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Review

An update on the conservation status and ecology of Korean terrestrial squamates

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ABSTRACT

The ecology of most squamates from the Republic of Korea is poorly understood: information on tolerances to environmental variables, movement patterns, home range sizes, and other aspects of their natural history and ecological requirements are lacking. In turn, this lack of knowledge presents an obstacle to effective conservation management. Currently and at the national level, two of Korea's eleven terrestrial snake species are listed as threatened or near threatened: *Elaphe schrenckii* and *Sibynophis chinensis*, and one out of the six lizard species (*Eremias argus*) is listed as threatened. However, various threats including habitat loss, climate change and poaching may have already but unknowingly elevated other Korean reptiles to threatened statuses. To help resource managers in developing conservation programs, we provide a summary of the literature on threats to Korean squamates, a national recommended threat status, and species accounts focused on Korean populations. We recommend listing *Hebius vibakari*, *E. argus*, *Scincella huanrenensis* and *Gekko japonicus* under a higher threat level than the one provided by either the Korean National Institute of Biological Resources or the IUCN Red List. Our results highlight that conservation plans are urgently needed for Korean squamates, mostly because of habitat destruction, and that additional research has to be conducted on most species as there is a clear need for integrated ecological studies and active monitoring programs.

1. Introduction

Although generally understudied, squamates (order Squamata) play important roles in their environments, serving as both predators and prey. Yet, little information is available on natural histories, population trends, and conservation needs for many species, on all continents (Goiran & Shine, 2013; Reading et al., 2010; Winne, Willson, Todd, Andrews, & Gibbons, 2007). For reptiles in general, the main threats include habitat loss and degradation (Breininger et al., 2012; Carpio, Oteros, Tortosa, & Guerrero-Casado, 2016; Mingo, Lötters, & Wagner, 2016), hunting (Breininger et al., 2012; Zhou & Jiang, 2004) and climate change (Penman, Pike, Webb, & Shine, 2010). This is also true of most reptiles found in the Republic of Korea (hereafter, Korea), where the paucity of data on most species and the growing risks in absence of conservation measures (Borzée, Struecker, Yi, Kim, & Kim, 2019) may have already resulted in the addition of species to the list of threatened Korean species.

The need for research on threats to species is further highlighted by Korea's recent and rapid development (Lee & Miller-Rushing, 2014). Following several decades of occupation and unchecked resource exploitation, Korea implemented an aggressive urbanization and industrialization program. While this has led to dramatic improvements in the standard of living for Korean citizens, it has also been a considerable strain on the environment and most wildlife populations (Lee & Miller-Rushing, 2014). Currently, habitat loss and fragmentation resulting from urban development are widespread and many species are threatened as a result (Borzée, Struecker et al., 2019).

While ecological research and conservation efforts have expanded in Korea in recent years (e.g. Do, Kim, Kim, & Joo, 2015), basic natural history data is still lacking for most species. This absence of baseline information on biodiversity and ecological conditions hinders effective conservation and restoration efforts on the Korean peninsula (Lee & Miller-Rushing, 2014). As new threats emerge, including some specific to Korea, combined with the persistent threats highlighted above,

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assessing the statuses and trends of wildlife populations is vital to the future of biodiversity on the peninsula. This is particularly true for less charismatic species, such as reptiles, which traditionally receive less attention than other larger animals (Clark & May, 2002; Fleming & Bateman, 2016; Trimble & Van Aarde, 2010). The latest taxonomic assessment recognized six lizard species and 11 terrestrial snake species in Korea, along with three species of sea snakes in the waters off Korea's coast (Song et al., 2012; see species accounts for discussion on species validity). Two species of sea kraits were also recorded in the waters off Jeju Island and the southern coast of Korea for the first time in 2017 (Park, Kim et al., 2017; Park, Koo, Kim, Choi, & Park, 2017). None of Korea's squamates are endemic, with most species widely distributed in East Asia.

In Korea, the Ministry of Environment categorizes endangered species under two levels: Class I (higher conservation priority level of the country) species are facing heightened extinction threats following drastic population declines due to natural or anthropogenic factors, and Class II species have experienced declines and face extinction in the near future in the absence of threat elimination or mitigating measures. With conservation becoming of greater importance in Korea (Lee & Miller-Rushing, 2014; Kim, Jin, & Yoo, 2018; Borzée, Struecker et al., 2019; Borzée, Kwon, Kyo Soung, & Jang, 2020; Koo, Park, Choi, & Sung, 2020), and with conservation programs becoming more inclusive of previously overlooked species (Noh, 2017), summaries of available knowledge and gaps are invaluable to the development of effective management programs.

To that end, we (1) summarized a list of conservation-oriented research on 17 species of Korean squamates and (2) identified major threats to their survival and conservation. To ensure an adequate review in terms of local threats and behavioral ecology we principally relied on research conducted in Korea, but species summaries for which there is no local data available are based on research conducted outside of the peninsula. In doing so, we hope to inspire studies on these species and motivate relevant agencies and researchers to develop effective squamate conservation programs in Korea.

2. Methodology

The content of both the sections on "conservation concerns" and "species accounts" is based on literature reviews. The searches were conducted without restriction on publication date through Google Scholar and the online literature search engine of Kangwon National University Library utilizing all the combinations possible for each following keywords alone or by pair, in both English or Korean: "reptile", "snake", "serpentes", "lizard", "sauria", "conservation", "threats". We also searched for common and scientific names of all species, including uncommonly used names and local names in Korean, and traced back all publications of interest cited by the focal article/report/governmental file. The conservation concerns are limited to threats in Korea, while the species accounts sometimes also include information from countries where the species also occurs. We did not use Scopus or JCR as a preliminary enquiry mimicked the results provided by Google Scholar. Additional references were however provided by the university library search Engine, likely because of the language used.

Our search results from the Korean literature highlight the general paucity of knowledge regarding Korean squamates, with several species lacking dedicated studies entirely (Table 1). *Eremias argus*, *Elaphe schrenckii*, and *Sibynophis chinensis* accounted for the majority of dedicated articles, resulting in seven, five and five publications respectively. In addition to species-specific studies, we found several studies, identified here as broad assessments, which included valuable information about the distributions of, and threats faced by, multiple Korean squamate species. These broad assessments included regional surveys (e.g., Chang et al., 2006; Jo, Kim, Hur, & Won, 2012), roadkill surveys (e.g., Park, Koo et al., 2017; Kim, Lee, & Park, 2018), and national red lists (e.g., NIBR, 2014; NIBR, 2019). Given the broader focus of these assessments, individual studies may count toward multiple species in Table 1 and though the information they provide is valuable, specifically dedicated research is needed to accurately assess the statuses and population trends of individual species.

Table 1
Number of studies specific to Korean squamates found during literature search. Studies are distinguished as being either species-specific or broad assessments, such as roadkill surveys covering multiple species, or national red lists published by the National Institute of Biological Resources.

Species	References	
	Species specific	Broad assessments
Elaphe dione	0	5
Elaphe schrenckii	5	4
Oocatochus rufodorsatus	2	4
Rhabdophis [tigrinus] lateralis	0	8
Lycodon rufozonatus	1	6
Hebius vibakari	1	3
Orientocoluber spinalis	0	4
Sibynophis chinensis	5	6
Gloydius brevicaudus	2	6
Gloydius ussuriensis	4	6
Gloydius saxatilis	3	1
Takydromus amurensis	0	2
Takydromus wolteri	1	2
Eremias argus	7	5
Scincella vandenburghi	0	4
Scincella huanrenensis	1	5
Gekko japonicus	3	3

2.1. Conservation concerns

2.1.1. Deforestation and habitat loss

While wood had been historically used as fuel and building material (Kim, 1451; Seo & Shim, 1808), deforestation was most intense during the Japanese colonization of Korea from 1910 to 1945 and during the Korean War from 1950 to 1953 (Kang, 1988; Tak, Chun, & Wood, 2007) An estimated three-quarters of Korea's forests were cut down during Japanese occupation, but Japan's withdrawal was followed by the Korean War, destroying much of the remaining forests and leaving Korea largely denuded (Lee & Miller-Rushing, 2014). Subsequent internal conflicts made conservation of low priority and it was not until the 1970s that reforestation began. While two-thirds of the country is now covered by forest (Tak et al., 2007), the rapid urbanization characteristic of modern Korean society again raises concerns about deforestation. The Ministry of Environment estimates that 12,000 ha of forest are lost annually due to urbanization and development (MOE, 2012). International events such as the Olympic Games in Korea in 2018 have resulted in the loss of forested areas at key sites, such as Mt. Gariwang, which in turn significantly affected the herpetofauna (Choi et al., 2018).

All Korean terrestrial reptiles use forested habitat during their life cycles, with some species showing preferences for specific forest types (Kim, Lee et al., 2011; Park, Min et al., 2014; Park, Son, Hwang, Lee, & Lee, 2014; Choi, Kwon, Kim, Yang, & Park, 2017). Some other species, such as *Elaphe schrenckii*, inhabit forested areas only (Song, 2007). Among the species using forest at some point of their life cycles, *Hebius vibakari*, *E. dione*, the three *Gloydius* sp., *Takydromus wolteri*, *Scincella vandenburghi* and *S. huanrenensis* intensively use forests and forest edge habitats (Do, Lee, Jang, Kim, & Yoo, 2016). The comparison of historical records from published studies and georeferenced museum vouchers provides further evidence of range contraction in some Korean squamates associated with the loss of suitable habitats (Stejneger, 1907; Shin, Jang, Allain, & Borzée, 2020).

2.1.2. Roads and development

In addition to impacting reptiles through habitat loss and fragmentation, urbanization and development also increase mortality through roadkills. Numerous studies have documented the impact of roads on herpetofauna and the factors that influence roadkill patterns such as sex, age, vagility, habitat preference, and abundance (Hartmann, Hartmann, & Martins, 2011; Jochimsen, 2005; Quintero-Ángel, Osorio-Dominguez, Vargas-Salinas, & Saavedra-Rodríguez, 2012). Seasonal activities of many squamates such as mate searching, oviposition, and migration to and from hibernacula may increase the risk of vehicular mortality, and more mobile species may be at greater risk than sedentary species (Bonnet, Naulleau, & Shine, 1999; Park, Jeong et al., 2017).

Several landscape factors were correlated with reptile roadkills on a 107 km stretch of road bordering Jiri Mountain National Park (Seo, Thorne, Choi, Kwon, & Park, 2015). These factors included roads with low vehicle speeds, roads with roadside shrubs, and roads with nearby forest and agricultural land. Using *Rhabdophis [tigrinus] lateralis* (see species account for discussion on naming) as a representative example, roads with low traffic volume which were far from villages and lacked road banking were correlated with vehicular mortality. Other research highlighted the importance of edge habitat, as most road mortalities were observed on roads where mountains bordered either crop fields or bodies of water (Park, Jeong et al., 2017). Most roadkill specimens were found between 200 and 400 m in elevation. Roadkills of ten snake species were collected, but five species accounted for 90 % of the 155 specimens between 2007 and 2012. In order of frequency these five species were *R. [tigrinus] lateralis*, *G. ussuriensis*, *E. dione*, *Lycodon rufozonatus*, and *G. brevicaudus*. Active foragers were also more likely to be killed on roads than ambush foragers, and males and adults were collected more frequently than females and subadults, respectively (Park, Jeong et al., 2017). While data from studies such as these are limited, they provide useful clues into the activity patterns, abundances, and distributions of Korean squamates. Further studies are needed however to accurately assess the impact of roads on squamate populations as well as the efficacy of eco-corridors in mitigating road mortalities.

2.1.3. Climate change

Climate change on the Korean peninsula has contributed to higher summer temperatures, more natural disasters, and heightened loss of biodiversity (Lee, Im, & Bae, 2019; MOE, 2012). The increasing temperatures have led to northward range shifts for numerous Korean plant species, including temperate evergreen broad-leaved trees and continued climate change may threaten other plant communities (Lee, Nam et al., 2010). Several studies predict changes in the distribution of Korean forests, generally with a northward and inland expansion of warm temperate and subtropical forests, and a decrease in subalpine forests (Cui et al., 2016; Koo, Park, Hong, Jang, & Seo, 2018; Lim et al., 2018). Despite potential range expansions, highly suitable habitats for some warm-adapted tree species (Koo, Park et al., 2018) and habitats suitable to multiple forest types (Lim et al., 2018) may decrease over time under climate change, contributing to a loss of biodiversity. In additions, human activities such as urban development and deforestation may exacerbate potential habitat loss and fragmentation. Further studies, particularly at the sub-province level, are needed to better predict local changes in forest habitats and how those changes may impact organisms inhabiting forests, such as snakes and lizards (Koo, 2018), as most vertebrates will see a shift in their suitable habitat within the century (Lee, Kang, & Sung, 2019).

The thermal tolerance of many reptiles is poorly understood, making predictions of their physiological abilities to adapt to climate change difficult. Increasing temperatures may exceed thermal optima for some species, negatively affecting fitness and potentially altering species' distributions (Bickford, Howard, Ng, & Sheridan, 2010). Climate change may also indirectly impact reptiles through detrimental effects on prey species, particularly amphibians. Increasing temperatures may reduce available dissolved oxygen in freshwater environments, leading to increased mortality of larval amphibians (Bickford et al., 2010). Thus, species primarily preying on anurans such as *Oocatochus rufodorsatus, L. rufozonatus* and *R. [tigrinus] lateralis* may be principally impacted. This is also supported by a generally higher proportion of threatened species in freshwater environments (Böhm et al., 2013). However, amphibians population dynamics follow different patterns under climate change scenarios, with for instance a decrease in population size in the Korean Crevice Salamander (*Karsenia koreana*; Borzée, Andersen et al., 2019) and an increase in the Far-Eastern Treefrog (*Dryophytes japonicus*; Koo, 2018), making it difficult to clearly predict the impact of climate change on reptiles. Some aquatic snakes prey on *D. japonicus*, in which case climate change is unlikely to impact all reptiles the same way.

While the nature of potential range shifts for Korean squamates remains largely unclear, climate change may already be causing a range expansion in some species, notably sea snakes into Korean waters. In the waters off the south coast of the Korean Peninsula, two species of sea kraits, *Laticauda semifasciata* and *L. laticaudata*, were recently recorded and correctly identified for the first time (Park, Kim et al., 2017; Park, Koo et al., 2017). Genetic analyses using mitochondrial cytochrome *b* gene sequences for twelve *L. semifasciata* caught in Korean waters revealed shared haplotypes with a group covering Taiwan and the southern Ryukyu Islands for six individuals, and shared haplotypes with a group covering the entire Ryukyu Archipelago for the other six individuals. Regional ocean currents may facilitate the movement of sea kraits into Korean waters with climate change increasing survival probabilities in the area via ocean warming (Park, Kim et al., 2017). While the single male *L. laticaudata* recorded in Korean waters thus far may have drifted for unknown reasons, more individuals may move into the area and survive for longer periods of time if ocean warming continues or intensifies (Park, Koo et al., 2017).

2.1.4. Poaching

Snakes are used for traditional medicine in Northeast Asian countries (Choi, 2018). In Korea, a permit issued by regional offices of the Ministry of Environment is required to capture any wild snakes. However, many snake species are captured and illegally processed for para-medical purposes. In addition, some species are sold for very high prices in illegal markets (e.g. *E. schrenckii*, *G. saxatilis*; Shim et al., 1998; Lee, Park, & Sung, 2012). Despite the absence of scientific interest on the subject, numerous news reports and articles illustrate the locally widespread illegal snake hunting. Based on these reports, it is assumed that poachers use drift fences and funnel traps to target snakes entering hibernacula in late fall or snakes emerging from hibernation in early spring. However, no study has yet comprehensively assessed the extent of this threat and a review of snake poaching in Korea and its effect on different species is needed.

2.1.5. Spread of disease associated with the pet trade

Although trade and capture regulations prevent Korean native herpetofauna from entering the pet trade, market demand for exotic herpetofauna is rapidly increasing in the country with the advent of online pet trade (Koo, Kwon et al., 2020; Koo, Park et al., 2020). In this case, a potential threat of exotic pet trade on native herpetofauna is the spread of emergent infectious diseases. For amphibians, global trade has been implicated in the spread of pathogens such as *Batrachochytrium dendrobatidis* and *B. salamandrivorans* (Kolby et al., 2014; Borzée et al., 2021), causing catastrophic decline of global amphibian diversity (Fisher & Garner, 2020). The same can also happen to reptiles, especially with regards to snakes, for which a fungus *Ophidiomyces ophiodiicola* is causing snake fungal disease in wild snake populations across the eastern United States and Europe (Lorch et al., 2016). This emerging pathogen is implicated in the decline of some isolated or imperiled snake populations in these regions (Lorch et al., 2016). Although the snake fungal disease is yet to be reported from Asian countries, it has been demonstrated that host susceptibility to this pathogen is widely distributed across snake phylogeny and ecologies (Burbrink, Lorch, & Lips, 2017), implicating the potential for this pathogen to spread globally via pet trade and invasive species. Considering that many Korean snakes are in the same clade as species currently identified with snake fungal disease (e.g. colubrids, natricids, crotalines), and that some of the affected species are commonly found in the pet trade, there is potential for *O. ophiodiicola* to invade Korean snake fauna in the future, if any contact between native and exotic species were to occur (e.g. at live exhibitions). Thus, any individual working with both native and exotic species should observe appropriate biosecurity protocol to prevent the introduction and spread of this pathogen into the country.

2.2. Species accounts

Brief taxonomical descriptions are provided for recently updated species and when important for threat categorization, however, the focus of the accounts presented here is to review current ecological information and how they relate to the conservation of Korean squamates. The threat status attributed by the Korean organization in charge, the National Institute of Biological Resources (NIBR), is referenced differently for each species because of changes in status, and because the version from 2011 provides greater details on threats than the versions from 2016, 2018 and 2019.

For each species we provide simplified regional threat assessments following the IUCN Red List categories and criteria as they are generally the most robust (Maes et al., 2015) and commonly used to inform on the need for conservation (Lamoreux et al., 2003; Rodrigues, Pilgrim, Lamoreux, Hoffmann, & Brooks, 2006). The IUCN Red List is divided into three threatened categories: Vulnerable, Endangered, or Critically Endangered, and evaluations are conducted against quantitative thresholds for five criteria that determine whether a species is at risk of extinction: A, population size reduction; B, geographic range size; C, small population size and decline; D, very small population and/or restricted distribution; and/or E, quantitative analysis of extinction risk. A species that does not meet one of these criteria is placed into one of the other non-threatened IUCN categories (Least Concern and Near Threatened).

While complete datasets for the assessments are rarely available (Maes et al., 2015), alternative protocols have been established (Hermoso, Kennard, & Linke, 2015; Mace et al., 2008), providing adequate proxies to assess biodiversity (Butchart, Akcakaya, Kennedy, & Hilton-Taylor, 2006). Here, we follow the IUCN Red List categories (IUCN Species Survival Commission, 2012) and criteria to suggest the current national IUCN status for each of the focal species (Table 2; Fig. 1). As datasets are generally unavailable for an assessment following each of the five criteria, we generally rely on the criteria A and B (www.iucnredlist.org/resources/redlistguidelines). We rely on abbreviations used by the IUCN Red List, with CR: Critically Endangered, EN: Endangered, VU: Vulnerable, LC: Least Concern and NT: Near Threatened.

3. Serpentes

3.1. Elaphe dione (Steppe rat snake)

Elaphe dione is a wide-ranging rat snake, found throughout most of Eurasia (Aghasyan et al., 2017). This species inhabits a variety of habitats, including evergreen and deciduous forests, meadows, and wetlands. In Korea, *E. dione* is found largely around cultivated areas such as rice paddies (NIBR, 2011). Given its wide distribution and assumed large population sizes, *E. dione* is considered a species of LC by the IUCN (Aghasyan et al., 2017). However, the NIBR notes that Korean populations seem to be declining as a result of poaching and habitat destruction (NIBR, 2018). In addition, *E. dione* may be more susceptible to road mortality than other Korean snakes; during a nine-year study in 15 Korean national parks, *E. dione* experienced the second-highest road mortality rate of the ten snake species included in the study (Kim, Lee et al., 2018).

Climate change may also affect *E. dione*, with summer observations of these snakes positively correlated with monthly mean temperatures and precipitation during preceding winters (Lee, Ra, & Park, 2011). This suggests that higher mean winter temperatures may reduce *E. dione* mortalities during hibernation. While the study was only five years in length, the authors note their results highlight the importance of long-term monitoring to assess the sensitivity of reptiles and amphibians to climate change (Lee, Ra et al., 2011).

Therefore, based on the wide extent of occurrence and area of occupancy of the species (criteria B), its expected large population size and widespread presence in a wide range of habitats, we agree with the LC status attributed both by the NIBR and the IUCN. We however suggest that while non-threatening to the species overall, the impacts of climate change and habitat degradation are likely to increase, and will likely result in a change of the species' status if the current patterns are maintained.

Table 2
Details of literature included in Table 1. These are the references providing species specific information for this review on conservation and behavioral ecology of Korean terrestrial squamates but does not include all the general references available on a specific species.

Species	Reference
Snakes	
Elaphe dione	NA
Elaphe schrenckii	(An, Park et al., 2010; Kim, Kim et al., 2012; Lee & Park, 2011; Lee et al., 2012; Park et al., 2015)
Oocatochus rufodorsatus	(Heo et al., 2014; Lee, Lee et al., 2011)
Rhabdophis [tigrinus] lateralis	NA
Lycodon rufozonatus	(Kim, Lee et al., 2013)
Hebius vibakari	(Koo, Chang et al., 2019)
Orientocoluber spinalis	NA
Sibynophis chinensis	(Kim & Oh, 2005, 2005; Kim & Oh, 2006; Koo, Kim et al., 2018, Koo, Park et al., 2019)
Gloydius brevicaudus	(Do et al., 2016, 2019)
Gloydius ussuriensis	(Do & Yoo, 2014; Do et al., 2016; Kim & Oh, 2014, 2015)
Gloydius saxatilis	(Do et al., 2016, Do, Nam et al., 2017; Do, Nam, Nam et al., 2017)
Lizards	
Takydromus amurensis	NA
Takydromus wolteri	(Jang, 2011)
Eremias argus	(Kim, Kim et al., 2010; Kim, Kim et al., 2010; Kim, Kim et al., 2011; Kim, Lee et al., 2011; Kim, Ra et al., 2012; Song et al., 2010, 2013)
Scincella vandenburghi	NA
Scincella huanrenensis	(Dong, 2005; Dong et al., 2007; Koo, Kwon et al., 2020)
Gekko japonicus	(Kim, Bae et al., 2017, 2019; Park et al., 2019)

3.2. Elaphe schrenckii (Amur ratsnake, Korean ratsnake or Russian ratsnake)

Elaphe schrenckii is a large colubrid and the largest terrestrial snake species found in Korea (Lee & Park, 2011). The taxonomy of the species is under consideration, with *E. schrenckii* and *E. anomala* considered as two distinct species in part of their range (Liu & Zhao, 2016; Utiger et al., 2002). However, low genetic differentiation between the two clades did not support a segregated species status in Korea (An, Park et al., 2010). Therefore, only *E. schrenckii* is currently recognized in Korea and we focus on this species here. If two species are recognised in the future, the threats are likely to be similar due to the expected overlapping ecological requirements between these two clades. One of the most prominent differences between these species is their body coloration: *E. schrenckii* has a black body with irregular dark brownish yellow bands and *E. anomala* has a light brown body with dark brown bands. However, significant colour variations in *E. schrenckii* across Korea make the use of coloration alone an insufficient tool for species identification (An, Park et al., 2010, An, Kim et al., 2010).

The species used to be widespread in Korea, except on Jeju island, and it is now restricted to specific localities (Do, Lee et al., 2017). The

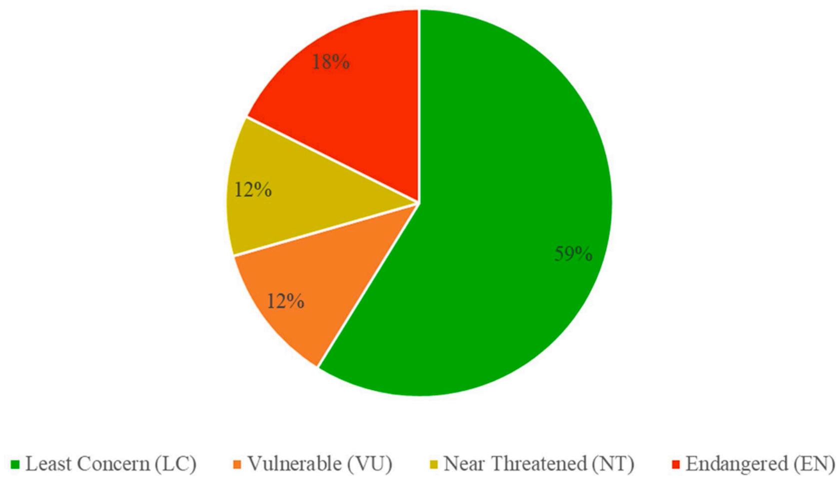

Fig. 1. Percentage of squamates in the Republic of Korea assigned to specific threat level in this study. This analysis is based on the 17 described species and on the data available at the time of the study and is likely to differ once more data becomes available.

recent decline resulted in the species being listed as a class I endangered species by the Korean Ministry of Environment from 2005 to 2018, at which date it has been down listed to class II of endangered species, and it is now listed as Vulnerable (NIBR, 2019). This assessment is largely due to habitat loss, fragmentation and poaching (Lee et al., 2012). *Elaphe schrenckii* is one of the few Korean snake species on which considerable ecological research has been conducted. It is also the only reptile species that has been bred in Korea with the purpose of restoring wild populations (Park, Choi, & Cho, 2015). Three wild-caught females successfully copulated with males in an outdoor breeding facility equipped with artificial hibernacula within the research forest of Kangwon National University in 2015, resulting in 34 eggs total, of which 22 hatched in artificial incubator (Park et al., 2015). Both adults and hatchlings were fed with frozen/thawed feeder mice and grew normally with this diet. However pathological conditions developed during captivity and one adult male died of a malignant tumor, and hearts were swollen abnormally in 13 out of 19 two-year-old juveniles. Subsequent veterinary examinations on one of the deceased juveniles revealed pericardial effusion, swollen hearts, thickened ventricular muscles, and necrotic myocarditis. Of 13 individuals that developed this condition, 12 died and only one survived (Park et al., 2015). Movement rates of radio-tracked captive-bred juveniles were negatively correlated with body weight, and distances moved were negatively correlated with mean daily humidity and daily precipitation (Kim, Kim, Kim, Kim, & Park, 2012). Radio-tracked juveniles were also frequently relocated underground or on the ground and exhibited difficulty foraging, with the body weight of most individuals decreasing during the study. Such patterns suggest careful consideration of release times and prey abundance at release sites for captive-bred snakes in reintroduction programs (Kim, Kim et al., 2012).

Assessing the importance of seven natural and five artificial habitat features, Lee et al. (2012) found that the factors that best explained the presence of *E. schrenckii* were annual solar radiation (MJ/cm^2/year), distance to a stream, distance to coniferous forest, distance to mixed forest, distance to farmland, distance to houses, and distance to barren ground. The use of artificial features such as stream banks and asphalt may relate to thermoregulation. Gravid females in particular selected paved roads, basking on them often and in some cases laying eggs along them. While artificial habitat features such as roads may aid snakes in thermoregulation, these features also expose snakes to greater risk of lethal vehicular encounters and poaching (Lee et al., 2012). In contrast, non-gravid females selected stream banks and bushes, while males preferred the cover of grasslands, concrete structures, and piles of stones.

Research also helped reveal details about the reproductive and overwintering cycles of *E. schrenckii* (Lee & Park, 2011). Using radio telemetry to track translocated and resident snakes in Worak Mountain National Park, oviposition was documented for three gravid *E. schrenckii* from 6 August to 18 September 2008. One female laid her eggs in a rock fence, while the other two females laid their eggs in stream banks. Prior to oviposition, females remained at these sites for an average of 4.3 weeks. These three gravid females later selected the rock cliffs of mountains for hibernacula, while one non-gravid female selected rocks near an agricultural field, and another non-gravid female and two males selected stream banks for hibernacula. The snakes began moving into hibernacula between 1 November and 9 December and emerged from them between 12 April and 1 May, with a mean hibernation period of 21.4 weeks. Throughout the study period, snakes preferred edge habitat, seeking out the mouths of mountain valleys which often held stream banks. Such habitat may balance the needs of thermoregulation and shelter from predators, as well as provide an early survival advantage to newly hatched offspring emerging from stream banks or oviposition sites in similar edge habitats.

Therefore, based on the observed reduction of population size and habitat quality for which causes of reduction have not ceased, we recommend the species to be nationally listed as VU (criteria A2ac). Population reduction under A2 is unlikely to have reached 50 % but has crossed the 30 % threshold for VU based on direct observations (A2a) and habitat quality (A2c). Habitat quality is however expected to be very close to the 50 % threshold, and an analysis on habitat degradation could result in the species being transferred to the EN category. This assessment conforms with the latest NIBR report (NIBR, 2019), and the species has not yet been assess by the IUCN. In addition, we highlight that the impacts of climate change and habitat degradation are likely to increase in the future, and will likely result in the species listing under a higher threat level if the current patterns are maintained.

3.3. *Oocatochus rufodorsatus (frog-eating rat snake)*

Oocatochus rufodorsatus is another rat snake species found throughout the Korean peninsula. It is often associated with water bodies and preys heavily on amphibians. In a survey of lagoons along Korea's east coast, *O. rufodorsatus* was the second most encountered reptile species, succeeded only by the invasive turtle *Trachemys scripta elegans* (Lee, Park, Lee, Kim, & Ra, 2010). The IUCN considers *O. rufodorsatus* a species of least concern, given its wide distribution throughout northeast Asia, as well as its tolerance of disturbed habitats and a lack of major threats (Ineich, 2010). In Korea, however, this species has become more difficult to find in recent years, likely due to water pollution and habitat degradation (NIBR, 2011).

Radio telemetry has highlighted the importance of aquatic habitats to *O. rufodorsatus* populations, with the majority of tracked snakes, both male and female, found a mean distance of 10.3 m from a pond or wetland (Lee, Lee, & Park, 2011). The mean daily distance moved for males and females did not differ significantly and was negatively correlated with both air and water temperature. Regarding hibernacula, after excluding an individual which traveled 397 m, the mean distance from water that snakes moved to overwintering sites was 18.7 m (7.1–41.4 m; $n = 4$). Hibernacula were in dry terrestrial areas and all faced south or southeast. While home ranges for postpartum females were larger than those of antepartum females, home range size did not differ between males ($n = 5$) and females ($n = 16$). These findings suggest that protection of pond and wetland habitats, as well as their surrounding terrestrial hibernacula, is necessary for the conservation of *O. rufodorsatus* (Lee, Lee et al., 2011).

The introduction of American bullfrogs (*Lithobates catesbeianus*) in Korea presents another potential threat to Korean snakes, through predation and alteration of prey-predator systems (Park, Min et al., 2014; Park, Son et al., 2014). How Korean snakes have responded to the spread of invasive bullfrogs in general is largely unknown, but morphological changes observed in *O. rufodorsatus* suggest adaptations to prey on bullfrogs: relative tail length (tail length/snout-vent length) was greater for both adults and hatchlings of *O. rufodorsatus* from a bullfrog-exposed population, compared to individuals from a bullfrog-unexposed population (Heo et al., 2014). Greater relative tail length may help improve foraging efficiency by permitting greater burst locomotion in pursuit of agile prey like bullfrogs. In addition to morphological changes, adults from the bullfrog-exposed population responded to bullfrog scent with tongue flicking more quickly than adults from the bullfrog-unexposed population. This shorter latency to respond to bullfrog scent may hint at an adaptation that allows *O. rufodorsatus* to recognize prey more quickly and increase foraging efficiency.

Therefore, based on the wide extent of occurrence and area of occupancy of the species (criteria B), its expected large population size (criteria A) and widespread presence in a wide range of habitats, we agree with the LC status attributed by the NIBR and the IUCN. The impacts of climate change and habitat degradation are unlikely to strongly affect the species due to its association with agricultural landscapes.

3.4. Rhabdophis [tigrinus] lateralis (tiger keelback)

Rhabdophis tigrinus in Korea was recently reassigned to *R. [tigrinus] lateralis*, elevating the clade from subspecies to species (Takeuchi, Ota, Oh, & Hikida, 2012, 2014). *Rhabdophis [tigrinus] lateralis* is one of four species of venomous snakes found in Korea (Rha et al., 2015). Where toad prey is available, these snakes can also be poisonous, sequestering toxic bufadienolides from consumed toads in nuchal glands (Hutchinson et al., 2013), making this genus the only snake genus being both venomous and poisonous (Hutchinson et al., 2007). Though research has been conducted on the mainland North East Asian *Rhabdophis* clade elsewhere, little has been done on Korean populations. Much of what is known about this species in Korea stems from broader studies on the effects of roads on vertebrate movements (Park, Jeong et al., 2017; Seo et al., 2015). Studies on *R. tigrinus* in Japan suggest an exclusively anuran diet (Tanaka & Ota, 2002) and seasonal shifts in prey selection corresponding to the changing availability of frog species from spring to summer (Hirai, 2004). From a conservation perspective, the specialized diet of *R. [tigrinus] lateralis* may make this species more susceptible to environmental changes stemming from anthropogenic land use and/or climate change, given the potentially negative impacts of these factors on anuran prey.

In Worak Mountain National Park for example, though increased winter temperatures led to greater numbers of *R. [tigrinus] lateralis* observed in spring and summer, annual minimum temperature negatively affected amphibian species diversity and evenness (Lee, Ra et al., 2011). Additionally, *R. [tigrinus] lateralis* experienced the highest rate of vehicular mortality of ten snake species observed across six Korean national parks (Kim, Lee et al., 2018). Snake mortalities were most frequent on roads connecting forests and aquatic habitats. Given the foraging strategies and habitat use of *R. [tigrinus] lateralis*, road development is likely another factor affecting Korean populations of this species.

While the IUCN has not formally assessed this species to date, the NIBR lists *R. [tigrinus] lateralis* as Least Concern, citing its nationwide distribution, including Jeju Island (NIBR, 2018). However, the NIBR also notes that populations have been in recent decline due to poaching and habitat destruction (NIBR, 2011). Therefore, based on the wide extent of occurrence and area of occupancy (criteria B) of the species, its expected large population size (criteria A) and widespread presence on a wide range of habitats, we agree with the LC status attributed by the NIBR. We however suggest that while non-threatening to the species overall, the impacts of climate change and habitat degradation are likely to impact the species.

3.5. Lycodon rufozonatus (red-banded snake)

Formerly *Dinodon rufozonatum*, this species was reassigned to *Lycodon rufozonatus* after a phylogenetic and morphological study synonymized the genus *Dinodon* with *Lycodon* (Guo et al., 2013). A study in China's Anhui province revealed *L. rufozonatus* to inhabit plains and valleys more frequently than hilly terrain (Bao et al., 2011). *Lycodon rufozonatus* is largely nocturnal and feeds on a variety of prey, including toads, frogs, fish, lizards, snakes and nestling birds (Lee et al., 2012).

Given the significance of frogs in the diet of *L. rufozonatus*, the invasive American bullfrog could present a threat through its impact on native Korean anurans (Borzée, Kosch, Kim, & Jang, 2017; Groffen, Kong, Jang, & Borzée, 2019). However, a study in China (Li, Ke, Wang, Smith, & Liu, 2011) suggests the ability of *L. rufozonatus* to adapt to the presence of American bullfrogs and utilize them as an abundant prey source. In areas invaded by bullfrogs, the species made up 52.0 % of prey items consumed by *L. rufozonatus* and was the main prey item, followed by native rice frogs (*Fejervarya* sp.; 28.4 % of prey items consumed). The proportion of American bullfrogs in the diet of *L. rufozonatus* was positively correlated with its density in water bodies. In both artificial pond experiments and at invaded sites, *L. rufozonatus* preferred bullfrogs over native anuran species (Li et al., 2011).

Also, studies on similar clades may provide useful information to natural resource managers. A study on the natural history of *Lycodon orientale*, a Japanese endemic, found that seasonal activity patterns and body condition were comparable between males and females (Yamasaki & Mori, 2015). Both sexes had peak activity levels during September, coinciding with the emergence of hatchling snakes. Body condition of adults was lowest during the summer and highest at the beginning and end of the active season which generally began in early May and lasted through late October. *Lycodon rufozonatus* may exhibit similar activity patterns and confirmation could help with the planning of long-term monitoring programs to assess population trends and develop management policies.

A study on a single *L. rufozonatus* investigated its daily activity patterns and habitat use (Kim, Lee et al., 2013). The individual tracked was only active from 4 pm to 2 a.m., with a peak activity between 6 pm and 10 pm. However, the individual tracked could not be exactly located 92.3 % of the time because it was either under leaf litter or underground. When located (7.7 %), the individual was actively moving along the surface substrate or hiding up in trees. Further study on activity pattern on captive *L. rufozonatus* specimens suggested that the activity of this species increase significantly after sunset (Kim, Jang, Roh, & Park, 2015). In additions, *L. rufozonatus* suffers vehicular mortalities, and this species is frequently recorded during roadkill surveys (Kim, Kim et al., 2017, Kim, Lee et al., 2018).

Therefore, based on the wide extent of occurrence and area of occupancy of the species (criteria B), its expected large population size (criteria B) and widespread presence on a wide range of habitats, we agree with the LC status attributed by both the NIBR and the IUCN. We however point out that despite being non-threatening to the species as a whole at the moment, the impacts of climate change, habitat degradation and poaching are likely to impact the species (Li et al., 2017; NIBR, 2011) and the species has become extirpated at some localities in Korea (Shin, Jang, Allain, & Borzée, 2020).

3.6. *Hebius vibakari* (Japanese keelback)

Previously attributed to *Amphiesma vibakari*, the genus name reverted to *Hebius* following Guo et al. (2014). Little information is available about the ecology of this species in Korea, although group mating has been recorded (Koo, Chang, & Song, 2019). The species can be found throughout the mainland and on Jeju Island, where it is considered locally abundant. The population on the mainland however is likely to be declining due to habitat loss, and especially deforestation. *Hebius vibakari* is present around ponds and riverine zones in forested areas, where it feeds on small fish, amphibians, amphibian larvae and worms (NIBR, 2011; Song, 2007). Its occurrence in forested protected areas of Far East Russia further highlights the importance of forest habitat for this species, though it also occurs near populated areas, including villages and the edges of large cities (Maslova et al., 2018).

Despite its expected large extent of occurrence, the strong association with forest is likely to result in a low area of occupancy for the species and a severely fragmented population. In addition, because of habitat fragmentation, the species is unlikely to adapt to the impacts of climate change. Therefore, we do not agree with the LC status attributed by the NIBR and recommend the species to be nationally listed as NT based on criteria A and B. This species has not been assessed by IUCN yet.

3.7. *Orientocoluber spinalis* (slender racer)

Formerly assigned to *Hierophis spinalis*, this species was reassigned to *Orientocoluber* based on morphological, osteological, and zoogeographical characteristics (Kharin, 2011). A widespread species, *O. spinalis* is found in China, Kazakhstan, Russia, Mongolia, and Koreas (Maslova, 2016; Maslova et al., 2018; Webb, Jones, & Byers, 1962). *Orientocoluber spinalis* inhabits grasslands and lowland forests in Korea. While more numerous in the south, the population size of this species in Korea is expected to be low (NIBR, 2011), but it is best characterized by a general paucity of knowledge. *Orientocoluber spinalis* is known to be an intermediate host to the worm *Sparganum mansoni*, however, the study reporting this result also showed higher prevalence in common colubrids and viperidae (Cho, Hwang, & Seo, 1973). Therefore, *S. mansoni* is not expected to be a threat to the species.

Because of the low population size, and despite its expected large extent of occurrence, the impact of habitat degradation is likely to result in a low area of occupancy and a severely fragmented population. In addition, because of habitat fragmentation, the species is unlikely to adapt to the impacts of climate change. Therefore, we agree with the LC status attributed by the NIBR and recommend the species to be nationally listed as NT based on criteria A and B, and we agree on the need for population monitoring and habitat protection (NIBR, 2018). The species has not been assessed yet by the IUCN.

3.8. *Sibynophis chinensis* (Chinese many-toothed snake)

Originally assigned to *S. collaris* by Paik (1982), a morphological analysis reassigned the species to *S. chinensis* (Kim & Oh, 2006). Acceptance of the taxonomic change has been slow, and the species was still listed as *S. collaris* by the Ministry of Environment in 2012 (MOE, 2012). The range of *S. chinensis* is closer to Korea than that of *S. collaris*, though it is not present on the mainland Korean peninsula (Jang, Kim, & Jang, 2016). Group mating behavior has been observed in autumn, but the exact mating season is unknown (Koo, Kim, Yang, & Oh, 2018). Although incubation period in its natural habitat is unknown, a gravid female captured and housed in captivity laid six eggs which hatched after 34–41 days (Banjade et al., 2020). Regarding habitat use, individuals collected from 1998 to 2005 were principally found in grassland habitat, suggesting that such areas should be protected for the benefit of this species (Kim & Oh, 2005). More recent research revealed farms and forests as important habitats for *S. chinensis*, with snakes observed in these areas more often than in grasslands or urban areas (Koo, Park, & Oh, 2019). This species was generally more common between 300 and 700 m in elevation and human development occurring within this elevational range contributes to habitat loss. While exact figures are not available, the population size of *S. chinensis* in Korea is believed to be small (NIBR, 2014), and individuals are most often encountered between May and July, when individuals can also be found as a result of vehicular collisions.

Currently, *S. chinensis* is the only reptile species protected by the highest conservation priority of the Ministry of Environment (EN Class I; NIBR, 2018). Because of an extent of occurrence < 5000 km^2, linked to the distribution of the species being restricted to Jeju island, and an estimated continuing decline of EOO, AOO and quality of the habitat, along with extreme fluctuations in AOO (Do, Lee et al., 2017; Koo, Park et al., 2019), we agree with the NIBR and recommend the species to be nationally listed as EN based on criteria B1b(i,ii,iii)c(ii)). The species is listed as LC by the IUCN (China Snakes Working Group, 2014).

3.9. *Gloydius brevicaudus* (short-tailed mamushi)

Three species of *Gloydius* have been described on the Korean Peninsula, and diversification of the genus is expected to have occurred about 9.89 m.y.a. (Xu et al., 2012). While most of the work conducted for this genus was in regard to envenomation (Han et al., 2018; Rha et al., 2015), the species are expected to be common and locally abundant (Lee, Park, Lee, Kim, & Ra, 2010). The three *Gloydius* species exhibit parapatric distribution patterns in Korea (Do et al., 2016) and a potential hybrid between *G. brevicaudus* and *G. saxatilis* was reported from Sobaek Mountain National Park (Do, Koo, & Song, 2019).

Gloydius brevicaudus is commonly found throughout the mainland Korean peninsula, but not on Jeju island. The species prefers field embankments connected to mountains, where it feeds on anurans, small rodents and grass lizards (*Takydromus* sp.; Shim et al., 1998). This species was one of the five species that were most heavily affected by vehicular mortalities (95 individuals, 12.9 %) during surveys conducted by Kim, Lee et al. (2018). It is also commonly poached for traditional medicine, and was incidentally found to carry nematodes (Choe et al., 2016).

Gloydius brevicaudus is listed as Least Concern in Korea (NIBR, 2018) and it has not been assessed yet by the IUCN. Therefore, based on the wide extent of occurrence and area of occupancy of the species (criteria B), its expected large population size (criteria A) and widespread presence on a wide range of habitats, we agree with the LC status attributed by the NIBR. The impacts of climate change and habitat degradation are unlikely to significantly impact the species due to its association with agricultural landscapes.

3.10. *Gloydius ussuriensis* (Ussuri mamushi)

Gloydius ussuriensis is one of the most commonly found snake species throughout mainland Korea and the surrounding islands, including Jeju (Jang et al., 2016). However, the population size of this species has been declining in Korea due to poaching (Shim et al., 1998). Furthermore, *G. ussuriensis* is one of the species most heavily affected by road developments and it is frequently recorded during roadkill surveys (Kim, Kim, Lee, Kim, & Park, 2013, 2017; Kim, Lee et al., 2018).

Gloydius ussuriensis is primarily a low altitude species and is heavily associated with the availability of water (Do & Yoo, 2014). Amphibians are primary prey species for *G. ussuriensis,* and comparison of microhabitat use by this snake and amphibians in water valleys revealed no significant differences. Amphibians accounted for 55.2 % of the diet of individuals on Jeju Island, while those on Gapa Islet fed exclusively on centipedes and lizards, potentially due to the density of alternative prey (Kim & Oh, 2014). *Gloydius ussuriensis* is expected to be sedentary, and individuals on Gapa Islet have home ranges between 8 and 167 m^2 (Kim & Oh, 2015), although these limited home ranges may stem from the limited availability of habitat on the islet, as much of it (0.87 km^2) is farmland.

Therefore, based on the wide extent of occurrence and area of occupancy of the species (criteria B), its expected large population size (criteria A) and widespread presence on a wide range of habitats, we agree with the LC status attributed by the NIBR. The impacts of climate change and habitat degradation are unlikely to significantly impact the species due to its association with agricultural landscapes. The species has not been assessed by the IUCN yet.

3.11. Gloydius saxatilis (rock mamushi)

Despite being assigned to a junior synonym of *G. intermedius* by some authors (Orlov & Barabanov, 1999), here we retain the name *G. saxatilis* following Xu et al. (2012). *Gloydius saxatilis* can be found in high altitude (Do, Nam, & Yoo, 2017), mountainous habitats of Korea and feeds on mice, squirrels, and anurans. This species is rarely found compared to the other two *Gloydius* species due to its habitat preference, and it is not present on Jeju island. In Korea, *G. saxatilis* is threatened by poaching because it is sold for a high price in illegal wildlife markets (Shim et al., 1998). Although present at low densities, this species is also affected by roadkill, especially on mountainside roads: *G. saxatilis* accounted for 25 of 736 snake roadkills (3.4 %) recorded during a nine-year survey of six Korean national parks (Kim, Lee et al., 2018).

Three courting pairs of *G. saxatilis* were observed in Chunma Mountain County Park, the first observation in September 2012 and the last two in August 2013 (Do, Nam, & Yoo, 2017). Males and females largely exhibited courtship behaviors typical of species from the family Viperidae, however females also exhibited an unusual "quivering" behavior, vibrating their bodies rapidly for one or more seconds. Following this behavior, males ceased courtship or separated themselves from the females. This behavior has not been reported in females of other viperid species.

A study using a combination of radio telemetry and translocations demonstrated that *G. saxatilis* translocated to lower elevations tended to move along an increasing altitudinal gradient, seeking out original habitats, while control individuals tended to move along their original altitude (Do, Nam, Nam et al., 2017). These results suggest that altitude is a limiting factor in the distribution of *G. saxatilis.*

Based on its wide extent of occurrence and area of occupancy (criteria B), the IUCN assessed *G. saxatilis* as LC (Guo, 2010), a designation mirrored in Korea (NIBR, 2018). While we agree with this assessment, we note that climate change is likely to have a strong impact on the species as it is generally not present at low elevation.

4. Sauria

4.1. Takydromus amurensis (Amur grass lizard)

Takydromus amurensis generally occurs on forested hills and mountains and it is frequently observed on roadside and mountain trails. This species is affected by mountainside developments and subjected to the risks of vehicular mortality. It is abundant across Korea but not present on Jeju island and the population is declining (Jang et al., 2016).

Based on the wide extent of occurrence and area of occupancy of the species (criteria B), its expected large population size (criteria A) and widespread presence in a wide range of habitats, we agree with the LC status attributed by the NIBR (2011). We however point out that despite being non-threatening to the species as a whole, habitat degradation is likely to increase and will negatively impact the species.

4.2. Takydromus wolteri (mountain grass lizard)

The habitats of *T. wolteri* is characterized by home ranges < 50 m^2 in grassland all across Korea (NIBR, 2011). Habitat degradation has shown to be strongly associated with population decline and further development of grasslands and the use of herbicides are expected to threaten the species further (Jang, 2011). The population of *T. wolteri* in Korea is declining but the species is currently nationally listed as LC (Jang et al., 2016; NIBR, 2011). The species has not been assessed by the IUCN. Based on the wide extent of occurrence of the species (criteria B) and its expected large population size (criteria B), we agree with the LC status. We however suggest that while non-threatening to the species overall, the effects of climate change and habitat degradation are likely to increase and will negatively impact the species.

4.3. Eremias argus (Mongolia racerunner)

Eremias argus is the only lacertid that has been listed as threatened in Korea (EN class II; NIBR, 2014), although updated as VU in the latest update (NIBR, 2019). In Korea, this species is mostly associated with riverside sand dunes for breeding (Kim, Kim, Kim, & Park, 2010) but it is also found in grasslands and mountain foothills with low tree cover on the western side of the country (Do, Lee et al., 2017; Kim, Kim, Kim, & Park, 2010). Radio-tracked individuals in one coastal dune almost exclusively used grass dune habitat year-round, including as hibernacula (Kim, Ra, & Park, 2012). Mean home range size for these individuals was 122.8 m^2. Home range estimates for four marked individuals in Taean-Haean Coast National Park ranged from 4 m^2 to 84 m^2 (Song, Koo, & Chang, 2010). The population size at this location was estimated to be between 226 and 796 individuals (Song, Chang, & Koo, 2013). The principal threat to *E. argus* is riverside construction such as channeling and subsequent habitat degradation (Kim, 2010; Kim, Lee et al., 2011; Kim, Kim, Kim, Ra, & Park, 2011). The population size of *E. argus* in Korea has been declining sharply, with an estimated > 70 % decrease over the past ten years (NIBR, 2011) and has been reported to be under threat of extinction in the near future at specific localities (Jang et al., 2016). For instance, this species was abundant in the area surrounding Seoul in the 1950's, but it is now extirpated from this region following urbanization (Shin, Jang, Allain, & Borzée, 2020). The species has been assessed as LC by the IUCN (Orlova, Terbish, Zhao, & Guo, 2019).

Therefore, based on the observed reduction of in both population size and habitat quality, for which causes of reduction have not ceased, and unlikely to change in the future, we recommend that *E. argus* be nationally listed as EN (A2abc + A4abc). Population reduction under A2 is unlikely to have reached 80 % but has clearly crossed the 50 % threshold for EN, from direct observations, index of abundance and habitat quality. Besides, the current threats to the species are unlikely to change in the future, based on the current rate of habitat conversion. This assessment does not reflects the latest national assessment as VU (NIBR, 2019) and should be used for a first assessment by the IUCN. In addition, we highlight that the impact of climate change is likely to increase in the future, with the species unable to follow the shift in adequate habitat because of habitat fragmentation.

4.4. Scincella vandenburghi (Tsushima smooth skink)

Scincella vandenburghi is distributed across Korea at various altitudes, in habitats ranging from humid forests to agricultural lands (Chang, Song, Lee, & Oh, 2006). The population size of *S. vandenburghi* increases with decreasing latitude (Song, 2007) but the overall population size of this species is decreasing because of habitat degradation and development (Jang et al., 2016). *Scincella vandenburghi* is listed as LC in Korea (NIBR, 2011) and globally by the IUCN (Ota, 2010), to which we agree based on the wide extent of occurrence of the species (criteria B) and its expected large population size (criteria A). We however suggest that while non-threatening to the species overall, the effects of climate change and habitat degradation are likely to increase and will negatively impact the species.

4.5. *Scincella huanrenensis*

Scincella huanrenensis is an ovoviviparous skink species known from Liaoning province in China, and several locations in Korea (Dong, Wang, Zhou, Lu, & Li, 2007). Mostly known from Gangwon Province, an additional locality was found in Juwangsan National Park in North Gyeongsang Province (Koo, Kwon, Chang, & Song, 2020). The habitat of this species is restricted to mountains of elevation greater than 400 m, where it is generally found hiding under rocks, fallen logs and in the leaf litter (Chang et al., 2006; Song, 2007). The degradation of forests for development is the main threat to this species throughout its range (Dong, 2005; Kim et al., 2015). *Scincella huanrenensis* is rare and observed infrequently, with a population size estimated to be small and fragmented (Jang et al., 2016), resulting in the species being listed as NT in Korea (NIBR, 2019). The species was mistakenly assessed by the IUCN using the population at the type locality only, resulting in a biased CR listing (Zhao & Li, 2019).

Based on a polygon drawn from the distribution of the species (data from GBIF.org downloaded on 10 September 2019), the species EOO is < 5000 km^2, with an observed continuing decline in EOO and area, and fluctuations in the number of locations. Under these criteria we recommend the species to be nationally classified as EN (B1bc(i,iii)).

4.6. *Gekko japonicus* (Schlegel's Japanese gecko)

The distribution of *G. japonicus* in Korea is restricted to some isolated patches in the southern regions (Kim, Bae, Kim, Kim, & Borzée, 2017, 2019; Stejneger, 1907), with the western population a possible recent colonization (NIBR, 2011). Radio-tracked individuals in an introduced suburban population were often found on artificial structures and nearby trees and exhibited considerable overlap in home range (Park, Kim, Fong, & Park, 2019). The population size is estimated to be small, although reliable information on population trends of this species in Korea is not available (Song et al., 2012). This species has not been assessed yet in Korea due to lack of information (NIBR, 2011), although listing as VU or EN was recommended based on the limited distribution and the low number of mature individuals (Kim et al., 2015). The IUCN assessed *G. japonicus* as LC, though this assessment does not appear to include Korean populations and is likely based on the species' wider distribution and presumed stable population trend (Yan, Cai, Wang, Yang, & Ota, 2019).

The species is restricted to sub-populations in Busan, Changwon and Mokpo (data from GBIF.org, downloaded on 10 September 2019), with extremely restricted EOO < 5000 km^2 and AOO < 20 km^2 (criteria B). While there is no indication the population size is declining as it is mostly found within cities, it is present in small numbers, and urban planning affecting the few neighborhoods where the species is present could result in its extinction (criteria A). Therefore, we recommend the species to be listed as VU (D2).

5. Conclusion

The summary presented here for 17 Korean squamates supports a generally similar assessment from the one provided by the Korean agency in charge of Red Listing, and the IUCN Red List (Table 3). While we estimated *Elaphe schrenckii* to be VU, the status of the species is likely to change in view of habitat destruction. On the other hand, we recommended listing under a higher threat level than the one recommended by either the NIBR or the IUCN Red List for *Hebius vibakari*, *Eremias argus*, *Scincella huanrenensis* and *Gekko japonicus*. Our results highlight that conservation plans are urgently needed for Korean squamates, mostly because of the generalised habitat destruction nationwide.

The status of the species is likely to change once additional data become available and population sizes are known, but also in case of potential pathogen introduction such as the snake fungal disease (*Ophidiomyces ophiodiicola*). Finally, these assessments are regional and only weakly reflect the threat status on the whole range of any of the species as none is endemic to the Republic of Korea.

Table 3
List of squamate species in the Republic of Korea and details on threat level, following the IUCN red list of species and the ranking given by the Korean Ministry of Environment. IUCN: DD = data deficient, LC = least concerned, NT = near threatened, VU = vulnerable, EN = endangered, CR = critically endangered, EW = extinct in the wild, EX = extinct and NE = not evaluated. Ministry of Environment: Class I - species have experienced drastic population declines due to natural or anthropogenic factors; Class II - species have experienced significant declines and face extinction in the near future in the absence of mitigating measures.

Scientific name	Threat status (IUCN Red List)	Threat status (Korean red list)	Conclusion of this review
Elaphe dione	LC	LC (declining)	LC, declining
Elaphe schrenckii	NE	VU	VU (A2ac)
Oocatochus rufodorsatus	LC	LC (declining)	LC, stable
Rhabdophis [tigrinus] lateralis	NE	LC (declining)	LC, stable
Lycodon rufozonatus	LC	LC (declining)	LC, stable
Hebius vibakari	NE	LC	NT, declining
Orientocoluber spinalis	NE	NT	NT, declining
Sibynophis chinensis	LC	EN (class I)	EN (B1b(i,ii,iii)c (ii))
Gloydius brevicaudus	NE	LC	LC, Stable
Gloydius ussuriensis	NE	LC	LC, Stable
Gloydius saxatilis	LC	LC	LC, Declining
Takydromus amurensis	NE	LC	LC, stable
Takydromus wolteri	NE	LC	LC, stable
Eremias argus	LC	VU	EN (A2abc + A4abc)
Scincella vandenburghi	LC	LC	LC, stable
Scincella huanrenensis	CR	NT	EN (B1bc(i,iii))
Gekko japonicus	LC	NE	VU (D2)

Declaration of Competing Interest

The authors report no declarations of interest.

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