Research article

Predicting the potential distribution and conservation needs of Travancore flying squirrel, *Petinomys fuscocapillus,* in Peninsular India and Sri Lanka, using GARP.

Honnavalli Nagaraj Kumara[a] and Ramamoorthy Suganthasakthivel[b*]

[a]Sálim Ali Centre for Ornithology and Natural History, Anaikatty P.O., Coimbatore 641108, Tamil Nadu, India. Email: honnavallik@gmail.com

[b]Kerala Forest Research Institute, Peechi, 680653, Kerala, India. Email: suganthan31@gmail.com

*Author for correspondence

Abstract

*Petinomys fuscocapillus, Jerdon 1847,*Travancore flying squirrel, is known to occur in the forests of India and Sri Lanka. In spite of extensive surveys very few individuals were recorded in the last century. For a better understanding of the possible range of distribution, the present study mapped the potential geographic distribution of the *P. fuscocapillus* from peninsular India and Sri Lanka. We utilized occurrence records of 32 confirmed sightings of *P. fuscocapillus* to model the species´potential geographic distribution by applying an ecological niche modelling (ENM) framework using Genetic Algorithm for Rule set Prediction (GARP). Results indicate that the modeled potential distribution of *P. fuscocapillus* in India is highly restricted to the narrow strip on western slope of the Western Ghats, and in Sri Lanka the predicted distribution is predominant in the lowlands of wet and intermediate zones. Further, about 88% of the modeled potential distribution range lies outside the protected area network and occupies lowland evergreen, semi-evergreen and its degraded forested stages. The narrow environmental niche of both known and modeled potential distribution and highly susceptible forests with less protection raise the need for conservation efforts and future studies.

Keywords Ecological niche modelling, GARP, OpenModeller, P*etinomys fuscocapillus*.

Cite this paper as: Kumara, H. N. and Suganthasakthivel, R. 2011. Predicting the potential distribution of Travancore flying squirrel *Petinomys fuscocapillus* in Peninsular India and Sri Lanka using GARP and its conservation. *Tropical Conservation Science* Vol. 4 (2):172-186. Available online: www.tropicalconservationscience.org

1

Introduction

The genus *Petinomys* is represented by only one species, *Petinomys fuscocapillus* (Jerdon, 1847) from Peninsular India and Sri Lanka, differentiated by more inflated auditory bullae than other species of *Petinomys* [1]. Two subspecies are at least known, viz. *P. f. fuscocapillus* [2] from the Western Ghats of Peninsular India and *P. f. layardi* [3] from Sri Lanka, which is a biodiversity hotspot. The distribution of both the subspecies was known only through a few possible occurrence reports available [4-7], and the distribution pattern is poorly addressed. In Peninsular India, *P. fuscocapillus* is known to occur in Nilgiris [8], High Wavy Mountains [4] and Anamalais [4, 9-11] in Tamil Nadu, and forests of Travancore and the Malabar Coast [6-7] in Kerala, and in western foothills of Western Ghats in Karnataka [12-13]. In Sri Lanka, the small Travancore squirrel is known to occur in the wet and dry zones of the Southern, Central, North Central, Sabaragamuwa and Uva provinces [14-15].

Though there is no proper population estimation or range of occupancy, the Travancore flying squirrel was thought to occur at lower densities in Peninsular India [8, 16] and hence was accorded the status of near threatened category in the IUCN red list [17]. Information on conservation aspects such as distribution, abundance and habitat requirements is important to identify threats, which enables development of a management strategy. The challenge is in assessing the threats of poorly sampled, lesser known, elusive and rare species like the nocturnal arboreal mammals. A biodiversity hotspot in the third world tropics experiences an enormous anthropogenic pressure [18] which has resulted in accelerated forest loss. The biodiversity hotspot of Western Ghats and Sri Lanka holds one of the world's most endangered forests [19]. Koprowski and Nandini [20] pointed out the lack of information on most of the flying squirrels from tropical forests and stressed the need for baseline data on distribution, population and conservation status. The distribution of the small Travancore flying squirrel was thought to be confined to the Western Ghats until it was recorded from the West coast region of peninsular India [7]. In Sri Lanka even that information was not available. This has led to a fuzzy assumed distribution for this species, and the range of occupancy is not available except for the few sight records, which are spread over a larger spatial extent. This warrants the need for an urgent effort to understand the present distribution of *P. fuscocapillus*.

Methods like ground surveys over vast regions are expensive and time-consuming. In the case of *P. fuscocapillus,* the conventional approaches fail to synthesize the whole range of its distributional pattern. Alternatives are the ecological niche models (hereafter "ENM") which reconstruct the potential distribution by combining the known occurrence records (accumulated through field surveys and other means) with the GIS coverages that summarize the background information of a particular region [21]. ENM are the best way to explore the availability of potential habitat, which will help in determining the possible range of distribution and planning further exploration.

Ecological niche can be defined as the range of ecological conditions within which a species is able to maintain its population [22]. A quantifiable character of the niche was developed by MacArthur [23] and is considered as the quantity that limits the geographical distribution of an organism. Ecological niches have been calculated by several approaches [24-28]. We followed the widely established and extensively tested model, "Genetic Algorithm for Rule-set Prediction" (hereafter "GARP"), which includes several inferential tools with an iterative, artificial-intelligence based approach and evolutionary computing environment [29-30]. GARP

1

has been known to produce accurate distribution predictions for numerous rare and threatened species, has predicted the invasive potential of alien and exotic weeds and disease outbreaks in different landscapes and regions for present and future climates, and has even reconstructed past environmental niches etc., [31- 35]. The attempt we make here is to produce a potential distribution map for *P. fuscocapillus* using an ecological niche modelling framework for planning future systematic scientific surveys and sampling.

Methods

We used a total of 32 unique point occurrences, of which 22 were from India and 10 from Sri Lanka [4, 7, 11-13]. Of the 22 points in India, 14 came from our field surveys in the states of Karnataka, Tamil Nadu and Kerala. The other 8 points were taken from the scientific reports and literature describing the occurrence of this species in the Western Ghats region. All the 10 points from Sri Lanka were taken from secondary sources which were computed and previously mapped [15]. The primary occurrence points from India during our surveys were recorded using a handheld Global Positioning System (with an accuracy of 5m) and converted into GIS. The secondary points in India and Sri Lanka were geo-coded with the topographic sheets at the scale of 1:50000 and Google Earth. We used 19 "bioclimatic" variables from the Worldclim dataset [36] and topographic variables *viz*., elevation, slope, aspect, flow direction, flow accumulation and compound topographic index (an index for water retaining capacity) from the Hydro-1K dataset [37]. The circular variable aspect is transformed into two components *viz.,* cosine and sine of the angle in order to represent the east and north respectively [38]. All the raster coverages were resampled to a resolution of 30 arc seconds (approximately one square kilometer pixels). Initially the modelling was applied to the total land mass of Peninsular India and Sri Lanka spanning from 6° N to 21° N. Based on the results, the modelling area was restricted to the Western Ghats and West Coastal India and Sri Lanka (Fig. 1). The modelling was done with three different combinations of environmental variables. The first combination is the full set containing all the 25 variables; the second is a restricted set containing the bioclimatic variables bio1, 2, 4, 5, 12, 13, 14, dem, aspect and slope. The third set is chosen by conducting a principal component analysis and reducing the variables based on the variance explained in first two axes. The total number of variables available by this procedure is 15.

The machine-learning method GARP predicts the model from the presence of data of the species and background information (raster layers describing the landscape) based on non-random associations. GARP uses half the set of presence records for the model development (training) and the other half for testing the quality of the model (testing). Two sets of 1250 points were selected by resampling from the intrinsic test data and randomly from the study region respectively to test the predictive accuracy in the model development [30]. Then the algorithm uses an iterative process of developing and modifying rules through four inferential methods called logistic regression, atomic rules, bioclimatic rules and negated range rules. Like the genetic evolution through crossover and mutation, the rules in the initial conditions were modified and evolved to reach the greater fitness with higher predictive accuracy. The quality of the rule is then tested with the data earlier set apart to maximize the significance and accuracy. The set of best rules thus retained is used to detect the potential distribution from the background information or the environmental variables [29]. The algorithms are run for 1000 iterations or until convergence.

The analyses were done using the desktop implementation Desktop GARP version 1.1.6, publicly available for download (http://www.lifemapper.org/desktopgarp) and the OpenModeller Desktop Version 1.1.0 (http://openmodeller.sourceforge.net).
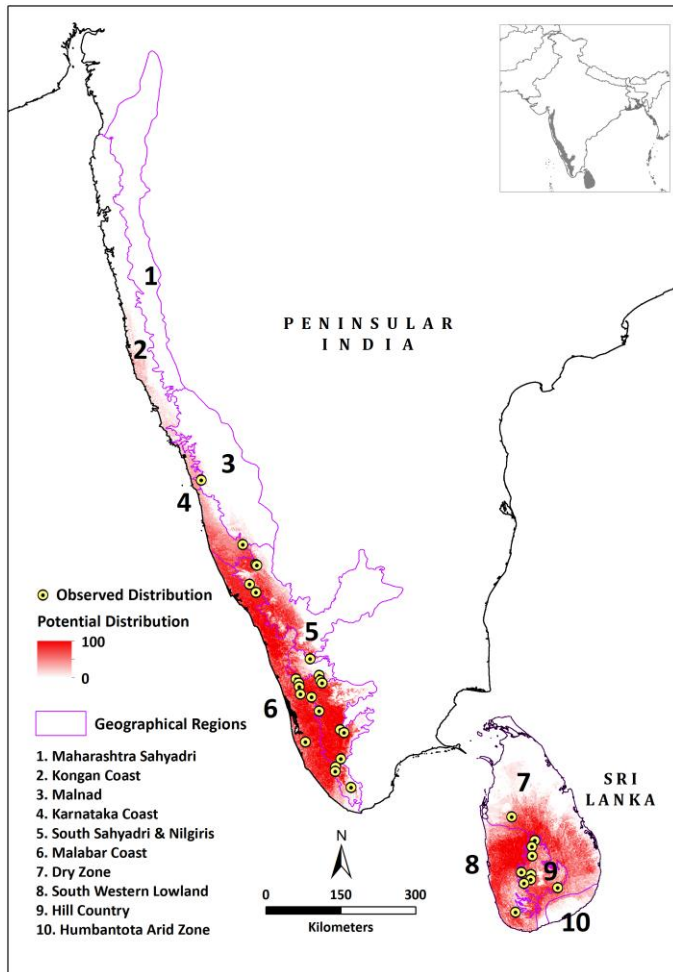

Fig. 1. Points of known occurrence and modeled potential distribution of Travancore flying squirrel *P. fuscocapillus* in peninsular India and Sri Lanka (Inset is the map of Indian Union and Sri Lanka showing the biodiversity hotspot of Western Ghats and Sri Lanka).

The binary predictions of GARP are susceptible to two types of prediction errors, namely errors of commission (inclusion of areas where the species is actually not present) and errors of omission (exclusion of habitable areas where the species is actually present) [39]. The failure to predict independent test points is the real omission error. The over-prediction areas (commission error) may be real or may result from historical effects in the species' geographic distribution such as dispersal constraints [40]. The recent best-practices recommendations [41] were followed to select best models from the multiple replicates. 100 replicates were developed, and external commission and omission error statistics were calculated. A soft omission threshold (<20%) was applied to retain the models and then 10 best models were selected based on the intermediate level of commission (i.e. median 50% of the commission index distribution).

The model quality was tested through the independent testing data (50%) set aside prior to modelling. The proportional area predicted provides an estimation of the occurrence points correctly predicted in random. A binomial probability test was used to test the significance of the departure from random expectations. The points were divided into four equal random sets; each set was used in developing the model and validated with the other half. The final model was run with all the available 32-point locality records.

The modeled output was intersected to provide an assessment of its conformity with the practical understanding of species' habitat preferences with the following available datasets of the study area, *viz.*, the Global Land Cover 2000 [42] and the Anthropogenic biomes [43] dataset - Anthromes version 2 (http://ecotope.org/anthromes/v2). Also the predicted distribution was intersected with the administrative boundaries (http://www.gadm.org), regional geographical units [44-45], climatic data [46-48] and protected area layers (http://www.ProtectedPlanet.net). The land use types of Global Land Cover 2000 were simplified according to the available vegetation type classification of India and Sri Lanka [49-52]. There was no uniform vegetation classification map available for the hotspot of Western Ghats and Sri Lanka, so based on the information available in GIS, we modified the Global Land Cover dataset according to a simplified category of the existing vegetation classification in the two countries. The boundary of the Western Ghats towards the West Coastal India is loosely defined. The Travancore flying squirrel at one instance was reported from a faraway locality from the forested Ghats [7]. So we applied the existing regional geographical classification scheme to be crossed with the modeled output in order to classify and understand the range of occupancy potential of this species across different geographical units. The forests of India and Sri Lanka were inhabited by people from historical times. To understand the human influence on the forests and adjacent ecosystems, we needed a more human-specific view point of the wilderness of the third world tropics like India and Sri Lanka. This is the reason we crossed modeled output with the Anthromes dataset, because it takes into consideration mainly the anthropogenic factor and its role in altering the ecosystem. This is very much needed in understanding the anomalous occurrences far away from the forested areas and the potentiality of the human altered ecosystems in harbouring the rare Travancore flying squirrel. All the GIS procedures were done in ArcGIS.

Results

All the four validation tests of *P. fuscocapillus* model predictions were significantly better than random (binomial tests, all $P \ll 0.05$). The binomial probabilities were significant at all predictive levels, in all cases. The success in predicting independent test data justifies the model accuracy and the construction of the final model with all the available points. There is not much difference in the pattern of the prediction between the three different combinations when applied with the total land mass of Peninsular India and Sri Lanka. However when the number of variables gets reduced, the extent of the predicted area increases. In the final model applied only to the Western Ghats – West Coastal Region of India and Sri Lanka, we therefore used all the 25 variables in the modelling process to obtain a relatively restricted output.

The potential distribution of *P. fuscocapillus* is restricted to the western slope of the Western Ghats Mountain range of India extending to the West coast region and a relatively broader range in Sri Lanka (Figure 1). All the known records of occurrence of the species fall within the

1

predicted potential distribution, hence the prediction is good. The total area of the potential distribution was about 6.4 % of the total land mass modelled in peninsular India and Sri Lanka (Table 1 a, b). The potential distribution in Peninsular India is ~52% (61,833 km^2) and in Sri Lanka it is ~ 48% (56,731 km^2). In Peninsular India, potential distribution falls within the southern and western states bordering Western Ghats, namely Kerala, Tamil Nadu, Karnataka, Goa and Maharashtra. In Sri Lanka, the potential distribution is represented in all the nine provinces. Within India, potential distribution is ~95% of the total administrative land area for the state of Kerala. This is followed by ~20.18% in the state of Karnataka, ~12.62% in Tamil Nadu, ~4.98% in Maharashtra and ~2.51% in Goa (Table 1a). In Sri Lanka, the potential distribution is spread in all the nine provinces; however, the North Central, Uva, Eastern, North western and central provinces have broader predictions ranging from 13.21-17.85% (Table 1b)

Table 1. Protection status of the area under modeled potential distribution of Travancore Flying Squirrel in a) India and b) Sri Lanka.

a

India States	Protected Area (km^2)		Non protected area (km^2)		Total predicted distribution (%)
	Predicted potential distribution	Relative area (%)	Predicted potential distribution	Relative area (%)	
Maharashtra	0	0	3077	5.67	3077 (4.98)
Goa	333	4.42	1222	2.25	1555 (2.51)
Karnataka	2265	30.08	10213	18.81	12,478 (20.18)
Kerala	2720	36.13	34200	62.98	36,920 (59.70)
Tamil Nadu	2211	29.37	5592	10.30	7803 (12.62)
Total	7529		54304		61,833

b

Sri Lanka

Provinces					
Central	652	5.37	4780	10.69	5432 (9.57)
Eastern	1433	11.81	6250	14.58	7953 (14.02)
North Central	2349	19.36	7775	17.38	10,124 (17.85)
Northern	375	3.09	4466	9.98	4842 (8.53)
North Western	472	3.89	7021	15.70	7493 (13.21)
Sabaragamuwa	4782	39.42	0	0	4782 (8.43)
Southern	191	1.58	4031	9.01	4222 (7.44)
Uva	1716	14.15	6485	14.50	8201 (14.46)
Western	30	0.25	3653	8.17	3683 (6.49)
Total	11,999		44,732		56,731

When intersected with the regional geographical unit boundaries, the Malabar Coast and South Sahyadries in the southwestern part of the peninsular India are more suitable where the majority of the potential distribution is seen (Figure 2a). This was followed by the Malnad region of the Western Ghats and Karnataka and Konkan coasts. All the three west coastal regions have over 63% of the total predicted area with potential distribution. In Sri Lanka, the dry zone has ~47% of the total area potentially predicted, followed by the southwestern lowland areas (~22%). The hill country (~11%) and the Humbantota arid zone (~3%) are the lowest predicted

regions (Fig. 2b). The overall elevation range of the *P. fuscocapillus* is restricted to the western precipitous medium and low elevation zone in the Western Ghats of Peninsular India, extending up to the west coast region. In Sri Lanka, the potential distribution is predominant in the lowland regions and the prediction in the central hill country region of Sri Lanka is mainly seen in the outer slopes where the elevation is medium and low (<1000m). In both the countries of India and Sri Lanka, higher elevations above 1400 m are not predicted.
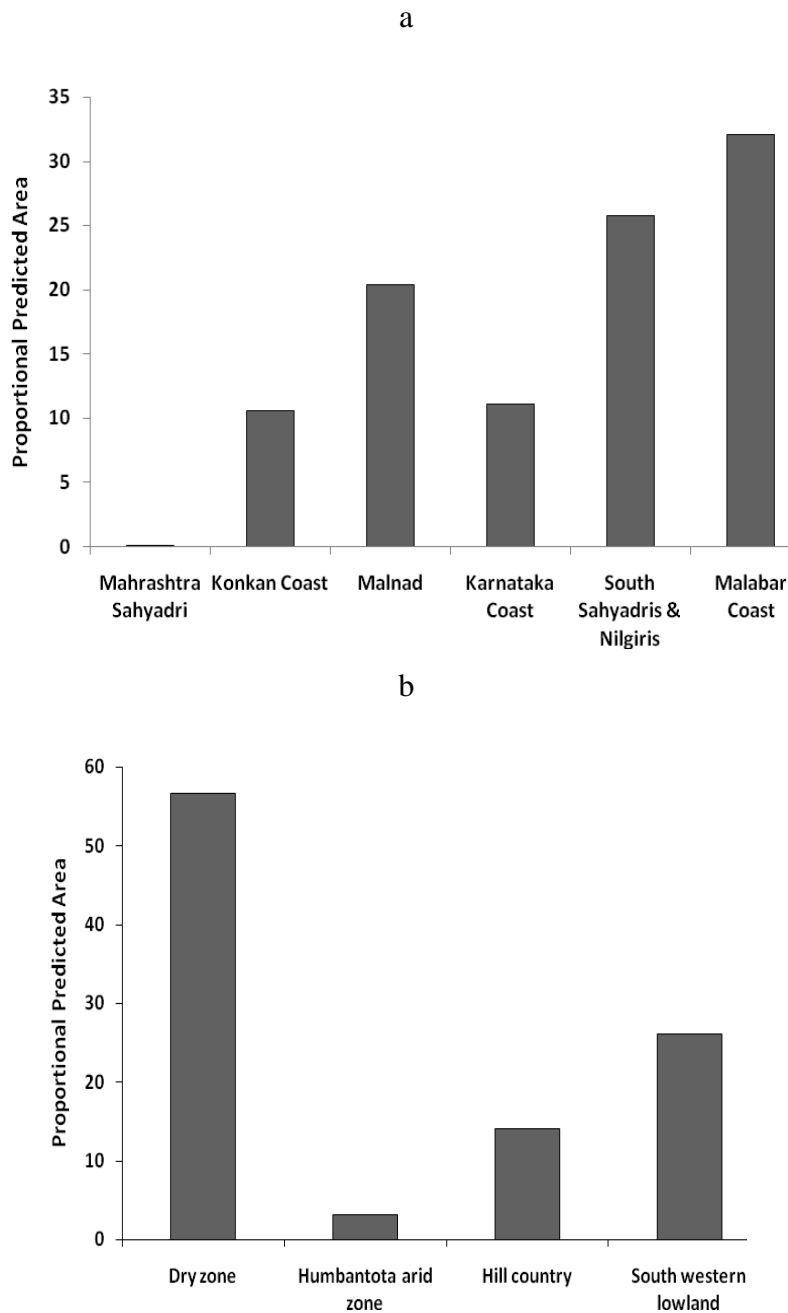
a

b

Fig. 2: Proportional predicted areas in different geographical regions of a) India and b) Sri Lanka.

The potential predictions were reduced to ~ 42% in India and ~50% in Sri Lanka when intersected with the forest cover of GLC 2000. Nearly half of the remaining potential distribution areas are found in the plantations and irrigated cropland land uses. The potential distribution in the forested areas is restricted to tropical lowland evergreen, evergreen and deciduous types in India and Sri Lanka (Figure 3a). Much of the modeled potential distribution (~84%) in the forested areas does not fall under protected area network. In India only 11.40% of the total potential predicted distribution falls under the strict protected area network, such as sanctuaries and national parks. In Sri Lanka the percentage potential distribution in the strict protected area network is 21%.
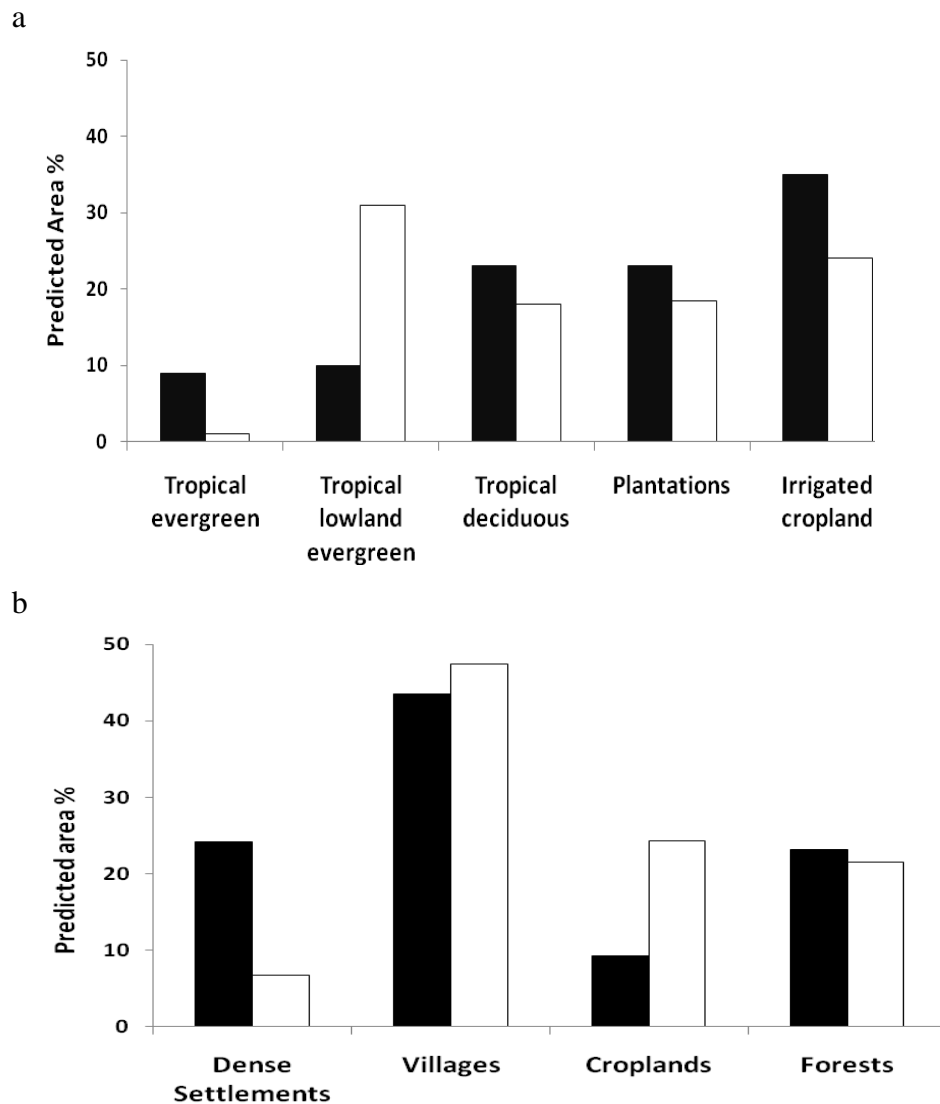

Fig. 3. Comparative graph of predicted potential areas spatially crossed with a) Global land cover facility 2000 and b) Anthromes dataset for peninsular India and Sri Lanka. Black bars represent India and white Sri Lanka. The global land cover classifications are simplified according to Pascal (1988) and Perera (1975).

Additionally, the status of the potential predicted non-forested areas and their implications were explained by intersection with the anthropogenic biomes of the world (Figure 3b). In India over 24% of the potential area is occupied by dense settlements of urban and semi urban areas, whereas it is only ~9% for Sri Lanka. The biome of irrigated, rain-fed and rice-growing villages occupies about 43.5% of potential area in India and 47.4% in Sri Lanka. The plantation equivalent croplands are more in the case of Sri Lanka (24.25%) and less in India (9.2%).

When crossed with the bioclimatic data of the south western region of peninsular India, the majority of the predicted areas fall in the high rainfall (annual average between 2000- 5000 mm) and warm (mean temperature coldest month above 23° C) regions with fewer numbers of dry months (3-5). In Sri Lanka, similarly, the predicted areas were correlated with the high rainfall, less dry months (1-2) and warm regions, excluding the higher elevation central hill country.
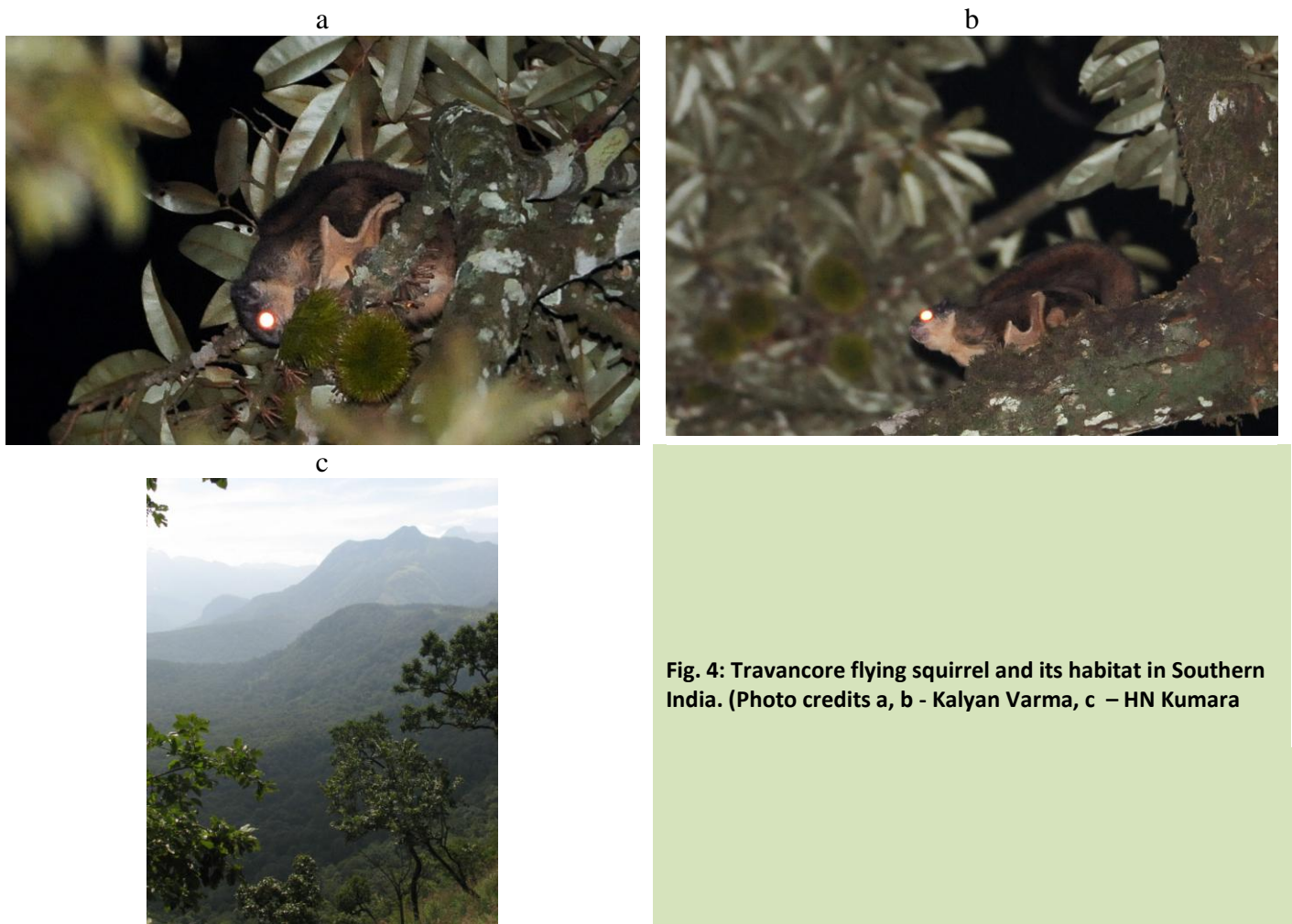
a

b

c

Fig. 4: Travancore flying squirrel and its habitat in Southern India. (Photo credits a, b - Kalyan Varma, c – HN Kumara

Discussion

This is the first ever attempt to model the potential distribution of the nocturnal and very rare *P. fuscocapillus* in southern India and Sri Lanka. Our motivation was to develop a model-based framework for future sampling, and to assess the conservation status of distinct populations to help plan systematic conservation strategies. Though the potential distribution of *P. fuscocapillus* appears to have been relatively large, the available habitat under tree cover was below 50% of the original. Conversely, the secured habitats available through the protected area network form a much smaller percentage. The variability of environmental parameters is very narrow, which shows the *P. fuscocapillus* may be restricted to a narrow environmental niche. This could be the reason that *P. fuscocapillus* occurs in low abundance and is rare in the wild. Hunting may be another reason for the rarity of this species in the wild,; also, at some places in India this species is considered a pest of plantations and is eliminated locally [22].

Many species of flying squirrels require large trees and contiguous canopy for gliding [53], which shows the importance of canopy for the movement of animals. The *P. fuscocapillus* is arboreal and known to adapt and survive in marginal habitats and agriculture plantations relatively distant from forests [7]. But it is necessary to understand the plasticity of adaptation and extent of survival rate in such habitat. The predominant potential distribution falls in the lowland evergreen and semi-evergreen biotopes of high and intermediate rainfall zones in both the countries. In the southwest coast of peninsular India, the Dipterocarp dominant lowland evergreen vegetation formations are the most depleted forest type [51] owing to increasing human density and occupation. Less than one fifth of the potential area of this forest type is under forests, with varying degrees of degradation [54]. In Sri Lanka, the largest contiguous forests are only to be found in the dry zone, and the lowland wet zone only has 9% of its original forest cover remaining [55]. The potential areas of *P. fuscocapillus* are only found in the lowland areas of wet and intermediate zones. The semi-evergreen forests of the dry and intermediate zones are subjected to drastic landuse changes [56], well explained by the extent of potential areas under village and cropland land uses (Anthromes data - Figure 3b). The main emphasis of the anthropogenic biome concept is in understanding the remnant ecosystems amidst the mosaic of human-influenced land use and land cover types [57]. The intersection with this dataset shows that almost half of the potential predicted areas of *P. fuscocapillus* are under severe anthropogenic land use types.

The Western Ghats barrier in the western margin of Peninsular India creates less clear horizontal zonation of the climatic belts [58-60]. The rainfall isohyets in the peninsula tend to orient east to west and the variation is high; the rainfall decreases drastically within 10 km from the crest margin of the hills towards the east, producing a tropical arid climate. Thus, the high rainfall-receiving west coastal region of India has been strongly   predicted. This is the phenomenon that makes the boundary of the Western Ghats towards the west porous. But in Sri Lanka, though the wet zone is restricted to the southwestern part of the island, the isohyets of dry zone were above 1500 mm, which in turn possess tree cover in the form of semi-evergreen forests [47, 61], hence, the extent of the predicted area is more in the inner region of the dry zone , which is an intermediate zone, and along the wet zone in Sri Lanka.

The nearest relative of the *P. fuscocapillus* is *P. hageni,* which is found in the island of Sumatra [1]. Both of these squirrels' respective native ranges are separated for a distance of over 2000 km. In the genus *Petinomys*, only one species, *P. setosus,* has its native range north of the tropic

of cancer. All other species are situated in the tropical wet zones of South East Asia. A comparative analysis of the dipterocarp dominant low elevation evergreen forests [51, 62-63] in peninsular India and Sri Lanka will help in understanding the disjunct distribution of this species. Gunawardene et al., [64] propose that certain faunal elements found in the wet zones of both the countries may be distinct from each other, unlike the dry zone species. Examining the existing and modeled potential distribution of shared species of both the countries, such as *P. fuscocapillus,* will open new vistas in geographical ecology of the Western Ghats and Sri Lanka biodiversity hotspot.

The range of known and potential distribution of *P. fuscocapillus* also harbours a more successful species of flying squirrel, *Petaurista philippensis*. This species is more abundant and also a very generalist species occurring in all the forested types [9, 16, 22, 24]. In comparison, the potential distribution of the *P. fuscocapillus* seems to be narrower than the *P. philippensis.* However, due to lack of studies, how resource and habitat utilization between these sympatric species has affected the distribution pattern of *P. fuscocapillus* is not known*.* Further studies might throw some light on the habitat preferences   of *P. fuscocapillus* which influence the distribution pattern.

Implications for Conservation

One of the main contributions of the present study is the generation of the first map detailing the modelled potential distribution of the *P. fuscocapillus* based on objective criteria, which can be dynamically updated with growing knowledge. Figure 4 shows the Tranvancore flying squirrel and its habitat in Southern India. The potential distribution in the forested areas falls under medium and low elevation evergreen forests. The most depleted forest types such as the low elevation evergreen forest and its various degraded stages in India should be considered for restoration. Likewise, forest plantations in the medium and low elevation zones of both the countries should be managed scientifically to maintain the canopy continuity forever. In human dominated landscapes at the west coast of peninsular India, the remnant forest patches and Sacred Groves should be given priority for conservation and should be included in the existing afforestation programmes. As half of the potential distribution falls under croplands and plantations adjacent to forest plantations and non-protected areas, strict enforcement of the law should be initiated to curb hunting in the forest fringes.

Acknowledgements

References

[1] Corbet, G.B. and Hill, J.E. 1992. *Mammals of the Indomalayan Region*. Oxford Univresity Press: New York.

[2] Jerdon, T.C. 1874. *A Hand book of the Mammals of India*. Reprint, 1984, Mittal Publications: Delhi.

[3] Kelaart, E.F. 1850. Description of new species and varieties of mammals found in Ceylon. *Journal of Ceylon Branch of Royal Asiatic Society* 2: 208-215.

[4] Hutton, A.F. 1949. Notes on the snakes and mammals of the High Wavy Mountains, Madurai district, South India, Part II-Mammals. *Journal of the Bombay Natural History Society* 48: 681-894.

[5] Phillips, W.M.A. 1935. *Manual of the mammals of Ceylon*. Colombo Museum.

[6] Wroughton, R.C. 1919.Summary of the results from the Indian Mammal Survey of the BNHS. *Journal of the Bombay Natural History Society* 26: 338-379.

[7] Kurup, G.U. 1989. Rediscovery of the small Travancore flying squirrel. *Oryx* 23: 2-3.

[8] Prater, S.H. 1971. *The Book of Indian Animals*. India: 4th Impression. Bombay Natural History Society: Bombay.

[9] Ashraf, N.V.K., Kumar, A. and Johnsingh, A.J.T. 1993. On the relative abundance of two sympatric squirrels of Western Ghats, India. *Journal of the Bombay Natural History Society* 90: 158-162.

[10] Sridhar, H., Raman, T.R.S. and Mudappa, D. 2008. Mammal persistence and abundance in tropical rainforest remnants in the southern Western Ghats, India. *Current Science* 94: 748-757.

[11] Umapathy, G. and Kumar, A. 2000. The occurrence of arboreal mammals in rainforest fragments in the Anamalai Hills, South India. *Biological Conservation* 92: 311-319.

[12] Kumara, H.N. and Singh, M. 2005. New site record of small Travancore flying squirrel (*Petinomys fuscocapillus fuscocapillus*) from Karnataka. *Journal of the Bombay Natural History Society* 102: 97-98.

[13] Kumara, H.N. and Singh, M. 2006. Distribution and relative abundance of giant squirrels and flying squirrels in Karnataka, India. *Mammalia* 70: 40-47.

[14] Bambaradeniya, C.N.B. 2006. *Fauna of Sri Lanka: Status of taxonomy, research and conservation*. The World Conservation Union and Government of Sri Lanka: Colombo.

[15] Molur, S., Srinivasulu, C., Srinivasulu, B., Walker, S., Nameer, P.O. and Ravikumar, L. 2005. *Status of South Asian Non-volant Small Mammals: Conservation Assessment and Management Plan (C.A.M.P.) Workshop Report*. Zoo Outreach Organisation / CBSG-South Asia, Coimbatore: India.

[16] Balakrishnan, M. and Xavier, F. 1995. Animal resources of Kerala: Prospects of resource utilization and employment and opportunities. *A compendium of essay on the VII Kerala Science Congress*. Govt. of Kerala: Thiruvananthapuram.

[17] Baillie, J.E.M. Hilton-Taylor, C. and Stuart, S.N. 2004. *IUCN Red List of Threatened Species. A global species assessment*. IUCN: Gland, Switzerland and Cambridge, UK.

[18] Kinnaird, M.F. Sanderson, E.W., O'Brien, T.G., Wibisono., H.T. and Woolmer, G. 2003. Deforestation trends in a tropical landscape and implications for endangered large mammals. *Conservation Biology* 17: 245-257.

[39] Puyravaud, J-P., Davidar, P. and Laurance, W.F. 2010. Cryptic loss of India's native forests. *Science* 329: 32.

[20] Koprowski, J.L. and Nandini, R. 2008. Global hotspots and knowledge gaps for tree and flying squirrels. *Current Science* 95: 851-856.

1

[21] Peterson, A.T. and Kluza, D.A. 2003. New distributional modeling approaches for gap analysis. *Animal Conservation* 6: 47–54.

[22] Grinnell, J. 1917. Field tests of theories concerning distributional control. *American Naturalist* 51: 115–128.

[23] MacArthur, R.H. 1972. *Geographical ecology: Pattern in the distribution of species*. Princeton University Press: Princeton.

[24] Busby, J.R., (1991). BIOCLIM – A bioclimatic analysis and predictive system. In: *Nature Conservation: Cost Effective Biological Surveys and Data Analysis*. Margules C. R. and Austin, M.P, (Eds.), pp.64-68. CSIRO: Canberra.

[25] Carpenter, G., Gillison, A.N. and Winter, J. 1993. DOMAIN: a flexible modeling procedure for mapping potential distributions of plant and animals. *Biodiversity Conservation* 2: 667-680.

[26] Nix, H.A. 1986. A biogeographic analysis of Australian elapid snakes. In: *Atlas of Elapid Snakes of Australia*, Longmore, R. (Ed.) pp. 4-15. Australian Flora and Fauna Series No. 7, Australian Government Publishing Service: Canberra.

[27] Phillips, S.J., Dudik, M. and Schapire, R.E. 2004. A maximum entropy approach to species distribution modeling. In: *Proceedings of the Twenty-first Century International Conference on Machine Learning*. pp.655-662. ACM Press: New York.

[28] Walker, P.A. and Cocks, K.D. 1991. HABITAT: a procedure for modelling a disjoint environmental envelope for a plant or animal species. *Global Ecology and Biogeography Letters* 1: 108-118.

[29] Stockwell, D.R.B. and Noble, I.R. 1992. Induction of sets of rules from animal distribution data: a robust and informative method of data analysis. *Mathematical and Computer Simulation* 33: 385–390.

[30] Stockwell, D.R.B. and Peters, D. 1999. The GARP modeling system: problems and solutions to automated spatial prediction. *International Journal of Geographic Information Science* 13: 143-158.

[31] Peterson, A.T. 2001. Predicting species' geographic distributions based on ecological niche modeling. *Condor* 103: 599-605.

[32] Peterson, A.T., Stewart, A., Mohamed, K.I. and Araujo, M.B. 2008. Shifting Global Invasive Potential of European Plants with Climate Change. *Public Library of Science ONE 3:* 1-7 e2441.doi:10.1371/journal.pone.0002441.

[33] Roura-Pascual, N., Brotons, L., Townsend, A.T. and Thuiller, W. 2009. Consensual predictions of potential distributional areas for invasive species: a case study of Argentine ants in the Iberian Peninsula. *Biological Invasions*, 11: 1017-1031.

[34] Kumara, H.N., Irfan-Ullah, M. and Kumar, S. 2009. Mapping potential distribution of slender loris subspecies in peninsular India. *Endangered Species Research* 7: 29-38.

[35] Williams, R., Fasina, F.O. and Peterson, A.T. 2008. Predictable ecology and geography of avian influenza (H5N1) transmission in Nigeria and West Africa. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 102: 471-479.

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

[37] USGS, 2001. HYDRO1k elevation derivative database, U.S. Geological Survey, http://edcdaac.usgs.gov/gtopo30/hydro/, Washington, D.C.

[38] MacLeod, C.D., Mandleberg, L., Schweder, C., Bannon, S.M. and Pierce, G.J. 2008. A comparison of approaches for modeling the occurrence of marine animals. *Hydrobiologia* 612: 21-32.

1

[39] Fielding, A.H. and Bell, J.F. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environment Conservation* 24: 38-49.

[40] Peterson, A. T., Soberon, J. and Sanchez-Cordero, V. 1999. Conservatism of ecological niches in evolutionary time. *Science* 285: 1265-1267.

[41] Anderson, R.P., Lew, D.A. and Peterson, A.T. 2003. Evaluating predictive models of species' distributions: criteria for selecting optimal models. *Ecological Modelling* 162:211-232.

[42] Bartholomé, E. and Belward, A.S. 2005. GLC 2000: A new approach to global land cover mapping from earth observation data. *International Journal of Remote Sensing* 26: 1959-1977.

[43] Ellis, E.C., Goldewijik, K.K., Siebert, S., Lightman, D. and Ramankutty, N. (2010). Anthropogenic transformation of the biomes, 1700-2000. *Global Ecology and Biogeography* 19: 1-18.

[44] DeSilva, S.F. 1959. *A regional geography of Ceylon*. Colombo Apothecaries: Colombo.

[45] Singh, R.L. 1977. *India: A regional geography*. National Geographical Society of India: Varanasi.

[46] Legris, P. and Viart, M. 1960. *Map of Bioclimates of India and Ceylon*. French Institute of Pondichery: Pondichery.

[47] Muller-Dombois, D. 1968. Ecogeographic analysis of a climate map of Ceylon with particular reference to vegetation. *The Ceylon Forester* 8: 39-58.

[48] Renard, Q., Muthusankar, G. and Pellisier, R., (2009). *Data paper - High resolution topographic and bioclimatic data for the southern Western Ghats of India*. Pondy Papers in Ecology no.8, French Institute of Pondicherry: Pondicherry.

[49] Gaussen, H., Legris, P., Viart, M. and Labroue, L. 1964. *International map of the vegetation: Ceylon*. French Institute of Pondichery: Pondichery.

[50] Greller, A.M. and Balasubramaniam, S. 1980. A preliminary floristic climatic classification of the forests of Sri Lanka. *The Sri Lanka Forester* 14: 163-169.

[51] Pascal, J.P. 1988. *Wet evergreen forests of the Western Ghats of India, ecology, structure, floristic composition and succession*. French Institute of Pondichery: Pondichery.

[52] Perera, N.P. 1975. A physiognomic vegetation map of Sri Lanka (Ceylon). *Journal of Biogeography* 2: 185-203.

[53] Bendel, P.R. and Gates, J.E. 1987. Home range and microhabitat partitioning of the Southern flying squirrel. *Journal of Mammalogy* 68: 243-255.

[54] Meher-Homji, V.M. 1996. Endangered vegetation types of peninsular India. *The Botanica*, 46: 18-24.

[55] Erdelen, W. 1988. Forest ecosystems and nature conservation in Sri Lanka. *Biological Conservation* 43: 115-135.

[56] Dargie, T.C.D. and Epitawatta, D.S. 1988.Environment, succession and land-use potential in the semi-evergreen forests of southern Sri Lanka. *Journal of Biogeography* 15: 209-220.

[57] Ellis, E.C. and Ramankutty, N. 2008. Putting people in the map: anthropogenic biomes of the world. *Frontiers in Ecology and Environment* 6: 439-447.

[58] Legris, P. and Blasco, F. 1969. *Variabilite des facteurs du climat: cas des montagnes du sud de L'Inde et de Ceylan*. Travaux de la Section Scientifique et Technique, Fascicule 1, Instutut Francais de Pondichery: Pondichery.

[59] Meher-Homji, V.M. 2001. *Bioclimatology and Plant Geography of Peninsular India*. Scientific Publishers: Jodhpur, India.

[60] Pascal, J.P. 1982. *Bioclimate maps of the Western Ghats*. French Institute of Pondichery: Pondichery.

[61] Dittus, W.P.J. 1977. The ecology of a semi-evergreen forest community in Sri Lanka. *Biotropica* 9: 268-286.

[62] Ashton. P.S. 1988. Dipterocarp biology as a window to the understanding of tropical forest structure. *Annual Review of Ecology and Systematics* 19: 347-370.

[63] Ashton, P.S. and Gunatilleke, C.V.S. 1987. New Light on the plant geography of Ceylon. *Journal of Biogeography* 14: 249-285.

[64] Gunawardene, N.R., Daniels, A.E.D., Gunatilleke, I.A.U.N., Gunatilleke CVS, Karunakaran, P.V., et al., 2007. A brief overview of the Western Ghats- Sri Lanka biodiversity hotspot. *Current Science* 93: 1567-1572.