Abyss. J. Sci. Technol. Vol. 7, No. 1, 2022, 29-38
ISSN 2616 – 4728 (Online); 2616 – 471X (Print)

Abyssinia Journal of Science and Technology

Effects of Forest Fragmentation on Plant Diversity and Regeneration of Woody Species in Qenfot Dry Afromontane Forest, Northeastern Ethiopia

Famos Assefa Molla[a]* and Tsegaye Gobezie[b]

[a] Department of Natural Resource Management, Kombolcha College of Agriculture, Kombolcha, Ethiopia
[b] Department of Forestry, College of Agriculture, Wollo University, Dessie, Ethiopia

ABSTRACT

Qenfote forest, which encompasses the remnant forest patches in northeastern Ethiopia, is undergoing fragmentation, leading to loss of habitat and then erosion of biodiversity. The theory of island biogeography describes that the number of species in oceanic islands can be affected by island size and isolation. This study intended to estimate the effect of patch size, and distance between patches (isolation) on the diversity and regeneration status of plant species. Stratified and proportional sampling strategies were implemented to collect data from forest patches. Forest patch size was identified by delineating each patch from Google Earth and distances between patches were also measured. Forest patches were grouped into three based on size (small 7 ha-20 ha, medium 20.1 ha-45 ha, and large above 45 ha) and into three isolation (distance apart) categories (nearest 0-4 km, medium 4.01 km-8 km, and far distance 8.01 km-11 km). For each category three replicated patches were selected and then systematic sampling was used to lay the transect lines within each nine sample patches. Vegetation data were collected from a total of 75 plots (20 m × 20 m) from every patch. Results showed that the number of species (species richness) found in small forests, medium forest patches, and large forest patches was 55±6.43, 66.67±7.96, and 77.67±10.42, respectively, while the Shannon diversity found in the small forests was 2.52±0.09, in medium forest patches 2.69±0.07 and in large forest patches 2.78±0.08. Both species diversity and species richness were increased with increasing patch size and decreased as distance increased from largest patch. Thus, we concluded that fragmentation in Qenfote forests affects plant diversity and regeneration status, a finding that supports the demands for forest restoration.

Keywords: Forest patch, Patch area, Patch distance, Species diversity, Species richness.

INTRODUCTION

Human-induced land-use and land cover changes have resulted in changes in the earth's ecosystem. Loss and degradation of natural habitat is a central risk to ecosystem function and global biodiversity (Haddad et al., 2015). The large and continued forest is less available as a habitat for biodiversity. Forest fragmentation is characterized as a course all through which a large continuous forest is changed into several smaller patches of smaller add-up areas that are disengaged from each other unlike the original forest (Fahrig, 2003). Natural forces and anthropogenic activities such as logging, road development, transformation to farming, or spreading fire result in forest fragmentation and affect biodiversity (Zhang et al., 2022). Forest size, shape, and, separation accounted for a strongly declining proportion of variability in tree diversity (Hill & Curran, 2003).

*Corresponding author: famoseasfa1@gmail.com

The island biogeography theory describes that the extent of species in oceanic islands can be affected by island size and separation (Laurance, 2010). The main testable forecasts of this theory are that the bigger and less confined the island, the higher the species number at which it ought to reach equilibrium (Munguía-Rosas & Montiel, 2014).

Species–area relationship is a common design of incremental species richness with increasing the size of forest area, but can take on distinctive forms and be clarified by different mechanisms (Joseph, 2003). Small patches can only support small populations, which have a higher risk of destruction than large populations because of the effects of genetic, and demographic environmental stochasticity (Jacquemyn et al., 2003). Distance between patches affects species diversity as it filters out plant species with a limited dispersal capacity, such as those with heavy seeds or those dispersed by abiotic vectors. Increased isolation, on the other hand, makes recolonization extremely implausible. Therefore, mechanisms other than dispersal capacity may also explain the observed effect of patch isolation on functional diversity (Sonnier et al., 2014).

Regeneration is additionally affected by fragmentation of species such as herbivores, their predators, or their parasitoids, which might result in a wide range of impacts of fragmentation on plants. A diminishment in plant performance in confined populations may too be caused by expanded herbivore pressure due to higher number of herbivores per unit area (Kolb, 2008). Seed predation may decrease in separated patches (Farwig et al., 2009) or wind-dispersed species may still colonize isolated patches and after that be set up within the non-appearance more competitive creature-scattered species (Ibanez et al., 2014), aggravating genetic isolation (Grashof-Bokdam, 1997). The island biogeography theory is used to predict plant species richness in terrestrial ecosystems (Zhang et al. 2021).

Biodiversity conservation is especially urgent in the tropics where a vastly diverse biota exists in the context of massive rates of habitat loss. The valuation of biodiversity and how human-induced disturbances affect it may provide more informative metric on current status of biodiversity (Fahrig, 2003). Most assessments of species loss have focused on tropical forests (Miles et al., 2006) Forests are undergoing fragmentation, leading to loss of habitat and then erosion of biodiversity (Jha et al., 2005).

Dry Afromontane forest covers 48% of both tropical and subtropical forests and it is exposed to fragmentation and disturbance (Hasnat & Hossain, 2020). Ethiopia is one of the biodiversity-rich countries in the world facilitating the eastern Afromontane and the horn of Africa hotspots (Miles et al., 2006). But it has experienced high fragmentation disturbance and degradation. Despite the high conservation values of the natural forest remnants in dryland Ethiopia, forest ecological studies in Ethiopia have focused on species richness and diversity, community structure, and comparisons therein (Awoke, 2018; Fisaha et al., 2013; Wassie et al., 2010; Aynekulu et al., 2012; Eshetu, 2002; Tekle et al., 1997). However, the effect of fragmentation on plant species composition was not studied at the local level. Therefore, this study was initiated to investigate the effects of those factors on the diversity and regeneration of plant species in Qenfot Afromontane forest in Meqdela district, South Wollo zone, Ethiopia. This study has the following research questions: how do patch size and isolation affect species diversity and regeneration of plant species. This study contained information to design appropriate forest restoration and management on fragmented forest patches in similar forests.

MATERIALS AND METHODS

Description of the Study Area:

The study was conducted in the Mekdella district which is located in the Northeastern highland of Ethiopia situated between 11°14′ to 11°19′ North and 38°94′ to 38°99′ East. Qenfot forest is found in Mekedella district, South Wollo Zone of Amhara Regional State, northeast Ethiopia (Fig.1). The district is situated 552 km north of Addis Ababa. Mekdella district is generally characterized by rough topographic features of gorges, flats, steep areas, and plateaus. The altitudinal range of Qenfot forest is found between 2480 m and 3077 m above sea level.

The metrological data recorded at Masha station from the years between 2008 to 2018 were analyzed using Climatol package in R software (R Core Team, 2018). A bimodal rainfall pattern was observed in the study area, finding an average rainfall of 1264 mm. From mid-January to April there was the least rainfall while the longest rainy season was from June to September. The maximum and minimum temperature of the area was 24.2 °C and 8.8 °C, respectively (Fig.2). The highest monthly temperature was recorded in May while the lowest was in August (Kombolcha Meteorological Branch office).

According to data obtained from the Central Statistical Agency (2007), the total population of Mekdella district is 175,751 where 87,816 (49.97%) are males and 87,935 (50.03%) are females. Of the total population, 35,127 (85.76%) are living around Qenfot dry Afromontane Forest where 17,710 (50.42%) of them are males and 17,747 (49.58%) are females. The livelihood of a majority of the population of Mekdela is from agriculture (Assefa et al, 2022). The major crops cultivated in the district were *Sorghum bicolor*, *Eragrostis tef*, *Triticum aestivum*, *Hordeum vulgare*, *Pisum sativum*, *Avena sativa*, and *Phaseolus vulgaris.*

Method of forest sampling strategy and vegetation data collection:

The basic information on the forest status, site condition, and number of forest patches was obtained during reconnaissance survey. Afterwards, forest patch size and distances between each patch were measured using Google Earth. The forest patch sizes were grouped into three (small 7 ha-20 ha, medium 20.1 ha-45 ha, and large above 45 ha), while the distance between patches, ranging from 0.1 km to 11 km, were grouped into (nearest 0-4 km, medium 4.01-8 km, and far distance 8.01-11 km). After grouping, the sample patch was chosen with three replications.

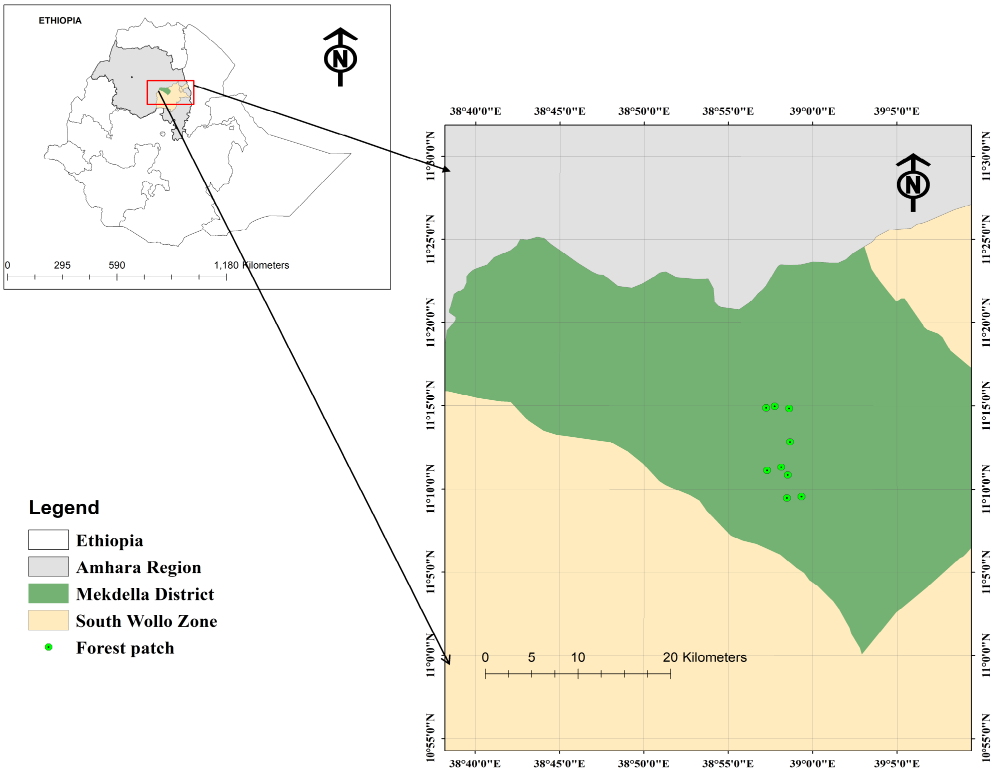

Fig. 1: Map of the study area, Tenta district, Amhara National Reginal State, Ethiopia.

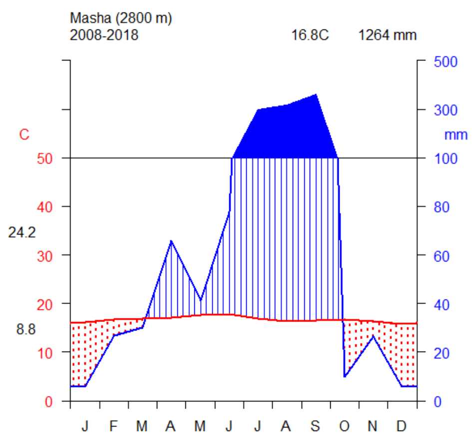

Fig 2: Rain fall and temperature of 2008 to 2018 (Masha station).

Stratified and proportional sampling strategies were implemented to collects data from forest patches. The number of sampling plots varied per forest patch based on area. In each sample forest patch the transect lines were established. The distance between two consecutive plots along a line transect was 100 m. The first line transect was aligned randomly at one side of the forest by avoiding the forest edge (at least 20 m into the forest). The distance between two parallel line transects was 150 m. The sampling intensity shown in Table 1 is greater than the required standard minimum sampling intensity (Sukumar et al., 1992).

Vegetation data were collected from a total of 75 sampling plots each 400 m^2 (20 m x 20 m) taken from 9 forest patches. The abundance of the sapling and shrubs was measured by laying 5 m by

Table 1: Area of sample patches with the proportion of sample plot

Patch Size group	Area (ha)	No. of samples	Total area of sample plot (ha)	Ratio	Average ratio
Small	7.94	4	0.16	2.02	1.48
Small	11.2	5	0.20	1.79	
Small	18.8	5	0.20	1.06	
Medium	41.6	8	0.32	0.77	1.04
Medium	24.1	8	0.32	1.33	
Medium	22.8	7	0.28	1.23	
Large	140.0	15	0.6	0.43	0.52
Large	90.7	12	0.48	0.53	
Large	63.5	11	0.44	0.69	
Total	420.64	75	3		

5 m subplots one at each corner and the center of 400 m^2 plots. For measuring the abundance of seedlings of woody species and herbs 1 m x 1 m subplots, one at each corner and one at the center of each 400 m^2 quadrant, were used.

The local name was recorded in each plot and their scientific name was identified using the numerous volumes of the Flora of Ethiopia and Eritrea. The specimens were placed and compared with authenticated specimens and confirmed at the herbarium of the Department of Biology, Wollo university.

Data analysis:

Analysis of plant species composition and diversity:

This study defined and measured species richness (S) as the total number of plant species within the sampling plots.

Shannon-Wiener Diversity index was used to analyze the species diversity (Shannon & Weaver, 1949):

$H= - \sum Pi*\ln Pi$

Where H: Shannon-Wiener Index; ∑: A Greek symbol that means "sum"; Pi: proportion of individual tree species; ln: Natural log

The high Wiener index indicates high diversity and often low disturbance whereas the low index value shows low diversity and often high disturbance.

The Shannon's equitability (E) index was used to indicate how evenly different species are distributed. The equitability or evenness of the species in each quadrant was computed using the formula:

Equitability $J = H'/Hmax$

Where J=species evenness; Hmax =lnS

Jaccard's similarity index was used to evaluate the similarity among the 9 forest patches in the study areas. Jaccard Similarity = (number of observations in both study site) / (number in either site) (Jaccard, 1912).

Effect of patch size on species diversity and regeneration status:

Patch size: All variables, number of species, number of saplings, and number of seedlings were analyzed as dependent variables in the regression analysis, whereas the area of patches (small, medium, and large) was used as the independent variable. The comparison of means was tested when a significant F-value was achieved; then the Tukey HSD Post Hoc analysis was applied to assess the effect of patch size on species diversity and regeneration status. The significance level was set at alpha <0.05.

Effect of distance between patches on species diversity and regeneration status:

Distance between patches: One-way ANOVA followed by Tukey HSD Post Hoc tests were used to analyze the effect of distance between patches on regeneration status and species diversity. Diversity index, species, seedlings, and sapling were used as the dependent variable, whereas distance (near, medium, and far) between patches was used as the independent variable. The significance level was set at alpha <0.05.

RESULTS

Floristic composition:

The study has shown that Qenfot dry Afromontane Forest contains a total of 45 families with 87 genera and 97 species. From this, Asteraceae, Lamiaceae, Fabaceae, Poaceae, and Solanaceae were the five most dominant families represented by 18, 8, 7, 7, and 5, respectively. These five dominant families together constituted 45 (46.39%) of the total species richness in Qenfot dry Afromontane Forest. The next dominant families were Malvaceae and Polygalaceae represented by 3 and the remaining such as Acanthaceae, Aloaceae, Anacardiaceae, Apocynaceae, Euphorbiaceae, Loganiaceae, Myrsinaceae, and Oleaceae, were represented by 2 and those constituted 22 (22.68%) of the total species. The rest 30 families that contributed 30.92% of the total species were represented by one species each. Those 97 plant species were collected from 9 patches of 75 plots (Table 2).

Similarity among forest patches:

The highest similarity with the largest patch was calculated with patch 6 (0.84) (Table 2) followed by patch 9 (0.74) while the least similarity with the largest patch was calculated with patch 5 (0.40) as indicated in Table 3.

Effects of distance between patches on species richness and diversity:

Both species richness and Shannon diversity were negative responses to increasing the distance of the patch. Species richness and Shannon diversity index of the nearest patch is 75±8.32, and 2.82±0.07 had a significant effect in the medium distance patch 66.67±7.96 and 2.65±0.10 and in the far distance species, richness (Table 4).

Effect of patch size on species richness and diversity:

Significant relationships between species richness and diversity were observed within the patches along with patch size (Table 4). When the patch area increased, both the species diversity and richness increased significantly at p=0.003, and along with patch size (Table 5). When the patch

Table 2 Species list per forest patch in Qenfot Dry Afromontane Forest, northeastern Ethiopia

No.	Species name	Family	Recorded species in the forest patch								
			1	2	3	4	5	6	7	8	9
1	*Acacia abyssinica* Hochst.	Fabaceae	*	*	*	*	*	*	*	*	*
2	*Acacia negrii* Pic.-Serm.	Fabaceae			*	*	*		*	*	*
3	*Acmella caulirhiza* Del.	Asteraceae			*	*	*		*	*	*
4	*Acokanthera schimperi* (A. DC.) Schweinf	Apocynaceae	*		*			*			*
5	*Adiantum raddianum* C. Presl	Adiantaceae	*	*	*	*		*	*	*	*
6	*Agave sisalana* Perro ex Eng.	Agavaceae	*	*	*	*	*	*	*	*	*
7	*Ageratum conyzoides* L.	Asteraceae		*	*	*	*	*	*	*	*
8	*Aloe camperi* Schweinf	Aloaceae	*	*	*			*	*	*	*
9	*Aloe pulcherrima* Gilbert & Sebsebe	Aloeaceae	*		*			*			*
1	*Andropogon abyssinicus* Fresen.	Poaceae	*		*	*	*			*	*
11	*Anthemis tigreensis* J. Gay ex A. Rich.	Asteraceae	*		*	*				*	*
12	*Argyrolobium ramosissimum* Bak.	Fabaceae	*	*	*	*		*	*	*	*
13	*Artemisia abyssinica* Sch. Bip. ex A. Rich.	Asteraceae	*		*						*
14	*Asparagus africanus* Lam.	Asparagaceae	*								*
15	*Becium grandiflorum* (Lam.) Pic.Serm.	Lamiaceae	*	*	*	*			*	*	*
16	*Bersama abyssinica* Fresen.	Melianthaceae	*	*	*	*		*	*	*	*
17	*Bidens prestinaria* (Sch. Bip.) Cufod.	Asteracea	*		*	*		*	*	*	*
18	*Buddleja polystachya* Fresen.	Loganiaceae	*	*	*		*	*			*
19	*Calpurnia aurea* (Ait.) Benth.	Fabaceae	*		*			*			*
22	*Carissa spinarum* L.	Apocynaceae	*					*			
21	*Clematis simensis* Fresen.	Ranunculaceae	*					*			
22	*Clerodendrum myricoides* (Hochst.) Vatke	Lamiaceae	*	*	*	*		*	*	*	*
23	*Clutia abyssinica* Jaub. & Spach.	Euphorbiaceae	*					*			
24	*Commelina benghalensis* L.	Commelinaceae	*	*	*	*	*	*	*	*	*
25	*Conyza pyrrhoappa* Sch. Bip. ex A. Rich.	Asteraceae	*					*			
26	*Conyza schimperi* Sch. Bip. ex A. Rich.	Asteraceae	*	*	*	*	*	*	*	*	*
27	*Cotula abyssinica* Sch. Bip. ex A. Rich.	Asteraceae	*		*			*		*	*
28	*Croton macrostachyus* Del.	Euphorbiaceae	*	*	*		*	*	*	*	*
29	*Cynodon dactylon* (L.) Pers.	Poaceae	*	*	*			*	*	*	*
30	*Cyperus longus* L.	Cyperaceae	*	*	*	*	*	*	*	*	*
31	*Datura stramonium* L.	Solanaceae	*	*	*	*	*	*	*	*	*
32	*Discopodium penninervium* Hochst.	Solanaceae	*	*	*			*	*	*	*
33	*Dodonaea angustifolia* L.f.	Sapindaceae	*	*	*	*	*	*	*	*	*
34	*Echinops longisetus* A. Rich.	Asteraceae	*	*	*			*	*	*	*
35	*Echinops macrochaetus* Fresen.	Asteraceae	*	*	*			*	*	*	*
36	*Erica arborea* L.	Ericaceae	*	*	*		*	*		*	*
37	*Eucalyptus globulus* Labill.	Myrtaceae	*	*	*	*	*	*	*	*	*
38	*Euclea racemosa* Murr.	Ebenaceae	*	*				*			
39	*Felicia abyssinica* Sch. Bip. ex A. Rich.	Asteraceae	*	*				*			
40	*Ficus palmata* Forssk.	Moraceae	*								

No.	Species name	Family	Recorded species in the forest patch								
			1	2	3	4	5	6	7	8	9
41	*Galium aparinoides* Forssk.	Rubiaceae	*	*				*		*	*
42	*Gomphocarpus purpurascens* A. Rich.	Asclepiadaceae				*					
43	*Helichrysum schimperi* (Sch. Bip. ex A. Rich.) Moeser	Asteraceae	*	*	*			*	*	*	*
44	*Heteropogon contortus* (L.) Roem. & Schult.	Poaceae				*		*	*	*	*
45	*Hibiscus macranthus* Hochst.ex A. Rich.	Malvaceae	*					*			
46	*Hyparrhenia anthistirioides* (Hochst. ex A.Rich.) Stapf	Poaceae	*		*			*		*	
47	*Hyparrhenia dichroa (*Steud.) Stapf	Poaceae	*	*		*	*	*	*	*	*
48	*Hypoestes forskaolii* (Vahl) R.Sch.	Acanthaceae	*					*			*
49	*Ipomoea tenuirostris* Choisy	Convolvulaceae	*					*			
50	*Jasminum grandiflorum* L.	Oleaceae	*					*			
51	*Juniperus procera* Hochst. ex Endl.	Cupressaceae	*		*	*	*				*
52	*Kalanchoe petitiana* A.Rich.	Crassulaceae	*					*			
53	*Laggera tomentosa* (Sch. Bip. ex A. Rich.) Oliv. &Hiern	Asteraceae	*					*			
54	*Lippia adoensis* Hochst.ex Walp.	Verbenaceae	*	*	*	*		*			
55	*Maesa lanceolata* Forssk.	Myrsinaceae	*	*				*			
56	*Malva parviflora* Hojer *Maytenus arbutifolia* (A. Rich.)	Malvaceae	*	*		*	*	*	*	*	*
57	*Maytenus arbutifolia* (A. Rich.) Wilczek	Celastraceae	*	*				*	*	*	*
58	*Medicago polymorpha* L.	Fabaceae	*	*	*	*	*	*	*	*	*
59	*Myrsine africana* L.	Myrsinaceae	*	*	*	*	*	*		*	*
6	*Nidorella zavattarii* (Lanza) Cufod.	Asteraceae	*	*	*	*	*	*	*	*	*
61	*Nuxia congesta* R.Br. ex Fresen.	Loganiaceae	*	*	*	*	*	*	*	*	*
62	*Olea europaea* L. subsp. Cuspidata (Wall.ex G. Don.) Cif.	Oleaceae	*	*	*	*	*	*	*	*	*
63	*Osyris quadripartita* Decn.	Santalaceae	*	*	*		*	*	*	*	*
64	*Otostegia integrifolia* Benth.	Lamiaceae	*	*	*	*	*	*	*	*	*
65	*Panicum monticola* Hook.f	Poaceae	*		*			*	*		*
66	*Pennisetum sphacelatum* (Nees) Th. Dur. & Schinz	Poaceae			*	*	*		*	*	
68	*Phaulopsis imbricata* (Forssk.) Sweet.	Acanthaceae	*	*	*	*	*	*	*	*	*
69	*Plantago africana* Verdc.	Plantaginaceae	*	*	*	*	*	*	*	*	*
70	*Plantago lanceolata* L.	Plantaginaceae		*	*	*		*		*	
71	*Plectranthus alpinus* (Vatke) Ryding	Lamiaceae	*		*		*		*	*	*
72	*Polygala abyssinica* Fresen	Polygalaceae	*	*	*	*				*	*
73	*Pteris pteridioides* (Hook.) Ballard	Pteridaceae	*		*	*		*	*	*	*
74	*Pterolobium stellatum (Forssk.) Brenan*	Fabaceae	*	*	*	*	*	*	*	*	*
75	*Rhus glutinosa* A. Rich.	Anacardiaceae	*	*	*	*	*	*	*	*	*
76	*Rhus retinorrhoea* Oliv.	Anacardiaceae			*		*		*	*	*
77	*Rosa abyssincia* Lindley.	Rosaceae			*		*		*	*	*
78	*Rumex nepalensis* Spreng.	Polygonaceae	*	*	*	*		*	*	*	*
79	*Rumex nervosus* Vahl.	Polygonaceae	*	*	*	*	*	*	*	*	*
80	*Salvia schimperi* Benth.	Lamiaceae	*	*		*		*	*	*	*

No.	Species name	Family	Recorded species in the forest patch								
			1	2	3	4	5	6	7	8	9
81	*Sanicula elata* Buch-.Ham. ex D. Don	Apiaceae	*	*				*	*	*	*
82	*Satureja punctata* (Benth.) Briq.	Lamiaceae	*	*	*	*	*	*	*	*	*
83	*Satureja simensis* (Benth.) Briq.	Lamiaceae	*					*		*	
84	*Sida schimperiana* Hochst. ex A. Rich.	Malvaceae	*	*	*	*	*	*	*	*	*
85	*Silene macrosolen* A. Rich.	Caryophyllaceae	*	*	*	*	*	*	*	*	*
86	*Solanecio gigas* (Vatke) C. Jeffrey	Asteraceae	*	*				*	*	*	*
87	*Solanum anguivi* Lam.	Solanaceae	*	*	*	*	*	*	*	*	*
88	*Solanum marginatum* L.f.	Solanaceae	*	*	*	*	*	*	*	*	
89	*Solanum nigrum* L.	Solanaceae	*	*				*		*	*
90	*Tapinanthus globiferus* (A. Rich.) Tieghem	Loranthaceae	*	*	*	*	*	*	*	*	*
91	*Thymus schimperi* Ron.	Lamiaceae	*				*	*		*	*
92	*Trifolium cryptopodium* Steud. ex A. Rich.	Fabaceae	*	*		*		*	*	*	*
93	*Urtica simensis* Steudel	Urticaceae	*		*	*	*		*	*	*
94	*Verbascum sinaiticum* Benth.	Scrophulariaceae	*							*	*
95	*Vernonia leopoldi* (Sch. Bip. ex Walp.) Vatke	Asteraceae	*					*	*	*	*
96	*Vernonia schimperi* DC.	Asteraceae	*	*	*	*	*	*	*	*	*
97	*Zehneria minutiflora* (Cogn.) C. Jeffrey.	Cucurbitaceae	*	*	*	*	*	*	*	*	*

Table 3: Jaccard similarity index of the study forest patches

Similarity ratio	Patch 1	Patch 2	Patch 3	Patch 4	Patch 5	Patch 6	Patch 7	Patch 8	Patch 9
Patch 1	1								
Patch 2	0.64	1							
Patch 3	0.62	0.59	1						
Patch 4	0.47	0.48	0.64	1					
Patch 5	0.40	0.63	0.60	0.61	1				
Patch 6	0.84	0.80	0.57	0.47	0.39	1			
Patch 7	0.54	0.67	0.68	0.68	0.57	0.60	1		
Patch 8	0.68	0.70	0.85	0.79	0.56	0.66	0.81	1	
Patch 9	0.74	0.64	0.76	0.72	0.54	0.66	0.74	0.82	1

Table 4: Effect of forest patch distance on species richness and diversity along with the near, medium, and far distance patches in Qenfot Afromontane Forest

Diversity variables	Near distance	Middle distance	Far distance	ANOVA	
				F-value	P-value
Number of species	75±8.32	66.67±7.96	55±6.42	21.98	0.007
Shannon diversity index	2.82±0.07	2.65±0.10	2.54±0.06	49.74	0.001

p-value significant at <0.05

Table 5: Effect of forest patch size on species richness and diversity within the small, medium, and large forest patches in Qenfot Afromontane Forest

Diversity variables	Small forest patches	Medium forest patches	Large forest patches	ANOVA	
				F-value	P-value
Number of species	55±6.43	66.67±7.96	77.67±10.42	35.91	0.003
Shannon diversity index	2.52±0.09	2.69±0.07	2.78±0.08	42.63	0.002

p-value significant at <0.05

Table 6: Effect of forest patch distance on regeneration status along the near, medium and far distance patches in Qenfot Afromontane Forest

Regeneration variables	Near distance	Middle distance	Far distance	ANOVA	
				F value	P-value
Number of seedlings (ha^{-1})	4328.13±1425	3116.33±667	2217.67±361	5.65	0.07
Number of saplings (ha^{-1})	1341.67±428	641.65±102	531.11±108	5.41	0.07
Number of adults (ha^{-1})	470.58±8	376.53±16	415.79±41	2.38	0.21

p-value significant at <0.05

Table 7: Effect of forest patch size on regeneration status along the small, medium, and large forest patches in Qenfot Afromontane Forest

Regeneration variables	Small forest patches	Medium forest patches	Large forest patches	ANOVA	
				F value	P-value
Number of seedlings (ha^{-1})	2243.67±439	2594.67±525	4741.67±1233	3.29	0.14
Number of saplings (ha^{-1})	529.12±124	742.34±171	1242.98±468	3.76	0.12
Number of adults (ha^{-1})	414.9±32	412.5±35	435.5±42.08	0.17	0.85

p-value significant at <0.05

area increased both the species diversity and richness increased significantly at p=0.003 and p=0.002, respectively (Table 5).

Effects of distance between patches on regeneration status of the forest:

The mean density of seedlings was 2217.67, 3116.33, and 4328.13 from higher to lower (p=0.07, f=5.65), respectively. Distance had no significant effect on the regeneration status of the study forest (Table 6).

Effect of patch size on regeneration status of the forest:

The mean density of seedlings ranges was 2243.67 ha^{-1} to 4741.67 ha^{-1}, from higher to lower (p=0.14, f=3.29) respectively. Even if the numeric values of seedling, sapling, and adult tree and shrub plants of the study area increased with the forest patch size; there was no significant difference in the natural regeneration status of the forest patches (Table 7).

DISCUSSION

Qenfot is one of the few remaining dry Afromontane Forest patches in the northeastern highland plateaus of Ethiopia. The effects of patch size and distance between patches on species diversity and regeneration status were studied to document relevant information to design appropriate restoration approaches. The forest patches contained a total of 45 families. The dominance of Asteraceae, Lamiaceae, Fabaceae, Poaceae, and Solanaceae has been reported in various floristic studies done by diverse researchers (Motuma, 2010; Yirga et al, 2019). Likewise, those families were also the dominant family (46.39%) of the total plant families in Qenfot dry Afromontane Forest. The dominance of Asteraceae and Fabaceae also shows their prevailing positions within the flora of Ethiopia. Their dominance may be due to having effective capability of fertilization and seed dispersal components that might have allowed them to adjust to a wide range of environmental conditions in the past (Tadesse et al., 2017).

A significant positive relationship between patch size species richness and diversity showed in the study area, whereas there was a negative relationship between the distance between forest patches and species richness and diversity. This is consistent with many past studies that detailed a positive relationship between species richness and diversity with the size of forest patch and a negative correlation with distance (Jacquemyn et al., 2001; Kumar, 2016). Although previous studies have obtained contrasting results for the effects of patch area and distance on species density (Arroyo-Rodrıguez et al., 2008; Farmilo et al., 2014). Where the patch size and distance of the forests increased the species diversity and richness also increased significantly in the study area at the time of the study. Therefore, we suggest that patch size and distance apart are crucial components of species density in fragmented forests. Our study's foremost noticeable result was that patch area and distance apart significantly predicted species density. Predominantly, the analytical values of these variables are sensible for fragmented forest areas (Munguía-Rosas & Montiel, 2014).

The results of this study showed variation in the number of naturally regenerated plant species, whereas our further analysis showed that the regeneration status due to patch area and patch distance apart was not statically significant. This indicated that distance and isolation didn’t affect the function of the forest with patch size and distance. The findings of the present study are concomitant with those studies in recognizing that biological dispersers and their movement affected by patch size and isolation (Arellano-Rivas, et al., 2018; Jacquemyn et al., 2003).

In conclusion, conservation and restoration efforts should consider the effects of isolation and patch areas on the setting of plant diversity conservation. This study found that both patch size and patch isolation (distance apart) significantly affected species richness and species diversity but regeneration status was not significantly affected by either patch size or isolation. The similarities between two patches were increased with decreasing distance apart and increasing patch size. It is essential to make communities aware of the function of forest patches for species conservation. This study is not enough to restore fragmented forest patches; further study on pollination, dispersal and soil seed bank assessment to identify vulnerable species due to patch size and isolation are indispensable.

ACKNOWLEDGEMENTS

The authors express gratitude to the Department of Biology, Wollo University for identification of plant species.

COMPETING INTERESTS

The authors have declared that they have no competing interest.

REFERENCES

Arellano-Rivas, A., De-Nova, A. J. & Munguia-Rosas, M. A. (2018). Patch isolation and shape predict plant functional diversity in a naturally fragmented forest. *Plant Ecology, 11*(1), 136-146.

Arroyo-Rodrı´guez, V., Pineda, E., Escobar F., & Benítez-Malvido, J. (2008). Values of small patches in the conservation of plant species diversity in highly fragmented rain forest. *Conservation Biology, 23*, 729-739.

Assefa, E., Ayalew, Z., & Mohammed, H. (2022). Impact of small-scale irrigation schemes on farmers livelihood, the case of Mekdela Woreda, North-East Ethiopia. *Cogent Economics & Finance, 10(1),* 1–20.

Awoke, T. G. (2018). Floristic Composition and Structural Analysis of Susgen-Bosena Forest, Ambasel District, North Wollo, Amhara Region, Ethiopia. *Abyssinia Journal of Science and Technology, 3(2),* 24–35.

Aynekulu, E., Aerts, R., Moonen, P., Denich, M., Gebrehiwot, K., Vagen, T. G., & Boehmer, H. J. (2012). Altitudinal variation and conservation priorities of vegetation along the Great Rift Valley escarpment, northern Ethiopia. *Biodiversity Conservation. 21*, 2691-2707.

Central Statistical Agency, (2007). *Population and Housing Census of Ethiopia, country report* (Country report). Addis Ababa , Ethiopia: Federal Democratic Republic of Ethiopia, Population and Housing Census, Commission Central Statistic Authority.

Eshetu, Z. (2002). Historical C3-C4 vegetation pattern on forested mountain slopes: Its implication for ecological rehabilitation of degraded highlands of Ethiopia by afforestation. *Journal of Tropical Ecology, 18(5),* 743–758.

Fahrig, L. (2003). Effects of Habitat Fragmentation on Biodiversity. *Annual Review of Ecology, Evolution and Systematic, 34*, 487-515.

Farmilo, B. J., Melbourne B. A., Camac, J. S., & Morgan, J. (2014). Changes in plant species density in an experimentally fragmented forest landscape: Are the effects scale-dependent. *Austral Ecology, 39*, 416-423.

Farwig, N., Bailey, D., Bochud, E., Herrmann, J. D., Kindler, E., Reusser, N., Schuepp, C. & Schmidt-Entling, M. H. (2009). Isolation from forest reduces pollination, seed predation and insect scavenging in Swiss farmland. *Landscape Ecology, 24*, 919-927.

Fisaha, G., Hundera, K., & Dalle, G. (2013). Woody plants' diversity, structural analysis and regeneration status of Wof Washa natural forest, North-east Ethiopia. *African Journal of Ecology, 51*, 599–608.

Grashof-Bokdam, C. (1997). Forest species in an agricultural landscape in the Netherlands: Effects of habitat fragmentation. *Journal of Vegetation Science, 8*, 21-28.

Haddad, N. M., Brudvig, A. L., Clobert, J., Davies, F.K., Gonzalez, A., Holt, D. A., Sexton, O. L., Austin, P.M., Collins, D. C., Cook, M. W., Damschen, I.E., Foster, L. B. Jenkins, N. C. King, J.A., William F., Laurance, F.W., Levey, J. D., Margules, R. C., Melbourne, A. B., Nicholls, O. B. , Orrock, Dan-Xia, J. L., Song, J. R. (2015). Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science Advances, 1*(2), e150005.

Hasnat, G. N., & Hossain, M. (2020). Global-Overview-of-Tropical-Dry-Forests. In Bhadouria et al., (Ed) Handbook of Research on the Conservation and Restoration of Tropical Dry Forests (pp. 1–23). IGI Global. India.

Hill, J. L., & Curran, P. J. (2003). Area, shape and isolation of tropical forest fragments: Effects on tree species diversity and implications for conservation. *Journal of Biogeography, 30*, 1391-1403.

Ibanez, I., Daniel S. W., Katz, Peltier, P., Samantha. M. W., Bengamin, T., & Barrie, C. (2014). Assessing the integrated effects of landscape fragmentation on plants and plant communities : the challenge of multiprocess – multiresponse dynamics. *Journal of Ecology, 102*, 882–895.

Jaccard, P. (1912). The Distribution of the Flora of the Alpine Zone. *New Phytologist, 11*(2), 37-50.

Jacquemyn, H., Butaye, H., & Hermy, M. (2003). Impacts of Restored Patch Density and Distance from Natural Forests on Colonization Success. *Restoration Ecology, 11*(4), 417-423.

Jacquemyn, H., Butaye, J., Dumortier, M., Hermy, M., & Lust, N. (2001). Effects of age and distance on the composition of mixed deciduous forest fragments in an agricultural landscape. *Vegetation Science, 12*(5), 635-642.

Jha, C. S, Goparaju, L., Tripathi, A., Gharai, B., Raghubanshi, A. S., & Singh, J. S. (2005). Forest fragmentation and its impact on species diversity: An analysis using remote sensing and GIS. *Biodiversity & Conservation, 14*, 1681-1698.

Joseph, N. E. (2003). Species -Area relationships and Marine Conservation. *The Ecological Society of America, 13*(1), 138-145.

Kolb, A. (2008). Habitat fragmentation reduces plant fitness by disturbing pollination and modifying response to herbivory. *Biological Conservation, 141*, 2540–2549.

Kumar, B. (2016). Effect ts of patch size , disturbances on diversity a and structural traits of tropical semi- evergreen forest in the lowland Indo Burm m hotspot : implication on conservation of the threatened tree spec ies. *Journal of Mountain Science, 13*(2), 1397-1410.

Laurance, W. F. (2010). Beyond Island Biogeography: Theory understanding habitat fragmentation in the real world. In J. B. Losos & R. E. Ricklefs (Eds.), *The Theory of Island Biogeography Revisited* (pp. 214–236). Princeton and Oxford: Princeton university press.

Miles, L., Newton, A. C., Defries, R. S., Ravilious, C., May, I., Blyth, S., Kapos, V., & Gordon, J. E. (2006). A global overview of the conservation status of tropical dry forests. *Journal of Biogeography, 33*, 491–505.

Motuma, D. (2010). Floristic and structural analysis of the woodland vegetation around Dello Menna, Southeast Ethiopia. *Journal of Forestry Research, 21(4)*, 395–408.

Munguía-Rosas, M. A., & Montiel, S. (2014). Patch Size and Isolation Predict Plant Species Density in a Naturally Fragmented Forest. *PLoS ONE, 9*(10), e111742.

R Core Team (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Shannon, C. E., & Weaver, W. (1949). The Mathematical thory of communication (1st Ed). Urbana, IL: University of Illinois Press.

Sonnier, G, Jamoneau, A., & Decocq, G. (2014). Evidence for a direct negative effect of habitat fragmentation on forest herb functional diversity. *Landscape Ecology, 29*(5),857-866.

Sukumar, R., Dattaraja, H. S., Suresh, J., Radhakrishnan, R., Vasudeva, S., Nirmala & Joshi V. N. (1992). Long-term monitoring of vegetation in a tropical deciduous forest in Mudumalai, Southern India. *Current Science, 62(9)*, 608-616.

Tadesse, Z., Kelbessa, E., & Bekele, T. (2017). Floristic composition and plant community analysis of vegetation in Ilu Gelan District, West Shewa Zone of Oromia region, Central Ethiopia. *Tropical Plant Research, 4*, 335–350.

Tekle, K., Backeus, I., Skoglund, J., & Woldu, Z. (1997). Vegetation on hill slopes in southern Wello, Ethiopia: Degradation and regeneration. *Nordic Journal of Botany, 17*, 483–493.

Wade, T. G., Riitters, Wickham, J. D., & Jones, K. (2003). Distribution and causes of global forest fragmentation. *Conservation Ecology, 7*(2), 7

Wassie, A., Sterck, F. J., & Bongers, F. (2010). Species and structural diversity of church forests in a fragmented Ethiopian Highland landscape. *Journal of Vegetation Science, 21*, 938-948.

Yirga, F., Marie, M., Kassa, S., & Haile, M. (2019). Impact of altitude and anthropogenic disturbance on plant species composition, diversity, and structure at the Wof-Washa highlands of Ethiopia. *Heliyon, 5*(8), 22-84.

Zhang, S., Zhang, Q., Yan, Y., Han, P., & Liu, Q. (2021). Island biogeography theory predicts plant species richness of remnant grassland patches in the agro-pastoral ecotone of northern China. *Basic and Applied Ecology, 54*, 14–22.

Zhang, Y., Sharma, S., Bista, M., & Li, M. (2022). Characterizing changes in land cover and forest fragmentation from multitemporal Landsat observations (1993-2018) in the Dhorpatan Hunting Reserve, Nepal. *Journal of Forestry Research, 33*(1), 159–170.