



# First population assessment of two cryptic Tiger Geckos (*Goniurosaurus*) from northern Vietnam: Implications for conservation

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**Abstract.**—The Cat Ba Tiger Gecko *Goniurosaurus catbaensis* Ziegler, Nguyen, Schmitz, Stenke and Rösler, 2008 is a recently discovered species endemic to Cat Ba Island, Hai Phong, Vietnam. Morphologically, *G. catbaensis* resembles *G. luyi* Grismer, Brian, Viets and Boyle, 1999, which was originally described in 1999 from southern China and was recorded in 2006 also in northeastern Vietnam. Both species inhabit remote limestone habitats, which suffer ongoing degradation and fragmentation due to agricultural development and the expansion of touristic sites. Tiger Geckos experience increasing interest in the international pet trade, which already resulted in local population extirpation of *G. luyi* due to unsustainable overexploitation for commercial use. However, impacts of anthropogenic pressures on wild populations, distribution ranges, and population sizes of *Goniurosaurus* species remain imperfectly studied. Herein we used a capture-recapture method to provide preliminary population size estimation of the endemic island dwelling species, *G. catbaensis*, in comparison to its cryptic continental relative, *G. luyi*, in order to evaluate their conservation status and assess the level of threats. Our study revealed relatively small population sizes and provided evidence for the negative impact of humans on the two *Goniurosaurus* species. Our research emphasizes the necessity to support the conservation of the species and their natural habitats, especially on the Cat Ba Archipelago. We further provide a new provincial record of *G. luyi* in Vietnam from Lang Son Province and record for the first time evidence for the occurrence of *G. catbaensis* on further offshore island in the Ha Long Archipelago.

**Key words.** Eublepharidae, distribution, population size, new record, endemism, conservation measures

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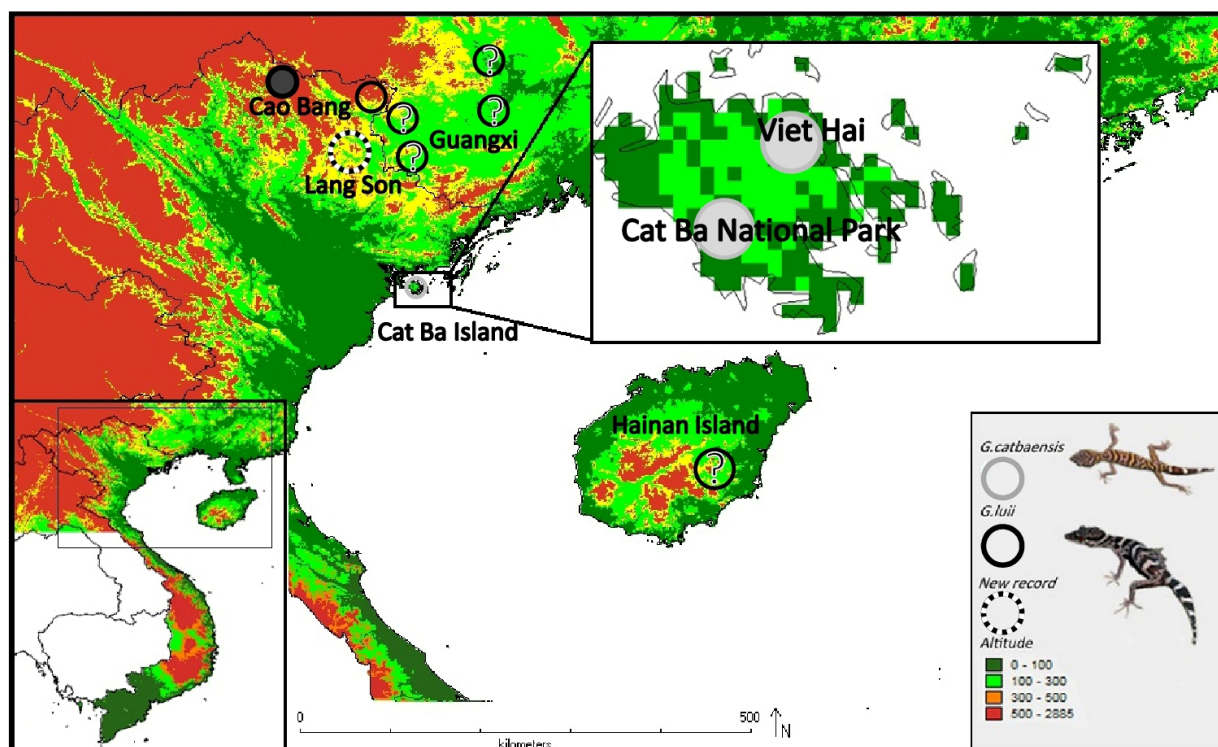
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## Introduction

Tiger Geckos of the genus *Goniurosaurus* have a restricted distribution range in Asia, from northern Vietnam over southern China eastwards to the Ruykuyu Archipelago of Japan. Currently, 17 species are recognized; most of them are endemic to small areas (Grismer et al. 1994,

1999; Seufer et al. 2005; Yang and Chan 2015; Ziegler et al. 2008). Tiger Geckos are popular in the international pet trade and the species *G. luyi* was reported being extirpated at its type locality in southern China shortly after its description (Stuart et al. 2006). Although Tiger Geckos are considered to be threatened by extinction due to overexploitation for the illegal trade and habitat de-

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**Fig. 1.** Distribution of the cryptic species *Goniurosaurus catbaensis* (gray circles) and *G. luyi* (black circles): Filled circles represent study areas; dashed circle represents new record of *G. luyi*; question marks indicate former localities or sites where the current presence is unclear. Occurrence records were represented as big circles to prevent showing exact locality data.

struction, only the members of the *G. kuroiwa* group are listed on the IUCN Red List of Threatened Species (Ota 2010). Knowledge about the status of the remaining *Goniurosaurus* populations is poor and for most species are not yet available. This study aims to contribute towards a better understanding about the population status of the two species, *Goniurosaurus catbaensis* and *G. luyi* in Vietnam. Both species are members of the *G. luyi* species group, which contains eight known species, *G. araneus* Grismer, Viets and Boyle 1999 from the northern portion of Vietnam, *G. banglingensis* Grismer, Haitao, Orlov, and Anajeva 2002 from Hainan Island, China, *G. luyi* Grismer, Viets and Boyle 1999 from northern Vietnam and southeastern mainland of China, *G. catbaensis* Ziegler, Nguyen, Schmitz, Stenke, and Rösler 2008 from Cat Ba Island of Vietnam, *G. huiliensis* Orlov, Ryabov, Nguyen, Nguyen, and Ho 2008 from northern Vietnam, *G. liboensis* Wang, Yang, and Grismer 2013 from the border region between Guangxi and Guizhou provinces, *G. kadoorieorum* Yang and Chan 2015, and *G. kwangsiensis* Yang and Chan 2015 from Guangxi Province, China. The members of this species group are morphologically very similar and their phylogenetic relationships are only partly resolved (Grismer et al. 1994, 1999; Seufer et al. 2005; Vu et al. 2006; Yang and Chan 2015; Ziegler et al. 2008). Hence, we investigated one of the most poorly known species, *G. catbaensis*, which is an endemic flagship species for Cat Ba Island in the Gulf of Tonkin, northern Vietnam. This island belongs to one of the most attractive tourist sites in Vietnam, but the impact of the

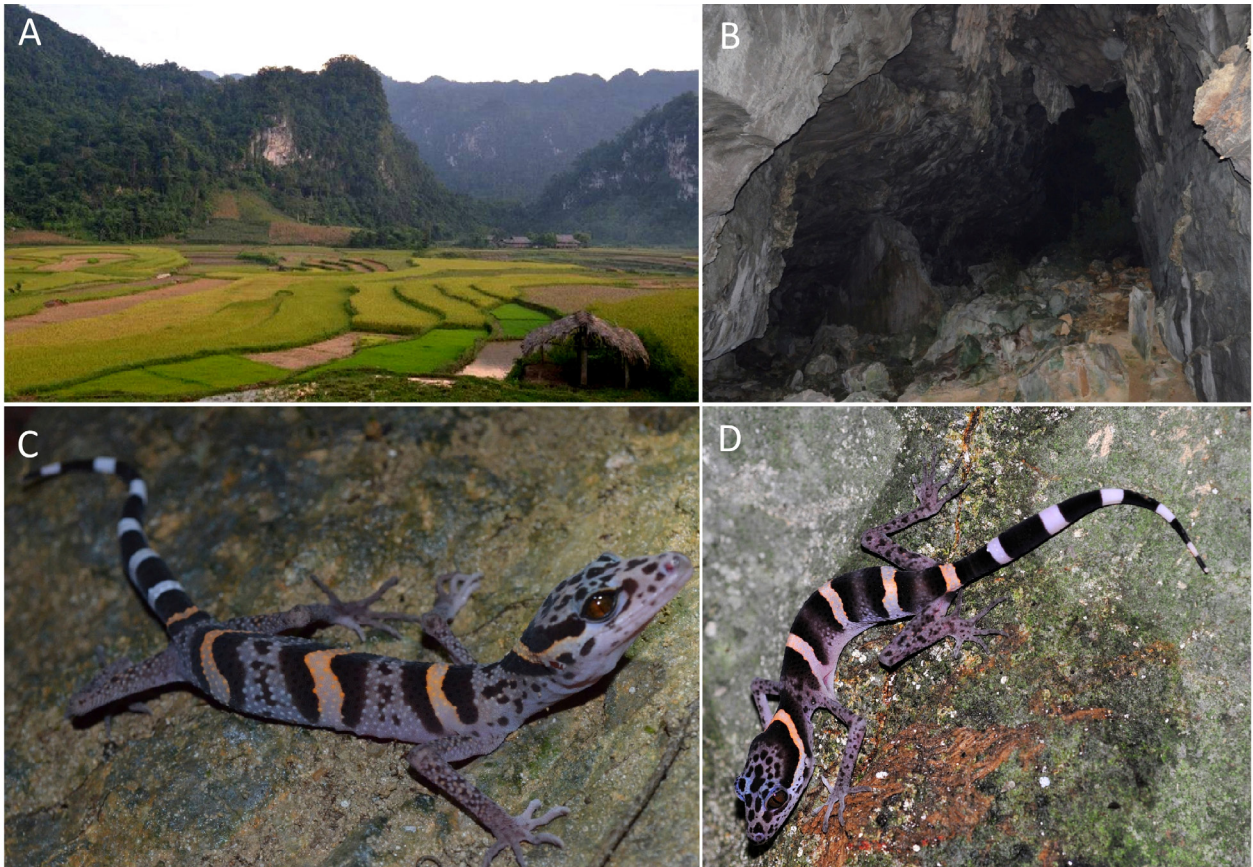
tourism on this ecosystem and its biodiversity is not yet fully understood.

Population size estimations provide essential information for the classification of the threat level of a species and are crucial for wildlife management and management of the long-term survival of populations and species (Reed et al. 2003; Traill et al. 2007). We therefore conducted the first population assessment of *G. catbaensis*, including population density, size, and structure, and evaluation of human impacts on the population. In comparison, we likewise studied its cryptic sibling species *G. luyi* on the mainland of northern Vietnam, which is also karst adapted, and occupies a similar ecological niche (Grismer 1999; Ziegler et al. 2008). *Goniurosaurus luyi* indeed shows a wider distribution range, but its natural history is still poorly known and data on its abundance in Vietnam is completely lacking to date (Grismer 1999; Yang and Chan 2015). By comparing populations of two closely related species, one from an island with the other in mainland ecosystems, we expected lower population densities in the mainland, stronger human impacts at tourist sites, and finally aimed to gain insights for improved conservation strategies for the Tiger Geckos in the future.

## Materials and Methods

**Study areas:** Study sites were selected based on previous surveys of the authors' on Cat Ba Island, Hai Phong City and in Ha Lang District, Cao Bang Province, north-





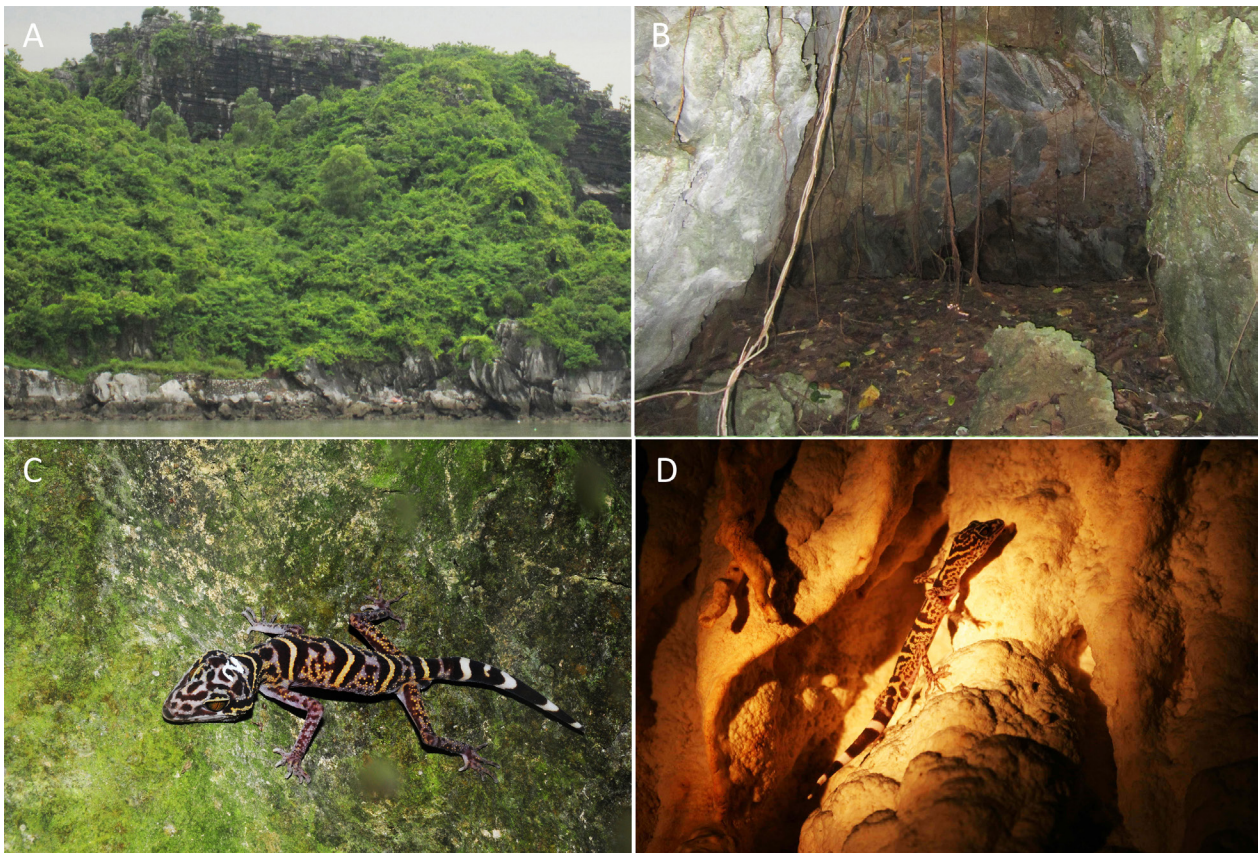
**Fig. 2.** **A:** Macrohabitat and **B:** Microhabitat of *Goniurosaurus luyi* in Ha Lang District, Cao Bang Province, North Vietnam; specimens of *G. luyi* from **C:** Cao Bang Province and **D:** Lang Son Province (new record). Photos Mona van Schingen, Marta Bernardes, and Tao Thien Nguyen.

ern Vietnam (e.g., Lehmann, 2013; Ziegler et al. 2008, see Fig. 1). Both areas comprise large limestone karst formations with secondary evergreen forest and share zoogeographic affinities (Fig. 2A, 3A). The limestone karst forest provides diverse habitats for a unique flora and fauna, and is recognized as arcs of biodiversity (Clements et al. 2006). While habitats in Cao Bang Province—situated at the border to China—lie outside protected areas, Cat Ba Island was recognized as “Cat Ba Archipelago Biosphere Reserve” (CBBR) by the UNESCO in 2004, due to its significant ecosystem and biodiversity values (CBBR Authority 2013). Besides the recent discovery of *G. catbaensis* by Ziegler et al. (2008), Cat Ba Island harbors 282 further species of terrestrial vertebrates, of which 22 are listed in the Red Data Book of Vietnam. Cat Ba is renowned for the endemic, Critically Endangered Golden-headed Langur (*Trachypithecus poliocephalus*). Cat Ba Archipelago as well as the adjacent Ha Long World Heritage Area account as the most popular tourist destination in Vietnam, annually attracting more than one million tourists (CBBR Authority 2013), and thus is facing several challenges from rapid tourism as well as aquaculture development, and climate change. During the present study, two sites on Cat Ba Island, which distinctly differed in the number of tourists, were selected in

order to evaluate if the presence of tourists might impact wild populations of *Goniurosaurus* (Fig. 1).

**Field surveys:** During a field survey in 2012 several *Goniurosaurus* cf. *luyi* specimens were observed in Lang Son Province. One voucher specimen was collected and deposited in the collection of the Institute of Ecology and Biological Resources (IEBR), Hanoi (TD-LS2012.1). The specimen was determined by comparison with further specimens of *G. luyi* from Cao Bang Province (ML-19, TAO-182, IEBR 3252, CB-2012.2, IEBR 3254, and IEBR 3253) and based on data from the literature (Grismer et al. 1999; Yang and Chan 2015). Exact locality data is not presented herein to prevent poaching (see also Yan and Chan 2015). For assessment of the population status of *G. catbaensis* and *G. luyi*, field surveys were conducted between June and August 2014, May 2015 and during a short time in June 2015, which is the non-hibernation season of *Goniurosaurus* (Grismer et al. 1999). Seven transects (1,100 to 4,200 m in length) along limestone cliffs or caves were repeatedly surveyed in periods of several days on Cat Ba Island and in Cao Bang Province. Surveys took place after sunset between 7:30 and 11:30 pm, when lizards were found active or foraging. Captured animals were individually marked with a





**Fig. 3.** **A:** Macrohabitat of *Goniurosaurus catbaensis* at the coast of Cat Ba Island; **B:** Limestone cliffs, the typical microhabitat of *G. catbaensis*; **C:** Adult male of *G. catbaensis* marked for population assessment; **D:** First evidence for the occurrence of *G. catbaensis* within limestone cave of small offshore Island in Ha Long Bay archipelago. Photos Hai Ngo, Tao Thien Nguyen, and Minh Le Pham.

permanent pen (Edding Eraser) and released on the same spot after taking measurements (see Fig. 3C). This marking technique has the advantage of being non invasive, inexpensive, and enables the short-term identification of animals, while markings last until the next shedding of the animals.

**Population analysis:** To estimate population sizes, we applied a “Capture-recapture Method” after Huang et al. (2008) by using an “Invisibility Rate Index,” which compensates for animals present but not detected during surveys. The method is described in more details in Huang et al. (2008) and van Schingen et al. (2014). Estimated population sizes were only applied for the specific surveyed sites, and did not encompass the entire populations of the species. Since it is impossible to survey all suitable habitats, density estimations in reference to the transect line were used as relative abundances of respective species. To assess the population structure, lizards were categorized into three age classes based on snout-vent length (SVL > 105 mm = adult, SVL > 85 mm = subadult, and SVL < 85 mm = juvenile), sexes, and in case of females, into gravid and non-gravid specimens. To test for differences in population structure between the island species *G. catbaensis* and the continental *G. luyi*, a Chi<sup>2</sup> test with  $\alpha = 0.05$  was applied with GraphPad

Prism version 5.0 for Windows, GraphPad Software, La Jolla California USA, [www.graphpad.com](http://www.graphpad.com). We further compared densities of *Goniurosaurus* in areas, which are frequently visited by tourists with areas where access is limited in order to evaluate if tourism affects wild populations.

**Molecular analysis:** In order to confirm the taxonomic assignment of the newly collected specimens of *Goniurosaurus* cf. *luyi* from Lang Son and Cao Bang, a fragment of the mitochondrial ribosomal gene, 16S, was amplified using the primer pair 16Sar and 16Sbr (Palumbi et al. 1991) for four samples (TD-LS2012.1, TAO-182, ML-19, IEBR-3254). Tissue samples were extracted using DNeasy blood and tissue kit, Qiagen (California, USA). Extracted DNA from the fresh tissue was amplified by PCR mastermix (Fermentas, Canada). The PCR volume consisted of 21  $\mu$ l (10  $\mu$ l of mastermix, five  $\mu$ l of water, two  $\mu$ l of each primer at 10 pmol/ $\mu$ l, and two  $\mu$ l of DNA or higher depending on the quantity of DNA in the final extraction solution). PCR condition was: 95 °C for five minutes to activate the taq; with 40 cycles at 95 °C for 30 s, 50 °C for 45 s, 72 °C for 60 s; and the final extension at 72 °C for six minutes.

PCR products were subjected to electrophoresis through a 1% agarose gel (UltraPure™, Invitrogen). Gels

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**Table 1.** Totally observed specimens, densities and estimated population size of *Goniurosaurus catbaensis* and *G. luii* in 2014 and 2015.

	2014			2015
	June	July	August	May
<b>Total Cat Ba Island</b>				
Species	<i>G. catbaensis</i>			
Total observed	—	17	12	14
D[ind/km of transect]	—	1.3	1.0	1.3
Population size	—	24	16	16
<b>Cat Ba National Park</b>				
Species	<i>G. catbaensis</i>			
Total observed	—	5	6	3
D[ind/km of transect]	—	0.9	1.1	0.9
Population size	—	5	8	3
<b>Viet Hai Commune</b>				
Species	<i>G. catbaensis</i>			
Total observed	—	12	6	11
D[ind/km of transect]	—	1.7	0.8	1.5
Population size	—	19	8	13
<b>Ha Lang District, Cao Bang Province</b>				
Species	<i>G. luii</i>			
Total observed	15	—	—	—
D[ind/km of transect]	0.8	—	—	—
Population size	21	—	—	—

were stained for 10 minutes in 1X TBE buffer at two pg/ml of ethidium-bromide, and visualized under UV light. Successful amplifications were purified to eliminate PCR components using GeneJET™ PCR Purification Kit (Fermentas, Canada). Purified PCR products were sent to Macrogen Inc. (Seoul, South Korea) for sequencing.

Sequences generated in this study were aligned with one another using De Novo Assemble function in the program Geneious v.7.1.8 (Kearse et al. 2012). They were then compared with other sequences using the Basic Local Alignment Search Tool (BLAST) in GenBank.

## Results

**New population record of *G. luii*:** Four sequences of 574 bps were obtained from the *Goniurosaurus* specimen collected in Lang Son Province. The sequences are almost identical to each other, except in two positions, and 99% to 100% similar to those of *Goniurosaurus luii* from GenBank, specifically the sequences with accession numbers EU499390, EU499391, KC765083, KM455054. The results confirmed that *Goniurosaurus* samples collected in Lang Son Province and in Cao Bang Province are conspecific with *G. luii*. Thus, our finding represents the first record of *G. luii* and the second recorded *Goniurosaurus* species from Lang Son Province, northern Vietnam. Previously, only *G. huuliensis* was known from Huu Lien Nature Reserve, Huu Lung district

in the South of Lang Son Province occurring at elevations of about 370 m (Orlov et al. 2008). *Goniurosaurus luii* was recorded from the north at similar elevations of about 364 m above sea level. Based on our current knowledge no sympatric occurrence of the two species has been recorded so far, but exact distribution boundaries remain unknown. The microhabitats of *G. luii* in Lang Son Province were densely vegetated limestone caves, which are similar to those observed in Cao Bang Province (Fig. 2B). The Geckos had been found active during night on cliffs or cave walls about 0.5–2.5 m above the ground. Most interestingly, our morphological examination of the newly recorded *G. luii* specimens from Lang Son Province showed that no significant differences in diagnostic characters compared with the recently described *G. kadoorieorum* (see Table 1, Fig. 3D). But the newly recorded specimens of *G. luii* from Lang Son Province slightly differed from both *G. luii* and *G. kadoorieorum* in having more nasal scales surrounding the naris (9 vs. 6–7 in *G. kadoorieorum* and 6–8 in *G. luii*) and more cilia (59–60 vs. 47–54 in *G. kadoorieorum* and 50–56 in *G. luii*) (see Yang and Chan 2015).

**Extended distribution range of *G. catbaensis*:** In this study *G. catbaensis* was recorded—besides already known sites in Cat Ba National Park (NP) and Viet Hai commune—on karst formations at the coastline of Cat Ba Island (Fig. 3B). An adult female was found on rocks

**Table 2.** Morphological characters of *Goniurosaurus luyi* from Guangxi (type series; Grismer et al. 1999), Lang Son and Cao Bang Province compared with *G. kadoorieorum* (Yang and Chan 2015). Length given in mm.

	<i>G. luyi</i> (type series, Guangxi, China, n=6)	<i>G. luyi</i> (Lang Son) (n=1)	<i>G. luyi</i> (Cao Bang) (n=6)	<i>G. kadoorieorum</i> (n=5)
SVL	—	112.13	78.93-121.21 (104.0±18.4)	68.9-118 (104.28±20.3)
TaL	—	62.42	54.95-65.67 (58.37±6.25)	59.8-69.5 (60.59±5.38)
AG	—	53.41	36.58-60.1 (49.41±9.24)	30.5-55.6 (49.3±10.61)
HL	—	28.92	21.74-30.68 (27.9±4.12)	18.3-30.5 (26.82±4.98)
HW	—	20.46	14.99-21.8 (18.72±3.09)	12.5-20.4 (18.28±3.46)
HH	—	12.85	7.89-14.95 (11.38±2.82)	8.3-13.3 (11.64±1.98)
SE	—	12.24	9.13-12.87 (11.35±1.71)	7.6-12.6 (11.28±2.11)
EE	—	11.58	8.35-12.36 (10.23±1.78)	6.5-10.9 (9.5±1.77)
SVL:TaL	—	1.79	1.35-2.34 (1.86±0.42)	1.15-1.83 (1.56±0.36)
SVL:HL	—	3.88	3.51-3.96 (3.71±0.17)	3.77-3.98 (3.88±0.08)
SVL:AG	—	2.09	2.07-2.17 (2.11±0.06)	2.05-2.26 (2.13±0.08)
HL:HW	—	1.41	1.39-1.66 (1.49±0.1)	1.39-1.5 (1.47±0.05)
SE:EE	—	1.06	1.03-1.23 (1.11±0.08)	1.14-1.25 (1.19±0.04)
SPL	9-12 (9.5±0.55)	10/9	10-12 (10.92±0.67)	10-11 (10.3±0.48)
IFL	9-11 (10±0.63)	10/10	8-11 (9.9±0.9)	9
N	—	9/9	6-8 (7.25±0.75)	6-7 (6.2±0.42)
IN	—	2	3-1 (1.5±0.84)	2
PostIN	—	6	3-5 (4.0±0.89)	3-9 (5.2±2.49)
PM	2-4 (3±0.89)	5	2-5 (3.83±0.98)	4-5 (4.8±0.45)
GP	—	8	7-11 (8.67±1.37)	8-11 (9.6±1.52)
PO	14-17 (15.8±1.17)	—	—	15-19 (16.7±1.16)
CIL	57-61 (59.5±1.87)	59/60	50-56 (53.83±1.75)	47-54 (51.7±2.58)
MB	119-144 (134.5±12)	122	105-132 (118.5±11.47)	124-132 (129.2±3.11)
GST	9-14 (12.2±1.34)	11/12	9-12 (11.2±0.94)	11-13 (12±1.05)
TL	33-34 (33.8±0.75)	31	32-35 (33.3±1.21)	30-34 (32.6±1.67)
DTR	—	22	19-23 (21.5±1.52)	22-24 (23.2±0.84)
LF1	—	9/10	9-10 (9.83±0.39)	10-11 (10.2±0.42)
LF4	—	19/20	19-20 (19.54±0.69)	17-19 (17.8±0.79)
LT1	—	11/9	9-10 (9.9±0.32)	10-11 (10.6±0.52)
LT4	21-24 (23.5±1.38)	24/24	22-25 (23.5±1.08)	21-24 (22.3±0.95)
PP (male)	23-29 (26±2.58)	—	17-24 (20.5±4.95) (n=2)	26-28 (26.75±0.96)
PP (female)	—	22 (pitted)	18-24 (20.0±3.5) (pitted, n=3)	Absent
PAT	—	2/2	1-2 (1.75±0.45)	1-2 (1.4±0.52)

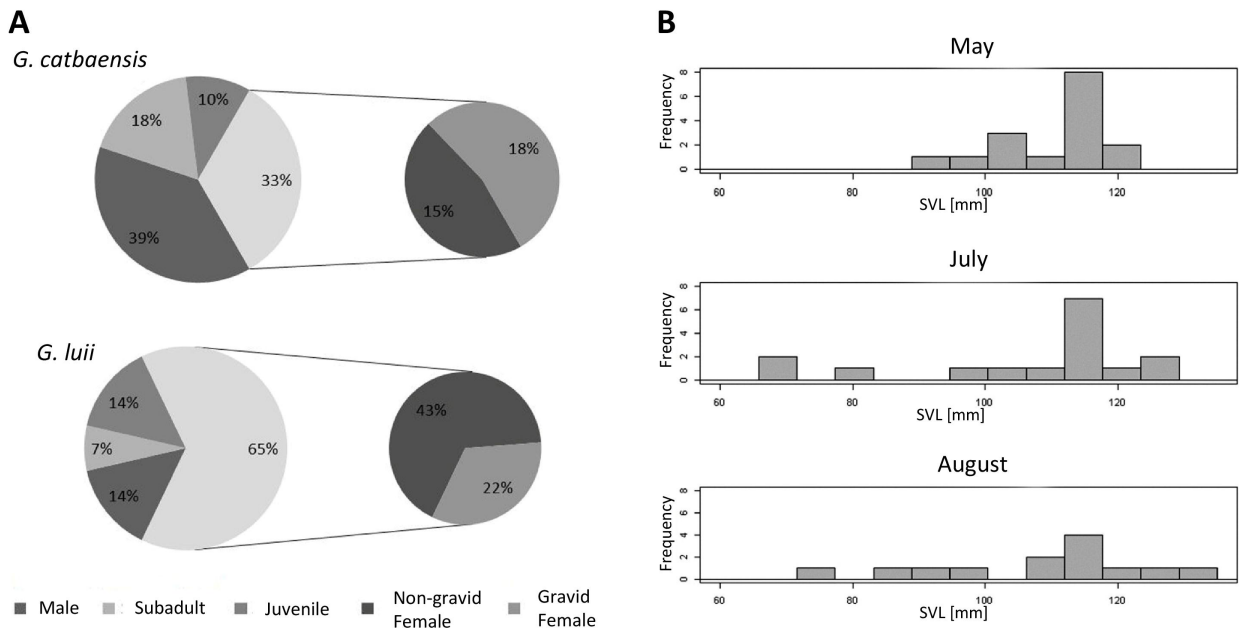
on the ground at an elevation of eight m above sea level. This sighting is the first observation of *G. catbaensis* in immediate proximity to the sea and provides an extended distribution range from forested areas to completely open areas close to the sea. In addition, first evidence for the occurrence of *G. catbaensis* on a small island within the Ha Long Bay is recorded based on a photo documentation by a tourist (Fig. 3D). The specimen was observed on the wall of a limestone cave on a very small offshore island. Based on color pattern and discernible scalation, the photographed specimen revealed to be *G. catbaensis*, although not all diagnostic characters for that species

could be confirmed due to the lack of a voucher specimen.

**Population status:** During the present study, *G. catbaensis* and *G. luyi* were found along five and seven transects, respectively. A total of 43 individuals of *G. catbaensis* and 15 individuals of *G. luyi* were captured. Based on an estimated invisibility rate index of 0.6, the *G. catbaensis* population on Cat Ba Island was estimated to comprise 16, 24, and 16 individuals in May, July, and August, respectively (Table 1). Furthermore, the encounter rates of *G. catbaensis* were always higher in Viet Hai



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**Fig. 4. A:** Average population structure of *Goniurosaurus catbaensis* and a continental *G. luyi* population from Cao Bang Province (May–August vs. June, respectively); **B:** Frequency histogram of Snout-vent length of *G. catbaensis* for the months May, July, and August.

Commune than in other sites near the headquarters of Cat Ba NP, where more tourists frequented. In comparison, the continental subpopulation of *G. luyi* was estimated to comprise about 21 individuals within the investigated site (Table 1). Monthly mean densities of *G. catbaensis* ranged between 1 and 1.3 individuals per km of surveyed transect, while densities were generally higher in Viet Hai Commune than in other sites within Cat Ba NP (Table 1; Fig. 4). With regard to temporal variations, the highest density of *G. catbaensis* was observed during the month of August compared to May and July. In comparison, the continental subpopulation of *G. luyi* was estimated at the density of 0.8 individuals per km/transect, slightly lower than the density of *G. catbaensis*.

The investigated population of *G. catbaensis* on average consisted mainly of adult males, followed by adult females, subadults, and juveniles (39%, 33%, 18%, 10%, respectively; see Fig. 4). In comparison, the population structure of continental *G. luyi* slightly differed, with adult females constituting the major proportion of the local subpopulation, followed by adult males, juveniles, and subadults (65%, 14%, 14%, 7%, respectively, see Fig. 4). Females were more abundant in populations of *G. luyi* than in those of *G. catbaensis* (Fig. 4). However, population structures did not differ significantly between the two cryptic species ( $\text{Chi}^2 = 5.2$ ;  $\text{df} = 3$ ;  $p = 0.158$ ). Most of the observed adult females were gravid (33% in Cao Bang vs. 54% on Cat Ba) between May and July. In July, all five encountered females of *G. catbaensis* were gravid, while no gravid females were observed in August. Frequency histograms of SVL showed a tendency of a monthly shift in presence of age classes in *G. catbaensis* ( $\text{Chi}^2 = 1.227$ ,  $\text{df} = 6$ ,  $p = 0.9755$ ; Fig. 4). Individuals with SVL less than 90 mm were only found

from July onwards. Similarly, animals with SVL larger than 120 mm were observed from July onward, while the largest individuals (SVL up to 110 mm) were recorded in August (Fig. 4).

## Discussion

**Distribution:** While most of the *Goniurosaurus* species are endemic and restricted to a small distribution range, our new record of *G. luyi* from Lang Son Province extended the distribution of this species in northern Vietnam. However, the distribution range of *G. luyi* probably overlaps with its cryptic relatives, i.e., *G. araneus*, *G. kadoorieorum*, and *G. kwangsiensis* (Chen et al. 2014; Yang and Chan 2015). Chen et al. (2014) indicated that *G. luyi* and *G. araneus* occur sympatrically in Guangxi Province, southern China, being only divided by a river system as a geographic boundary, which also is the barrier for *G. yingdeensis* and *G. indet.* The recently described *G. kadoorieorum* and *G. kwangsiensis* were also discovered from Guangxi Province, although information about exact locality was not provided (Yang and Chan 2015). Our morphological investigation of *G. luyi* from Vietnam revealed no distinct morphological differences between *G. luyi* and *G. kadoorieorum*. Thus, the validity of the newly described *G. kadoorieorum* should be verified by genetic analyses in the future. A similar case of cryptic diversity within a small geographic range is found in the *G. kuroiwae* complex, consisting of five species, in the Ryukyu Archipelago, Japan (Chen et al. 2014). Definite overlaps in distribution ranges of different *Goniurosaurus* species have only been reported for less closely related congeners, *G. lichtenfelderi* and *G.*

*luii* thus far. Although *G. luii* is the second known species of *Goniurosaurus* (after *G. huuliensis*) from Lang Son Province, they are not sympatric inhabitants. While *G. luii* was recorded from northern Lang Son, *G. huuliensis* had been only recorded from Huu Lien Nature Reserve in the southern part of the province. It can be assumed that the two species are geographically separated, however exact distribution boundaries have not yet been identified.

At present, *G. catbaensis* is endemic to Cat Ba Archipelago and it is expected to be found on other offshore islands in Ha Long Bay. Besides, other reptile species such as *Pseudocalotes brevipes* and *Rhynchophis boulengeri* have been observed at the coastline of Cat Ba Island, while *R. boulengeri* was even observed swimming in the ocean (Nguyen et al. 2011). In addition, two specimens of the *Gekko palmatus* complex were sighted on a small offshore island in Cat Ba Archipelago in 2015. These findings highlight the potential of Cat Ba Archipelago and Ha Long Bay as a laboratory for future studies to understand island biogeography of tropic lizards. These studies are recommended to investigate species communities, species relationships, and explore if similar speciation processes are underway on these small offshore islands comparable to those reported in *Anolis* lizards on Caribbean islands (e.g., Losos and Schluter 2000; Losos and Thorpe 2004).

**Population status:** Species with restricted distribution ranges are especially vulnerable to anthropogenic threats, such as habitat loss or degradation, overexploitation, and climatic changes (Hanski 1991; Reed et al. 2003; Traill et al. 2007). The population size plays a crucial role in long term survival of species, and a minimum viable size of at least 3,000–7,000 individuals is required to maintain a stable population over a longer time period (Reed et al. 2003; Traill et al. 2007). Preliminary estimates of *G. catbaensis* revealed a small population size that varied monthly between 16 and 24 individuals. These values only reflect the situation at the two known sites of the species on the island and might not capture the population over the entire range of the taxon. We assume that future surveys will probably uncover further occurrences, which is supported by the recent sighting of potential *G. catbaensis* on a small offshore island. However, *G. catbaensis* is still relatively restricted in its distribution and exclusively relies on the presence of limestone habitats in remote areas. Thus, the total population size of the species is assumed to be relatively small, and not exceeding the size of a minimum viable population.

Accordingly, *G. catbaensis* had been found in a fairly low density of 1.2 individuals per km, which only occurs in the sites containing suitable habitats such as limestone cliffs and caves. The habitats only cover a portion of the Cat Ba Archipelago, since karst formations alone represent only one of several ecosystems present on Cat Ba Island with an area of about 170 km<sup>2</sup> (CBBR Authority,

2013). Our findings suggest that higher abundances of *G. catbaensis* were generally found in remote sites, which were less frequently visited by tourists. The results might indicate a negative impact of tourism on the population of *G. catbaensis*. As tourism is developing rapidly on the island, wild populations and suitable habitats are likely to steadily decrease in the future.

A comparative investigation of the continental *G. luii* population in Cao Bang Province revealed similar size estimations of about 21 individuals (vs. 16–24 individuals of *G. catbaensis* on Cat Ba), based on the same number of surveyed transects. The sites, where *G. luii* was observed, were remote and far away from human settlements. This observation affirms our assumption that the presence of humans negatively impacts the occurrence of *Goniurosaurus* species.

**Population structure:** In both investigated species, adult females represented the dominant group, which might be an indication for a territorial or aggressive behavior between males, which probably disperse more than females (Vitt and Pianka 1994). The proportion of males tends to be higher in the island population of *G. catbaensis* compared with the continental population of *G. luii*. This finding might be explained by the limited dispersal ability on the island due to limited availability of suitable habitats. Accordingly, the fact that relatively higher numbers of gravid females were found on the island, compared with the continental population, might have resulted from the respective higher density of males in the population. Furthermore, gravid females in both populations of *G. catbaensis* and *G. luii* were encountered between May and July, confirming the observation of Grismer et al. (1999) that July is the reproduction season of *G. luii*.

## Implications for Conservation

Tiger Geckos, in particular *Goniurosaurus luii* and *G. araneus*, have been used for traditional medicine by local people and became very popular in the trade since the 1990s (Grismer et al. 1999; Chen et al. 2014; Yang and Chan 2015; Ziegler et al. 2015). Grismer et al. (1999) reported an exemplary case of one dealer exporting over 10,000 individuals of *G. luii* and *G. araneus* to the USA for the pet trade. Already before its description in 1999, *G. luii* had been overexploited for commercial use in China, which presumably led to the extirpation from its type locality in Pingxiang (Grismer et al. 1999; Stuart et al. 2006). According to Yang and Chan (2015), local villagers mentioned to have been paid by dealers for collecting large quantities of live *Goniurosaurus*, which is a common scenario within the non-sustainable reptile trade (e.g., Huang et al. 2008). A similar scenario might have taken place simultaneously in Vietnam. As a result, even extensive field surveys, e.g., Nguyen et al. (2009), Orlov et al. (2008), Ziegler et al. (2008), and by our team in



2010 and 2014 in Cao Bang Province, failed to record any specimen of *G. araneus*.

These findings emphasize how fast local populations of range-restricted species can be extirpated due to over-exploitation (e.g., Huang et al. 2008; van Schingen et al. 2015). The international demand for *Goniurosaurus* species among hobbyists still remains high. The long term monitoring of local pet markets and internet sources by Yang and Chan (2015) showed that almost all *Goniurosaurus* species are subject to extensive pet trade. Sometimes, the species fetch alarmingly high prices. Observations by our team confirmed the regular trade in respective species in international reptile fairs, e.g., in Hamm and Dortmund, Germany, or on internet platforms such as www.terrarakistik.com. The species are available for sale from as low as 15 EUR up to several hundred Euros per individual.

In many cases, the origin of the species and their legal export permits remain questionable. Among them, *G. catbaensis* has been observed in European pet markets, even though it was only described relatively recently. Anthropogenic threats, such as poaching, habitat degradation, and introduced predators together with a small distribution range of 1,600 km<sup>2</sup> imperiled the insular *G. kuroiwae* species group, endemic to the Ryukyu Archipelago of Japan, leading to its inclusion in the IUCN Red List as Endangered (Ota 2010). Yang and Chan (2015) argued that most *Goniurosaurus* species from China and Vietnam are similarly or even more threatened than the Japanese species, since Japan is more advanced in species conservation management.

Our study suggests that the insular *G. catbaensis* is very sensitive to the impacts of humans, and subject to overexploitation to supply the international pet trade. Besides illegal collection, habitat destruction for touristic purposes has dramatically increased the pressure on the wild population of *G. catbaensis*. According to interviews with local villagers, several karst areas of Cat Ba Island, comprising unique and important habitats for the species, have recently been converted to a huge tourist resort and further tourism development has been planned. Such development would seriously threaten *G. catbaensis* and the unique fauna and flora of the Cat Ba Archipelago, which requires urgent conservation measures to protect the species from imminent extinction.

## Recommendations

Due to the restricted distribution range of *G. catbaensis* and the rising anthropogenic threats to its natural populations, we recommend to include this species in the IUCN Red List. Since this study provided evidence for negative impact of tourism on the presence of *G. catbaensis*, the public access to core habitats of the species needs to be restricted by local authorities. Based on our results, *G. catbaensis* was found more frequently at some spots in the vicinity of Viet Hai Village. The sites should there-

fore be considered a priority zone for the species conservation. Future surveys will evaluate the relevance of further sites as key habitats for conservation of *G. catbaensis*. Furthermore, the Vietnamese authorities should strictly control illegal collection of *G. catbaensis* as well as other *Goniurosaurus* species. Currently, all *Goniurosaurus* species are considered to be threatened by commercial use (Chen et al. 2014; Grismer et al. 1999; Yang and Chan 2015; Ziegler et al. 2015) and the international demand for Tiger Geckos still remains high. Because of their restricted distribution ranges and low densities, all *Goniurosaurus* species are especially vulnerable to unsustainable harvest, which already caused the local extinction of at least one species. As a first step to reduce poaching and to control the international trade in *Goniurosaurus* species, we further recommend assessment of trade status for all species of the genus *Goniurosaurus* with a view to including them in the appendices of the Convention of International Trade in Endangered species (CITES).

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