BIOGEOGRAPHIC RESPONSE OF RHODODENDRONS TO CLIMATE CHANGE IN THE SIKKIM HIMALAYA

Pradeep Kumar

ABSTRACT

The paper models the biogeography of genera Rhododendron, mainly tree varieties, in response to climate change. The modelling algorithm used in the paper estimates the target probability distribution by finding the probability distribution of maximum entropy. For assessing the impact of climate change on Rhododendrons in Sikkim Himalayas, occurrence localities of Rhododendrons were determined with the help of handheld GPS. The occurrence location data was partitioned in to training and test data. A set of species occurrence records that was not previously used in the modelling was used as independent test data. For doing the niche modelling the relevant climatic data was taken from Worldclim. The relevant environmental variables of bioclimatic layers in GIS format were projected and the boundaries were extracted by masking the Sikkim area in ArcGIS. These modelled bioclimatic layers were used in Maxent for getting the current distribution (niche) and this was finally projected for future climate scenario. The future climate change scenario adopted here is the scenario SRES-A1B (Special Report on Emission Scenario corresponding to A1: Maximum energy requirements - emissions differentiated dependent on fuel sources. B: Balance across sources). Maxent model produced reasonable potential distribution of Rhododendrons. It is found that the suitable bioclimatic envelope for Rhododendron has shrunk considerably under the envisaged climate change scenario. The statistical criteria used to estimate accuracy of the model is Area under ROC (Receiver Operating Curve).

KEYWORDS: *Rhododendrons, Climate Change, Maxent modelling, Distribution*

Rhododendron hodgsonii found in the sub-alpine conifer forests of Sikkim. Photo courtesy S. Anbalagan

Rhododendron campanulatum in full bloom in Yumthang valley, North Sikkim

Climate has long been identified as a primary control on the geographic distribution of plants (Forman 1964). Therefore plants may be expected to exhibit marked redistribution in response to climate change (McKenny et al. 2007). In the short to medium term, human-induced fragmentation of natural habitat and invasive species are particular threats to biodiversity. But looking 50 years into the future and beyond, the effects of climate are likely to become increasingly prominent relative to the other factors (Wilfred 2007). Fourth Assessment Report of IPCC (IPCC 2007) concluded that resilience of many ecosystems is likely to be exceeded this century by an unprecedented combination of climate change, associated disturbances (e.g. flooding, drought, wildfire and insects) and other global change drivers (e.g. land use change, pollution, fragmentation of natural systems and over exploitation of resources).

Even though increasing evidence shows that recent human-induced environmental changes have already triggered species range shifts (Wilfred 2007), changes in phenology and species extinctions, accurate projections of species' responses to future environmental changes are more difficult to ascertain. Over the course of this century, net carbon uptake by terrestrial ecosystems is likely to peak before mid-century and then weaken or even reverse, thus amplifying climate change (IPCC 2007). For increase in global average temperature exceeding 1.5-2.5 degree centigrade and the concomitant CO_2 concentration, there are projected major changes in the ecosystem structure and function, species ecological interactions and shifts in species geographical ranges with predominantly negative consequences for biodiversity and ecosystem goods and services, e.g. water and food supply (IPCC 2007) . The most predictable impact includes upward migration of several taxa leading to changes in species composition and competition at higher altitudes. Many alpine species in the process of edging uphill in Sikkim may run over rarer species near mountain summits. Some species would not be able to migrate due to topographic and man-made barriers. The changed phenology would affect the process of pollination.

Whole Himalayan region, including the Tibetan Plateau, has shown consistent trends in overall warming during the past 100 years (Yao et al. 2006) . Various studies suggest that warming in the Himalayas has been much greater than the global average of 0.74°C over the last 100 years (IPCC 2007).

Rhododendrons cover a vast section of south-eastern Asia between the north-western Himalaya through Nepal, Sikkim, eastern Tibet, Bhutan, Arunachal Pradesh, upper Burma and western and central China. More than 90% of the world's natural population of Rhododendrons is from this region. On record, 98% of the Indian species is found in the Himalayan region, of which 72% is found in Sikkim. In the light of these facts, Sikkim may be considered as the most appropriate location for conservation and propagation of Rhododendrons in India (Singh et al. 2003). Rhododendrons form dominating species all along the cool temperate, subalpine and alpine zones in the Sikkim Himalaya. It supports a wide range of plants and animals and, if disturbed, can degrade habitats and threaten associated biodiversity. Rhododendron is the only group of plants that has continuum in the aforesaid ecotone and beyond doubt, maintains the biological sustenance in this fragile zone (Singh et al. 2003). In India, the genus Rhododendron is mainly distributed in the Himalayan region specially as a dominant forest taxa in eastern parts. The genus could be regarded as a keystone element for the high altitude areas having more or less direct implication on the soil and moisture regime of the location. (Paul et al. 2005).

As temperatures rise and glaciers retreat, species shift their ranges to follow their principal habitats and climatic optima. However, the ability of species to respond to a changing climate varies. Shifts in species' ranges during past major global climate changes indicate that all species have climatic limitations beyond which they cannot survive (Xu et al. 2007). Alpine plant species on mountain ranges with restricted habitat availability above the tree line will experience severe fragmentation, habitat loss, or even extinction if they cannot move to higher elevations. The disappearance of some extant climates increases the risk of extinction for species with narrow geographic or climatic distributions and disruption of existing communities. Therefore, it is high time that the vulnerability of the species in response to climate change is evaluated and adaptive measures taken to conserve the biodiversity.

DATA AND METHODS;

Target Species and Occurrence Data

The state tree of Sikkim is Rhododendron i.e. *Rhododendron niveum*. Since the phenological responses provide one of the best biological indicators of climate change, the first flowering dates of some species show striking correlation with the average temperature of particular month. For example *R. ponticum* shows a striking correlation with the average temperature of April-May indicating that the species is sensitive to temperature changes (The Rhododendron Phenology Project at Royal Botanical Garden). Rhododendrons, with its distribution in the temperate forests along an altitudinal gradient would be an ideal species to explore. The 38 species of Rhododendrons in the Sikkim Himalayas show a barrel-shaped altitudinal distribution based on nine different altitudinal distribution ranges categorized between 1500 and 6000 m (Pradhan and Lachungpa 1990). *R. arboreum* is a common species. In the present study whole genera of Rhododendrons found in Sikkim has been considered. For the present study 112 locations where Rhododendrons are found were recorded with handheld Garmin GPS (Global Positioning System) (Horizontal Accuracy (95%) ± 9.3 meters). These locations were distributed throughout Sikkim. However, while plotting them on map it was found that the sampling locations were concentrated in only certain parts of Sikkim. Based on the personal visits and experience of author about the distribution of Rhododendrons in Sikkim it was found that the sampling was biased. Therefore, based on the experienced visits 63 more occurrence locations were marked on the maps and accordingly their longitudes and latitudes were automatically derived in the ArcGIS software (ESRI, Redlands, California, USA).

Environmental Variables

The environmental variables used for the modelling were the bioclimatic variables. Bioclimatic variables are derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables. The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation), seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters). A quarter is a period of three months (1/4 of the year).

They have been coded as follows:

BIO1	=	Annual Mean Temperature
BIO2	=	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	=	Isothermality (P2/P7) (* 100)
BIO4	=	Temperature Seasonality (standard deviation *100)
BIO5	=	Max Temperature of Warmest Month
BIO6	=	Min Temperature of Coldest Month
BIO7	=	Temperature Annual Range (P5-P6)
BIO8	=	Mean Temperature of Wettest Quarter
BIO9	=	Mean Temperature of Driest Quarter
BIO10	=	Mean Temperature of Warmest Quarter

BIO11 = Mean Temperature of Coldest Quarter
BIO12 = Annual Precipitation
BIO13 = Precipitation of Wettest Month
BIO14 = Precipitation of Driest Month
BIO15 = Precipitation Seasonality (Coefficient of Variation)
BIO16 = Precipitation of Wettest Quarter
BIO17 = Precipitation of Driest Quarter
BIO18 = Precipitation of Warmest Quarter
BIO19 = Precipitation of Coldest Quarter

Statistically downscaled datasets were used. These data were originally downloaded from the IPCC data portal and re-processed using a spline interpolation algorithm of the anomalies and the current distribution of climates from the WorldClim database developed by (Hijmans et al. 2005) . The data resolution used was 30 seconds (0.93 km x 0.93km = 0.86 km^2 at the equator).

The datasets pertain to both the current period and the future climate change scenario. The future climate change scenario pertained to HadClim Emission scenario SRES-A1B (corresponding to A1: Maximum energy requirements - emissions differentiated dependent on fuel sources. B: Balance across sources) (2080). Even though the altitude is an important variable, it was not used in the modelling since the environmental variables related to temperature are related with altitude and it was expected that the temperature would change in case of climate change but not the altitude.

Temperate, subalpine and alpine forests of Sikkim harbor as many as 38 species of *Rhododendrons*

Modeling Procedure

Mechanistic models would require detailed understanding of the physiological response of species to environmental factors. However in the case of Sikkim there is poor understanding, in quantitative terms, of growth parameters of the plants found in Sikkim. Therefore this method was ruled out and correlative methods of modelling were used. These correlative methods commonly utilize associations between environmental variables /environmental conditions that are suitable for a species by associating known species occurrence records with suites of environmental variables that can reasonably be expected to affect the species physiology and probability of persistence. This is basically a bio-climate envelope modeling. The central premise of this approach is that the observed distribution of a species provides useful information as to the environmental requirements of that species (Pearson 2007). Having run the modeling algorithm, a map can be drawn showing the predicted species distribution. The ability of the model to predict the known species distribution should be tested at this stage. A set of species occurrence records that have not previously been used in modeling should be used as independent test data. The ability of the model to predict the independent data can be assessed using a suitable test statistic (Pearson 2007).

For the present study novel modelling method called maximum entropy distribution or Maxent (ver. 3.3.3a) (Phillips et al. 2006) was used. Maxent is a general-purpose method for making predictions or inferences from incomplete information. It is a maximum entropy based machine learning program that estimates the probability distribution for a species occurrence based on environmental constraints distribution by finding the probability distribution of maximum entropy (i.e., that is most spread out, or closest to uniform), subject to a set of constraints that represent our incomplete information about the target distribution (Phillips et al. 2006). The model expresses the suitability of each grid cell as a function of the environmental variables at that grid cell. A high value of the function at a particular grid cell indicates that the grid cell is predicted to have suitable conditions for that species. The computed model is a probability distribution over all the grid cells. It uses a sequential-update algorithm that iteratively picks a weight λj and adjusts it so as to minimize the resulting regularized log loss (Dudik et al. 2004).

All the bioclimatic layers in file format ASCII were used with same resolution of 30ARC seconds. Out of the available occurrence locations only 70% were used in calibrating the model and remaining 30% were used for testing the model. Regularization multiplier was fixed at 1. Maximum number of background points was fixed at 10000. Replicated run types were cross validated and maximum iterations were fixed at 500. The outputs were obtained in logistic format. Logistic format gives the probability of occurrence within the probability range of 0 to 1. The model trained on current climate data set of environmental layers was "projected" by applying it to the future climate data set of environmental layers pertaining to SRES A-1B. For doing the threshold independent assessment receiver operating characteristic (ROC) analysis, which characterizes the performance of model at all possible thresholds by a single number, the area under the curve (AUC) was used. The AUC test is derived from the Receiver Operating Characteristic (ROC) Curve. The ROC curve is defined by plotting sensitivity against '1 – specificity' across the range of possible thresholds. Sensitivity and specificity are used because these two measures take into account all four elements of the confusion matrix (true and false presences and absences). It is conventional to subtract specificity from 1 (i.e. 1 – specificity) so that both sensitivity and specificity vary in the same direction when the decision threshold is adjusted (Pearce and Ferrier 2000).

RESULTS AND DISCUSSION

The output format for predicted distributions in Maxent is raw, logistic or cumulative. For raw output, the output values are probabilities (between 0 and 1) such that the sum over all cells used during training is 1. For logistic output, the values are again probabilities (between 0 and 1), but scaled up in a non-linear way for easier interpretation. If *p(x)* is the raw output for environmental conditions *x*, the corresponding logistic value is *c p(x) / (1 + c p(x))* for a particular value of *c* (namely, the exponential of the entropy of the raw distribution). For the cumulative output format, the value at a grid cell is the sum of the probabilities of all grid cells with no higher probability than the grid cell, times 100. Cumulative output is best interpreted in terms of predicted omission rate: if we set a cumulative threshold of *c*, the resulting binary prediction would have omission rate *c*% on samples drawn from the Maxent distribution itself, and we can predict a similar omission rate for samples drawn from the species distribution. The idea of cumulative threshold has also been made use of in the ROC analysis.

When used with the environment occurrence records and environment layers mentioned in Data and Methods above, the Maxent model produced reasonable potential distribution of Rhododendrons. Figure 1 and Figure 2 represent the logistic output of Maxent model, which is the easiest to conceptualize: it gives an estimate between 0 and 1 of probability of presence. Figure 1, is a representation of the Maxent model for Rhododendron. Warmer colours show areas with better predicted conditions; red indicating high probability of suitable conditions for the species, green indicating conditions typical of those where the species is found, and lighter shades of blue indicating low predicted probability of suitable conditions. White dots show the presence locations used for training, while violet dots show test locations.

Figure 2 represents the projection of the Maxent model for Rhododendron onto the environmental variables for future climate under SRES A1B Scenario (2080s). It is found that the suitable bioclimatic envelope for rhododendron has shrunk considerably under the envisaged climate change scenario.

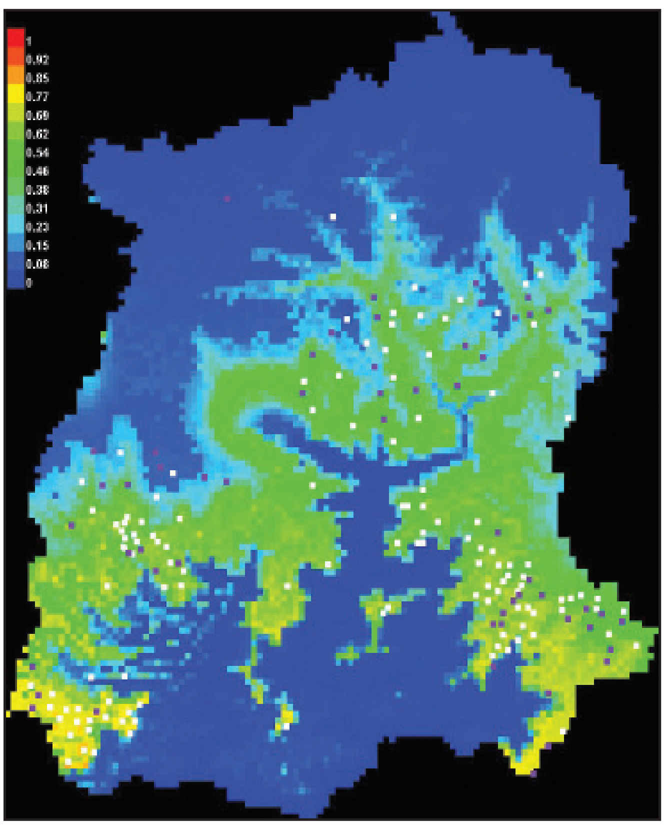

Figure 1: Representation of the Maxent model for current distribution of Rhododendron.

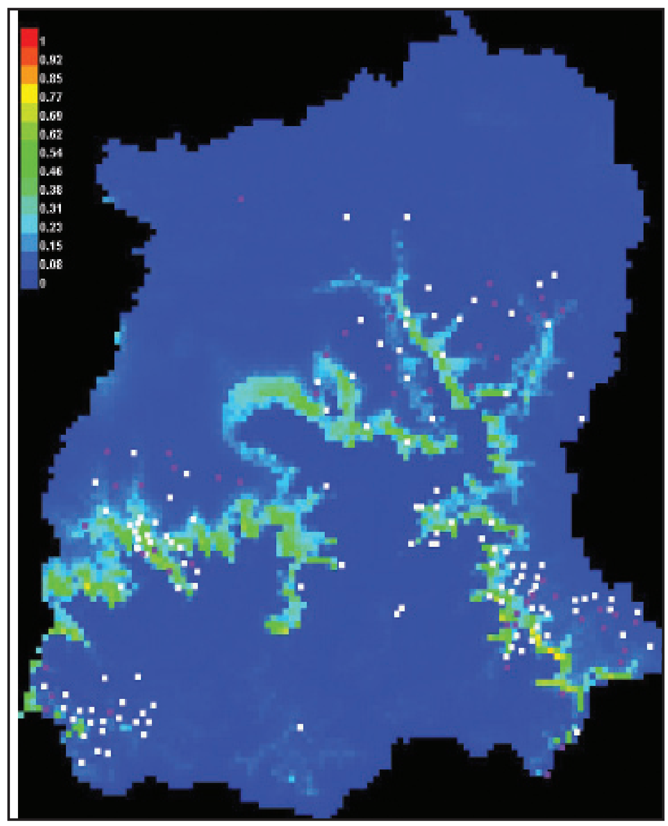

Figure 2: Projection of the Maxent model for Rhododendron onto the environmental variables for future climate under SRES A1B Scenario (2080s). Warmer colours show areas with better predicted conditions. White dots show the presence locations used for training, while violet dots show test locations

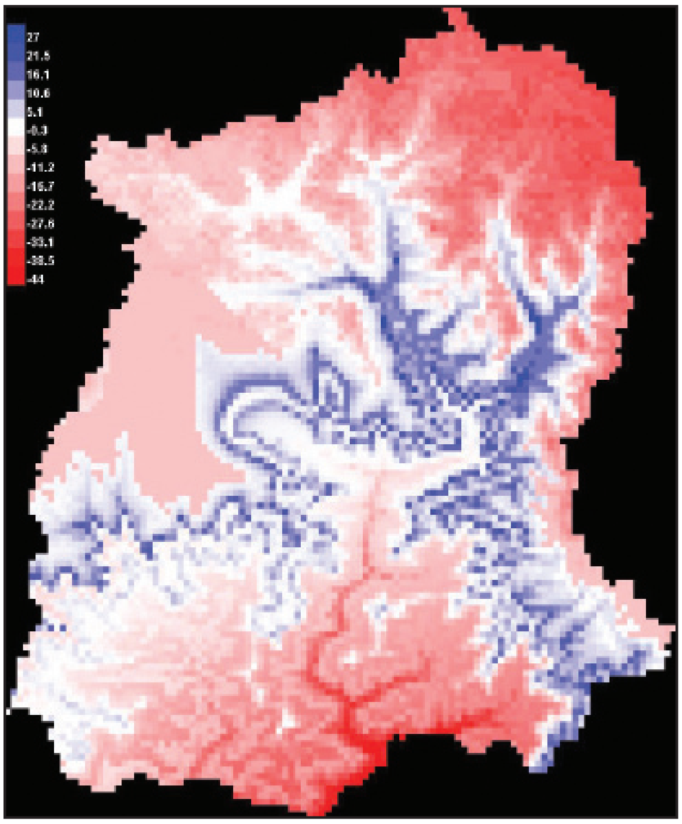

Figure 3, Comparison of the environmental similarity of variables in future climate to the environmental data used for training the model with the current climate

The Figure 3 compares the environmental similarity of variables in future climate to the environmental data used for training the model. In this Figure the areas in red have one or more environmental variables outside the range present in the training data, so predictions in those areas should be treated with strong caution.

These predictions give a broad idea about the impact of climate change on Rhododendrons. The predictions also outline geographic space, where the Rhododendrons would be affected most and to what extent. The colours in Fig 1. and Fig 2. had been logscaled to bring out the minor differences. Even though the nature would not follow discrete and interval based distribution, however for the sake of easy understanding and conceptualization the logistic probability distribution was plotted in four different classes i.e. 0%-25%, 25%-50%, 50%-75% and 75% to 100% by slicing the distribution in four equal classes by importing the maxent logistic distribution to ArcInfo. The resulting class based logistic distribution for both the current climate and future climate is shown in Fig. 4 and Fig.5 respectively.

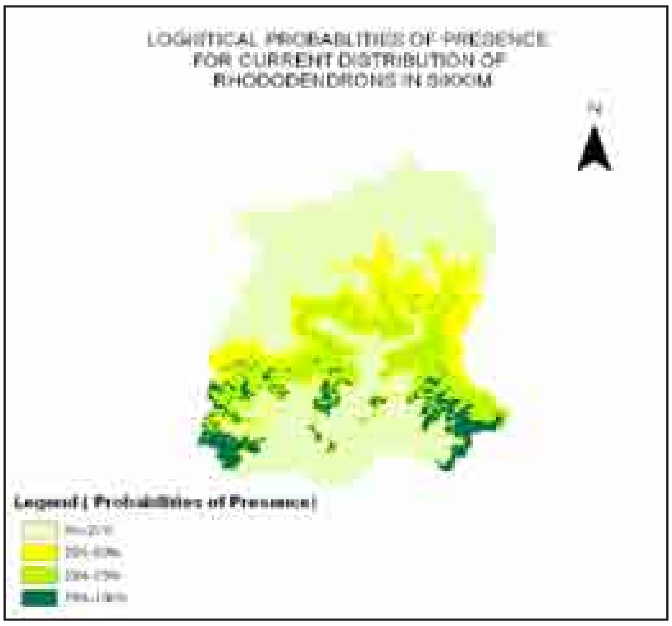

Figure 4: Logistical probabilities of presence for current distribution of Rhododendrons

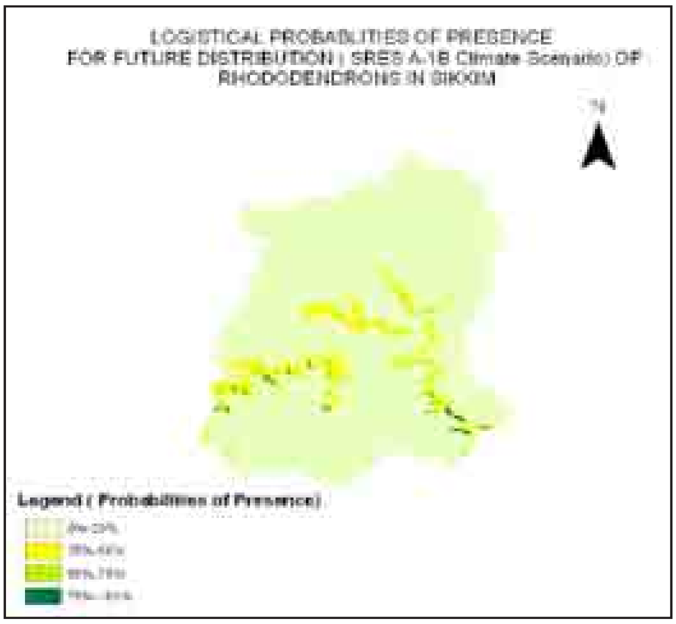

Figure 5: Logistical probabilities of presence of Rhododendrons in SRESA-1B climate scenario

The word of caution to be added here is that reduction in the probabilities of presence does not mean that the Rhododendrons would have gone by 2080s in those areas in the projected climate scenario. It simply means that the optimum climatic niche or relative suitability of that area would have reduced by that amount.

Next question arises how accurate are these projections or with what confidence these figures be considered. The 30 % of the sample records randomly set aside for testing allowed the program to do some simple statistical analysis. Much of the analysis used the use of a threshold to make a binary prediction, with suitable conditions predicted above the threshold and unsuitable below. The Fig 6. shows how testing and training omission and predicted area vary with the choice of cumulative threshold. The omission rate should be close to the predicted omission, because of the definition of the cumulative threshold. In the current instance the omission rate is found to be reasonably close to the predicted omission.

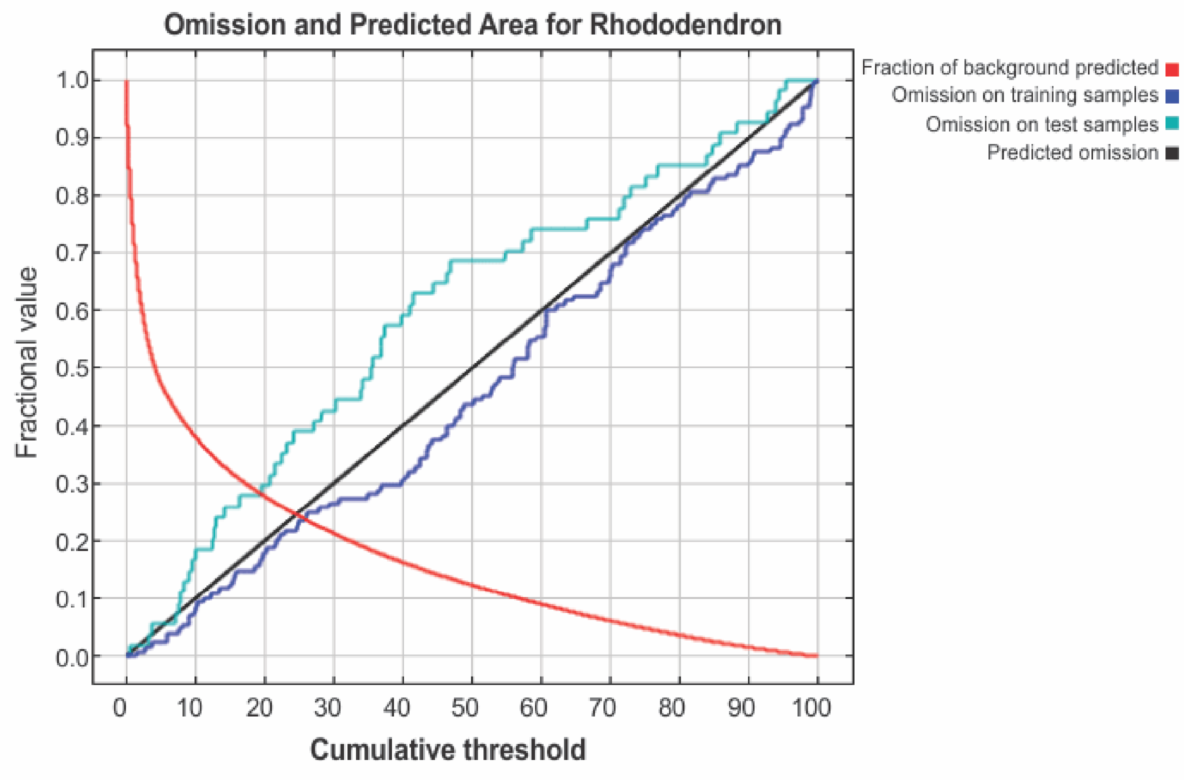

Figure 6: Omission and Predicted Area for Rhododendron

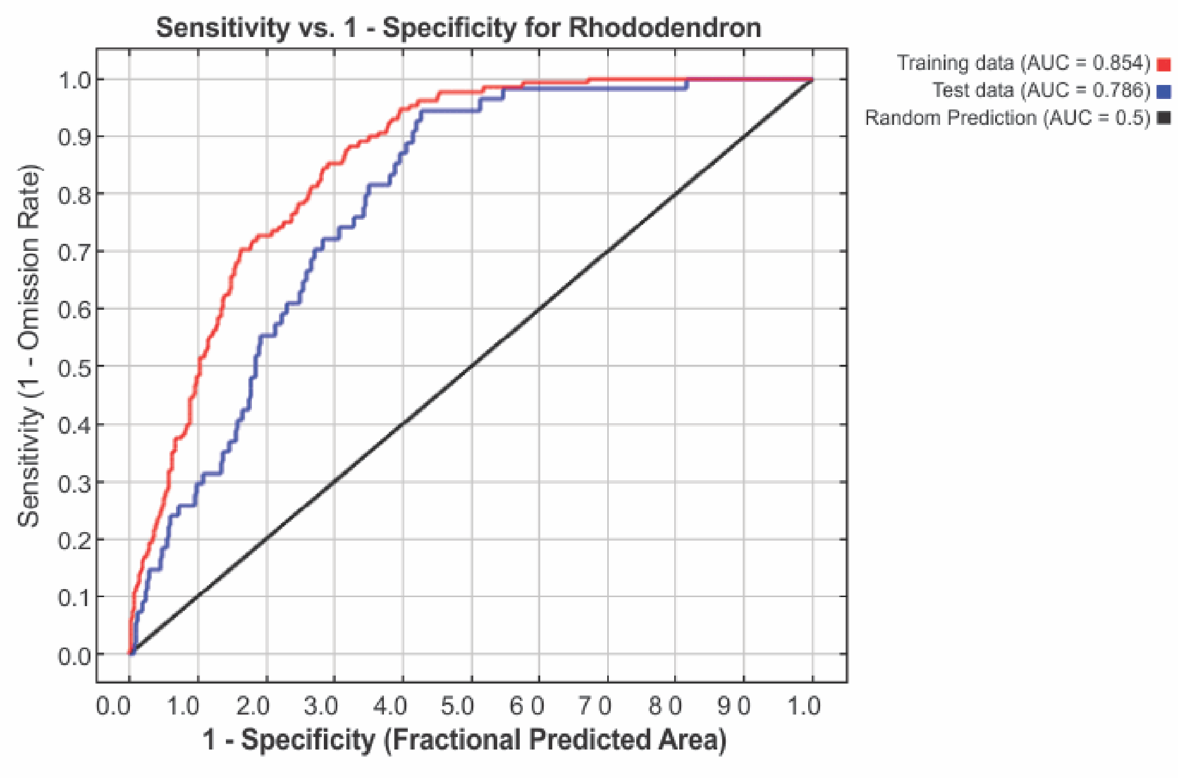

Figure 7: Sensitivity vs. 1- Specificity for Rhododendron

To further test the accuracy of predictions by maxent the Receiver Operating Characteristic (ROC) analysis, which characterizes the performance of model at all possible thresholds by a single number, was performed. Figure 7 gives the receiver operating curve for both training and test data. The area under the ROC curve (AUC) is also given. The red (training) line shows the "fit" of the model to the training data. The blue (testing) line indicates the fit of the model to the testing data. The turquoise line shows the line that would be expected if the model was no better than random. If the blue line (the test line) falls below the turquoise line then this indicates that model performs worse than a random model would. The further towards the top left of the graph that the blue line is, the better the model is at predicting the presences contained in the test sample of the data. The maxent in the present case produced the reasonable results. The AUC for training data was 0.854 and that for test data was 0.786. It is to be recalled that the random prediction would give and AUC of just 0.5.

These results on extent and locations of Rhododendron distributions in both the current and future climate scenarios give a deep insight to the conservation planners about the kind of strategy that needs to be adopted for conserving Rhododendrons in the face of climate change. The modelled distribution gives precise locations which are vulnerable and may need attention in case the Rhododendrons are to be preserved there or in case their replacement by other species is planned. However several challenges were observed while doing this analysis. These predictions can be made more robust if the limitations like unavailability of the high spatial resolution climate data, selection of all the bioclimatic variables and not only the suitable bioclimatic variables, non inclusion of other variables like soil type, vegetation dynamics, inter-specific competition, natural disturbance and landscape heterogeneity, dispersal mechanism etc are also considered. Further increased level of carbon-di-oxide may have a different physiological effect on Rhododendrons which has not been considered here.

BIBLIOGRAPHY

Austin, M. "Spatial prediction of species distribution: an interface between ecological theory and statistical modelling." *Ecol. Model* 157 (2002): 101-118.

Chatterji, Sudipto. *Climate Change and Rhododendrons in Himalayas.* Winrock International.

Dudik, M, S J Phillips, and R E Schapire. "Performance guarentees for regularized maximum entropy density estimation." *17th Annual Conference on Computational Learning Theory.* New York: ACM Press, 2004. 655-662.

Forman, RTT. "Growth under controlled conditions to explain the hieracrchial distribution of a moss,Tetraphis pellucida." *Ecological Monographs*, no. 34 (1964): 1-25.

Hijmans, J Robert, E Susan Cameron, L Juan Parra, G Peter Jones, and Andy Jarvis. "Very high resolution interpolated climate surfaces for global land areas." *International Journal of Climatology* 25 (2005): 1965-1978.

IPCC. "Summary for Policy Makers." *Climate Change 2007: The Physical Sciences.* Geneva: IPCC 21, 2007.

Kirschbaum, M. U. F., M. G. R. Cannell, R. V. O. Cruz, Galinski W., and W. P Cramer. "Climate change impacts on forests." In *Climate Change 1995, Impacts, Adaptation and Mitigation of Climate Change: Scientific–Technical Analyses*. Cambridge: Cambridge University, 1996.

Krishna, A P, S Chettri, and K K Singh. "Human Dimensions of Conservation in the Khangchendzonga Biosphere Reserve." *Mt. Res. Dev.* 24 (2002): 328-331.

Leach, D G. *Rhododendrons of the World.* New York: Scribner, 1961.

Liu, X., and B. Chen. "Climatic Warming in the Tibetan." *In International Journal of Climatology,* 20 (2000): 1729-1742.

McKenny, W Daniel, H John Pedlar, Kevin Lawrence, Kathy Campbell, and F Michael Hutchinson. “Potential impacts of climate change on the distribtution of north American trees.” *BioScience* 57, no. 11 (December 2007): 939-948.

Paul, A, M L Khan, A Arunchalam, and K Arunachalam. “Bioversity and Conservation of Rhododendrons in Arunachal Pradesh n the Indo-Burma biodiversity hot spot.” *Current Science* 89, no. 4 (2005): 623.

Pearce, J, and S Ferrier. “Evaluating the predictive performance of habitat models developed using logistic regression.” *Ecological Modelling* 133 (2000): 225-245.

Pearson, Richard G. “Species’ Distribution Modeling for Conservation Educators and Practitioners. Synthesis.” *American Museum of Natural History.* 2007. http://ncep.amnh.org.

Phillips, Steven J, and Miroslav Dudik. “Modelling Species Distribution with Maxent: new extensions and a comprehensive evaluation.” *Ecography* 31 (2008): 161-175.

Phillips, Steven J, R P Anderson, and R E Schapire. “Maximum entropy modeling of species geographic distributions.” *Ecological Modelling* 190 (2006): 231-259.

Pradhan, K C. *The Rhododendrons of Sikkim.* Tadong, Sikkim: Sikkim Adventures, Botanical Tours and Travels, 2010.

Pradhan, U C, and S T Lachungpa. *Sikkim Himalayan Rhododendrons.* Kalimpong, West Bengal: Primulaceae Books, 1990.

Rawat, Gopal S. “Predicting impact of climate change on Himalayan flora.” *International Workshop on Climate Change and its impact on flora in South Asia Region.* Lucknow: National Botanical Research Institute,Lucknow, India, 2008. 59-60.

Shrestha, A.B., C.P. Wake, P.A. Mayewski, and J.E. Dibb. “Maximum Temperature Trends in the Himalaya and Its Vicinity:An Analysis Based on Temperature Records from Nepal for the Period 1971-94.” *Journal of Climate* 12: 2775-2787.

Singh, K K, S Kumar, L L Rai, and A P Krishna. “Rhododendron Conservation in Sikkim Himalayas.” *Current Science* 85, no. 5 (September 2003): 602-606.

The Rhododendron Phenology Project at Royal Botanical Garden.
Wilfred, Thuiller. *Nature*, August 2, 2007: 550.

Xu, Jianchu, Arun Shrestha, Rameshananda Vaidya, Mats Eriksson, and Hewitt Kenneth. *The Melting Himalayas: Reginal Challenges and Local Impacts of Climate Change on Mountain Ecosystems and Livelihoods.* Technical, Kathmandu, Nepal: ICIMOD, 2007, 7.

Yao, T D, et al. “Record and Temperature Change over the Past 100 years in Ice Cores on the Tibetan Plateau.” *Science in China:Series D Earth Science*, 2006: 1-9.

AUTHOR

Pradeep Kumar
Forest Secretariat, Deorali,
Gangtok -737101, Sikkim, India
Email: sk034.ifs@nic.in

Rhododendron falconeri is an associate species in the oak forests, which are vulnerable to the impacts of ascending forest fires