Modeling environmental niche of Himalayan birch and remote sensing based vicarious validation

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Abstract: The objective of the study was to model the environmental niche of a dominant treeline species (Himalayan birch or Betula utilis) in alpine region of Indian Himalaya and validate the findings using ground truth supported satellite remote sensing technique. It deals with the generation of bioclimatic indices from temperature and precipitation data, followed by fundamental environmental niche modeling based on the presence-only records of the alpine treeline ecotone (ATE) boundary species. The predicted fundamental environmental niche was validated in Uttarakhand, India using the alpine treeline ecotone boundary (a surrogate to realized niche), which was generated using IRS-P6 (LISS-III) satellite data for year 2006. The result demonstrates the ability of the niche models in assessing the probable extent of Himalayan birch distribution and its presence in treeline ecotone of Uttarakhand and the technique could be further used for modeling future scenario of the alpine treeline in Indian Himalaya.

Resumen: El objetivo del estudio fue modelar el nicho ambiental de una especie dominante del límite de la vegetación arbórea (abedul del Himalaya o Betula utilis) en la región alpina del Himalaya indio, así como validar los hallazgos con técnicas satelitales de percepción remota apoyadas en verificación de campo. Se generaron índices bioclimáticos de datos de temperatura y precipitación, seguido del modelado del nicho fundamental ambiental con base en registros sólo de presencia de las especies del ecotono alpino del límite de la vegetación arbórea. El nicho ambiental fundamental predicho fue validado en Uttarakhand, India, utilizando el borde del ecotono del límite alpino de la vegetación arbórea (un sustituto del nicho realizado), que se generó a partir de datos de satélite IRS-P6 (LISS-III) para el año 2006. El resultado demuestra la habilidad de los modelos de nicho para evaluar la extensión probable de la distribución del abedul del Himalaya y su presencia en el ecotono del límite de la vegetación arbórea de Uttarakhand. Además, la técnica podría usarse para modelar escenarios futuros del límite alpino de la vegetación arbórea en los Himalaya indios.

Resumo: O objetivo do estudo foi modelar o nicho ecológico de uma espécie dominante (videoeiro dos Himalaias ou Betula utilis) na linha de árvores da região alpina do Himalaia indiano e validar os resultados das observações por detecção remota por satélite com as observações da realidade de terreno. Aborda-se a geração de índices bioclimáticos a partir dos dados de temperatura e precipitação, seguida da modelação do nicho ambiental fundamental apenas com base nos registos de presença das espécies de fronteira do ecotono alpino (ATE) da linha limite de árvores. O nicho fundamental ambiental predito foi validado em Uttarakhand,
Índia usando o limite alpino da linha de árvores do ecótono alpino (um substituto para nicho efectuado), que foi gerada usando dados do satélite IRS-P6 (LISS-III) para o ano de 2006. O resultado demonstra a capacidade dos modelos de nicho para avaliar a extensão provável da distribuição do videoeiro dos Himalaias e a sua presença no ecótono da linha de árvores de Uttarakhand e que a técnica pode ainda ser utilizado para a modelação de cenários futuros da linha de árvores alpina nos Himalaias indianos.

**Key words:** Alpine treeline ecotone (ATE), bioclimatic indices, environmental niche, GARP, NDVI, remote sensing, Uttarakhand.

**Introduction**

With the current concern on the impact of global climate change to plant distribution, speciation and extinction, it is important to study the climate sensitive species. Species living on their physiological limits are sensitive enough to such changes and can be used as indicators. Alpine treeline species are climatically determined ecotones and very sensitive to changing temperature regime. Grabherr *et al.* (1994) and Gottfried *et al.* (1998) reported an upward elevation migration of the alpine-nival (uppermost) flora, a change they linked to climatic warming. Panigrahy, Anitha, Kimothi & Singh (2010); Panigrahy, Singh, Thapliyal, Kimothi & Parihar (2010) and Singh *et al.* (2012) also reported upward migration of alpine treeline in Indian Himalaya. Myneni *et al.* (1997) reported increased plant growth from 1981 to 1991 in the northern arctic latitudes and related it to increased CO₂ levels and warmer temperatures. Examining climatic preferences of indicator species using bioclimatic niche modeling is a key tool in understanding the shifts in the fundamental environmental niche of alpine treeline species due to global change impacts. Accurate modeling of the present fundamental environmental niche of climate sensitive species is important, so that, the response of species as a result of changing climatic scenario could be modeled with better accuracies. Most modeling approaches developed for predicting plant or animal species distributions have their roots in quantifying species-environment relationships.

The environmental niche can be viewed as the set of environmental conditions that allow a given species in question to survive, reproduce and grow. However, a species can occupy only a part of its fundamental environmental niche in a particular ecosystem - that is its realized niche. The fundamental environmental niche models are basically aimed at providing a detailed prediction of distributions by relating presence of species to environmental predictors. For example, species distribution models have been used to study relationships between environmental parameters and species richness (Mac Nally & Fleishman 2004), characteristics and spatial configuration of habitats that allow persistence of species in landscapes (Araújo & Williams 2000; Scotts & Drielsma 2003), invasive potential of non-native species (Peterson 2003), species distributions in past (Peterson *et al.* 2004) or future climates (Skov & Svenning 2004) and ecological and geographic segregation of the distributions of closely-related species (Cicero 2004).

A review of literature has shown that, there are lots of methods for modeling species distributions that vary in how they model the distribution of the response, select relevant predictor variables, define fitted functions for each variable, weight variable contributions, allow for interactions, and predict geographic patterns of occurrence (Burgman *et al.* 2005; Guisan & Zimmerman 2000). Species presence-only (Carpenter *et al.* 1993) or presence and absence (Keating & Cherry 2004; Zaniewski *et al.* 2002) records are used popularly for such modeling based either on calculations of envelopes or distance-based measures. However, in comparison to the fundamental niche model showing maximum possible climatic level for species in question, the realized-niche may still appear quite below it (Malyshev 1993) because of limitations of such models in taking care of dispersal, competition or other abiotic factors.

Presently there are very few studies on the distribution of treeline ecotone species in the Himalaya. Information of the potential distribution of the treeline species in Himalaya is impor-
Fig. 1. Location map of study area draped over false colour composite (FCC) of IRS P6 (LISS-III).

Venant in view of the initiatives by various stakeholders in understanding and conservation of Himalayan Ecosystem. With the above facts in mind, it is important to evaluate performances of such models. In improving evaluation of model performance independent, well structured presence-absence datasets for validation should be used. However, such datasets have rarely been used or available to evaluate predictions from presence-only models. There could be possibility of using simulated data (Austin et al. 1995) and assessing whether responses are correctly predicted, or modeling with both presence-only and presence-absence data and comparing the fitted functions. In the present study, we have adopted a novel approach by using the remote sensing data to evaluate the performance of the prediction with some constraints mainly due to lack of good field inventories. The primary aim of this study is to evaluate the capacity of presence-only occurrence data for predicting Himalayan birch distributions with vicarious validation of the prediction using remote sensing derived surrogate parameter (Alpine Treeline Ecotone: ATE boundary). The ATE boundary is majorly populated with Himalayan birch (*B. utilis*) commonly known as “Bhojpatra” to form present-day alpine treeline in the study area (Uttarakhand).

**Methods**

The study was carried out in Uttarakhand state falling in western Himalayan ecoregion. Uttarakhand has a geographic area of 5.35 million ha (=1.6 % of India) and 64.79 % of the state’s geographic area is under forest (FSI 2008). It extends between 77° 34’ and 81° 03’E Longitude and 28°43’ and 31° 28’N Latitude (Fig.1). The state has two main traditional politico cultural regions known as Garhwal and Kumaon. The state comprises of 13 districts housing important national parks of India such as the Corbett National Park, the Rajaji National Park and the Nanda Devi Biosphere Reserve. Uttarakhand is bordered by China in the north and Nepal in the east. Two of India’s major rivers, the Ganga and the Yamuna, originate in the glaciers of the state. The state can be divided into three physiographic regions *viz.*, the Himalaya, the Shivaliks and the plains. Northern parts of the state are covered by the high
Himalayan ranges and glaciers, while the lower reaches are densely forested. The state comes under the west Himalayan biogeography zone characterized by drought-resistant plants dominated by the gregarious conifer forests of chir, blue pine, deodar, and fir (Champion & Seth 1968). Main forest types occurring in the study area are conifer forest, alpine meadows, temperate broadleaved forest, tropical moist deciduous forests, scrubs, and others. The sub-alpine and alpine zone of the state starts from elevation of 2500 m and above with very low annual precipitation (dry alpine region) and areas with high annual precipitation (wet alpine region). The sub-alpine forests that occur above the elevation zones of 3000 m are characterized by the presence of *B. utilis* and *Abies spectabilis* (Khanna & Chaturvedi 2000). This study area was selected because of its status as home to *B. utilis* as one of the leading alpine treeline ecotone (ATE) species.

The entire study is done in two major parts, the first part deals with the generation of bioclimatic indices from temperature and precipitation data, followed by fundamental environmental niche modeling based on the presence-only records of the alpine treeline ecotone (ATE) boundary species (*B. utilis*). The second part deals with the current ATE boundary delineation using IRS-P6 (Resourcesat-1) LISS-III data. Further, evaluation of the modeling results was done on the basis of their spatial co-occurrences. The methodology flowchart is given in Fig. 2.

**Climatic data & bioclimatic indices**

To generate the bioclimatic indices the prerequisite condition is to have good quality climatic records at best possible spatial resolution. Current climatic (Version 1.4, release 3) data based on observations from year 1950 - 2000 were taken from World Clim (Hijmans et al. 2005; http://www.worldclim.org). The minimum temperature, maximum temperature and monthly total precipitation data were used for generating more biologically meaningful variables i.e. 19 bioclimatic indices (Fig. 3) using BIOCLIM model implemented in DIVA-GIS (ver. 7.1.7.2). Bioclimatic indices as a surrogate terms are used to approximate energy and water balances at a given location. They 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).

**Species occurrence data**

The Global Biodiversity Information Facility (GBIF, http://data.gbif.org) was chosen because of the rich and free accessibility of the species data. Presence-only data was used as it was found by Elith et al. (2006) that, the presence-only data are useful for modeling species distributions than presence-absence data. The database downloaded with the geographical location information was converted to geographic information system (GIS) ready vector point features. The total number of searches on *Betula* genus returned 1,760 locations of family Betulaceae. Further searches specifically on *Betula utilis* returned only 61 locations. The total point location data of 1,821 were further checked for its locations reliability. Out of the 61 locations on *B. utilis*, 16 locations were finally selected as input to the GARP environmental niche model (Fig. 4). The criterion for selection was nearness to the Indian Himalayan region. This was done as GPS location of *B. utilis* was not available for Uttarakhand. The study may have some limitations in projecting *B. utilis* distribution due to variations in the precipitation regimes in Nepal Himalaya and Uttarakhand Himalaya.

**GARP based prediction of Betula utilis distributions**

To predict the *B. utilis* distribution from presence-only occurrence data, GARP (Genetic Algo-
Fig. 3. Bioclimatic Indices derived using BIOCLIM model.


GARP uses a set of rules (e.g. adaptations of regression and range specifications) that best predicts the species distribution (Stockwell & Peters 1999). Like a typical genetic algorithm, which requires a genetic representation of the solution domain, and a fitness function to evaluate the solution domain, the set of filtered point localities, where the species is known to occur and a set of geographic layers representing the environmental (temperature, precipitation and topography based) space that might limit the species' capabilities to survive, were given as input to the GARP model. The model gives final solution as environmental conditions under which the species should be able to maintain populations.

The method assumes that bioclimatic predictor variables control the native distribution of alpine treeline species, and mainly these factors are responsible for the potential distribution of the species. Based on only 15 to 20 records of locations of a species from its native home range (species input data), the method can predict the potential distribution (home range, or niche) of a species.
Current Alpine Treeline Ecotone (ATE) boundary delineation

The altitude above 3,000 metres is generally considered a zone of sub-alpine and alpine vegetation. The ASTER GDEM was taken to carry out the zonation. Cloud free (< 10 %) IRS-P6 LISS-III images acquired during October - December, 2006 were used for delineation of current alpine treeline ecotone (ATE) boundary. IRS-P6 LISS-III images were georeferenced using the image to image matching technique. To make all images comparable DN values were converted to reflectance (Panigrahy, Singh, Thapliyal, Kimothi & Parihar 2010). Further, the NDVI was calculated using following formula:

\[ \text{NDVI} = \frac{\rho_{\text{NIR}} - \rho_{\text{R}}}{\rho_{\text{NIR}} + \rho_{\text{R}}} \]

where, \( \rho_{\text{NIR}} \) is reflectance of Near Infrared band and \( \rho_{\text{R}} \) is reflectance of Red band. The NDVI \( \geq 0.4 \) were subjected to “iso-NDVI-line” generation coupled with visual interpretation based editing in shadow areas. The 8th Cycle digital FSI forest maps (FSI 2002) were used for cross-checking of ATE boundary. Limited numbers of ground truths were also carried out to ascertain the treeline thresholds, boundaries and presence of \( B. \text{utilis} \). Phenological correctness of ATE was also ensured using 10 years (1999 - 2008) time-series NDVI data from SPOT-VGT. This approach has limitations in delineating exact alpine treeline ecotone using NDVI which extracts the vegetation component in a pixel as a cumulative response. Since the alpine treeline ecotone signature constitutes the background reflectance of bare rocks, thin vegetation and scattered trees, the NDVI value may show large variability.

Vicarious validation of predicted Betula utilis distribution

The most rigorous evaluation of any model is a test of its ability to correctly predict independent data that have not been processed by the model. In this work, GARP model based result was evaluated by comparing the independent occurrences of ATE boundary from satellite based remote sensing data. Validation of such predictions generally requires direct field measurements. However, establishing a linear correspondence
between predicted *B. utilis* distribution *vis-a-vis* independent remote sensing based derived ATE boundary can be used with the ground knowledge of *B. utilis* being the ATE boundary species in the study area. Since, presence of trees is much easier to validate at moderate (23.5 m) resolution satellite data than any other method; we refer this process as vicarious validation.

ATE boundary measuring 2,962 km in surface length was subjected to station point generations for validation. The station points were generated at equal spacing of 1 km over the ATE boundary and the values of *B. utilis* distribution raster (predicted by GARP model) were transferred to the vector “treeline” station points. The percentage of station points having predicted distribution raster values were computed. The Global-ASTER DEM at 30 m spatial resolution was also used to see the elevation distribution of ATE boundary as well as GARP predicted area.

### Uncertainty assessment

To establish the overall uncertainty in the study, an analysis was carried out. The satellite based mapping in such terrain has two error components; horizontal mapping error and vertical error due to DEM. Mapping uncertainty of 50 m for LISS-III and 20 m of ortho-rectification error was used to compute the uncertainty in ATE boundary mapping. Combining these errors using quadratic sum of the errors the overall uncertainty in the current ATE assessment comes out to be ± 54 m. A methodology given by Fielding & Bell (1997) was used to establish the accuracy of the GARP model based prediction. The area under curve (AUC) derived from the receiver operating characteristic (ROC) plot of this model can be interpreted as a measure of the ability of the algorithm to discriminate between a suitable environmental condition and a random analysis background pixel (Manel *et al.* 2001). The ROC score with total area under curve was 0.93 and correct classification accuracy of GARP was found to be 86.95 %.

### Results and discussion

Analysis was carried out to evaluate the fundamental environmental niche of *B. utilis* under current bioclimatic conditions. Fig. 5 shows the map of predicted environmental niche of *B. utilis*. The modeled response shape matches accurately with the current alpine treeline. The validation results, however, show that 84 % of the ATE points were in conformance with the GARP predicted locations. The remaining 16 % locations were falling in lower reaches and found to be the zone of *Abies* sps. (another treeline species in alpine Himalaya). The areas modeled above ATE boundary are found to be covered by other vegetation (NDVI = 0.25 - 0.4; e.g. shrubs and grasslands). The ATE highest elevation was found to be 4,573 m with mean value of 3,558 m. The GARP predicted distribution shows highest elevation up to 6,156 m with mean value of 4,172 m for the distribution. Interestingly, the remote sensing based other vegetation line (shrubs and grasslands) maximum elevation is found to be 6,157 m. This clearly indicates that the fundamental niche of *B. utilis* is already occupied by other vegetation. GARP model is capable of modeling the fundamental environmental niche of *B. utilis* with the 86.95 % accuracy. The model fails in capturing the exact realized-niche because of its inherent limitation to account for dispersal mechanisms, competition or other abiotic factors which are complex in nature and difficult to model. Further, the results need to be confirmed with post field validation, as the GARP model has been trained using other location data. Nevertheless, notwithstanding these limitations, the study generates useful information about the probable distribution of *B. utilis* in the sub-alpine zones of Uttarakhand Himalaya. With further ground validation the study can provide valuable insights into the potential distribution of *B. utilis* and in case of climate change, upward movement of the fundamental niche of the species.

### Conclusions

*Betula utilis* bioclimatic envelop overlaps 84 % of the remotely sensed treeline ecotone. This establishes the fact that the environmental conditions of the alpine zone of Uttarakhand are conducive for the dominance of *B. utilis* as a treeline species. The modeled fundamental niche shape matches accurately; however, the realized-niche (remotely sensed ATE boundary) still appears quite below the maximum bioclimatic level because of modeling limitations of dispersal, competition or other abiotic factors. This also suggests that in changing climatic conditions, *B. utilis* still has enough summit levels to populate.

The good agreement between the predicted environmental niche and the independent remote
sensing based ATE boundary (realized-niche) shows the potential use of such models towards understanding of the future climatic scenario of such climate sensitive species. This also provides insights into whether and how the increasingly available data on climatic conditions and species presence can be used for improving knowledge of species distribution ranges. The modeling accuracy of 86.95 % is encouraging but the inherent limitation of not being able to account for complex issues like dispersal, competition or other abiotic factors warrants further improvement for better scenario building.

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