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FACTORS ASSOCIATED WITH DETECTION PROBABILITY AND SITE OCCUPANCY OF THE LONG-TAILED SKINK (*Eutropis longicaudata*) IN THE ALUOI AREA, CENTRAL VIETNAM

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Lizard species are rarely detected with perfect accuracy, regardless of the method employed. Nondetection of a species at a site does not necessarily mean the species was absent unless the detection probability was 100%. We assessed the influence of site covariates (less disturbed habitat and disturbed habitat) and sample covariates (temperature, humidity, rainfall) on the occupancy of *Eutropis longicaudata* in the Aluoi area, central Vietnam. Based on detection/nondetection data over nine visits at 40 less disturbed sites and 39 sites with disturbed habitats, the distribution of *E. longicaudata* was estimated using site occupancy models. From the best model, we estimated a site occupancy probability of 0.595, a 12.05% increase over the naive occupancy of 0.531 at which *E. longicaudata* skinks were actually observed. The site covariate of the less disturbed habitat was an important determinant of site occupancy, which was not associated with the variable of disturbance habitats. In the combined AIC model weight, *p*(precipitation), *p*(temperature), and *p*(humidity) have 92%, 36%, and 21% of the total, respectively; providing evidence that environmental conditions (especially precipitation) were important sample covariates in modelling detection probabilities of *E. longicaudata*. In terms of occupancy probability, the combined weight for the ψ(less disturbed habitat) model and the ψ(disturbed habitat) model were 60% and 32%, respectively. Our results substantiate the importance of incorporating detection and occupancy probabilities into studies of habitat relationships and suggest that the less disturbed habitat associated with weather conditions influence the occupancy of *E. longicaudata* in central Vietnam.

Keywords: bootstrap; lizards; maximum likelihood; metapopulation; monitoring; reptiles.

INTRODUCTION

Studies on site occupancy of various species and their spatial distribution have been conducted in recent years to inform and develop the model of imperfect detection (MacKenzie et al., 2002; Bailey et al., 2004, 2007; Roloff et al., 2011). Solely using count data and not allowing for detectability is discouraged (e.g., Seber, 1982; Williams et al., 2002) since inferences regarding the effects of site characters on occupancy for wildlife will be difficult or impossible to discern reliably (e.g., Gu and Swihart, 2004). Many conservation programs seek to provide inferences about regions that are too large to be completely surveyed. Therefore, a subset of regions are surveyed, with site selection conducted in a manner that permits application to the entire region of interest (Thompson, 1992; Yoccoz et al., 2001; MacKenzie et al., 2002; Pollock et al., 2002).

Human activities such as timber harvest, land conversion to monoculture crops or other developments, and manipulation of natural waterways have heavily eroded tropical primary rainforests, plantation and secondary forests in central Vietnam (Nguyen et al., 2013a). These actions have created forest fragments, and severely impacted biodiversity and associated natural interactions and processes. Similar to other landscapes in this region, habitats in the Aluoi area have been manipulated and transformed, creating metapopulations of species in the entire region, including the Long-tailed Skink, *Eutropis longicaudata* (Nguyen et al., 2013a; Dang, 2017).

Currently, populations of *E. longicaudata* are decreasing due to land-use change and habitat loss or degradation, global climate change, and overexploitation for

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consumption (Nguyen et al., 2009; Dang, 2017). However, little is known about many aspects of the population ecology of *E. longicaudata* in Vietnam and large-scale studies of occupancy models for this species are nonexistent. Information on detection probability and site occupancy for *E. longicaudata* skinks in less disturbed habitats and disturbed habitats in the Aluoi area is lacking. It is especially critical as these terrestrial habitats have been identified as important to herpetological conservation programs (Lehtinen and Galatowitsch, 2001; Weyrauch and Grubb, 2004; Reilly et al., 2007; Vitt and Caldwell, 2009; Nguyen et al., 2013a).

In this study, we used detection/nondetection data for each site over multiple visits to assess the occupancy of *E. longicaudata* in the Aluoi area, central Vietnam. We tested the hypothesis that differences in sampling and site covariates result in different detection and occupancy probabilities for *E. longicaudata* in two specific habitat types (less disturbed and disturbed habitat). We predicted that the occupancy of *E. longicaudata* would be higher in less disturbed habitats than in disturbed habitats. We also tested the influence of sampling covariates (i.e., temperature, humidity, and rainfall) on the detection probability of *E. longicaudata* skinks.

MATERIAL AND METHODS

Study region. The fieldwork took place in the Aluoi area, Thua Thien Hue Province (15°59′30″ – 16°44′30″ N 107°00′56″ – 108°12′57″ E), central Vietnam. Seasonal monsoons and a tropical climate characterize this study area, with annual temperatures averaging 22.6 ± 0.26°C (ranging from 16.9 ± 0.39°C in January to 26.6 ± 0.36°C in June) and an annual mean precipitation of 3492 ± 229 mm. Most of the rain is concentrated in the main rainy season from September to December (monthly mean: 738 ± 96 mm) and a reduced rainy season (monthly mean: 173 ± 23 mm) from May to August, whereas the period from January to April is relatively dry, with monthly mean rainfall of 94 ± 12 mm (data obtained from the General Statistics Office of Vietnamese Government over the last 10 years; Nguyen et al., 2013b).

At our study area, we determined minimum daily temperatures ranged from 22.6°C (March) to 23.7°C (June) and maximum daily temperatures ranged from 26.1°C (March) to 35.7°C (May), both with a generally increasing trend over the sampling period (March to July) in the dry season. During the study period, air temperature and relative humidity were not correlated ($n = 711$, $r = -0.351$, $P = 0.065$) and, therefore, used simultaneously in detection modelling. In 2017, this region had a relatively dry period (the dry season) that extended from February to July, with monthly precipitation ranging from 47 – 115 mm.

Field sampling. From March to July 2017 (the breeding season of *E. longicaudata* in this study area), we conducted nine surveys for *E. longicaudata* at each site (Dang, 2017). We sampled 79 sites consisting of 20 × 50 m plots (1000 m^2 each site), 40 in less disturbed sites (public lands with forestry plantations, acacia forests, ferns and shrubs, which are less affected by activities of cattle, poultry, human, and so on; we called "less disturbed habitat" = YT) and 39 in disturbed sites (private ownership with microhabitat types of wild pineapple, cactus, shrubs, lawns, bare land, and non-canopy, which are affected by activities of human, cattle, poultry; we called "disturbed habitat" = XT) (Fig. 1). Each site was located at least 500 m apart to ensure independence among sites. We considered less disturbed habitats and disturbed habitats as site covariates to evaluate the occupancy of *E. longicaudata* in this study region. We visited and sampled each site every two weeks, and each site was sampled on the same day. During each survey, a team of two people walked slowly with a roughly equal pace along the site for 15 – 20 min and visually searched for *E. longicaudata* skinks between 8:30 and 16:30 h.

Data analysis. To determine site occupancy, it is necessary to simply record whether the target species is detected 1 or not detected 0 during each survey at each site when visited. Using field observations, we determined the disturbing level of habitat types at each site, and a site covariate of strong disturbance (XT) was defined as 1 if the site showed evidence of the disturbed habitat belonging to private lands and 0 otherwise (YT, less disturbed habitats belonging to public lands). Air temperature, relative humidity, and rain were used as sample covariates to estimate detection probability. At each site visit, air temperature (temp) and relative humidity (humid) were recorded using a WISEWIND thermometer (Taiwan). The rain was defined as 1 if the site showed evidence of rain and 0 otherwise (i.e., sunny and/or unidentified rain-sunny).

We used the program PRESENCE version 12.10 and single-season occupancy models to estimate detection and occupancy probabilities. This model assumes that sites or patches were closed to changes in occupancy between the first and last surveys of a given sampling season (i.e., no colonization or extinction events within a sampling season), and detection of *E. longicaudata* skinks at a site/quadrat is independent of detecting the species at other sites/quadrats (MacKenzie et al., 2006). For this study: p_j is the probability of detecting *E. longicaudata* during the jth survey, given it is present; ψ is the proportion of sites occupied by *E. longicaudata* skinks.

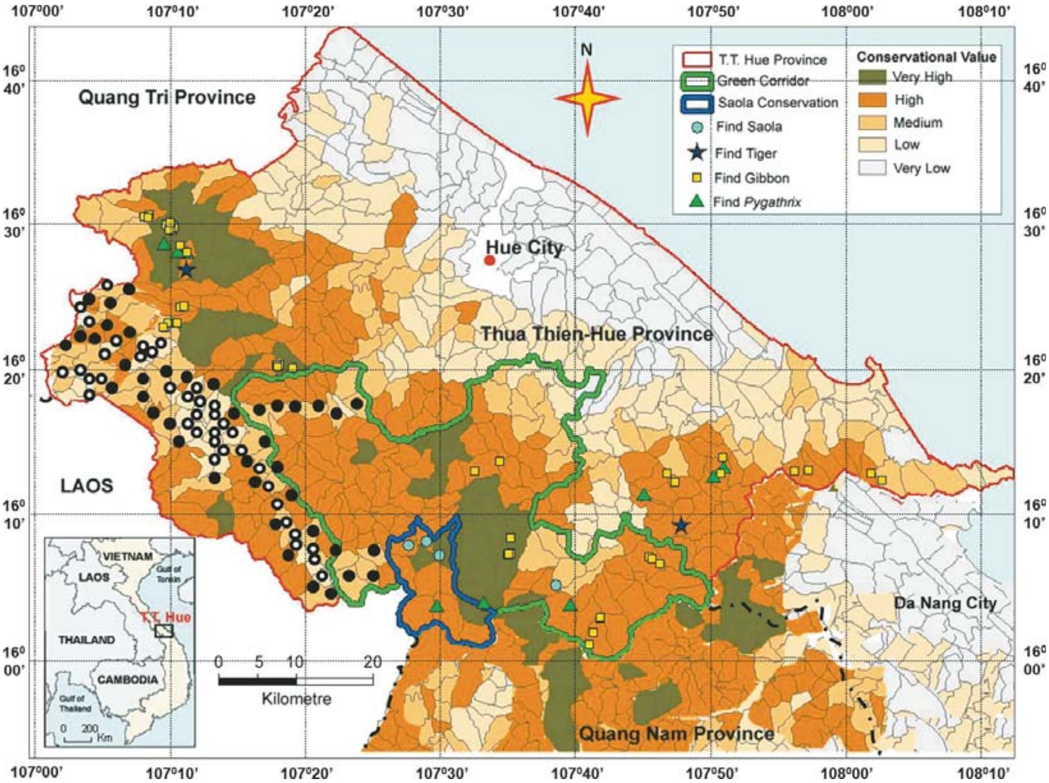

Fig. 1. Location of survey sites in the Aluoi area, Thua Thien-Hue Province, central Vietnam, showing 39 sites in disturbed habitats (open circles) and 40 sites in less disturbed habitats (filled circles), where *Eutropis longicaudata* was monitored.

The first modelling approach we used assumes that detection and occupancy probabilities with respect to *E. longicaudata* are constant across sites and surveys [denoted $\psi(\cdot)p(\cdot)$]. The second approach assumes constant occupancy among sites, but detection probabilities can vary among nine survey occasions [denoted $\psi(\cdot)p(\text{survey})$]. Previous studies suggest that the detection probability = 0.15 in the model $\psi(\cdot)p(\cdot)$ is needed for unbiased occupancy modelling (Bailey et al., 2004; O'Connell et al., 2006).

We adopted the Akaike Information Criterion for small sample size (AICc) and reference Burnham and Anderson (2002) and Mazerolle (2006) to make inferences. Models with AIC differences of <2.0 have a substantial level of empirical support and should be considered when making statistical inferences or reporting parameter estimates of the best models. An overdispersion parameter ($\hat{c}$) from 10,000 bootstrap samples was also estimated using the program PRESENCE version 12.10 for the global model (the most general model in the model set or the model with the most parameters) from the candidate models. All data are presented as mean ± SE (unless otherwise noted) with a confidence interval of 95% (CI).

RESULTS

The Skink *E. longicaudata* was detected at least once at 42 of the 79 sites (14 sites in disturbed habitats and 28 sites in less disturbed habitats), yielding an overall naive occupancy of 0.531. There conceivably can be several locations where *E. longicaudata* skinks were present but simply never detected during nine survey occasions. The detection/nondetection results among different surveys and different habitat types are shown in Table 1. Our detection-corrected occupancy estimates at each site ranged from 0.111 – 0.667 (average naive occupancy = 0.294 ± 0.021). The proportion of sites occupied by *E. longicaudata* from the constant model [$\psi(\cdot)p(\cdot)$] was 0.562 ± 0.061 (CI = 0.443 – 0.674). The second model assumes that all sites have the same occupancy probability, but that p can vary among nine survey occasions. The proportion of sites occupied based on the second model [$\psi(\cdot)p(\text{survey})$] was 0.561 ± 0.059 (CI = 0.441 – 0.668). However, the occupancy estimate in the best model [$\psi(\text{YT})p(\text{rain, temp})$] was 0.595 ± 0.194 (CI = 0.361 – 0.755).

The estimated occupancy probability is very similar in the two models (0.562 and 0.561 from the first and secondary models, respectively). When estimating occupancy probabilities including only the two models [(ψ(·)*p*(·)] and [ψ(.)*p*(survey)], both models give essentially the same results, and both are about 5.74% larger than the naive occupancy estimate of 0.531 (suggesting that *E. longicaudata* was never detected at one in every nine surveys). However, we believe that the distribution of *E. longicaudata* skinks in less disturbed habitats were larger than in disturbed habitats (Table 2).

The global model (the model including the most parameters with Akaike weight values) from the candidate set (Table 2), [ψ(YT)*p*(rain, temp, humid)], does not show any evidence of lack of fit using 10,000 bootstrap iterations (χ^2-test: $\chi^2 = 641.76$, $P = 0.101$, $\hat{c} = 1.05$). Detectability for *E. longicaudata* skinks varied among nine surveys and among sampling sites with previously disturbed histories (Fig. 2). Based on $\Delta AIC_c < 2.0$, six top models have substantial support (Table 2). Thus, these models were considered to infer parameter estimates. In terms of model weights of sample covariates, the *p*(precipitation), *p*(temperature), and *p*(humidity) models have 91.9%, 35.5% and 20.8% of the total, respectively. In terms of the marginal odds ratio of precipitation compared to temperature and humidity: evidence ratio [Akaike weight of the *p*(rain) model/Aikaike weight of the *p*(temp) model] = 2.6 times and evidence ratio [Akaike weight of the *p*(rain) model/Aikaike weight of the *p*(humid) model] = 4.4 times. Our results provide clear evidence that precipitation is an important factor for detection probabilities of *E. longicaudata* in central Vietnam. Like this, there is strong support that the detection probability of *E. longicaudata* is affected by precipitation and less support for the other factors (especially relative humidity).

The highest-ranking models included the effect of less disturbed habitat (YT) on the occupancy of *E. longicaudata* (Table 2). In terms of occupancy probability, based upon rankings and AIC model weights, the combined weight for the less disturbed habitat model was 60%, and the disturbed habitat model was 32% (Table 2), indicating certain evidence that the probability of occupancy is higher at the less disturbed habitat sites than at

TABLE 1. Summarizing the Detection/Nondetection Data for *Eutropis longicaudata* Among Different Surveys and Different Habitat Types in the Aluoi Area, Central Vietnam

Surveys	Detection/Nondetection	
	Less disturbed habitat	Disturbed habitat
I	0.154	0.125
II	0.231	0.151
III	0.128	0.275
IV	0.282	0.025
V	0.179	0.051
VI	0.179	0.051
VII	0.128	0.201
VIII	0.385	0.025
IX	0.231	0.025

TABLE 2. Summary of the AIC Model Selection Procedure for *Eutropis longicaudata* from 79 Sites Belonging to Less Disturbed Habitats and Disturbed Habitats of the Aluoi Area, Central Vietnam

Models	AIC_c	ΔAIC_c	*w*	*K*	$-2l$
ψ(YT), *p*(rain, temp)	496.20	0.00	0.249	6	486.20
ψ(YT), *p*(rain)	496.20	0.00	0.249	5	486.20
ψ(XT), *p*(rain)	497.89	1.69	0.107	5	485.89
ψ(XT), *p*(rain, temp)	497.89	1.69	0.106	6	485.89
ψ(YT), *p*(rain, humid)	497.94	1.74	0.104	6	485.94
ψ(XT), *p*(rain, humid)	497.94	1.74	0.104	6	485.94
ψ(YT), *p*(rain, temp, humid)	499.88	3.68	0.041	7	485.88
ψ(XT), *p*(rain, temp, humid)	499.88	3.68	0.039	7	485.88
ψ(YT), *p*(humid)	553.33	57.13	0.000	3	547.33
ψ(XT), *p*(humid)	553.33	57.13	0.000	3	547.33
ψ(YT), *p*(temp, humid)	554.99	58.79	0.000	4	546.99
ψ(XT), *p*(temp, humid)	554.99	58.79	0.000	4	546.99
ψ(XT), *p*(temp)	562.33	66.13	0.000	3	556.33
ψ(YT), *p*(temp)	562.33	66.13	0.000	3	556.33
ψ(·), *p*(·)	566.73	70.53	0.000	2	562.73
ψ(·), *p*(survey)	575.53	79.33	0.000	10	555.53

Note. ΔAIC_c is the difference in AIC value for a particular model when compared with the top-ranked model; *w* is the AIC model weight; *K* is the number of parameters; $-2l$ is twice the negative log-likelihood value; YT, less disturbed habitats; XT, disturbed habitats; temp, temperature; humid, humidity; rain, weather conditions of sunny, rain, and unidentified rain-sunny.

the disturbed habitat sites (evidence ratio [Akaike weight of the ψ(less disturbed habitat)/Aikaike weight of the ψ(disturbed habitat)] = 1.9 times). This showed that the less disturbed habitat was a strong determinant of *E. longicaudata* occupancy in the Aluoi area, Central Vietnam.

DISCUSSION

In terms of site occupancy probability, the occupancy of *E. longicaudata* in the Aluoi area is not associated with disturbed habitats. Excluding the two basic models, the three models include the covariate of disturbed habitats with the values of $\Delta AIC_c > 57.1$ units and all AIC model weights are equal zero. Relying on all AIC model weights, the covariate of less disturbed habitats included about 64.4% of the total. These findings were similar to previous studies that *E. longicaudata* skinks were mainly found in less disturbed habitats in central Vietnam (Dang, 2017; Vuong et al., 2017). In fact, we sampled a relatively broad gradient of habitat types (40 sites were classified as less disturbed habitats and 39 sites were classified as disturbed habitats) and the Long-tailed Skink (*E. longicaudata*) was only found at 14 sites (each site only found a respective individual) of the 39 sites in disturbed habitats at the Aluoi area, central Vietnam.

Lizard species are ectothermic and information on the site occupancy of skinks is unavailable. Most of the large-scale reptile conservation programs rely on remotely sensed data to describe spatial patterns in occupancy (Nguyen et al., 2009; Vitt and Caldwell, 2009). However, we believe that abundant precipitation, air temperature, and relative humidity during our sampling season may have lessened the effect of habitat types for *E. longicaudata* skinks in the Aluoi area. This is because weather conditions were important sample covariates (especially precipitation) for occupancy and detectability of *E. longicaudata* in the Aluoi area, central Vietnam. Although we failed to detect a temperature-precipitation interaction on detectability in our study, these two variables often interact to influence movement physiology of lizards (Reilly et al., 2007; Vitt and Caldwell, 2009). Previous studies showed that some lizard species have indicated a preference for habitat types with forested canopies compared with fragmented forests or open-vegetation types in disturbed habitats (Dang, 2017; Reilly et al., 2007). In fact, the presence of a forestry canopy that regulates air temperature and forest soil moisture appears more critical in determining the survival of skinks and movement models (Dang, 2017; Vitt and Caldwell, 2009).

The occupancy of skinks relates only to site characteristics, whereas the probability of detecting a species during a single survey can change with survey characteristics (e.g., precipitation and temperature) or site characteristics (e.g., habitat variables such as disturbed and undisturbed histories; MacKenzie et al., 2006). An observed absence at a site occurs if the species was truly absent or if the species was present at that site but simply not detected; while nondetection of a species does not mean that the species was truly absent unless the probability of detecting the species was 100%. That is the reason why previous occupancy studies are often impeded by imperfect detectability (MacKenzie et al., 2003; Gu and Swihart, 2004). Therefore, the proportion of sites where a species of interest is detected will always be an underestimate with respect to the true occupancy level in the study region when the detection is imperfect. Inferences regarding the effects of site characteristics on habitat occupancy will be difficult or impossible to describe exactly (Gu and Swihart, 2004). The best model [ψ(YT)*p*(precipitation, temperature)] (Table 2), with an occupancy estimate of 0.595 comparing to the naive occupancy of 0.531 was reliable.

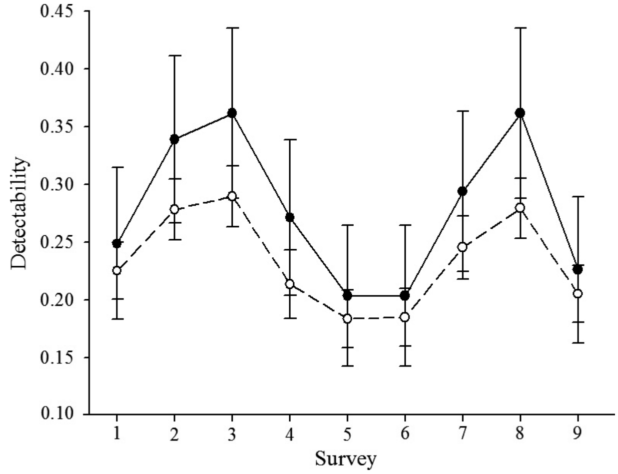

Fig. 2. Estimating the average pattern of detectability across surveys and among sites with different disturbance histories of *Eutropis longicaudata* in the Aluoi area, central Vietnam. The less disturbed habitat (solid line, filled circles) and the disturbed habitat (broken line, open circles).

A brief examination of the estimated detection probabilities indicates why the overall level of occupancy is estimated to be 12.05% higher than the naive occupancy. Estimates for detection probabilities for each sampling covariate showed that rainfall was the most important covariate. There is a reasonable level of substantial differences among sampling covariates (precipitation, temperature, and relative humidity). Furthermore, the detection of a species at each site is indeed indicative of the presence but nondetection of a species is not equivalent to the absence unless the detecting probability of the species was one, and a species can go undetected at a site or some sites even when present. Therefore, nondetection sites of a skink represent a case where the target species (*E. longicaudata*) was never detected. These sites could either be unoccupied, which mathematically is $(1 - \psi)$, or they could be occupied but we never detected the target species during k survey occasions, which mathematically is $\psi(1 - p_j)^k$. Both of this detectability have been included in maximum likelihood methods incorporated in program PRESENCE to obtain estimates of site occupancy for *E. longicaudata* skinks in this study region.

The effects of habitat factors on occupancy and detectability of reptiles emphasize the importance of conducting longer-term studies for describing critical habitat relationships (Dang, 2017). The importance of environmental factors (rainfall, temperature and relative moisture) on reptile breeding activity and capture proportions (MacKenzie et al., 2006; Dang, 2017; Vuong et al., 2017), and hence detection probability, has been well documented. In many cases, precipitation and temperature are expected to be good predictors of detectability for reptile species. Although we did not analyze interactions between temperature, moisture and precipitation on detectability in the present study, these variables often interact to affect reptile timing and movement physiology (Dang, 2017; Vitt and Caldwell, 2009).

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