SPI calculation was performed separately: one considering all 18 species including the ecosystem-disturbing species, and another excluding the three ecosystem-disturbing species (Table 5).

Predicted potential habitats under climate change

For the environmental variables in SDM to predict reptile potential habitats, nine variables (Bio03, Bio04, Bio05, Bio13, Bio17, digital elevation model [DEM], Slope, Topographic Wetness Index [TWI], D_water) were selected from 19 Bioclim variables and four topography-related variables, considering their correlations (Table 6; Shin *et al.*, 2024). The final ensemble model accuracy ranged from a minimum of 0.869 to a maximum of 0.999,

Table 2. Environmental variables used in the species distribution models

Category	Variable	Variables description (unit)
Climate	Bio03	Isothermality (mean diurnal range/ temperature annual range)×100 (%)
	Bio04	Temperature seasonality (standard deviation×100)
	Bio05	Max temperature of warmest month (°C)
	Bio13	Precipitation of wettest month (mm)
	Bio17	Precipitation of driest quarter (mm)
Geography	DEM	Digital elevation model (altitude; m)
	Slope	Slope calculated from DEM (°)
	TWI	Topographic Wetness Index calculated from DEM (unitless)
	D_water	Distance from inland water (m)

Table 3. Rankings of environmental variable importance for 18 species

Scientific name	Bio03	Bio04	Bio05	Bio13	Bio17	DEM	Slope	TWI	D_water
Amphiesma vibakari	7	5	2	8	1	3	4	9	6
Dinodon rufozonatum	9	1	4	7	3	6	5	8	2
Elaphe dione	9	3	1	8	5	6	7	4	2
Hierophis spinalis	6	2	1	3	5	4	9	7	8
Oocatochus rufodorsatus	6	4	8	7	5	1	9	2	3
Rhabdophis tigrinus	7	2	6	8	4	5	9	3	1
Takydromus amurensis	8	7	1	9	5	4	2	6	3
Takydromus wolteri	7	1	3	5	8	2	9	4	6
Scincella huanrenensis	6	7	1	8	4	2	9	5	3
Scincella vandenburghi	5	2	4	8	3	7	1	9	6
Gloydius brevicaudus	6	2	5	4	1	7	9	8	3
Gloydius saxatilis	4	7	1	8	2	3	5	6	9
Gloydius ussuriensis	8	3	1	9	4	2	7	6	5
Pseudemys concinna	2	4	5	3	8	1	9	6	7
Pseudemys nelsoni	3	2	1	7	8	4	9	6	5
Trachemys scripta	6	1	3	4	5	2	9	8	7
Pelodiscus maackii	4	9	8	5	6	2	7	1	3
Pelodiscus sinensis	6	1	3	2	7	4	9	5	8

DEM, digital elevation model; TWI, Topographic Wetness Index.
*Ecosystem-disturbing (invasive) species.

Table 4. Results of reptile habitat area (km^2) assessment using SDM: Current (2010) and SSP2-4.5 scenario (2020-2090)

Scientific name	2010	2020	2030	2040	2050	2060	2070	2080	2090
Amphiesma vibakari	10,768.48	10,403.12	8,865.98	10,965.35	10,733.22	13,346.92	11,372.53	6,702.55	6,238.58
Dinodon rufozonatum	19,383.96	18,509.20	15,277.36	14,813.59	20,976.97	24,405.49	22,374.94	23,322.51	21,662.03
Elaphe dione	25,172.08	24,913.64	27,316.94	30,201.40	30,726.47	36,984.37	35,390.98	30,395.41	29,601.76
Hierophis spinalis	4,013.51	3,298.57	3,027.37	2,381.07	2,278.54	2,344.35	2,152.86	2,356.56	2,253.09
Oocatochus rufodorsatus	21,008.52	13,604.87	4,117.19	1,305.80	1,558.45	951.09	507.87	1,297.01	605.97
Rhabdophis tigrinus	37,487.76	34,877.00	31,393.01	29,046.41	29,689.16	31,203.16	27,362.44	27,649.75	28,438.51
Takydromus amurensis	26,281.18	20,540.93	14,959.86	14,373.24	11,357.87	10,251.72	8,600.98	6,245.57	4,917.11
Takydromus wolteri	22,687.81	23,143.03	18,787.31	18,728.84	23,650.45	27,649.62	27,102.07	26,159.65	24,033.25
Scincella huanrenensis	1,000.02	349.64	1,947.26	2,055.65	28.19	21.37	28.16	15.55	21.37
Scincella vandenburghi	23,387.13	24,826.29	24,150.38	30,184.48	34,337.80	40,397.83	39,173.77	29,670.98	27,644.57
Gloydius brevicaudus	16,578.15	21,074.63	32,615.60	38,859.77	41,798.34	50,228.70	48,693.01	40,774.65	38,650.80
Gloydius saxatilis	6,093.94	5,915.16	6,472.01	8,563.03	9,631.22	12,513.86	12,198.70	10,070.10	9,558.15
Gloydius ussuriensis	30,336.19	23,096.57	14,011.24	12,464.94	11,791.14	11,167.37	8,785.78	6,654.43	5,447.64
Pseudemys concinna	11,434.76	26,179.02	28,634.31	19,297.71	15,617.68	10,545.04	8,228.89	8,053.93	6,107.88
Pseudemys nelsoni	6,441.49	18,903.71	35,741.08	45,241.18	46,368.73	47,355.90	45,726.31	44,082.83	33,145.02
Trachemys scripta	15,920.42	30,711.69	47,702.36	48,668.97	45,892.22	34,797.94	27,705.94	28,520.50	20,407.38
Pelodiscus maackii	11,607.66	11,172.77	5,876.91	3,098.61	3,530.43	2,983.95	1,985.38	2,528.75	1,783.96
Pelodiscus sinensis	5,745.09	4,326.06	2,611.56	1,424.15	2,697.70	2,947.14	3,009.20	4,336.57	3,403.67

SDM, species distribution model; SSP, Shared Socioeconomic Pathway.
*Ecosystem-disturbing (invasive) species.

Table 5. Results of reptile habitat area (km^2) assessment using SDM: Current (2010) and SSP5-8.5 scenario (2020-2090)

Scientific name	2010	2020	2030	2040	2050	2060	2070	2080	2090
Amphiesma vibakari	10,768.48	11,328.39	6,928.27	6,492.68	13,138.51	16,408.51	28,310.55	20,892.78	7,576.12
Dinodon rufozonatum	19,383.96	17,735.75	24,100.15	23,384.64	24,150.33	28,202.66	25,878.43	21,665.18	17,048.31
Elaphe dione	25,172.08	24,571.46	28,867.48	29,248.76	35,565.54	40,705.94	49,900.41	47,107.58	34,535.96
Hierophis spinalis	4,013.51	2,971.38	3,705.27	2,922.78	2,743.30	3,517.14	3,004.04	1,895.94	1,344.03
Oocatochus rufodorsatus	21,008.52	9,880.41	10,631.02	5,266.18	975.38	429.29	7.00	3.99	39.23
Rhabdophis tigrinus	37,487.76	33,119.59	33,626.49	32,078.85	32,162.42	34,156.98	35,401.11	34,424.98	30,272.89
Takydromus amurensis	26,281.18	19,829.18	11,872.78	9,597.37	10,690.00	8,227.24	6,904.57	4,330.83	1,724.03
Takydromus wolteri	22,687.81	23,253.41	25,497.81	24,766.88	27,933.29	32,749.49	33,722.12	28,556.46	19,795.22
Scincella huanrenensis	1,000.02	489.38	66.10	34.99	20.41	9.71	11.66	18.47	19.44
Scincella vandenburghi	23,387.13	25,792.16	21,912.56	23,879.51	39,992.46	47,041.45	59,911.46	56,325.22	32,386.43
Gloydius brevicaudus	16,578.15	18,950.56	29,719.40	34,106.45	44,806.18	51,479.73	62,957.28	64,608.31	55,124.73
Gloydius saxatilis	6,093.94	4,848.30	7,358.11	7,983.66	11,016.37	16,371.67	18,833.51	18,374.67	15,348.42
Gloydius ussuriensis	30,336.19	21,624.92	13,544.06	10,392.72	11,207.52	9,053.84	6,785.32	3,131.89	1,212.87
Pseudemys concinna	11,434.76	28,735.03	27,682.93	17,566.75	9,655.00	5,399.17	2,660.96	1,873.26	1,447.30
Pseudemys nelsoni	6,441.49	23,952.57	34,562.69	42,015.57	45,539.51	26,033.26	10,902.82	6,289.67	3,342.56
Trachemys scripta	15,920.42	34,444.94	53,316.90	50,087.60	33,909.12	17,813.40	8,015.41	4,050.35	2,909.95
Pelodiscus maackii	11,607.66	8,163.68	9,346.81	5,112.30	2,396.70	2,067.62	835.37	731.28	1,198.46
Pelodiscus sinensis	5,745.09	3,433.49	5,710.58	4,900.42	2,610.56	2,729.23	1,266.68	1,548.02	2,991.87

SDM, species distribution model; SSP, Shared Socioeconomic Pathway.
*Ecosystem-disturbing (invasive) species.

with an average value of 0.965 (Fig. 3).

Across the 18 species, the most frequently first-ranked predictor (environmental variable) was Bio5 (maximum temperature of the warmest month) in seven species (*Elaphe dione, Hierophis spinalis, Takydromus amurensis, Scincella huanrenensis, Gloydius saxatilis, Gloydius ussuriensis, and Pseudemys nelsoni*) followed by Bio4 (temperature seasonality) in four species (*Dinodon rufozonatum, Takydromus wolteri, Trachemys scripta, and Pelodiscus sinensis*) and Bio17 (precipitation of the driest quarter) in two species (*Amphiesma vibakari and Gloydius brevicaudus*). DEM was the top predictor for two species (*Oocatochus rufodorsatus and Pseudemys concinna*) while single-species leaders were Slope for *Scincella vandenburghi*, TWI for *Pelodiscus maackii*, and D_water (distance to inland water) for *Rhabdophis tigrinus*. No species had Bio03 or Bio13 as the highest-ranked predictor (Table 7).

The area of current (Table 5) and future (two scenarios: SSP2-4.5, SSP5-8.5) habitats was calculated for 18 reptile species. Based on the current (2010) potential habitat, the species with the largest areas in the Republic of Korea were the tiger keelback (*Rhabdophis tigrinus*), the Ussuri mamushi (*Gloydius ussuriensis*), and the Amur grass lizard (*Takydromus amurensis*), in that order. The species with the smallest areas were the dwarf skink (*Scincella huanrenensis*), the slender racer (*Hierophis spinalis*), and the Chinese softshell turtle (*Pelodiscus sinensis*), in that order. The species with the largest overlap area (intersection area) between predicted potential habitat and protected areas were the Amur grass lizard (*Takydromus amurensis*), Ussuri mamushi (*Gloydius ussuriensis*), and the tiger keelback (*Rhabdophis tigrinus*), in that order. Conversely, the species with the smallest overlap areas were the dwarf skink (*Scincella huanrenensis*), Chinese softshell turtle (*Pelodiscus sinensis*), and Florida red-bellied cooter (*Pseudemys nelsoni*). A larger potential habitat area did not necessarily correspond to a larger overlap area with

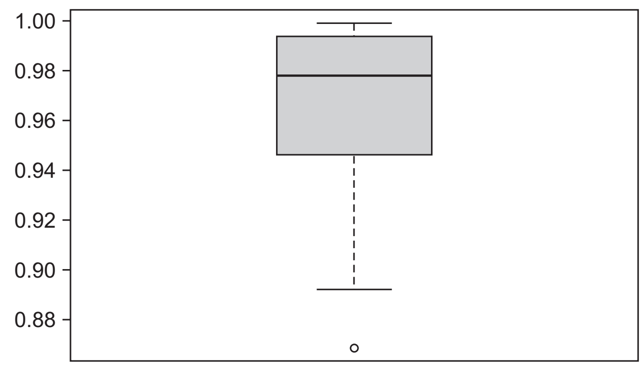

Fig. 3. Accuracy of the ensemble species distribution models.

Table 6. Proportion (%) of SDM-predicted habitat within protected areas: Current (2010) and SSP2-4.5 scenario (2020-2090)

Scientific name	2010	2020	2030	2040	2050	2060	2070	2080	2090
Amphiesma vibakari	31.29	29.45	30.37	29.73	30.12	29.23	30.26	32.15	31.68
Dinodon rufozonatum	16.70	16.30	17.40	17.92	16.12	15.57	15.89	15.21	15.26
Elaphe dione	19.19	19.00	18.69	18.99	18.24	17.32	17.71	18.13	18.30
Hierophis spinalis	25.37	23.36	22.25	23.39	24.32	24.96	25.03	23.69	23.78
Oocatochus rufodorsatus	13.11	15.15	19.88	21.98	20.71	20.30	21.91	19.21	23.63
Rhabdophis tigrinus	14.45	15.29	15.37	16.02	15.70	15.36	15.94	15.88	15.84
Takydromus amurensis	25.58	26.61	28.85	29.56	30.10	31.44	32.94	33.70	36.03
Takydromus wolteri	13.32	13.25	14.03	14.56	14.09	13.74	13.70	13.93	14.42
Scincella huanrenensis	44.56	52.42	17.43	16.02	52.32	58.20	47.67	76.75	59.84
Scincella vandenburghi	18.73	19.24	19.09	19.29	19.64	19.86	20.05	20.00	19.82
Gloydius brevicaudus	19.12	18.19	18.01	18.45	17.73	17.25	17.68	17.42	17.47
Gloydius saxatilis	40.15	39.47	39.06	36.48	33.39	31.58	33.06	32.68	32.44
Gloydius ussuriensis	22.00	23.21	25.30	26.63	28.37	29.93	31.23	32.24	33.49
Pseudemys concinna	12.25	10.37	13.95	15.56	16.39	17.09	18.42	18.83	19.34
Pseudemys nelsoni	11.17	9.11	10.14	10.58	11.31	12.27	13.53	13.59	15.01
Trachemys scripta	9.51	9.48	10.80	13.10	14.38	15.69	16.60	17.00	18.41
Pelodiscus maackii	14.86	17.93	21.39	23.43	22.50	21.45	23.70	23.17	26.98
Pelodiscus sinensis	10.90	12.61	14.96	18.64	13.42	12.59	11.89	11.92	12.70

SDM, species distribution model; SSP, Shared Socioeconomic Pathway.
*Ecosystem-disturbing (invasive) species.

Table 7. Proportion (%) of SDM-predicted habitat within protected areas: Current (2010) and SSP5-8.5 scenario (2020-2090)

Scientific name	2010	2020	2030	2040	2050	2060	2070	2080	2090
Amphiesma vibakari	31.29	28.43	28.59	30.36	28.86	26.97	23.37	25.14	27.84
Dinodon rufozonatum	16.70	16.12	14.78	15.09	15.45	14.83	15.58	16.39	17.01
Elaphe dione	19.19	18.57	17.78	17.68	17.29	16.49	16.27	16.71	18.28
Hierophis spinalis	25.37	24.33	20.89	21.53	23.72	22.84	24.08	26.85	28.18
Oocatochus rufodorsatus	13.11	15.84	15.31	15.71	20.40	20.35	24.33	25.22	30.73
Rhabdophis tigrinus	14.45	15.27	14.67	14.81	15.25	14.91	15.17	15.18	14.62
Takydromus amurensis	25.58	27.24	28.55	30.19	31.11	33.43	36.13	39.49	46.97
Takydromus wolteri	13.32	13.22	13.13	13.31	13.32	13.29	13.57	13.91	14.54
Scincella huanrenensis	44.56	37.26	50.89	56.84	62.97	81.66	54.65	45.54	44.27
Scincella vandenburghi	18.73	19.21	19.88	20.05	19.36	19.10	19.11	19.34	21.39
Gloydius brevicaudus	19.12	18.15	16.21	16.66	17.15	17.06	17.71	18.31	19.24
Gloydius saxatilis	40.15	43.18	32.73	32.58	32.25	28.91	31.41	32.98	35.73
Gloydius ussuriensis	22.00	23.51	24.50	26.30	29.51	32.46	36.23	44.13	54.21
Pseudemys concinna	12.25	10.77	14.70	15.79	17.08	18.27	25.00	34.73	43.48
Pseudemys nelsoni	11.17	9.40	10.85	11.28	12.45	15.22	15.72	17.24	23.79
Trachemys scripta	9.51	9.47	11.49	14.01	15.83	17.65	18.88	26.05	35.97
Pelodiscus maackii	14.86	19.34	18.82	19.95	22.27	22.69	32.16	34.56	30.73
Pelodiscus sinensis	10.90	12.51	13.46	13.72	14.68	14.34	12.52	14.37	14.33

SDM, species distribution model; SSP, Shared Socioeconomic Pathway.
*Ecosystem-disturbing (invasive) species.

protected areas.

Assessment of the Species Protection Index results

The species with the highest ratio of protected area to potential habitat area (intersection area between potential habitat and protected areas) based on current standards were the dwarf skink (*Scincella huanrenensis*), the Amur mamushi (*Gloydius saxatilis*), and the Asian keelback (*Amphiesma vibakari*), in that order (Table 5). The species with the lowest ratios were the red-eared slider turtle (*Trachemys scripta*), Chinese softshell turtle (*Pelodiscus sinensis*), Florida red-bellied cooter (*Pseudemys riori*), and river cooter (*Pseudemys concinna*), in that order. The overlap rate between habitats of species designated as ecosystem-disturbing species and protected areas was low. Furthermore, a high potential habitat area did not necessarily correlate with a high overlap rate with protected areas. The dwarf skink (*Scincella huanrenensis*) had the smallest potential habitat area yet exhibited the highest overlap rate with protected areas.

The current SPI score considering all species is 26.74 points, while the SPI score excluding ecosystem-disturbing species is 28.16 points. The SPI score adjusted to the Republic of Korea context based on SCT criteria is 36.62 points when considering all species and 38.53 points when excluding disturbance species. The SPI score was higher in all cases when ecosystem-disturbing species were excluded. The species with the highest SPS values were the dwarf skink (*Scincella huanrenensis*), the Amur mamushi (*Gloydius saxatilis*), and the Amur grass lizard (*Takydromus amurensis*), in that order. When the SCT criteria were modified to suit the Republic of Korea conditions, the ranking changed to the Amur mamushi (*Gloydius saxatilis*), the Amur grass lizard (*Takydromus amurensis*), and the Asian keelback (*Amphiesma vibakari*). The SPS values for the three ecosystem-disturbing species remained the lowest under both SCT methods.

Under the future SSP2-4.5 scenario, the SPI value excluding ecosystem-disturbing species remained lower than the current value (28.16) until 2070, then showed an increasing trend after 2080 (Fig. 4; Appendix 1). In the future SSP5-8.5 scenario, the SPI value excluding ecosystem-disturbing species also remained lower than the current value until 2050, then showed an increasing trend after 2060 (Fig. 5; Appendix 2). Both scenarios indicate that the SPI value decreases in the near future but increases in the more distant future.

The future trend of the SPI score, adjusted to reflect the Republic of Korea conditions based on the SCT standard, is as follows. Even in this case, when examining SPI values excluding ecosystem-disturbing species relative to the baseline, the SSP2-4.5 scenario showed lower SPI values

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than the current baseline value (38.53) (Fig. 4; Appendix 3). For the SSP5-8.5 scenario, values remained low until 2050 but showed a tendency to increase after 2060 (Fig. 5; Appendix 4). The SSP5-8.5 scenario exhibited similar trends regardless of whether the SCT criteria were modified or not.

The results of SPI value changes under future climate change scenarios, distinguishing between ecosystem-disturbing (invasive) species and non-disturbing (non-invasive) species, are as follows. Under the SSP2-4.5 scenario, the SPI values for ecosystem-disturbing species were significantly lower in the initial period (2010–2030), but the gap narrowed after 2040 (Figs. 4, 5). The SSP5-8.5 scenario also showed a similar pattern to the SSP2-4.5 scenario: a large gap in SPI values between ecosystem-disturbing species and non-disturbing species during the initial period (2010-2030), which sharply decreased by 2040. After 2090, the SPI values of ecosystem-disturbing species tended to exceed those of non-disturbing species. This suggests that ecosystem-disturbing species could rapidly infiltrate protected areas due to climate change.

Decomposition into (1) total predicted habitat area (Tables 1, 2) and (2) the proportion within protected areas (Tables 3, 4) shows that late-century SPI increases arise from higher PA representation despite range loss. For example, *Takydromus amurensis* declines in area (2010→2090: 26,281.18→4,917.11 km^2 under SSP2-4.5; 26,281.18→1,724.03 km^2 under SSP5-8.5), while its PA proportion rises (SSP2-4.5: 25.58→36.03%; SSP5-8.5: 25.58→46.97%). *Gloydius ussuriensis* exhibits a similar pattern, with area declines coupled with strong increases in PA proportion (SSP2-4.5: 22.00→33.49%; SSP5-8.5: 22.00→54.21%). These patterns are consistent with upslope/poleward shifts and spatial concentration of suitable climates into the Republic of Korea's mountainous PA.

Discussion

Our findings point to a consistent hierarchy of ecological controls rather than a single dominant driver of reptile suitability under warming. Thermal regimes—maximum

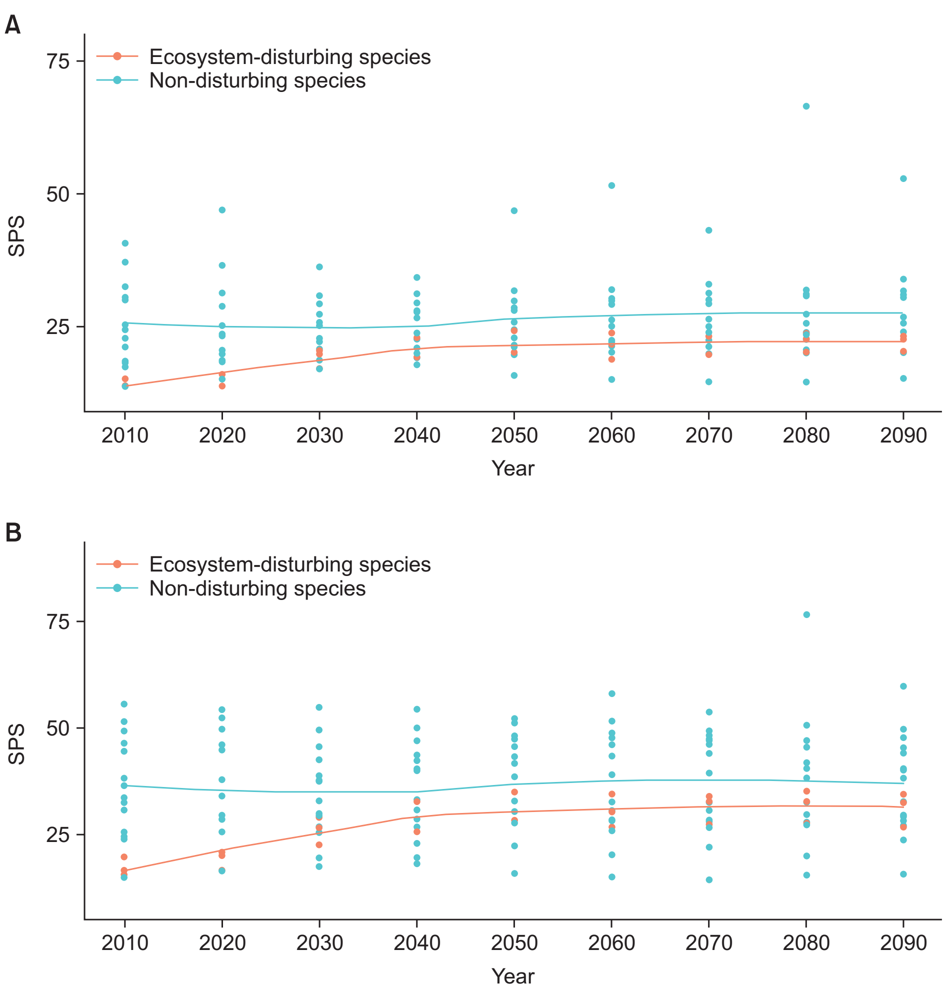

Fig. 4. Results of reptile SPS assessment using species distribution models (SSP2-4.5 scenario): (A) original baseline conservation target, (B) revised baseline conservation target. SPS, Species Protection Score; SSP, Shared Socioeconomic Pathway.

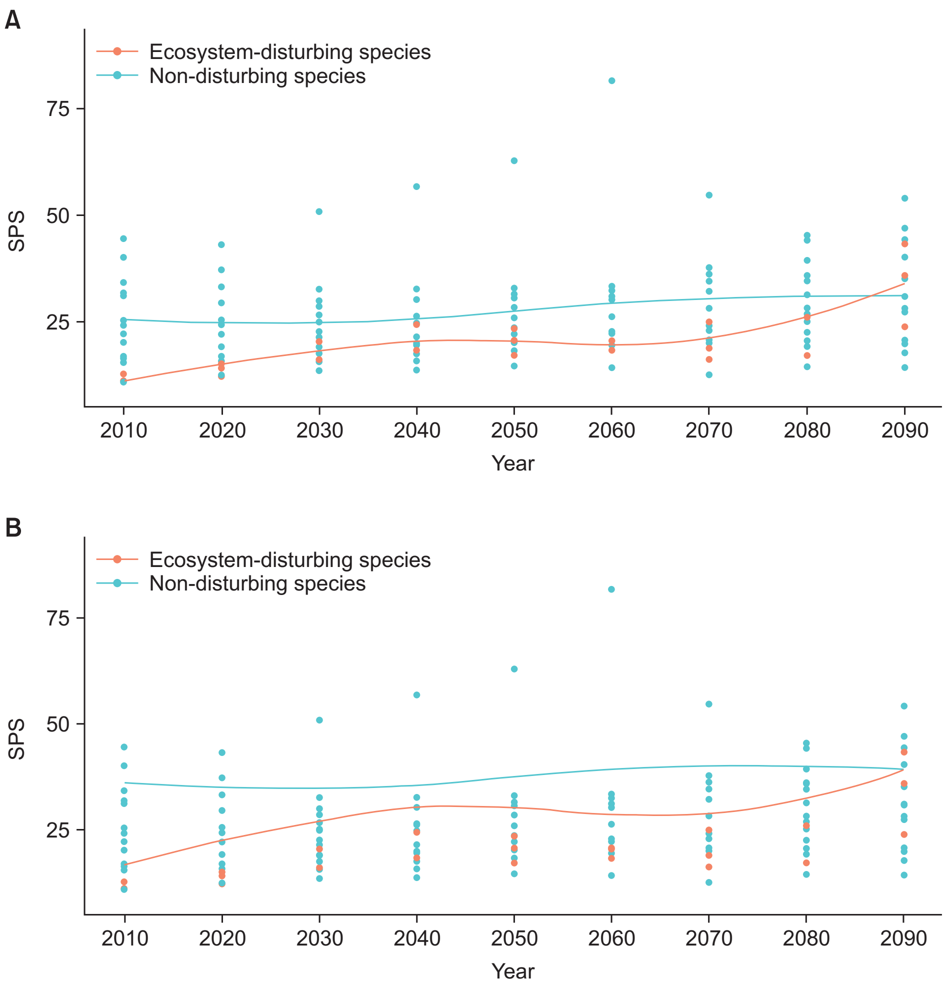

Fig. 5. Results of reptile SPS assessment using species distribution models (SSP5-8.5 scenario): (A) original baseline conservation target, (B) revised baseline conservation target. SPS, Species Protection Score; SSP, Shared Socioeconomic Pathway.

temperature of the warmest month (Bio5) and temperature seasonality (Bio4)—recurrently constrain lacertids (Lacertidae) and pit vipers (Crotalinae), consistent with theory and observations that climate warming tightens thermal safety margins and reshapes activity budgets and distributional limits in ectotherms (Sunday *et al.*, 2014; Chen *et al.*, 2011; Pecl *et al.*, 2017). In semi-aquatic taxa, hydrological and moisture variables (Topographic Wetness Index, distance to inland water, precipitation of the driest quarter) exert the greatest influence, underscoring the buffering and corridor functions of riparian and wetland systems as rainfall regimes are reconfigured. Topography (DEM, slope) consistently provides a second-tier variable importance, highlighting the role of elevational gradients and micro-refugia in enabling short-distance climate tracking (Jones *et al.*, 2016; IPCC, 2022). Interpreting suitability through this lens favors conservation strategies that pair lowland vulnerability management with reinforcement of elevational belts, microtopography, and riparian connectivity.

An apparent late-century rebound of SPI is best read as a change in representation, not as a wholesale improvement in habitat quantity or risk. Two non-exclusive mechanisms likely operate: (1) upslope/poleward displacement of suitable climates toward the mountain-biased PA network in the Republic of Korea, and (2) contraction with spatial concentration, whereby the remnants of suitability are disproportionately captured inside or adjacent to existing PAs. These processes are consistent with observed and predicted redistribution dynamics under rapid warming and with the configuration of the national PA portfolio (Chen *et al.*, 2011; Sunday *et al.*, 2014; Jones *et al.*, 2016). To prevent misinterpretation, we decomposed, for each species and time slice, total suitable area and the fraction overlapping PAs, allowing SPS/SPI trajectories to be interpreted as joint outcomes of area change and PA capture rather than as proxies for reduced extinction risk.

Rising representation within PAs should therefore not be equated with improved conservation status. Korea-specific pressures—rapid urbanization, dense road networks and fragmentation, coastal reclamation, and riparian modification—can degrade habitat quality inside and around PAs and constrain dispersal to emerging climates (Do *et al.*, 2022). Ecosystem-disturbing (invasive) reptiles may further exploit warmer conditions and linear infrastructure to establish along riverine and coastal corridors that intersect PA boundaries, emphasizing the need for biosecurity, early detection–rapid response, and targeted management at PA interfaces (IPCC, 2022; Pecl *et al.*, 2017). Because SPI measures representation rather than impact, parallel indicators (e.g., invasive incidence within PAs) should be tracked to ensure that rising SPI for invasives is not misread as a positive outcome.

Positioning SPI within policy frameworks requires balancing international comparability with national relevance. As a GBF Target 3 component indicator reported annually by Map of Life (Jetz *et al.*, 2022; Kim *et al.*, 2024), SPI should be presented using the published log-linear SCT rule (<10,000 km^2→100%; ≥250,000 km^2→15%) to maintain interoperability. At the same time, a clearly labeled sensitivity analysis using the Republic of Korea-adjusted lower bound (e.g., 1,000 km^2) can better reflect small national extent and the prevalence of small-range species in domestic planning. Dual reporting—global-rule SPI for GBF alignment and context-tuned SPI for national siting and management—avoids conflation while informing decisions at both scales (Jetz *et al.*, 2022; Kim *et al.*, 2024).

Uncertainties and limitations deserve explicit treatment. Ensemble SDMs mitigate but do not remove sensitivity to algorithm choice, thresholds, and global climate model (GCM)/SSP selection; these propagate into SPI and warrant uncertainty bands and multi-GCM aggregation (Franklin, 2009; Thuiller *et al.*, 2009; Koo *et al.*, 2017). We did not apply species weights nor include endangered taxa, limiting comparability with some global assessments; future work should evaluate weighting schemes that elevate endemics and threatened species (Block *et al.*, 2024; Jetz *et al.*, 2022). Moreover, dynamic land-use/land-cover change and explicit connectivity metrics were not yet integrated, despite their central roles in realized distributions and PA overlap; combining these with SDM suitability and continuing updates with national survey data will sharpen inference and policy salience (Miller *et al.*, 2004; Peters & Herrick, 2004; Shin *et al.*, 2024).

Taken together, the SPI framework—interpreted through the paired lenses of range trajectories and PA capture—offers a decision-ready measure of where protection most effectively represents climate-suitable habitats for reptiles as conditions warm. Delivering on the 30% target will depend not only on area expansion but on climate-informed configuration: securing elevational gradients and micro-refugia, reinforcing riparian/wetland connectivity, and institutionalizing invasive-species management at PA edges. In this role, SPI complements area-based goals by directing limited conservation effort to places where representation gains—and thus the prospects for persistence—are likely to be greatest (IPCC, 2022; Jones *et al.*, 2016; Kim *et al.*, 2024).

Conclusion

This study constructed ensemble SDM models for 18 reptile species (average AUC 0.965) and calculated SPI based on protected area representativeness to evaluate changes under different climate change scenarios. The current SPI was 26.74 for all species and 28.16 excluding ecosystem-disturbing species. Adjusting the SCT lower limit to 1,000 km^2 to reflect the Republic of Korea conditions increased these values to 36.62 and 38.53, respectively. Both scenarios (SSP2-4.5, SSP5-8.5) showed declines in the mid-term but recovery and increases in the late term. Ecosystem-disturbing species are likely to surpass general species in the long term, highlighting the importance of managing their penetration within protected areas. This suggests that a large potential habitat area does not necessarily equate to a high protection rate, indicating that the key is not how much is protected but where. However, limitations such as excluding endangered species, not applying weights, and not integrating connectivity, land-use change, and uncertainty may cause differences from international comparative values. Policy-wise, achieving the protected area expansion target (30%) alongside precise relocation to reptile core habitats, enhanced connectivity, proactive management of ecosystem-disturbing species, dual reporting under the Republic of Korea and international standards, and quantification of priority weighting and uncertainty are expected to increase the SPI's utility in decision-making. Furthermore, integrating with other taxonomic groups and refining the assessment procedures in the future is expected to further enhance the reliability of its policy utility.

Author Contributions

Conceptualization: MSS, SRK. Data curation: MSS, BRK. Formal analysis: MSS. Funding acquisition: MSS, SRK. Investigation: MSS, BRK. Methodology: MSS, BRK, SRK. Project administration: SRK. Resources: MSS, BRK, SRK. Software: MSS. Supervision: SRK. Validation: MSS, SRK. Visualization: MSS, BRK. Writing – original draft: MSS. Writing – review & editing: BRK.

Conflict of Interest

The authors declare that they have no competing interests.

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Appendix 1. Results of reptile SPS and SPI assessment using species distribution models (SSP2-4.5 scenario; Original baseline conservation target)

Scientific name	2020	2030	2040	2050	2060	2070	2080	2090
Amphiesma vibakari	29.79	30.37	30.51	30.73	31.68	31.36	32.15	31.68
Dinodon rufozonatum	19.49	19.62	20.03	20.08	20.41	20.21	19.62	19.21
Elaphe dione	25.08	25.49	26.86	25.97	26.50	26.64	25.71	25.70
Hierophis spinalis	23.36	22.25	23.39	24.32	24.96	25.03	23.69	23.78
Oocatochus rufodorsatus	16.51	19.88	21.98	20.71	20.30	21.91	19.21	23.63
Rhabdophis tigrinus	22.87	22.07	22.34	22.06	22.00	21.75	21.74	21.92
Takydromus amurensis	32.91	32.33	32.74	31.19	31.68	32.94	33.70	36.03
Takydromus wolteri	17.05	16.86	17.48	18.26	18.81	18.63	18.70	18.80
Scincella huanrenensis	52.42	17.43	16.02	52.32	58.20	47.67	76.75	59.84
Scincella vandenburghi	25.36	24.92	27.29	29.19	31.52	31.42	28.11	27.14
Gloydius brevicaudus	22.69	26.24	28.81	28.56	30.14	30.44	27.76	27.23
Gloydius saxatilis	39.47	39.06	36.48	33.39	33.61	34.94	32.78	32.44
Gloydius ussuriensis	29.84	27.82	28.32	29.70	30.87	31.23	32.24	33.49
Pseudemys concinna	13.93	19.36	18.85	18.61	17.35	18.42	18.83	19.34
Pseudemys nelsoni	10.96	15.31	17.63	19.05	20.87	22.65	22.39	22.00
Trachemys scripta	13.49	18.43	22.55	24.12	23.43	22.75	23.55	22.72
Pelodiscus maackii	18.50	21.39	23.43	22.50	21.45	23.70	23.17	26.98
Pelodiscus sinensis	12.61	14.96	18.64	13.42	12.59	11.89	11.92	12.70
SPI (Overall mean across all species)	23.69	22.99	24.08	25.79	26.47	26.31	27.33	26.92
SPI (Overall mean across all species excluding ecosystem-disturbing [invasive] species)	25.86	24.05	24.95	26.83	27.65	27.32	28.48	28.04

SPS, Species Protection Score; SPI, Species Protection Index; SSP, Shared Socioeconomic Pathway.
*Ecosystem-disturbing (invasive) species.

Appendix 2. Results of reptile SPS and SPI assessment using species distribution models (SSP5-8.5 scenario; Original baseline conservation target)

Scientific name	2020	2030	2040	2050	2060	2070	2080	2090
Amphiesma vibakari	29.44	28.59	30.36	31.15	31.07	32.28	31.27	27.84
Dinodon rufozonatum	19.03	19.28	19.49	20.18	20.46	20.84	20.63	19.82
Elaphe dione	24.39	24.74	24.72	26.05	26.26	28.34	28.35	27.23
Hierophis spinalis	24.33	20.89	21.53	23.72	22.84	24.08	26.85	28.18
Oocatochus rufodorsatus	15.84	15.58	15.71	20.40	20.35	24.33	25.22	30.73
Rhabdophis tigrinus	22.37	21.63	21.44	22.09	22.11	22.82	22.58	20.70
Takydromus amurensis	33.30	29.94	30.19	31.71	33.43	36.13	39.49	46.97
Takydromus wolteri	17.04	17.46	17.53	18.30	19.38	20.02	19.27	17.77
Scincella huanrenensis	37.26	50.89	56.84	62.97	81.66	54.65	45.54	44.27
Scincella vandenburghi	25.67	25.11	26.08	30.60	32.39	36.34	35.66	31.07
Gloydius brevicaudus	21.87	22.79	24.69	28.45	30.15	34.53	36.18	35.12
Gloydius saxatilis	43.18	32.73	32.58	33.14	33.29	37.77	39.36	40.35
Gloydius ussuriensis	29.57	26.67	26.61	30.47	32.46	36.23	44.13	54.21
Pseudemys concinna	14.96	20.15	18.57	17.08	18.27	25.00	34.73	43.48
Pseudemys nelsoni	12.24	16.17	18.21	20.80	20.40	16.11	17.24	23.79
Trachemys scripta	14.09	20.63	24.45	23.41	20.86	18.88	26.05	35.97
Pelodiscus maackii	19.34	18.82	19.95	22.27	22.69	32.16	34.56	30.73
Pelodiscus sinensis	12.51	13.46	13.72	14.68	14.34	12.52	14.37	14.33
SPI (Overall mean across all species)	23.14	23.64	24.59	26.53	27.91	28.50	30.08	31.81
SPI (Overall mean across all species excluding ecosystem-disturbing [invasive] species)	25.01	24.57	25.43	27.75	29.53	30.20	30.90	31.29

SPS, Species Protection Score; SPI, Species Protection Index; SSP, Shared Socioeconomic Pathway.
*Ecosystem-disturbing (invasive) species.

Appendix 3. Results of reptile SPS and SPI assessment using species distribution models (SSP2-4.5 scenario; Revised baseline conservation target)

Scientific name	2020	2030	2040	2050	2060	2070	2080	2090
Amphiesma vibakari	46.08	45.76	47.13	47.49	48.66	48.39	45.50	44.14
Dinodon rufozonatum	29.61	30.00	30.66	30.36	30.66	30.48	29.54	29.01
Elaphe dione	37.65	38.11	39.97	38.61	39.01	39.30	38.24	38.28
Hierophis spinalis	28.64	26.83	27.00	27.87	28.74	28.40	27.30	27.20
Oocatochus rufodorsatus	25.34	25.43	22.94	22.24	20.30	21.91	20.02	23.63
Rhabdophis tigrinus	33.77	32.77	33.30	32.86	32.69	32.52	32.49	32.72
Takydromus amurensis	49.80	49.47	50.17	48.12	49.02	49.29	46.96	47.77
Takydromus wolteri	25.68	25.60	26.55	27.48	28.11	27.87	28.02	28.27
Scincella huanrenensis	52.42	19.43	18.02	52.32	58.20	47.67	76.75	59.84
Scincella vandenburghi	38.08	37.47	40.61	43.15	46.15	46.09	41.87	40.56
Gloydius brevicaudus	34.30	38.89	42.28	41.72	43.49	44.03	40.62	39.97
Gloydius saxatilis	54.37	54.86	54.52	51.29	51.71	53.80	50.74	49.75
Gloydius ussuriensis	44.95	42.66	43.57	45.77	47.65	46.96	45.55	45.35
Pseudemys concinna	20.87	28.88	28.60	28.43	26.82	27.28	27.75	26.82
Pseudemys nelsoni	16.64	22.58	25.63	27.64	30.25	32.91	32.60	32.57
Trachemys scripta	20.06	26.69	32.61	35.03	34.61	34.00	35.14	34.39
Pelodiscus maackii	28.55	29.43	28.39	27.93	25.81	26.52	27.04	29.64
Pelodiscus sinensis	16.29	17.57	19.72	15.84	15.11	14.33	15.41	15.66
SPI (Overall mean across all species)	33.51	32.91	33.98	35.79	36.50	36.21	36.75	35.87
SPI (Overall mean across all species excluding ecosystem-disturbing [invasive] species)	36.37	34.29	34.99	36.87	37.69	37.17	37.74	36.79

SPS, Species Protection Score; SPI, Species Protection Index; SSP, Shared Socioeconomic Pathway.
*Ecosystem-disturbing (invasive) species.

Appendix 4. Results of reptile SPS and SPI assessment using species distribution models (SSP5-8.5 scenario; Revised baseline conservation target)

Scientific name	2020	2030	2040	2050	2060	2070	2080	2090
Amphiesma vibakari	45.42	40.75	42.66	47.86	47.40	48.18	47.29	40.47
Dinodon rufozonatum	28.95	28.99	29.34	30.33	30.54	31.24	31.15	30.21
Elaphe dione	36.64	36.89	36.85	38.43	38.44	40.92	41.10	40.23
Hierophis spinalis	29.24	26.18	25.80	28.10	28.34	29.01	29.80	29.54
Oocatochus rufodorsatus	24.49	24.08	21.12	20.40	20.35	24.33	25.22	30.73
Rhabdophis tigrinus	33.13	32.00	31.81	32.77	32.69	33.68	33.37	30.80
Takydromus amurensis	50.46	46.14	46.34	49.01	49.52	51.45	51.02	51.29
Takydromus wolteri	25.66	26.19	26.32	27.34	28.72	29.62	28.75	26.93
Scincella huanrenensis	37.26	50.89	56.84	62.97	81.66	54.65	45.54	44.27
Scincella vandenburghi	38.47	37.91	39.22	44.83	46.96	51.72	51.01	46.06
Gloydius brevicaudus	33.20	33.94	36.51	41.38	43.43	48.92	51.13	50.32
Gloydius saxatilis	57.07	47.27	47.92	51.17	50.79	57.34	59.81	61.70
Gloydius ussuriensis	44.65	40.94	41.15	47.03	49.15	51.41	53.57	55.90
Pseudemys concinna	22.32	30.11	28.27	26.26	24.69	29.45	38.47	46.12
Pseudemys nelsoni	18.41	23.89	26.59	30.23	30.57	24.89	24.07	29.23
Trachemys scripta	20.82	29.64	35.28	34.63	31.73	27.80	33.22	43.08
Pelodiscus maackii	28.60	28.71	26.66	25.74	25.56	32.16	34.56	31.62
Pelodiscus sinensis	15.45	18.41	18.17	17.23	16.97	13.00	15.41	17.25
SPI (Overall mean across all species)	32.79	33.50	34.27	36.43	37.64	37.77	38.58	39.21
SPI (Overall mean across all species excluding ecosystem-disturbing [invasive] species)	35.25	34.62	35.11	37.64	39.37	39.84	39.92	39.15

SPS, Species Protection Score; SPI, Species Protection Index; SSP, Shared Socioeconomic Pathway.
*Ecosystem-disturbing (invasive) species.