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Do not leave understudied species behind: Ecological adaptations, demography, and threat analysis of an endemic *Gekko* species in northern Vietnam for conservation purposes

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Abstract. One of the major obstacles that limits the effectiveness of conservation efforts in many species is the lack of knowledge concerning their threat status. The recently described species, *Gekko canhi*, is a gecko endemic to northern Vietnam. As a range-restricted species being found only in limestone karst forests, it is imperilled by human impacts, including habitat degradation and climate change. In this study, we carried out fieldwork at the type locality in Huu Lien Nature Reserve of Lang Son Province to obtain data on the ecological requirements, population demography, and threats to the species. *Gekko canhi* is identified as a rock-adapted inhabitant of evergreen karst forests with high vegetation coverage, requiring stable microclimatic conditions and dry substrates. Population density proved to be very low, rendering the species vulnerable to ongoing anthropogenic impacts such as forest conversion and limestone mining. To protect it together with the co-existing fauna and flora in their unique karst forest habitats, we recommend reinforcing in situ conservation measures in concert with community education initiatives.

Key words. Squamata, Gekkonidae, *Gekko canhi,* human impacts, Huu Lien Nature Reserve, karst forest, population density, rock specialist.

Introduction

The genus *Gekko* is a diverse lizard group containing more than 85 species (Uetz et al. 2023). There seems to be no end to the description of new *Gekko* species from extensive taxonomic reassessments of species complexes and new discoveries from remote areas. Accordingly, nearly 30% of the known *Gekko* species have been discovered in the last ten years (Uetz et al. 2023). In terms of conservation concerns, a total of 14 species have been assessed as globally threatened in the IUCN Red List (Critically Endangered – CR: 1 species; Endangered – EN: 2 species; and Vulnerable – VU: 11 species) (Iucn 2023). Based on morphological and molecular analyses, 17 species of *Gekko* have been recorded from Vietnam, which are assigned to five distinct groups: the *Gekko japonicus* group with five species (*G. adleri, G. canhi, G. palmatus, G. scientiadventura,* and *G. truongi*), the *Gekko gecko* group with two species (*G. gecko* and *G. reevesii*), the *Gekko petricolus* group with seven species (*G. badenii, G. canaensis, G. grossmanni,*

G. phuyenensis, G. russelltraini, G. takouensis, and *G. vietnamensis*) and the *Gekko lionotum* group with two species (*G. kabkaenbin* and *G. tokehos*), and *G. trinotaterra*, which previously were classified as *Ptychozoon* (Ngo & Gamble 2011, Phung & Ziegler 2011, Nguyen et al. 2013, Zang et al. 2014, Luu et al. 2017, Grismer et al. 2019, Wood et al. 2020, Nguyen et al. 2021). First found in Lang Son and Lao Cai provinces, northern Vietnam, *G. canhi* was described as a new species based on its morphological distinction from all congeners (Rösler et al. 2010). Being syntopic with a threatened Tiger Gecko (i.e., *Goniurosaurus huuliensis*), Ngo et al. (2021) noted that wild populations of *G. canhi* and its habitats may potentially be imperilled by anthropogenic activities (e.g., rock mining, timber logging, poaching and climate change). As a consequence, Ngo et al. (2022b) recommended certain conservation measures be implemented. However, no specific conservation action plan has as yet been developed to protect the endemic *G. canhi* due to a lack of knowledge about its biology.

In this study, we carried out surveys at the type locality of *G. canhi* (i.e., Huu Lien Nature Reserve – NR) to evaluate the conservation status of this species. Based on data obtained, we conducted analyses of its morphological adaptations, demography, microhabitat selection, and potentially threatening factors. We expected that the species has a small population density and is adapted to a unique microhabitat. If true, *G. canhi* may be particularly vulnerable to ongoing human impacts in Huu Lien NR and conservation measures would urgently be required.

Materials and methods

Field surveys

Our study site was selected within the known distribution of *G. canhi*, viz. around the type locality in Huu Lien NR, Lang Son Province, based on previous observations, literature, and interviews with local people (Orlov et al. 2008, Rösler et al. 2010). The landscape of Huu Lien NR is predominantly evergreen forests on limestone karst formations in an area of 9,734 ha, ranging from 100 to 638 m a.s.l. (Fig. 1) (Anon 1990). Four transects (T1 to T4) were set up along forest paths or patrol trails of forest rangers. The length and area of each survey transect were measured to evaluate the population density (see details below), using Quantum GIS software (QGIS Version 3.12.0, Development Team. 2020; available online at http://qgis.osgeo.org [accessed in December 2022]). The lengths of the surveyed transects ranged from 0.52 to 0.78 km and covered areas of between 0.83 and 2.1 km² (Table 1). We carried out two or three surveys per transect per month, always during the active season of the species in May, July, and October, in 2022. To ensure a high detection probability, transect surveys were carried out between 1900. and 2400 hrs, since the target species is nocturnal and spends the day hidden in rocky crevices (Rösler et al. 2010). Each survey was conducted by at least two researchers and a ranger. All geckos encountered were captured by hand and subsequently released at their points of collection after taking photos, recording habitat parameters, and taking measurements.

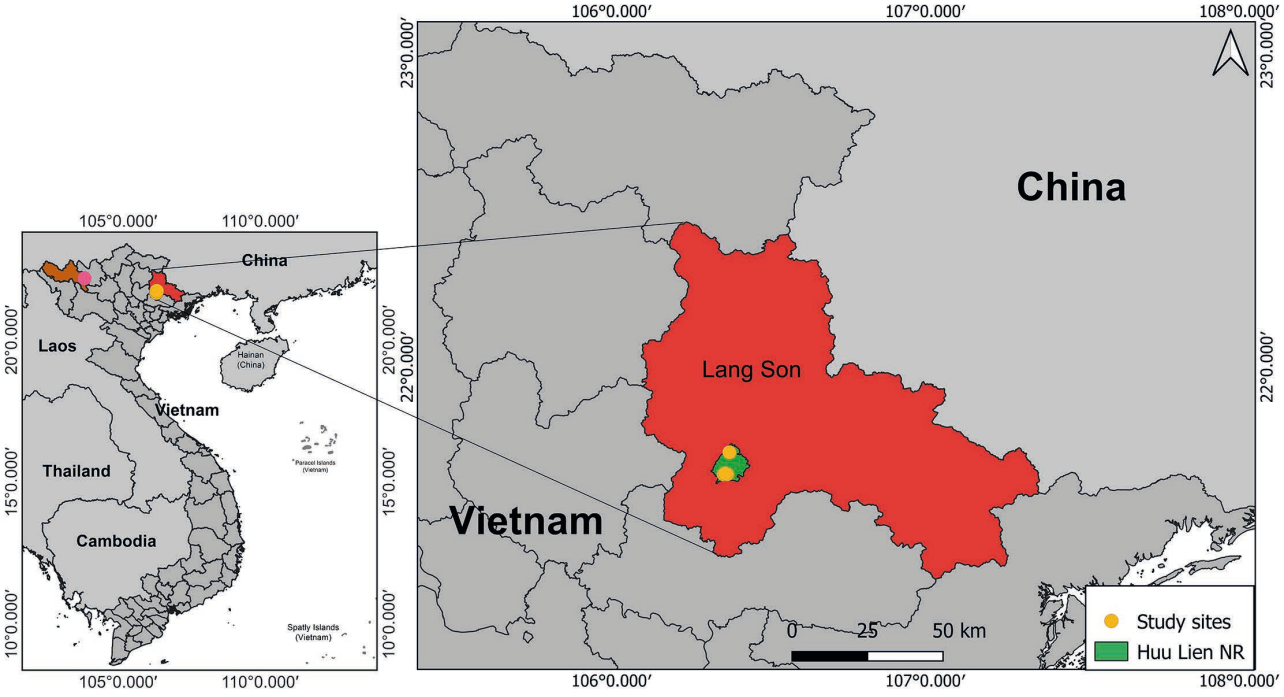

Figure 1. Map of study sites in Huu Lien Nature Reserve, Lang Son Province (yellow circles) and locality of the paratype of *Gekko canhi* in SaPa, Lao Cai Province (pink circle), Vietnam.

Table 1. Morphological characteristics of *Gekko canhi* (mean ± standard deviation, minimum – maximum); measurements of length are given in mm.

Characteristics	Juveniles (n = 14)	Females (n = 44)	Males (n = 34)
SVL	58.5 ± 2.86 (43.4–71.9)	90.9 ± 1.4 (75.6–105.5)	87.3 ± 1.3 (75.0–97.0)
TL	65.5 ± 3.1 (51.9–83.5)	90.7 ± 3.4 (21.3–115.5)	86.7 ± 3.6 (27.2–111.1)
AG	27.7 ± 1.4 (20.4–35.45)	46.0 ± 0.9 (34.2–60.2)	42.7 ± 0.8 (33.3–49.8)
BW	9.02 ± 0.4 (7.0–10.4)	15.04 ± 0.5 (10.5–20.6)	14.3 ± 0.4 (10.2–17.6)
BH	6.14 ± 0.4 (4.9–9.0)	8.6 ± 0.3 (5.9–12.2)	8.3 ± 0.3 (5.8–11.5)
HL	17.9 ± 0.96 (13.2–20.6)	24.5 ± 0.4 (20.4–28.7)	24.9 ± 0.5 (21.2–27.6)
HW	12.9 ± 0.6 (10.0–15.5)	18.1 ± 0.3 (13.7–20.9)	18.3 ± 0.4 (15.0–20.4)
HH	6.3 ± 0.24 (5.1–7.2)	8.7 ± 0.2 (6.4–10.7)	8.8 ± 0.2 (6.9–11.0)
CH	5.3 ± 0.2 (4.6–6.1)	7.1 ± 0.2 (5.3–8.7)	7.3 ± 0.2 (5.9–8.7)
MW	11.9 ± 0.7 (9.0–14.1)	16.4 ± 0.3 (12.9–19.96)	16.4 ± 0.3 (13.6–18.9)
ML	11.3 ± 0.8 (7.2–14.7)	16.7 ± 0.3 (14.0–19.5)	16.7 ± 0.3 (12.95–18.5)
IO1	6.6 ± 0.3 (5.2–8.0)	9.3 ± 0.2 (7.3–10.98)	9.3 ± 0.2 (7.7–10.8)
IO2	9.6 ± 0.45 (7.5–10.96)	13.2 ± 0.3 (10.3–16.5)	13.4 ± 0.3 (11.2–15.6)
SE	7.1 ± 0.3 (5.0–8.0)	10.0 ± 0.2 (8.3–12.5)	9.97 ± 0.2 (8.2–11.5)
ED	4.9 ± 0.2 (4.0–5.5)	6.8 ± 0.1 (5.3–8.0)	7.0 ± 0.1 (5.8–8.2)
EE	5.5 ± 0.15 (4.8–6.0)	7.4 ± 0.1 (6.1–8.8)	7.4 ± 0.2 (6.0–9.0)
AD	2.7 ± 0.2 (1.7–3.4)	3.6 ± 0.1 (2.8–4.3)	3.7 ± 0.1 (3.0–4.1)
FFL	24.1 ± 1.3 (18.0–29.2)	34.6 ± 0.5 (27.5–39.4)	34.9 ± 0.6 (29.5–39.2)
HLL	30.2 ± 1.7 (22.0–36.95)	44.2 ± 0.7 (35.4–50.9)	44.2 ± 0.7 (36.6–48.0)

Morphological characteristics

A total of nineteen phenotypic characteristics were measured in the field with dial callipers to the nearest 0.1 mm at the right side of the body of each individual. Abbreviations: AD = diameter of auditory meatus; AG = axilla to groin distance, from posterior edge of forelimb insertion to anterior edge of hindlimb insertion; BH = maximum body height, from top of dorsum to belly; BW = maximum body width, greatest width of torso, taken at level of midbody; CH = cheek height, from posterior edge of labial to top of head in the parietal region; ED = diameter of eye, greatest diameter of orbit; EE = eye to ear distance, from posterior margin of eye to posterior margin of ear opening; FFL = forelimb length, from axilla to the tip of the fourth finger; HH = maximum head height; HL = head length, from the tip of snout to posterior edge of occiput; HLL = hindlimb length, from groin to the tip of the fourth toe; HW = maximum head width; IO1 = interorbital distance, between anteriormost points of eyes; IO2 = interorbital distance, between posteriormost points of eyes; ML = mouth length, from tip of snout to last posterior labial edge; MW = mouth width, distance between last posterior labial edges on each side; SE = snout to eye distance, measured from tip of snout to anteriormost point of eye; SVL = snout–vent length, from tip of snout to vent; TL = tail length, from vent to tip of tail;

Population demography

To assess the population structure of *G. canhi*, geckos were categorized into two age classes based on their snout–vent lengths (SVL < 75 mm = juveniles, SVL ≥ 75 mm = adults, which is when males and females can be clearly identified based on external morphological characteristics). Sexing of adults was based on the presence of large, swollen hemipenial bulges indicating males, whereas their absence indicated females. Population densities of *G. canhi* were calculated on the basis of total individuals per kilometre (individuals/km) and per area (individuals/km²) relative to each surveyed transect and day, including recaptured individuals (i.e., individuals/km/day and individuals/km²/day). Each newly encountered individual of *G. canhi* was marked with a permanent pen (Edding Eraser) to identify recaptures in each monthly survey.

Microhabitat selection

Regarding microclimatic parameters, air temperature (°C) and relative humidity (%) were measured with a digital thermometer (TFA Dostmann/Wertheim Kat. No. 30.5015) at the location where geckos were captured. We used an infrared thermometer (Measupro IRT20) to measure temperatures (°C) at the substrate surface and at the ventral body surface of animals. We furthermore documented the weather conditions (raining or not) of each survey day.

Assessing the microhabitat, we recorded the following characteristics: substrate type (classified as rock, dead wood, branch, leaves), substrate condition (dry or wet), height (vertical distance from the ground to the animal, in m), exposure (outside or inside cave/crevice), and canopy (percentage of vegetation coverage above each animal – estimated by direct observation). The activity status of each

Table 2. Number of observed individuals of, and monthly density variation in, *Gekko canhi* (recaptured individuals in brackets); ind = individuals; obs = observations; Mean-values are presented in bold.

Parameters	Transect 1	Transect 2	Transect 3	Transect 4	Total-**Mean**
Transect length (km)	0.52	0.55	0.55	0.78	2.4
Area (km²)	0.83	0.85	0.83	2.1	4.61
May 2022					
Total obs	7	17 (2)	7 (1)	-	31 (3)
Adults obs	6	13	6	-	25
Density (ind/km)	13.5	30.9	12.7	-	**19.0**
Density (ind/km/day)	4.5	11.5	4.8	-	**6.9**
Density (ind/km²)	8.4	20.0	8.4	-	**12.3**
Density (ind/km²/day)	2.8	7.45	3.2	-	**4.5**
July 2022					
Total obs	2	1	5	-	8
Adults obs	1	1	3	-	5
Density (ind/km)	3.8	1.8	9.1	-	**4.9**
Density (ind/km/day)	1.9	1.8	4.5	-	**2.8**
Density (ind/km²)	2.4	1.2	6.0	-	3.2
Density (ind/km²/day)	1.2	1.2	3.0	-	**1.8**
October 2022					
Total obs	20 (2)	19	16 (3)	1	56 (5)
Adults obs	19	18	12	1	50
Density (ind/km)	38.5	34.5	29.1	1.3	**25.8**
Density (ind/km/day)	14.1	11.5	11.5	1.3	**9.6**
Density (ind/km²)	24.1	22.4	19.3	0.5	**16.6**
Density (ind/km²/day)	8.8	7.5	7.6	0.5	**6.1**

animal was recorded as resting, feeding or moving. Coordinates of captured individuals, together with altitude, were recorded with a Garmin 64 GPS. The specific coordinate data can be requested from the authors.

Threat assessment

Day excursions were carried out to obtain evidence of anthropogenic activities (such as deforestation, agriculture, and poaching) within the Huu Lien NR and its surroundings. We documented the information through our direct observations and interviews with local communities.

Results

Morphological characteristics

The mean snout–vent length (SVL) of juveniles was 58.5 ± 2.86 mm (range 43.4–71.9 mm), that of adult females was 90.0 ± 1.4 mm (range 75.6–105.5 mm), and of adult males 87.3 ± 1.3 mm (range 75.0–97.0 mm) (Fig. 2, Table. 1). Mean values and ranges (minimum–maximum) of the other morphological characteristics recorded from juveniles, females and males of *G. canhi* are summarized in Table 1 and illustrated in Figure 2.

Population status

We observed a total of 95 individuals of *G. canhi* along the four surveyed transects in three different months. The highest number of individuals (56, including 50 adults) was observed in October, whereas May yielded 31 (including 25 adults) and July eight (including five adults) (Table 2). We noted eight recaptures within these months.

There was considerable variation in observed population densities across the survey months. The highest population densities were recorded in October with a mean of 9.6 individuals/km/day and 6.1 individuals/km²/day, while densities were lower in May with a mean of 6.9 individuals/km/day and 4.5 individuals/km²/day, and lowest in July with a mean of 2.8 individuals/km/day and 1.8 individuals/km²/day. The overall highest population density was documented along transect T1 in October with 14.1 individuals/km/day and 8.8 individuals/km²/day, whereas the lowest was documented in transect T4 in October with only 1.3 individuals/km/day and 0.5 individuals/km²/day.

We also documented a monthly variation in the population structure. In particular, adult males accounted for the major proportion of 48.4% in May, while the observed population of *G. canhi* consisted mainly of juveniles and adult females (37.5%, respectively) in July and adult females (55.4%) in October (Fig. 3).

Microhabitat selection

All geckos were recorded within evergreen broadleaf forest on karst formations, covered with medium and small woody trees, intermixed with ferns, shrubs and vines (Fig. 4). In Huu Lien NR, the species was found at low altitudes from 150 to 342 m a.s.l. (Table 3). The geckos examined had an average body temperature of 22.15°C ± 0.25 (18.9–28.7°C, n = 86). Regarding environmental conditions, substrate temperatures ranged from 18.9–28.5°C (22.2 ± 0.23°C, n = 89), air temperatures from 18.6–27.8°C (23.3 ± 0.27°C, n = 70) and relative humidity from 66–92% (79.22 ± 0.8%, n = 69) (Fig. 5, Table 3).

Table 3. Microhabitat characteristics of *Gekko canhi* in Huu Lien Nature Reserve.

Parameters	Number	Min–Max	Mean ± SE
Altitude a.s.l. [m]	94	150–342	208 ± 2.38
Humidity [%]	69	66.0–92.0	79.22 ± 0.79
Air temperature [°C]	70	18.6–27.8	23.28 ± 0.27
Substrate temperature [°C]	89	18.9–28.5	22.22 ± 0.23
Animal ventral surface temperature [°C]	86	18.9–28.7	22.15 ± 0.25
Canopy cover [%]	87	0–100	76.26 ± 3.33
Perch height above ground [m]	92	0.2–3.0	1.21 ± 0.06

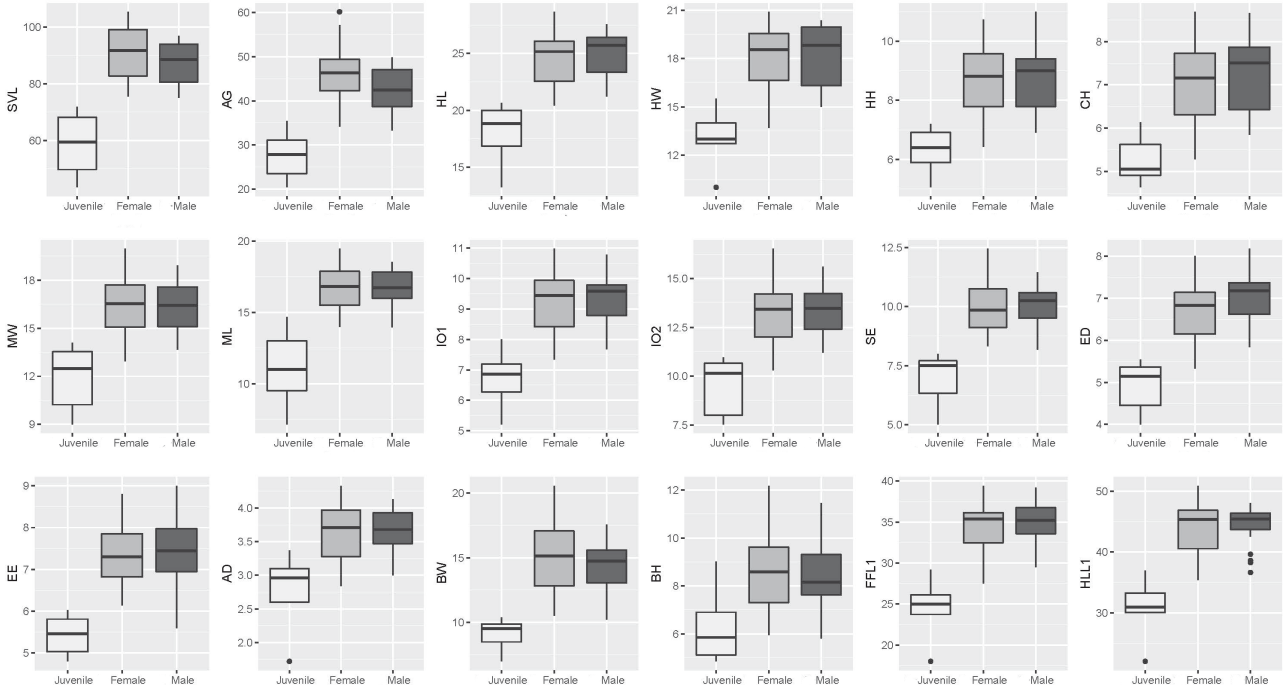

Figure 2. Box plots of eighteen morphological characteristics of *Gekko canhi*.

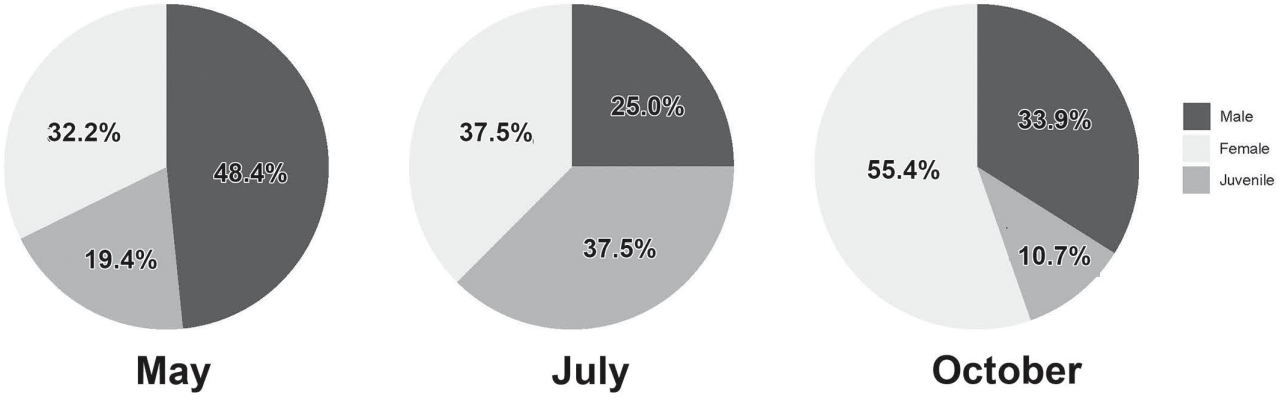

Figure 3. Monthly variation in the population structure of *Gekko canhi* in Huu Lien Nature Reserve.

The vast majority of geckos were encountered on rock substrates (94.6%, n = 88), followed by a very few that were perched on dead wood (3.2%), and only 2.2% were spotted on trees (Branches – 1.1% and Leaves – 1.1%) (Figs 4, 6). On these substrates, the geckos preferred dry (78.5%) rather than wet conditions (Fig. 6). The majority of individuals were encountered outside their shelters (75%) and in a state of rest (96.8%) (Fig. 6). Residing spots of *G. canhi* were identified mostly under a dense canopy cover with a mean of 76.3 ± 3.33% (n = 87) (Fig. 5, Table 3). We found the geckos at an average height above the ground of 1.2 ± 0.06 m (0.2–3.0 m, n = 92) (Fig. 5, Table 3).

Threats

According to interviewed local rangers and communities, *G. canhi* is so far not collected for the pet trade and/or traditional uses (e.g., medicine and food).There is no evidence of this species being offered in the national and international pet trade. However, other human impacts, such as road construction and cement manufacturing in Lang Son Province have destroyed parts of the natural habitat of *G. canhi* and syntopic animals (including the critically endangered Tiger Gecko, *Goniurosaurus huuliensis*) (Fig. 7). Furthermore, timber logging has strongly fragmented a large area of protected forests in Huu Lien NR, which have been gradually replaced by industrial crops or grassland (Fig. 7).

Discussion

Population status

This is the first study to evaluate the population status of the endemic gecko *Gekko canhi* in Huu Lien NR, Lang Son Province, northern Vietnam. As a result of surveys during three different months, we recorded a considerable variation in observed individuals and population densities. In particular, the highest values were documented along most transects in October, whereas only a few individuals (eight) were observed, and low densities (2.8 individuals/km/day and 1.8 individuals/km^2/day) were calculated in July. This difference could be explained by unstable environmental conditions of the tropical monsoon climate during the survey months. In July, extremely high air temperatures (nearly 40°C) during the day and/ or heavy rains at night might offer suboptimal conditions for the gecko foraging (Phan pers. obs). Being poikilotherms, the activity and performance of these geckos are greatly influenced by ambient temperatures (Van Schingen et al. 2015, Ngo et al. 2018, Ngo et al. 2019a, Vicente et al. 2019). Similar observations

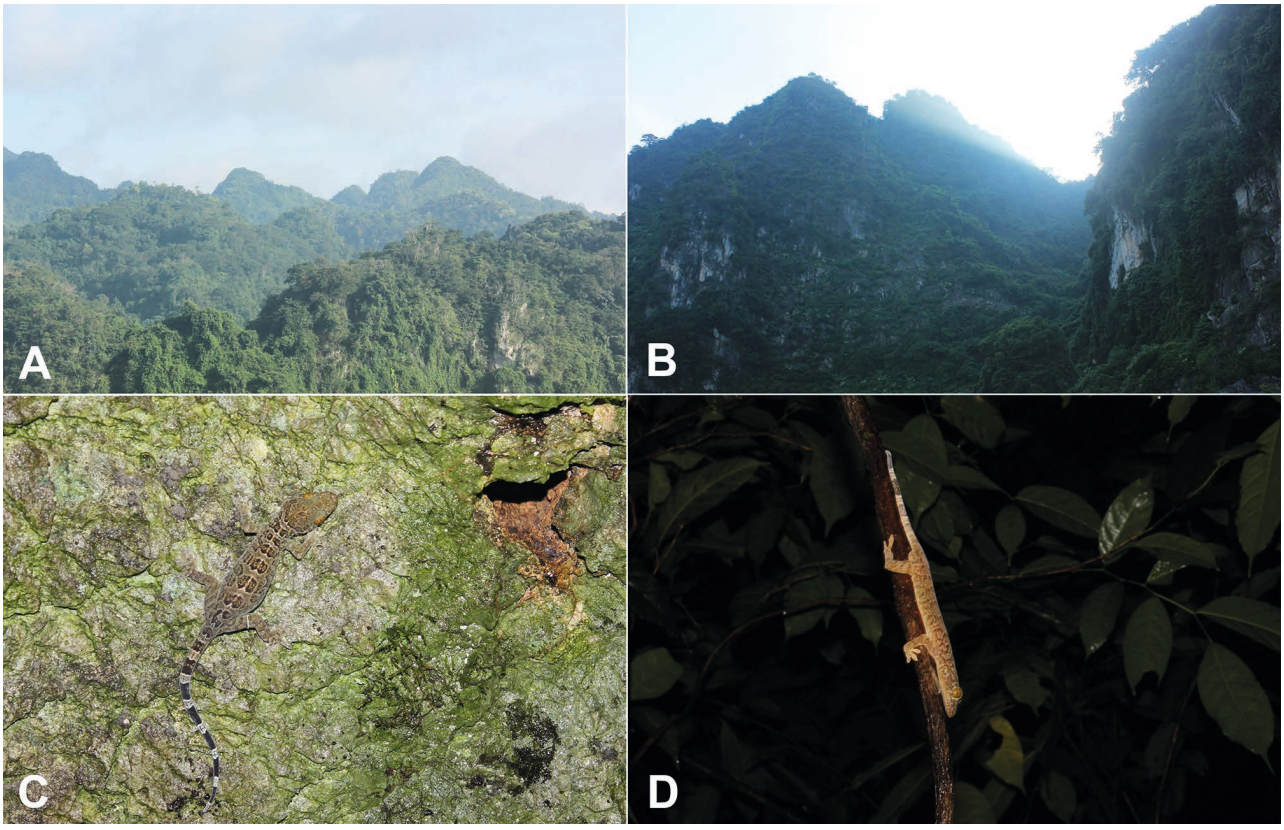

Figure 4. Habitat of *Gekko canhi* in Huu Lien Nature Reserve (A, B), and individuals of *Gekko canhi* on different substrates (rock versus branch, respectively, C, D).

were made in a species of Tiger Gecko (*Goniurosaurus lichtenfelderi*) in Tay Yen Tu NR, Bac Giang Province, Vietnam, with high population densities being recorded in August 2019, and no geckos being found at the same location in September 2019 because of a sudden drop of air temperatures below 18°C (Ngo pers. obs.).

We confirmed the occurrence of *Gekko canhi* in relatively low population densities, which are much lower than the densities recorded for other threatened Vietnamese gecko species (Ngo et al. 2016, 2019b). The average population density of *G. canhi* was calculated to be approximately 16.6 individuals/km and 6.0 individuals/km/day. The highest observed population density for *G. canhi* was 38.5 individuals/km (Table 2). In comparison, densities of the critically endangered gecko *Cnemaspis psychedelica* were estimated to be higher than 120 individuals/km at suitable habitat sites and the endangered Tiger Gecko species *Goniurosaurus catbaensis* from Ha Long Bay was observed to occur at densities of more than 60 individuals/km (Ngo et al. 2016, 2019b). Given the small number of recaptures, the low rates during survey months indicate a rather low detection rate of *G. canhi* in its natural habitats (Table 2). Therefore, the relatively low population densities we recorded for this species most likely underestimate the real population size.

Aside from the record at the type locality in Huu Lien NR in Lang Son Province, another individual (the paratype) of *G. canhi* was documented from Sa Pa District in Lao Cai Province (Fig. 1) (Rösler et al. 2010). However, the population in Sa Pa District has not been recorded again since its discovery. We recommend conducting additional surveys to confirm the occurrence of this species in Lao Cai Province with new sightings. Furthermore, molecular analyses should be conducted to identify the phylogenetic position and the degrees of relatedness of the subpopulations of this species.

Ecology

Rösler et al. (2010) documented the type specimens of *G. canhi* from evergreen secondary forests around an altitude of 200 m in Huu Lien NR, Lang Son Province, and from 1,500 m in Sa Pa, Lao Cai Province, northern Vietnam. Ours is the first study providing more insights into the species' habitat selection. We confirm that *G. canhi* is

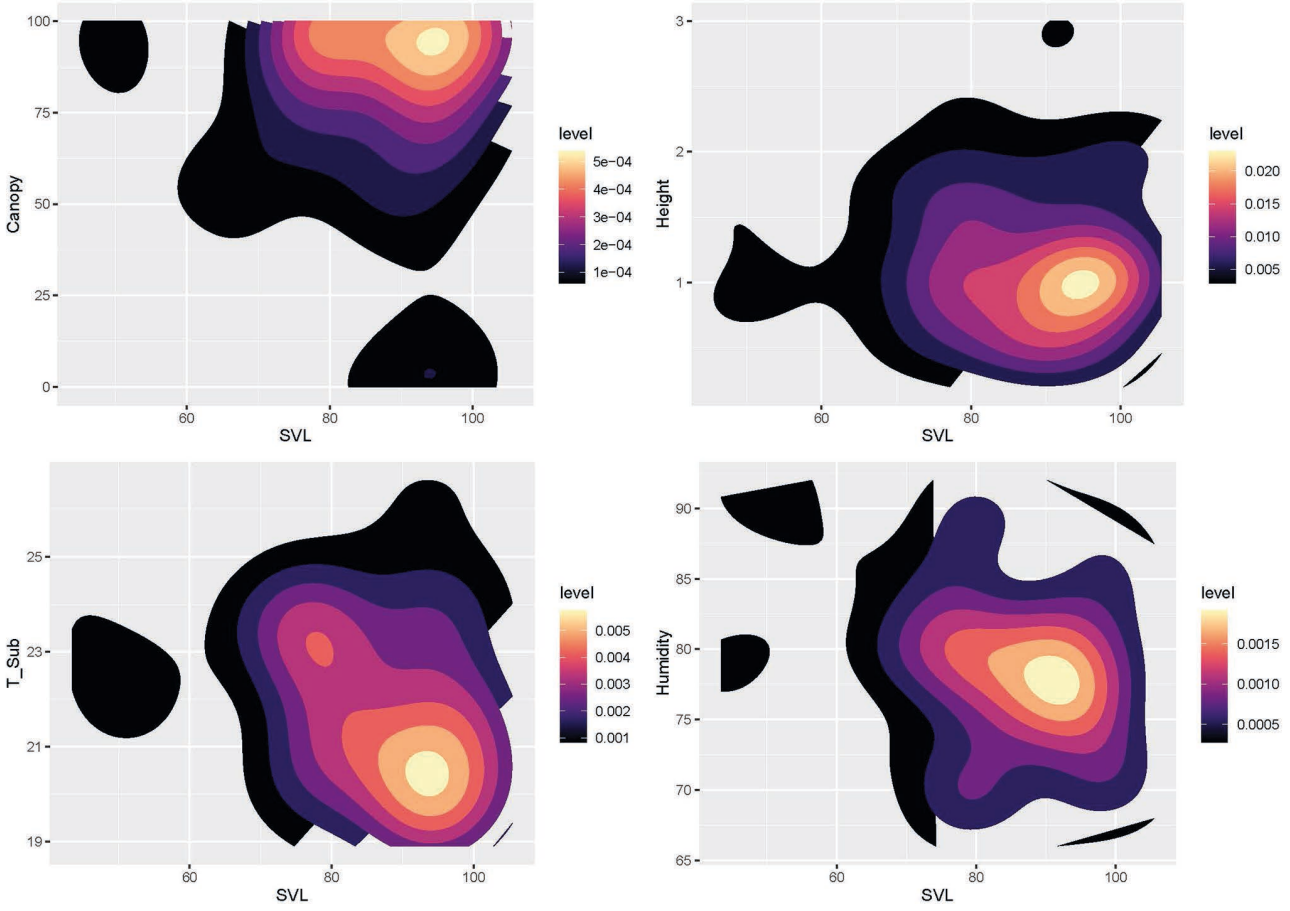

Figure 5. Density plots of microhabitat characteristics, including Canopy (upper left); Height (upper right); Substrate Temperature (lower left); Humidity (lower right) in relation to the snout–vent lengths of *Gecko canhi* individuals.

a karst-dwelling specialist in the evergreen forest at altitudes below 400 m a.l.s. in Huu Lien NR. Similarly, relatives in the *Gekko japonicus* group from Vietnam, Laos, and southern China were also described as rock-dwelling species inhabiting karst forest ecosystems (Rösler et al. 2005, Nguyen et al. 2013, Yang 2015, Luu et al. 2017). Our study furthermore revealed the microhabitat of *G. canhi* to be characterized in detail by dense vegetation cover, high relative humidity, and stable ambient temperatures. The gecko occupies spots at low heights above the ground, preferably a substrate of dry rocks that offer small crevices for sheltering. Crevices in solitary karstic boulders or caves can also serve as shelters for the geckos to hide within during the day as well as evade predators. These habitat features are similar to those used by the syntopic Tiger Gecko *Goniurosaurus huuliensis* (Ngo et al. 2022a).

Conservation

Although *G. canhi* is not known to be a target species for the pet trade, consumption or use in traditional medicine, species occupying unique karstic habitats at low population densities, may in general be particularly vulnerable to human impacts (e.g., deforestation and limestone mining). Occurring syntopically with the Tiger Gecko *Goniurosaurus huuliensis, G. canhi* may be compromised considerably by future climate change as well (Ngo et al. 2021, 2022a). Based on confirmed locality records in Lang Son and Lao Cai provinces, *G. canhi* is apparently distributed within a small area (less than 5,000 km^2), and its natural habitats continue to degrade under human impacts (Figs 1, 7). Thus, the endemic species fulfils the criteria of B1ab(i,iii) to be re-assessed at least as Vulnerable (VU) in the IUCN Red List (IUCN 2023). In order to prevent the species from becoming seriously threatened, we recommend taking preventative conservation measures to safeguard the wild populations of *G. canhi*.

Conservation measures to improve capacity-building for local rangers, and raise awareness for biodiversity in the local human communities have been proposed to protect *Goniurosaurus huuliensis* in Huu Lien NR (Ngo et al. 2022a, b). Based on SDM (Species Distribution Modelling) predictions, the Huu Lien NR and surrounding districts from Lang Son and Thai Nguyen provinces should be highly prioritized as core refugia for the Tiger Gecko

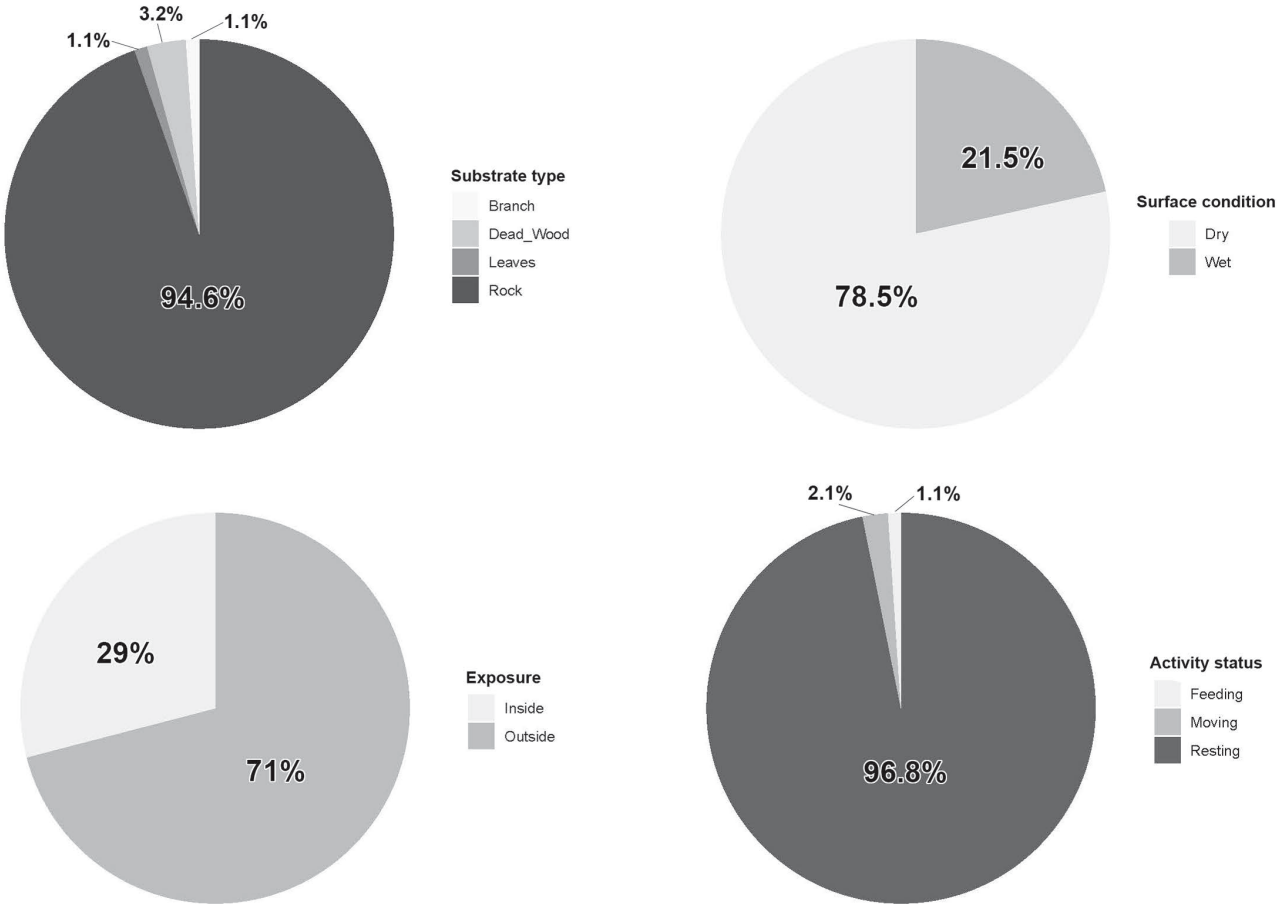

Figure 6. Microhabitat selection of *Gekko canhi,* including substrate type (upper left), surface condition (upper right), exposure (lower left), and activity status (lower right).

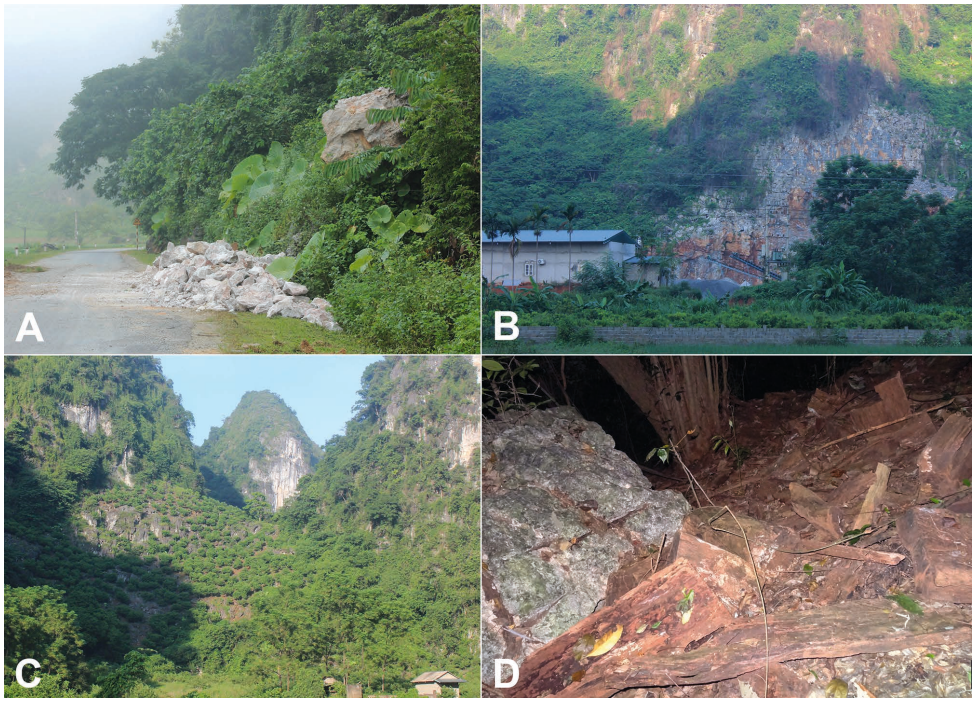

Figure 7. Degradation of natural habitats of *Gekko canhi*: (A) Rock collapse; (B) rock mining for cement production; (C) forest conversion to cropland; (D) logging.

(Ngo et al. 2021). Occurring in the same microhabitat as *Goniurosaurus huuliensis* in Huu Lien NR, *G. canhi* should also be included in the latter's in-situ conservation plan, protecting all karst-dwelling geckos simultaneously rather than through separate efforts. With the data presented herein, we intend to contribute to the conservation of Vietnam's karst ecosystems that harbour a unique and threatened biodiversity.

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