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Variation in Tree Species Richness along an Elevation Gradient in the Modi River Basin, Annapurna Conservation Area, Nepal

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Abstract

In this study, we studied the pattern and relationship between tree species richness along an elevation gradient in the southern aspect of Modi River Basin, Annapurna Conservation Area (ACA), Central Nepal. Altogether, 30 quadrats were established at 15 elevation bands between 1000 m and 3800 m above the mean sea level. Thirty tree species belonging to 21 families were recorded; Fabaceae had the highest number of species (4 spp.) followed by Betulaceae (3 spp.) and Anacardiaceae (3 spp.). Canonical correspondence analysis (CCA) tool was applied which revealed that the species richness and distribution varied significantly along an elevation gradient. The bimodal pattern of species richness was observed. It is concluded that the higher the elevation level, the lesser the number of tree species, thus, the trees in study site eschewed higher elevation levels.

Keywords: Altitude, Aspect, Bi-modal pattern, Canonical correspondence analysis (CCA), Distribution, Slope

Introduction

Environmental gradients related to climate, topography and vegetation are the prime factors influencing the broad-scale pattern of species richness in mountain areas (Cantlon, 1953; Moura et al., 2016). Since long, mountain ranges have been studied to determine ecological speciation, colonization and environmental filtering and also to improve our understanding of the process that have formed mountainous communities (Graham et al., 2014). Patterns of species richness in mountain systems and mechanisms determining them have received substantial attention in ecological research (Rahbek, 2005). For many groups of animals and plants, the diversity peak occurs at an intermediate point of the elevational gradient, while for others, diversity shows idiosyncratic diversity patterns (Kreft et al., 2010; McCain, 2005). These diversity patterns are influenced by topography, area, habitat heterogeneity, climate, edaphic conditions, evolutionary history and human activities (Kluge et al., 2006; Rai et al., 2017; Tuomisto et al., 2014; Vetaas et al., 2019).

Understanding biodiversity patterns along the elevational gradients have been a hot topic of debate for decades between bio-geographers, and biodiversity conservationists (Lomolino, 2001). The species richness and composition patterns among plant communities are also affected by the slope and aspect of the localities (Nuzzo, 1996). Though, aspect is found to be a less significant predictor, it could improve the explanatory ability of precipitation in describing the plant richness pattern (Sharma et al., 2019). The south-facing and steeper slopes are drier than the north-facing slopes; northern and northeastern slopes have low temperatures and higher soil and air moisture contents as compared to southern and other slopes at the same altitude due to less solar exposure and higher moisture content and evapotranspiration in Himalayan areas (Baduni & Sharma, 1996; Måren et al., 2015; Shrestha et al., 2007).

For the mountain areas, land use and geographic factors such as aspect and slope elevation, slope degree and fluctuations are considered as the main topographic factors affecting the vegetation diversity and distribution patterns indirectly (Sanders et al., 2007; Sanders & Rahbek, 2012). Moreover, elevation is also one of the decisive factors for diversity patterns because it presents the changes in the availability of resources such as temperature, soil moisture and snow cover (Barry, 1992; Körner, 2000). However, species assemblage in alpine vegetation of central Nepal has shifted downward rather than upward due to the warmer winter, increased precipitation, reducing grazing pressure (Bhatta et al., 2018). Species richness normally decreases with increasing elevation. However, a hump and a plateau have been documented in species richness curves in the Nepal Himalaya (Acharya et al., 2011; Panthi et al., 2007). A linear decrease in either number or proportion of pioneer species diversity was observed with increasing elevation, which was correlated with temperature, rainfall, and human disturbance trends (Martínez-Camilo et al., 2018). In this study, we hypothesized that there is a significant relation between elevational gradient and diversity of tree species. The study attempted to answer the following questions: Does species richness and diversity vary significantly with elevation along the gradient studied? Are variations along the elevation gradient in these structural attributes monotonic, unimodal or otherwise? What are the main environmental variables associated with these variations? The answers to these questions seek to contribute to knowledge about tree species richness and diversity patterns from sub-tropical and temperate to Alpine type zone along the Modi River Basin, Annapurna Conservation Area, Central Nepal.

Materials and Methods

Study site

Annapurna Conservation Area (ACA) is located in Nepal's Central region (28.325°N, 84.397°E to 28.603°N, 84.455°E and 29.235°N, 83.772°E to 28.482°N, 83.648°E), covers 7629 square km and is the largest protected area of the country (Department of National Parks and Wildlife Conservation [DNPWC], 2016). Having unique geographical features and various climatic conditions (from sub-tropical and temperate to arid desert type) the area is endowed with diverse habitats for diverse flora and fauna (National Trust for Nature Conservation [NTNC], 2013).

The core study area for this study extends from Birethanti (1000 m asl) to nearby Annapurna Base

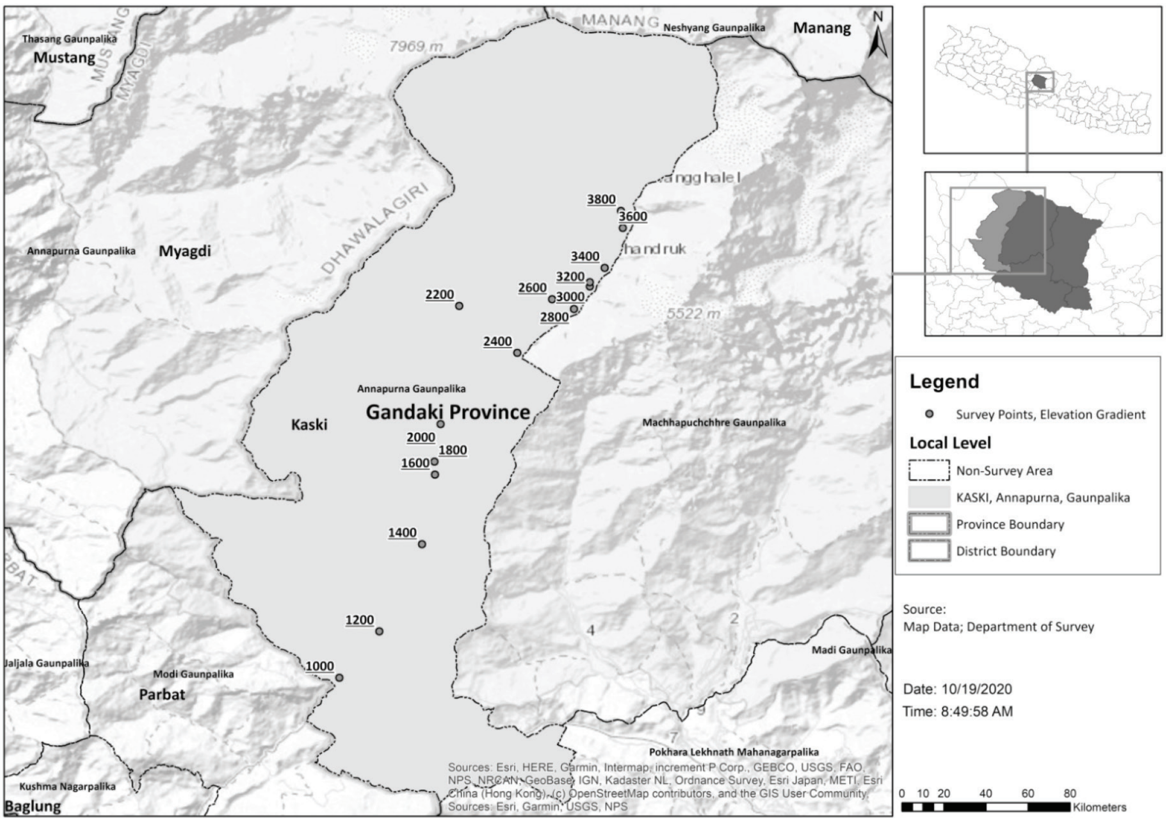

Figure 1: Study area showing different study locations along the Annapurna Base Camp

Camp (3800 m asl) along the Modi River Basin. The meteorological data from the year 2007 – 2017 were taken from Ghandruk (2012 m asl) and nearby Pokhara Airport (1400 m asl) stations. High precipitation and a considerably hot and humid atmosphere (82.42% / August and 56.86% / April in Pokhara) generally characterize the climate of Annapurna Conservation Area. Climatic data showed the monthly average maximum and minimum temperature of Pokhara to be 31.25°C in June and 7.25°C in January respectively, while mean annual precipitation of Pokhara and Ghandruk were 3621.73 mm and 4083.34 mm respectively. The number of frost days is generally high in Ghandruk and adjoining areas at higher altitude. (Source: Department of Hydrology and Meteorology, Nepal. 2019).

Study design

Vegetation sampling: The study was conducted in August 2018. Fifteen elevation levels were investigated at regular intervals of 200 m starting from 1000 m asl (Birethanti) to 3800 m asl (in between Machhapuchhre Base Camp and Annapurna Base camp). At each elevational level, two random quadrats, each 25 m × 2.5 m in size, were laid within an interval of ±50 m horizontal distance, mainly along the main trail, to reduce the sampling bias caused by spatial autocorrelation (Scheidegger et al., 2010) with the help of measuring tape (Cai Hong company). A total of 30 quadrats were established and sampled during the study period.

Sampling for environmental variables: All the tree species within each quadrat were recorded in order to record as many species as possible. If the same species occurred in the next plot, it was recorded as "1" and if not "0". Two replicate plots of the same elevation were later merged into one. Apart from the ones within the quadrats, the tree species occurring along the main trail were also noted to maximize the understanding of available species. Latitude, longitude and elevation of each sampling quadrat were recorded by Global Positioning System (GPS, Garmin 60csx). Floristic composition of forest i.e. tree species having diameter at breast height (DBH, breast height taken as 1.37m) ≥ 10 cm was recorded using diameter tape (20 m × 5 m, Yammayo Company). Canopy coverage was estimated with the help of a densiometer (Spherical densiometer model-A, Robert E. Lemmon, forest densiometer) and tree height was determined by Clinometers (Germany).

Specimen collection and identification

Most of the plant species were identified in the field with the help of 'Flowers of the Himalaya' (Polunin & Stainton, 1984) and its supplement (Stainton, 1988). The species unidentified in the field were confirmed and identified at the National Herbarium and Plant Laboratories (KATH), Godawari, Lalitpur. All the specimens are deposited at the Botany Department of Amrit Campus, Tribhuvan University- as graduate students' collections are deposited here. Nomenclature follows the Catalogue of Life (Bánki et al., 2022)

Data analysis

All the data were entered as a data matrix. The dataset comprised species matrix with 30 quadrats and tree species was used for the analysis. Canonical Correspondence Analysis (CCA) is a direct gradient analysis (terBraak, 2002) which we applied here to understand the species composition. The change in species number was analyzed through an application of R Studio by R Console version 4.1.3 (R Development Core Team 2022). A vegan package in R was used for Detrended Correspondence Analysis (DCA). The regression graphs were drawn by using Microsoft Excel (Microsoft Office 2008).

Results and Discussion

Species composition

A total number of 30 tree species belonging to 21 families and 27 genera were recorded (Appendix). Fabaceae was the largest family with four genera. Similarly, Betulaceae, Anacardiaceae, Juglandaceae and Sapindaceae were each represented by two genera (Figure 2). The remaining families were monotypic represented by a single genus.

The bi-plot based on the CCA results revealed the elevational gradient as a prime factor to govern plant species composition (Figure 3). Moreover*, Ficus* *auriculata* Lour., *Rhododendron arboreum* Sm., *Betula utilis* D.Don, *Betula alnoides* Buch.-Ham. ex D.Don, *Holarrhena pubescens* (Buch.-Ham.) Wall. ex G. Don and *Acer pectinatum* Wall. were frequently influenced by the elevation. *Quercus semecarpifolia* Sm., *Hypericum* species, *Brucea javanica* (L.) Merr. and *Machilus odoratissimus* Nees also might be affected by elevation; however, slope had major effect on these species. Canopy was another variable that had a major effect on *Prunus cerasoides* Buch.-Ham. ex D. Don, *Salix karelinii* Turcz. ex Stschegl., *Acer acuminatum* Wall. ex D. Don, *Toxicodendron succedaneum* (L.) Kuntze, *Toona ciliata* M. Roem. and *Erythrina arborescens* Roxb. Similarly, *Alnus nepalensis* D.Don, *Choerospondias axillaris (*Roxb.) B. L. Burtt & A. W. Hill, *Bombax ceiba* L., *Bauhinia purpurea* L. and *Macaranga indica* Wight had a large positive correlation with height, DBH and tree density per hectare. However, there were negative correlations for these species with slope and elevation of the studied area (Table 1).The other tree species like *Viburnum erubescens* Wall. ex DC., *Juglans regia* L., *Engelhardia spicata* Lesch. ex Blume and *Adenanthera pavonina* L. etc were apparently not affected by any environmental variables.

In mountainous regions, elevation has the most pronounced effects in limiting plant species and community types (Chawla et al., 2008). As elevation changes, geographical and climatic conditions change sharply (Bandopadhyay, 2016). Many environmental factors (e.g., temperature, precipitation, atmospheric pressure, solar radiation and wind velocity) change systematically with elevation. Therefore, elevational gradients are powerful natural experiments for testing the ecological and evolutionary responses of forests to environmental changes (Cui et al., 2005; Körner, 2007).

Mountain slopes, with significant bioclimatic amplitude, generally harbors more species at the bottom than the top (Vetaas & Grytnes, 2002). In the studied sites, slopes had a major effect on plant species like *Quercus semecarpifolia, Brucea javanica, Machilus odoratissimus* etc.; however, these species might also be affected by elevation. Changes in slope, aspect and elevation lead to changes in humidity, temperature, soil type and other factors that influence the variation of forest communities (Virtanen et al., 2010; Vittoz et al., 2010; Zhang, 2005). Canopy cover was another factor that has strongly affected the species like *Prunus cerasoides, Toxicodendron succedaneum, Toona ciliata* and *Erythrina arborescens*. The canopy coverage of tree species may create specific micro sites below its crown that will function as a biodiversity filter upon the plants that attempt to regenerate under it (Gandolfi et al., 2007). Woody canopy coverage showed a significant negative

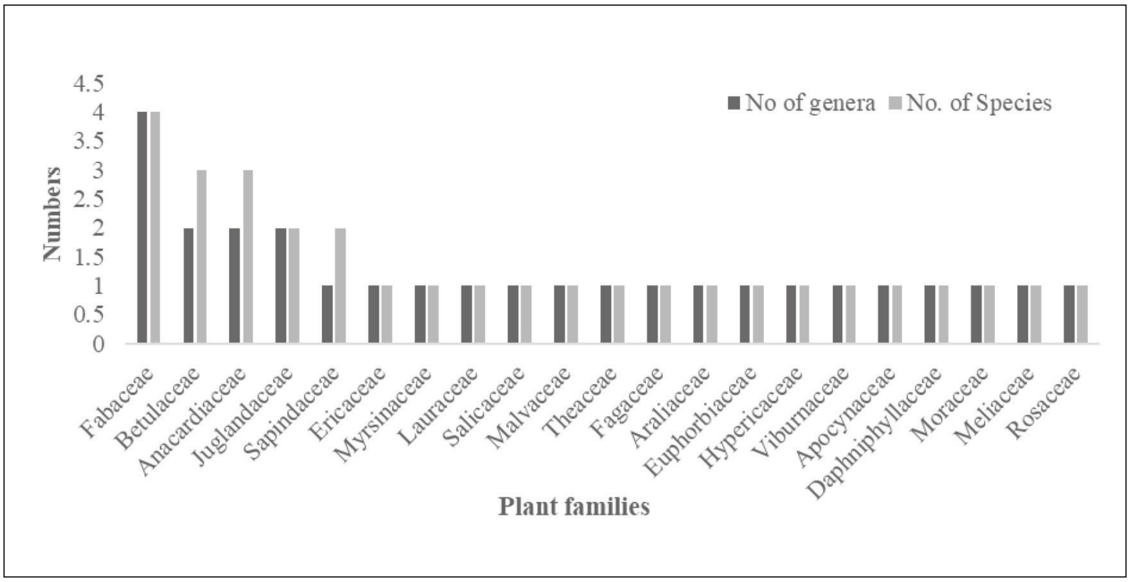

Figure 2: The total number of families with the number of genera and species

relationship with woody species diversity in an Arid Trans-Himalayan Landscape, Nepal (Paudel & Vetaas, 2014). This is due to woody canopy cover likely producing different degrees of shade and greater litter load or cover on the forest floor in the landscape of Trans-Himalayan.

Pattern of species richness

The pattern of tree species richness in study area along an elevation gradient is shown in Figure 4. There is a gradual decrease in tree species richness with increasing altitude except for altitude at 2600 m asl and 2800 m asl, then sharp decline in species richness up to 3800 m asl from the altitude above 2800 m asl. Species richness did not vary sharply between 1400 m asl and 2600 m asl, but above 2800 m asl it decreased exponentially ($\beta = -0.353, R^2 = 0.586$) with an increase in altitude and dropped to the minimum above 3600 m asl (Figure 4). Thus, the overall distribution patterns of tree species showed bimodal patterns of distribution with maximum richness at 1400 m asl and 2800 m asl (Figure 4). The correlation between the richness of tree species and elevation was negative and significant ($r = -0.776, p < 0.01$). We accepted the hypothesis that there is a significant relationship between the elevational gradient and the diversity of tree species.

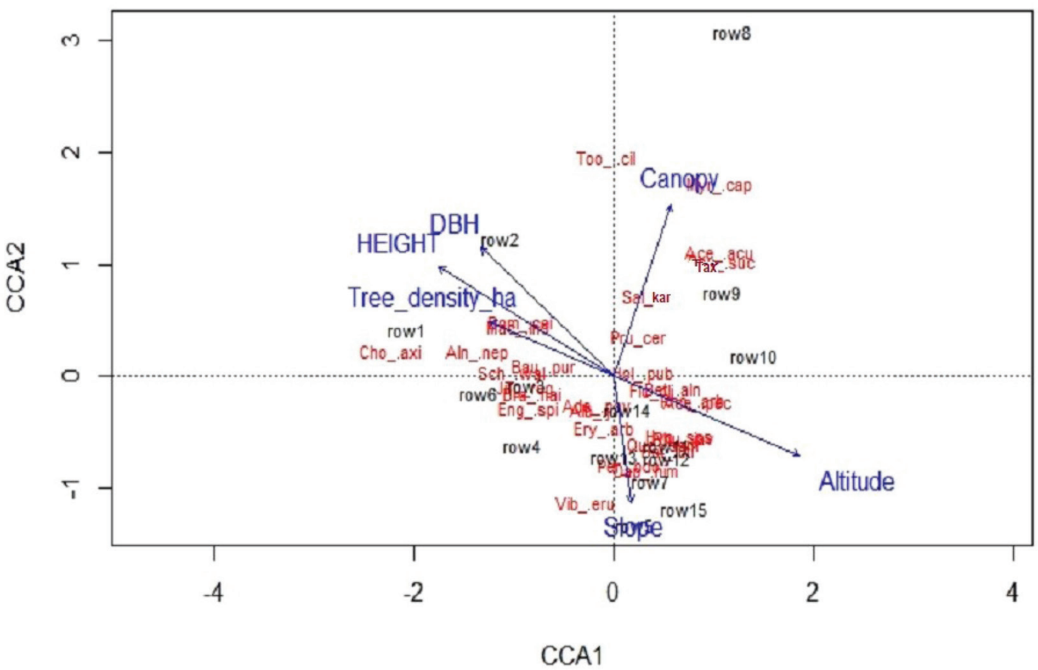

Figure 3: Canonical Correspondence Analysis (CCA) plots showing the relationships between environmental variables and tree species

Table 1: Bi-plot scores for constraining environmental variables on elevational gradient along Modi river basin of Annapurna conservation area

	CCA1	CCA2	CCA3	CCA4
Altitude	0.75135	-0.2864	-0.2088	0.4560
Tree density/ha	-0.49965	0.1953	-0.2929	-0.6777
Slope	0.06933	-0.4575	0.3244	-0.2385
Canopy	0.23143	0.6224	0.5662	-0.3898
DBH	-0.53924	0.4658	-0.1306	-0.2126
Height	-0.70925	0.3977	0.1095	-0.1210

Note: CCA = Canonical correspondence analysis

In this research, shifts in mid-elevation peaks with changes in elevation steps indicate scale effects on richness patterns. Earlier studies also reported the influence of scale with change in extent by smoothening (Nogués-Bravo et al., 2008; Rahbek, 2005). A similar pattern of the result was found in the arid mountainous areas of the Ili River Valley of Xinjiang (Tian et al., 2012; Xu et al., 2011). The results obtained concerning species richness index as investigated by Takayuki and Toshiyuki (2014) in the central Japan temperate altitudinal gradient also showed a rare bimodal trend. The bimodal pattern may be caused by the interaction of water and energy along the elevational gradient, but several non-environmental factors may also influence the patterns such as area (Whittaker et al., 2001).

Species abundances in nature are affected by multiple factors simultaneously and, depending on their covariance patterns, it may be analytically difficult or impossible to discern their separate effects (Zobel, 1997). The intervals of 200 m used in the studied sites do not represent equal area because of the topography of the Modi River Basin of ACA. Therefore, the area effect could also account for the decline of species richness of trees along the Modi River Basin in high elevation ranges. In particular, competition between species may also lead to a bimodal response, if a (specialist) species can out-compete another (more generalist) species at the middle of a gradient but not at its extremes (Ellenberg & Mueller-Dombois, 1974). Similar patterns of species richness were also found by different researchers (Acharya et al., 2011; Baniya et al., 2010; Paudel & Šipoš, 2014; Paudel et al., 2018) from different parts of Nepal.

The tendency of overlapping habitats and resources in middle elevation area could be partially responsible for the higher species richness (Trigas et al., 2013). Therefore, it was observed that species richness had a bi-modal (i.e. first peak at 1400 m asl and second at 2800 m asl) response to altitude in this study area. Mark et al. (2000) found topographic features (elevation, slope and exposure) to be responsible for the macro scale patterns of alpine vegetation distribution in Mount Armstrong, New Zealand. Other factors, such as eco-physiological constraints, soil fertility, topography, reduced growing season, low temperature and low productivity may also affect the pattern of species richness along elevation gradients (Körner, 1998).

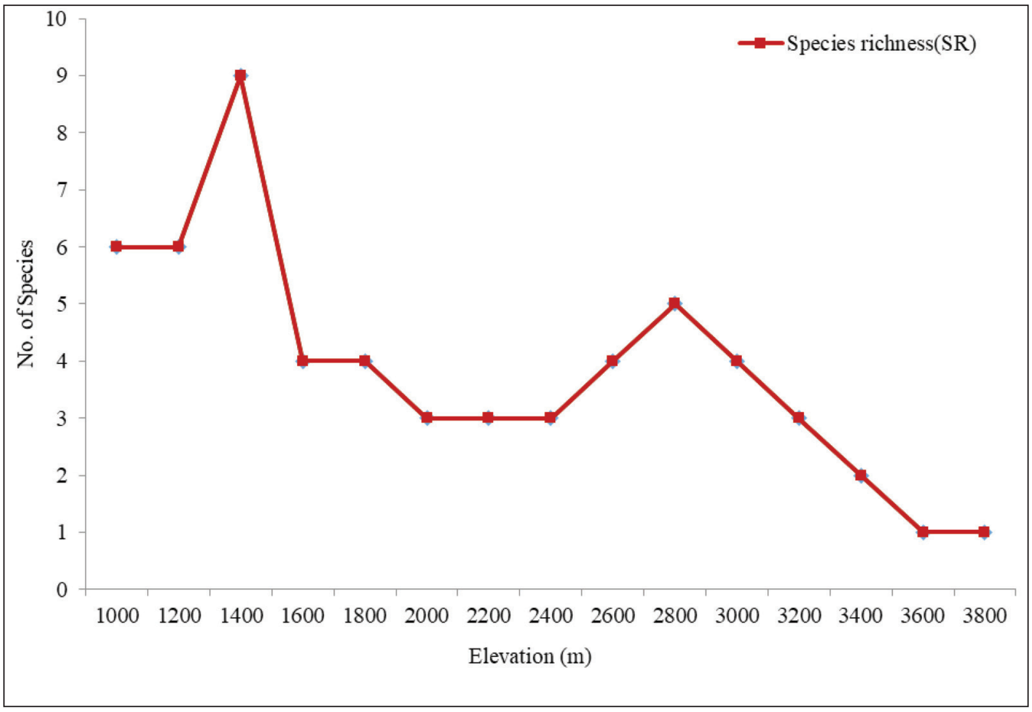

Figure 4: The pattern of species richness along with altitudinal gradient

Conclusion

Tree species richness in the studied site depicted a bimodal pattern with a peak at 1400 m asl and 2600 m asl. Tree species richness displayed a negative and strong correlation with elevation. Climatic and environment related factors influenced the observed tree species pattern, whereas no empirical evidence was linked to the mid-domain effect. Many other factors such as different biotic and abiotic factors, past history and human disturbance should be assessed regularly to gain a better understanding of the distribution of plant communities along elevational gradients that influences the mountainous forest. This study suggests that the distribution and species richness patterns of different tree species are largely regulated by altitude and climatic factors.

Author Contributions

SD and MPD conceptualized a project, RPK and SD collected data; RPK, SD and MPD analyzed, interpreted data. RPK wrote the manuscript. All authors read and approved the final manuscript.

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References

Acharya, K. P., Vetaas, O. R., & Birks, H. J. B. (2011). Orchid species richness along Himalayan elevational gradients. *Journal of Biogeography*, *38,* 1821-1833.

Baduni, N. P., & Sharma, C. M. (1996). Effect of aspect on the structure of some natural stands of *Quercus semecarpifolia* in a Himalayan moist temperate forest. *Indian Journal of Forestry, 19*, 335-341.

Bandopadhyay, S. (2016). Does elevation impact local level climate change? An analysis based on ûfteen years of daily diurnal data and time series forecasts. *Paciûc Science Review A: Natural Science and Engineering*, *18*, 241-253.

Bánki, O., Roskov, Y., Döring, M., Ower, G., Vandepitte, L., Hobern, D., Remsen, D., Schalk, P., DeWalt, R. E., Keping, M., Miller, J., Orrell, T., Aalbu, R., Adlard, R., Adriaenssens, E., Aedo, C., Aescht, E., Akkari, N., Alonso-Zarazaga, M. A., et al. (2022). *Catalogue of Life Checklist* (Version 2022-01-14). Catalogue of Life. https://doi.org/10.48580/d4tp

Baniya, C.B., Solhøy, T., Gauslaa, Y., & Palmer, M. (2010). The elevation gradient of lichen species richness in Nepal. *Lichenologist*, *42*, 83-96.

Barry, R. G. (1992). *Mountain Weather and Climate* (2nd ed.). Routledge.

Bhatta, K. P., Grytnes, J. A., & Vetaas, O. R. (2018). Downhill shift of alpine plant assemblages under contemporary climate and land-use changes. *Ecosphere, 9*, e02084. https://doi.org/10.1002/ecs2.2084

Cantlon, J. E. (1953).Vegetation and microclimates on north and south slopes of Cushetunk Mountain, New Jersey. *Ecological Monographs, 23*, 241-270.

Chawla, A., Rajkumar, S., Singh, K., Lal, B., Singh, R., & Thukral, A. (2008). Plant species diversity along an altitudinal gradient of Bhabha Valley in western Himalaya. *Journal of Mountain Science*, *5*, 157-177.

Cui, H. T., Liu, H. Y., & Dai, J. U. (2005). *Research on mountain ecology and alpine tree line*. Science Press.

Department of National Parks and Wildlife Conservation. (2016). *Protected areas of Nepal* [in Nepali].

Ellenberg, H., & Mueller-Dombois, D. (1974). *Aims and Methods of Vegetation Ecology*. John Wiley & Sons Inc.

Gandolfi, S., Joly, C. A., & Rodrigues, R. R. (2007). Permeability impermeability: canopy trees as biodiversity filters. *Scientia Agricola*, *64*, 433-438.

Graham, C. H., Carnaval, A. C., Cadena, C. D., Zamudio, K. R., Roberts, T. E., Parra, J.L., McCain, C.M., Bowie, R.C.K., Moritz, C., Baines, S. B., Schneider, C. J., VanDerWal, J., Rahbek, C., Kozak, K. H., & Sanders, N. J. (2014). The origin and maintenance of montane diversity: Integrating evolutionary and ecological processes. *Ecography*, *37*, 711-719.

Kluge, J., Kessler, M., & Dunn, R. R. (2006). What drives elevational patterns of diversity? A test of geometric constraints, climate and species pool effects for Pteridophytes on an elevational gradient in Costa-Rica. *Global Ecology and Biogeography*,*15*, 358-371.

Körner, C. (1998). A re-assessment of high elevation treeline positions and their explanation. *Oecologia*, *115*, 445-459.

Körner, C. (2000). Why are there global gradients in species richness? Mountains might hold the answer. *Trends in Ecology &* Evolution, *15*, 513-514.

Körner, C. (2007). The use of altitude in ecological research. *Trends of Ecology & Evolution*, *22*, 569-574.

Kreft, H., Jetz, W., Mutke, J., & Barthlott, W. (2010). Contrasting environmental and regional effects on global pteridophyte and seed plant diversity. *Ecography*, *33*, 408-419.

Lomolino, M.V. (2001). Elevation gradients of species-density: Historical and prospective views. *Global Ecology and Biogeography*, *10*, 3-13.

Måren, I. E., Karki, S., Prajapati, C., Yadav, R. K., & Shrestha, B. B. (2015). Facing north or south: Does slope aspect impact forest stand characteristics and soil properties in a semiarid trans-Himalayan valley?. *Journal of Arid Environments, 121*, 112-123.

Mark, A. F., Dickinson, K. J .M., & Hofstede, R. G. M. (2000). Alpine vegetation, plant distribution, life forms, and environments in a perhumid New Zealand region: Oceanic and tropical high mountain affinities. *Arctic, Antarctic, and Alpine Researc*h, *32*, 240-254.

Martínez-Camilo, R., González-Espinosa, M., Ramírez-Marcial, N., Cayuela, L., & Pérez-Farrera, M. Á. (2018). Tropical tree species diversity in a mountain system in Southern Mexico: local and regional patterns and determinant factors. *Biotropica, 50,* 499-509.

McCain, C. M. (2005). Elevational gradients in diversity of small mammals. *Ecology*, *86,* 366-372.

Moura, M. R., Villalobos, F., Costa, G. C., & Garcia, P. C. A. (2016). Disentangling the role of climate, topography and vegetation in species richness gradients. *Plos one*, *11*, e0152468.

Nogués-Bravo, D., Araújo, M. B., Romdal, T., & Rahbek, C. (2008). Scale effects and human impact on the elevational species richness gradients. *Nature*, 453 (7192), 216.

National Trust for Nature Conservation NTNC. (2013). *Annual report 2012; National Trust for Nature Conservation*.

Nuzzo, V. A. (1996). Structure of cliff vegetation on exposed cliffs and the effect of rock climbing. *Canadian Journal of Botany*, *74*, 607-617.

Panthi, M. P., Chaudhary, R. P., & Vetaas, O. R. (2007). Plant species richness and composition in a trans-Himalayan inner valley of Manang District, central Nepal. *Himalayan Journal of Sciences, 4*, 57-64.

Paudel, S., & Vetaas, O. R. (2014). Effects of topography and land use on woody plant species composition and beta diversity in an arid trans-Himalayan landscape, Nepal. *Journal of Mountain Science, 11*, 1112-1122.

Paudel, P. K., & Šipoš, J. (2014). Conservation status affects elevational gradient in bird diversity in the Himalaya: A new perspective. *Global Ecology and Conservation, 2*, 338-348.

Paudel, P. K., Sipos, J., & Brodie, J. F. (2018). Threatened species richness along a Himalayan elevational gradient: Quantifying the influences of human population density, range size, and geometric constraints. *BMC Ecology, 18*, 1-8.

Polulin, O., & Stainton, J. D. A. (1984). *Flowers of the Himalaya*. Oxford University Press.

Rai, S. K., Sharma, S., Shrestha, K. K., Gajurel, J. P., Devkota, S., Nobis, M., & Scheidegger, C. (2017). Environmental covariates of species richness and composition of vascular plants of Olangchung Gola and Ghunsa valleys of Eastern Nepal. *Asian Journal of Conservation Biology*, *6*, 94-104.

Rahbek, C. (2005). The role of spatial scale and the perception of large-scale species-richness patterns. *Ecology Letters*, *8*, 224-239.

Sanders, N. J., Lessard, J. P., Fitzpatrick, M. C., & Dunn, R. R. (2007). Temperature, but not productivity or geometry, predicts elevational diversity gradients in ants across spatial grains. *Global Ecology and Biogeography, 16*, 640-649.

Sanders, N. J., & Rahbek, C. (2012). The patterns and causes of elevational diversity gradients. *Ecography, 35*, 1-3.

Scheidegger, C., Nobis, M. P., & Shrestha, K. K. (2010). Biodiversity and livelihood in land use gradients in an era of climate change - outline of a Nepal Swiss research project. *Botanica Orientalis*, *7*, 7-17.

Sharma, N., Behera, M. D., Das, A. P., & Panda, R. M. (2019). Plant richness pattern in an elevation gradient in the Eastern Himalaya. *Biodivers. Conserv.*, *28*, 2085-2104.

Shrestha, B. B., Ghimire, B., Lekhak, H. D., & Jha, P.K. (2007). Regeneration of tree line Birch (*Betula utilis* D. Don) forest in trans-Himalayan dry valley in central Nepal. *Mountain Research and Development*, *27*, 259-267.

Stainton, J. D. A. (1988). *Flowers of the Himalaya A Supplement*. Oxford University Press.

Takayuki, T., & Toshiyuki, S. (2014). Species richness of seed plants and ferns along a temperate elevational gradient in central Japan. *Plant Ecology*, *215,* 1299-1311.

terBraak, C. J. F. (2002). *CANOCO- A FORTAN Program for canonical community ordination by (partial) (detrended) (canonical) correspondence analysis, principal component analysis and redundancy analysis* (Version 4.5). Wageningen.

Tian, Z.P., Zhuang, L., & Li, J. G. (2012).The vertical distribution of vegetation patterns and its relationship with environment factors at the northern slope of Ili River Valley: a bimodal distribution pattern. *Acta Ecologica Sinica, 32*, 1151-1162.

Trigas, P., Panitsa, M., & Tsiftsis, S. (2013). Elevational gradient of vascular plant species richness and endemism in Crete - the effect of post-isolation mountain uplift on a continental island system. *PLoS ONE*, *8*, 1-14.

Tuomisto, H., Zuquim, G., & Cárdenas, G. (2014). Species richness and diversity along edaphic and climatic gradients in Amazonia. *Ecography*, *37*, 1034-1046.

Vetaas, O. R., & Grytnes, J. A. (2002). Distribution of vascular plant species richness and endemic richness along the Himalayan elevation gradient in Nepal. *Global Ecology and Biogeography*, *11,* 291-301.

Vetaas, O. R., Paudel, K. P., & Christensen, M. (2019). Principal factors controlling biodiversity along an elevation gradient: Water, energy and their interaction. *Journal of Biogeography*, *46*, 1652-1663.

Virtanen, R., Luoto, M., RäMä, T., Mikkola, K., Hjort, J., Grytnes, J. A., & Birks, H. J. B. (2010). Recent vegetation changes at the high-latitude tree line ecotone are controlled by geomorphological disturbance, productivity and diversity. *Global Ecology and Biogeography, 19,* 810-821.

Vittoz, P., Bayfield, N., Brooker, R., Elston, D. A., Duff, E. I., Theurillat, J. P., & Guisan, A. (2010). Reproducibility of species lists, visual cover estimates and frequency methods for recording high-mountain vegetation. *Journal of Vegetation Science, 21*, 1035-1047.

Whittaker, R. J., Willis, K. J., & Field, R. (2001). Scale and species richness: Towards a general, hierarchical theory of species diversity. *Journal of Biogeography*, *28,* 453-470.

Xu, Y., Chen, Y., Li, W., Fu, A., Ma, X., Gui, D., & Chen, Y. (2011). Distribution pattern of plant species diversity in the mountainous Region of Ili River Valley, Xinjiang. *Environmental Monitoring and Assessment*, *177*, 681-694.

Zhang, J. T. (2005). Succession analysis of plant communities in abandoned crop lands in the Eastern Loess Plateau of China. *Journal of Arid Environments*, *63*, 458-474.

Zobel, M. (1997). The relative role of species pools in determining plant species richness: An alternative explanation of species coexistence?. *Trends in Ecology and Evolution*, *12,* 266-269.

Appendix: Thirty tree species recorded from the study site

S. N.	Species Name	Family
1	*Acer acuminatum* Wall. ex D.Don	Sapindaceae
2	*Acer pectinatum* Wall.	Sapindaceae
3	*Adenanthera pavonina* L.	Fabaceae
4	*Albizia julibrissin* Durazz	Fabaceae
5	*Alnus nepalensis* D.Don	Betulaceae
6	*Bauhinia purpurea* L.	Fabaceae
7	*Betula alnoides* Buch.-Ham. ex D.Don	Betulaceae
8	*Betula utilis* D.Don	Betulaceae
9	*Bombax ceiba* L.	Malvaceae
10	*Brassaiopsis hainla* (Buch.-Ham.) Seem.	Araliaceae
11	*Brucea javanica* (L.) Merr.	Anacardiaceae
12	*Choerospondias axillaris* (Roxb.) B.L. Burtt & A.W. Hill	Anacardiaceae
13	*Daphniphyllum himalense* (Benth.) Müll.Arg	Daphniphyllaceae
14	*Engelhardia spicata* Lesch. ex Blume	Juglandaceae
15	*Erythrina arborescens* Roxb.	Fabaceae
16	*Ficus auriculata* Lour.	Moraceae
17	*Holarrhena pubescens* (Buch.-Ham.) Wall. ex G. Don	Apocynaceae
18	*Hypericum* sps.	Hypericaceae
19	*Juglans regia* L.	Juglandaceae
20	*Macaranga indica* Wight	Euphorbiaceae
21	*Machilus odoratissimus* Nees	Lauracea
22	*Myrsine capitellata* Wall.	Myrsinaceae
23	*Prunus cerasoides* Buch.-Ham. ex D. Don	Rosaceae
24	*Quercus semecarpifolia* Sm.	Fagaceae
25	*Rhododendron arboreum* Sm.	Ericaceae
26	*Salix karelinii* Turcz. ex Stschegl.	Salicaceae
27	*Schima wallichii* (DC.) Korth.	Theaceae
28	*Toona ciliata* M. Roem.	Meliaceae
29	*Toxicodendron succedaneum* (L.) Kuntze	Anacardiaceae
30	*Viburnum erubescens* Wall. ex DC.	Viburnaceae