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Source: Revue suisse de Zoologie, 123(2) : 241-251

Published By: Muséum d'histoire naturelle, Genève

URL: https://doi.org/10.5281/zenodo.155297

Revue suisse de Zoologie (September 2016) 123(2): 241-251 ISSN 0035-418

Discovery of a new crocodile lizard population in Vietnam: Population trends, future prognoses and identification of key habitats for conservation

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Abstract: The crocodile lizard, a globally endangered species with a restricted range in southern China and northern Vietnam, is an increasingly demanded species in the international pet trade. Poaching activities brought the species to the brink of extinction, while ongoing habitat destruction represents an additional peril to the species. Especially the Vietnamese population is extremely small with a preliminary estimation of less than 100 individuals. According to predictions of the species potential distribution, we conducted targeted field surveys to search for further populations in Vietnam in order to update the species' conservation status. We could prove the practical and efficient applicability of this theoretical model by the discovery of a new population from a predicted forest site near the international border between China and Vietnam. Based on monitoring of the Vietnamese population from 2010 to 2015 we further provide an overview about current population trends, which revealed dramatic local declines of more than 50% of effective population sizes and the species' extirpation at a third of all known sites. In addition, we predicted future scenarios of suitable habitats and compared these results with actual forest cover in order to define key habitats for effective conservation measures.

Keywords: Niche modeling, new population record, climate change, priority areas for conservation, population dynamics, conservation planning

INTRODUCTION

The crocodile lizard (*Shinisaurus crocodilurus*), which was originally described by Ahl (1930) from small isolated areas in southern China and only relatively recently discovered from North Vietnam by Le & Ziegler (2003) (see also Ziegler *et al.*, 2008), is currently at the brink of extinction (van Schingen *et al.,* 2015a). Its outstanding color patterns and primeval appearance make the species evermore desired in the international trade. Since the 1980s, Chinese specimens are being internationally traded resulting in dramatic population declines to only 950 individuals in 2008 (Huang *et al.,* 2008; van Schingen *et al.,* 2015a). Individuals of the much smaller Vietnamese population just recently entered the international pet trade in amounts that are not sustainable for wild populations (van Schingen *et al.,* 2015a). While the heavily diminished wild populations are steadily shrinking the international demand for new bloodlines, especially from Vietnam is rising (van Schingen *et al.,* 2015a). In addition, ongoing habitat destruction currently imperils all populations of the ecologically highly specialized species (Huang *et al.,* 2008; van Schingen *et al.,* 2014b, 2015b). A previous study revealed an effective population size – defined as number of mature individuals – of only less than 100 individuals in Vietnam, distributed among three separated subpopulations (van Schingen *et al.,* 2014b). However, the appearance of relatively high numbers of allegedly Vietnamese specimens in the trade indicate that potentially unknown subpopulations must exist, which are probably still only known by local collectors (van Schingen *et al.,* 2015a). Due to the unsustainable trade in *S. crocodilurus* the species was listed on CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) Appendix

Manuscript accepted 24.02.2016
DOI: 10.5281/zenodo.155297

II and recently as Endangered on the IUCN (International Union for Conservation of Nature) Red List of Threatened species (Huang *et al.,* 2008; Nguyen *et al.,* 2014). Facing the current alarming conservation status, the discovery of further potential subpopulations and the identification of key habitats is crucial for improved conservation measures. A first niche model approach predicted that the overall suitable habitats of *S. crocodilurus* are rare, fragmented, and poorly covered with protected areas (van Schingen *et al.*, 2014a). Species distribution models (SDMs) represent an increasingly applied tool to predict the potential distribution and to identify suitable habitats of species (e.g., Rödder *et al.,* 2010; Rödder & Schulte, 2010). However, these models are principally theoretical and have been rarely proven valid in the field. One aim of the present study was to use the predicted potential distribution of *S. crocodilurus* as a base to search for further occurrences in order to verify the approach and provide updated information on the population and conservation status of the species. We further provide an overview about current population trends of Vietnamese crocodile lizards based on population monitoring over the recent years.

At present, climate change is recognized as one of the major forces biasing species distribution and it is assumed to imperil numerous tropical lizard species, due to their narrow temperature tolerances (e.g., Araújo & Rahbek, 2006; Beaumont *et al.,* 2007; Sinervo *et al.,* 2012; Huey *et al.,* 2012; Tewksbury *et al.,* 2012). Crocodile lizards are semi-aquatic habitat specialists adapted to remote and densely vegetated, clean streams within evergreen broadleaf forest and regarded as dependent on annual moderate cool temperatures (Ning *et al.,* 2006; van Schingen *et al.,* 2014a, 2015b). Thus, *S. crocodilurus* is likely being affected by climatic change and habitat alteration. In China, Li *et al.* (2012) already projected that all suitable habitats for the crocodile lizard will vanish by 2080. Thus, another aim of the present study was to predict future scenarios of habitat suitability in order to identify key habitats for *S. crocodilurus*, which remain in the future. Since SDMs alone cannot incorporate every single factor to predict habitat suitability, we combined results of a Maxent model with detailed vegetation data to identify, which of the predicted suitable habitats still comprise intact and connected broadleaf forest. Based on this approach we aim to define priority areas for improved conservation measures and provide recommendations on where 1) nature reserves need to be upgraded, 2) newly established, or 3) forest corridors must remain to allow genetic exchange between populations, and 4) sites are most suitable for future restocking / release programs.

METHODS

Population status: According to our previous niche model approach (van Schingen *et al.,* 2014a) one of the largest areas of connected suitable habitats was predicted to be situated in the border region of China and Vietnam. However, no field research focusing on the species has been carried out in this region so far. Based on our preliminary predictions we conducted a field survey in the border area between China and Vietnam in June 2015 in order to verify the accuracy of SDMs and update the current population status of *S. crocodilurus* in Vietnam.

To evaluate population dynamics and the current status of the crocodile lizard in Vietnam, we analyzed population data from all known localities [Tay Yen Tu Nature Reserve (NR) (N 106.81168°, E 21.17190°), Bac Giang Province; Yen Tu (N 106.70006°, E 21.16716°) and Dong Son-Ky Thuong NRs (N 107.11962°, E 21.15358°), Quang Ninh Province], collected during field surveys in 2010, 2013, 2014 and 2015 (see van Schingen *et al.,* 2014b, 2015a for methods). All surveys had been conducted by our team during the rainy season between May and July. Since 2010 each individual with a snout-vent length (SVL) > 100 mm had been permanently marked by a passive integrated transponder (PIT) tag for individual identification and long term population monitoring (see van Schingen *et al.,* 2014b for details). Individuals were categorized in age classes based on SVL (for methods see van Schingen *et al.,* 2014b, 2015b). Methods conform with IUCN Resolution 4.015 (Guidelines regarding research and scientific collection of threatened species). Data of in total 52 night surveys were included in this analysis (Table 1). Population sizes were estimated according to Huang *et al.* (2008) and van Schingen *et al.* (2014b), with a slightly modified formula given as: $N = \Sigma [m(1 + i/x)]$. Hereby N is the total population size, m is the total number of observed individuals along one stream including all surveys within one season, i is the "invisible rate" index ($i = [\Sigma(b_n - a_n)]/\Sigma a_n$, where a_n is the number of observed individuals in stream n during the first survey and b_n is the total number of observed individuals in stream n) and x is the number of surveys in transect n during one survey. For the invisibility rate i we used the rate calculated by van Schingen *et al.* (2014b) to make the data comparable. A Chi²-test was applied to test for temporal differences in population structure using PAST version 2.17 (Hammer *et al.,* 2001). Significant difference was declared for $p < 0.05$.

Modeling: Based on 41 occurrence records and a set of environmental factors, we predicted the future potential distribution of *S. crocodilurus* with Maxent (Phillips *et al.,* 2006). All occurrence records from northern Vietnam were compiled during own field surveys between 2013 and 2015, while records from southern China were derived from literature (Huang *et al.,* 2008; Huang *et al.,* 2014; van Schingen *et al.,* 2014b) or were provided by researchers (Z. Wu in *litt.,* 2013). For minimizing effects of spatial autocorrelation and to ensure the independency of the records, we only included the two outermost occurrences of

Table 1. Summary of observed, estimated and recaptured *Shinisaurus crocodilurus* in Vietnam between 2010 and 2015.

	Tay Yen Tu		Yen Tu			Dong Son-Ky Thuong			Hai Ha (new)	Total
Variable	Site 1	Site 2	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	
2010										
Total (observed)	4	9	*	*	*	*	*	*	*	13
Mature (obs.)	3	4	*	*	*	*	*	*	*	7
Juveniles (obs.)	0	2	*	*	*	*	*	*	*	2
Night surveys	5	4	*	*	*	*	*	*	*	9
Total (estimated)	5	12	*	*	*	*	*	*	*	17
Mature (est.)	4	5	*	*	*	*	*	*	*	9
2013										
Total (observed)	7	33	3	8	*	2	4	5	*	62
Mature (obs.)	3	11	2	8	*	2	2	3	*	31
Juveniles (obs.)	2	21	1	0	*	0	1	0	*	25
Recaptures	1	1	*	*	*	*	*	*	*	2
Night surveys	3	5	1	2	*	1	1	1	*	14
Total (estimated)	10	42	7	13	*	5	9	12	*	98
Mature (est.)	4	14	5	13	*	5	5	7	*	53
2014										
Total (observed)	9	25	0	7	7	1	1	1	*	51
Mature (obs.)	5	6	0	0	1	1	0	0	*	13
Juveniles (obs.)	3	18	0	7	5	0	0	0	*	33
Recaptures	3	3	0	0	*	1	0	1	*	8
Night surveys	2	3	0	1	1	1	1	1	*	10
Total (estimated)	15	36	0	16	16	2	2	2	*	91
Mature (est.)	8	9	0	0	2	2	0	0	*	22
2015										
Total (observed)	27	25	0	0	20	0	4	5	12	93
Mature (obs.)	10	10	0	0	4	0	2	1	1	28
Juveniles (obs.)	10	13	0	0	15	0	1	4	11	54
Recaptures	6	7	0	0	1	0	2	1	*	17
Night surveys	6	6	0	1	2	1	1	1	1	19
Total (estimated)	33	31	0	0	34	0	9	12	28	147
Mature (est.)	12	12	0	0	7	0	5	2	2	41

*Asterisks indicate that respective site was not known at time point

one site in the analyses (Jennings & Veron, 2011; Jennings *et al.,* 2013). Since *S. crocodilurus* is heavily dependent on specific climatic conditions and restricted to certain altitudinal ranges (van Schingen *et al.,* 2014a, 2015b), we used the following 19 bioclimatic variables: BIO1 "Annual Mean Temperature", BIO2 "Mean Diurnal Range" (Mean of monthly [max temp - min temp]), BIO3 "Isothermality" (P2/P7) (*100), BIO4 "Temperature Seasonality" (standard deviation *100), BIO5 "Max Temperature of Warmest Month", BIO6 "Min Temperature of Coldest Month", BIO7 "Temperature Annual Range" (P5-P6), BIO8 "Mean Temperature of Wettest Quarter", BIO9 "Mean Temperature of Driest Quarter", BIO10 "Mean Temperature of Warmest Quarter", BIO11 "Mean Temperature of Coldest Quarter", BIO12 "Annual Precipitation (year)", BIO13 "Precipitation of Wettest Month", BIO14 "Precipitation of Driest Month", BIO15 "Precipitation

Seasonality" (Coefficient of Variation), BIO16 "Precipitation of Wettest Quarter", BIO17 "Precipitation of Driest Quarter", BIO18 "Precipitation of Warmest Quarter" and BIO19 "Precipitation of Coldest Quarter" obtained from the WorldClim global climate database (www.worldclim.org assessed in July 2015; Hijmans *et al.,* 2005), and an elevation layer derived from the Consortium for Spatial Information (CGIAR-CSI. Available from http://srtm.csi.cgiar.org, assessed in July 2015; Reuter *et al.,* 2007) as environmental predictors. The potential distribution was predicted for the current and future (2020, 2050 and 2080) situations, while the resolution of bioclimatic layers decreased from 800 m (present time) to 8000 m for future prognoses. We reduced the resolution of originally 3 m of digital elevation data to fit with bioclimatic data. Suitable habitats for *S. crocodilurus* were modeled using 10033 points (9992 background points and 41 present records) to determine the Maxent distribution. The model was trained with a randomly selected subset of the species' presence records (80%), while the remaining records were used to evaluate the model performance. The study extent for predictions was selected according to van Schingen *et al.* (2014a), covering the whole distribution range of the species. Besides specialization to climatic conditions and a distribution to a restricted elevation range, the crocodile lizard is further associated to undisturbed forest (e.g., Huang *et al.,* 2008; Ning *et al.,* 2009; van Schingen *et al.,* 2014b). Thus, we combined the results of the Maxent predictions with actual vegetation coverage, which has been classified from Landsat 8 satellite images (LC81260452014364LGN00, and LC81260462014364LGN00, resolution of 30 m), derived from the United States Geological Survey (USGS), available from http://glovis.usgs.gov (accessed July 2015). We calculated the "effective suitable area" consisting of closed forest coverage and suitable habitats according to Maxent predictions for the species' distribution range in northern Vietnam. This prediction was only made for the current situation, since no future prognoses for vegetation data are existent. The vegetation maps were classified by ERDAS with supervisor classification and all maps were created using ArcGIS software by Esri.

RESULTS

New population: According to predictions by SDMs we discovered a new population of *S. crocodilurus* in Hai Ha District, Quang Ninh Province close to the Chinese border (around N 21.196146°, E 106.882572°). This population represents the northernmost record of the species in Vietnam, about 60 km distant from the closest Vietnamese population in Dong Son-Ky Thuong Nature Reserve, and is situated outside of any protected area. Accurate locality data are not presented to prevent targeted poaching in this area. We observed a total of 12 individuals along a single forested lowland stream at low elevations between 131 and 198 m above sea level (a.s.l.). With respect to elevation, this finding represents the lowermost record of *S. crocodilurus* in general (vs. 200-1500 m a.s.l. in China and 180-850 m a.s.l. in Vietnam, see van Schingen *et al.,* 2014a). The habitat mostly resembled habitat sites in Dong Son-Ky Thuong NR, characterized by relatively broad lowland streams within mixed broadleaf and bamboo forest (van Schingen *et al.,* 2015b). We found all animals resting on branches, mostly above backwater pools, which is accordant to previous observations at known sites (van Schingen *et al.,* 2015b). The accompanying herpetofauna was similar to habitats within the Yen Tu Mountain range and Dong Son-Ky Thuong NR, and represented by high abundances of *Quasipaa* sp., *Sinonatrix* sp. and *Sphenomorphus cryptotis*. We observed only a single young adult (Fig. 1A) with a snout-vent length of 142 mm, while the remaining 11 individuals were juveniles (Table 1, Fig. 1B). Furthermore, we only encountered animals along one single stream in the area. Our interviews with local villagers revealed that crocodile lizards had been very abundant throughout the whole region until two years ago. Apparently, the population dramatically decreased due to poaching for the pet trade. Numerous local villagers are allegedly hunting the lizards for sale to traders from Hai Phong City or Hanoi. According to local villagers, only adult individuals are being collected for the trade, since juveniles cannot be sold. Meanwhile, it is allegedly extremely difficult even for the locals to still find the species in the wild.

Population trends: During four years of field research in 2010, 2013, 2014 and 2015 in Vietnam, we encountered a total of 192 different individuals of *S. crocodilurus*. From 2013 onwards, we annually recaptured 2 to 17 individuals marked in the year(s) before. Of the individuals marked in 2010 we only recaptured two lizards in 2013, whereof one individual was still recaptured in 2015. In 2010 we only surveyed Tay Yen Tu NR, while we discovered new sites in Yen Tu and Dong Son-Ky Thuong NRs in 2013 (Table 1). In total we discovered nine different sites inhabited by *S. crocodilurus* until 2015. Since the last field survey in 2015, we found that crocodile lizards were probably extirpated from three (one third) of these sites (Table 1). Our study revealed an overall increase in total population size to currently approximately 147 individuals distributed over all known occurrences in Vietnam (Fig. 2A). However, regarding the effective population size – considering only mature individuals – the estimated wild population slightly decreased from 2013 to 2015 to about 41 individuals (Fig. 2A).

Comparing different regions, Tay Yen Tu NR contained the largest known subpopulation with currently about 64 estimated total individuals, whereof we considered 24

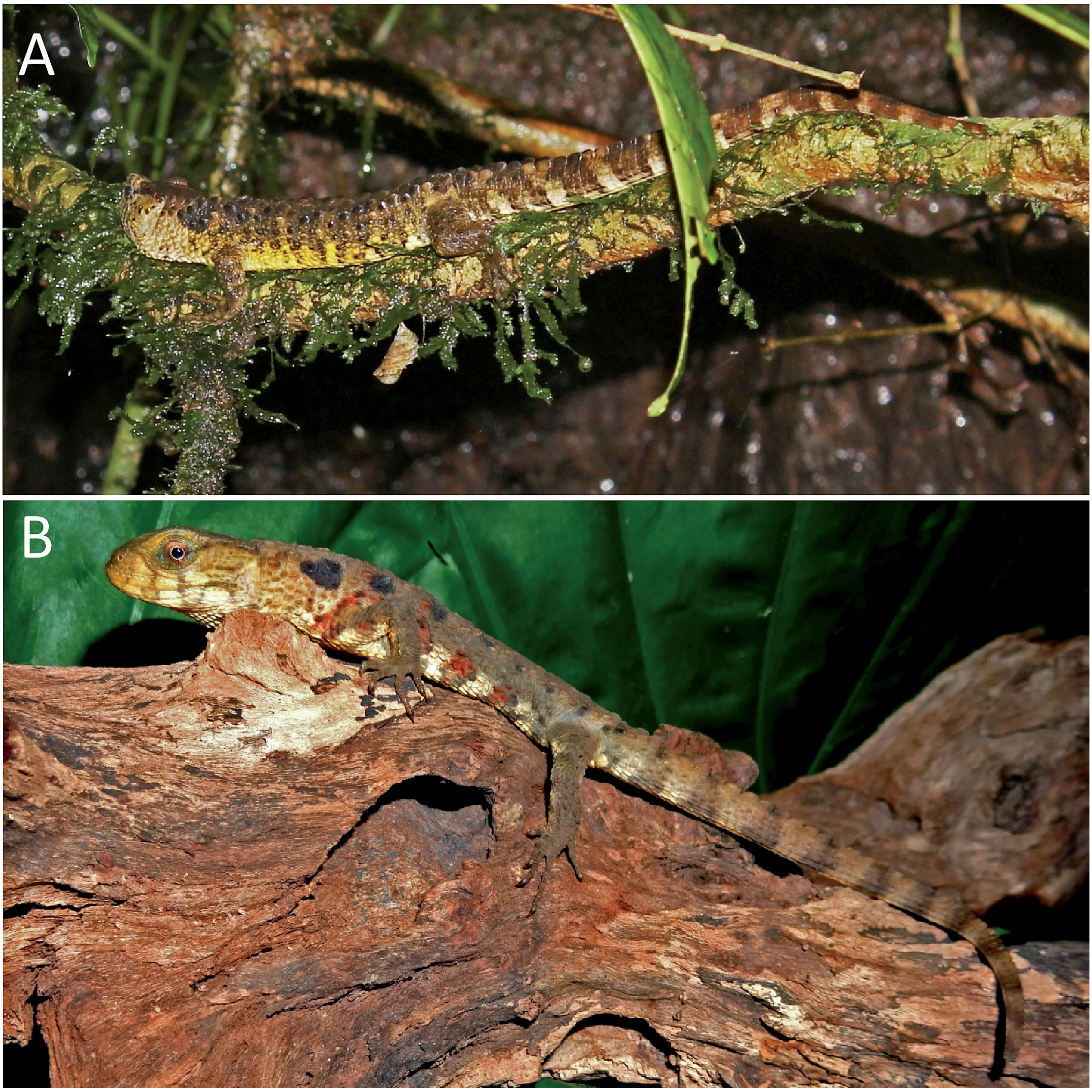

Fig. 1. New population of *S. crocodilurus* from Hai Ha District, Quang Ninh Province, Vietnam. (A) Adult in the habitat. (B) Juvenile. Photos C.T. Pham and M. van Schingen.

to be mature. We estimated the other three populations to consist in total of 21 to 34 and regarding mature individuals of two to seven mature individuals (Table 1, Fig. 2B). In fact we only encountered one to four mature individuals in 2015 each in Yen Tu NR, Dong Son-Ky Thuong NR and the new population at the border with China, respectively. Only in Tay Yen Tu NR the effective population size almost doubled throughout the last five years, while the other populations experienced a 57 to 60% decrease in mature individuals between 2013 and 2015, respectively (Table 1, Fig. 2C). Furthermore, a significant change in the population structure was recorded between 2010 and 2015 (Chi^2=18.53, df=6; p=0.005; Fig. 3). We found that mature individuals represented more than half (54%) of the population still in 2010, while the relative portion of this group decreased to 30% in 2015 (Fig. 3).

Suitable habitats: Of the environmental predictors the “Mean Diurnal Range“ (27.1%), “elevation” (19.8%) and “Annual Mean Temperature” (12.4%) had highest relative contributions on the Maxent model predicting current suitable habitats. With respect to future prognoses the predictor “Mean Diurnal Range”

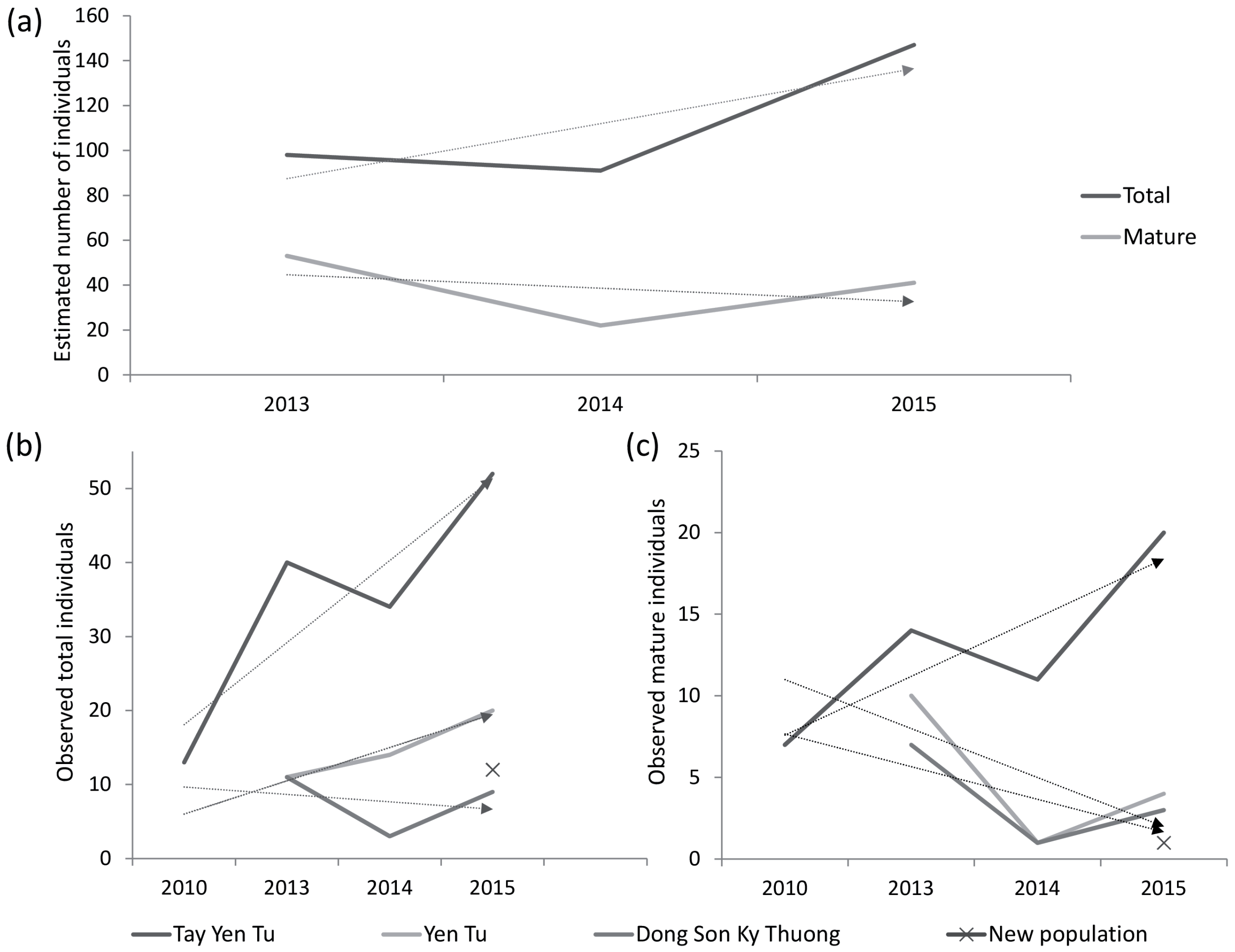

Fig. 2. Population trends of *S. crocodilurus* in Vietnam from 2010 to 2015. (A) Estimated total population sizes in Vietnam. (B) Observed total subpopulation sizes. (C) Observed effective subpopulation sizes. Arrows indicate trend lines.

gained in importance and remained the predictor with the highest relative contribution (39.3%, 30.5% up to 45.2%) in 2020, 2050 and 2080, respectively. Accordingly, response curves of the respective predictor indicate a restricted tolerance of *S. crocodilurus* to high diurnal temperature amplitudes and a strong dependence on constant and moderate temperature ranges. The relative contributions of other parameters only increased for later scenarios of the model, e.g. the "Mean Temperature of the Coldest Quarter" did not contribute to the present and the 2020 model, while this predictor became more important for the predictions from 2050 to 2080. In comparison to the bioclimatic predictors, the contribution of the factor "elevation" remained relatively constant (6.9 to 12.4%) throughout all predictions. Variables reflecting temperature data generally revealed higher contributions to the Maxent distribution than variables referring to precipitation, independent of the projected time period.

The model revealed only small proportions of the studied area to provide suitable habitats, which were further assumed to decrease from 5% to less than 0.3% between 2020 and 2080 (Fig. 4A-D). Our model suggested that the only remaining contiguous area of highly suitable habitat in Vietnam encompasses the Yen Tu Mountain Range, adjacent Dong Son-Ky Thuong NR and extends to the northeastern border with China (Fig. 4D). The areas with highest suitability throughout the whole distribution range were projected to be situated in Vietnam.

Combining the Maxent results with vegetation data, the effective suitable area was predicted to encompass about 263 km² (4.2%), 1253 km² (20.11%), 200 km² (3.2%) and 945 km² (15.2%), respectively of the distribution range in northern Vietnam, ranked from high to low suitability (Fig. 5). Accordingly, forests are already heavily fragmented, especially around present occurrence records. Core regions with intact forest coverage still exist in some parts of the Yen Tu Mountain Range, Dong Son-Ky Thuong NR. One of the major areas of contiguous forest expands from the eastern border of

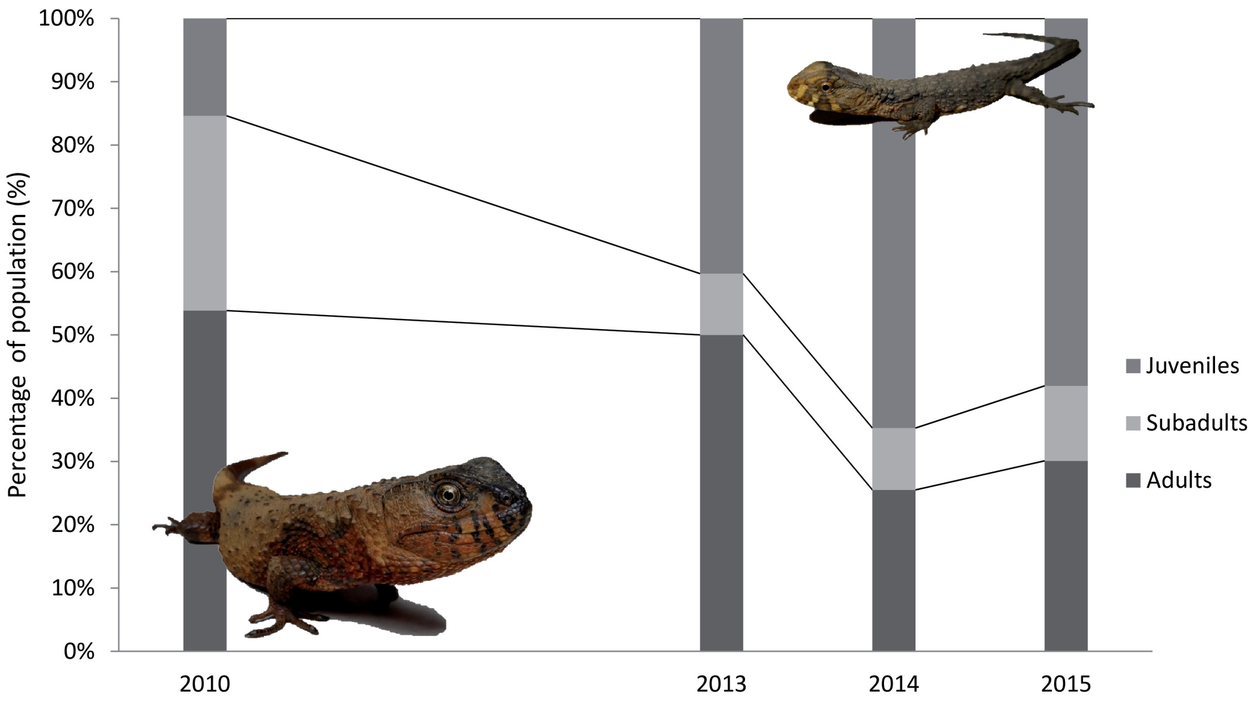

Fig. 3. Observed population structure of Vietnamese *S. crocodilurus* from 2010 to 2015. Photos M. van Schingen.

Tay Yen Tu NR and the western border of Dong Son-Ky Thuong NR, which forms an important corridor between the two reserves still inhabiting *S. crocodilurus.* Another major area of high suitability is situated in Hai Ha District in the Northeast of Quang Ninh Province, near the border to China. This region currently lies outside of any designated protected area (Fig. 5).

DISCUSSION

New population: The discovery of a new *S. crocodilurus* population in Vietnam based on predictions by SDMs (van Schingen *et al.,* 2014b) underlines the practical applicability and reliability of such theoretical models as useful tool to plan field research. This newly recorded population might represent one explanation of the noticeable high amounts of Vietnamese crocodile lizards currently present in the trade (van Schingen *et al.,* 2015a). Local villagers confirmed that adult crocodile lizards were heavily collected for the trade throughout the region in recent years. While *S. crocodilurus* reportedly was still relatively abundant some years ago, since recent years adult crocodile lizards were heavily collected for the trade throughout the region. These reports fit with our observations of almost exclusively juveniles. We assume the (former) presence of further *S. crocodilurus* subpopulations at the border region of Vietnam and China, which is promoted by SDMs (van Schingen *et al.,* 2014b) and statements of local villagers.

Since the new population is situated in-between the known Vietnamese and Chinese populations, a detailed genetic study of the population along with two others might provide important knowledge about the species' evolutionary history and phylogenetic relationships of the populations. The new population likely represents a kind of "missing link" between the known Vietnamese and Chinese populations. Such an analysis is currently being conducted by our team in order to determine if *S. crocodilurus* in China and Vietnam are indeed genetically differentiated. The results will be essential for designing appropriate measures, for both in-*situ* and *ex-situ* conservation, for this rare, unique, and endangered species.

Population trends: The overall increase in estimated crocodile lizards from 2010 to 2015 most likely resulted from the simultaneous increase in known sites, newly discovered populations and numbers of excursions. Evidence was provided by an increase in encountered juveniles over the last years, concurrent with a dramatic decrease in mature individuals (even though new populations were included in the estimations). Mature individuals are crucial for a stable and reproducing population (Reed *et al.,* 2003). *S. crocodilurus* reaches sexual maturity only after 2-4 years, and adults give birth only once a year (Zhao *et al.,* 1999; Bever *et al.,* 2005; Yu *et al.,* 2009). Since juveniles are also more sensitive to diseases, environmental changes and have a higher risk of mortality (Bever *et al.,* 2005; Zollweg & Kühne, 2013), we expect the present lack of mature individuals to cause a rapid decline in genetic diversity

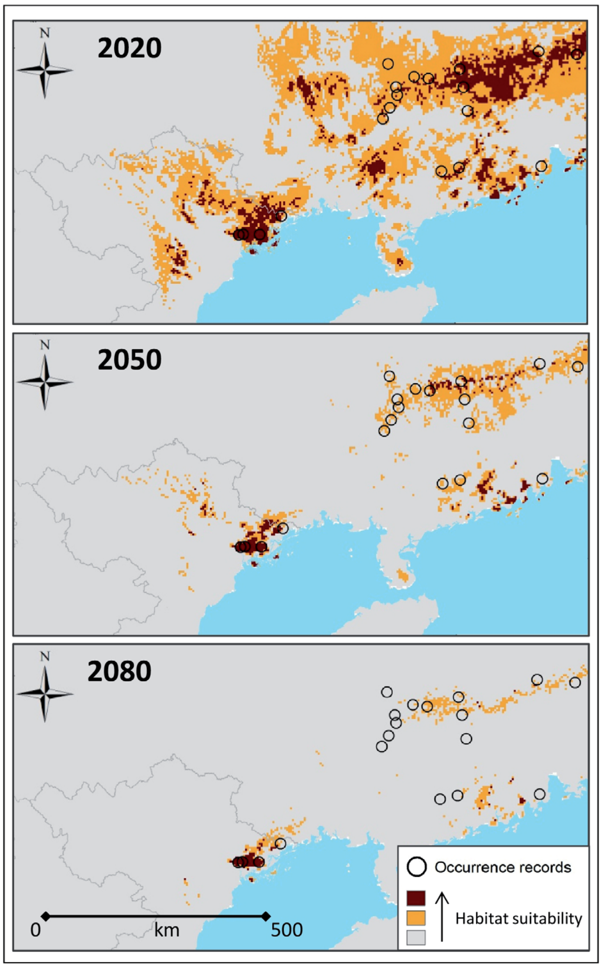

Fig. 4. Predicted suitable habitats for *S. crocodilurus* in the period between 2020 to 2080, based on bioclimatic data and elevation. Habitat suitability increases from yellow to dark brown.

and lead to local extinction. According to our data, crocodile lizards probably vanished from one third of the known sites already two years after discovery. The present scenario elucidates the severity of the current extinction risk, and how promptly local populations can cease. We assume that this observed local loss of mature lizards resulted from targeted poaching rather than from other threats, which would affect juveniles and adults in the same manner. In addition, our interviews with local villagers confirmed the frequent targeted poaching of only adult individuals for the pet trade.

Despite potential further populations, only known by local collectors, are not included in these estimates, our data clearly revealed current dramatic local population declines and repeated cases of local extinction. Chinese populations suffered from similarly severe local population declines of up to 90% and local extinctions (Huang *et al.,* 2008). But these declines were recorded within a time period of 26 years, while we observed comparable patterns in Vietnam within 1-2 years only. Because crocodile lizards are strongly sedentary and have specialist ecological requirements, they are particularly prone to local extinction (van Schingen *et al.,* 2014b). The aforementioned lack of adult individuals and specialized life history traits further impair the population recovery from anthropogenic pressures. Cases of local species extirpation due to poaching shortly after discovery have already been recorded in the region for other enigmatic and range restricted lizards, such as the Tiger Gecko *Goniurosaurus luii* (e.g., Stuart *et al.,* 2006). Vietnam is currently recognized as major consumer and exporter of wildlife (e.g., Nghiem *et al.,* 2012; Sodhi *et al.,* 2010). Illegal trade in Vietnamese crocodile lizards has been already frequently recorded, also in European markets (Kanari & Auliya, 2011; van Schingen *et al.,* 2015a). The high international demand of crocodile lizards is currently fueling the pressure on wild populations in magnitudes that are currently – and probably never were – sustainable, emphasizing the need of straight and enforced conservation measures (van Schingen *et al.,* 2015a).

Priority areas and recommendations for conservation: Li *et al.* (2012) already projected that all present habitats of *S. crocodilurus* in China will vanish until 2080. Accordingly, our model revealed an alarming, almost 95% loss of suitable habitats for *S. crocodilurus* from 2020 to 2080 throughout its distributional range. Only less than 0.26% of the study extent was predicted to still comprise suitable habitats in 2080, whereof most important regions were situated within the Yen Tu Mountain range and the border region between Vietnam and China. However, the prediction did not consider vegetation coverage, since future prognoses of habitat destruction are quite difficult. Based on the current high deforestation rate (Sodhi *et al.,* 2010) and the strict dependence of the species on undisturbed evergreen broadleaf lowland forest (e.g., Huang *et al.,* 2008; Ning *et al.,* 2006; van Schingen *et al.,* 2015b), we assume that the effective suitable area for *S. crocodilurus* will be smaller than the predicted calculation assumes. This particular forest type is considered as especially vulnerable and fast disappearing in Southeast Asia (Meijaard & Sheil, 2008) and has already been substantially cleared in northern Vietnam (Tordoff *et al.,* 2000), with some fragmented remains extending from the Yen Tu region to the Chinese border in Quang Ninh Province. In spite of the isolated and small population sizes, the preservation of forest corridors between localities seems a beneficial strategy to promote genetic exchange between subpopulations, besides upgraded local habitat protection at sites where *S. crocodilurus* occurs (Tewksbury *et al.,* 2002; Christie & Knowles, 2015). Based on our data, we recommend the maintenance of a corridor connecting contiguous Yen Tu and Tay Yen Tu NRs with Dong Son-Ky Thuong NR (within the

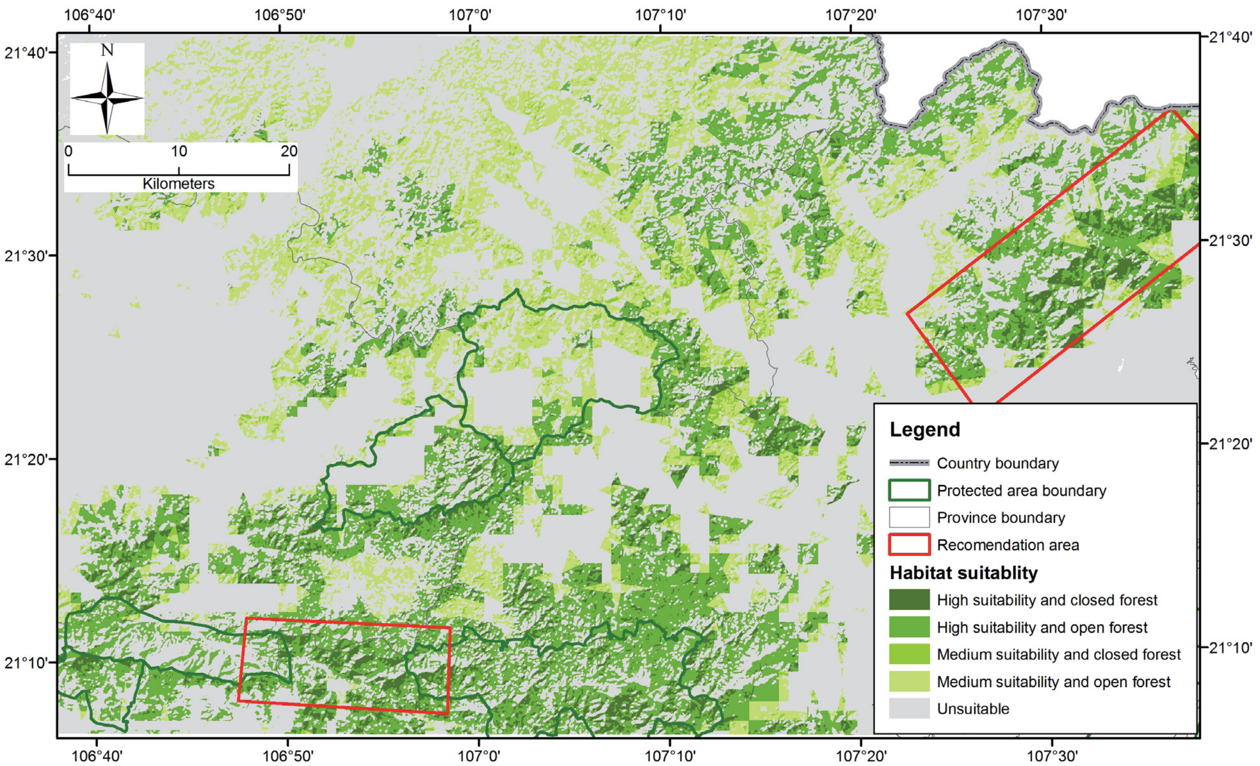

Fig. 5. Predicted suitable habitats throughout the distribution range of *S. crocodilurus* in northern Vietnam, using combined vegetation, bioclimatic and elevation data. Red squares indicate recommended priority areas for habitat conservation (bottom left: proposed corridor to link two existing reserves; top right: proposed reserve to be established in the future).

following coordinates: N 21.443772°, 107.378751°; N 21.532099°, E 107.684383°; N 21.359082°, E 107.441705 and N 21.608404°, E 107.612774°; Fig. 4). According to our present predictions and van Schingen *et al.* (2014b), the border region between Vietnam and China represents a further important area of high suitability, affirmed by the new population record. Interviews with local villagers gave evidence for a relatively broad distribution of the species in this region, which additionally contains another large area of contiguous and intact forest. However, this area is poorly studied and lies outside any protected area. This area probably possesses a high biodiversity value and further field research is required in order to evaluate its priority status for the establishment of a potential new nature reserve. Since the area was predicted to remain highly suitable still in 2080, it potentially also comprises suitable sites qualifying for a release program once the sites are sufficiently protected and should be considered for the establishment of a new reserve (N 21.170357°, E 106.794988°; N 21.127556°, E 106.874795°; N 21.154382°, E 106.974255° and N 21.196146° E 106.882572°).

Our previous SDSs proved successful in predicting sites of occurrence of *S. crocodilurus*. The existence of additional populations can be inferred from current trade patterns (van Schingen *et al.,* 2015a). Based on new satellite information, targeted surveys would be feasible to discover additional extant subpopulations. In face of the high extinction risk due to poaching, we recommend the immediate planning of further field research in areas of predicted habitat suitability, with the focus on the border area of Vietnam and China.

The dimension of impacts of climate change on tropical lizards are controversially debated (Tewksbury *et al.,* 2002; Sinervo *et al.,* 2012; Tewksbury *et al.,* 2012). *S. crocodilurus* represents a basal lineage of lizards, which experienced climatic shifts since the Cretaceous (Zhao *et al.,* 1999; Zollweg & Kühne, 2013). Currently, the two extant subpopulations are living under different climatic conditions in China and Vietnam. Chinese crocodile lizards are known to hibernate during the cold months, but a respective behavior is not studied for Vietnamese lizards which are exposed to more constant and moderate temperatures throughout the year (van Schingen *et al.,* 2015b). As a first step to explore the ability of *S. crocodilurus* to adapt to climatic changes, we recommend basic research on thermobiology and hibernation behavior in Vietnam.

ACKNOWLEDGEMENTS

We are very grateful to T. Pagel and C. Landsberg (Cologne Zoo), C.X. Le and T.H. Tran (IEBR, Hanoi) for their support of research and conservation work in Vietnam. For supporting field work and issuing relevant permits, we thank the directorates of the Tay Yen Tu, Yen Tu and Dong Son-Ky Thuong NRs, Forest Protection departments of Bac Giang and Quang Ninh provinces. This research is partially supported by the project "Development of information system for management and monitoring nature resources in national parks and nature reserves in northwestern Vietnam using remote sensing and GIS techniques and VNREDSat-1 image (VT/UD-01/14-15)" of the Space Technology National Program of the Vietnam Academy of Science and Technology (VAST). Nature conservation-based biodiversity research and environmental education in the Yen Tu Mountain Range is mainly funded by Cologne Zoo, the Institute of Ecology and Biological Resources (IEBR), the Amphibian fund of Stiftung Artenschutz/VdZ (Verband der Zoologischen Gärten e.V.), the European Association of Zoos and Aquaria (EAZA), the European Union of Aquarium Curators (EUAC), the Nagao Natural Environment Foundation (Japan), the World Association of Zoos and Aquariums (WAZA), the Alexander von Humboldt Foundation and the University of Cologne. Thanks to Wolfgang Böhme (Zoologisches Forschungsmuseum Alexander Koenig, Bonn), Andreas Schmitz and Peter Schuchert (Muséum d'histoire naturelle, Genève) for commenting on a previous version of the manuscript. We are very thankful to H.A. Thi, M. Bernardes, H.N. Ngo and L. Barthel for their assistance in the field.

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