

NICHE SEGREGATION IN MICROHABITAT USE OF THREE SYMPATRIC *CYRTODACTYLUS* IN THE PHONG NHA-KE BANG NATIONAL PARK, CENTRAL VIETNAM

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Abstract.—We collected field data to characterize and segregate the microhabitat use of the three sympatric bent-toed geckos *Cyrtodactylus phongnhakebangensis*, *C. cryptus*, and *C. roesleri*. These species were recently discovered to occur in one of the last remaining karstic rainforest formations in Vietnam, the Phong Nha-Ke Bang National Park of Central Vietnam. Between July and September 2010, we found 126 individual geckos in six independent areas by visual encounter surveys. We assessed habitat data in order to enable a microsite comparison of the different species. We found syntopic occupation of one study site by *C. phongnhakebangensis* and *C. roesleri*, and sympatric occurrence with *C. cryptus*. Our study shows niche segregation in microsite use for *C. cryptus* and niche overlap for *C. roesleri* with *C. phongnhakebangensis*. It may be inferred that the syntopic sibling species did not develop microhabitat partitioning, while the sympatric gecko adjusted to occupy different types of habitat.

Key Words.—Bent-toed Gecko; Gekkonidae; habitat preferences; karst forest; Squamata.

INTRODUCTION

The tropical forests of Vietnam are topographically and environmentally complex and harbor an extraordinarily high and partially undiscovered species richness (Brooks et al. 2006; Shchipanov and Kalinin 2006; Giam et al. 2010). In particular, karst forests are known as arks of biodiversity (Clements et al. 2006). For example, 139 species of amphibians and reptiles have been recorded in the karst forest of the UNESCO world heritage site Phong Nha-Ke Bang National Park (Ziegler and Vu 2009; Ziegler et al. 2010). However, published habitat descriptions of the herpetofauna and quantitative information on their ecological requirements are lacking (Nguyen et al. 2009). In addition, available habitat information is descriptive and no statistical analyses of reptile niches have been published so far for Vietnam. As reptiles are one of the groups most endangered by global biodiversity decline (Gibbons et al. 2000; Butchart et al. 2010), it is particularly important to know the individual habitat parameters to develop adequate protection activities (Gibbons et al. 2000; Fischer et al. 2003). Therefore, detailed knowledge on species-habitat relationships is urgently needed (Matern et al. 2007; Tadevosyan 2007).

One highly diverse reptile group is the gecko genus *Cyrtodactylus*, the bent-toed geckos (Kluge 2001). Twenty-four *Cyrtodactylus* species are known at present in Vietnam, of which 20 have been described in the past decade (Ngo and Chan 2010; Ngo et al. 2010; Ngo and Pauwels 2010; Ziegler et al. 2010). Three phenetically

similar, cryptic species have been recently discovered in the Phong Nha-Ke Bang (PNKB) National Park in Central Vietnam. First, *C. phongnhakebangensis* was described in 2002. *Cyrtodactylus cryptus* was later discovered by Heidrich et al. (2007). In 2010, *C. phongnhakebangensis* was split into two species: *C. phongnhakebangensis* and *C. roesleri* (Ziegler et al. 2002; Heidrich et al. 2007; Ziegler et al. 2010).

When different species inhabit the same biotopes, it might not necessarily mean that they are dependent on the same resources. Species might have adapted strategies to limit direct competition, which might be fundamental for their co-existence (Noble et al. 2011). Environmental changes might affect these species in very different ways, and for any conservation effort, it is important to provide relevant biological information on the specific target species (Dennis 2003).

Only limited knowledge is available on the niche segregation of these sympatric *Cyrtodactylus* in the karstic forest formation of PNKB (Ziegler et al. 2010). While comparing the habitats of two of these species, *C. phongnhakebangensis* and *C. cryptus*, Heidrich et al. (2007) stated that *C. cryptus* mainly occupied tree trunks and that *C. phongnhakebangensis* seemed to prefer karst cliffs, but no quantitative ecological investigations have been conducted so far for these species.

In this study, we compare the ecological niches and abundance of *C. phongnhakebangensis*, *C. cryptus*, and the recently described *C. roesleri* (which was not treated as a separate species by Heidrich et al. in 2007). We follow Dias and Rocha (2007) in classifying ecological



FIGURE 1. *Cyrtodactylus cryptus* (left), *C. phongnhakebangensis* (upper right side) and *C. roesleri* (lower right side) in their microhabitats. (Photographed by Jacqueline Loos)

niches by the three dimensions of diet, microhabitat, and activity period. We focused our analyses on microhabitat use of the three sympatric *Cyrtodactylus* in order to generate ecological insights into their spatial requirements. To find out if the Bent-toed Geckos in PNKB share their microhabitat with congeners, we checked their abundance in space by collecting and comparing habitat and morphometric parameters to draw conclusions on niche preferences.

MATERIALS AND METHODS

Study species.—*Cyrtodactylus phongnhakebangensis* was discovered first in 2001 (Ziegler et al. 2002). With a maximum snout-vent length (SVL) of 104.4 mm, it is the largest of the PNKB bent-toed geckos (Heidrich et al. 2007). *Cyrtodactylus cryptus* has an intermediate size with a maximum SVL of 90.8 mm. The recently discovered *C. roesleri* is the smallest of the Bent-toed Geckos in PNKB with a maximum SVL of 75.3 mm (Ziegler et al. 2010). There is still uncertainty about the phylogenetic status of *C. cryptus*, but it is known that the sympatrically occurring *C. roesleri* and *C. phongnhakebangensis* represent sibling species (Ziegler et al. 2010, Schneider et al. 2011). The three species can be unambiguously distinguished in the field by several morphological characters (for details see Table 4 in Ziegler et al. 2010). All three species are nocturnal and have characteristic long hindlimbs and flattened bodies. They are able to climb vertical rock surfaces and trees using their claws, but they are neither strictly cave dwelling nor arboreal (Fig. 1).

Study sites.—The study sites are located within PNKB National Park and its surrounding buffer zone, Quang Binh Province, Central Vietnam (Fig. 2). PNKB National Park Lies within the Truong Son (also known as Annamite) mountain range and the maximum altitude exceeds 1,000 m above sea level (asl). The climate is characterized by a rainy and a dry season with maximum precipitation of 501 mm in September and with the lowest precipitation of 41 mm in February. The mean annual rainfall is 2,000–2,500 mm. Mean monthly temperatures vary between 13.2° C in January and 31.1° C in June (Ziegler et al. 2004; Hijmans et al. 2005). The vegetation consists mainly of dense evergreen primary karst forest (Haus et al. 2009). We investigated six different study sites, located between 50 to 600 m asl (listed below in order from North to South): (1) Hoa Son: karst formations and small caves within lowland primary forest; (2) Ban On: karst formations surrounded by some huge trees and plantations at a distance of less than 1 km; (3) Cha Noi: overgrown riverbed, adjacent karst cliffs with a cave and agglomeration of karst on the top of a mountain; (4) Hang E: large karst block with many small caves in a valley with fragments of secondary but mainly primary forest; (5) Temple: karstic rocks with partially secondary forests, including a river; (6) U Bo: primary lowland evergreen forest on granitic and karst hills with many streams along Ho Chi Minh Road.

Sampling.—We searched at locations where geckos had previously been observed and in surrounding areas before the rainy season from July until September 2010. We detected geckos by visual encounter surveys after

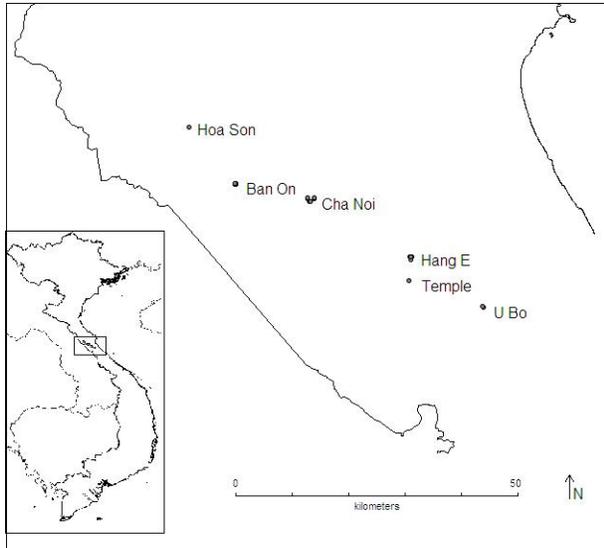


FIGURE 2. Location of geckos found within the study plots in Quang Binh Province, Central Vietnam.

sunset, usually between 1900 and 0100, and captured them by hand. We measured SVL and tail length (TaL) with a digital slide caliper and total body mass with an electronic balance (type MAUL alpha, Jacob Maul GmbH, Bad König, Germany). We recorded tail condition, sex, and age class (juvenile approx. < 55 mm; adult approx. > 55 mm) for every specimen. Because of the lack of knowledge about these species, we used these cutoffs as conservative values in determining age class in combination with the typical coloration of the tail tips in juveniles (pers. obs.).

For individual identification when recaptured, we marked each animal using identification (ID) numbers. We painted these numbers on the dorsal surface using an Edding 4000 (Edding UK Ltd., St. Albans, Hertfordshire AL4 0JY) waterproof paint stick based on watercolor and food color. In addition, we took digital photographs of the dorsal pattern. We relied on these photographs to check if newly caught individuals were recaptures that had had an ecdysis between July and September. Identification of species was based on Ziegler et al. (2010). We marked the exact place of observation using a rope, then measured perch height and perch diameter. We recorded geographic coordinates and elevation by a Garmin© eTrex GPS during a subsequent revisit of the site at daylight because the low reception in the dense forest required plenty of time to record the position. Furthermore, we estimated the following parameters individually in a one meter radius around the location of each gecko: the percentage of overhead cover (from rocks and trees); and the percentage (in 5% increments) of ground cover by mosses, grasses, herbs, shrubs, stones (= rocks with a diameter < 50 cm), rocks (= rocks with a diameter > 50 cm), bare soil, litter, deadwood,

and water. Additionally, we measured the height (in cm) of moss, grass, herbs, shrubs, and rocks using a tape measure and counted the number of trees (living and dead wood) within a 5 m radius. We also recorded the distance to the nearest neighbor of any *Cyrtodactylus* species.

Statistical analysis.—We applied Spearman rank correlation analysis to all of the environmental parameters and avoided autocorrelation by excluding the variables with a Spearman rho ≤ -0.7 or ≥ 0.7 from further calculation. The variables considered for further calculations were: Perch Height, Overhead Rock, Tree Cover, Moss Cover, Herb Cover, Shrub Cover, Stone Cover, Rock Cover, Deadwood Cover, Bare Soil Cover, and Litter Cover. We used a Linear Model (LM) to test for relationships between the environmental and morphometric parameters by backward selection.

We used separate Generalized Linear Models (GLM) for the categorical variables to determine significant differences between the three species. We used both continuous data and percentage data as predictors of presence/absence in the binomial GLM. All assumptions of the GLM were met. Although there can be a problem of Type I error inflation in multiple model studies, the goal of our study was to provide an initial analysis of habitat preference of the geckos, and we refrained from correcting the family-wise Type I error rate (Roback and Askins 2005). We conducted a Principal Component Analysis (PCA) using the environmental variables that were statistically significant. Further, we conducted a t-test to compare the differences in Perch Height (the heights of the karst formations on which geckos were found) between *C. phongnhakebangensis* and *C. roesleri* (the two species found on karst formations). We conducted all tests with R 2.12 (R Foundation for Statistical Computing, Vienna, Austria.) with vegan (Vegan: community ecology package. 2011. Available from <http://CRAN.R-project.org/package=vegan>) and used a significance level of $P < 0.05$ (Venables and Ripley 2002, Calenge 2006).

RESULTS

In total, we found 126 individuals (58 f = female, 56 m = male, 11 j = juveniles, and one u = unidentified) during 28 night surveys at the six study plots (Table 1). There were 96 *C. phongnhakebangensis*, 18 *C. roesleri*, and 12 *C. cryptus*. Ziegler et al. (2010) recorded *C. roesleri* only from Minh Hoa district (Hoa Son), thus our findings of the species at Cha Noi represent a new locality record. *Cyrtodactylus roesleri* appeared syntopically with *C. phongnhakebangensis* with a minimum distance of 140 m. We found *C. cryptus* at a minimum distance of 1.2 km from individuals of other

TABLE 1. *Cyrtodactylus* captured during the study period; f = female, m = male, j = juvenile, and u = unidentified.

Place	Coordinates (WGS 84)		Elevation asl (m)	<i>C. phongn.</i>	<i>C. roesleri</i>	<i>C. cryptus</i>
	N	E				
Ban On	17.66262	105.97255	270	11f, 9m		
Cha Noi	17.63896	106.10325	307	5f, 2m, 4j	7f, 1m, 3j	1f, 1m, 1j
Hang E	17.54270	106.26187	70	28f, 34m, 1j		
Hoa Son	17.75776	105.89571	290		1f, 3m, 2j	
Temple	17.50172	106.25972	60	1f, 2m		
U Bo	17.45890	106.38211	591			4f, 4m, 1u

species. The linear model for morphometric parameters and environmental predictors demonstrated that lengths of the geckos (SVL) were significantly related with perch height ($F = 7.378$, $df = 99$, $P = 0.008$, $R^2 = 0.07$).

There was significant separation between *C. phongnhakebangensis* and *C. cryptus* and between *C. phongnhakebangensis* and *C. roesleri* (Table 2). We elucidated the main differences between the three gecko species in Perch Height, Overhead Rock, Tree Cover, and ground cover by the different ground cover elements (Moss, Herb, Shrub, Stone, Rock, Deadwood, Bare Soil, and Litter). These findings show clear differences for *C. cryptus* compared to the sympatrically occurring *C. roesleri* and *C. Phongnhakebangensis*. These differences are also clearly illustrated by the PCA (Fig. 3).

We found 93% of *C. phongnhakebangensis* and 94 % of *C. roesleri* on karst formations. The karst formations where we found *C. phongnhakebangensis* were on average 8.42 m tall and significantly exceeded the average height of 2.42 m of the karst formations on which *C. roesleri* was found ($t = 3.09$, $df = 95.46$, $P = 0.003$). We detected 82% of all *C. phongnhakebangensis* and 53% of all *C. roesleri* in caves or under rock prominences. *Cyrtodactylus cryptus* was neither found on rock formations nor in caves, but on vegetation, litter, and anthropogenic structures.

DISCUSSION

We observed similar microhabitat use by two sympatrically occurring species within heterogeneous forest sites and a clear niche segregation for the third species. We found *Cyrtodactylus roesleri* and *C. phongnhakebangensis* in a surrounding with a high amount of rock cover, while *C. cryptus* seems not to be associated with karst areas at all. Many gecko species

show adaptations to karstic environments (e.g., Grismer et al. 2009), which provide crevices and caves for oviposition and shelter. Hence, *C. cryptus* might have adapted differently to acquire access to these requirements. Preliminary molecular phylogenies confirm a close relationship between the karst-associated species *C. phongnhakebangensis* and *C. roesleri*, while *C. cryptus* is a phylogenetically more distant species (Ziegler et al. 2010).

Although differences in microhabitat use might mirror habitat availability (Johnson et al. 2006), the chosen habitat characteristics show not only the potential niche, but also the realized niche. Habitat segregation is obvious for *C. cryptus*, but the observed overlap in common resource use between *C. roesleri* and *C. phongnhakebangensis* does not necessarily indicate competition as gekkonids often have highly specific microhabitat preferences (Welton et al. 2009). The remaining question is whether this sympatric occurrence enforces interspecific competition or if they evolved to co-exist by other ways of resource partitioning.

All three species use niches in the vertical dimension, which are especially variable in tropical forests (Bobrov 1993). The parameters of the selected microhabitat correlated with morphometric values such as size or weight, and the largest species, *C. phongnhakebangensis*, seems to occur at higher perches and more often inside caves. We found *C. phongnhakebangensis* more often on larger karst formations and a variety of caves, whereas *C. roesleri* occurred on smaller karst agglomerations. Grismer et al. (2010) reported similar results for a gecko in Malaysia: syntopic species inhabited different types of habitats and the smaller geckos occurred on vegetation versus the bigger ones on stone. Habitat segregation by different use of substrates is also known for other lizard species (e.g., Du Plessis and Mouton 2011).

TABLE 2. Results of separate GLMs between species and environmental variables. Numbers show the estimates, stars indicate levels of significance: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$. Only significant statistics are reported.

Habitat parameters		<i>C. cryptus</i>	<i>C. phongn.</i>
Perch height	<i>C. phongn.</i>	1.9169**	
	<i>C. roesleri</i>	-1.155 *	-0.7387 *
Overhead Rock Cover	<i>C. phongn.</i>		
	<i>C. roesleri</i>		-0.5855 *
Moss Cover	<i>C. phongn.</i>		
	<i>C. roesleri</i>		0.6309**
Herb Cover	<i>C. phongn.</i>	-0.8041**	
	<i>C. roesleri</i>		
Stone Cover	<i>C. phongn.</i>	-0.7342**	
	<i>C. roesleri</i>	-9.411 *	
Rock Cover	<i>C. phongn.</i>	1.6002***	
	<i>C. roesleri</i>	1.443 **	
Bare Soil Cover	<i>C. phongn.</i>	3.408 *	
	<i>C. roesleri</i>		
Litter Cover	<i>C. phongn.</i>		
	<i>C. roesleri</i>		0.514 *

Similar to our results, Noble et al. (2011) distinguished niche partitioning within a shared habitat for two different gecko species using different perch heights. *Cyrtodactylus roesleri* might use the broadest niche, and it may exhibit a higher variability than the other two species. A better distinction could be generated from climatic niche and in particular, resource analyses to investigate potentially differing climatic and/or trophic niches.

Cyrtodactylus cryptus was the only gecko found in a man-made environment, beneath the Ho-Chi-Minh-Highway within the National Park. Though it is not a widespread species, this might imply that *C. cryptus* has not been negatively affected by anthropogenic habitat modifications (as is also known for other gecko species in tropical regions, e.g., Rödder et al. 2010). Even in protected nature reserves, habitat destruction and clandestine hunting (e.g., for traditional medicinal purposes, for food, and for souvenir to sell) continues (Tuyet 2001). To be able to protect rare and endemic species, their habitat requirements should be considered carefully and examined to determine habitat availability and habitat use in multiple localities. Individuals in different locations may respond differently to threats (Johnson et al. 2006). In one of the study areas (Temple), which was known to be densely populated by *C. phongnhakebangensis*, we found only three individuals but also observed new anthropogenic constructions expanding into the forest site. The

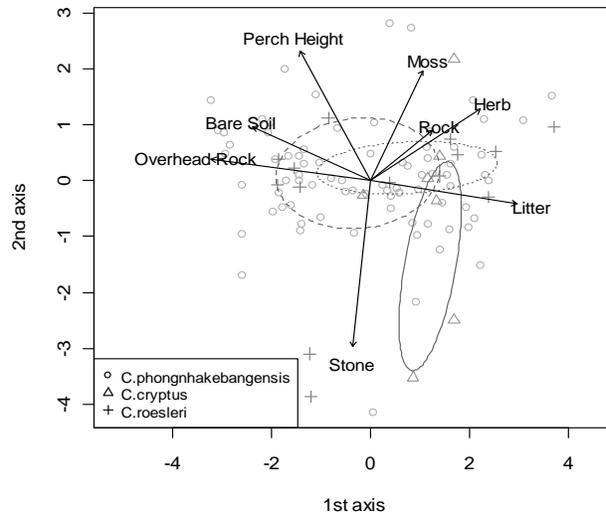


FIGURE 3. Niche model of the three species of *Cyrtodactylus* in Phong Nha-Bang, Vietnam. Solid line: *C. cryptus*, dashed line: *C. phongnhakebangensis*, dotted line: *C. roesleri*. Explained variance: 1st axis = 35%, 2nd axis = 16%.

disappearance of *C. phongnhakebangensis* might show its limited tolerance of human activity in the forests. Sumontha et al. (2010) support this assumption, as they detected species of *Cyrtodactylus* only in undisturbed areas.

Our results contribute to a possible Red List assessment as a baseline, because we surveyed several places, where the occurrence of the species has been known before. Future monitoring could be conducted at exactly the same sites. Furthermore, our findings suggest a sensitivity toward human activities, especially for *C. phongnhakebangensis*. Regular monitoring is urgently needed to document the possible decline of this endemic species. This possible decline also should inform population education to limit the use of these animals for souvenir selling and superstitious medicinal purposes.

Monitoring biodiversity is one pillar of conservation activities of non-governmental organizations, and these activities contribute to tackling biodiversity loss and are important to document biodiversity threats (Butchart et al. 2010). Nonetheless, long term management should enable the participation of local communities in protection of endemic species and vulnerable environments (Boissiere et al. 2009). As people in remote areas often directly depend upon biodiversity and the services it provides (Tuyet 2001; Butchart et al. 2010), prevention of hunting and illegal logging is urgently needed. To achieve a more sustainable development of the region simultaneously, we suggest that coherent educational programs to establish public environmental awareness be implemented (Sodhi et al. 2004). Until now, only a few of the species occurring in tropical southeast Asia have been assessed by the IUCN

(Clements et al. 2006), although this region with high endemism rates is especially vulnerable to biodiversity loss (Bauer et al. 2009). Therefore, more precise investigations into the differences and ecological requirements of these species and regular monitoring activities are needed in order to allow a valid status assessment in the IUCN Red List.

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