

# Finding the green in differently disturbed forests under different weather conditions: detection and occupancy of the green pit viper *Trimeresurus (Cryptelytrops) macrops* at the Sakaerat Biosphere Reserve, Thailand



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**Abstract** The response of venomous snakes to anthropogenic landscape disturbance remains scarcely studied in tropical regions. Green pit vipers are among the most diverse venomous snakes in the Southeast Asian tropics and bite the highest number of people of any group of venomous snakes where they are found, yet conservation and snakebite management efforts have been hindered by limited prior studies of these organisms in both natural and anthropogenically disturbed landscapes. Subsequently, we sought to address key knowledge gaps regarding the persistence and response of green pit vipers to anthropogenic disturbance. Utilizing repeated field surveys coupled with remote sensing landscape feature data, we fit single-season Bayesian occupancy models to investigate the potential influences of weather variables on detection and various landscape features on the persistence of the big-eyed pit viper (*Trimeresurus (Cryptelytrops) macrops*). Temperature and humidity marginally positively influenced detection. The probability of *T. macrops* occupancy increased with increasing distance to buildings and houses, roads, water, and increased canopy height and elevation but decreased with increasing distance to the core zone of the reserve, natural forest, and if a site was a plantation. Our findings suggest that anthropogenic landscape disturbance influences the presence of *T. macrops* within a biosphere reserve in Thailand, contrary to the general perception that the species is resilient to land-use change. We strongly suggest further study of the green pit viper response to human disturbance, which would significantly benefit conservation and snakebite management plans for these diverse organisms.

**Keywords:** human landscapes; viper, conservation, snakebite management, bayesian occupancy analysis

## 1. Introduction

Snakes are a diverse group of vertebrates, with an estimated > 3,000 species present worldwide (Pincheira-Donoso et al 2013). These organisms serve as critical predators and prey within ecosystems. Approximately 19% of snake species are threatened with extinction (Böhm et al 2013), and the World Health Organization recently classified snakebite as a “neglected tropical disease” (Chippaux 2017) with between 1.8- a total of 2.7 million people each year are maimed and killed due to bites by venomous snakes (Chippaux 1998; Kasturiratne et al 2008; Suraweera et al 2020). Curating knowledge to address conservation and snakebite management concerns is challenging due to the natural history, particularly the cryptic nature, of snakes.

Southeast Asia is a complex biodiversity hotspot with many unique habitats that endure many threats, particularly deforestation and tree plantations, hunting and trade, mining, reservoir construction, wetland drainage, fire,

pollution, invasive species, disease, and climate change (Hughes 2017). More than 218 species of reptiles have been described from Thailand, although it has retained the smallest area of remnant forest cover in Southeast Asia (Sodhi et al 2010). Concerningly, Southeast Asia is generally underrepresented in studies investigating faunal responses to habitat loss and human-modified landscapes (Trimble and Aarde 2012).

Green pit vipers are one of the most diverse and frequently encountered obligate vertebrate predator groups in the Asian tropics (>40 species, Uetz and Hallermann 2015), yet natural history and general ecology information for most species remains scarce to nonexistent beyond initial species description and anecdotes. At least eight green pit viper species, likely more, are present in Thailand (Chanhome et al 2011), with new species being described as recently as 2011 (*T. phuketensis*, Sumontha et al 2011). One species of green pit viper found in Thailand is Endangered, *Trimeresurus kanburiensis*, due primarily to its limited

distribution and illegal harvest for the pet trade (IUCN 2012). Concerningly, review of the IUCN Red List status of most green pit viper species present in Thailand suggests either Data Deficient or Least Concern assessments with few citations (thus, primarily relying on anecdotal evidence).

Snakebite is a common and devastating environmental and occupational disease in rural developing countries in the tropics (Warrell 2010). Green pit vipers are a medically important group of venomous snakes in Southeast Asia (Warrell 2010). In Thailand specifically, *T. albolabris* and *T. macrops* account for 40% of total bites (Viravan et al 1992) and up to 95% for Bangkok (Meemano et al 1987; Mahasandana and Jintakune 1990).

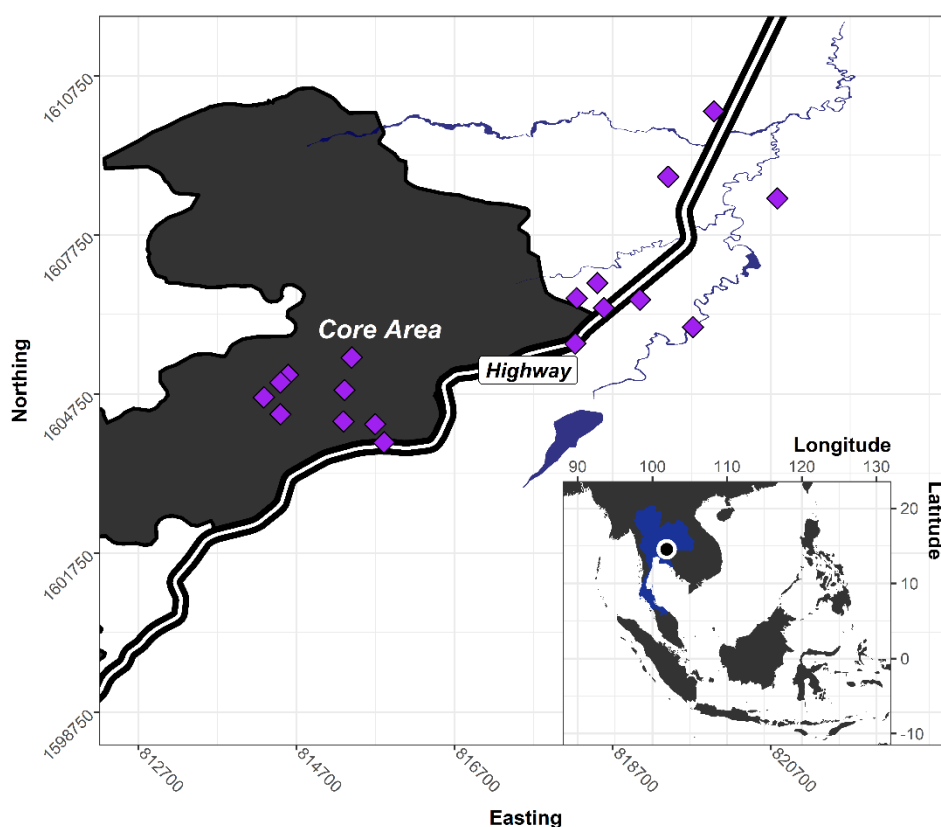
To address the significant current conservation and snakebite management knowledge gap for green pit vipers, we investigated the occupancy and detection probability of the big-eyed pit viper (*Trimeresurus macrops*) within the landscape of the Sakaerat Biosphere Reserve in Nakhon Ratchasima province, Thailand. We aimed to determine the factors that influence the occupancy patterns of big-eyed pit vipers, including natural and anthropogenic land

features. We also sought to determine the influence of temperature and humidity on detection. Our predictions included the following: *T. macrops* occupancy would be higher in natural landscape features and lower in anthropogenic features, and higher detection would be observed with increased temperature and humidity.

## 2. Materials and Methods

### 2.1. Study area

The study was conducted within the Sakaerat Biosphere Reserve (SBR), located in Nakhon Ratchasima Province, Thailand (14.44–14.55°N, 101.88–101.95°E). The reserve has an 80 km<sup>2</sup> core area that is strictly protected to preserve and maintain species diversity, genetic variation, and landscapes and ecosystems. The buffer and transitional areas, which consist mostly of agricultural and settlement areas, comprise a combined 360 km<sup>2</sup> area. We selected 18 sites within the SBR, 9 within the core area and 9 within the buffer and transition areas (Figure 1).



**Figure 1** Study area. The main map shows the Sakaerat Biosphere Reserve core area with the immediately adjacent rural (buffer and transition) area. Study survey sites (purple) are indicated with diamond symbols. Water sources in the rural area are depicted in blue, and a major road (Highway 304) is also indicated. The main map is projected using UTM zone 47P, with scales in meters and a north orientation. The inset map shows the study location relative to Southeast Asia, with scales in degrees.

The core area predominantly consists of primary growth dry evergreen forest (60%), dry dipterocarp forest (18%), and secondary plantation forest (Tongyai 1980). Dry evergreen forest is primarily characterized by tree species such as *Hopea adorata* interspersed with lianas and Moraceae thorn

brush understory cover (Tongyai 1980). Dry dipterocarp forest is endemic to Southeast Asia and is characterized by thick *Vietnamosasa pusilla* grass ground cover and dipterocarp trees such as *Shorea siamensis* and *Shorea obtusa* (Lamotte et al 1998). The transition zone of SBR

comprises nearly 82% of the total area and is characterized by isolated forest fragments in a patchwork of agricultural fields, small plantation forests, and human settlements. Sparse grassland and bamboo groves are interspersed between various habitat types, and human settlement and anthropogenic disturbed land account for 40% and agriculture for 2.98% of the total reserve area (Ongsomwang and Suttivanich 2013).

The intensive study area within Sakaerat includes the southeastern portions of the core and buffer area with closely adjacent portions of the transition area of the Sakaerat Biosphere Reserve with representative sites in the core, buffer, and transition areas within. The elevation for the area ranges from 250–540 m. The mean annual precipitation was  $87.4 \pm 4.80$  mm during the study period from 2014–2017, with peaks of rain in May and September with a short intermittent dry season in between (SERS 2017). For consistency, May–end of October was considered the rainy season. A cold dry season was observed between November and the end of January, and a hot dry season was observed between February and the end of April. The mean annual minimum temperature was  $20.2 \pm 0.35$  °C, the mean maximum temperature was  $34.7 \pm 0.78$  °C, and the mean humidity was  $75.6 \pm 2.28\%$ .

## 2.2. Survey methods

We attempted to conduct each survey opportunistically for an hour, although some sites did take longer or shorter depending on environmental or site-specific characteristics. However, every site was surveyed for at least 0.5 hours and a maximum of 2.5 hours between 1800 and 0300. For logistic and safety purposes, 2 surveyors at minimum searched the different sites, although guests were occasionally invited to participate. A previous radiotelemetric study (Strine et al 2015; Barnes et al 2017) suggested night to be the most active period, and optimal survey times for green pit vipers and headlights and flashlights were used to detect them during surveys. Each site was surveyed at least twice.

## 2.3. Data analyses

To estimate the occupancy and detection probability of *T. macrops* at 18 sites within the Sakaerat Biosphere Reserve in 2015–2016, Bayesian single-season models were utilized. Site ( $\psi$ ) variables (estimated in m) we thought could be important to *T. macrops* occupancy and subsequently modeled with detection held constant (no variables;  $p$ ) included closest distance to water, closest distance to houses and buildings, closest distance to roads, closest distance to natural forest, closest distance to core zone, canopy height, and elevation. One site variable with binary response (yes or no) was also modeled with detection held constant, plantation. Temperature and humidity were modeled as detection ( $p$ ) variables with the site held constant (no variables;  $\psi$ ).

Detection variables, temperature and humidity, were collected in the field at the start of surveys approximately 1.2 m above ground level. The closest distances to water, buildings, natural forests, and core zones were estimated using Euclidean distance in ArcGIS 10.1. The closest distance to the road was estimated using satellite imagery (obtained from the “osm” R package; Padgham et al 2017) and Euclidean distance (using the “st\_distance” function in the “sf” package of R; Pebesma et al., 2018) in the program R. Canopy height was obtained from Simard et al. (2011); (CH; 1 km. resolution).

Due to the exploratory nature of this study, the potential correlation of variables, and to promote scientific analysis best practices (namely, avoiding the fallacy “hypotheses after results are known”, HARKING), we did not attempt to run all combinations (“dredging”) of variables into the models. Uninformative priors (Logistic (0,1)) were applied due to the lack of previous detection and occupancy knowledge and study for green pit vipers (including *T. macrops*).

All single-season models (and evaluation of models) were conducted in R (R Core Team, 2018) with the “ubms” package (Burkner 2017), which fits occupancy models in a Bayesian framework using Stan (Carpenter et al 2017). For each model, we specified three chains run for 25,000 warmup and 50,000 postwarmup iterations, for a minimum total of 55,000 simulation draws. We reviewed Gelman–Rubin statistic *Rhat* values and trace plots to check for Markov chain Monte Carlo (MCMC) chain convergence (Gelman and Rubin 1992) and used MacKenzie–Bailey chi-square tests (MacKenzie and Bailey 2004) to assess model goodness-of-fit. Models were compared to each other using the leave-one-out cross-validation information criterion (LOOIC; Vehtari et al 2019). Credible intervals (CRI) are presented alongside parameter estimates (logit scale), which may be interpreted similar to that of a confidence interval but instead provide a range of posterior values that includes 95% of the probability. The strength of the covariate effect was evaluated based on those credible intervals and whether or not they overlapped 0 (strong effect = CRI do not overlap zero, weak effect = CRI overlap zero). All R codes, including variable data extraction (distance to road and canopy height) and general model formation are archived on Open Science Framework database ([https://osf.io/merc5/?view\\_only=cebac0b260e34d3bb23a798c684d52e2](https://osf.io/merc5/?view_only=cebac0b260e34d3bb23a798c684d52e2)).

## 3. Results

A total of 174 visual encounter surveys were conducted at the 18 sites between September 2015 and November 2016. The total survey effort was 480.5 surveyor hours (calculated as observers x number of hours searched). A total of 31 green pit vipers and all adults (clearly > 450 mm total body length by visual estimation, Strine et al 2015) were detected during 24 surveys at 4 sites.

The information criteria (leave-one-out; LOO) of the two detection models, temperature and humidity, were

very similar (Table 1). Distance to core zone, distance to houses and buildings, distance to natural forest, and elevation were very similar, distance to water was slightly worse, and whether a site had a plantation or not was suggested to perform quite a bit better. The model fit was suggested to be better for humidity than temperature, and both were moderately adequate. Distance to houses and buildings was the least fit among occupancy models, and distance to water was the best, with the rest of the site models performing similarly to each other.

**Table 1** Summary of single season Bayesian models for estimating big- eye pit viper (*T. macrops*) detection probability and occupancy information criterion (leave-one-out; LOO) and model fit (goodness-of-fit; GOF). Detection variables included temperature ("Temp") and humidity ("Hum"). Occupancy variables included closest distance (m) to water ("Water"), closest distance to house and buildings ("House"), closest distance to roads ("Road"), distance to natural forest ("NatFor"), distance to core zone ("CoreDist"), canopy height ("CH"), and elevation ("Elevation"). One occupancy variable with a binary response (yes or no) was also modeled, plantation ("Plantation").

Model type	Model	LOOIC	GOF
Detection	Hum	135.61	0.87
	Temp	135.37	0.77
Occupancy	CoreDist	137.00	0.70
	Elevation	137.55	0.73
	House	137.35	0.66
	Road	137.96	0.73
	NatFor	137.40	0.72
	CH	136.73	0.75
	Plantation	133.60	0.74
	Water	138.97	0.78

#### 4. Discussion

No prior study has comprehensively investigated both the detection and occupancy of any green pit viper species, which carries significant conservation and snakebite management implications. Conservation assessments and categorizations of this group currently fail to adequately recognize this knowledge gap, potentially overestimating the presence of species such as *T. macrops* (Least Concern, IUCN, Stuart et al 2012) or underestimating others such as the related *T. kanburiensis* (Endangered, IUCN, Chan-Ard et al 2022). Understanding under what conditions and where green pit vipers are found has the potential to optimize resources for future conservation and snakebite management efforts.

Our study does illustrate challenges in assessing the detection and occupancy of green pit vipers. Detection of vipers was low in our study, which was consistent with previous snake studies (0.0001- 0.46 Nafus et al 2020; Durso et al 2011). Finding green pit vipers was personnel and time intensive, with 15.5 personnel hours per *T. macrops* observed, with passive methods such as camera traps (regularly utilized for mammal and bird study, not applicable to reptiles due to the use of IR sensors to detect animals, Welbourne et al 2017) and sound recorders (birds, mammals, and insects, Obrist et al 2010) not being applicable to snakes. Funnel traps, which have been used to estimate the detection and occupancy of snakes in other studies, are not effective with green pit vipers (Strine 2014; Crane et al 2018) due to the arboreality and limited

The probability of detecting *T. macrops* increased marginally with higher humidity and temperature (Figure 2). Occupancy probability increased with increasing distance to buildings and houses, roads, and water and increased canopy height and elevation but decreased with increasing distance to the core zone of the reserve, natural forest, and if a site was a plantation (Figure 3). It is worth noting that the credible intervals for all models overlapped zero, however, suggesting that the variable effects were weak (Table 2).

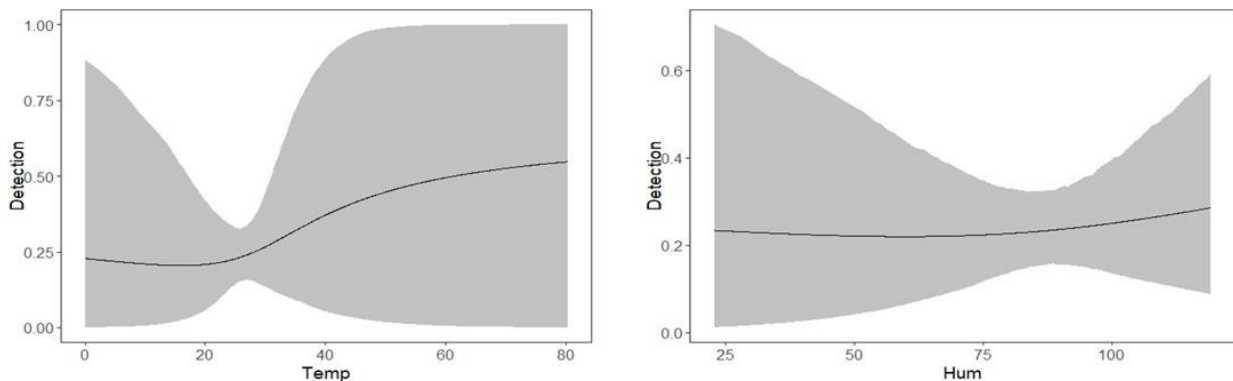
horizontal movement displayed by this group (Barnes et al 2017; Strine et al 2018). We have observed vipers remaining at ambush sites for > 1 month.

Due to the exploratory nature of our study and the desire to gain as much information about the specific survey sites as possible, we continued to survey sites even after vipers were detected at them. Others have suggested cessation of surveys at individual sites after organisms are detected at them to potentially be a more logistically effective study design for assessing occupancy, although this method may be biased toward overestimating detection probability and underestimating occupancy (Medina-Romero et al 2019). Resources, time and personnel might best be focused within a shorter period of time.

We employed a single-season model approach due to logistics (unable to concentrate an adequate number of personnel within a single weather season), and personal experience with those sites before and after this current work app (a) suggest that *T. macrops* did not violate the species presence state occupancy assumption that *T. macrops* did not display site colonization or extinction at our study sites, but this is a significant potential concern for future study. If employing high numbers of personnel, it is worth noting that there are multiple groups of similarly green arboreal snakes (*Boiga cyanea* and *Gonyosoma oxycephalum* at our specific study site) that could be misidentified as green pit vipers, and at least two other species of green pit vipers are also present (*T. albolabris* and

*T. vogeli*) (“false positives”) but are much less frequently observed (< 5 of each species during the study duration), so

adequate training is necessary.



**Figure 2** Probability of detecting big-eyed pit vipers (*Trimeresurus macrops*) at Sakaerat Biosphere Reserve depending on (a) temperature (“Temp”) and (b) humidity (“Hum”) estimated from posterior distribution. Upper and lower 95% credible intervals are presented in the gray bands.

A common theme in reptile detection and occupancy studies specifically is the initial “dredging” of models (usually through selecting variables and combinations with the lowest AIC or BIC), which arguably promotes poor statistical practices and could have serious conceptual implications. Attempting to describe trends observed from those selected models (thus presenting unexpected findings as a prior hypothesis) may result in hypotheses after results are known (“HARKing”), a serious questionable research practice (Kerr 1998; Fraser et al 2018). Variables in dredged models can also be collinear (such as seasonality, temperature, and humidity variables) and potentially not intuitive to the real world, run the risk of “collider bias,” and may not be appropriate for studies where inference is the objective (Stewart et al 2022). It is important to recognize that our current study 1) utilized limited numbers of detection and occupancy variables and 2) variables were chosen based off prior observation and study of the authors. There are additional variables that almost certainly strongly impact the detection of vipers and their occupancy of sites, and we were careful not to claim that any variables selected in the current study were the only or most likely strongest influencers of the detection or occupancy of *T. macrops*.

Temperature has been implicated in influencing the activity patterns of snakes prior to our study (Hart et al 2015; Strine et al 2018) and has similarly been suggested to affect detection (Bauder et al 2017; Jordaan et al 2021). This has largely been attributed to poikilothermic physiology, with snakes attempting to balance body temperature through behavior. We wondered if *T. macrops* would be more detectable with increased humidity due to anurans forming a significant part of their diet (Orlov et al 2002; Cox et al 2012). Our findings that increased humidity increased detectability were consistent with other reptile studies including a terrestrial Southeast Asian pitviper (*Calloselasma rhodostoma*, Daltry et al 2006) and multiple riparian Southeast Asian snake species (5 species) (Asad et al 2021).

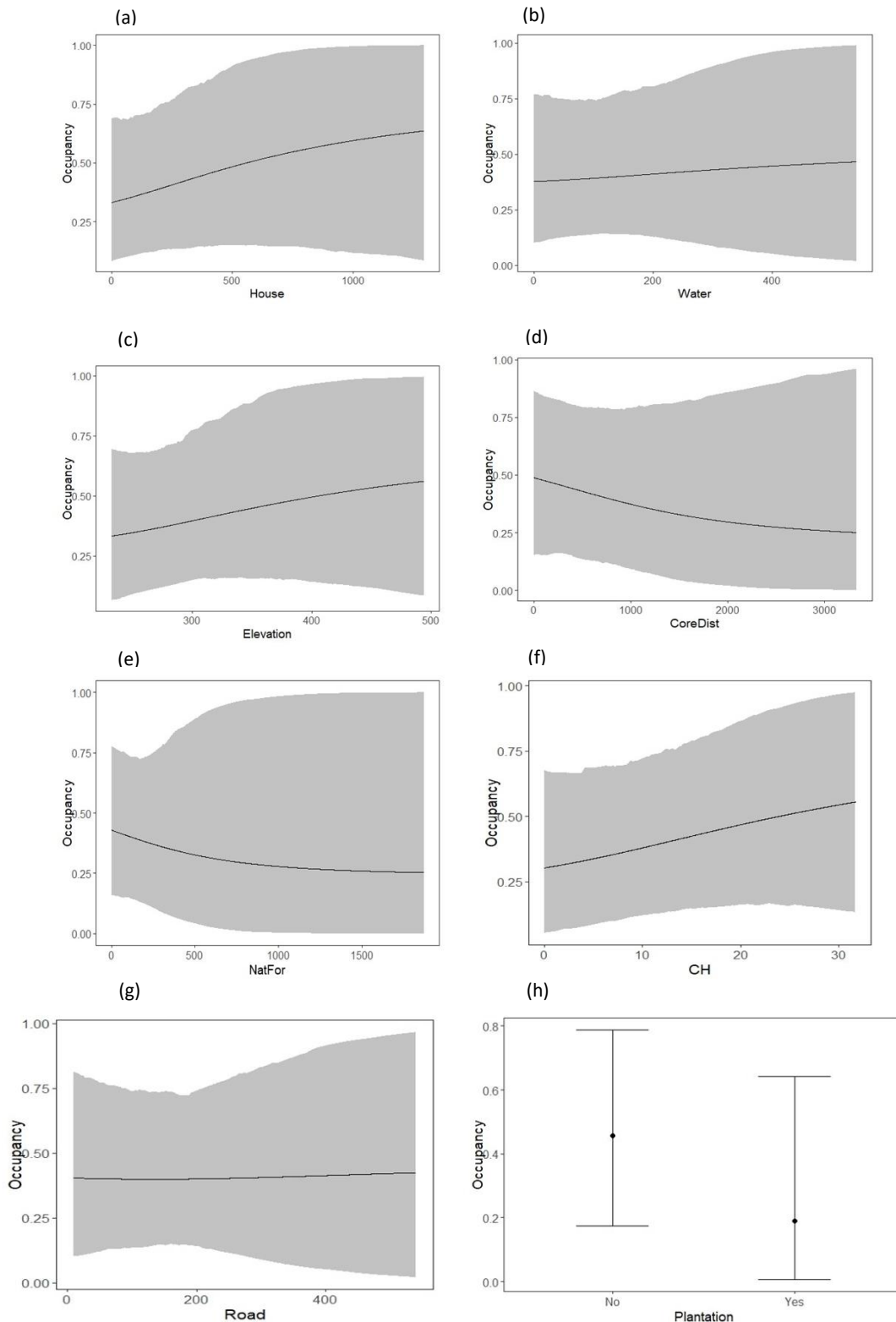
Detection variables that were not modeled but would likely have been highly correlated to those in our study include seasonality and rain. A previous radiotelemetric study has suggested that *T. macrops* uses a variety of forest layers (Barnes et al 2019, Strine et al 2018), and the ability to detect them in complex vegetation and habitat is likely lower than that in less dense and homogenous areas. Finding vipers in complex environments and confirming species correctly (two other green pit viper species and two phenotypically similar unrelated snake species were present at our study site) suggest observer experience could be worth modeling, although experience quantification could be challenging. The type and quality of illumination, light sources such as headlights or torches, of observers have not been modeled to our knowledge for the detection of snakes but could be especially relevant (although similarly difficult to quantify as observer experience) for green pit vipers, which can be observed > 10 m in the forest canopy.

Although difficult to assess, a detection covariate that to our knowledge has never been investigated but is likely crucial for quantifying the ability to observe nocturnal organisms is the amount of light used by observers during surveys. Although this (a) | change throughout the night as battery power wanes, a baseline (likely using lumens as a unit) could optimize detectability. Our personal observation suggests that powerful headlights and spotlights (>1,500 lumens) can be useful for finding vipers that are arboreal (> 5 m in trees) and open habitat but are expensive and highly intrusive to organisms (easily inducing flight responses) when searching the ground in closed dense forests. Low-power lights are inexpensive, but detectability is likely much lower, particularly for arboreal animals. Green pit viper coloration is highly cryptic during the day (personal observation), and at night, artificial light is reflected differently from vegetation (typically dull and dark green) and vipers (bright, “highlighter” green). In addition to being less visible to observers due to coloration, green pit vipers rest and shelter in habitat much more frequently during the

(b)

day (Strine et al 2018; Barnes 2021), so conducting surveys during the day would not be a viable alternative and would

have even lower detection probabilities than what we observed.



**Figure 3** Probability of big-eyed pit vipers (*Trimeresurus macrops*) occupying sites at Sakaerat Biosphere Reserve (SBR) depending on (a) distance to houses and buildings (“House”), (b) distance to water (“Water,” m), (c) elevation above sea level (“Elevation,” m), (d) distance to SBR core zone (“CoreDist,” m), (e) distance to natural forest (“NatFor,” m), (f) canopy height (“CH,” m), (g) distance to roads (“Road,” m), and (h) whether a plantation was part of the site (“Plantation,” yes or no) estimated from posterior distribution. Upper and lower 95% credible intervals are presented in the gray bands and black vertical lines.

**Table 2** Summary of single season Bayesian models for estimating big-eye viper (*T. macrops*) detection probability and occupancy. Detection variables included temperature (“Temp”) and humidity (“Hum”). Occupancy variables included closest distance (m) to water (“Water”), closest distance to house and buildings (“House”), closest distance to roads (“Road”), distance to natural forest (“NatFor”), distance to core zone (“CoreDist”), canopy height (“CH”), and elevation (“Elevation”). One occupancy variable with a binary response (yes or no) was also modeled, plantation (“Plantation”). Credible intervals (Cris) are presented alongside parameter estimates (“Estimate”), which may be interpreted similar to that of a confidence interval but instead provide a range of posterior values that includes 95% of the probability.

Model type	Model	Estimate	CRI
Detection	Hum	0.0648	-0.363,0.533
	Temp	0.184	-0.641,1.225
Occupancy	CoreDist	-0.559	-1.86,1.11
	Elevation	0.567	-1.00,2.71
	House	0.673	-0.803,2.95
	Road	0.000877	-1.57, 1.77
	NatFor	-0.493	-2.69,2.16
	CH	0.689	-0.805,2.66
	Plantation	-1.74	-5.14,0.775
	Water	0.172	-1.23,1.79

Four of our site variables, distance to natural forest, distance to houses and buildings, canopy height, and distance to the Sakaerat Biosphere Reserve core zone, suggest *T. macrops* to potentially be sensitive to anthropogenic habitat disturbance. The IUCN Red List categorization for *T. macrops* suggests that the species is a habitat generalist and resilient to disturbance, which while persistence of the species in Bangkok and some rural sites in our study may support this, potential for local extinction and loss might be preliminarily indicated by this current occupancy work. The buffer and transition areas of SBR are primarily rural, with agriculture being highly dynamic and lacking a heterogeneous vertical structure; many snakes, including green pit vipers, are primarily limited within these habitat matrices during most of their life stages to small and frequently isolated features, such as canals that retain vegetation and shelter, such as rocks that mimic more natural forested habitats (green pit vipers, Barnes et al 2017; banded kraits, Knierim et al 2019; king cobras, Marshall et al 2020; Burmese pythons, Smith et al 2021). We hypothesize that consistent retention of vertical habitat features and limited mortality of individual snakes may be what enable green pit vipers to persist in many parts of the Sakaerat Biosphere Reserve and other similar disturbed habitats.

While our study sites were stable in habitat, agriculture directly adjacent to sites in the buffer and transition zones was highly dynamic. We were not specific about types of buildings in terms of size or function due to the exploratory nature of the study, but size and use could influence the occupancy of vipers in the immediate area. Similarly, various local agriculture types experience distinct and unique treatments, including rotation, harvest, and rodenticide, insecticide, and herbicides, which have the potential to impact green pit viper ecology both directly and indirectly. A previous radiotelemetric study in the rural area of SBR suggested that *T. macrops* rarely utilized agriculture (Barnes et al 2017), which may reflect the dynamic nature of these habitats, and instead spent a majority of their time in plantations with long rotations (such as rubber) or

agricultural canals (“klongs”), which consistently retain vegetation and potential shelters such as boulders and scree. Two vipers did spend extensive (> 2 weeks) time within close proximity (< 10 m) of households during that study, however.

No human-caused mortality (direct, intentional, or indirect) of green pit vipers was documented during the Barnes et al. (2017) study, nor did we observe any mortality during this current work. Local people were relatively tolerant or open to moving (rather than killing) green pit vipers, which may be attributed to their small size and ambush foraging lifestyle. Larger and more active elapids in SBR do experience anthropogenic mortality due to plastic (*Ophiophagus hannah*, Strine et al (2014), roadkill (*O. hannah*, Marshall et al 2018), traps set to capture fish (*Bungarus candidus*, Crane et al 2016), and agriculture (*B. fasciatus*, Knierim 2018).

Green pit vipers inflict the highest number of venomous snakebites in Thailand, which, while not usually fatal, could influence the perceptions of these animals. New species are described or split on an almost yearly basis, yet natural history and ecological studies (beyond descriptions, splits, and anecdotes) remain scarce. Where green pit vipers are present and what influences detection in different areas is a current significant knowledge gap hindering snakebite management and conservation efforts. Our study identifies key considerations and challenges needed to adequately determine the occupancy and detection of green pit vipers. While potentially logistically intensive and expensive, understanding the persistence of different green pit viper species would assist with the identification of areas to optimize conservation and snakebite management efforts.

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### Ethical considerations

Not applicable.

### Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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### References

- Asad S, Ng ST, Sikui J, Rödel MO (2022) Variable detectability and El-Nino associations with riparian snakes in Sabah, Malaysian Borneo. *Journal of Tropical Ecology* 38:25-30.
- Barnes CH (2021) Comparative green pit viper behavior and activity. Suranaree University of Technology. (Doctoral dissertation).
- Barnes CH, Strine CT, Suwanwaree P, Hill III J (2017) Movement and home range of green pit vipers (*Trimeresurus* spp.) in a rural landscape in Northeast Thailand. *Herpetological Bulletin* 142:19-28.
- Bauder JM, Stevenson DJ, Sutherland CS, Jenkins CL (2017) Occupancy of potential overwintering habitat on protected lands by two imperiled snake species in the Coastal Plain of the southeastern United States. *Journal of Herpetology* 51:73-88
- Böhm M, Collen B., Baillie JE, Bowles P, Chanson J, Cox N, Hammerson G, Hoffmann M, Livingstone SR, Ram M., Rhodin AG (2013) The conservation status of the world's reptiles. *Biological Conservation* 157:372-385.
- Bürkner PC (2017) brms: An R package for bayesian multilevel models using stan. *Journal of Statistical Software*.
- Carpenter B, Gelman A, Hoffman MD, Lee D, Goodrich B, Betancourt M, Brubaker MA, Guo J, Li P, Riddell A (2017) Stan: A probabilistic programming language. *Journal of Statistical software* 76.
- Chan-Ard T, Grismer L, Stuart B (2022) *Trimeresurus kanburiensis* (amended version of 2012 assessment). In The IUCN Red List of Threatened Species 2022. <http://dx.doi.org/10.2305/IUCN.UK.2012-1.RLTS.T192181A2052063.en>
- Chanhome L, Cox MJ, Vararuchapong T, Chaiyabutr N, Sitprija V (2011) Characterization of venomous snakes of Thailand. *Journal of Asian Biomedicine* 5:311-328.
- Chippaux JP (1998) Snake- bites: Appraisal of the global situation. *Bulletin of the World Health Organization* 76:515-524.
- Chippaux JP (2017). Snakebite envenomation turns again into a neglected tropical disease! *Journal of Venomous Animals and Toxins Including Tropical Diseases* 23.
- Cox MJ, Hoover MF, Chanhome L, Thirakhupt K (2012) *The Snakes of Thailand*, 1st Edition. Sirabutr Printing, Bangkok, Thailand.
- Crane M, Oliver K, Silva I, Aksornneam A, Artchawakom T, Strine CT (2016) A report of a Malayan Krait snake *Bungarus candidus* mortality as by-catch in a local fish trap from Nakhon Ratchasima, Thailand. *Tropical Conservation Science* 9:313-320.
- Daltry JC, Ross T, Thorpe RS, Wüster W (1998) Evidence that humidity influences snake activity patterns: a field study of the Malayan pit viper *Calloselasma rhodostoma*. *Ecography*, 21:25-34.
- Durso AM, Willson JD, Winne CT (2011) Needles in haystacks: estimating detection probability and occupancy of rare and cryptic snakes. *Biological Conservation* 144:1508-1515.
- Fraser H, Parker T, Nakagawa S, Barnett A, Fidler F (2018) Questionable research practices in ecology and evolution. *PLoS One* 13:e0200303.
- Hart KM, Cherkiss MS, Smith BJ, Mazzotti FJ, Fujisaki I, Snow RW, Dorcas ME (2015) Home range, habitat use, and movement patterns of non-native Burmese pythons in Everglades National Park, Florida, USA. *Animal Biotelemetry* 3:8.
- Hughes AC (2017). Mapping priorities for conservation in Southeast Asia. *Biological Conservation* 209:395-405.
- Gelman A, Rubin DB (1992) Inference from iterative simulation using multiple sequences (with discussion). *Statistical Science* 7:457-472.
- Jordaan A, Heideman NJ, Buschke, FT (2021) Topography-derived variables provide insight into habitat occupancy of a cryptic snake, *Bitis atropos*. *Austral Ecology* 46:1287-1297.
- Kasturiratne A, Wickremasinghe AR, de Silva N, Gunawardena, NK, Pathmeswaran A, Premaratna R, Savioli L, Lalloo DG, de Silva HJ (2008) The global burden of snakebite: A literature analysis and modelling based on regional estimates of envenoming and deaths. *PLoS Medicine* 5:1591-1604.
- Kerr NL (1998) HARKing: Hypothesizing after the results are known. *Personality and Social Psychology Review* 2:196-217.
- Knierim TK (2018) The spatial ecology, habitat use, and activity of banded kraits (*Bungarus fasciatus*) in the Sakaerat Biosphere Reserve. Suranaree University of Technology. (Master's thesis).
- Knierim TK, Strine CT, Suwanwaree P, Hill III JG (2019) Spatial ecology study reveals nest attendance and habitat preference of banded kraits (*Bungarus fasciatus*). *Herpetological Bulletin* 150:6-13.
- MacKenzie DI, Bailey LL (2004) Assessing the fit of site-occupancy models. *Journal of Agricultural Biological & Environmental Statistics* 9:300-318.
- Marshall BM, Strine CT, Jones MD, Theodorou A, Amber E, Waengsothorn S, Suwanwaree P, Goode M (2018) Hits close to home: repeated persecution of king cobras (*Ophiophagus hannah*) in Northeastern Thailand. *Tropical Conservation Science* 11:1-14.
- Marshall BM, Crane M, Silva I, Strine CT, Jones MD, Hodges CW, Suwanwaree P, Artchawakom T, Waengsothorn S, Goode M. (2020) No room to roam: King Cobras reduce movement in agriculture. *Movement Ecology* 8:1-14.
- Nafus MG, Mazzotti FJ, Reed RN (2020) Estimating detection probability for Burmese pythons with few detections and zero recaptures. *Journal of Herpetology* 54:24-30.
- Obrist MK, Sueur GPJ, Riede K, Llusia D, Márquez R (2010) "Bioacoustics approaches in biodiversity inventories." *Abc Taxa* 8:68-99.
- Orlov N, Ananjeva N, Khalikov R (2002) Natural history of pitvipers in Eastern and Southeastern Asia. *Biology of the Vipers* 345-361.
- Padgham M, Rudis B, Lovelace R, Salmon M (2017) osmdata. Version 0.1.8.
- Pebesma E (2018) sf: Simple Features for R. URL <https://CRAN.R-project.org/package=sf>. R package version 0.6-1.
- Pincheira-Donoso D, Bauer AM, Meiri S, Uetz P (2013) Global taxonomic diversity of living reptiles. *PLoS One* 8:e59741.
- R Development Core Team (2018) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Available at <http://www.R-project.org/>
- Simard M, Pinto N, Fisher JB, Baccini A (2011) Mapping forest canopy height globally with spaceborne lidar. *Journal of Geophysical Research: Biogeosciences* 116:04021.
- Smith SN, Jones MD, Marshall BM, Waengsothorn S, Gale GA, Strine CT (2021) Native Burmese pythons exhibit site fidelity and preference for aquatic habitats in an agricultural mosaic. *Scientific Reports* 11:1-13.





- Sodhi NS, Posa MRC, Lee TM, Bickford D, Koh LP, Brook BW (2010) The state and conservation of Southeast Asian biodiversity. *Biodiversity and Conservation* 19:17-328.
- Strine CT (2014) The ecological study of green pit vipers in Sakaerat environment research station, Nakhon Ratchasima. Suranaree University of Technology. (Doctoral dissertation).
- Strine CT, Silva I, Crane M, Nadolski B, Artchawakom T, Goode M, Suwanwaree P (2014) Mortality of a wild king cobra, *Ophiophagus hannah* Cantor, 1836 (Serpentes: Elapidae) from Northeast Thailand after ingesting a plastic bag. *Asian Herpetological Research* 5:284-286.
- Strine C, Silva I, Barnes CH, Marshall BM, Artchawakom T, Hill III J, Suwanwaree P (2018) Spatial ecology of a small arboreal ambush predator, *Trimeresurus macrops* Kramer, 1977, in Northeast Thailand. *Amphibia-Reptilia* 39:335-345.
- Stuart B, Chan-Ard T, Thy N (2012) *Cryptelytrops macrops*. The IUCN red list of threatened species. Version 2015.1. [www.iucnredlist.org](http://www.iucnredlist.org). Downloaded on 05 June 2015.
- Sumontha M, Kunya K, Pauwels OSG, Nitikul A, Punnadee S (2011) *Trimeresurus* (Popeia) *phuketensis*, a new pitviper (Squamata: Viperidae) from Phuket Island, southwestern Thailand. *Russian Journal of Herpetology* 18:185-194.
- Suraweera W, Warrell D, Whitaker R, Menon GR, Rodrigues R, Fu SH, Begum R., Sati P, Piyasena K, Bhatia M, Brown P, and Jha P (2020) Trends in snakebite mortality in India from 2000 to 2019 in a nationally representative mortality study. *eLife* 9:1-37.
- Trimble MJ, van Aarde RJ (2012) Geographical and taxonomic biases in research on biodiversity in human-modified landscapes. *Ecosphere* 3:1-16.
- Uetz P, Hallermann J (2015) Reptile database. <http://reptile-database.reptarium.cz>. Accessed on March 01, 2015.
- Vehtari A, Gabry J, Magnusson M, Yao Y, and Gelman A (2019) loo: Efficient leave one-out cross-validation and WAIC for Bayesian models. R package version 2.2.0: <https://mc-stan.org/loo>
- Warrell DA (2010) Guidelines for the clinical management of snake-bites in the southeast Asia region. World Health Organization, Regional Office for South East Asia, New Delhi, pp. 1-67.
- Welbourne DJ, Paull DJ, Claridge AW, Ford F (2017) A frontier in the use of camera traps: surveying terrestrial squamate assemblages. *Remote Sensing in Ecology and Conservation* 3:133-145.