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A case study on trade in threatened Tiger Geckos (*Goniurosaurus*) in Vietnam including updated information on the abundance of the Endangered *G. catbaensis*

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Abstract

Tiger geckos of the genus *Goniurosaurus* are considered as a susceptible reptile group, due to their restricted distribution ranges, specialisation to specific microhabitats and generally low population densities. While still new species have been discovered recently, *Goniurosaurus* species are threatened by extinction through habitat loss and collection for the pet trade. Of the 19 described species, for only eight species, the conservation status has been assessed within the IUCN Red List between 2016 and 2018 and all have been classified in the threat categories VU (Vulnerable), EN (Endangered) and CR (Critically Endangered). *Goniurosaurus* spp. are popular in the international pet market at least since the 1990s and several species experienced local extirpations as a consequence of massive over-collection in the past. However, tiger geckos have not been paid much attention for conservation, amongst others, due to the lack of comprehensive knowledge on their conservation status and biology. This study provides an overview of international trade in *Goniurosaurus* based on available data from 1999 to 2018 in the U.S. as well as data from online surveys

and interviews in Europe and Vietnam, with the main focus on species native to Vietnam. All five tiger gecko species known from Vietnam were found in the local trade as wild captures for the national and international market and / or in the U.S. and Europe for relatively higher prices. We found that entire trade chains are very long (including several transfers and dealers involved) and that keeping and transport happen under poor conditions. We herein provide updated information on the abundance of the Endangered Cat Ba Tiger Gecko, which was recently shown to not only occur at its type locality, Cat Ba Island, Hai Phong City, North Vietnam, but also to inhabit small offshore islands in the Ha Long Bay, Quang Ninh Province. While the wild effective population was found to be relatively stable on four islands in Ha Long Bay, consisting of about 124 and 129 individuals in July 2017 and April 2018, respectively, the abundance of other sub-populations, impacted by anthropogenic pressures were found to be very low (2–10 individuals). Based on our findings, we propose stringent conservation measures to more efficiently protect wild tiger gecko populations, such as the inclusion in the Governmental Decree in Vietnam, the assessment of remaining species in the IUCN Red List of Threatened Species and the inclusion in the Appendices of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Keywords
Pet markets, Vietnam, abundance, anthropogenic pressures, conservation

Introduction

Tiger geckos of the genus *Goniurosaurus* currently comprise 19 species with a disjunct distribution in Southeast Asia and East Asia (Chen et al. 2014; Grismer et al. 1994, 1999; Honda and Ota 2017; Liang et al. 2018; Yang and Chan 2015; Zhou et al. 2018; Ziegler et al. 2008). The genus contains a high level of local endemism and many species have been recorded only from a single locality, mountain range or archipelago of China, Japan and Vietnam. *Goniurosaurus* is also considered as one of the most susceptible reptile groups due to its generally low population densities and restricted distribution areas, which make tiger geckos particularly threatened by extinction through habitat loss and over-harvesting for the pet trade (Ngo et al. 2016b; Yang and Chan 2015).

Tiger geckos have been recorded in the international pet market at least since the 1990s (Rösler 1995; Stuart et al. 2006; Yang and Chan 2015). Some rare species are fetching high prices in relation to other gekkonids (e.g. US$2000 / per individual of *Goniurosaurus luii*), which provides great incentives for poaching and excessive collection (Grismer et al. 1999; Stuart et al. 2006). However, the scale of the international demand for tiger geckos, as well as trade levels and patterns, are unknown due to tiger geckos are not listed in CITES. Thus, we herein present an attempt to outline domestic and international trade activities in *Goniurosaurus* species in order to inform decision-makers and develop conservation strategies.

The insular Cat Ba Tiger Gecko (*Goniurosaurus catbaensis*) was originally discovered on Cat Ba Island in Hai Phong City, north-eastern Vietnam (Ziegler et al. 2008). A preliminary population assessment of *G. catbaensis* revealed that its effective population size at the type locality is extremely small with less than 24 individuals (Ngo et al. 2016b). The species are considered to be vulnerable to anthropogenic disturbances and

ongoing demand has been recorded in pet markets, as well as on internet platforms for many years (Ngo et al. 2016b; Ngo et al. in press). Over-collection for the pet trade has probably led to local extirpation of *G. luii* and *G. araneus* from their respective type localities in the past (Stuart et al. 2006; Yang and Chan 2015). In addition, habitat destruction for touristic purposes may increase the pressure on the wild *G. catbaensis* population (Ngo et al. 2016b; Nguyen et al. 2018b).

Recently, Ngo et al. (in press) confirmed for the first time that *G. catbaensis* occurs outside its type locality, , by also providing a microhabitat characterisation of *G. catbaensis* throughout its distribution range in Cat Ba Ha Long archipelagos. The present study was conducted to further provide a first assessment on the population size of and threats impacting subpopulations of the Cat Ba Tiger Gecko from Ha Long Bay.

Methods

Analysis of trade

To obtain an overview on the availability and evidence for trade in *Goniurosaurus* spp. in Vietnam, we surveyed several pet markets in both southern and northern Vietnam (including Hai Phong City, Quang Ninh Province, Ha Noi City, Ho Chi Minh City and Dong Nai Province) in March 2018, based on public information on the internet. Five local dealers were questioned in order to determine the origin, availability, demand, price and use of traded species. To investigate the reptile market in the European Union (EU) for the availability of *Goniurosaurus* spp., we further screened online markets (online shops, internet platforms and forums, Facebook) and visited the largest reptile fair "Terraristika" in Hamm, Germany in March and June 2018. Names of interviewees were kept anonymous to ensure data privacy rights.

Furthermore, we analysed import volumes of *Goniurosaurus* spp. into the United States (U.S.). Data were obtained from the LEMIS database of the U.S. Fish & Wildlife Service, which included all recorded imports of *Goniurosaurus* spp. into the U.S. from 1999 to 2018. The purpose of trade in *Goniurosaurus* was categorised as (B) "breeding in captivity or artificial propagation", (H) "hunting trophies", (P) "personal", (S) "scientific", (T) "commercial" and (Z) "zoo". The source of specimens was differentiated between wild (W), captive bred (C), captive born (F) and ranched (R), animals following the CITES definition in Res. Conf. 12.3 (Rev. Cop17).

Field survey

Field surveys were conducted in Ha Long Bay in July 2017 and April 2018 during the non-hibernation season of *Goniurosaurus catbaensis* (Grismer et al. 1999; Ngo et al. 2016b). We conducted a total of 24 night excursions between 19:30 h and 05:00 h of the next day, when the lizards were found to be active (Ngo et al. 2016b; Ziegler et al.

Table 1. Study sites in Ha Long Bay, Quang Ninh Province, Vietnam.

Study sites (Transect)	Transect Length (m)	Area of survey sites (m^2)	Elevation a.s.l. (m)	Habitat types
Island 1 (T-1)	380	5 000	4–99	Shrub vegetation on limestone karst
Island 2 (T-2)	300	2 180	5–20	Shrub vegetation on limestone karst
Island 3 (T-3)	200	1 180	10–72	Shrub vegetation on limestone karst
Island 4 (T-4)	410	5 560	14–67	Shrub vegetation on limestone karst
Total	1290	13 920	4–99	Shrub vegetation on limestone karst

2008). Four survey transects (T-1 to T-4) were set up on four offshore islands, with length of 200 to 410 m each. The islands, covering a total area of 13,920 m^2 (Table 1). Thereof, two transects (T-3, T-4) were selected based on previous surveys by Ngo et al. (2016b) and two further sites were surveyed according to recommendations by interviewed staff of the Management Board of Ha Long Bay (T-1, T-2). Study sites were located within shrub vegetation on limestone outcrops at elevations between 4 and 99 m a.s.l (Table 1). Boat surveys were also conducted at night to search for animals on out-surfaces of limestone karsts close to the oceanic surface. Coordinates and elevations of each captured individual were recorded with a GPS Garmin 64. However, GPS data is not presented herein, to prevent the misuse of the data.

Population analysis

To estimate population, a "mark-recapture method" was applied. In case of one-time mark and recapture event at two sites (T1, T3), the "Lincoln-Peterson Index" and, in the case of several recapture events at two remaining sites (T2, T4) (e.g. Caughley 1980; Schlüpmann and Kupfer 2009; Smith and Smith 2009; Nguyen et al. 2018a), the "Schnabel Index" was applied. Therefore, all encountered individuals were captured and individually marked with passive integrated transponder (PIT) tags (ISO FDX-B Glastransponder, 1.4 × 9 mm). The microchip was injected under the skin on the left body side behind the shoulder. All captured and recaptured individuals were identified with a transponder reader and afterwards released immediately at the spot of capture (van Schingen et al. 2014; Smyth and Nebel 2013). Each transect was repeatedly surveyed in intervals of two days. Estimated population sizes only refer to the surveyed sites and do not encompass the entire wild population of the species. Since it is impossible to survey all potentially suitable habitats in the region, density estimates with reference to transect lines were used as relative abundances.

To assess the population structure of *G. catbaensis*, lizards were categorised into three age classes, based on the snout-vent length (juvenile with SVL < 85 mm, sub-adult with 85 mm ≤ SVL < 105 mm and adult with SVL ≥ 105 mm) (Ngo et al. 2016b). We also differentiated between sexes and between gravid and non-gravid females. Sexes could only be determined clearly for adult and sub-adult specimens as males have enlarged swollen cloacal and 16–21 precloacal pores, while those are lack-

ing in females (Ziegler et al. 2008). Furthermore, the time was noted for each encounter to evaluate the activity pattern of the species. To test for differences in population structure between July 2017 and April 2018, as well as between islands and time of the day, a c^2 test with $P \leq 0.05$ was applied. Statistical analyses were performed with the SPSS software, version 16.0 (SPSS Inc., Chicago).

Anthropogenic Impacts

Potential threats to *G. catbaensis* were investigated in Ha Long Bay and Cat Ba Archipelago. Evidence for harvesting of *G. catbaensis* was obtained through interviews with local dealers, market surveys and a literature survey. Other potential anthropogenic impacts, namely "tourist activities" and "habitat degradation" were recorded by our own observations and interviews with local fishermen (Ngo et al. 2016b; Ngo et al. in press). Depending on the frequency and extent of recorded negative impacts, threats to each of the sub-populations were classified as "not recorded", defined as never being recorded, "low" as being rarely observed, "medium" as being recorded several times, or "high" as being recorded frequently or the extent of destruction was evaluated as too high.

Results

Trade

Most, if not all *Goniurosaurus* species were found being sold in the international pet market in Europe and the U.S. during the present study. According to the LEMIS database of the U.S. Fish & Wildlife Service, a total of 16,714 specimens of *Goniurosaurus* spp. have been imported into the U.S. (mean of 835 ± 1082 individuals annually) between 1999 and 2018 (Fig. 1A). The majority of specimens were imported on genus level as *Goniurosaurus* spp. (44.5%). Amongst the others, the most imported species was *G. lichtenfelderii* (43.6%, n = 7281 individuals), followed by *G. hainanensis* (6%), *G. luii* (3.6%), *G. orientalis* (1.3%) and *G. kuroiwae* (1%) (Fig. 1C). The vast majority of imported specimens were traded for commercial purposes (97%), while only 3% were imported for scientific and zoo purposes (Fig. 2B). A number of 11,515 specimens (68.9%) were wild caught and 5,086 animals (30.4%) were imported as bred in captivity (Fig. 2A). Thereby, most *Goniurosaurus* species imported into the U.S. were from Taiwan (40.5%) as a major exporter, followed by Hong Kong (32.2%), China (15.7%), Indonesia (5.2%) and other CITES Parties (6.4%) (Fig. 1B).

In March 2018, market surveys showed that the trade in *Goniurosaurus* in the EU mainly takes place online, but also in reptile fairs. It was recorded that specimens for sale fetch prices between US$35–200 on the international internet markets, e.g. price for two unsexed juveniles or one male of *G. araneus* was recorded for sale for US$150, *G. bawanglingensis* for €175 per pair (US$200), *G. catbaensis* for US$195–230 per

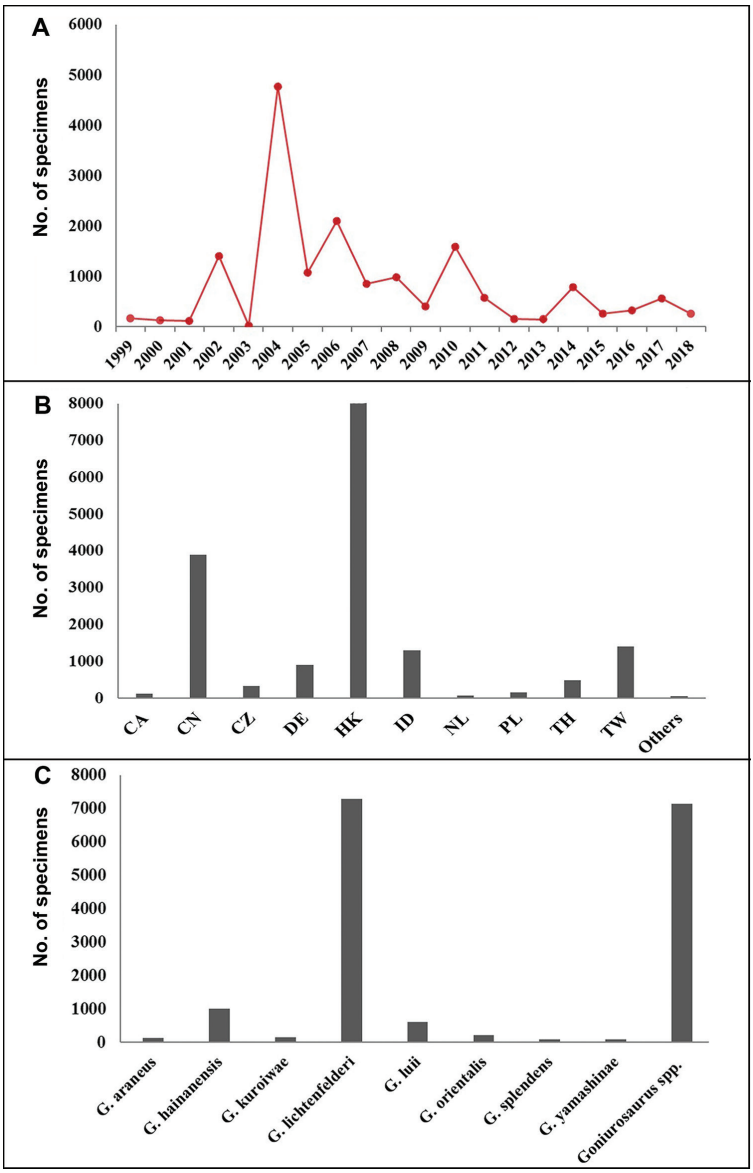

Figure 1. International trade in *Goniurosaurus* species between 1999 to 2018 to or from the U.S. **A** Annual volumes of import into the U.S. **B** number of exported specimens per exporting party (CA = Canada; CN = China; CZ = Czech Republic; DE = Germany; HK = Hong Kong; ID = Indonesia; NL = Netherlands; PL = Poland; TH = Thailand; TW = Taiwan) **C** number of imported specimens per species into US. Source: LEMIS database of the U.S. Fish & Wildlife Service (1999–2018).

specimen or for €300 (US$340) per pair, *G. hainanensis* for US$45–150 per specimen, *G. huuliensis* for US$400 per pair or US$150 for one male, *G. lichtenfelderii* for US$70–100 per specimen and *G. luii* for US$175 per two juveniles or for US$40–60 per pair or one (Table 2).

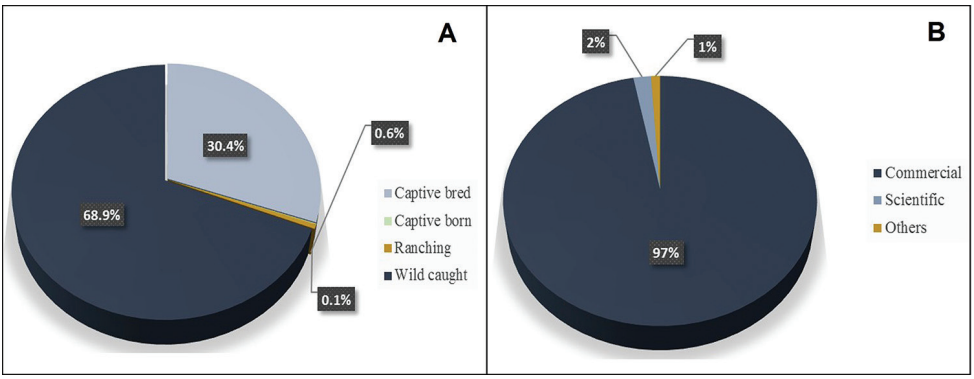

Figure 2. International trade in *Goniurosaurus* species from 1999 to 2018 to or from the U.S. **A** Source of animals **B** purpose of trade. Source: LEMIS database of the U.S. Fish & Wildlife Service (1999–2018).

Table 2. International trade in several *Goniurosaurus* species in Europe based on online investigations and interviews with dealers on reptile fairs (own surveys in 2018 and data from Altherr et al. *in lit.* 2019).

Species	Trade type	Place	Country	Price (USD) per specimen
G. araneus	Offer	Internet Shops	Europe	150–170 (€142)
G. bawanglingensis	Offer	Fair, Internet Shops	Germany, Europe	€67–250 (or €175 per pair)
G. catbaensis	Offer	Fair, Internet Shops	Germany, Europe	195–230 (or €300 per pair)
G. hainanensis	Demand and Offer	Internet Shops, Shops, and Private	Czech Republic, France, Germany	45–150
G. huuliensis	Demand and Offer	Internet Shops and Private	Europe	€160–220 (€400 per pair)
G. lichtenfelderii	Demand and Offer	Internet Shops and Private	Europe	70–100
G. luii	Demand and Offer	Fair, Internet Shops	France, Germany, Europe	40–170

Furthermore, Altherr et al. (*in lit.* 2019) reported a total of 835 specimens of *Goniurosaurus* spp. were observed for sale on 142 different online adverts with prices ranging from €35–300 (US$40–365) between September 2017 and September 2018, whereof, *G. araneus* (n = 56) were offered for sale of €142, *G. bawanglingensis* (n = 102) for €67–250 *G. catbaensis* (n = 29) for €170, *G. hainanensis* (n = 162) for €35–140, *G. huuliensis* (n = 41) for €160–220, *G. lichtenfelderii* (n = 97) and *G. luii* (n=150) for €35–142.

According to interviews with local dealers in Vietnam in March 2018, all five native *Goniurosaurus* species have been frequently recorded in local pet shops from Dong Nai Province and Ho Chi Minh City in northern Vietnam, on Social Media, e.g. Facebook, Zalo online and other internet platforms. These tiger geckos were usually wild-caught by local villagers who live within the species' distribution range and then sold for little money to dealers to be either offered in local pet shops or be sold to other traders. *Goniurosaurus* specimens were found to be locally offered for sale at US$7–25 per animal in pet shops in Vietnam (Table 3). According to dealers in pet shops, *Goniurosaurus* specimens have been regularly exported from Vietnam to Thailand and Indonesia without any permits for higher prices of US$100–150 per individual. Charges consist of at least 20–50 specimens per deal. Afterwards, specimens would allegedly be mainly exported further to Europe and the United States (Table 3).

Table 3. Information on local trade in and international trade pathways for *Goniurosaurus* species in Vietnam based on interviews with local dealers in 2018.

Species	Sources	Offered in pet shops	Country of destination	Minimum quantity per deal for export	Price (USD) per specimen*
G. araneus	China	Dong Nai Province	Thailand, Indonesia, EU and the U.S.	50	(2): 100–150
G. catbaensis	Cat Ba NP, Hai Phong city, Viet Nam	Dong Nai Province, Ho Chi Minh City	Thailand, Indonesia, EU and the U.S	>= 20	(1): 7–25 (2): 150
G. huuliensis	Huu Lien NR, Lang Son Province, Viet Nam	Dong Nai Province, Ho Chi Minh City	Thailand, Indonesia, EU and the U.S.	>= 20	(1): 20–25 (2): 100
G. lichtenfelderii	Yen Tu, Quang Ninh Province, Viet Nam	Dong Nai Province	Thailand, Indonesia, EU and the U.S.	>=20	(1): 20–25 (2): 100
G. luii	Cao Bang Province, Viet Nam	Dong Nai Province, Ho Chi Minh City	Thailand, Indonesia, EU and the U.S.	50	(1): 20–25 (2): 100–150

*(1): for locals; (2): for export

Population status of *Goniurosaurus catbaensis*

We observed a total of 73 animals (54 adults) in July 2017 on four islands and a total of 93 individuals (70 adults) in April 2018 within sites covered by the shrub vegetation on three islands in Ha Long Bay. We did not find any specimens of *Goniurosaurus* on out-surfaces of karst formations by boat surveys. The total population size at the survey areas was estimated at 175 individuals in July 2017 and 180 animals in April 2018. Regarding the effective population size – considering only mature animals – this estimated wild population was relatively similar to about 124 and 129 individuals in July 2017 and April 2018, respectively (Table 4). With respect to each sub-population, the number of estimated animals was highest on island 1 (86 individuals) (Table 4).

The mean density of *G. catbaensis*, along suitable habitat sites in Ha Long Bay, was estimated to be around 6 individuals and 4.5 adults per 100 m transect length during April and 9.1 individuals and 7 adults per 100 m transect length during July. By comparing different sites, the highest abundance was estimated at nearly 12 individuals per 100 m/ transect length at site 1 in April, while we found the lowest density of 2 animals per 100 m/ transect length at site 2 in July (Table 4).

In both investigated months, the sex ratio of adults was relatively balanced with a little higher percentage of females of *G. catbaensis* (57% and 55%, respectively). The percentage of gravid and non-gravid females significantly differed between both months ($c^2 = 21$; df = 2; $P < 0.001$), while 44% of females (n = 14) were gravid in July 2017 (Fig. 3A) and 95% of females (n = 41) were non-gravid in April 2018 (only two females were gravid). With respect to the presence of different age classes, the population structure was relatively similar between two months ($c^2 = 3.04$; df = 2; $P = 0.219$) with most of the observed animals being identified as adults (75% in July 2017 and 80% in April 2018 see Fig. 3B). Frequency histograms of SVL (Min–Max = 53.42–125.28 mm, n = 149) showed a slight shift in the presence of small juveniles between July and April ($c^2 = 19.88$; df = 7; $P = 0.006$). Individuals with the smallest SVL

Table 4. Summary of the population assessment of *Goniurosaurus catbaensis* including observed individuals, densities (D) and population size estimates (N) in Ha Long Bay in July 2017 and April 2018. Ind: individuals; Asterisks indicate missing data (no survey).

	Island 1 (T-1)	Island 2 (T-2)	Island 3 (T-3)	Island 4 (T-4)	Total
July-2017					
Total (observed)	27	7	20	19	73
Mature (obs.)	17	3	16	18	54
D observed [ind/100 m of route]	7.1	2.3	10	4.6	6
D [mature/ 100 m of route]	4.5	1	8	4.4	4.5
N_{mature}	36	4	33	50	**124**
N_{total}	56	16	49	54	**175**
April-2018					
Total (observed)	45	*	15	33	93
Mature (obs.)	28	*	12	30	70
D [ind/100 m of route]	11.8	*	7.5	8.1	9.1
D [mature/100 m of route]	7.3	*	6	7.5	7
N_{mature}	60	*	27	45	**129**
N_{total}	86	*	45	49	**180**

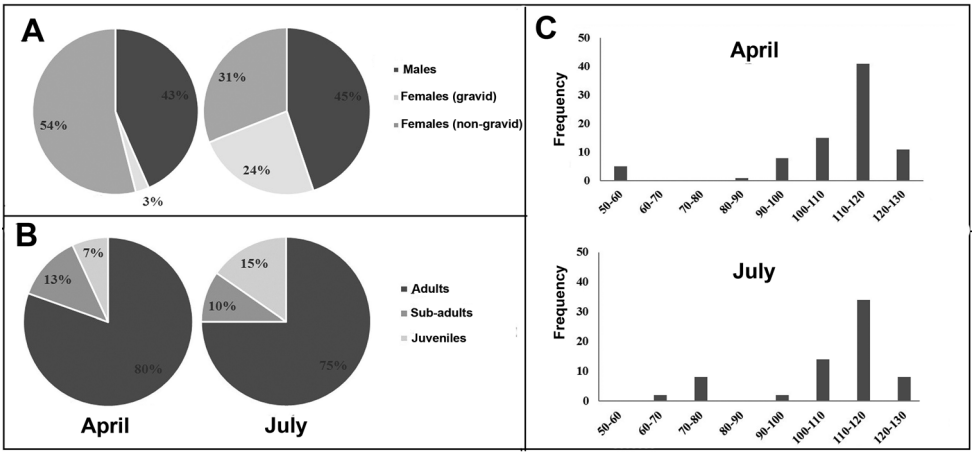

Figure 3. A, B Population structure of *Goniurosaurus catbaensis* from Ha Long Bay (July 2017 and April 2018, respectively) **C** Frequency histogram of snout-vent length of *G. catbaensis* for the months April and July.

(50–60 mm) were only found in April, while juveniles with longer SVL (60–80 mm) were exclusively found in July. The number of adults with SVL ranging between 110–120 mm accounted for the highest percentage in both months (Fig. 3C).

Daily activity

With regard to the daily activity pattern, *G. catbaensis* was found to be active at night from approximately 20:00 h to 04:00 h. The vast majority of lizards (98 animals or

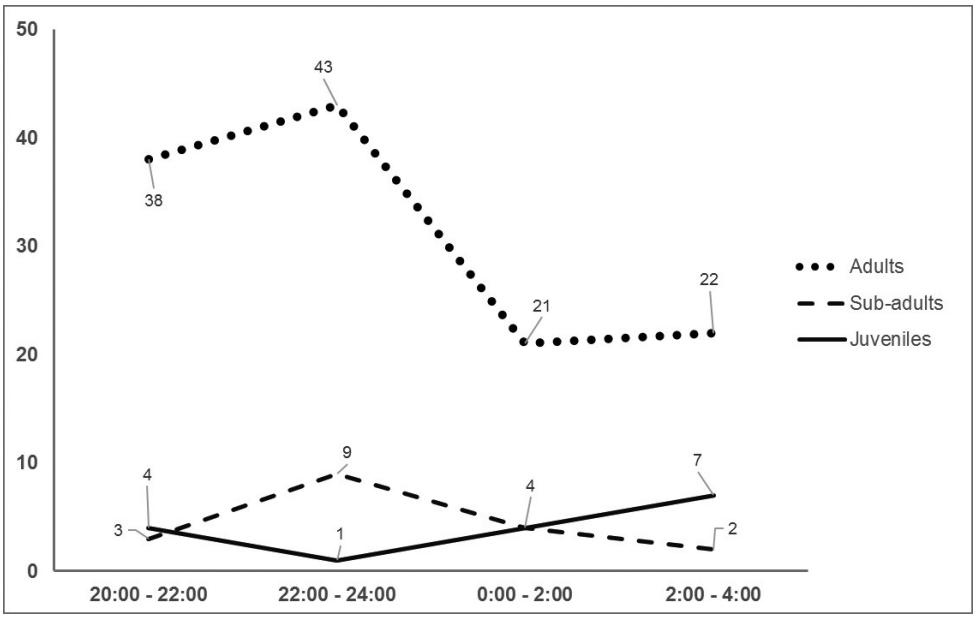

Figure 4. Number of observed *Goniurosaurus catbaensis* specimens at different time intervals in Ha Long Bay.

62% of the recorded lizards) were observed between 22:00 h and 24:00 h. We further found a difference in population structure amongst different times of the day (c^2 = 14.39; df = 6; P = 0.026 < 0.05). Particularly, we observed that more adult specimens were active during the first four hours between 20:00 h and 24:00 h (n = 81 account 65.3% of captured adults), while juveniles were frequently found either before 22:00 h or mainly between 00:00 h and 04:00 h. Most juveniles were found between 02:00 h and 04:00 h (Fig. 4).

Threat evaluation

The number of captured animals and the size of sub-populations of *G. catbaensis* from Ha Long Bay in Quang Ninh Province were compared with other differently affected sub-populations in Cat Ba Archipelago of Hai Phong City. In the Cat Ba National Park and Ha Long Bay's tourist caves, total anthropogenic impacts were considered to be "Medium" and local populations were relatively small (2–10 individuals). A strong flood event in 2015 appeared to have caused the local extirpation of *G. catbaensis* at one site in Viet Hai Commune on Cat Ba Island (Table 5). The mean population size of the species was highest within untouched sites on four islands in Ha Long Bay (Table 5), where total anthropogenic impacts were considered as "Low".

Table 5. Recorded impacts on *Goniurosaurus catbaensis* at known sites. Single impacts were ranked according to severity as "not recorded" defined as never being recorded, "low" as being rarely observed, "medium" as being recorded several times, or "high" as being recorded frequently, or the extent of destruction was evaluated too high.

Study sites	Population size (Mean)	Harvest	Tourist activities	Habitat degradation	Total impacts
Sites near the headquarters of Cat Ba National Park (NP) – Ngo et al. 2016b	5	Medium	High	Medium	Medium
Viet Hai Commune – Cat Ba NP – Ngo et al. 2016b	10	Medium	Medium	Low	Medium
One site in Viet Hai Commune – Cat Ba NP – Ngo et al. in press	0 (in August 2015)	Not recorded	Not recorded	High	High
Ha Long Bay (4 islands) – Current study	51	Not recorded	Not recorded	Low	Low
Ha Long Bay's Caves (4 caves) – Current study	2 (total animals)	Not recorded	High	Medium	Medium

Discussion

Trade

Ngo et al. (in press) provided evidence for the collection of at least three of five native species, namely *G. catbaensis, G. huuliensis* and *G. luii* in Vietnam for the domestic trade. During our recent market surveys in 2018, we further recorded that all five native tiger geckos are being collected for sale and also kept as pets in Vietnam, while some tiger geckos including *G. araneus, G. luii* (Grismer et al. 1999), *G. catbaensis* (Bauer 2009) and *G. lichtenfelderii* (Liu 1993) were reported to be used in traditional medicine in China. Our interviews identified commercial revenues in relation to the domestic and international pet trade as the most common incentive for domestic collection in Vietnam. Janssen and Shepherd (2019) documented that the *Goniurosaurus* is the most popular endemic genus offered for sale on the Nansei Islands in Japan.

All tiger geckos have a restricted distribution ranges and are – like many endemic reptiles – extremely vulnerable to exploitation, so that international trade can quickly become a significant threat for extinction (Janssen and Indenbaum 2019; Janssen and Shepherd 2018; Lyons and Natusch 2013). Accordingly, many endemic species have not been seen any more over a long period of time in recent years and some taxa are considered extinct at their type localities (Lindenmayer and Scheele 2017; Meiri et al. 2018). Evidence from extensive field works in recent years suggests that populations of *G. araneus* in Vietnam and *G. luii* in China have been extirpated at their respective type localities in the past due to over-harvesting for the pet trade (Stuart et al. 2006, Yang and Chan 2015, pers. obs.).

Goniurosaurus spp. have been popular in the international pet market at least since the 1990s (Stuart et al. 2006; Yang and Chan 2015). According to the LEMIS database, a total of 16,714 specimens of *Goniurosaurus* spp. have been imported into the U.S. between 1999 and 2018. The U.S., together with Japan and the European Union, are considered as three important destinations for the transaction of reptile species

including tiger geckos (Auliya et al. 2016; Janssen and Indenbaum 2019; Sollund and Maher 2015). Several individuals of the Huu-Lien Tiger Gecko, endemic to Vietnam, were observed in some reptile shops in Japan (Janssen and Indenbaum 2019). Janssen and Shepherd (2019) found that all *Goniurosaurus* species, endemic to Japan and being nationally protected by law, are offered for sale in the EU and the U.S. in large quantities for prices reaching up to US$714 for single specimens.

We herein observed most *Goniurosaurus* species for sale in the EU online as well as in reptile fairs. Accordingly, Altherr et al. (*in lit.* 2019) spotted a total of 835 specimens of *Goniurosaurus* spp. for sale on different social media platforms between 2017 and 2018. These observations, during random physical as well as internet market surveys, only reflect snapshots of current EU trade in tiger geckos. Actual trade volumes remain unknown – as *Goniurosaurus* spp. are not as yet listed in the CITES Appendices – but are likely to be higher.

Stuart et al. (2006) supported the idea that captive breeding can reduce further demand on wild-caught animals. Our study indeed showed that a large quantity of animals offered for sale was labelled as captive bred in Europe and several reports on successful captive breeding in *Goniurosaurus* species exist (e.g. Einsfelder 2016; Kaverkin 2000). However, wild-caught animals are still being imported into the EU and the U.S. in large quantities. During the recent ten years, there were still about 4,000 imports of wild specimens to U.S. recorded. Endemic tiger geckos of China and Vietnam, which were imported into the U.S. as wild-caught specimens, originated from non-range states, likely without any related permits from countries of origin.

According to interviewees in Vietnam and Europe, captive-bred animals were not yet available in quantities to meet the global demand and wild animals were generally offered for much cheaper prices than captive-bred animals. Furthermore, wild-caught specimens are considered to have a high mortality rate during transport and stockpiling (Sollund and Maher 2015), even though no studies exist that assessed mortality rates between collection and export or between export and country of destination in *Goniurosaurus*. According to local dealers, wild animals are usually kept for a long time clumped together in small boxes and then transported with motorbikes, trains, ships or air freights under poor conditions without supply of food and water. It is likely, that many of the sensitive animals die before reaching their final destination. According to our interviews, local dealers from Vietnam nowadays usually contact local collectors who are living close to the habitats of *Goniurosaurus* species via online wildlife trade groups, for example, on Facebook and pay about US$4 – 5 per individual for collection during the active season of the species. We found *G. araneus* amongst the animals offered in Vietnam (likely imported from China), a species which has probably already been extirpated from its type locality in Vietnam (Ngo et al. 2016b). After collection, specimens are frequently transported via motorbike to Hanoi, northern Vietnam and then transported by train or motorbike to pet shops in Dong Nai and Ho Chi Minh City, southern Vietnam. Some specimens are sold in Vietnam, but the majority of animals are allegedly transported by train or boat to Thailand and Indonesia as intermediary countries without any permits, as they reach higher prices than on the national market. From there, these animals are mainly exported to Europe and the U.S. (Fig. 5). As such, the entire trade chains are rather long as they include numerous stations.

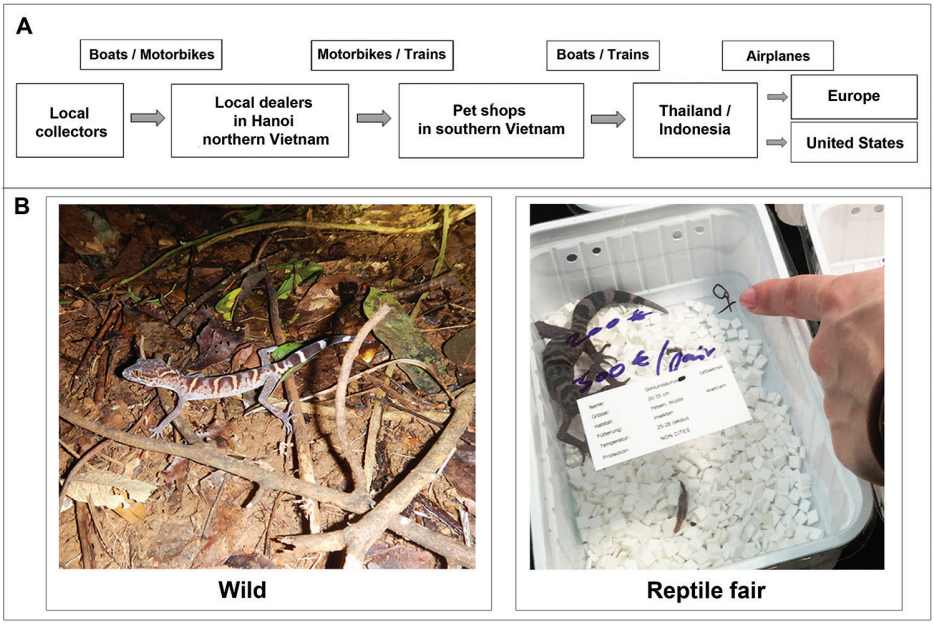

Figure 5. One case example showing the route of local and international trade in *Goniurosaurus catbaensis*.

Population status of *Goniurosaurus catbaensis*

Recent population estimates of the Cat Ba Tiger Gecko at its type locality on Cat Ba Island suggested extremely low population sizes (Ngo et al. 2016b; Nguyen et al. 2018b). Ngo et al. (in press) recently recorded new sub-populations of *G. catbaensis* on further small islands in the adjacent Ha Long Bay. The present data suggest that these sub-populations are stable and actively reproducing. Densities of *G. catbaensis* on islands in Ha Long Bay were, on average, 6 animals / 100 m, some magnitudes higher than on Cat Ba Island (0.08 – 0.17 animals / 100 m, Ngo et al. 2016b). The species is not evenly distributed over the small islands, but only occurs along limited habitat sites. A survey on a population of the closely related *G. luii* in the north of Vietnam revealed a similar low density of 0.08 specimens / 100 m (Ngo et al. 2016b). Extremely high exports and a local extirpation have been reported for this species in the past (Stuart et al. 2006).

Similar research on another enigmatic Vietnamese gecko species, *Cnemaspis psychedelica,* endemic to small islands in the south of Vietnam, revealed a density of 12–19.2 animals / 100 m and an estimated population size of 365–732 individuals (Ngo et al. 2016a). The population of the threatened gecko, *Gonatodes daudini* endemic to St. Vincent and the Grenadines, was estimated at abundances of 87–218 animals / ha in 2010 and has significantly declined to 19 animals / ha) in 2018 (with a total population of 9952 individuals) and over-harvesting being reported as the major threat to the species (Bentz et al. 2011; Shepherd et al. 2019). Overharvesting for the international trade has also been reported as a major threat to *Lygodactylus williamsi*, an electric blue gecko endemic to a small range in Tanzania. Flecks et al. (2012) estimated a density of 353 specimens / ha and

a total population size of 148,684 ± 112,365 adults of this species. As such, these geckos are examples for range restricted, endemic species with small populations that appear to be especially threatened by trade. As a consequence, all three gecko species have been recently included (*C. psychedelica* and *L. williamsi* at CoP17) or proposed for inclusion (*Gonatodes daudini* for CoP18) on CITES Appendix I to regulate international trade in these species.

The recorded abundances in *G. catbaensis* also appear to be extremely low compared to other threatened and endemic geckos. The lowest abundances of *G. catbaensis* were found at touristic sites on Cat Ba Island. Conversely, abundances were relatively stable on the islands in Ha Long Bay, which comprised intact habitats and were not affected by human activities, as they were too small and inaccessible. Harvesting has not been recorded on these small islands so far. Thus, it is likely that the much lower densities of the species on Cat Ba Island are the result of anthropogenic pressures, especially collection for the pet trade.

Conclusions

As *G. catbaensis* was found to occur in very low densities and has extremely restricted habitat ranges (small islands) that are subject to stochastic weather events, the species appears to be extremely vulnerable to harvesting, which appears to be the case for the entire genus.

Endemic species are considered to be especially vulnerable to over-exploitation (Janssen and Indenbaum 2019). The present study confirmed that tiger geckos are not only locally used, but a subject of the international pet market. Compared to the low densities and small populations in the wild, the number of specimens currently found in the international trade appears to be considerably large. As such, it can be assumed that ongoing uncontrolled harvesting might further imperil *Goniurosaurus* spp. in the future. Tiger geckos are neither sufficiently protected by law nor part of conservation programmes, due to the lack of substantial knowledge on the species conservation status and probably due to the general lack of public as well as political interest in biodiversity conservation. To date, exact impacts of trade on the species cannot be identified, as data of legal trade are only recorded for species listed in the CITES Appendices in most countries. However, at the time of writing, the inclusion of all *Goniurosaurus* species from China and Vietnam in CITES Appendix II has been proposed by China, Vietnam and the EU to be decided at the Conference of the parties (CoP18) in May-June 2019, in Sri Lanka.

Recommendations for conservation

Some *Goniurosaurus* taxa are only found within protected areas in Vietnam, for example *G. catbaensis* in Cat Ba National Park and Ha Long Bay World Heritage site, *G. huuliensis* in Huu Lien Nature Reserve, *G. lichtenfelderi* in Bai Tu Long National Park and animals can only be collected with appropriate permits from local authorities. At the time of writing this manuscript, all *Goniurosaurus* species native to Vietnam

have been included in Group IIB of the Governmental Decree 06/2019/ND-CP, which came into force on 10 March 2019 and prohibits the collection of and trade in respective species without permits in Vietnam (The Government of Vietnam 2019). In China, *G. hainanensis* was listed as a species of terrestrial wildlife, which are beneficial or of important economic or scientific value. Furthermore, *G. hainanensis* and *G. bawanglingensis* were listed as wildlife under special protection in Hainan Province. According to Janssen and Shepherd (2019), all *Goniurosaurus* species, endemic to Japan, are currently listed under the law for the Conservation of Endangered Species of Wild Fauna and Flora (LCES), which prohibits – amongst others – the collection and selling of respective species. Eight species of *Goniurosaurus* have been recently included in the IUCN Red List and were assessed in the threat categories VU, EN and CR. In fact, it has been specifically paid more attention regarding conservation activities for *G. catbaensis* after its inclusion in the IUCN Red List as "Endangered" in 2016 (Nguyen et al. 2016). Training programmes have been held by IUCN Vietnam since November 2018 to enhance monitoring skills of researchers in Ha Long Bay and Cat Ba National Park in order to protect wild sub-populations of *G. catbaensis*. Signboards highlighting the conservation needs of *G. catbaensis* have been provided to the scientific department of Ha Long Bay (Fig. 6), which represents a first step towards meaningful conservation of the species.

Figure 6. Signboard handed over to the Ha Long Bay Management Department to point to the threats and conservation need of the Cat Ba tiger gecko in English and Vietnamese languages.

To further improve the conservation status of *Goniurosaurus* species, we recommend the following measures:

- The inclusion of *Goniurosaurus* spp. in the Appendices of CITES in order to better control and monitor trade in wild specimens. The current proposal to include all *Goniurosaurus* species from China and Vietnam in CITES Appendix II should be supported. Likewise, we acknowledge that the Japanese *Goniurosaurus* clade may warrant listing in the CITES Appendices. Therefore, a listing could be considered in the future, as also proposed by Janssen and Shepherd (2019). A listing of the Japanese species in Appendix III, as suggested by Janssen and Shepherd (2019), might be a favourable interim solution.
- As the lack of adequate information on the biology and conservation status of single species can impede conservation measures, a timely assessment of the remaining *Goniurosaurus* species in the IUCN Red List is strongly advised. Therefore, more species specific research is needed to fully understand conservation requirements.
- It is likely that, with more research, further cryptic species or new occurrences of this genus will be discovered in the future. Thus, it is strongly recommended to conceal exact locality data as well as detailed descriptions of localities for such new species or population records in order to prevent targeted collection, as has happened in the past.
- We recommend to improve or establish coordinated ex-situ breeding programmes for all species and to build up a stable captive population in order to a) serve as the backup population for restocking measures (also in the light of extreme population declines e.g. due to stochastic weather events) and b) to meet the demand for tiger geckos in the trade and thereby reduce the pressure on wild populations.

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