EFFECT OF TOPOGRAPHY ON THE DISTRIBUTION OF TROPICAL MONTANE FOREST FRAGMENTS: A PREDICTIVE MODELLING APPROACH

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BUNYAN M, BARDHAN S, SINGH A & JOSE S. 2015. Effect of topography on the distribution of tropical montane forest fragments: a predictive modelling approach. Topography and elevation influence vegetation across biomes in terms of species composition and assemblages. Topographical variables have been used to determine species richness, regional biodiversity patterns, forest health, species distributions and gradients of exotic species. Within the Western Ghats of India, the potential of geographic information systems and remotely-sensed data in characterising tropical montane forests (locally known as sholas) has been investigated. In this study, the influence of topographical variables in determining the presence of shola fragments was tested. A multiple logistic regression approach was used to predict presence or absence of insular fragments in the matrix of grasslands using elevation data. We observed that topographical variables significantly predicted whether the vegetation type was shola or non-shola. Of all the variables, aspect (as quantified in eastness and northness) strongly determined the presence of shola fragments whereas wetness index and curvature of slope influenced the results to a lesser extent. Positive correlation of wetness index with the presence of shola fragments suggested the maintenance of shola by hydrological regulation.

Keywords: Shola forests, Western Ghats, GIS, biodiversity, species composition, shola fragments

INTRODUCTION

The influence of topography on vegetation across biomes is well known. For example, increasing elevation changes plant communities. For a given latitude, a change in elevation implies a shift upward in species composition and assemblages progressively to alpine or boreal communities. Although the influence of other topographical variables on processes has been known for a while, research continues to be directed at it. Recently, topographical variables have been used to determine species richness (Hofer et al. 2008), regional biodiversity patterns (Coblentz & Riitters 2004), forest canopy health (Stone et al. 2008), species distributions (Warren 2008) and gradients in exotic species (Qian 2008). This is driven in part by the global availability of high resolution elevation data (e.g. www.landcover.org) coupled with the availability of high speed computing platforms (Coblentz & Riitters 2004). Within the Western Ghats, the potential of geographic information systems (GIS) and remotely-sensed data in tropical ecosystems from the perspective of a landscape was recognised early (Menon & Bawa 1997). Studies have since utilised these tools to highlight gaps in the network of conservation areas (Ramesh et al. 1997), quantify threats (Barve et al. 2005) and prioritise areas for conservation.

Topographically-based analyses are especially insightful in mountainous regions, presumably due to the extent of topography-related heterogeneity. In a study on tropical montane forests in Ethiopia, topography-related variation in soil physicochemical characteristics and proximity to water accounted for differences in forest communities (Aerts et al. 2006). Similarly,

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a study in an Indonesian tropical montane forests revealed that topography induced variation in relative humidity and wind velocity influenced presence of species (Sri-Ngernyuang et al. 2003). Abiotic environment (e.g. temperature, soil moisture) is important in determining the ability of plants to establish, grow and reproduce (Gurevitch et al. 2002). An extensive determination of the abiotic environmental variables at the scale of a landscape (or larger) may not be feasible. However, the relative ease of determination of topographical variables using extensive, large-scale elevation data make these variables suitable surrogates for abiotic environmental conditions.

Tropical montane forests topography can result in creation and maintenance of abrupt boundaries or edges. For instance, the Cordilleras in the Dominican Republic exhibit a discrete tropical montane–pine forests ecotone maintained by a combination of fire and frost (Martin et al. 2007). Similarly, abrupt boundaries have been observed for tree islands in the Ecuadorian Andes (Coblentz & Keating 2008). In the Western Ghats, tropical montane forests (or sholas) consist of insular forest fragments in a matrix of grasslands (Jose et al. 1996, Bunyan et al. 2012a). Carbon isotope analysis of peat samples from the ecosystem mosaic reveals a cyclical shift in dominant vegetation type (forest or grassland) corresponding to glacial cycles (Sukumar et al. 1995). The edge is thus assumed to be natural in origin although its persistence may be due to a combination of natural (fire, frost, edaphic) and anthropogenic (fire) factors. Shola fragments are characterised by high species diversity (α-diversity) and endemism (Jose et al. 1994, Nair & Menon 2001). In addition, fragments have been shown to have high degree of complementarity, i.e. high diversity among fragments (Bunyan et al. 2012b). Since patterns in plant distributions are non-random (Greig-Smith 1979), predicting their occurrence is dependent on quantifying ecological variables controlling incidence (Franklin 1995). In this study, the influence of topographical variables in determining the presence of shola fragments was tested. A multiple logistic regression approach was used to predict presence or absence of insular fragments in the matrix of grasslands in two disjunct study sites in southern India using elevation data.

Since the south-west monsoon contributes bulk of the rainfall in both our study sites, we hypothesised that the presence of fragments will be negatively correlated with eastern aspects (hereafter eastness). Further, we hypothesised weak or no correlations with northern aspects (hereafter northness), since north–south aspects are not expected to be significant at the low latitudes of our study sites. Preliminary field observations indicate that shola fragments are more likely to be found on steeper, wetter slopes. Accordingly, we also hypothesised that presence of shola fragments would be positively correlated with wetness index.

At a regional scale, we expected differences between study sites at macro scale (as defined by Delcourt & Delcourt 1988). Although topographical variables are assumed to be acting similarly on the same ecosystem mosaic, differences in site history may result in differences in response to topographical variables (Bader & Ruijten 2008).

MATERIALS AND METHODS

Study area

Two distinct areas, one in the Eravikulam National Park (Eravikulam) and another in the Nilgiris were selected for the purpose of our study. Eravikulam is located in the Anaimalai Hills within the state of Kerala, India (Figure 1). The park consists of a base plateau at an elevation of 2000 m surrounded by peaks with maximum elevation of 2695 m at Anaimudi. The soil is classified as Vertisols and described as Arachaen igneous in origin and consisting of granites and gneisses. Soils are sandy clay, have moderate depth (30–100 cm) and are acidic (pH 4.1–5.3). Mean maximum temperature recorded within Eravikulam is 16.6 °C while mean minimum temperature is 6 °C. Eravikulam receives rainfall of approximately 5200 mm annually from the south-west and the north-east monsoon with the former contributing as much as 85% of the annual rainfall with a brief dry period (January till April). Although contiguous rainforest formations can also be found at lower elevations, vegetation in the park is predominantly shola–grassland ecosystem mosaic consisting of rolling grasslands interspersed with dense, insular shola fragments. Additionally,

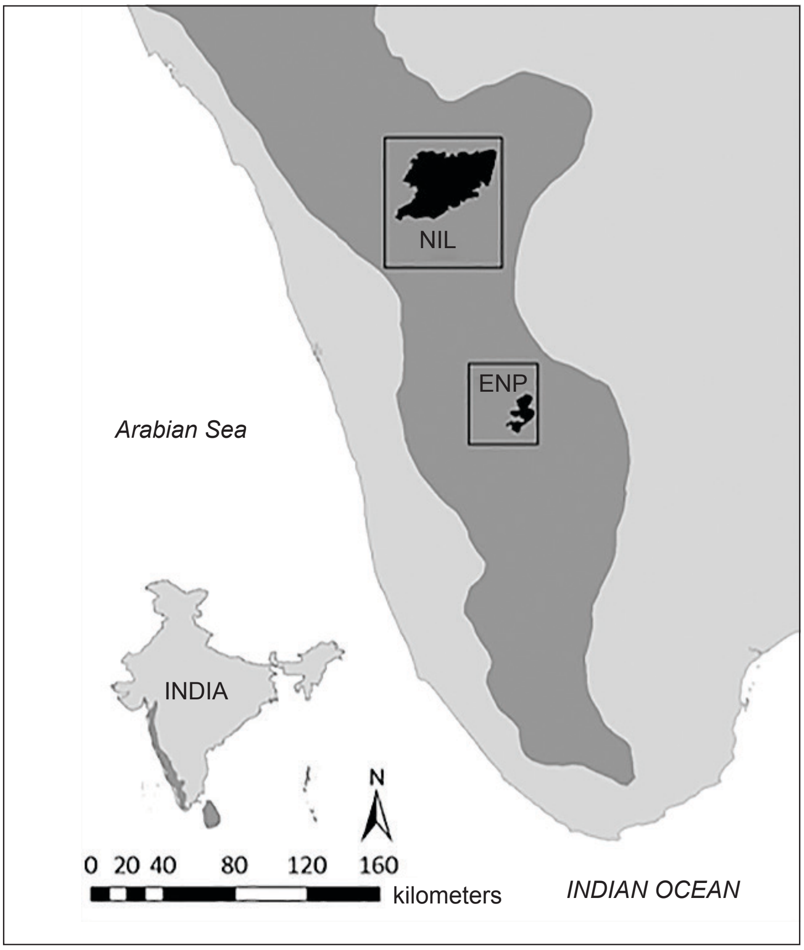

Figure 1 Location of study sites, Nilgiris (NIL) and Eravikulam National Park (ENP) in the Western Ghats, India

exposed rock formations and cliffs and lower elevation forests occupy 5.9 and 8.5% of the total area of Eravikulam (Menon 2001).

The second study area Nilgiris is located in the state of Tamilnadu and includes the Mukurthi National Park in the Nilgiri Biosphere Reserve. Details on the second study site are reported in Zarri et al. (2008). Together, our two study sites represent the two largest contiguous extents of the high elevation shola–grassland ecosystem mosaic.

Imagery pre-processing and data preparation

Elevation was derived by digitising topographical maps at a scale of 1:50,000 (58 F/4, 58 F/3; Survey of India (http://www.surveyofindia.gov.in/)) at 20-m intervals for Eravikulam (ArcGIS 9.2) to generate digital elevation model. Remotely-sensed enhanced thematic mapper plus (ETM+) imagery (acquisition date: 14 January 2001) was used to identify and digitise shola fragments in Eravikulam. Images were pan-sharpened and a principal component analysis low-pass filter was used to enable clearer delineation of shola fragments from grasslands (ERDAS Imagine 9.2). Similarly a digital elevation model (at 30-m contour intervals) and a landscape map were generated for the Nilgiri Hills (see Zarri et al. 2008 for details). In both these areas, these contour intervals represented the best scale of elevation information available. In addition to elevation, all other topographic covariate layers were developed using digital elevation models (Table 1). A grid of random points was generated for Eravikulam (1341 points) and the Nilgiris (2188 points). Shola points were identified by overlaying the points with digitised shola fragments and declaring all other points as non-shola. In order to further distinguish shola

Table 1 Topographical variables used to predict presence of shola fragments in the Western Ghats, southern India

Model parameter	Description
Northness	sin (aspect)
Eastness	cos (aspect)
Wetness index	ln $(A_s/(\tan(\beta))$ †‡
Location code	Boolean (Eravikulam = 1, Nilgiris = 0)

A_s: flow accumulation grid, β: slope (radians); †Moore et al. 1993, ‡Gessler et al. 1995

fragments from non-shola forest types, all points below 1700 m were masked and excluded from further data analysis because at elevations below 1700 m, separation of shola vegetation from evergreen forest may require more intensive land cover classification model which was beyond the scope of this investigation. Estimates of topographic covariates were extracted for these points (Eravikulam: 401 shola, 940 non-shola, Nilgiris: 666 shola, 1522 non-shola).

Digital elevation model was used to derive the following topographical variables: slope, aspect (eastness and northness), curvature of the slope and wetness index (Table 1). The wetness index (also termed compound topographical index) combines topographical variables with resource variables (moisture) while the other variables represent direct topographical variables. Curvature of the slope was calculated using ArcGIS 9.2. Positive curvature indicates that the surface is downwardly convex at that cell while negative curvature indicates that the surface is upwardly concave at that cell. A value of zero indicates that the surface is flat.

Predictive modelling

In order to quantify topographically-dependent variables that influence the distribution of sholas in the ecosystem mosaic, three models were generated. For the first model, data for the two areas were combined and a dummy variable was introduced to test for differences between sites. Since these two areas represent disjunct ecosystems (distance between Eravikulam and Nilgiris ~ 120 km), the dummy variable would test for regional differences. A multiple logistic regression model was used for deriving estimates of the coefficients for topographical parameters and area under the receiver operating characteristic curve (AuC). The AuC value is the proportion of randomly-drawn pairs of shola and non-shola points that are correctly classified using the multiple logistic regression model. A value of 0.50 therefore indicates a random process (i.e. there is an equal probability of the point being shola or non-shola), whereas a value ≥ 0.50 indicates a non-random process. A total of 76% of the data were randomly selected for training the model and 25% were retained as a cross-validation set. This process was repeated to 1000 iterations and a dataset containing parameter coefficients and AuC estimates for each iteration was created. Two-tailed t-tests were used to test for (1) AuC estimates to be significantly different from random (AuC > 0.50) and (2) significance of parameter coefficients ($\beta_i > 0$). We used R programming (2008) language throughout.

Two additional models were developed using the data subsets (Eravikulam and Nilgiris) to cross validate each other. This was done to obtain conservative estimates of our parameter coefficients and increase the robustness of our model. For the second model, the Eravikulam data subset was used to train the model and this was used to predict the presence of shola fragments in Nilgiris. Similarly, for the third model, the Nilgiris data subset was used to train the model and this was used to predict the presence of shola fragments in Eravikulam. As with model 1 (the combined model), a multiple logistic regression model was used and repeated to 1000 iterations on the second and third models to obtain topographical coefficients and AuC estimates for Nilgiris and Eravikulam respectively. AuC values from models 2 and 3 were then compared using t-test ($p < 0.05$). When the two models were compared, data subset for the model with significantly larger AuC was declared as a better predictor of the presence of shola fragments based on topographical variables. Two-tailed t-tests were used to compare the strength and direction of topographical parameter coefficients across models 2 and 3.

RESULTS

Combined model

For the combined model, topographical variables significantly predicted whether the vegetation type was shola or non-shola. The distribution of shola fragments was significantly different from random as indicated by the area under the receiver operating curve (AuC = 0.714, standard error (SE) = 0.0005, $p < 0.0001$). All topographical variables were highly significant ($p < 0.0001$, Table 2). Coefficients for northness were positive while those of eastness were negative as related to the presence of shola fragments ($p < 0.0001$). Coefficients for wetness index, slope and elevation were positive and negative for curvature of the slope (for all $p < 0.0001$). Significant differences were also seen between the study sites ($p < 0.0001$) with the Nilgiri data subset predicting presence of shola fragments in Eravikulam better than the use of the latter dataset to predict shola fragments in the former ($p < 0.0001$).

Data subsets

The Nilgiris data subset was able to distinguish shola fragments from non-shola in Eravikulam better (AuC_{NIL} = 0.624) than vice versa (AuC_{ERV} = 0.709). While all parameter coefficients from both models differed in magnitude, they did not differ in direction (Table 2 and Figure 2). For both models, aspect (as quantified in eastness and northness) strongly determined the presence of shola fragments whereas no change wetness index (β_{CTI}) and curvature of slope (β_{CUR}) influenced the results to a lesser extent.

DISCUSSION

Results from our multiple logistic regression models clearly indicated the influence of topography-induced variation on the location of shola fragments relative to the surrounding non-shola matrix. AuC estimates provided statistical validation for strong non-random pattern of shola fragments in the mosaic. The effect of elevation in determining the presence of shola fragments was unexpected in all our models *a priori.* This could be due to our exclusion of points below 1700 m. However, at elevations below 1700 m, separation of shola vegetation from evergreen forest might require a more intensive land cover

Table 2 Topographical parameter coefficients and AuC estimates for predictive models

Model output	Model type (number)		
	Combined	Nilgiris	Eravikulam
	(1)	(2)	(3)
AuC	0.71	0.62	0.70
Parameter coefficient			
Intercept	-8.2730	-9.6763	-6.7185
Elevation	0.0032	0.0038	0.0024
Slope	0.0234	0.0459	-0.0023
Northness	0.3895	0.5703	0.3327
Eastness	-0.1324	-0.2673	-0.1080
Curvature of the slope	-0.0416	-0.0634	-0.0365
Wetness index	0.0582	0.0215	0.0914
Location	-0.2786	–	–

Coefficients represent mean values from 1000 runs; training datasets for the models were pooled data from the Eravikulam and Nilgiris data subsets for the combined model, Eravikulam for the Nilgiris model and Nilgiris for the Eravikulam model; all parameter coefficients were significant at $p < 0.0001$; AuC = receiver operating characteristic curve

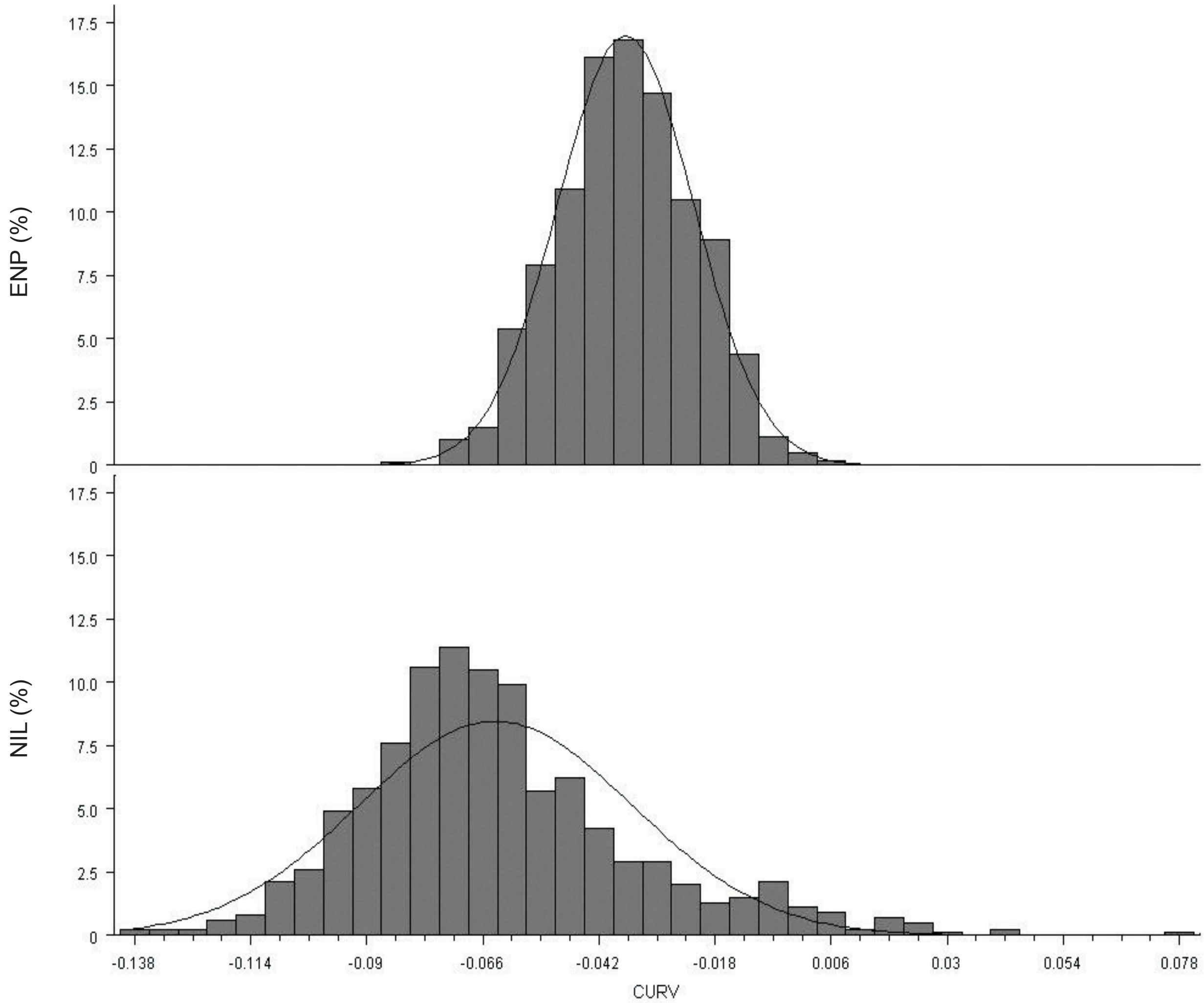

Figure 2 Histogram of curvature of the slope coefficients (CURV) for Eravikulam National Park (ENP) and Nilgiris (NIL) data subsets; superimposed curves represent normal curves

classification model which was beyond the scope of this investigation. Shola fragments below 1700 m (mid-elevation sholas) have also been shown to differ compositionally and structurally from high elevation shola fragments and might warrant a formal partitioning into forest sub-types (Bunyan et al. 2012a). Digitised shola fragments in Eravikulam and field observations indicated the presence of fragments (as large as 2 ha) at 2500 m and absence only from the highest peaks, possibly due to the extremely steep terrain on those peaks (e.g. Anaimudi). The topographical limitation on elevation in the Western Ghats prohibited the formation of true tree line as seen in other tropical montane forest ecosystems (Troll 1973, Bader & Ruijten 2008). This might explain the lack of strength associated with elevation in our models.

Shola fragments were also likely to be found on northern and western aspects. The proportion of rainfall attributed to the south-western monsoon in Eravikulam and the Nilgiris might explain the preponderance of shola fragments on western slopes which support our hypothesis. The dependence of shola fragments on the availability of soil moisture is also reflected in the direction of the response to the wetness index (compound topographical index). The response to wetness index is significant as topographical variables that combine a measure of topography with resource variable (such as compound topographical index) have been shown to predict patterns in vegetation better than those that measure topography alone (Franklin et al. 2000). Significant bias of shola fragments to north-facing slopes was unexpected and contrary to our hypothesis. Aspect induced variations in solar exposure along a north–south gradient are unlikely to be significant at the latitude associated with the study sites (10° 05'–11° 32' N). During the months corresponding to the south-western monsoon (May till October) significant differences in wind exposure are predicted as southern aspects (exposed to monsoonal winds) are likely to have higher exposure to wind than northern aspects. This might limit the establishment of tree cover on southern aspects. However, evidence for wind exposure-related restriction of shola fragments in this study is tenuous at best. In addition to wind, diurnal variation in radiation causes aspect-related differences in the tree line in Andean tropical montane forest (Bader & Ruijten 2008). The authors surmise that more radiation is received earlier in the day (i.e. eastern aspects) which causes photo inhibition in maladapted plants. Lack of data on diurnal variation in intensity of radiation from our study, however, precluded such conclusions.

Curvature of the slope (or terrain shape index) is a measure of the shape of the landform. For shola fragments, presence of shola fragments was significantly linked to negative coefficients which are indicative of concave slopes. This is in accordance with field observations and proves our hypothesis. Similarly, the coefficient for slopes was positive, i.e. sholas were present on steeper, more inaccessible terrain.

Comparison of data subsets

The use of the Nilgiri dataset to predict the presence of shola fragments in Eravikulam produced better results. However, the coefficient of topographical parameters was stronger for the Nilgiri model. This could be explained by differences in the history of the study sites as Bader and Ruitjen (2008) suggested from their study in Andean tropical montane forests. Between the two study sites, Eravikulam was better, having received formal protection from colonial times and was used as a game reserve by colonial rulers. Further, unlike tropical montane forests in other parts of the Western Ghats (including the Nilgiri) historical management of the grasslands (and indeed even the sholas) in Eravikulam did not involve extensive afforestation with exotic plantations. While the influence of topographical variables on shola presence/absence in Eravikulam (and consequently using that data subset to predict presence/absence of fragments) was more indicative of processes with limited human influence, both sites were not completely free of human influence.

Implications for the shola–grassland edge

Historically, theories on the persistence of the shola–grassland edge in the ecosystem mosaic include frost, frequent fires and other edaphic limitations. While shola and grassland soils have been shown to exhibit little variation in soil physicochemical properties and soil depth, topographical variables such as wetness index can also provide insights into patterns of fire and frost. Areas with high wetness index also indicate wetter areas that are likely to be precluded by fire, protecting tropical montane fragments. Studies have shown that patterns in water accumulation and frost occurrence are often similar. Areas with high wetness index (such as depressions) are likely to have higher occurrence of frosts, reducing the potential for shola fragment persistence (Blennow 1998). This is in contrast to the shola–grassland ecosystem mosaic where sholas are located within depressions. Thus, the positive correlation of wetness index with the presence of shola fragments indicated that, in addition to strong linkage to hydrological regulation, fire rather than frost might be responsible for the maintenance of the edge. Additionally, patterns in exposure to wind might also be responsible for the edge.

CONCLUSIONS

A common problem associated with predictive modelling is the lack of discrete boundaries between habitat patches and high variation within patches (Hofer et al. 2008). The sharp edge between shola fragments and grasslands in the shola–grassland ecosystem mosaic can therefore provide significant insights without the limitations that are associated with other systems. The topographical variables used in our study significantly predicted whether the vegetation type was shola or non-shola. This study also showed that shola fragments are maintained by hydrological regulation. It also suggests that fire rather than frost might be responsible for the distinct shola edges. Predictive models are useful tools for restoration efforts and at larger scales can provide inputs into existing restoration efforts. The use of topographical variables to predict the presence of shola fragments represented a subset of static, environmental sorting variables influencing the distribution of shola fragments. The inclusion of dynamic variables such as fire history and regime and biotic interactions (e.g. topography induced dispersal limitation) might provide further insights and enhance our understanding of the shola–grassland ecosystem mosaic.

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