Heliyon 6 (2020) e03121

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Topographic variables to determine the diversity of woody species in the exclosure of Northern Ethiopia

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ARTICLE INFO

Keywords:
Environmental science
Ecology
Environmental assessment
Environmental health
Environmental management
Environmental pollution
Exclosure
Topographic variables
Diversity
Woody species

ABSTRACT

Exclosures are established with the objective of rehabilitating degraded lands and restoring of woody vegetation. Various studies have been conducted to evaluate the success of exclosure on restoring woody species diversity. However, works focusing on the effect of topographic factors on woody species diversity are scarce. Understanding the factors that determine woody species diversity is important for management purposes. Therefore, this paper analyzes the effect of altitude, slope, and aspect as topographic variables on woody species diversity in Dawsura exclosure in northern Ethiopia. Data on species identity, abundance, slope, elevation and aspect were recorded from 58 sampling plots. Different diversity indices were used to analyze the data and one-way ANOVA and linear regression was conducted. There were a total of 34 woody species represented 15 families, of which 62% and 38% were trees and shrubs respectively. Altitude ($r^2 = 0.63$, $p = 0.000$ and $r = 0.794$, $p < 0.01$) and slope ($r^2 = 0.57$, $p = 0.002$ and $r = 0.68$, $p < 0.01$) correlated significantly and positively with Shannon diversity, whereas aspect ($r^2 = 0.12$, $p = 0.378$ and $r = 0.27$, $p > 0.05$) did not correlate significantly with Shannon diversity. Woody species diversity at moderate (1.44) and high (1.85) altitudes was significantly different from that of low (0.86) altitude areas ($p = 0.0013$). Furthermore, significantly higher woody species diversity was recorded at steep slope (1.88) and moderately steep slope (1.62) areas as compared to the gentle slope (0.95) areas. No significant variation was observed in woody species diversity among the aspect categories ($p > 0.05$). The study concludes that woody species diversity is largely regulated by slope and altitude than aspect in the exclosure. We suggest other environmental and anthropogenic variables should be taken into consideration in future studies on woody species diversity.

1. Introduction

Land is increasingly becoming a scarce resource due to immense pressure from anthropogenic activities specifically human population growth. Ethiopia is one of the most environmentally degraded countries in the Sahel belt (Nana-Sinkam, 1995; Hawando, 1997; Bishaw, 2001). In Ethiopia, previous works showed that land degradation over the most recent three decades cover around 23% of the land area (Gebreselassie et al., 2016). Moreover, the soil in Ethiopia is exposed to extreme degradation as a result of deforestation, agricultural land expansion and overgrazing (Lemenih et al., 2005; Kindu et al., 2015; Solomon et al., 2018). This can lead to the reduction of ecosystem services and goods.

In order to rehabilitate degraded dryland vegetation is taken as a major remedy by the government and local communities in Ethiopia (Taddese, 2001; Birhane et al., 2017). Different measures of soil and water conservation have been undertaken which were aimed to restore the degraded environments. The establishment of exclosures was one of such measures (Birhane et al., 2017). Exclosures among various land management and rehabilitation mechanisms are flourishing strategies practiced to improve species diversity and ecosystem productivity (Birhane et al., 2006, 2017; Yayneshet et al., 2009).

Tigray, northern Ethiopia, is one of the regions severely affected by land degradation (Yami et al., 2007). In Tigray, efforts have been made at local and regional levels to reverse land degradations, prevent further

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https://doi.org/10.1016/j.heliyon.2019.e03121
Received 16 July 2019; Received in revised form 13 September 2019; Accepted 23 December 2019

degradations and rehabilitate the degraded natural resources. As part of this effort, communities and local authorities of Tigray has established exclosures to recover degraded grazing lands about three decades ago (Birhane et al., 2006; Mekuria and Yami, 2013). As a result, exclosure has become one among the different types of land uses prevailed in Tigray and Northern Ethiopia in general (Meire et al., 2013). Establishment of exclosure have proven to be effective in reducing runoff, soil erosion, enhancing organic matter accumulation, facilitating vegetation recovery and improving biodiversity (Birhane et al., 2006; Descheemaeker et al., 2006a, 2006b; Aynekulu et al., 2009; Mekuria et al., 2009; Yayneshet et al., 2009).

Dawsura –Tembien is one of the areas that have been affected by land degradation. As part of the environmental rehabilitation programs, exclosure of Dawsura-Tembien was established in 1991/2 (personal communication with the Bureau of agriculture of the district (Ashebir G/kidan)). Since then, Dawsura began to recover and has been considerably changed and become densely vegetated area (Mekuria and Yami, 2013). However, the type of plant species found and their density are not evenly distributed across the landscape in the exclosure. Vegetation recovery and distribution depends on both natural and human factors (Zhang et al., 2013, 2016a). Environmental variables such as topographic factors are among many that have a significant influence on plant diversity, richness and density (Gracia et al., 2007; Zhang et al., 2013).

In Ethiopia previous works have documented studies on assessment of the role of exclosure in improving species composition, diversity, and density of vegetation (Abebe et al., 2006; Birhane et al., 2006; Yayneshet et al., 2009; Abiyu et al., 2011; Mekuria and Yami, 2013; Gebremedihin et al., 2018). Nevertheless, studies focusing on the influence of topographic factors on woody species diversity are limited. Understanding spatial patterns in biodiversity and the underlying factors behind them are essential to design rigorous management strategies. Therefore, the aim of this study is (i) to analyze the relationship between topographic factors and woody species diversity; and (ii) to identify the key topographic variables influencing tree density, plant species diversity, richness and evenness. The results of this study can deliver important information to policy makers and stakeholders to establish conservation and management strategies.

2. Materials and methods

2.1. Study area

Dawsura exclosure is located in the central zone of Tigray Region, Northern Ethiopia. Geographically, it is placed at 13.568º to 13.59° N and 39.00̊ to 39.023E. Exclosure of Dawsura – Tembien occupy a total land area of 336.17 ha and the exclosure belongs to two administrative districts namely *Degua Tembien* and *Tanqua abergele*. The altitude of the exclosure increases as one approaches the part that belongs to *Degua Tembien* administrative district. The exclosure has a dry semi-arid climate according to the agro-ecological zones of Ethiopia. The area is characterized by variable topography with flat and undulating land with 1–5° of slope in the south and rises gradually from broad and gentler slopes to steeper and narrower hilly landscapes in the north with a slope ranging from 5 to 35°. Elevation of the study area ranges between 1670 and 2138 m above the sea level. The study area has a single rainy season, with its peak varying between June and September. The area receives between 400 and 900 mm rainfall per annum. Temperature varies between 21 and 41 °C on the low land areas and between 14 and 21 °C on the high land areas. According to WRB's soil taxonomy, Calcaric Cambisols, Vertic Leptosols, Vertic Cambisols, Lithic Leptosols and Regosols are dominant soil types in the study area (WRB, 2006).

2.2. Woody species inventory

A reconnaissance survey was made to delineate the boundary of the study area, to define the actual total area and choose the bearing and number of transect lines as well before the actual field data collection started. Later on, data were collected from three aspect categories; West (247.5–292.50), Southwest (202.5–247.50) and South direction (157.5–202.50) along three altitudinal ranges; high (1986–2138 m), moderate (1826–1986 m) and low (1670–1826 m) and in three slope categories; gentle slope (0–5°), moderate slopes (6–20°), and steep slopes (21–35°). Three transect lines were established across three altitudinal, aspect and slope gradients of the study area. Each transect line consisted of 6 sample plots. In total, 54 plots were located at intervals of 100 m along transects. Each plot contained two nested compartments with the main plot having 20 m × 20 m size and subplot 5 m × 5 m size. In the main plot, height and diameter of all species above 3 m heights were recorded using diameter tape and hypsometer respectively. In the subplot, all shrubs with height between 1 and 3 m were recorded. Species were identified with their local names using the knowledge of local people. The scientific names of each species were identified using species reference book (Bekele, 2007).

2.3. Indexes calculated and data analysis

Shannon-Weiner Diversity Index (H′) was used to analyze species diversity in the exclosure using PAST version 3.0 software. The formula for H′ is given as;

$$H' = -\sum pi\ (Ln\ pi)$$

where, pi is the proportional abundance of the i^{th} species; Ln pi is the natural logarithm of each pi value.

The woody species diversity within the different topographic variable categories was compared using one-way analysis of variance (ANOVA). Tukey honestly significant difference (HSD) post-hoc tests were performed to separate means across the different levels of topographic variables. Statistical tests were performed with SAS 9.0. Significant differences were considered at $p < 0.05$. To identify change in species diversity along the topographic variables, linear regression analyses were done. Shannon-wiener index was considered as the dependent variable, while aspect, slope, and altitude, was used as the independent variables. To assess the correlation between species diversity and topographic variables, Pearson correlation analysis was performed using Minitab Software, version 16.0. Significant differences were considered at $p < 0.05$.

3. Results

3.1. Vegetation characteristics

A total of 34 woody species belonging to 15 families were recorded from all plots (Table 1). *Acacia Sieberiana* (34.6%), *Dichrostachys cinerea* (20.5%), *Dodonaea angustifolia* (10.5), *Comberetem molle* (9.1%), Betremishe (8.3%) and *Acacia etbaica* (6.9%) were the dominant species contributing 89.9% of the total species observed.

85.4% and 14.6% of the trees and shrubs were in the 1–5 m and 5–10 m height class respectively (Figure 1). 42% and 41.1% of the trees and shrubs were found in the diameter class of 1–5 and 5–10 cm respectively (Figure 1). Generally, the diameter class distribution of woody species showed an inverted J-shaped.

3.2. Density, richness and woody species diversity along altitudinal gradient

Tree density per plot ranged between 13 and 36, with significantly highest value recorded in moderate altitude and the lowest being in low altitude (Table 2). Species richness was significantly higher at the high altitude compared to the moderate and low altitude. Woody species diversity varied from 0.86 to 1.85, with the highest value recorded in the high altitudinal gradient and the lowest in low altitude. Species evenness showed no significant variation between the altitudinal gradient.

Pearson correlation analysis showed that altitude plays an important role in regulating trees and shrubs density, species richness and species

Table 1. List of woody species identified in the exclosure of Dawsura-Tembien.

S.No	Varnicular_name	Scientific_name	Family	Life form
1	Kileow	*Euclea racemosa Subsp. Sehimperi*	Ebenaceae	Shrub
2	Mebetti	*Acokanthera schimperi*	Apocynaceae	Tree
3	Nefacia (Sibkana)	*Acacia sieberiana*	Fabaceae	Tree
4	Chea	*Acacia abyssinica Hochst. ex Benth*	Fabaceae	Tree
5	Qeyeh-Chea	*Acacia seyal Delile*	Fabaceae	Tree
6	Tseada-Chea	*Acacia sieberiana Delile*	Fabaceae	Tree
7	Tselim-Chea	*Acacia mellifera Delile*	Fabaceae	Tree
9	Tahses	*Dodonaea angustifolia*	Sapindaceae	Shrub
10	Gonnok	*Dichrostachys cinerea*	Fabaceae	Tree
11	Rewey	*Celtis Africana*	Ulmaceae	Tree
12	Tetale	*Rhus retinnohira*	Anacardiaceae	Tree
13	Anqu	*Commiphora Africana*	Combretaceae	Tree
14	Chequente	*Pittosporum viridiflorum*	Pittosporaceae	Tree
15	Haziba/Weiba	*Combretum molle*	Combretaceae	Tree
16	Tslimo	*Maytenus undata*	Celastraceae	Tree
17	Seraw	*Acacia etbaica Schweinf.*	Fabaceae	Tree
18	Milaou	*Ximenia Americana*	Olacaceae	Tree
19	Andel	*Capparis tomentosa Lam.*	Capparaceae	Shrub
20	Kiremti yekelo	*Unidentified*	Unidentified	Shrub
21	Hailuchiko	*Unidentified*	Unidentified	Shrub
22	Betremishe	*Grewia mollis*	Malvaceae	Shrub
23	Alendia	*Ormocarpum pubescence*	Fabaceae	Shrub
24	Koramo	*Maerua angolensis*	Capparaceae	Tree
25	Awihicherengih	*Cordia monoica*	Boraginaceae	Tree
26	Shishey	*Boscia angustifolia*	Capparaceae	Shrub
27	Keretatimo	*Grewia kakothamnos K.Schum*	Malvaceae	Shrub
28	Harmazo	*Flueggla virosa*	Euphorbiaceae	Shrub
29	Hutsawits	*Calpurnia aurea L*	Fabaceae	Shrub
30	Tetera	*Ozoroa insignis*	Anacardiaceae	Tree
31	Hable	*Grewia villosa*	Tiliaceae	Shrub
32	Dugdugugna	*Lannea fructicosa*	Anacardiaceae	Tree
33	Hambohambo	*Senna singueana (Del.)Lock*	Fabaceae	Shrub
34	Kebkeb	*Maytenus senegalensis (Lam.) Exell*	Celastraceae	Tree

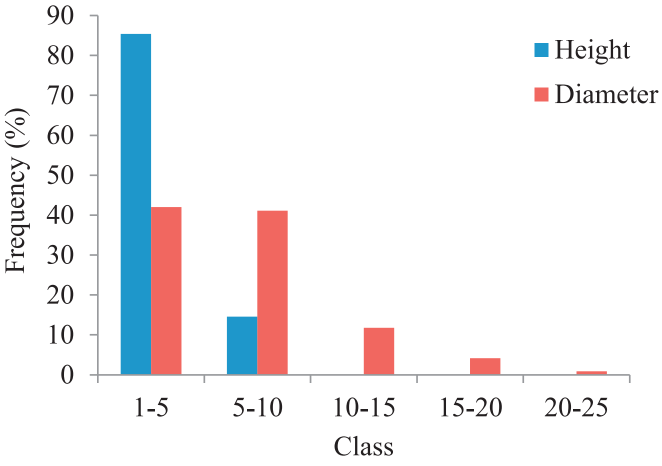

Figure 1. Distribution of height and diameter classes in the study area.

Table 2. Diversity of woody species across altitudinal ranges of the exclosure. Values within a row with same letters are not significantly different ($p > 0.05$) according to Tukey's HSD test.

Parameters	Altitudinal range			P-value
	Low	Moderate	High	
Individuals	13.1 ± 4.11^{b}	35.83 ± 8.73^{a}	32 ± 3.23^{ab}	0.0343
Species richness	3.67 ± 0.80^{b}	6.5 ± 0.99^{b}	10 ± 0.68^{a}	0.0003
Diversity (H′)	0.86 ± 0.19^{b}	1.44 ± 0.13^{a}	1.85 ± 0.12^{a}	0.0013
Evenness	0.75 ± 0.08^{a}	0.70 ± 0.06^{a}	0.66 ± 0.06^{a}	0.6282

diversity. Moreover, slope had greater impacts on density, species richness, species diversity and species evenness (Table 3). The highest statistically significant correlations were found between altitude and species richness ($r = 0.882$, $p < 0.01$), followed by slope and individuals ($r = 0.843$, $p < 0.01$). The lowest correlation was found between aspect and individuals ($r = 0.06$, $p > 0.05$). With increasing altitude, woody species diversity recorded in each plot increased linearly (Figure 2). Maximum species diversity (2.8) was recorded at about 2138 while the minimum (0.35) was recorded at 1670 m altitude.

3.3. Density, richness and woody species diversity along aspect categories

Tree density ranged between 12 and 25.5, with the highest value observed in southwest facing aspect while the lowest was recorded in west facing aspect class (Table 4). However, there was no significant ($p > 0.05$) difference in tree density among the aspect categories. Similarly, there was no significant difference in species evenness among the aspect categories, though higher species evenness was recorded in the west facing aspect category. There was no clear pattern of species diversity along the aspect categories (Figure 3). Links between aspect and species diversity were not significant ($p > 0.05$).

3.4. Density, richness and diversity of woody species across slope classes

Tree density significantly varied from 7.5 to 31.83, with the highest value recorded in steep slope class and the lowest in gentle slope (Table 5). Species richness was significantly higher at steep slope (9.83) followed by moderately steep slope (6.5) and gentle slope (3.33). Woody species diversity was significantly ($P < 0.05$) affected by slope. The highest diversity recorded in the steep slope while the lowest diversity was found in gentle slope (Table 5). The values of Shannon diversity index for the gentle, moderately steep and steep areas were 0.95, 1.62 and 1.88, respectively. Species evenness was not significantly affected by slope; though highest value was recorded in gentle slope.

Links between slope and species diversity remained significant (Figure 4), with 0.57 coefficient of determination (R^2). Species diversity increased and then decreased along altitudinal gradients. Maximum species diversity (2.11) was recorded at 10° and 20° slope while the minimum (0.56) was recorded at 3.5° slope.

4. Discussion

The present study revealed that altitude has a significant effect on species diversity and richness. Altitude is a key variable affecting species diversity in mountains, as observed in numerous studies (Rahbek, 2005; Fetene et al., 2006; Muhumuza and Byarugaba, 2009; Kebede et al., 2013; Cui and Zheng, 2016). Similarly, a study by Kebede et al. (2013) reported that aspect, slope and altitudinal variation in Ethiopian landscapes has influenced the existence of varied vegetation types and floristic diversity. Our study also supports the results given by Zhang et al. (2013), who revealed elevation was among the most important factors that most influenced community distribution and species diversity in the Baihua Mountain Reserve, Beijing, China. A covariance analysis by Yuan et al. (2014) also revealed that altitude significantly correlated with the individual number and richness of plants in karst montane forests in Southwest Guangxi, China. In this study, woody species richness and diversity increased as altitude increased. The highest altitude had the highest value of woody species richness and diversity. In

Table 3. Pearson correlation coefficients between diversity indices and topographic variables.

Diversity indices	Topographic variables		
	Altitude (m)	Slope (°)	Aspect (°)
Tree density	0.502*	0.843**	0.060
Species richness	0.882**	0.766**	-0.140
Shannon diversity	0.794**	0.679**	0.269
Species evenness	-0.391	-0.575*	-0.123

Stars indicate significant effects *$p < 0.05$; **$p < 0.01$.

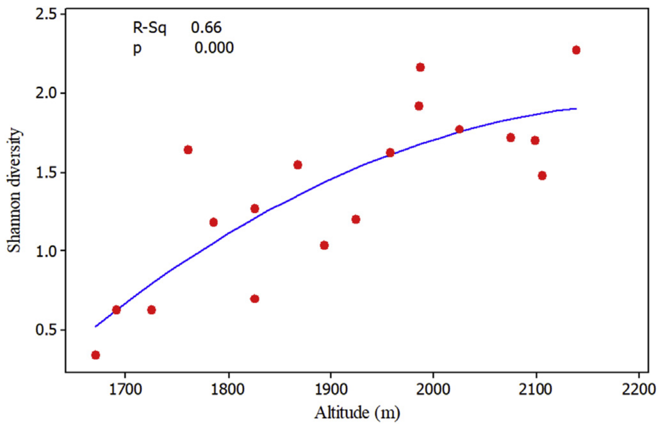

Figure 2. Woody species diversity along altitudinal gradients.

Table 4. Diversity of woody species across aspects of the exclosure and the open grazing areas. Values within a row with same letters are not significantly different ($p > 0.05$) according to Tukey's HSD test.

Parameters	Aspect categories			P-value
	South facing	Southwest facing	West facing	
Tree density	19.7 ± 5.20^{a}	25.5 ± 10.24^{a}	12.0 ± 1.98^{a}	0.3870
Species richness	9.0 ± 0.23^{a}	7.0 ± 1.15^{a}	7.5 ± 0.56^{a}	0.1849
Diversity (H′)	1.52 ± 0.26^{a}	1.15 ± 0.20^{a}	1.48 ± 0.27^{a}	0.5273
Evenness	0.95 ± 0.15^{a}	0.81 ± 0.18^{a}	1.07 ± 0.21^{a}	0.5956

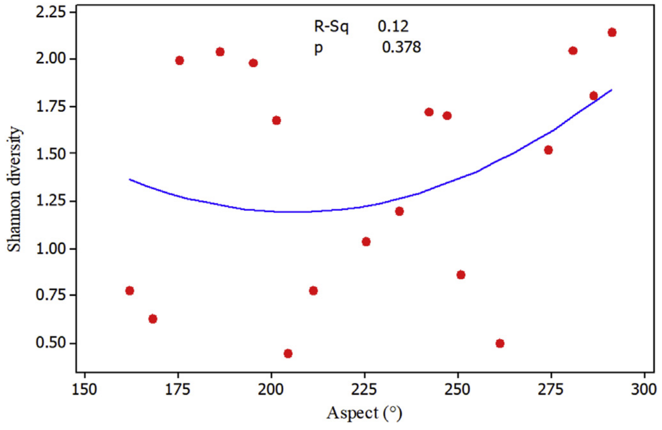

Figure 3. Woody species diversity along aspect categories.

Table 5. Value of mean diversity indices of woody species across slope gradients. Values within a row with same letters are not significantly different ($p > 0.05$) according to Tukey's HSD test.

Parameters	Slope classes			P-value
	Gentle slope	Moderately steep slope	Steep slope	
Tree density	7.5 ± 2.57^{b}	12.67 ± 3.1^{b}	31.83 ± 2.9^{a}	<0.0001
Species richness	3.33 ± 0.61^{c}	6.5 ± 0.99^{b}	9.83 ± 0.60^{a}	<0.0001
Diversity (H′)	0.95 ± 0.12^{b}	1.62 ± 0.12^{a}	1.88 ± 0.06^{a}	<0.0001
Evenness	0.86 ± 0.06^{a}	0.84 ± 0.05^{a}	0.69 ± 0.04^{a}	0.0939

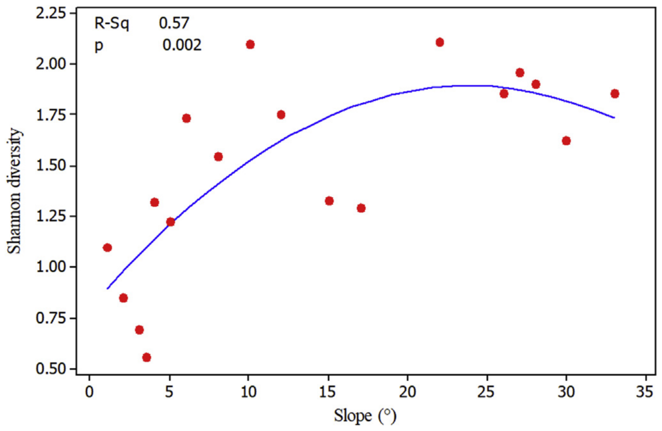

Figure 4. Woody species diversity along slope classes.

agreement with this study, Cui and Zheng (2016) also reported Shannon diversity index increased with altitude, with the highest diversity being recorded in the highest altitude in evergreen broadleaf forests in southern China. Zhang et al. (2013) found the highest species diversity appeared in the middle elevation and under medium disturbance intensity in the Baihua Mountain Reserve, Beijing, China. Maximum diversity at an intermediate elevation has the most commonly observed pattern (Hegazy et al., 1998; Kessler, 2001; Arvid Grytnes and Vetaas, 2002; Austrheim, 2002; Kebede et al., 2013), highlighting the role of suitable temperature in those areas. In contrary to the present study, Heydari and Mahdavi (2009) study showed that the low altitudes (1400–1500 and 1500–1600 m ranges) have the most, while the upper altitudes (1800–1900 and 1900–2000 m ranges) have the least diversity in Melah Gavan protected area, Iran. Gracia et al. (2007) also reported that species richness decreased with elevation in temperate forests in central Pyrenees (NE Spain), which is in close correlation with the decrease of mean air temperature. With increasing elevation, the total number of species recorded in each plot decreased linearly in Temperate Mountain Forests of Northern China (Zhang et al., 2016b).

The difference in species richness and diversity among the altitudinal gradient is due to the variation in climate variables, deforestation, human interaction, encroachment pressure and soil erosion (Amjad et al., 2013; Bertuzzo et al., 2016; Cui and Zheng, 2016). Climate is a visible factor affecting species distribution and richness in many areas (Fang and Lechowicz, 2006). In this study the low species diversity recorded at low altitude is as a result of anthropogenic disturbances and low precipitation. High-altitude areas have higher precipitation, which favors plant growth, while low-altitude areas lack adequate rainfall and cannot meet moisture requirements for plant growth. Similarly, Wondie et al. (2012) also stated that forests grow preferentially on high altitude in the Simen Mountains National Park, a World Heritage Site in northern Ethiopia. In general terms in the context of Ethiopian forests, due to uncontrolled human and livestock population growth, forests have been restricted to inaccessible and sacred areas which causes artificial deficit of plants occurrences in gentle and accessible slopes (Nyssen et al., 2009).

The present study also revealed that slope has a significant effect on species diversity and richness. Slope has been recognized as an effective factor on diversity and richness (Boll et al., 2005; Cui and Zheng, 2016). Wolf et al. (2012) argued that slope has a significant effect on woody species diversity, because they determine water availability. A study by Yuan et al. (2014) also revealed that slope and aspect had a significant effect on species richness. A study in Melah Gavan protected area, Iran by Heydari and Mahdavi (2009) also showed that slope had a significant effect on biodiversity and richness of plants. However, Legendre et al. (2009) and Song and Cao (2017) found that the effects of slope on distribution of richness was weak in a subtropical broad-leaved forest of China. In this study, woody specie richness and diversity increased with slope. Higher species richness and diversity was recorded in steep slopes. The increase in species richness and diversity with slope is resulted from the less human disturbance at steep slopes. This result is in agreement with the findings of Wondie et al. (2012) who stated that forests develop preferentially on high and steep terrain. In contrary to our study, Zhang et al. (2013) study reported that species diversity was negatively correlated with slope in the Baihua Mountain Reserve, Beijing, China. Heydari and Mahdavi (2009) also indicated that low slope (0–25%) had highest diversity and richness in Melah Gavan protected area, Iran. The discrepancies in species diversity along slope is due to variation in management and other biophysical characteristics.

Meanwhile, woody species richness and diversity have shown no significant changes with aspect. In agreement with the present study, woody species richness and diversity have shown no significant changes with aspect in central Pyrenees (Spain) (Gracia et al., 2007). However, the present study does not support the results of Kutiel (1992) and Wolf et al. (2012) where species richness and diversity affected by aspect. For example, Kutiel (1992) found higher species diversity in the south-facing slope due to the presence of herbaceous, mainly annual, plants in a Mediterranean ecosystem. Heydari and Mahdavi (2009) found highest plant richness in southern aspect while it was not significantly different in the other aspects. Higher differences in alpha and beta diversity between the aspects of Braka was found by Paudel and Vetaas (2014). In this study, the low variation in species richness and diversity is due to the aspect categories considered. In the present study the aspect categories were south facing, southwest facing and west facing which does not have significant difference in solar radiation resulting in insignificant difference in aspect-related gradients of humidity, soil moisture, and both air and soil temperatures.

5. Conclusions

The present study highlights the relationship between woody species diversity and topographic variables. Our findings revealed that diversity indices such as individual plant number, Shannon diversity and species richness are best explained by both altitude and slope. However, aspect did not show any significant relationship with woody species diversity. Woody species diversity and richness increased with increase in altitude and slope. Higher altitudinal gradient had comparatively higher woody species diversity than lower altitudinal gradient which implies that lower altitudinal gradient should receive prioritized conservation efforts. Besides, significantly higher species diversity was found in moderate and steep slopes as compared to the gentle slope. The study suggests that species diversity and species richness pattern of different tree species are largely regulated by topographic variables. The topographic gradient effect of woody species diversity is the result of an interaction of socio-economic and natural factors. This research is important to inform policy makers on how diversity is varying along topographic variables for further planning and intervention. Moreover, the present study attempted to evaluate the effect of topographic variables on woody species diversity, yet further studies should be done on the effect of other physical and anthropogenic factors on species diversity.

Declarations

Author contribution statement

Goiteom Woldu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Negasi Solomon, Hadgu Hishe: Analyzed and interpreted the data; Wrote the paper.

Hailemariam Gebrewahid: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Mewcha Amha Gebremedhin: Conceived and designed the experiments; Wrote the paper.

Emiru Birhane: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

We are grateful to Mekelle University and Abiyi Addi college of Teacher's Education for providing an opportunity to the first author to study MSc. We are also grateful to the two anonymous referees for constructive comments on an earlier version of this manuscript.

References

Abebe, M.H., Oba, G., Angassa, A., Weladji, R.B., 2006. The role of area enclosures and fallow age in the restoration of plant diversity in northern Ethiopia. Afr. J. Ecol. 44.

Abiyu, A., Lemenih, M., Gratzer, G., Aerts, R., Teketay, D., Glatzel, G., 2011. Status of native woody species diversity and soil characteristics in an exclosure and in plantations of Eucalyptus globulus and cupressus lusitanica in northern Ethiopia. Mt. Res. Dev. 31, 144–152.

Amjad, M.S., Arshad, M., Chaudhari, S.K., Manzoor, K., Fatima, S., Mustafa, G., Malik, N.Z., Akrim, F., 2013. Altitudinal variation in plant species diversity and its components at Kotli hills, Azad Kashmir. Ars 66.

Arvid Grytnes, J., Vetaas, O.R., 2002. Species richness and altitude: a comparison between null models and interpolated plant species richness along the himalayan altitudinal gradient, Nepal. Am. Nat. 159, 294–304.

Austrheim, G., 2002. Plant diversity patterns in semi-natural grasslands along an elevational gradient in southern Norway. Plant Ecol. 161, 193–205.

Aynekulu, E., Denich, M., Tsegaye, D., 2009. Regeneration response of juniperus procera and olea europaea subsp cuspidata to exclosure in a dry afromontane forest in northern Ethiopia. Mt. Res. Dev. 29, 143–152.

Bekele, A., 2007. Useful trees and shrubs of Ethiopia: identification, propagation, and management for 17 agroclimatic zones. RELMA in ICRAF Project. World Agroforestry Centre, Eastern Africa Region.

Bertuzzo, E., Carrara, F., Mari, L., Altermatt, F., Rodriguez-Iturbe, I., Rinaldo, A., 2016. Geomorphic controls on elevational gradients of species richness. Proc. Natl. Acad. Sci. 113, 1737–1742.

Birhane, E., Mengistu, T., Seyoum, Y., Hagazi, N., Putzel, L., Rannestad, M.M., Kassa, H., 2017. Exclosures as forest and landscape restoration tools: lessons from Tigray Region, Ethiopia. Int. For. Rev. 19, 37–50.

Birhane, E., Teketay, D., Barklund, P., 2006. Actual and potential contribution of exclosures to enhance biodiversity of woody species in the drylands of Eastern Tigray. J. Drylands. 1, 134–147.

Bishaw, B., 2001. Deforestation and land degredation in the Ethiopian highlands: a strategy for physical recovery. Northeast Afr. Stud. 8, 7–25.

Boll, T., Svenning, J.-C., Vormisto, J., Normand, S., Grández, C., Balslev, H., 2005. Spatial distribution and environmental preferences of the piassaba palm Aphandra natalia (Arecaceae) along the Pastaza and Urituyacu rivers in Peru. For. Ecol. Manage. 213, 175–183.

Cui, W., Zheng, X.-X., 2016. Spatial heterogeneity in tree diversity and forest structure of evergreen broadleaf forests in southern China along an altitudinal gradient. Forests 7, 216.

Descheemaeker, K., Muys, B., Nyssen, J., Poesen, J., Raes, D., Haile, M., Deckers, J., 2006a. Litter production and organic matter accumulation in exclosures of the Tigray highlands, Ethiopia. For. Ecol. Manage. 233, 21–35.

Descheemaeker, K., Nyssen, J., Rossi, J., Poesen, J., Haile, M., Raes, D., Muys, B., Moeyersons, J., Deckers, S., 2006b. Sediment deposition and pedogenesis in exclosures in the Tigray highlands, Ethiopia. Geoderma 132, 291–314.

Fang, J., Lechowicz, M.J., 2006. Climatic limits for the present distribution of beech (Fagus L.) species in the world. J. Biogeogr. 33, 1804–1819.

Fetene, M., Assefa, Y., Gashaw, M., Woldu, Z., Beck, E., 2006. Diversity of Afroalpine Vegetation and Ecology of Treeline Species in the Bale Mountains, Ethiopia, and the Influence of Fire. Land use change Mt Biodiversity 25–38.

Gebremedihin, K.M., Birhane, E., Tadesse, T., Gbrewahid, H., 2018. Restoration of degraded drylands through exclosures enhancing woody species diversity and soil nutrients in the highlands of Tigray, Northern Ethiopia. Nature consevation research 3, 1–20.

Gebreselassie, S., Kirui, O.K., Mirzabaev, A., 2016. Economics of land degradation and improvement in Ethiopia. In: Nkonya, E., Mirzabaev, A., von Braun, J. (Eds.), Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development. Springer International Publishing, Cham, pp. 401–430.

Gracia, M., Montané, F., Piqué, J., Retana, J., 2007. Overstory structure and topographic gradients determining diversity and abundance of understory shrub species in temperate forests in central Pyrenees (NE Spain). For. Ecol. Manage. 242, 391–397.

Hawando, T., 1997. Desertification in Ethiopian highlands. Rala report, p. 200.

Hegazy, A.K., El-Demerdash, M.A., Hosni, H.A., 1998. Vegetation, species diversity and floristic relations along an altitudinal gradient in south-west Saudi Arabia. J. Arid Environ. 38, 3–13.

Heydari, M., Mahdavi, A., 2009. Pattern of plant species diversity in related to physiographic factors in Melah Gavan protected area, Iran. Asian J Biol Life Sci 2, 21–28.

Kebede, M., Yirdaw, E., Luukkanen, O., Lemenih, M., 2013. Plant community analysis and effect of environmental factors on the diversity of woody species in the moist Afromontane forest of Wondo Genet, South Central Ethiopia. Biodiversity: Res Conser 29, 63.

Kessler, M., 2001. Patterns of diversity and range size of selected plant groups along an elevational transect in the Bolivian Andes. Biodivers. Conserv. 10, 1897–1921.

Kindu, M., Schneider, T., Teketay, D., Knoke, T., 2015. Drivers of land use/land cover changes in Munessa-Shashemene landscape of the south-central highlands of Ethiopia. Environ. Monit. Assess. 187, 452.

Kutiel, P., 1992. Slope aspect effect on soil and vegetation in a Mediterranean ecosystem. Isr. J. Bot. 41, 243–250.

Legendre, P., Mi, X., Ren, H., Ma, K., Yu, M., Sun, I.-F., He, F., 2009. Partitioning beta diversity in a subtropical broad-leaved forest of China. Ecology 90, 663–674.

Lemenih, M., Karltun, E., Olsson, M., 2005. Soil organic matter dynamics after deforestation along a farm field chronosequence in southern highlands of Ethiopia. Agric. Ecosyst. Environ. 109, 9–19.

Meire, E., Frankl, A., De Wulf, A., Haile, M., Deckers, J., Nyssen, J., 2013. Land use and cover dynamics in Africa since the nineteenth century: warped terrestrial photographs of North Ethiopia. Reg. Environ. Chang. 13, 717–737.

Mekuria, W., Veldkamp, E., Haile, M., Gebrehiwot, K., Muys, B., Nyssen, J., 2009. Effectiveness of exclosures to control soil erosion and local community perception on soil erosion in Tigray, Ethiopia. Afr. J. Agric. Res. 4, 365–377.

Mekuria, W., Yami, M., 2013. Changes in woody species composition following establishing exclosures on grazing lands in the lowlands of northern Ethiopia. Afr. J. Environ. Sci. Technol. 7, 30–40.

Muhumuza, M., Byarugaba, D., 2009. Impact of land use on the ecology of uncultivated plant species in the Rwenzori mountain range, mid western Uganda. Afr. J. Ecol. 47, 614–621.

Nana-Sinkam, S.C., 1995. Land and Environmental Degradation and Desertification in Africa. Issues and Options for Sustainable Economic Development with Transformation. United Nations Economic Commission for Africa and/or the Food and Agriculture Organization of the United Nations, Addis Ababa, Ethiopia.

Nyssen, J., Haile, M., Naudts, J., Munro, N., Poesen, J., Moeyersons, J., Frankl, A., Deckers, J., Pankhurst, R., 2009. Desertification? Northern Ethiopia re-photographed after 140 years. ScTEn 407, 2749–2755.

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. J. Mt. Sci. 11, 1112–1122.

Rahbek, C., 2005. The role of spatial scale and the perception of large-scale species-richness patterns. Ecol. Lett. 8, 224–239.

Solomon, N., Hishe, H., Annang, T., Pabi, O., Asante, I., Birhane, E., 2018. Forest cover change, key drivers and community perception in Wujig Mahgo Waren forest of northern Ethiopia. Land 7, 32.

Song, C., Cao, M., 2017. Relationships between plant species richness and terrain in middle sub-tropical Eastern China. Forests 8, 344.

Taddese, G., 2001. Land degradation: a challenge to Ethiopia. Environ. Manag. 27, 815–824.

Wolf, J., Fricker, G., Meyer, V., Hubbell, S., Gillespie, T., Saatchi, S., 2012. Plant species richness is associated with canopy height and topography in a neotropical forest. Remote Sens. 4, 4010.

Wondie, M., Teketay, D., Melesse, A.M., Schneider, W., 2012. Relationship between topographic variables and land cover in the simen mountains national Park, a world heritage site in northern Ethiopia. Int. J. Remote. Sens. Appl. 2, 36–43.

WRB, 2006. A Framework for International Classification, Correlation and Communication. FAO, Rome.

Yami, M., Gebrehiwot, K., Stein, M., Mekuria, W., 2007. Impact of area enclosures on density and diversity of large wild mammals: the case of may Ba'ati, Douga Tembien District, Central Tigray, Ethiopia. EAJS 1.

Yayneshet, T., Eik, L.O., Moe, S.R., 2009. The effects of exclosures in restoring degraded semi-arid vegetation in communal grazing lands in northern Ethiopia. J. Arid Environ. 73, 542–549.

Yuan, T.-X., Zhang, H.-P., Ou, Z.-Y., Tan, Y.-B., 2014. [Effects of topography on the diversity and distribution pattern of ground plants in karst montane forests in Southwest Guangxi, China]. Ying yong sheng tai xue bao = J applied ecology 25, 2803–2810.

Zhang, C., Li, X., Chen, L., Xie, G., Liu, C., Pei, S., 2016a. Effects of topographical and Edaphic factors on tree community structure and diversity of subtropical mountain forests in the lower Lancang river basin. Forests 7, 222.

Zhang, J.-T., Xu, B., Li, M., 2013. Vegetation patterns and species diversity along elevational and disturbance gradients in the Baihua mountain Reserve, Beijing, China. Mt. Res. Dev. 33, 170–178.

Zhang, W., Huang, D., Wang, R., Liu, J., Du, N., 2016b. Altitudinal patterns of species diversity and phylogenetic diversity across temperate mountain forests of northern China. PLoS One 11, e0159995.