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Ecological niche modeling of the medicinally important genus *Spilanthes* (Asteraceae) in Peninsular India

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ABSTRACT

The species of *Spilanthes* are annual herbs of the family *Asteraceae*. Amongst six species recorded so far, two species *S. calva* and *S. paniculata* are native to India while *S. ciliata, S. radicans* and *S. uliginosa are immigrant species.S. oleracea* is an introduced species from Brazil. In this study, the utility of niche modeling to identity the ecological niche for this important genus was explored using two modeling softwares- DIVA-GIS and MaxEnt. One hundred and ninetynon-overlapping occurrence points from primary and secondary data were used for developing models. The model predicted the current distribution of *Spilanthes* species. All models developed had statistically significant AUC values. The niche overlap analysis of *Spilanthes* species exhibited a high degree of niche overlap between the native and immigrant species. The predicted potential distribution of this species using MaxEnt is useful in planning effective conservation measures as well as its sustainable utilization foritsmedicinal values. The details of the study are discussed herein.

Key words : *Spilanthes,* DIVA-GIS, MaxEnt, Niche overlap, Conservation.

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INTRODUCTION

In recent years, ecological niche models (ENMs) have been used in predicting the ecological niche of a species. The above models were developed based on the concept of ecological niche theory, proposed by Grinnell (1917) and Hutchinson (1957) refers to a set of conditions within which a species is able to maintain its population. The ENM's used the current distribution of a species in conjunction with different bioclimatic layers in order to predict its potential suitable habitats. The ENMs employ various mathematical techniques to relate the occurrence of species to environmental data (Guisan and Zimmerman, 2000). The niche prediction is done through algorithms or principles which integrated the species occurrence information and environmental data to determine the suitable location for the establishment of the plant species. Of late, ENMs have been widely used in a number of applications, ranging from the conservation and management of species (Meyer et al. 2006; Papes, 2006; Craig, 2011), predicting the impact of global climate change (Peterson, 2004; Foden et al. 2007), predicting the spread of invasive species (Peterson and Vieglais, 2003; Peterson, 2003; Ganeshaiah, 2003), understanding of the evolution and diversification of taxa (Graham, 2004; Knowels, 2009) and in identifying hot-spots of genetic diversity (Shivaprakash et al. 2013). A handful of studies have shown ENM's ability to detect the distinct ecological niche of a species even outside its actual distribution (Peterson and Vieglais. 2001, Pearson et al. 2007).

India is a mega biodiverse country (Sandhya et al. 2006) and one of the four biodiversity hot-spots. The sub-continent is ahome to 15,000 plants species including *Spilanthes*Jacq. of family *Asteraceae*,which is found throughout the old and new world tropics (Jansen 1981). *Spilanthes* commonly known as 'Toothache' plant is mainly used in traditional medicines (Haw and Keng, 2003; Tiwari et al., 2011). In traditional medicine, this is used for its immunomodulator, antiscorbutic and anesthetic properties and as digestive tonics (Tiwari et al. 2011; Sahu et al. 2011; Leng et al. 2011). While flowers and leaves are used in the treatment of various diseases and disorders, certain parts of this plant have been reported for antimalarial and antibacterial activities (Haw and Keng, 2003; Yadav and Singh, 2010). Out of six species of Spilanthesreported from peninsular India, *S. calva, S. ciliata, S. oleracea, S. paniculata, S. radicans and S. uliginosa,S. calva and S. paniculata* are native to India, while *S. ciliata, S. radicans* and *S. uliginosa* are immigrant species; *S. oleracea* is introduced species from Brazil. Previous studies on characterization of the species based morphological and genetic data set, clearly demarcated the existence of the six species mentioned above (Lavanya et al 2014a, 2014b in press). Another study on the chemical profiling of the aforementioned species, also supported the unique chemotaxonomic significance of these species (Lavanya et al. 2014,unpublished).

The medicinal plants in India face multifaceted threats in different aspects ranging from over-exploitation and habitat loss due to anthropogenic pressures (Dhar et al. 2000, Rai et al. 2000; Ravikumar et al. 2000), few studies explored the possible utility of ENM's in conserving the medicinally important plant species in the subcontinent (Triveni et al. 2015, Yang et al. 2013). Ecological niche modeling of medicinal plants can yield useful insights for its proper management, sustainable utilization, species restoration and conservation (Yang et al. 2013). Ecological niche models have been successfully used to map the potential habitats of the customary medicinal plants used by Australian aborgins, which is disappearing due to heavy habitat loss (Gaikwad et al. 2011). In this study, ecological niche models were employed to predict the habitat suitability of six *Spilanthes* species using geographic information system for biodiversity analysis (DIVA-GIS, Hijmans et al. 2001) and maximum entropy (MaxEnt, Philips et al. 2007). In addition to mapping the distribution of the above species, an attempt was made to model the potential suitable habitats of these species for its proper utilization and conservation, as well as the extent of the predicted areas within the subcontinent.

MATERIALS AND METHODS

Selection of the study area :

Peninsular Indian region (lat. 10°-26°N and long. 68°-90°E, alt.300 and 1,800 m and annual rainfall is between 75 and 150 cm) which covers the Deccan plateau of Southern India surrounded by the bay of Bengal in the east, Arabian sea in the west and Indian ocean in the south was selected as the study area. All the species of *Spilanthes* occurring in diverse habitats were documented.

Selection of study species and their occurrence data

Occurrence points of six species of *Spilanthes* viz., *S. calva, S. ciliata, S. oleracea, S. paniculata, S. radicans and S. uliginosa* were explored. The occurrence records were collected from field surveys, herbarium and published literature (all floras of regions covering peninsular India and other research publications).

Environmental variables

In this study, 19 bioclimatic variables were derived from globally interpolated data-sets (source: http:/ /www.worldclim.org, Supplementary material Table A1). The climate layers from worldclim were created by interpolating the observed climate from climate stations around the world, using a thin-plate smoothing spline set to a resolution of approximately 1 km, over the 50-year period, from 1950 to 2000 (Hijmans et al. 2005). These bioclim layers represented variables of climate which has a deterministic role in determining the species distribution (Waltari et al. 2007). All layers used in this study were resampled to 1000m resolution and clipped for the Indian sub-continent using the software QGIS.

Ecological Niche modeling (ENM)

The softwares viz., DIVA-GIS V.7.5 (Sundar and Mitsuko 2005)and MaxEnt (Philips et al. 2006) were used for modeling the potential distribution of six species of *Spilanthes.* The MaxEnt and DIVA GIS use presence only data of the study taxa along with the user specified environment layers to create the potential distribution map of a species. The software DIVA-GIS used a BIOCLIM (Bio-climatic analysis and prediction system) model. Bioclimis one of the earlier modeling techniques, tallying species occurrence points for each environmental variable including 95% of the distribution (i.e., excluding extreme 5% of the distribution) along each ecological dimension. Details of the algorithm was obtained from Busby (1991). The MaxEntapproach estimated the environmental niche of a species by finding a probability distribution which is based on a distribution of maximum entropy (with reference to a set of environmental variables) (Phillips et al. 2006). The DIVA-GIS uses climatological data obtained from places of occurrence of the species to iteratively search for similar agro-ecological habitat features in the rest of the landscape and thus, predict the distribution of the species. The model predicted areas of habitat suitability ranging from highly suitable (excellent) to non-suitable. In MaxEnt, the default settings were used for the prediction. A logistic output was chosen to visualize the habitat suitability values ranging from 0 (unsuitable) to 1 (optimal). A 20% of the data points were used for model validation. To measure the relative importance of the variable, Jackknifing test was performed for every individual model. The analysis presented here, used 25% as random seed which was run for 10 replicates and maximum of 5000 iterations. Model validation was conducted by calculating the area under curve (AUC) under receiver operating systems (ROC, Fielding and Bell 1997).A ROC plotwas built by plotting the sensitivity values and thefalse positive fraction for all available probabilitythresholds (Manel et al. 2001). The AUC value is a direct measurement of the model predictive ability, which reflected the model's ability to distinguish between the presence records and random background points (Philips 2006). The AUC values ranged from 0.5 to 1.0 where models with AUC values >0.9 have very good prediction abilities while >0.8 and >0.7 were considered as good and useful categories (Sweats 1988). The software ArcMap.10 was used to calculate the area under the highly suitable categories (≥ 70 % suitable) for each species in the sub-continent. The niche overlap among species was measured using the software ENM Tools. As a measure of niche overlap, the Schoener's D (Schoener 1968) and I statistic (Warren et al. 2008) was calculated using the software ENM Tools.

Results and Discussion

The species of *Spilanthes* were annuals, found distributed mainly in the wetlands, near paddy fields and rarely in dry lands almost throughout the Peninsular India region. The species were found in hilly regions at cold climates as well. The Spilanthes species were herbaceous in nature and found growing well in loose marshy soils. *S. calva* and *S. oleracea* produced flowers and fruits throughout the year, while other species flowered seasonally; *S. ciliata* during June to January, *S. paniculata* during August to December, S. radicans during October to May and S. uliginosa during March to September.

A total of 190 non-overlapping occurrence points

Table 1. Ecological niche modeling of six species of *Spilanthes* in Peninsular India on overlapping occurrence points and area under curve (AUC) values. *Native species, Total area of the Indian sub-continent: 3,287, 264 km^2 .

Species	No. of occurrence points	AUC±SD	Predicted area under ≥70 suitability category (km^2)	Highly suitable area within the Indian subcontinent (%)	Percentage contribution of the variable BIO 4 temperature seasonality
*S. calva**	83	0.927±0.02	26315	0.8	45.6
S. ciliata	14	0.970±0.05	46026	1.4	50.1
S. oleracea	21	0.959±0.02	28171	0.85	64.5
*S. paniculata**	36	0.932±0.02	56322	1.7	50.5
S. radicans	22	0.964±0.01	28672	0.87	58
S. uliginosa	14	0.855±0.15	38159	1.1	66.9

were selected in the present study. The species were identified with the help of floral keys, comparison with herbarium samples, type specimens wherever available and consultation with the flora experts. Both the primary and secondary data were geo-referenced to specific locations on earth surface, using a (GIS) platform (Supplementary material Fig. A1)

Ecological niche modeling and model evaluation

Thepotential suitable areas of six study species were developed from 19 environmental variables using DIVA-GIS and MaxEnt. The potential distribution map of six species of *Spilanthes* using MaxEnt is shown in Fig. 1.

The warmer colored areas represented the more suitable area of each individual study species. The model developed using MaxEnt was discussed here since it is known to produce better prediction as compared to the other similar modeling platforms (Elith et al. 2006). The distribution models developed by DIVA-GIS are presented as supplementary material (Fig. A2). All models developed using the MaxEnt exhibited significant AUC values ranging from

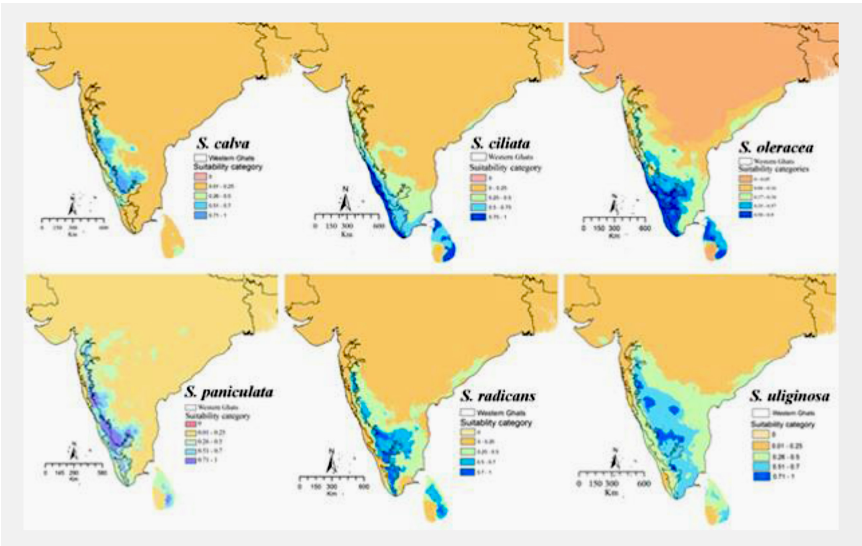

Figure 1: Ecological niche models of *Spilanthes* species viz., *S. calva, S. ciliata, S. oleracea, S. paniculata, S. radicans* and *S. uliginosa* respectively using MaxEnt model.

Table 2. Percentage niche overlap between species pair of *Spilanthes* using Schoener's D (Schoener 1968) statistics

Species	*S. calva*	*S. ciliata*	*S. oleracea*	*S. paniculata*	*S. radicans*	*S. uliginosa*
S. calva	**	54.2	60.5	58.2	63.1	59.6
S. ciliata		**	77.1	62.2	68.2	66.1
S. oleracea			**	61.7	78.6	66.3
S. paniculata				**	59.2	68.3
S. radicans					**	69.1
S. uliginosa						**

0.855- 0.996 for 10 replicates in each species. The highly suitable area (≥ 70 suitability) of each species in comparison with the total land area of the Indian sub-continent showed that *S.paniculata* occurs in most areas under the highly suitable category within the Indian sub-continent (56322Km^2), while *S.calva* occupied least area under the highly suitable category (26315Km^2). For all the species growing in India, temperature seasonality (BIO4) was the major bioclim variable influencing the distribution of *Spilanthes* species in India; this range from 66.9-45.6% among different species (Table 1) and importance of each variable was determined by Jackknifing test which is detailed in Supplementary Fig. A3

No. of non-overlapping occurrence points, Area under curve (AUC), extend of suitable area of occurrence and highest percentage contribution for niche modeling of six species of *Spilanthes* in peninsular India.

Niche overlap

The present study indicated that the niche overlap among different species of *Spilanthes* were considerably high. The niche overlap estimate (Schoner's D) between different species pair shown in Table 2. Most of the species were found to have high niche overlap which ranged from 0.78 (between *S.radicans* and *S.oleracea*) to 0.54 (between *S. calva* and *S. ciliata*). The I statistics was also estimated as an independent measure of niche overlap in this study (Supplementary Table A2). In both indices there was linear correlation in overlap values. The niche overlap

SUPPLEMENTRAY MATERIAL:

Table A1: Environmental variables used in the model development

BIO 1	Annual temperature	http:/ /www.worldclim.org
BIO 2	Mean diurnal temperature range [mean of monthly (max temp–min temp)]	http:/ /www.worldclim.org
BIO 3	Isothermality (P2/P7) (×100)	http:/ /www.worldclim.org
BIO 4	Temperature seasonality (standard deviation×100)	http:/ /www.worldclim.org
BIO 5	Max temperature of warmest month	http:/ /www.worldclim.org
BIO 6	Min temperature of coldest month	http:/ /www.worldclim.org
BIO 7	Temperature annual range (P5–P6)	http:/ /www.worldclim.org
BIO 8	Mean temperature of wettest quarter	http:/ /www.worldclim.org
BIO 9	Mean temperature of driest quarter	http:/ /www.worldclim.org
BIO 10	Mean temperature of warmest quarter	http:/ /www.worldclim.org
BIO 11	Mean temperature of coldest quarter	http:/ /www.worldclim.org
BIO 12	Annual precipitation	http:/ /www.worldclim.org
BIO 13	Precipitation of wettest month	http:/ /www.worldclim.org
BIO 14	Precipitation of driest month	http:/ /www.worldclim.org
BIO 15	Precipitation seasonality (coefficient of variation)	http:/ /www.worldclim.org
BIO 16	Precipitation of wettest quarter	http:/ /www.worldclim.org
BIO 17	Precipitation of driest quarter	http:/ /www.worldclim.org
BIO 18	Precipitation of warmest quarter	http:/ /www.worldclim.org
BIO 19	Precipitation of coldest quarter	http:/ /www.worldclim.org

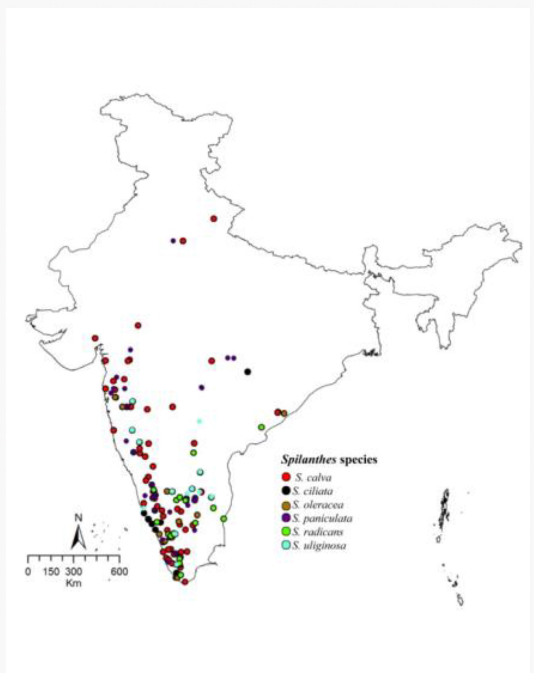

Figure 2 : Occurrence points of different Spilanthes species in peninsular India

among immigrant species was high when compared to that among native species.

Areas predicted but which are not colonized by the species are suitable areas for prioritization of conservation since it could act as possible habitats for introduction/cultivation for large scale usage. In this regard MaxEnt could be used as a potential tool for finding suitable habitat for different medicinal plants and could also aid in its sustainable extraction and utilization. The model also predicted potential distribution areas in Andaman Nicobar Islands and parts of Sri Lanka and South East Asia, which needs to be explored carefully.

Although model could predict potential suitable habitat for *Spilanthes* species in India using MaxEnt, care should be taken into consideration while generalizing the outcomes of this study. The significantly high amount of niche overlap observed in this study could be further tested by exhaustive sampling of individual species.

The major research in medicinal plants in India is done in terms of its chemical profiling (Paulraj et al. 2014), exploring antibacterial properties (Ahamed et

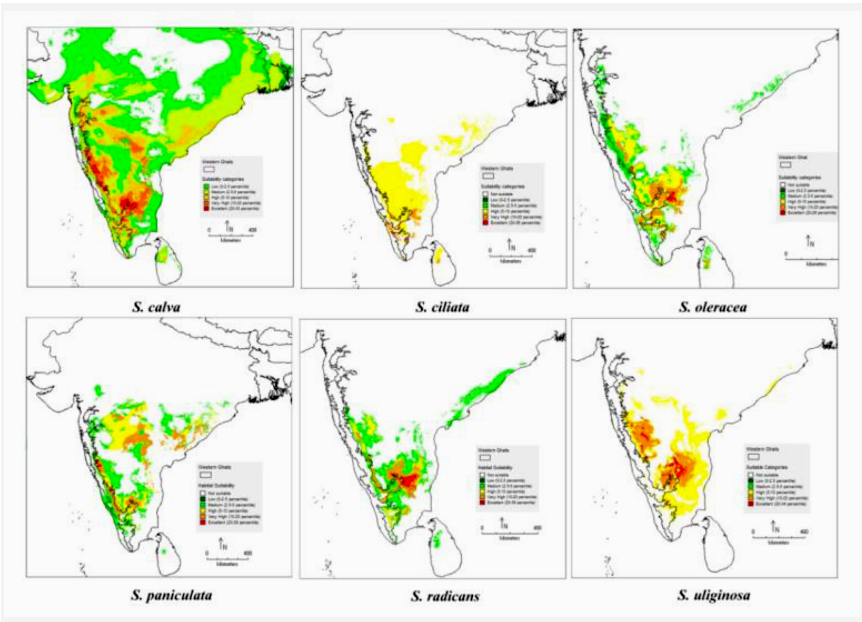

Figure 3 : Ecological niche model output for species of *Spilanthes* viz., *S. calva, S. ciliata,S. oleracea,S. paniculata, S. radicans* and *S. uliginosa* using DIVA-GIS model.

al. 1998; Nascimetno et al. 2000; Paulraj et al. 2014). The ecological models for a species are equally necessary for the complete authentication of a species. The study does not take into account the species biotic interactions or impact of invasive species as well as the anthropogenic influences. The above factors could manifest themselves in novel and unexpected ways.

The present study throws light on the strategy that could be employed in the future conserva-

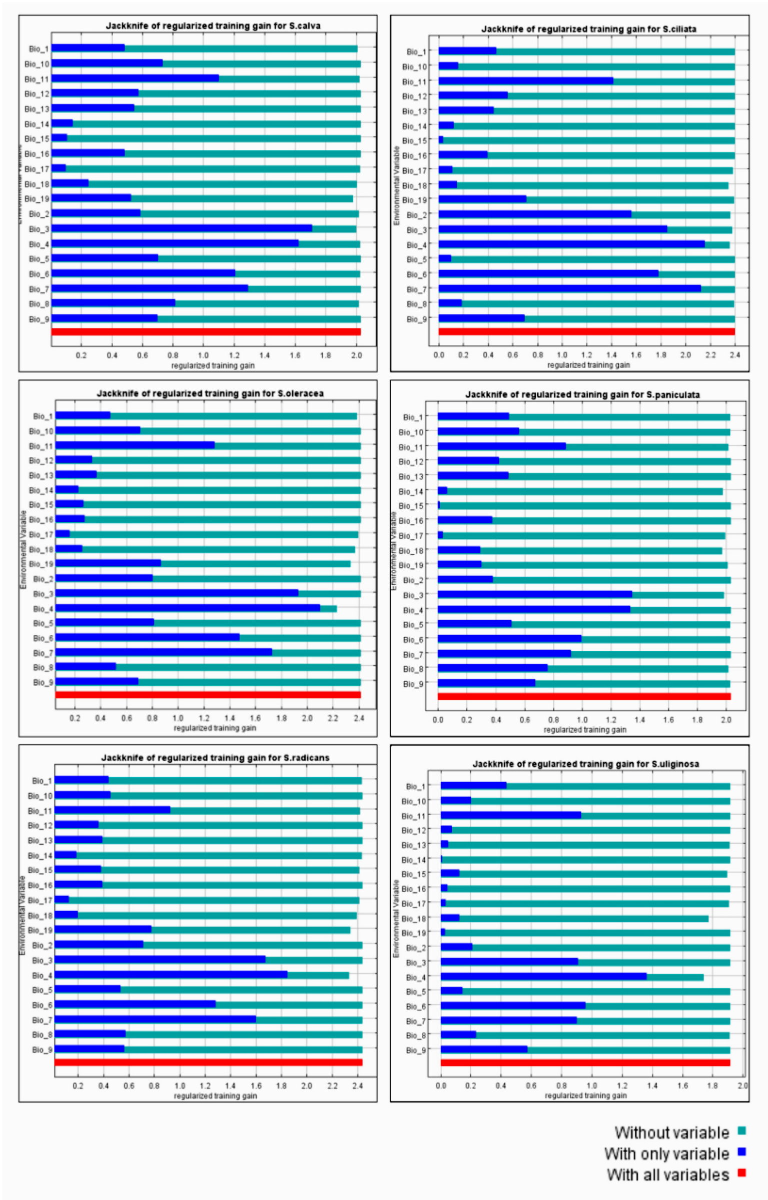

Fig. 4. Importance environmental variables determined by Jackknifing test for each species of *Spilanthes* viz., *S. calva, S. ciliata, S. oleracea, S. paniculata, S. radicans and S. uliginosa.*

Table 2A : Percentage niche overlap between species pair of *Spilanthes* using I statistics (Warren et al. 1968) statistics.

Species	*S. calva*	*S. ciliata*	*S. oleracea*	*S. paniculata*	*S. radicans*	*S. uliginosa*
S. calva	**	83.9	88	85.5	89	88.2
S. ciliata		**	94.3	88.5	91.1	90.8
S. oleracea			**	85.2	95.9	89.7
S. paniculata				**	84	91
S. radicans					**	92.12
S. uliginosa						**

tion of *Spilanthes* species in the Western Ghats and simultaneously its sustainable utilization in traditional medicines.

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REFERENCES

Ahamed I., Mehmood Z., Mohammad F. (1998) Screening of some Indian medicinal plants for their antimicrobial properties. J. Ethnopharmacol. 62 (2) : 183—193.

Asha V., Jeeva S., Paulraj K. (2014) Phytochemical and FT-IR spectral analysis of *Caralluma geniculata* Grev. et Myur. an endemic medicinal plant. J. Chem and Pharmac. Res. 6 (7) : 2083—2088.

Busby J.R. (1991) BIOCLIM - A Bioclimatic Analysis and Prediction System. In: Margules C.R. and Austin M.P. (eds). Nature Conservation: Cost Effective Biological Surveys and Data Analysis. Canberra: CSIRO, pp. 64—68.

Craig R., McClain, James C.S., Hurlbert A.H. (2014) Dispersal, environmental niches and oceanic-scale turnover in deep-sea bivalves. Proc. R. Soc. B. doi:10.1098/rspb.2011.2166.

Dhar U., Rawal R.S., Upreti J. (2000) Setting priorities for conservation of medicinal plants—A case study in the Indian Himalaya. Biol. Conserv. 95 (1) : 57—65.

Elith J., Graham C.H., Anderson R.P., Dudik M., Ferrier S. et al. (2006) Novel methods improve prediction of species distributions from occurrence data. Ecography. 29 : 29—151.

Fielding A.H., Bell J.F. (1997) A review of methods for the assessment of prediction errors in conservation presence /absence models. Environ. Conserv. 24 : 38—49.

Gaikwad J., Wilson P.D., Ranganathan S. (2011) Ecologi cal niche modeling of customary plants used by Australian Aborgins to identify species rich and culturally valuables areas for conservation. Ecol. Modelling 222 : 3437—3443.

Ganeshaiah K.N., Barve N., Chandrashekara K., Swamy M., Uma Shaanker R. (2003) Predicting the potential geographical distribution of the sugarcane wooly aphid using GARP and DIVA-GIS. Curr. Sci. 85 (11) : 1526—1528.

Grinnell Joseph (1917) The niche-relationships of the California Thrasher PDF. The Auk 34 : 427—433. doi:10.2307/4072271.

Guisan A., Zimmerman N.E. (2000) Predictive habitat distribution models in ecology. Ecol. Modelling 135 : 147—186.

Haw A.B., Keng C.L. (2003) Micropropagation of *Spilanthes acmella* L, a bio-insecticide plant, through proliferation of multiple shoots. J. Appl. Hort. 3 (5) : 65—68.

Hijmans R.J., Cameron S., Parra J., Jones P., Jarvis A. (2005) Very high resolution interpolated climate surfaces for global land areas. Int. J. Clim. 25 : 1965—1978.

Hijmans R.J., Cruz E.M., Rojas, Guarino L. (2001) DIVA-GIS, Version 1.4. A geographic information system for the management and analysis of genetic resources data. Manual, International Potato Center, Lima, Peru.

Hutchinson G. E. (1957) Concluding remarks. Cold Spring Harbor Symposia on Quantitative. Biol. 22 (2) : 415—427.

Irfan-Ullah M., Giriraj A., Murthy M.S.R, Peterson A.T. (2007) Mapping the geographic distribution of *Aglaia bourdillonii* Gamble (Meliaceae) an endemic and threatened plant, using ecological niche modelling. Biodivers. Conserv.16 : 1917—1925.

Jansen R.K. (1981) Systematics of *Spilanthes* (Compositae: Heliantheae). Syst. Bot. Monogr. 6 : 231—257

Lavanya et al. (2014 a,b) In press.

Leng T.C., Ping N.S., Lim B.P., Keng C.L. (2011) Detection of bioactive compounds from *Spilanthes acmella* (L.) plants and its various in vitro culture products. J. Med. Pl. Res. 5 : 371—378.

Manel S., Williams H.C., Ormerod S. J. (2001) Evaluating presence–absence models in ecology: The need to account for prevalence. J. Appl. Ecol. 38 : 921—931.

Meyer E.M.A., Peterson T., Jorge L.S., Lloyd F.K. (2006) Ecological niche modelling and prioritizing areas for species reintroductions. Oryx 40 (4) : 411—418.

Nagaraju S.K., Gudasalamani R., Barve N., Ghazoul J., Narayanagowda G.K. et al. (2013) Do Ecological Niche Model Predictions Reflect the Adaptive Landscape of Species?: A Test Using *Myristica malabarica* Lam., an Endemic Tree in the Western Ghats, India. PLoS ONE 8(11): e82066. doi:10.1371/journal.pone.0082066

Nascimento G.G., Locatelli J., Freitas P.C., Silva G.L. (2000) Antibacterial activity of plant extracts and phytochemicals on antibiotic-resistant bacteria. Brazil. J. Microbiol. 31 (4) : 247—256.

Pearson R.G., Dawson T.P. (2003) Predicting the impacts of climate change on the distribution of species: Are bioclimatic envelope models useful? Global Ecol. Biogeorg. 12 : 361—371.

Pearson R.G., Raxworthy C.J., Nakamuram M., Peterson A.T. (2007) Predicting species distribution form small number of occurrence records: A test case using cryptic-geckos in Madagascar. J. Biogeogr. 34 : 102—117.

Peterson A.T. (2003) Predicting the geography of species' invasions via ecological niche modeling. Quart. Rev. Biol. 78 (4) : 419—433.

Peterson A.T., Monica P., Eaton M. (2007)Transferability and model evaluation in ecological niche modeling: A comparison of GARP and MaxEnt Ecography. 30 : 550—560.

Peterson A.T., Vieglais D.A. (2001) Predicting invasions using ecological niche modeling: New approaches from bioinformatics attack a pressing problem. Biol. Sci. 51 : 363—371.

Philips S.J., Anderson R.P., Schapire R.E. (2006) Maximum entropy modeling of species geographic distributions. Ecol. Modelling 190 : 231—259.

Rai L.K., Prasad P., Sharma E. (2000) Conservation threats to some important medicinal plants of the Sikkim Himalaya. Biol. Conserv. 93 (1) : 27—33.

Ravikumar K., Ved D.K., Vijaya Sankar R., Udayan P.S. (2000) 100 Red listed medicinal plants of conservation concern in Southern India.

Raxworhty C.J., Ingram C.M., Rabibosa N., Pearson R.G. (2007) Applications of ecological niche modeling for species delimitation: A review and empirical evaluation using day geckos (*Phelsuma*) from Madagascar. Syst. Biol. 56 (6) : 907—923.

Sahu J., Jain K., Jain B., Sahu R.K. (2011) A review on phytopharmacology and micropropagation of *Spilanthes acmella.* Pharmacol. Online Newsl. 2 : 1105—1110.

Sandhya B., Thomas S., Isabel W., Shenbagarathai R. (2006) Ethnomedicinal plants used by the valaiyan community of Piranmalai hills (reserved forest), Tamilnadu, India. A pilot study. Afr. J. Trad. Complemen. and Alternative Med. (AJTCAM) 3 (1) : 101—114.

Schoener T.W. (1968) The Anolis lizards of Bimini: Resource partitioning in a complex fauna. Ecology 49 : 704—726.

Shivaprakash K.N., Ramesha B.T., Umashaanker R., Dayanandan S., Ravikanth G. (2014) Genetic Structure, Diversity and Long TermViability of a Medicinal Plant, Nothapodytes nimmoniana Graham.(Icacinaceae), in Protected and Non-Protected Areas in the Western Ghats Biodiversity Hotspot. PLOS ONE | DOI:10.1371/journal.pone.0112769. 1—25

Sundar S.S., Mitsuko C. (2005) A geographical information system for the analysis of biodiversity data. GIS Resource Document (WWW document). URL http://www.pop.psu.edu/gia-core/pdfs/gis_rd_02-27.pdf

Swets K. (1988) Measuring the accuracy of diagnostic systems. Science 240 : 1285—1293.

Tiwari K.L., Jadhav S.K., Joshi V. (2011) An updated review on medicinal herb genus *Spilanthes*. Chin J. Integr. Med. 9 : 1170—1178.

Triveni H.N., Gunaga S.V., Ramesh B.H.N., Vasudeva R. (2015) Ecological niche modeling, population status and regeneration of *Coscinium fenestratum* colebr.(Menispermaceae): A medicinally important liana of the central Western Ghats. Trop. Ecol. 56 (1) : 101—110.

Waltari E., Hijmans R.J., Peterson A.T., Nyari A.S., Perskins S.L., Guralnick R.P. (2007) Locating *Pleiston cenerefugia,* comparing phylogeographic and ecological niche model predictions. Plos One2:doi:10.1371/journal.pone.0000563

Warren D.L., Glor R.E., Turelli M. (2008) Environmental niche equivalencyversus conservatism: Quantitative approaches to niche evolution. Evolution 62 : 2868—2883.

Yadav K., Singh B. (2010) Micropropagation of *Spilanthes acmella* Murr.-An important medicinal plant. Nature and Sci. 8 : 5—11.

Yang X.Q., Kushwaha S.P.S., Saran S., Xu J., Roy P. S.(2013) Maxent modeling for predicting the potential distribution of medicinal plant *Justicia adhatoda* L. in Lesser Himalayan foothills. Ecol. Engg. 51 : 83—87.