Tropical Ecology **58**(2): 271–282, 2017 ISSN 0564-3295

www.tropecol.com

Predicting Potential Habitat Suitability for an Endemic Gecko *Calodactylodes aureus* and its Conservation Implications in India

S. M. MAQSOOD JAVED[1*], MITHUN RAJ[2] & SUNIL KUMAR[3]

[1]*H.No. 2-5-26/H, Flat No. 122, 1st Floor, HHH Suites, Pillar No. 202, Upparpalle Rajendranagar, Hyderabad, Ranga Reddy District-500048, Telangana, India*

[2]*Plot No. 28, Sri Sai Nagar Colony, Kanajiguda, Secunderabad, Hyderabad– 500015, Telangana, India*

[3]*1499 Campus Delivery, Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, Colorado, 80523, USA*

Abstract: The Indian Golden Gecko *Calodactylodes aureus* (Beddome 1870) is an endemic reptile species largely confined to the Eastern Ghats, India. To estimate its potential habitat suitability, species distribution modelling (SDM) was carried out based on occurrence data and climatic and topographic datasets. We used Maximum Entropy (MaxEnt) model for predicting potential habitat suitability for *C. aureus*. The MaxEnt model predicted potential suitable habitat for *C. aureus* mainly in the northern and southern parts of Eastern Ghats spread across Odisha, Andhra Pradesh and Tamil Nadu states. Majority of the suitable habitat areas identified by MaxEnt are outside the protected areas and experience high anthropogenic pressure. Slope and mean diurnal range in temperature were the strongest predictors of *C. aureus* habitat suitability in the Eastern Ghats. Our results can be effective tools in exploring new ways of understanding *C. aureus* ecology and biogeography, and for planning and future surveys, and prioritizing conservation activities.

Key words: Biodiversity conservation, habitat suitability modelling, geckos, MaxEnt, maximum entropy model, protected areas.

Handling Editor: William Pitt

Introduction

The Indian Golden Gecko *Calodactylodes aureus* (Beddome 1870) occurs in rupicolous habitats in forested tracts along the seasonal streams and few areas close to human habitation (Fig. 1a, b) (Bauer & Das 2000; Javed *et al.* 2007; Russell & Bauer 1989). It was rediscovered in 1986 after more than 100 years. The Gekkonoidae family are the most primitive living saurians and the genus *Calodactylodes* consists of large, distinctive geckos endemic to rocky habitat in peninsular India and Sri Lanka. The genus *Calodactylodes* can be identified on the basis of derived digital structure, the presence of paraphalanges, bright yellow gular patch (in adult males) and distinctive vocalization. The Golden Gecko is of special interest to herpetologists worldwide as it represents one of the two known species in the genus *Calodactylodes,* which are considered as Gondwanan relics (Bauer & Das 2000). It is unclear how extensive the range of *C. aureus* is, but the few localities known suggest that it is widespread in the southern portion of Eastern Ghats. It is expected to occur wherever appropriate rocky habitats are present. The portion of the Eastern Ghats inhabited by *C. aureus* is relatively xeric and the vegetation is dominated by dry

*Corresponding Author; e-mail: javedbiodiversity@gmail.com

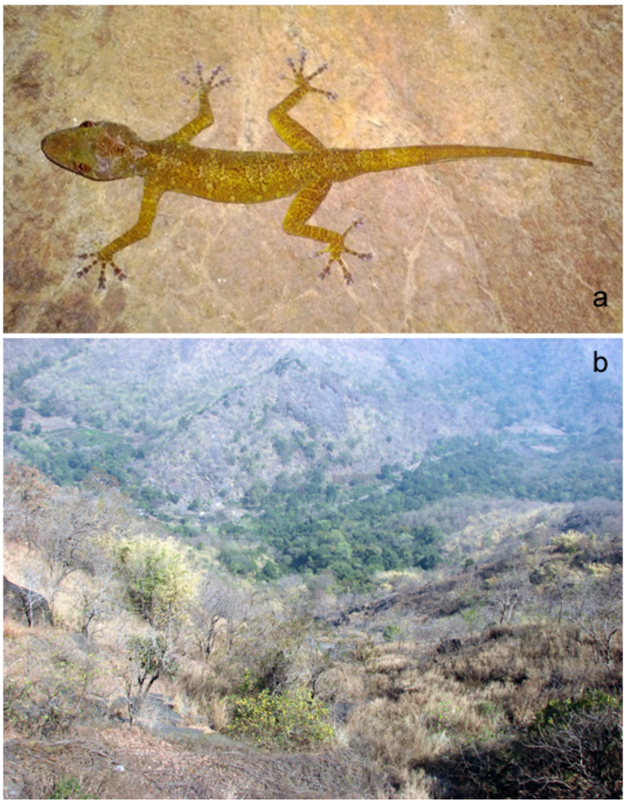

Fig. 1. **(a)** The Indian Golden Gecko (*Calodactylodes aureus*) in its natural habitat; **(b)** Overview of typical habitat of *C. aureus* depicting hilly terrain with valley bearing dry deciduous forest. (Photographed by S. M. Maqsood Javed).

deciduous and thorn scrub (Legris & Meher-Homji 1982). Diet mainly consists of small insects and larval forms.

The present study was conducted using Species Distribution Modelling (SDM) techniques to develop a broader understanding of its potential habitat distribution, biogeography, and the relevance of these techniques in biodiversity conservation practices considering climatic and topographical factors.

Assessing the status, pattern and range distribution is a challenge, especially when a species is cryptic, shy, nocturnal as well as semi-diurnal in nature. However, it is essential to more precisely determine the distribution of a species in the wild, particularly when it is an endemic and threatened by deforestation, habitat fragmentation and anthropogenic exploitations (Kumara *et al.* 2009). The genus *Calodactylodes* (Beddome 1870) is restricted to tropical South Asia and is represented by two species: the Indian Golden Gecko *Calodactylodes aureus* and the Sri Lankan Golden Gecko *Calodactylodes illingworthorum* (Deraniyagala 1953). *Calodactylodes aureus* is distributed along the coastal hills of Andhra Pradesh, southern Odisha and northern Tamil Nadu regions of Eastern Ghats, India (Bauer & Das 2000; Dutta *et al.* 2005; Javed *et al.* 2007; Chakrapani *et al.* 2014).

There have been several reports of discovery (unpublished) and photography of a gecko similar to *C. aureus* from Castle Rock, north Karnataka (Bauer & Das 2000) which suggest either a wider peninsular distribution for *C. aureus* or the occurrence of a new species in the northern Western Ghats. Whereas, Chettri & Bhupathy (2010) mentioned that these reports from northern Western Ghats are erroneous. However, in a very recent development this gecko was recorded for the first time from the state of Karnataka (Srinivasulu *et al.* 2014) which further strengthens the claims of wider distribution than known range within India. *Calodactylodes aureus* is of special interest to herpetologists worldwide due to its unique toe morphology and breeding habits (Javed *et al.* 2007; Sreekar *et al.* 2010). *Calodactylodes aureus* possess a unique pattern of paraphalangeal cartilages and paired structures occurring lateral to the joints in the digits of the geckos (Russell & Bauer 1989). This gecko generally prefers riparian habitat with boulders and dense vegetation. It also has a very unique breeding plan or behaviour; lays eggs under the roof of the boulders and more than one female lays eggs at same site as a case of egg laying site fidelity. The clutch size varies from five to several eggs with very tough eggshell. Therefore, *C. aureus* is placed in Schedule I (Part II) of the Indian Wildlife Protection Act, 1972, and is listed as “Least Concern” in IUCN Red list. However, key factors like, typical toe morphology, breeding habit, threats to its habitat and restricted known current distribution strongly makes a case of elevating the status of *C. aureus* to an “Endangered” species under IUCN Red list.

Currently, as per confirmed occurrences, *C. aureus* thrives in small pockets restricted to a defined set of ecological conditions in its known distribution range which is under a series of ever increasing anthropogenic threats. Recently, sightings from the vicinity of earlier known locations were published along with brief information on its breeding and habitat selection (Chettri & Bhupathy 2010; Kalaimani & Nath 2012; Sreekar *et al.* 2010). But, there is still lack of comprehensive information on its ecology and potential habitat distribution, which is very crucial

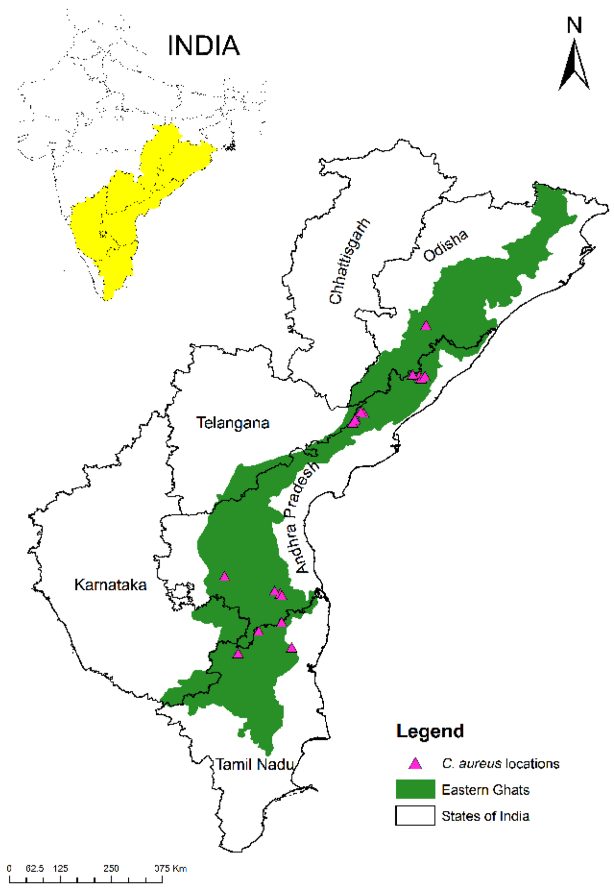

Fig. 2. Study area map showing the Indian Golden Gecko (*Calodactylodes aureus*) occurrence points in the Eastern Ghats.

for sustainable conservation of this species. Thus, identifying potential distribution range of this endemic Gecko species using Species Distribution Models (SDM) becomes important in the tropical region of the Eastern Ghats where vast areas still remain unexplored.

SDMs are being widely used at multiple scales to predict the geographical distribution of habitat suitability or species potential distributions (Franklin 2009; Kumar & Stohlgren 2009; Rushton *et al.* 2004; Scott *et al.* 2002). These models and their resulting predictions are used for conservation planning and land management (Burgman *et al.* 2005; Ferrier *et al.* 2002), and to predict the impacts of climate change on species and ecosystems (Araújo *et al.* 2006; Iverson & Prasad 1998; Khanum *et al.* 2013). Furthermore, predictions from SDMs have been used to address basic research questions in ecology and biogeography regarding environmental versus biotic control on species distribution and abundance, niche differentiation and patterns of species richness even with low occurrence data (Jetz & Rahbek 2002; Pearson *et al.* 2007; Raxworthy *et al.* 2003; Sreekumar *et al.* 2016).

This study was conducted after collecting occurrence points and establishing a model based on SDM. Our study is an attempt to produce potential habitat distribution maps of *C. aureus* using SDM for planning future surveys using systematic scientific sampling and habitat evaluation. These maps fill persisting gaps and provide valuable biogeographical information that may help target surveys to accelerate the discovery of unknown populations of *C. aureus* in peninsular India (Raxworthy *et al.* 2003). It is also important to note that these maps identify regions that have similar environmental conditions where the species currently maintains populations and should not be interpreted as the actual limits of the range of the species (Pearson *et al.* 2007).

Materials and methods

We used SDM methods that have been successfully executed using a small sample size in the context of endangered and threatened species (Kumar & Stohlgren 2009; Pearson *et al.* 2007). It is well known that the distribution data on cryptic, nocturnal, threatened and endangered species are often sparse and clustered (Ferrier *et al.* 2002). But, the aforesaid methodology paves the way to overcome difficulties in modeling species' suitable habitat using smaller number of samples.

We collected 22 occurrence points for *C. aureus* species from our surveys using Garmin eTrex GPS during an earlier regional herpetofauna inventory, opportunistic visits and published data from the Eastern Ghats, peninsular India (Fig. 2). During the survey, a conventional distance sampling and a line transect method was adopted. Opportunistic searches were carried out during day and night and included slow walking among the rock boulders along all the habitats over a vast area. Both vertical and horizontal crevices in rock boulders were searched intensely for recording the presence of golden geckos. Every rock boulder was searched for the presence of geckos and number of geckos observed was noted down. We state clearly that no specific permissions were required for these locations/activities because the species is also sighted in and around the public places. It is currently not listed as an Endangered or Threatened species. No specimen was collected.

Study area

The Eastern Ghats are represented by several broken and isolated hills of the Deccan Plateau. These hills (11°03′–22°03′ N and 77°02′–87°02′ E) extend over a stretch of 1,750 km starting from south of the Chota-Nagpur Plateau in Odisha to south western peninsula in Tamil Nadu via passing through the state of Andhra Pradesh (Mani 1995) (Fig. 2). The total area of the Eastern Ghats comprises of about 232,290 km^2. According to Rodgers *et al.* (2002), the Eastern Ghats were included under 6C Eastern Highlands of the Deccan Plateau, which is one of the biologically richest 'Biogeographic Zones' in India. The northern and southern sections of the Eastern Ghats are separated by the delta of the River Godavari, which is approximately 130 km in width. Other important breaks are formed by the drainages of the rivers Mahanadi and Krishna. The Biligirirangan Hills at 1,750 m is the highest range in the Eastern Ghats. Moisture regimes show a general gradient, from a relatively mesic northern range, with dry and moist deciduous forests, to a relatively dry southern subzone, with dry deciduous and thorn scrub (Legris & Meher-Homji 1982). Unlike the Western Ghats, studies on the distribution of reptiles in the Eastern Ghats are scanty (Bauer & Das 1999). Srinivasulu and Das (2008) recommended detailed analysis of faunal relationships along the Eastern Ghats, including comparative diversity of lineages as an effect of breaks in the continuity of the ranges, humidity, and elevation effects. They also recorded fragmented distribution of species like *C. aureus* that is known from both north and south of the range of Eastern Ghats; reinforcing the argument for more sampling of the fauna.

Data and model building

We used 22 occurrence points for *C. aureus* habitat suitability modeling; two occurrences were dropped during spatial filtering to reduce model complexity and minimize the effects of spatial autocorrelation (Boria *et al.* 2014). We considered 23 environmental predictor variables representing climate (19 bioclim variables; Hijmans *et al.* 2005), vegetation and topography (elevation, slope, and aspect). All environmental predictor variables were re-sampled to ~1 km × 1 km spatial resolution (Albers Equal Area Conic projection, WGS 84 datum). Twenty environmental variables including bioclimatic and elevation were extracted from the WorldClim database (Hijmans *et al.* 2005) (http://www.worldclim.org/) and a global land cover variable data of 1 km resolution was downloaded from the European Commission web site (http://bioval.jrc.ec.europa.eu/products/glc2000/products.php). Slope and aspect were generated in GIS using elevation data from WorldClim database.

Model development and analysis

It has been shown that the choice of predictor variables has a significant effect on model accuracy (Peterson & Nakazawa 2008). Models developed with predictor variables that have a direct effect on species distribution are considered more accurate, biologically informative and generalizable (Austin *et al.* 2006). Furthermore, SDM results are difficult to interpret when predictor variables are correlated (Kivinen *et al.* 2008); so only less correlated variables (Pearson correlation coefficient $|r| < 0.80$) were used in the MaxEnt model (Dormann *et al.* 2013).

We used Maximum Entropy model "MaxEnt" version 3.3.3k (Phillips *et al.* 2006; http://www.cs.princeton.edu/~schapire/maxent/) as it uses presence-background data and has been shown to perform well for species with small sample sizes (Benito *et al.* 2009; Elith *et al.* 2006; Hernandez *et al.* 2006; Kumar & Stohlgren 2009; Ortega-Huerta & Peterson 2008; Papes & Gaubert 2007; Pearson *et al.* 2007; Wisz *et al.* 2008). Initially 22 variables were considered in the model (Appendix A), but based on training gain; variable contribution and multicollinearity only four variables were finally used - mean diurnal range in temperature (bio2), temperature annual range (bio7), precipitation of driest quarter (bio17) and slope. We used "(n – 1) jackknife" or "leave-one-out" approach suggested by Peterson *et al.* (2011). Pearson *et al.* (2007) used a delete-one jackknife to develop a test assessing the statistical significance of ENMs made with small numbers of occurrence records (Shcheglovitova & Anderson 2013). Initially, default settings in MaxEnt were used viz., the convergence threshold (10^{-5}), the maximum number of iterations (5000) and the logistic output format (Phillips & Dudík 2008). The MaxEnt model was run with different regularization parameter values (1.0, 1.5, and 2.0). The "fade-by-clamping" procedure was used to avoid erroneous predictions outside the environmental range of training data. We ran 20-fold cross-validation for testing the model performance. A bias surface was generated using SDM toolbox (Brown 2014) and used in MaxEnt to account for possible sampling bias in *C.*

aureus occurrence data. Model was trained for the Eastern Ghats extent which includes currently reported *C. aureus* occurrences and areas that have been accessible to the species to disperse and colonize (Soberon & Peterson 2005). This model was then projected to peninsular India including four states (Fig. 2).

Model performance was evaluated using the Area Under the Receiver Operating Characteristic (ROC) Curve (AUC) (Elith *et al.* 2006; Phillips *et al.* 2006) and omission rates at two thresholds (Boria *et al.* 2014; Kumar 2014). AUC is a threshold independent measure of discrimination and varies from 0.5 to 1. An AUC value of 0.5 represents a model with random predictions and values closer to one represent higher discrimination. An AUC value between 0.9–1.0 show excellent model performance; 0.8–0.9 = good; 0.7–0.8 = average; 0.6–0.7 = poor; 0.5–0.6 = insufficient (Thuiller *et al.* 2003). The AUC values should be interpreted with caution as it gives equal weights to commission and omission errors (Lobo *et al.* 2008; Peterson *et al.* 2008). Because of the small sample size we could not calculate Partial AUC ratio as suggested by Peterson *et al.* (2008). Two omission rates (OR) were calculated following Boria *et al.* (2014): OR at 0% training mission or lowest predicted threshold (LPT), and 10 % training omission. Omission rates assess a model's performance ability; lower OR indicates higher performance. Specificity (i.e. percentage of correctly classified absences) was not used because no absence data were available. To evaluate the importance of environmental predictor variables, we used jackknife procedure in MaxEnt. Variables that produced the highest training gains are considered to be the most important predictor variables (Kouam *et al.* 2010). We also examined the response curves that show the relationships between the environmental predictor variables and the probability of species presence.

Initial model was run with default settings in MaxEnt. However, the default settings produced relatively complex model and higher test omission rates. MaxEnt model included only Linear, Quadratic and Hinge features because of smaller sample size. Next, several experiments were conducted with different combinations of environmental variables and regularization multiplier values (ranging from 1–3) and optimal model was selected based on highest test AUC values, and lower omission rates.

For an appropriate model, areas of high probability will cover the majority of presence records and areas with low probability will be characterized by lower possibility of presence records or species absence (Yost *et al.* 2009). MaxEnt model produced a continuous layer of probability of presence for *C. aureus*. We used "minimum training presence logistic threshold of 0.1" and a "10th percentile training presence logistic threshold of 0.3", thresholds to convert it to binary maps showing suitable and unsuitable habitat for *C. aureus*. The predicted probability of presence was reclassified into four arbitrary habitat suitability classes (0.0–0.1, 0.1–0.3, 0.3–0.6 and > 0.6) and a relative habitat suitability map was prepared. Further, area of each class was calculated by tabulating in Geographical Information System (GIS) environment. The SDM predicted area was calculated following data manipulation in GIS environment. The SDM was confined to Eastern Ghats of peninsular India using accepted Eastern Ghats boundary obtained from open source followed by extrapolation using projection layers of peninsular India. DIVA GIS domain version 7.5.0 was used for handling and preparation of maps. A combined map of potential distribution of *C. aureus* was prepared by overlaying currently known occurrences. The extent of overlap between the protected area (PA) network and the spatial distribution of suitable and unsuitable habitat obtained from the current study was analysed by superimposing the respective combined map of four states (Andhra Pradesh, Karnataka, Odisha and Tamil Nadu) in peninsular India.

Results

Distribution range prediction of *C. aureus* was exceptional and coincided well with the known distribution of the species. The model predicted suitable habitat were more extensive and reached beyond the study area boundary (Eastern Ghats) towards the other parts of peninsular India (Figs. 3, 4). The average test AUC value for this model was 0.84 and model correctly predicted the known range of the species (Fig. 5; Table 1). The percent variables contributions and jackknife procedure in MaxEnt showed that slope and mean diurnal range in temperature (bio2) had the greatest effects on *C. aureus* distribution (Table 1 and 3; Fig. 5). The probability of presence of *C. aureus* increased with increaseing slope, and initially increased with an increase in temperature annual range (up to 5 °C) and then decreased slowly (Fig. 6A, B). The probability of presence was

Table 1. MaxEnt model selection summary for Gecko.

Model variables (in order of their decreasing importance)	Number of environmental variables	Regularization Parameter (L)	0% Test Omission Rate	10% Test Omission Rate	Average test AUC
Slope, bio2, bio7, bio17	**4**	**1.0**	**0.10**	**0.10**	**0.84**
Slope, bio2, bio7, bio17	4	1.5	0.15	0.15	0.82
Slope, bio2, bio7, bio17	4	2.0	0.15	0.15	0.81
Slope, bio2, bio17	3	1.0	0.05	0.20	0.83
Slope, bio2, bio17	3	1.5	0.10	0.15	0.82
Slope, bio2, bio17	3	2.0	0.10	0.15	0.82
Slope, bio7, bio2	3	1.0	0.05	0.20	0.85
Slope, bio7, bio2	3	1.5	0.05	0.15	0.83
Slope, bio2	2	1.0	0.10	0.15	0.81
Slope, bio2	2	1.5	0.10	0.15	0.80
Slope, bio2, bio7, bio17, elevation	5	1.5	0.25	0.25	0.81
Slope, bio2, eastness, bio7, bio17, elevation	6	1.5	0.25	0.25	0.79

Note: Bio2 is mean diurnal range in temperature; bio7 is temperature annual range; and bio17 is precipitation of driest quarter; AUC is area under the Receiver Operating Characteristic (ROC) curve. The best model is shown in **bold**.

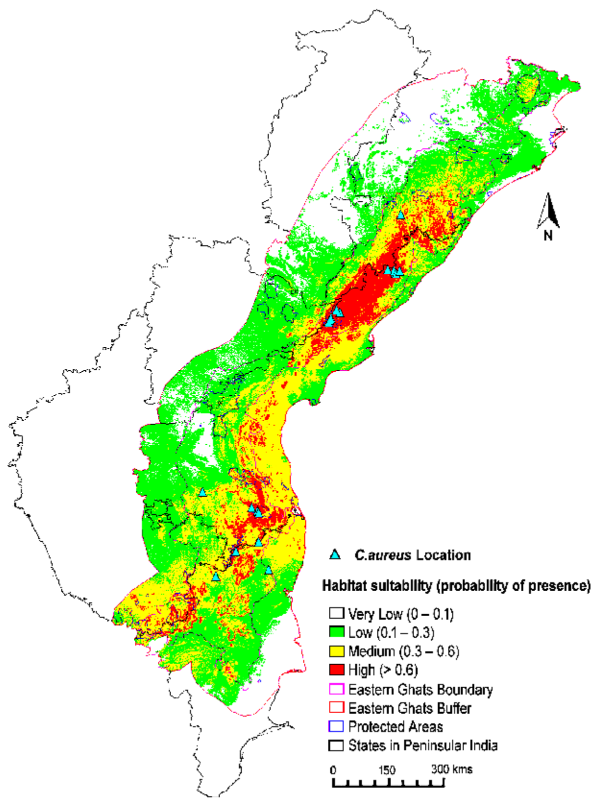

Fig. 3. Predicted habitat suitability (probability of presence) for the Indian Golden Gecko (*C. aureus*) in peninsular India.

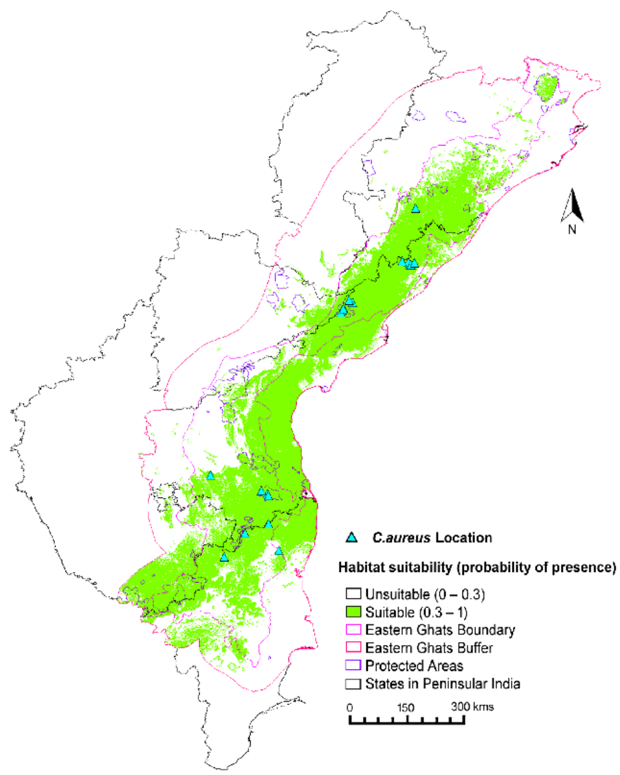

Fig. 4. Predicted suitable and unsuitable areas for the Indian Golden Gecko (*C. aureus*) covered under Protected Areas network in Peninsular India. Binary map was prepared based on 10th percentile training presence logistic threshold of 0.3.

Table 2. Estimates of relative contributions of the environmental variables to the MaxEnt model for distribution modeling of the Indian Golden Gecko (*C. aureus*) in the Eastern Ghats of India. Values shown are averages over 20 runs.

Variable	Percentage contribution	Permutation importance
Slope[¥]	48.3	15.7
Mean diurnal range in temperature (Bio2; °C)*	20.2	23.7
Temperature annual range (Bio7; °C)*	20.1	26.6
Precipitation of driest quarter (Bio17; mm)*	11.4	34.0

Data sources: *Bioclim variables (Bio1–Bio19) were obtained from WorldClim dataset (http://www.worldclim.org/).
¥Surface Radar Topography Mission (SRTM) - http://srtm.csi.cgiar.org/

highest at the intermediate levels of temperature annual range (Fig. 6C), and was highest when precipitation of driest quarter was between 5–25 mm (Fig. 6D).

The best MaxEnt model predicted a total of 418,176 km² area as suitable for *C. aureus* with a threshold of 0.1. The class with the highest suitability (> 0.6) for the *C. aureus* had an area of about 60,956 km² (Fig. 3). However, the binary map of predicted probability with a threshold of 0.3 revealed about an area of 209,975 km² (Fig. 4). A combined binary map of potential distribution range of *C. aureus* and Protected Areas (PAs) network indicated that very small predicted potential area is covered by the existing PAs (Fig. 4; Table 2). Currently, 38 PAs are known from the buffer study area spread across six states of peninsular India including Eastern Ghats, covering an area of 25,810 km² representing 4.66% of the total study area (i.e., 553,704 km²). In total within the 38 PAs only 7 PAs have the potential predicted suitable habitat of 7,687 km², which is about 29.7% of the total PAs area (i.e., 25,810 km²).

Discussion

SDMs were applied to predict potential suitable habitat for *C. aureus* which has restricted distribution only in parts of the Eastern Ghats in

Table 3. Protection status of the area under modeled potential distribution of the Indian Golden Gecko (*C. aureus*) in the states of peninsular India.

States in peninsular India	Number of PAs (Protected Areas) within Eastern Ghats + Buffer Zone	Total area under PAs (km²) within Eastern Ghats + Buffer Zone	Total PAs area covered by MaxEnt (km²) within Eastern Ghats + Buffer Zone
Andhra Pradesh	13	1767	1768
Karnataka	5	1809	1767
Odisha	12	3159	2353
Tamil Nadu	1	32	32
Telangana	3	1855	526
Total	34	8622	6446

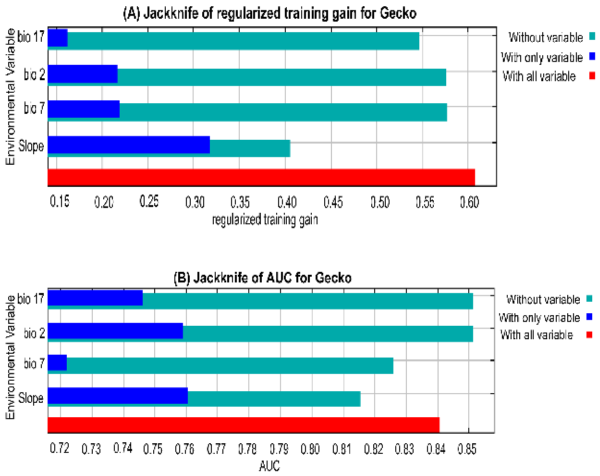

Fig. 5. Environmental variable contributions to (A) regularized training gain, and (B) AUC (Area under the curve) of the final model for the Indian Golden Gecko (*C. aureus*). The x-axis represents a measure of model predictive ability using 'regularized training gain' and 'AUC.' Values shown are average over 20 replicate runs.

peninsular India. The predictive maps for *C. aureus* showed highly suitable habitats in the northern and southern regions of Eastern Ghats surrounding the occurrence points. A few isolated populations are found on the edge of the predicted distribution range or have left with very little potential predicted area as revealed by the model. MaxEnt model projections to peninsular India revealed probable extension of predicted suitable range beyond the boundary of the Eastern Ghats. Of the four predictor variables used to build our model, slope and mean diurnal range in tempe-

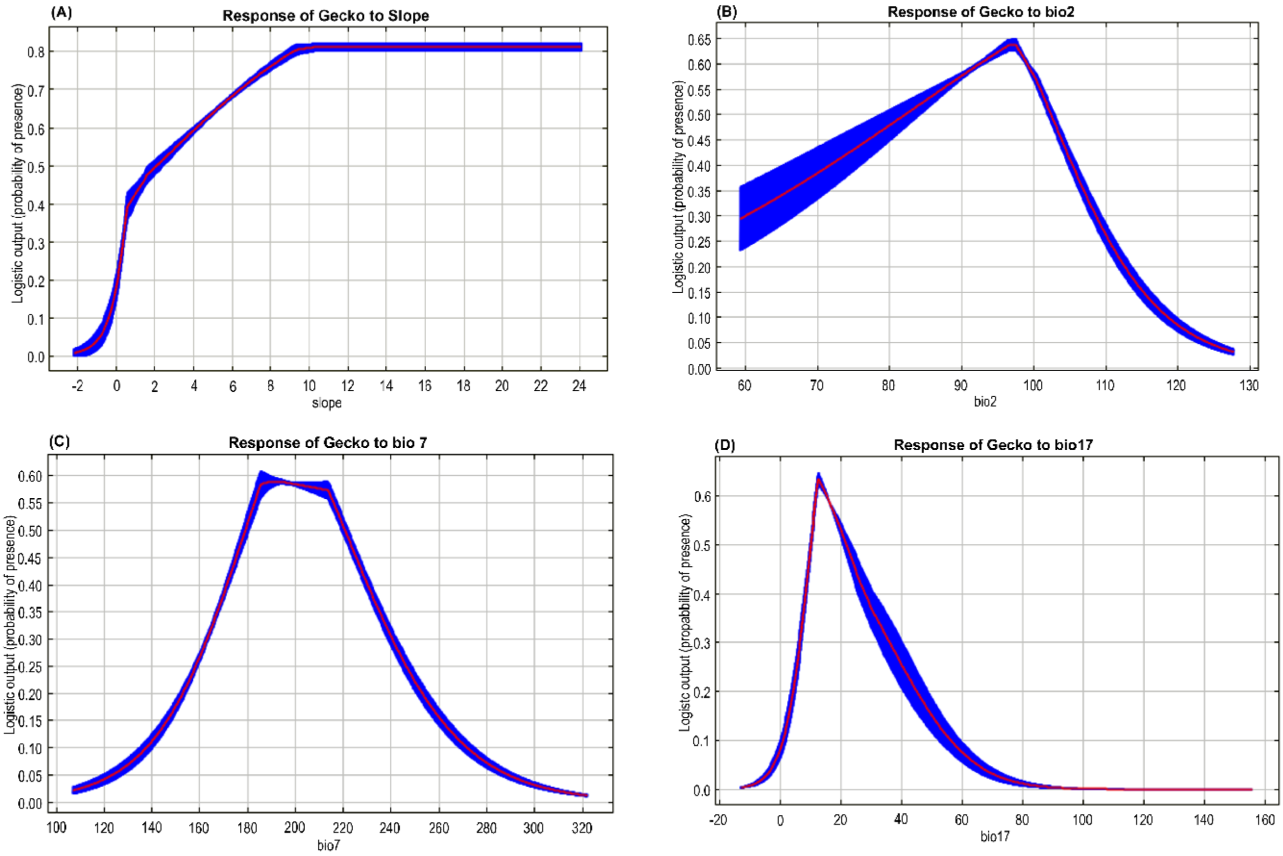

Fig. 6. Relationships between top environmental predictors and the probability of presence of the Indian Golden Gecko (*Calodactylodes aureus*); (A) Slope (%), (B) Mean diurnal range (mm; Bio2 Bioclimatic variable), (C) Temperature annual range (°C; Bio7 Bioclimatic variable), and (D) Precipitation of driest quarter (mm; Bio17 Bioclimatic variable). Each of the following curves represents a different MaxEnt model created using only the corresponding variable. Blue margins are ±1 standard deviation calculated over 20 replicates.

rature (bio2) emerged as the strongest range predictors. The mean diurnal range in temperature was important predictor of suitable habitat because of its potential influence on *C. aureus* physiology and daily activities. A projected map of the potential prediction of the *C. aureus* in peninsular India indicates wider distributional range, hereby confirming previous suggestions about possible extension of distribution of this species by Bauer and Das (2000).

The results of this study indicate that SDMs offer important new insights on the biogeography of *C. aureus* throughout the five states of peninsular India. Importantly, we found that the potential ranges of *C. aureus* are poorly covered by the existing protected areas (PAs). The major PAs that contain the potentially suitable habitat for *C. aureus* are the Eturnagaram, Kawal, Koundinya, Papikonda, Sri Penisula Narasimhaswamy, and Sri Venkateshwara in Andhra Pradesh; Badrama, Debrigarh, Karlapat, Khalasuni, Lakhari Valley, and Sunabedain Odisha; and Bannerghatta, Bhadra, Biligiri Rangaswamy Temple, Cauvery, Dandelli, and Shettihalli in Karnataka. Our study presents a preliminary map of *C. aureus* habitat suitability. We suggest that our results should be used to design science-based surveys for collection of presence-absence data for *C. aureus* covering its predicted range. This presence-absence data should be used in a future study to generate better habitat suitability maps which can be used for recommending establishment of additional PAs in the region to safeguard this endemic gecko along with its associated biodiversity. Creation of additional PAs will be helpful to check the rate of deforestation and other negative anthropogenic factors within the region. This study also showed SDMs to be useful tools for predicting the species distribution at primary level. Apart from being a useful planning tool it can also be customised to play a vital role in assessing the impact of climate change on species distribution as well as an effective tool in monitoring and evaluation of conservation programmes (e.g. Khanum *et al.* 2013).

Conservation implications

The known distribution of the Indian *C. aureus* is restricted to the Eastern Ghats of Andhra Pradesh, Odisha and Tamil Nadu. Initially trade was considered to be a major threat to this endemic gecko (Molur & Walker 1998). However, the current studies show that human interference can be a greater problem because most of the Gecko's habitat is present outside the Pas (Kalaimani & Nath 2012; Kalaimani & Nath 2013; Reddy *et al.* 2013). The developments during the past decade have increased many folds and drastically fragmented the populations and have cornered them to a few pockets along the Eastern Ghats. Each of these populations is exposed to human interferences respective to the socio-cultural and developmental activities specific to the region. In Odisha and north coastal Andhra Pradesh the major threat to the habitat has been extensive mining for bauxite, iron and other minerals. The problem has been compounded due to the socio-cultural aspects of indigenous communities in the region. Frequent shifting cultivation and lack of awareness towards biodiversity conservation has restricted the populations of *C. aureus*. In Andhra Pradesh the major threat to the viable habitat in the Papikonda National Park is due to construction of large multi-purpose dam that has the potential to submerge the entire habitat of the Gecko. This has serious conservation implications as its unique habitual instincts are closely linked to its habitat. In Tamil Nadu, habitat loss due to land use conversion from natural vegetation to cultivation is predominant. Large boulders and crevices are an important part of Gecko's breeding habitat which are being plundered to fuel various developmental activities in the region. Given the current conservation status of the *C. aureus* it may soon become extinct without upgrading its IUCN status. Therefore, suitable steps to preserve its existing potential habitat are strongly recommended.

Acknowledgments

We express our sincere thanks to Dr. George Zug, Dr. Aaron Bauer, Mr. Stephen Mahony and Dr. Girish Jathar for encouragement, guidance, reviewing draft manuscript, sharing literature and providing vital suggestions. We also thank two anonymous reviewers whose comments improved the manuscript. SK acknowledges the Natural Resource Ecology Laboratory at Colorado State University for providing logistical support.

Author Contributions

Conceived and designed the experiments: SMMJ and SK. Performed the experiments: SMMJ, SK and MR. Analyzed the data: SMMJ, SK, MR. Wrote the paper: SMMJ, SK, MR.

References

Araújo, M. B., W. Thuiller & R. G. Pearson. 2006. Climate warming and the decline of amphibians and reptiles in Europe. *Journal of Biogeography* **33**: 1712–1728.

Austin, M. P., L. Belbin, J. A. Meyers, M. D. Doherty & M. Luoto. 2006. Evaluation of statistical models for predicting plant species distributions: role of artificial data and theory. *Ecological Modelling* **199**: 197–216.

Bauer, A. M. & I. Das. 1999. The systematic status of the endemic south Indian gecko *Hemiphyllodactylus aurantiacus* (Beddome 1870). *Journal of South Asian Natural History* **4**: 213–218.

Bauer, A. M. & I. Das. 2000. A review of the gekkonid genus *Calodactylodes* (Reptilia: Squamata) from India and Sri Lanka. *Journal of South Asian Natural History* **5**: 25–35.

Benito, B. M., M. M. Martínez-Ortega, L. M. Muñoz, J. Lorite & J. Penas. 2009. Assessing extinction-risk of endangered plants using species distribution models: a case study of habitat depletion caused by the spread of greenhouses. *Biodiversity and Conservation* **9**: 2509–2520.

Boria, R. A., L. E. Olson, S. M. Goodman & R. P. Anderson. 2014. Spatial filtering to reduce sampling bias can improve the performance of ecological niche models. *Ecological Modelling* **275**: 73–77.

Brown, J. L. 2014. SDMtoolbox: a python-based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses. *Methods in Ecology and Evolution* **5**: 694–700.

Burgman, M., D. B. Lindenmayer & J. Elith. 2005. Managing landscapes for conservation under uncertainty. *Ecology* **86**: 2007–2017.

Chettri, B. & S. Bhupathy. 2010. Three little known reptile species from the Araku Valley, Eastern Ghats with notes on their distribution. *Journal of Threatened Taxa* **2**: 1109–1113.

Chakrapani, I. S., Chanikyudu, B., Rao, R. J. & M. Rajasekhar. 2014. Status survey of the Indian Golden Gecko, *Calodactylodes aureus* (Beddome, 1970) in YSR Kadapa and SPSR Nellore Districts of Andhra Pradesh, India. *World Journal of Zoology* **9**: 21–27.

Deraniyagala, P. E. P. 1953. A new *Calodactylode*s gecko from Ceylon. *Journal of Royal Asiatic Society (Ceylon)* **3**: 27–28.

Dormann, C. F., J. Elith, S. Bacher, C. Buchmann, G. Carl, G. Carré, J. R. G. Marquéz, B. Gruber, B. Lafourcade, P. J. Leitão, *et al.* 2013. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography* **36**: 27–46.

Dutta, S. K., B. Mohanty & P. P. Mohapatra. 2005. Niyamgiri unravelled. *Sanctuary Asia* **25**: 56–57, 59.

Elith, J., C. H. Graham, R. P. Anderson, M. Dudík, S. Ferrier, A. Guisan, *et al*. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* **29**: 129–151.

Ferrier, S., G. Watson, J. Pearce & M. Drielsma. 2002. Extended statistical approaches to modelling spatial pattern in biodiversity in northeast New South Wales. I. Species-level modelling. *Biodiversity and Conservation* **11**: 2275–2307.

Franklin, J. 2009. Mapping species distributions. pp. 338.: *Spatial Inference and Prediction*. Cambridge University Press, Cambridge.

Hernandez, P. A., C. H. Graham, L. L. Master & D. L. Albert. 2006. The effect of sample size and species characteristics on performance of different species distribution modeling methods. *Ecography* **29**: 773–785.

Hijmans, R. J., S. E. Cameron, J. L. Parra, P. G. Jones & A. Jarvis. 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* **25**: 1965–1978.

Iverson, L. R. & A. M. Prasad. 1998. Predicting abundance of 80 tree species following climate change in the eastern United States. *Ecological Monograph* **68**: 465–485.

Javed, S. M. M., A. Waran & F. Tampal. 2007. On the occurrence of Golden Gecko *Calodactylodes aureus* in Papikonda Hills, Eastern Ghats, India. *Zoo's Print Journal* **22**: 2727–2729.

Jetz, W. & C. Rahbek. 2002. Geographic range size and determinants of avian species richness. *Science* **297**: 1548–1551.

Kalaimani, A. & A. Nath. 2012. A new locality and micro-habitat usage by *Calodactylodes aureus* (Beddome 1870) from Tamil Nadu, Eastern Ghats, Southern India. *Herpetotropicos* **8**: 49–54.

Kalaimani, A. & A. Nath. 2013. The Indian Golden Gecko *Calodactylodes aureus* (Beddome, 1870) in Tamil Nadu, India. *Taprobanica* **5**: 81–84.

Khanum, K., A. S. Mumtaz & S. Kumar. 2013. Predicting impacts of climate change on medicinal Asclepiads of Pakistan using MaxEnt Modeling. *Acta Oecologica* **49**: 23–31.

Kivinen, S., M. Luoto, R. K. Heikkinen & K. Saarinen. 2008. Threat spots and environmental determinants of red-listed plant, butterfly and bird species in boreal agricultural environments. *Biodiversity and Conservation* **17**: 3289–3305.

Kouam, M. K., P. M. Masuoka, V. Kantzoura & G. Theodoropoulos. 2010. Geographic distribution modeling and spatial cluster analysis for equine piroplasms in Greece. *Infection Genetics and Evolution* **10**: 1013–1018.

Kumara, H. N., M. Irfan-Ullah & S. Kumar. 2009. Mapping potential distribution of Slender Loris subspecies in peninsular India. *Endangered Species Research* **7:** 29–38.

Kumar, S., L. G. Neven & Y. L. Wee. 2014. Evaluating correlative and mechanistic niche models for assessing the risk of pest establishment. *Ecosphere* **5**: 1–23.

Kumar, S. & T. J. Stohlgren. 2009. MaxEnt modeling for predicting suitable habitat for threatened and endangered tree *Canacomyrica monticola* in New Caledonia. *Journal of Ecology and Natural Environment* **1**: 94–98.

Legris, P. & V. M. Meher-Homji. 1982. The Eastern Ghats: vegetation and bioclimatic aspects. pp. 1–17. *In: Proceedings of the National Seminar on Research, Development, and the Environment of the Eastern Ghats*. Andhra University Press and Publications, Waltair, India.

Lobo, J. M. Jiménez-Valverde, A. & R. Real. 2008. AUC: a misleading measure of the performance of predictive distribution models. *Global Ecology and Biogeography* **17:** 145–151.

Mani, M. S. 1995. *Biogeography in India*. Surya Publications, Dehradun, India.

Molur, S. & S. Walker. 1998. *Report of the Workshop "Conservation Assessment and Management Plan for Reptiles of India"*. Zoo Outreach Organization and Conservation Breeding Specialist Group, Coimbatore, India.

Papes, M. & P. Gaubert. 2007. Modelling ecological niches from low numbers of occurrences: assessment of the conservation status of poorly known viverrids (Mammalia, Carnivora) across two continents. *Diversity and Distributions* **13**: 890–902.

Pearson, R. G., C. J. Raxworthy, M. Nakamura, & A. T. Peterson. 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. *Journal of Biogeography* **34**: 102–117.

Peterson, A. T. & Y. Nakazawa. 2008. Environmental data sets matter in ecological niche modelling: an example with *Solenopsis invicta* and *Solenopsis richteri*. *Global Ecology and Biogeography* **17**: 135–144.

Peterson, A. T., M. Papes & J. Soberon. 2008. Rethinking receiver operating characteristic analysis applications in ecological niche modeling. *Ecological Modelling* **213**: 63–72.

Peterson, A. T., J. Soberón, R. G. Pearson, R. P. Anderson, E. Martínez-Meyer, M. Nakamura & M. B. Araújo. 2011. *Ecological Niches and Geographic Distributions*. Monographs in Population Biology, Princeton University Press, Princeton, NJ.

Phillips, S. J., R. P. Anderson & R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling* **190**: 231–259.

Phillips, S. J. & M. Dudík. 2008. Modeling of species distributions with MaxEnt: new extensions and a comprehensive evaluation. *Ecography* **31**: 161–175.

Ortega-Huerta, M. A. & A. T. Peterson. 2008. Modelling ecological niches andpredicting geographic distributions: a test of six presence-only methods. *Revista Mexicana de Biodiversidad* **79**: 205–216.

Raxworthy, C. J., E. Martínez-Meyer, N. Horning, R. A. Nussbaum, G. E. Schneider, M. A. Ortega-Huerta & A. T. Peterson. 2003. Predicting distributions of known and unknown reptile species in Madagascar. *Nature* **426**: 837–841.

Reddy, Y. A., P. Indira, T. Pullaiah, B. Sadasivaiah, K. R. K. Swamy & S. S. Rani. 2013. Range extension of Indian Golden Gecko *Calodactylodes aureus* in Andhra Pradesh, India. *Reptile Rap* **15**: 41–42.

Rodgers, W. A., H. S. Panwar & V. B. Mathur. 2002. *Wildlife Protected Areas in India: A Review* (Executive Summary). Wildlife Institute of India, Dehradun, India.

Rushton, S. P., S. J. Ormerod & G. Kerby. 2004. New paradigms for modelling species distributions? *Journal of Applied Ecology* **41**: 193–200.

Russell, A. P. & A. M. Bauer. 1989. The morphology of the digits of the golden gecko, *Calodactylodes aureus* and its implications for the occupation of rupicolous habitats. *Amphibia-Reptilia* **10**: 125–140.

Shcheglovitova, M. & R. P. Anderson. 2013. Estimating optimal complexity for ecological niche models: A jackknife approach for species with small sample sizes. *Ecological Modelling* **269**: 9–17.

Scott, J. M., P. J. Heglund, F. Samson, J. Haufler, M. Morrison, M. Raphael & B. Wall. 2002. *Predicting Species Occurrences: Issues of Accuracy and Scale*. Island Press, Washington, D.C., USA.

Soberon, J. & A. T. Peterson. 2005. Interpretation of models of fundamental ecological niches and species' distributional areas. *Biodiversity Informatics* **2**: 1–10.

Sreekar, R., C. Srinivasulu, M. Seetharamaraju & C. A. Srinivasulu. 2010. Selection of egg attachment sites by the Indian Golden Gecko *Calodactylodes aureus* (Beddome 1870) (Reptilia: Gekkonidae) in Andhra Pradesh, India. *Journal of Threatened Taxa* **2**: 1268–1272.

Sreekumar, V. B, Sakthivel R. S. & K. A. Sreejith. 2016. Distribution mapping and conservation of *Rhopaloblaste augusta* (Kurz) H. E. Moore in Nicobar Islands, India. *Tropical Ecology* **57**: 271–277.

Srinivasulu, C. & I. Das. 2008. The herpetofauna of Nallamala Hills, Eastern Ghats, India: an annotated checklist, with remarks on nomenclature, taxonomy, habitat use, adaptive types and biogeography. *Asiatic Herpetological Research* **11**: 110–131.

Srinivasulu, B., C. Srinivasulu, T. A. Shah, G. Devender & H. Kaur. 2014. First confirmed record of *Calodactylodes aureus* (Reptilia) from Karnataka, India. *Taprobanica* **6**: 53–54.

Thuiller, W., M. B. Araújo & S. Lavorel. 2003. Generalized models vs. classification tree analysis: predicting spatial distributions of plant species at different scales. *Journal of Vegetation Science* **14**: 669–680.

Wisz, M. S., R. J. Hijmans, J. Li, A.T. Peterson, C.H. Graham & A. Guisan. 2008. Effects of sample size on the performance of species distribution models. NCEAS Predicting Species Distributions Working Group. *Diversity and Distribution* **14**: 763–773.

Yost, A. C., S. L. Petersen, M. Gregg & R. Miller. 2008. Predictive modeling and mapping sage grouse (*Centrocercus urophasianus*) nesting habitat using maximum entropy and a long-term dataset from southern Oregon. *Ecological Informatics* **3**: 375–386.

(Received on 22.05.2015 and accepted after revisions, on 29.02.2016)

Supporting Information

Additional Supporting information may be found in the online version of this article.

Table S1. Environmental variables used for distribution modeling of the Indian Golden Gecko (*Calodactylodes aureus*) in the Eastern Ghats of India. Sources of Data: BIO1–BIO19 were obtained from WorldClim dataset (Hijmans et al. 2005) at (www.worldclim.org). Topographic data were obtained from Surface Radar Topography Mission (SRTM; http://srtm.csi.cgiar.org/). The land use land cover data layer was acquired from European Commission, Joint Research Center, Global Land cover 2000 Products (http://bioval.jrc.ec.europa.eu/products/glc2000/products.php).