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

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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 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 (r² = 0.63, p = 0.000 and r = 0.794, p < 0.01) and slope (r² = 0.57, p = 0.002 and r = 0.68, p < 0.01) correlated significantly and positively with Shannon diversity, whereas aspect (r² = 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 and positively with Shannon diversity, whereas aspect (r² = 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 < 0.01). 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 have shown 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...
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, enclosure has become one among the different types of land uses prevailed in Tigray and Northern Ethiopia in general (Meire et al., 2013). Establishment of enclosure 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, enclosure 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 enclosure. 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 enclosure 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; Gebremedhin 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 enclosure is located in the central zone of Tigray Region, Northern Ethiopia. Geographically, it is placed at 13.568° to 13.59° N and 39.00 to 39.023E. Enclosure of Dawsura – Tembien occupy a total land area of 336.17 ha and the enclosure belongs to two administrative districts namely Degua Tembien and Tanqua abergele. The altitude of the enclosure increases as one approaches the part that belongs to Degua Tembien administrative district. The enclosure 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 (247.5–292.5°), Southwest (202.5–247.5°) and South direction (157.5–202.5°) 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 x 20 m size and subplot 5 m x 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 enclosure using PAST version 3.0 software. The formula for H' is given as;

\[ H' = - \sum p_i \ln p_i \]

where, \( p_i \) is the proportional abundance of the \( i \)th species; \( \ln p_i \) is the natural logarithm of each \( p_i \) 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.
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 statistical 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$^\circ$ and 20$^\circ$ slope while the minimum (0.56) was recorded at 3.5$^\circ$ 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; Petene 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

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**Table 1.** List of woody species identified in the exclosure of Dawsura-Tembien. Values within a row with same letters are not significantly different ($p > 0.05$) according to Tukey's HSD test.

| Parameters | Altitudinal range | Low | Moderate | High |
|-----------|------------------|-----|----------|------|
| Individuals | 13.1 ± 4.11$^a$ | 35.83 ± 8.73$^b$ | 32 ± 3.23$^{ab}$ | 0.043 |
| Species richness | 3.67 ± 0.80$^b$ | 6.5 ± 0.99$^b$ | 10 ± 0.68$^b$ | 0.0003 |
| Diversity (H’) | 0.86 ± 0.19$^a$ | 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 |

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

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 ± 2.5a | 12.67 ± 3.1b | 31.83 ± 2.9a | <0.0001 |
| Species richness | 3.33 ± 0.61a | 6.5 ± 0.99b | 9.83 ± 0.60a | <0.0001 |
| Diversity (H′) | 0.95 ± 0.12a | 1.62 ± 0.12a | 1.88 ± 0.06a | <0.0001 |
| Evenness   | 0.86 ± 0.06a | 0.84 ± 0.05a | 0.69 ± 0.04a | 0.0939 |

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 been 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 (Nyyssen 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 species 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 Baituwa 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

Goitom 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.

Haillemariam 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.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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