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Modeling habitat suitability to predict the potential distribution of the Sri Lankan Green Pit Viper

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Abstract

Snake distribution and habitat modeling serve multiple valuable purposes, one of which involves establishing a systematic approach for collecting and assessing data related to the presence and influence of diverse factors on snake distribution patterns. The main objective of this study is to explore the habitat association of the Sri Lankan Green Pit Viper (*Peltopelor trigonocephalus*) and develop models to assess the suitability of different habitats within the island Sri Lanka. We modeled the suitable habitat for this species using the maximum entropy algorithm, combining presence data collected over two years (from April 2021 to April 2023) with a set of seven environmental variables (annual precipitation, annual mean temperature, precipitation of coldest quarter, elevation, land use, isothermality, Euclidean distance to water). We assessed the importance of different environmental variables through jackknife tests. We evaluated the predictive ability of the models using the area under the receiver operating characteristic curve. We discovered that the primary explanatory variables influencing the distribution of the species were annual mean temperature, annual precipitation, and elevation, contributing significantly at 35%, 31.6%, and 20%, respectively. The Sri Lankan Green pit viper inhabited riparian, forest, and open habitats, with the highest number of individuals recorded in riparian areas. We presented the first habitat suitability models for the Sri Lankan Green Pit Viper, offering valuable insights for conservation biologists and land managers involved in preserving this species.

Key words: Maxent, species distribution modelling, *Peltopelor trigonocephalus*, Sri Lanka

1. Introduction

The biodiversity of terrestrial animals living in forest regions faces a grave threat due to climate change. This environmental phenomenon results in population declines and the loss of habitats for various animal and plant species, placing their existence in danger (Pounds et al., 1999; Moritz et al., 2008; Pimm, 2008; Karger et al., 2021). Reptiles are of utmost importance as secondary consumers at the core of ecosystems, rendering them a crucial group for the conservation of biodiversity (Raxworthy et al., 2008; Tewksbury et al., 2008; Huey et al., 2009; Lourenço-de-Moraes et al., 2019). The limited ability of reptile species to disperse effectively increases their risk of extinction, as they are unable to migrate to suitable environments (Parmesan, 2006; Sinervo et al., 2010; Hoffmann & Sgrò, 2011; Do et al., 2017a). Consequently, numerous scientific investigations have analyzed and predicted the geographic distribution of reptile species in diverse climate change scenarios, with a primary focus on biogeography and conservation biology, aiming to protect and preserve biodiversity (Brito et al., 2011a; Rugiero et al., 2013; Caten et al., 2017). One of the difficulties faced by conservation biologists are identifying the key aspects of global climate change and predicting the range of a species (Root & Schneider, 2006).

Today, the management of habitats, assessment of the possible effects of environmental changes on species populations and informing conservation efforts are all aided by distribution modeling (Williams et al., 2009; Sarhangzadeh et al., 2013; Yazarloo et al., 2017, 2019; Hosseinian Yousefkhani, 2019). Phillips et al. (2006) indicated the use of the Maxent (maximum entropy) model in predicting the potential distribution range of the focus species in the current investigation. The approach simply uses occurrence data and is frequently used for modeling species distributions. The popularity of this method among researchers is related to its capacity to expedite and minimize costs in comparison to other modeling methodologies (Warren et al., 2011; Adjaye, 2011; Bassi et al., 2015). Moreover, important species-habitat interactions have been discovered using these models, which have been used to model species distribution and environmental niches. Using only "presence" data and environmental factors minimizes bias and frequently produces reliable findings (Phillips et al., 2006; Pearson et al., 2007; Merow et al., 2013; Merow & Silander, 2014). When using MaxEnt models, wider regional distributions have often been the primary emphasis, with global bioclimatic factors playing a significant role. Previous studies have successfully utilized this model for animal habitat modeling by applying presence-only data (Suarez-Seoane et al., 2008; Anado'n et al., 2012; Wen et al., 2015).

Peltopelor is a genus of pit vipers (Reptilia: Serpentes: Viperidae: Crotalinae) which has a wide distribution across Southern Asia, Indo–Malayan archipelago, Southeast Asia, China, Japan, and the Pacific Islands It belongs to family Viperidae, in which 50 species are currently recognized in the world, and the number is still growing (Chen et al., 2021). *Peltopelor* species are all arboreal or semi-arboreal and nocturnal (Malhotra et al. 2011). They camouflage themselves in trees and lush vegetation during daytime and have more slender and elongated bodies than most terrestrial pit vipers to facilitate movement through trees and bushes above the ground (Malhotra et al., 2011). The proposed study concentrates on the species *P. trigonocephalus*, a species endemic to Sri Lanka. *Peltopelor trigonocephalus* is commonly known as the "Sri Lankan Green Pit Viper or Palapolaga." It is widely distributed in all three climatic zones of the island, except higher hills and arid zones. Three primary climatic zones, wet zone, intermediate zone, and dry zone, have been established based on the amount and distribution of yearly rainfall. Moreover, this species is relatively more common in the wet zone and rain forest areas and found occasionally in plantations of cardamom, cocoa, coffee, and tea spanning over altitudes from 153 to 1,000 m (De silva 2009). We constructed a bioclimatic model to evaluate the effect of bioclimatic variables in Sri Lanka using *Peltopelor trigonocephalus* as a model of the Green Pit Viper (GPV) species. This study we used maximum entropy modeling to study the potential distribution of The Sri Lankan Green Viper based on geographical distribution data and environmental predictor variables, with the following objectives: 1 to determine which environmental factors are correlated with the distribution of this species; and 2) identify habitat types for Green pit viper conservation in

Sri Lanka. We anticipate receiving further information on ecological requirements to predict its possible geographical distribution.

2. Materials and methods

Study site

The study site was in three climatic zones of Sri Lanka (6.00° N to 9.00° N, 79.60° E to 81.60° E) (Fig. 1). The wet zone encompasses a region with a reasonably high mean annual rainfall of over 2,500 mm and no significant dry spells. The dry zone is defined as a region with an average annual rainfall of less than 1,750 mm and a distinct dry season that lasts from May to September. The Intermediate zone denotes a region with an average annual rainfall of 1,750 mm to 2,500 mm and a brief but noticeable dry season. Although these climatic zones were defined by the amount and distribution of annually rainfall, other physical variables such as soil, topography, height, vegetation, and land use had a significant role in their formation (Gunawardena. & Pabasara, 2016).

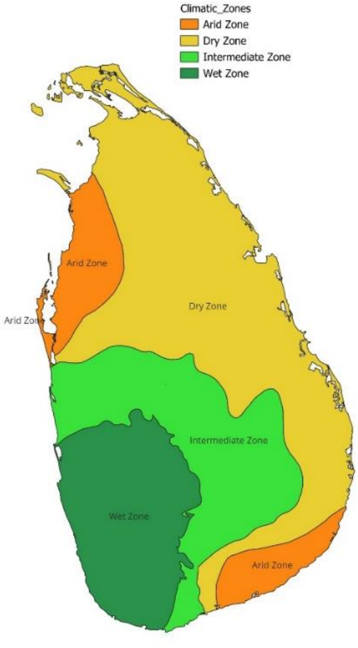

Figure 1. map of three climatic zones of Sri Lanka

Collection of presence data

The locations where we observed Green pit vipers (Fig. 1) through a visual survey conducted in the three climatic zones of Sri Lanka from April 2021 to April 2023 covering three habitat types, riparian, forest and open (Dhananjani et al., 2022). Additionally, we gathered information on the species' occurrence points from the field researches, published papers and books (Rathnayaka et al., 2017 and Somaweera 2006) and databases (www. inaturalist.org). Records included latitude and longitude coordinates determined using the Global Positioning System (GPS), with a positional accuracy between 10m and 20m. Instances of multiple observations of the species at the same location and time were treated as single observations, resulting in 179 observations in the georeferenced species point occurrence points. During our field surveys, we successfully identified, photographed, and released all living snakes encountered. In cases where snakes were found deceased, we also conducted identification and photography whenever feasible, recording the geographic coordinates of each snake location and providing brief descriptions of the habitats and microhabitats where they were found.

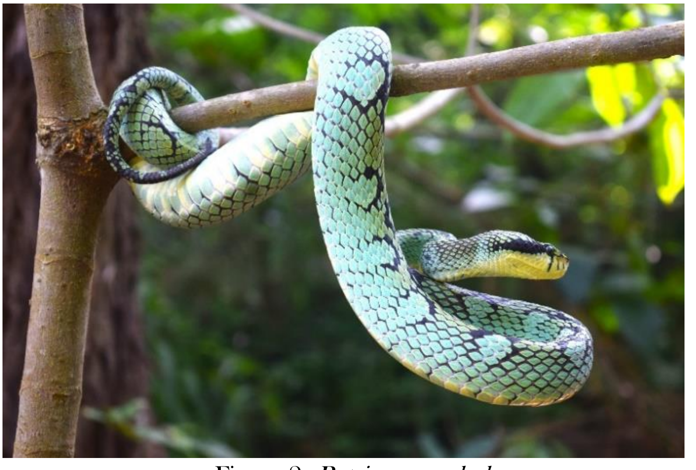

Figure 2. *P. trigonocephalus*

Geographical data

We acquired nineteen bioclimatic variable raster maps from WorldClim version 2.1 (www.worldclim.org) data and extracted the relevant data specifically for the study site. We carried out this extraction process using a mask in ArcGIS software. Additionally, we created raster maps of elevation based on a digital elevation model (DEM) and calculated the Euclidean distance to water sources using the Euclidean distance tool. We considered these variables as continuous variables. Furthermore, land use cover was used as a categorical variable (Sunny et al., 2023) (Table 1). We resampled the raster maps with different spatial extents and resolutions to match the parameters of the nineteen bioclimatic variables (30 seconds~1km2) (Phillips et al. 2006). After accounting for multicollinearity (>75%), we considered ten covariates for the final analysis. (using ENMTools in R version 4.1.2).

Maximum entropy implementation

Maxent software compares the maximum presence data with the data of the environment variables using the entropy approach (Philips et al., 2006). We converted climate variables to ASCII format using GIS software. Then, we evaluated each of the predicted variables using the randomkfold method and determined the degree of importance of the variable. We selected "Cross-validate" as the run type for each replicated run with a replicate number of 10. To minimize potential errors in our sample, we set the maximum iteration to 10000, as recommended by Do et al. (2016, 2017a) and Yun et al. (2020). We created response curves and generated jackknife tests of variable importance along with random seed and plot data. We used the jackknife estimator to detect the importance of each variable.

We tested regularization multipliers of 0.5, 1, 1.5, and 2 to obtain the best-fit model (reviewed in Merow et al., 2013). We evaluated the performance of the model by calculating the Area Under the Curve (AUC) value using Receiver Operating Characteristics testing (ROC). We commonly use AUC values in studies that utilize habitat prediction programs to assess the effectiveness of the model. However, it is important to note that AUC values can be highly sensitive to various model conditions, such as the quantity of samples and the size of the background (Phillips & Dudk, 2008; Phillips et al., 2009; Jiménez-Valverde, 2012).

Table 1. Variables considered for modeling (Variables used for modeling indicated by 'X' mark)

Abbreviation	Variable	Description	Model usage
Bio1	Annual Mean Temperature	Continuous	×
Bio2	Mean Diurnal Range (Mean of monthly (max temp - min temp))	Continuous	
Bio3	Isothermality (BIO2/BIO7) (×100)	Continuous	×
Bio4	Temperature Seasonality (standard deviation ×100)	Continuous	
Bio5	Max Temperature of Warmest Month	Continuous	
Bio6	Min Temperature of Coldest Month	Continuous	
Bio7	Temperature Annual Range (BIO5-BIO6)	Continuous	×
Bio8	Mean Temperature of Wettest Quarter	Continuous	
Bio9	Mean Temperature of Driest Quarter	Continuous	
Bio10	Mean Temperature of Warmest Quarter	Continuous	
Bio11	Mean Temperature of Coldest Quarter	Continuous	
Bio12	Annual Precipitation	Continuous	×
Bio13	Precipitation of Wettest Month	Continuous	
Bio14	Precipitation of Driest Month	Continuous	
Bio15	Precipitation Seasonality (Coefficient of Variation)	Continuous	
Bio16	Precipitation of Wettest Quarter	Continuous	
Bio17	Precipitation of Driest Quarter	Continuous	
Bio18	Precipitation of Warmest Quarter	Continuous	
Bio19	Precipitation of Coldest Quarter	Continuous	×
elevation		Continuous	×
dtw	Euclidean distance to water	Continuous	×
biocatog	Land use	Categorical	×

3. Results

Presence data of species

During transect observations, 156 individuals of the Green pit viper directly observed. For the remaining observations, information recorded in literature was relied upon. After excluding repeated occurrences within 1km², 179 occurrence points for the Green pit viper were used as input for MaxEnt presence data.

Habitat suitability and distribution

The ROC results yielded >0.80 area under the receiver operating curve (AUC=0.828) values for green pit viper species, indicating good prediction values for MaxEnt models (Fig. 3). Based on the generated habitat suitability maps (Fig. 4), it was determined that a high presence suitability of the Green pit viper was observed in habitats located near the wet zone. The jackknife test of training gain showed that Bio 12 (35%), Bio1 (31.6%), Bio19 (3.9%) and elevation (20%) were the main factors contributing to Green pit viper habitat selection (Fig. 5). The permutation importance rates in the MaxEnt model prediction indicated that Bio 12, Bio1, Bio19 and elevation as the main factors affecting the model. The response curves provided additional evidence supporting our findings. Since annual precipitation (Bio12) is the most important variable, the occurrence of green pit vipers increases with precipitation up to a point, with suitability decreasing as annual precipitation increases above 4000 mm, indicating a positive correlation between the two variables (Fig. 6A). The response of the species distribution to annual mean temperature (Bio1) indicated that there is an optimum condition in a short range of temperatures (between 21°C and 23.6°C). The Green pit viper is associated with an average annual temperature of 22-23.6°C, and in high mountains area with an average annual temperature of lower than 14°C, as well as in areas above 24°C, the suitability of its habitat decreases. Similarly, high values of Bio1 (a measure of annual temperature) and elevation were associated with a decrease in the occurrence of the Green pit viper within its habitat, indicating a negative correlation (Fig. 6B). These response curves provide a detailed explanation for the relationship between environmental factors and the presence of the green pit viper.

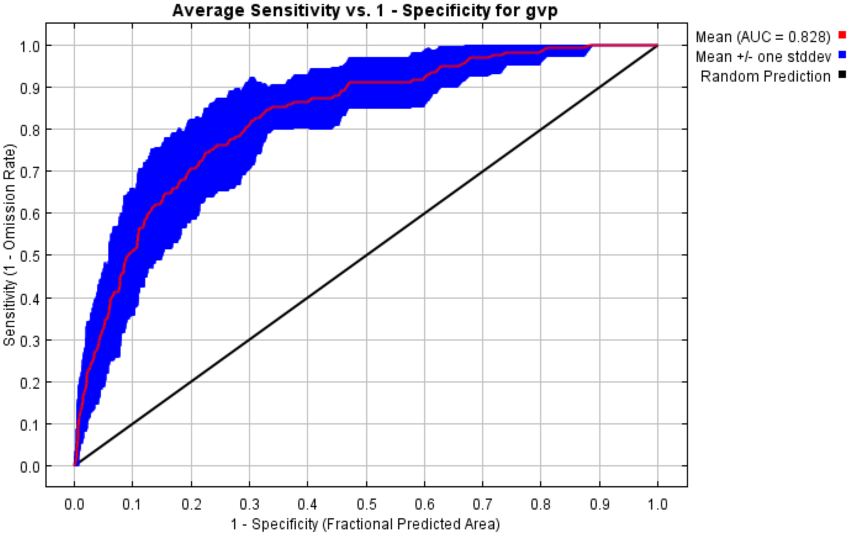

Figure 3. ROC cure- average sensitivity vs specificity for Green pit viper

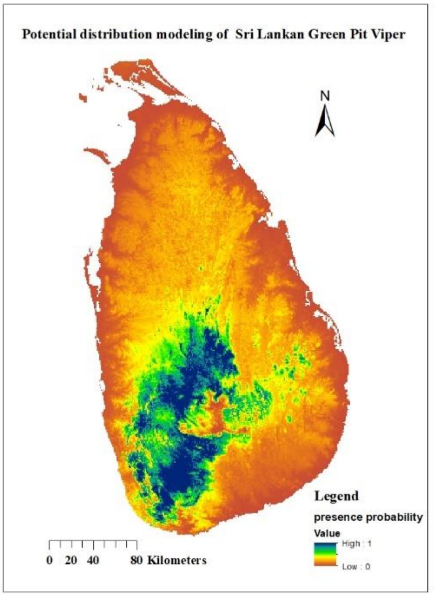

Figure 4. Potential distribution modeling of *P. trigonocephalus* in Sri Lanka obtained with Maxent 3.4.3

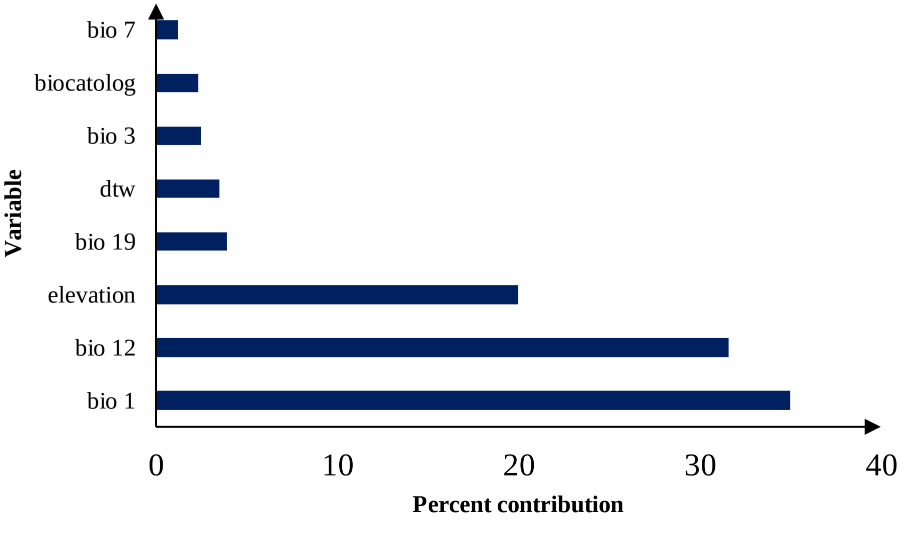

Figure 5. Contribution of environmental variables

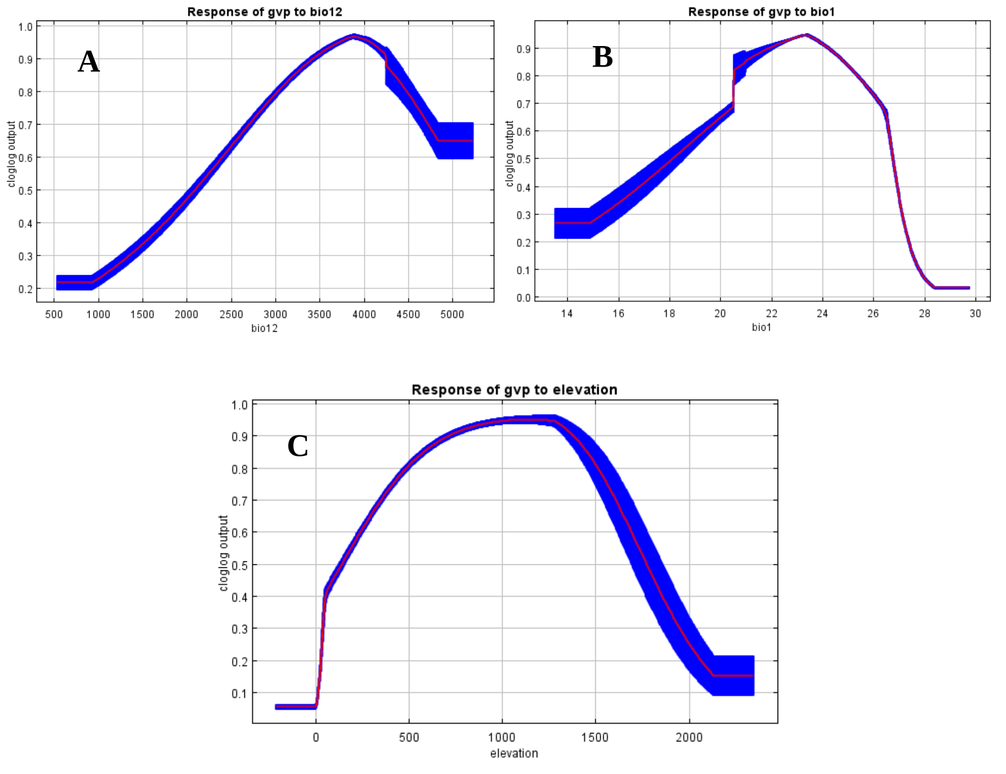

Figure 6. Response curves for selected variables: (A) bio12 (B) bio1 (C) elevation

Percentage of *P. trigonocephalus* found in different types of habitats

The majority (71.42%) of *P. trigonocephalus* individuals occurred in riparian habitats, where their abundance was highest. We found the remaining individuals (25.34% and 3.23%) in forest and open habitats, respectively, with the open habitats having the lowest percentage of their presence (Fig. 8).

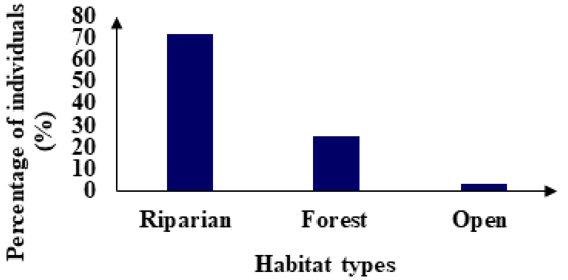

Figure 8. Percentage of *P. trigonocephalus* found in different types of habitats

4. Discussion

The distribution of the Sri Lankan Green pit viper in Sri Lanka is being studied in one of the first studies in Sri Lanka to use the MaxEnt modeling method. Analysis of relative importance of variables included in the best model show differences in Sri Lanka. A species distribution map was generated using annual precipitation, annual temperature, temperature annual range (Bio5-Bio6), precipitation of coldest quarter, land use, elevation, and Euclidean distance to water. Annual precipitation (Bio12), annual temperature (Bio1), and elevation were the major environmental factors that influenced the distribution of the Sri Lankan Green Pit Viper. Combination of models for three climatic zones of Sri Lanka demonstrates the high importance (35%) of Bio1 parameter – annual temperature. Hence, this was especially visible in the jackknife estimator results (Fig. 9), where the highest contribution for the MaxEnt model was Bio1. The findings indicated that the occurrence of Green pit vipers in their habitats would decline at high temperatures. Therefore, Green pit vipers were showing high adaptability to annual temperature.

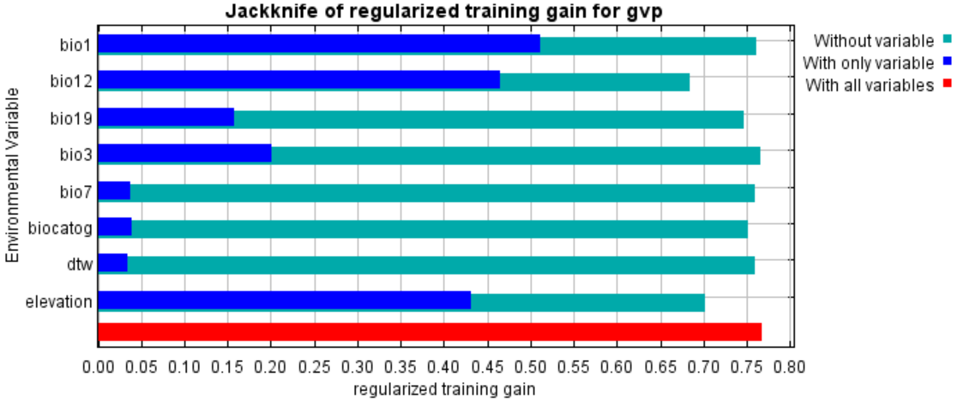

Figure 9. Jackknife test of environmental variables in training data

The results of this study further supported the hypothesis that temperature-related variables, such as Bio1, were important environmental factors affecting Green pit viper distribution. Moreover, increased temperatures significantly influence the life cycle of viper species, resulting in a decline in their population sizes, as demonstrated in studies carried out by Corti et al. (2011) and Rugiero et al. (2013). Huey (1982) recorded snakes as being ectothermic species, meaning they rely on external heat sources to regulate their body temperature and facilitate their physiological and behavioral activities. Consequently, in temperate and subtropical regions, snake activity tends to decrease as temperatures increase. It is conceivable that the heightened activity observed in snakes during the low-temperature period is primarily a result of their necessity to engage in feeding activities at lower temperatures (Kadota 2011). According to Campbell & Solorzano (1992), the primary environmental factor that restricts the range of reptiles is believed to be the ambient temperatures. The close relationship between the body functions of reptiles and the environmental temperature, as discussed by Greer (1980), indicates that the thermal tolerances of these animals are strongly linked to the temperatures found in their habitats and their geographical distribution.

The presence suitability was positively increased with precipitation (Bio12). This was visible in the jackknife estimators followed by the contribution of Bio12 which was the second most important parameter. Moreover, various studies have established a positive correlation between air relative humidity, rainfall, and the prevalence of tropical snakes, emphasizing rainfall as a significant factor influencing their seasonal activities (Bernarde et al., 2006; Turci et al., 2009). The rainy season has been associated with an increase in the population of snakes, primarily due to enhanced forest productivity and the greater availability of specific prey species such as anurans and lizards (Martins et al., 1999; Oliveira & Martins, 2001). Researchers have also suggested a correlation between the pattern of the rainy season and the flooding of land areas near streams, which subsequently impacts the locations of riverine villages and leads to the migration of snakes to upland areas. This phenomenon can be attributed to the higher density of snakes and their increased movement in search of prey during this period (Feitosa et al., 2015). In the Amazon region, there is a strong association between the rainy seasons and the prevalence of juvenile snakes (Bernarde & Abe, 2006; Turci et al., 2009). Snake species such as *Bothrops atrox* and *Bothrops bilineatus* exhibit heightened activity during months with higher levels of rainfall (Martins et al., 1999; Oliveira & Martins, 2001).

According to this investigation, elevation emerged as the third most influential environmental factor with regards to the distribution of pit vipers. Studies conducted by Luiselli (2006), Do et al. (2016, 2017a) have established a clear association between elevation and various climate factors, particularly temperature. Furthermore, the current study corroborated the finding that pit vipers do not inhabit higher elevations (Fig. 6C), reinforcing the notion that elevation plays a crucial role in constraining their distribution. The findings of the current research reveal that green pit viper species exhibit a preference for a moderate range of temperatures and elevations. De Silva (2009) previously documented occasional sightings of Green pit vipers in various agricultural settings, including cocoa, coffee, and tea plantations, spanning elevations from 153 to 1,000 m. However, our observations have detected the occurrence of Green pit vipers at elevations as low as 60 m. In summary, the results of this study revealed the geographic and climate conditions suitable for the habitation of Green pit vipers in the current distribution range.

In our study, Green pit viper occupied a variety of habitats, including riparian, forest, and open habitats. Moreover, Green pit vipers were more frequently observed in riparian habitats compared to forests and open areas. This suggests that Green pit vipers have a preference for dense vegetation and streams, as these habitats serve as their preferred living space. Riparian habitats are located at the edge of a mixed environmental zone that offers thermal heterogeneity. These areas are constantly shaded and receive filtered sunlight. Snakes, including the Green pit vipers, have the ability to utilize both open, sunny habitats to increase their body temperatures and forested areas to lower their body temperatures through the provision of shaded regions. Green pit vipers select their preferred environmental factors based on the availability and dispersal of resources essential for their survival, such as food and shelter. The rapid expansion and development of the road network in the country, coupled with the ongoing loss of habitat in protected areas, have resulted in a significant increase in the number of animals being killed on roads. Among these road casualties, Green pit vipers have been observed as well, indicating incidents of vehicle collisions when the snakes attempt to cross roads in order to reach their habitats. This suggests that a reduction in road construction is necessary in many of Sri Lanka's protected areas. This study represents one of the first attempts to model the habitat suitability of the Green pit viper in three climatic zones in Sri Lanka. The findings of this research can be utilized to facilitate the conservation and management of the focal species, as well as their natural habitats.

5. Conclusions

Our results showed that "annual precipitation, annual mean temperature, and elevation" were the curial factors that set the distributional limits of this species at a fine spatial scale. However, other climatic factors that were slightly incorporated into our models influence the spatial distribution of species. This species is mainly located in the three climatic zones covering riparian, forest, and open habitats and has restricted habitat requirements. Therefore, to conserve these species, habitats that afford the required physical conditions for their existence should be protected.

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Conflict of interests
The authors declare that they have no competing interests.

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