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Diversity Patterns of Vascular Plants at Varied Elevations in Arghakhanchi, West Nepal

Baburam Nepali[1,2], John Skartveit[3] & Chitra Bahadur Baniya[1*]
[1]Central Department of Botany, Tribhuvan University, Kirtipur, Kathmandu, Nepal
[2]Butwal Multiple Campus, Tribhuvan University, Butwal, Nepal
[3]University College, NLA, Bergen, Norway
[*]**Email:** cbbaniya@gmail.com

Abstract

The genuine image of biodiversity, as well as their germplasm, is visualized by the turnover of species rather than their similarities in each location. The major goal of this study was to determine the β-diversity pattern of vascular plants growing at 100 m contour elevations and to explore its association with α-diversity and elevation. Primary data were gathered utilizing 4-6 10 x 10 m^2 quadrats at 100 m contour elevation, on both the south and north sides, in Arghakhanchi district, west Nepal. Beta diversity represents the change in diversity of species between two communities and is measured by two different matrices: species turnover and similarity. Between two adjacent elevational bands, the species turnover was calculated using the Bray-Curtis dissimilarity index and similarity was assessed using the Jaccard index technique in the Vegan package for R version 4.03. The species richness (α-diversity) and β-diversity indices (Bray-Curtis dissimilarity index and Jaccard similarity index) were regressed by generalized linear model (GLM) method with elevation. The species richness and Jaccard similarity index suggests statistically significant unimodal structure with elevation; however, Bray-Curtis dissimilarity index suggests statistically significant but reverse unimodal pattern. As a result, rather than species turnover, the presence of more related species usually creates the peak area of a unimodal pattern of alpha diversity. The geographical scale of biodiversity loss or its effective preservation by human activities is revealed by beta-diversity. Any region with high beta diversity suggests a wide variety of species, which aids in the administration of conservation programs.

Keywords: α-diversity, Bray-Curtis method, Jaccard similarity index, Similarity index

Introduction

Space and time bring the drastic variation in distribution of biodiversity as well as their ecological processes. The totality of all biotic variety, from the level of genes to ecosystems, is known as biodiversity, and it is frequently employed as a gauge of the health of biological systems. Current biodiversity is being molded by ecological and evolutionary processes that are being revealed through phylogenetic and temporal investigations. (Yadav & Mishra, 2013). It will serve as the biosphere's foundation for many generations to come in addition to the present. The term "biodiversity" refers to the quantity, variety, and variability of living things within a region or an ecosystem (Heywood & Watson, 1995). The biodiversity can be measured in the form of functional categories (Ecosystem, species and genetic diversity) and theoretical categories (alpha, beta and gamma diversities) (Whittaker, 1972).

Alpha diversity is the species richness present within each forest or each site or each plot. Generally, alpha diversity or species richness is used to show relationship against elevation, latitude, climates, time etc. and patterns vary other environmental conditions. The latitudinal decline of diversity is a universal phenomenon (Hillebrand, 2004). It is frequently asserted that the elevational gradient mirrors the latitudinal gradient and species richness is expected to monotonically decline (i.e. as a result of decreased temperature and subsequent fall in productivity) (Rahbek, 1995). But, the most observed pattern is hump shaped in altitudinal zonation of biodiversity in mountains which can be described well by the mid-domain effect (Fischer et al., 2011; Liang et al., 2020). In northern China, trees exhibit a unimodal trend while shrub species exhibit a linear decline versus elevation, indicating that the elevation pattern is growth form specific (Zhang et al., 2016). The curves are positively skewed and the unimodality is most evident in the most of the global elevational diversity (Guo et al., 2013). According to studies of species distribution, roughly 50% exhibit a Gaussian curve in relation to elevation, whereas 25% show a monotonically falling trend and 25% follow neither of these distributions (Nogués-Bravo et al. 2008). The distribution pattern of a species may depend on its distribution range.

The degree of species compositional variation across sample units, or beta diversity, has evolved into a key method for relating the spatial organization of species assemblages to ecological processes (Ricotta, 2017). Beta diversity, represents by the species diversity between any two patches and their communities (Maiti & Maiti, 2011), measures the change in diversity of species from one site to another. A high beta diversity index indicates a low level of similarity (nestedness), while a low beta diversity index shows a high level of similarity. Fontana et al. (2020) showed that species turnover increases with increasing elevational distance along the gradient for the majority of plant and insect groups, but nestedness was reduced in pastured grasslands in the European Alps. In the Northwest Himalaya, India, the contribution of species replacement or the turnover component to the observed dissimilarity was substantially larger than the nestedness component (Wani et al., 2022). The turnover of species and the nestedness function the two elements of beta diversity.

The deep learning of alpha, beta and gamma diversity frameworks offers a potent and adaptable new technique for evaluating biodiversity patterns (Andermann et al., 2022). Alpha diversity and gamma diversity differ in terms of geographical size. Spatial environmental heterogeneity is an important driver of species diversity (Walters & Martiny, 2020). Large-scale biogeographical patterns have been studied extensively over the Himalayan altitudinal gradients, but no discernible pattern has been found. In places of the Himalayas where fragile soil composition, local anthropogenic pressures and climate change are relatively substantial, knowledge of the alpha diversity and diversity patterns along elevation gradients might assist frame for successful conservation plans (Nanda et al., 2021). According to published research, the humped form represents a typical pattern of species richness in relation to elevation. The reason behind the formation of peaks is not properly studied or identified.

Finding out the elevational pattern of alpha diversity, and beta diversity (species turnover and nestedness) in the Arghakhanchi district are the primary objectives of this study. The other goal is to determine the true cause of the generating peak in the species pattern.

Materials and Methods

Location and vegetation of study area

This research was done in the Narapani-Masina and Resunga-Malarani landscapes of the Arghakhanchi district in western Nepal (27°45' to 28°06'N latitude and 80°45' to 83°23'E longitude) (Figure 1). The research area's elevation ranges from 200 m in the tropical zone to above 2200 m in the lower temperate region, and 177,200 people call this district home (Central Bureau of Statistics [CBS], 2021). Arghakhanchi's neighboring districts are Palpa and Rupandehi to the east, Gulmi to the north, Kapilvastu and Rupandehi to the south and Pyuthan and Dang to the west.

This district is divided into four physiographic zones: lower tropical (less than 300 m asl includes 0.2%), higher tropical (300-1000 m asl covers 51%), subtropical (1000-2000 m asl covers 49%) and temperate zone (more than 2000 m asl contains 0.2%) (Barnekow Lillesø et al., 2005). The maximum temperature ranges between 36°-38°C in May and July and minimum temperature ranges from 9°-11°C in January (Department of Hydrology and Meterology [DHM], 2019). There have been significant variations in the amount of rainfall, with the yearly rainfall at Khanchikot station ranging from 678.2 to 2454 mm (DHM, 2020).

The Terai and Siwalik areas (below 1000 m asl) in Arghakhanchi district are covered with tropical forest, including main species: *Shorea robusta, Dalbergia sissoo, Senegalia catechu* and *Adina*

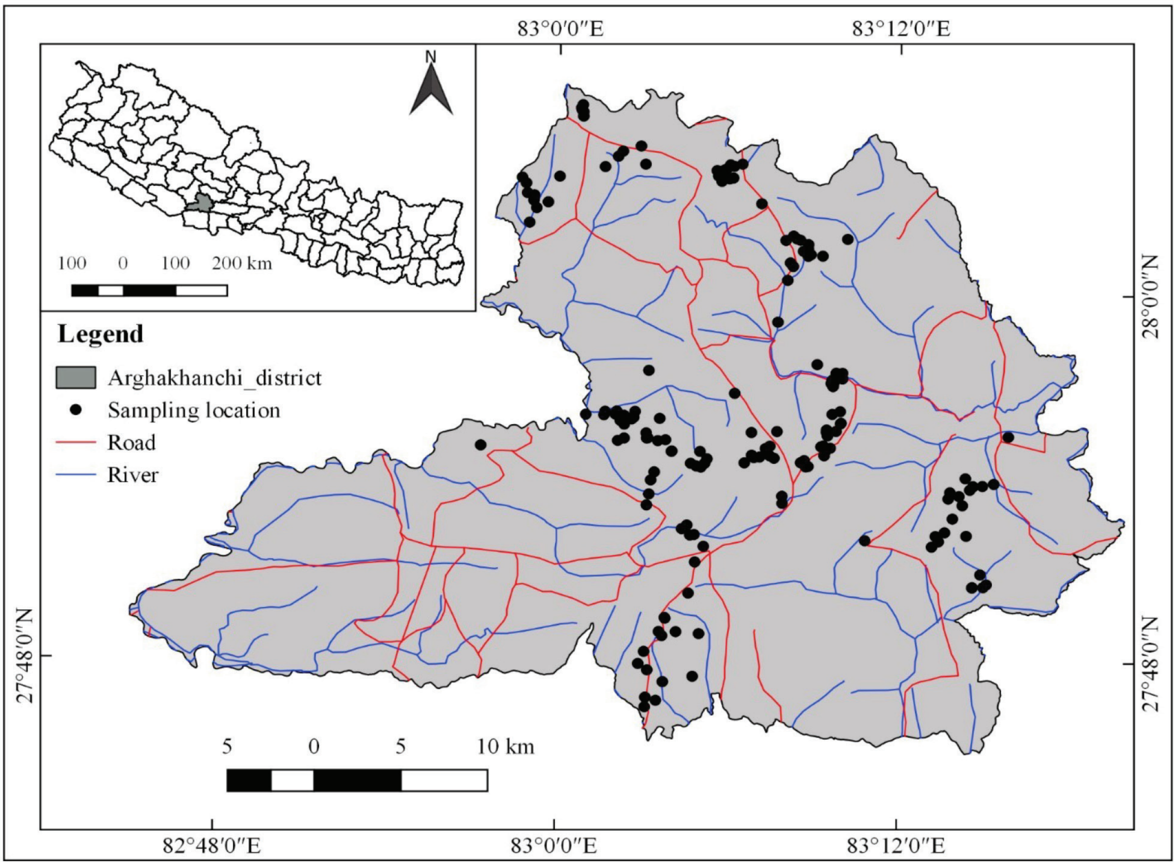

Figure 1: Map of study area with plant sampling sites

cordifolia. The Chure soil in the southern half of the district is more brittle and dry (Singh, 2017). *Shorea robusta* inhabits in the lower belt of the subtropical region (1000-2000 m asl), whereas *Schima walichii, Pinus roxburghii, Diploknema butyracea, Castonopsis indica*, etc. grow in the upper belt. There is more moisture in north-facing landscapes than in south-facing ones. Over 2000 m, *Castonopsis, Quercus*, *Rhododendrons*, etc. cover the majority of this area (Department of Forest Research and Survey [DFRS], 2018).

Study design and data collection

During the first visit, it was decided to divide the entire elevational range of Arghakhanchi district (200-2200 m) into 21 elevation bands each measuring 100 meters. The requisite size of quadrat for sampling of vegetation was determined by following the species area-curve method. A stratified random sample technique was used along the walking trail's horizontal axis at intervals of 100 meters in elevation for the north and south sides of the Narapani-Masina and Resunga-Malarani landscapes. At each 100 m elevation band, 2/2 plots were typically tested on either side of the walking route. In each elevation range, the number of plots was increased to six if various plant types were present. Two plots were set apart by between 100 and 150 meters. The species richness of all sampling plots was recorded in a field note copy.

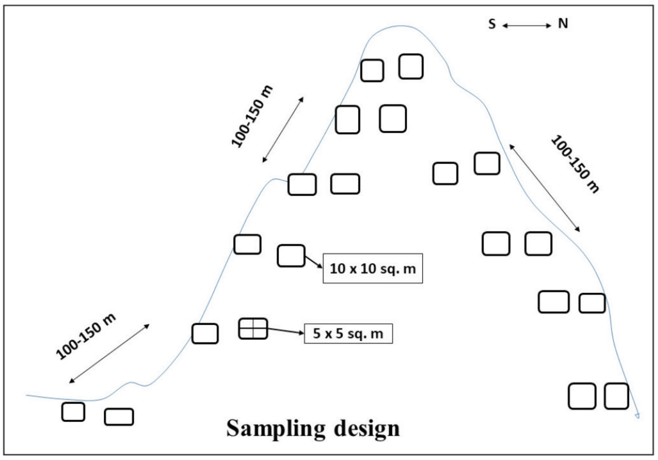

Figure 2: Design for sampling plots in north and south aspect in study site

Later, one voucher specimen of each plant species was collected for further identification. The scientific names of each species and their growth forms (herb, climber, fern, shrub and tree) were identified by comparing with already identified specimens present in National Herbarium and Plant Laboratories (KATH), Godawari, Kathmandu. They are deposited in Tribhuvan University Central Herbarium (TUCH), Central Department of Botany, Kirtipur. The combined species richness of all sampled plots at each 100 m elevational band was considered as species richness of each band.

Statistical analysis of data

The relationship between the abundance of species richness and elevation was expressed using the regression model known as the Generalized Linear Model (GLM) (Hastie & Pregibon, 1993). The error dispersion present in the analysis was removed by use of the Quasi-poisson method.

The species turn over (species dissimilarity) and nestedness (species similarity) are two measures of beta diversity. The species turn over value was calculated by Bray-Curtis Dissimilarity technique (Bray & Curtis, 1957) in R between two adjoining 100 m elevation bands.

The Bray-Curtis Dissimilarity is calculated as:

$$BCij = 1 - (2*Cij)/(Si + Sj)$$

where:

- C_{ij}: The sum of the lesser values for the species found in each site.
- S_i: The total number of specimens counted at site *i*
- S_j: The total number of specimens counted at site *j*

Similar to this, the Jaccard similarity index (Chung, 2018) was estimated by following the formula. In the R Software Package "Jacquard" was used to estimate the Similarity index at same bands.

$$J(A, B) = \frac{!\, A \cap B\, !}{!\, A \cup B\, !}$$

Where,

J = Jaccard similarity index

A = Set 1

B= Set 2

Then, in order to determine the elevational pattern, the Bray-Curtis dissimilarity index value and the Jaccard similarity index were regressed using the GLM technique.

The Post-Hoc Analysis with Tukey's test **(**Bevans, 2020) was used to know the significance differences between alpha diversity (species richness) and elevation as well as beta diversity and elevation for the two aspects of landscapes. The goal of the Tukey's test is to identify the groups in samples that differ from one another. The post hoc test is used to compare means, just as Tukey's, on the basis of the data gathered.

Results and Discussion

Species diversity

A total of 553 species of vascular plants belonging to 115 families and 379 genera was recorded within the study site (Table 1). Among them, 402 species were belonging to dicot and rest was monocot (98 species), ferns and fern-allies (50 species) and gymnosperm (3 species).

Table 1: Total biodiversity of study area

S.N.	Plant group	Families	Genera	Species	Ratio of species (%)
1	Dicots	83	284	402	72.7
2	Monocots	16	69	98	17.7
3	Gymnosperms	1	1	3	0.5
4	Ferns	15	25	50	9.1
	Total	115	379	553	

Relationships of alpha diversity and beta diversity with elevation

The abundance of species is an expression of alpha diversity. There was an alpha diversity of 13-309 per elevation band (Appendix). Similarly, beta diversity is measured using two metrics: species turnover and nestedness. The values for the Bray-Curtis dissimilarity index and the Jaccard similarity

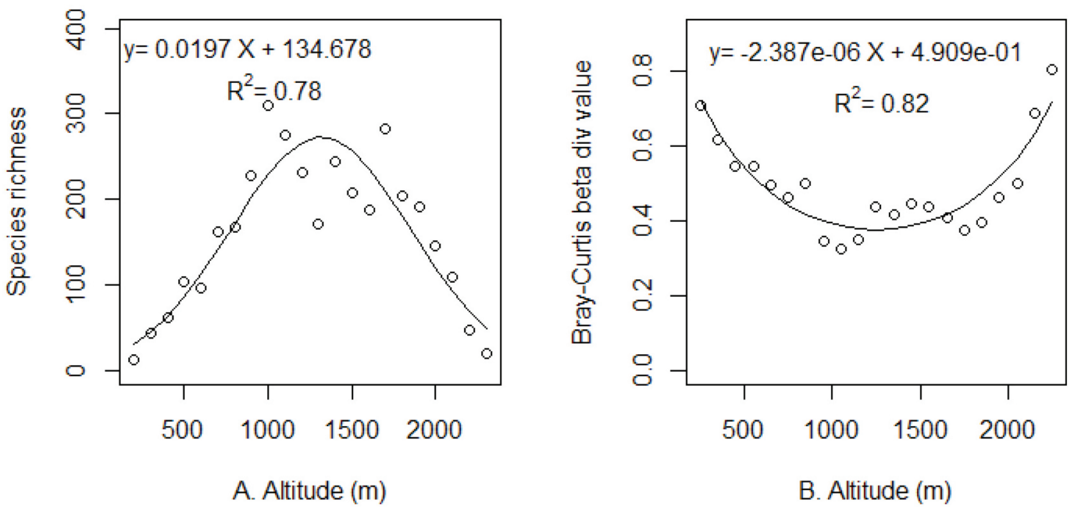

Figure 3: Regression plot applied by GLM method to show relation of species richness, **A.** Alpha diversity with elevation, **B.** Beta diversity against elevation

index were respectively 0.33-0.79 and 0.32-0.70. (Appendix).

Using the GLM regression approach, the alpha diversity, or species richness as well as the beta diversity indices were analyzed to demonstrate the association with elevation. The species richness first increased with height and then began to decline after reaching mid-elevation, even though the elevation increased further, revealing the significant unimodal pattern.($R^2 = 0.78$ & $p < 0.05$, Figure 3A) showing maximum species 264 at 1300 m. However, the elevation started to rise as the beta dissimilarity index value began to fall, indicating a substantial reverse unimodal structure ($R^2 = 0.82$ & $p < 0.05$, Figure 3B) with elevation.

The variation in pattern in the north and south aspects was also shown by the regression analysis of the species richness and Bray-Curtis dissimilarity index. Although the north perspective had a bimodal pattern, the south aspect's alpha diversity revealed a large unimodal structure (Figure 4A). Beta dissimilarity index values at the north and south aspects showed similar differences (Figure 4B) as in aspect wise species richness.

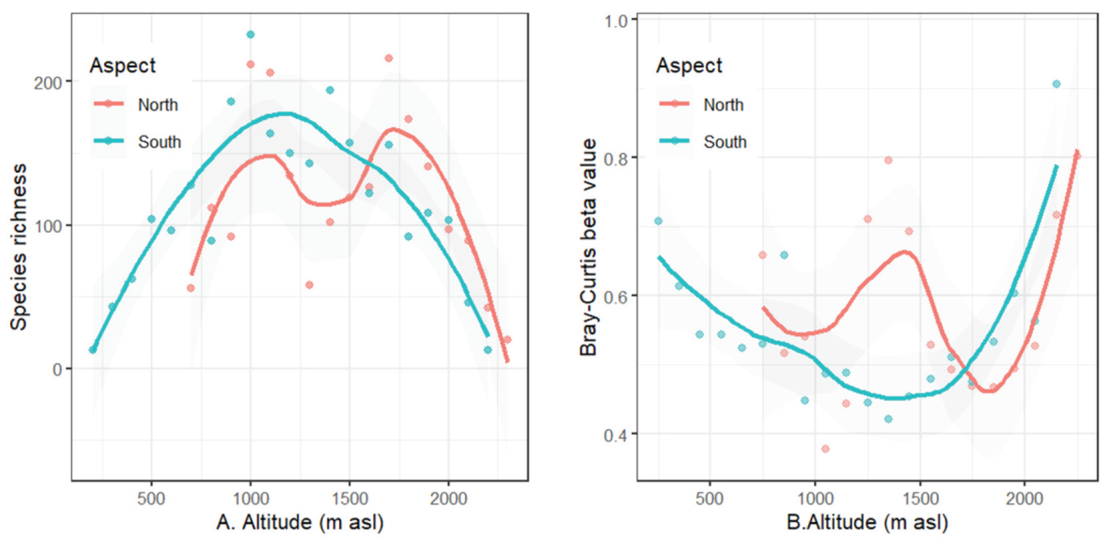

Figure 4: Regression plot applied by GLM method to show relation of, **A.** species richness of two aspects (north and south) with elevation, **B.** Beta diversity of two aspects against elevation

To ascertain if there is a significant difference in the species richness of two features, the Tukey post hoc test is performed. The difference in the Bray-Curtis dissimilarity index value at two aspects was also determined using a similar technique. The test results for both cases revealed that there was no noticeable variation in species richness (Figure 5A) and the beta dissimilarity index (Figure 5B) at two aspects.

Using a generalized linear model, it was attempted to demonstrate how nestedness (species similarity) and species turn over (Bray-Curtis dissimilarity) relate to alpha diversity (Figure 6A and 6B). The statistically significant unimodal pattern with elevation was demonstrated by both the species richness (alpha diversity) and species nestedness (similarity index). However, the dissimilarity index demonstrated a reverse unimodal pattern with elevation that was also statistically significant.

Discussion

Floral diversity and elevational pattern: The fact, that the studied area has 553 species of vascular plants from 115 families and 379 genera shows the diversity of the plant population in Arghakhanchi district. The study area is situated in Nepal's tropical and subtropical zone, which is appeared as place of biodiversity rich. A robust unimodal structure was shown by the regression of species richness (alpha diversity) of the 100 m contour elevation, indicating that mid-elevation sites (1300 m) had a larger species richness than low and high elevation sites.

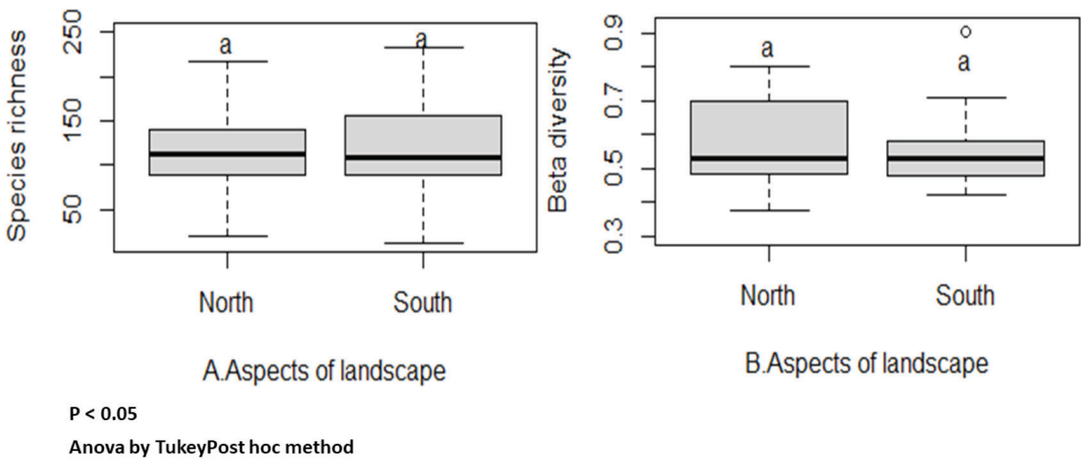

Figure 5: Result of Tukey Post hock test of **A.** species richness, **B.** Bray-Curtis dissimilarity index between of two aspects (north and south) ($p < 0.05$)

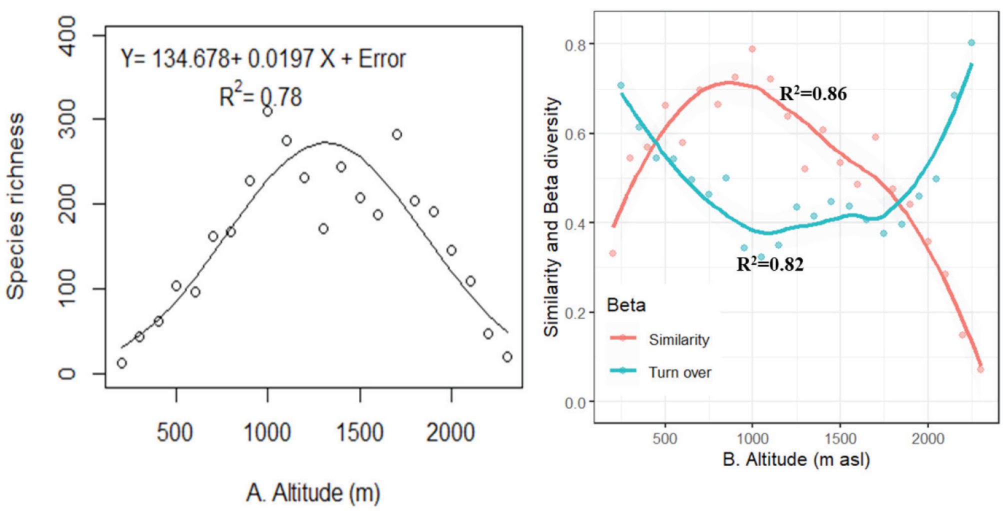

Figure 6: Diagram showing regression result applied by GLM method to show the relation of, **A.** species richness, **B.** beta diversity indices (similarity index and dissimilarity index)

The previous study based on interpolated data (Nepali et al., 2020) had also showed that a statistically significant unimodal pattern ($R^2 = 0.91$; $p < 0.001$) of total vascular species richness with elevation having a maximum richness of 471 species at 1300 m asl. Similarly, individual taxa: gymnosperm, dicot, monocot and pteridophytes species richness also showed a highly significant unimodal altitudinal richness pattern. This study demonstrated that both investigations using interpolated and actual data revealed the peak region of the unimodal pattern with the greatest species richness at the same height.

Elevational relationship of alpha diversity and beta diversity indices: The outcome of regression of species richness reveals a statistically significant unimodal trend for species richness or alpha diversity against elevation. This result was also supported by outcome of work in Nepal (Bhattarai et al., 2004; Nepali et al., 2020; Subedi et al., 2015) and abroad (Acharya et al., 2011; Grytnes et al., 2006; Lee et al., 2012). In mountainous areas, the hump-shaped structure is a frequently occurring pattern of species (Liang et al., 2020). The observed unimodal pattern in species richness may be predicted accurately by the mid-domain effect, which helps to explain patterns of altitudinal richness. The mid-domain effect is caused by overlapping of species of two or more communities.

Beta diversity is the change in diversity of species between two or more ecosystems in an area. The interpretation and explanation of variation in community composition among sites is intimately tied to the concept of "nestedness" and "turnover" (i.e., beta diversity, Anderson et al., 2011). The Bray-Curtis dissimilarity index represents the species turnover ratio and the Jaccard similarity index represents the nestedness ratio of common species between two communities. The Bray-Curtis dissimilarity index regression result displays a statistically significant but inverted hump-shaped structure. This finding was also supported by result of spatial turn over and elevation (Bhattarai et al., 2004). In contrast to this finding, beta diversity also demonstrated a unimodal link between altitude and the variety of vascular plants in the Faroe Islands, Europe (Fosaa, 2004), as well as a subarctic mountain tundra (Naud et al., 2019). According to Fontana et al. (2020), species turn over reduced in plant and insect groups in pastured grasslands in the European Alps as elevational distance increased.

The regression result of species nestedness or Jaccard similarity index reveals a statistically significant unimodal structure against elevation. According to the hump-shaped structure of species richness and Jaccard's similarity index, the peak was created by the presence of more similar species. This may be due to ecotone effect of two adjoining vegetation. Species richness (i.e. alpha diversity) and beta diversity index of species per 100 m contour elevation show the reverse relation to each other. There was less beta diversity index value due to more species similarity at mid-elevation. Generally, a high beta diversity index indicates a low level of similarity, while a low beta diversity index shows a high level of similarity. Therefore, in this study, alpha diversity per elevation gradients and species turnover (dissimilarity index) of beta diversity exhibit the inverse relationship.

A region that serves as a transition between two forests or ecosystems is known as an ecotone. It is well known that the species richness and composition of a forest ecotone can alter, mostly in sub-alpine regions (Shrestha & Vetaas, 2009), but that a smaller ecotone can also form where two types of forests meet. The transition zone between two vegetation communities is thought to have more species than the neighboring communities (Sharma et al., 2014).

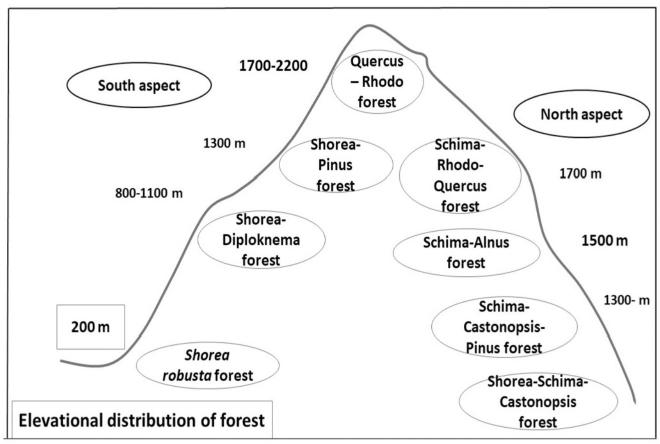

Figure 7: Distribution of forest in two aspects of study area

According to the sketched Figure 7 of this research site, the existence of more comparable species between two close forests also explains the impact of a high species region that produces an ecotone. The decreasing trend of species from the equator to the poles and from low to high elevations is mostly caused by the beta diversity's trend toward decline (Sabatini, 2017). Any location may have high species richness due to either the presence of significant turn covered species (high dissimilarity index value) or high species similarity. The high species richness in this work is experimentally proved by presence of high value of Jaccard similarity index or more similar species at mid-elevation. Interspecific competition may be the main element in the establishment of plant communities at moderate elevations, whereas environmental filtration is the main driver in the formation of plant communities at high and low altitude (Zhang et al., 2016).

According to Var der Plas et al. (2014), sustaining high multifunctionality at local scales depends on other variables than diversity, but at the landscape scale, a high turnover (species dissimilarity or beta diversity) in the community composition of forest plants can aid in preserving as many ecological services as feasible. When a location exhibits a high beta diversity in species presence in any flora, this type of research aids in identifying the area as a biodiversity hotspot. This may be useful for planning a conservation area or running any sustainable initiatives for environmentalists.

Conclusion

This research tried to show the elevational relationship of alpha diversity with beta diversity (species similarity and species turn over) of vascular plant species in Arghakhanchi, west Nepal. Alpha diversity or species richness as well as species similarity in the form of Jaccard similarity index showed the significant unimodal structure with elevation. However, species turn over in the form of Bray-Curtis dissimilarity index showed the reverse relation or the reverse unimodal pattern against elevation. The outcome demonstrates that places with high species richness do not always have substantial species turnover. It is concluded that the existence of significant species similarity causes the unimodal pattern of species richness against elevation gradient to arise.

Author Contributions

Baburam Nepali designed the study, collected and analyzed data and prepared manuscript draft. John Skartveit edited draft and language and gave suggestion. Chitra Bahadur Baniya conceptualized, designed the study, did statistical analysis and draft correction and corresponding and main supervision.

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Appendix: The table showing the alpha diversity species per elevation band and beta diversity indices between two elevation bands (Mid elevation* indicates the mean elevation to indicate the two adjoining elevation bands)

For Alpha diversity		**For Beta diversity**		
Elevation (m)	**Species richness**	**Mid elevation* (m)**	**Beta diversity indices**	
			Jaccard's similarity index	**Bray-curtis dissimilarity index**
200	13			
300	43	250	0.332	0.707
400	62	350	0.545	0.614
500	104	450	0.569	0.544
600	96	550	0.663	0.544
700	162	650	0.579	0.496
800	167	750	0.697	0.463
900	228	850	0.664	0.501
1000	309	950	0.726	0.344
1100	275	1050	0.788	0.324
1200	231	1150	0.722	0.350
1300	172	1250	0.638	0.436
1400	245	1350	0.520	0.414
1500	208	1450	0.607	0.447
1600	188	1550	0.535	0.437
1700	283	1650	0.485	0.407
1800	205	1750	0.591	0.376
1900	191	1850	0.476	0.395
2000	145	1950	0.441	0.460
2100	110	2050	0.357	0.499
2200	48	2150	0.285	0.685