4th International Conference on Water Resources and Arid Environments (ICWRAE 4): 595-599
5-8 December 2010, Riyadh, Saudi Arabia

Restoration of Degraded Semi-Arid Communal Grazing Land Vegetation Using the Exclosure Model

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Abstract: Degradation of communal grazing land vegetation is a widespread problem throughout sub Saharan Africa and its restoration is a challenge for the management of many semi-arid areas. This study assessed the effectiveness of different age (young versus old) exclosures on species composition and diversity, biomass production and woody structure in northern Ethiopia. The species composition and diversity of herbaceous and woody plants was higher in the exclosures than in the grazed areas. The mean aboveground biomass measured inside the exclosures was more than twice that of the adjacent grazed areas and more biomass was produced from the young than the old exclosures. The study showed that degraded semi-arid vegetation is able to recover in a relatively short time when protected. Extended protection, however, reduces herbaceous species diversity and biomass. Therefore, it is suggested that a slight shift in management where exclosures protected for longer periods may be moderately used by livestock.

Key words: Biomass • Diversity • Herbaceous • Rangeland • Woody

INTRODUCTION

Degradation of communal grazing land vegetation is a widespread problem throughout sub Saharan Africa and its restoration is a challenge for the management of many semi-arid areas. A clear understanding of the interrelationship between vegetation and grazing by domestic livestock is essential to properly address vegetation degradation problems. Two contrasting paradigms have been developed in relation to livestock-vegetation interaction. The first paradigm is based on the traditional succession model, which asserts that grazing by livestock has a damaging impact on vegetation [1]. The succession model emphasizes herbivory as the single most important factor shaping vegetation attributes. As the model largely ignores the spatial and temporal variability of ecosystems typical of semi-arid environments, an alternative paradigm that emphasizes this variability is suggested [2, 3].

In the semi arid grazing systems of northern Ethiopia, vegetation restoration efforts invariably take the form of establishing a network of exclosures that essentially excludes disturbance including grazing for extended number of years. This is despite the fact that much of the interaction between herbivores and the natural vegetation has been studied from the perspective of wildlife [4] and it is believed that the effect of wildlife on ecosystem states might diverge from that of domestic animals in many ways [5]. Comprehensive empirical evidence on the success of restoring degraded communal livestock grazing lands using the exclosure model is also generally meager. Specifically, the impact of protection and its duration (fallow age) of communal grazing lands on species composition and diversity, aboveground biomass production and woody structural attributes is lacking. Despite the many reports for more humid areas, the specific relationship between productivity and species richness in the arid and semi-arid ecosystems is not extensively researched [6].

MATERIALS AND METHODS

Study Area: The study was carried out in the semi arid grazing systems in Tigray region of northern Ethiopia. The average annual rainfall ranges from 500-700 mm and temperature from 20-28°C. Altitude varies between 1700 to 2300 meters. The vegetation is typical of the East African montane area that is part of the Sudano-Sahelian transition sub-zone [7] and common plant formations include mesophyllic deciduous woodland, mixed evergreen and deciduous open woodland.

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Exclosure Description and Sampling: An exclosure refers to a specific land unit that is protected from the activities of a particular class of animals using appropriate barriers and is commonly used to determine the potential for restoration of degraded grazed rangelands [8]. The exclosures used in this study were communal grazing lands degraded by human induced causes and subsequently protected from anthropogenic disturbances since the 1990s.

A total of six randomly selected exclosures, 50-120 ha in size and 3-10 km apart (measured using Garmin GPS 72 (Garmin International Inc., USA)), were grouped into two broad fallow ages (years since effective protection initiated) from less than 8 years (hereinafter called 'young exclosures') to more than 12 years (hereinafter called 'old exclosures'). To minimize the effects of spatial variations, an exclosure was included only when its location relative to others was no farther than 10 km. In each exclosure, three parallel line transects of approximately 1.2 km long were designated and four 10X10 m plots/transect used. These plots were used for woody species composition, diversity and structure sampling. Similarly, adjacent areas outside the exclosures that were open for year round grazing were delineated and the same number of transects and plots used. Within each of the large plots used for woody species sampling, six 0.5X0.5 m small quadrats were nested and marked by four wooden pegs for herbaceous species composition, diversity and biomass sampling. The species composition of herbaceous and woody species was assessed using the quadrat count method [9]. The species composition of exclosures and grazed areas and the young and old exclosures was compared using the Sørensen's Similarity Index and species diversities in the exclosures and grazed areas were computed using the Shannon-Weiner Index [10]. The Shannon-Weiner Index (H) was converted to effective number of species diversity using the following formula [11]: $N_1 = \text{Exp}(H')$. Where: N_1= Effective number of species; H'=Shannon-Weiner function. Herbaceous aboveground biomass production was estimated using the destructive method [9]. Woody vegetation structure was analyzed by measuring canopy diameter, canopy height and stem height of woody species [12].

Data Analysis: Species composition and diversity data were analyzed using the nonparametric Kruskal-Wallis test. Linear regression was used to determine the relationship between species diversity and productivity of the herbaceous layer. ANOVA was applied for woody structure and herbaceous aboveground biomass data. Data analysis was carried out using SAS [13] and Tukey's HSD test used to compare mean values of the parameters.

RESULTS AND DISCUSSION

Species Composition and Diversity: The difference in herbaceous and woody species composition between the exclosures and grazed areas was significant (herbaceous: χ^2= 6.36, DF 1, P=0.01; woody: χ^2= 8.90, DF=1, P<0.003). The Similarity Index for herbaceous and woody species between the exclosures and grazed areas was 0.45 and 0.46, respectively. The Similarity Index for herbaceous and woody species between the young and old exclosures was 0.54 and 0.62, respectively (Table 1).

Tall erect grass genera such as Aristida and Sporobolus dominated the exclosures while in the adjacent grazed areas species with prostrate and creeping life forms such as *Cynodon dactylon* and *Tragus racemosus* invariably dominated the ground cover. A similar pattern of shifts in species composition of areas subjected to grazing was found in different semiarid vegetation types [14, 15].

Herbaceous species diversity was higher in the exclosures than in the adjacent grazed areas (χ^2=11.8; DF=1; P<0.006) (Table 2). The high diversity measured in the exclosures might be explained by increased litter

Table 1: Similarity Index[1] of herbaceous and woody species composition in exclosures and grazed areas (Mean±SE[2])

	Protection		Fallow age	
Vegetation	Protected vs. grazed	P[3]	Young vs. old	P
Herbaceous	0.45±0.03	0.012	0.54±0.05	0.485
Woody	0.46±0.07	0.003	0.62±0.10	0.658

[1] Sørenson's similarity index. [2]SE = standard error of the means; [3]P, probability

Table 2: Mean diversity of herbaceous and woody species in exclosures and grazed areas

	Protection			Fallow age		
Vegetation	Protected	Grazed	P	Young	Old	P
Herbaceous	4.00±0.30	2.70±0.10	<0.0001	4.50±0.30	3.40±0.40	0.021
Woody	5.47±0.29	2.97±0.14	<0.0001	4.98±0.23	5.97±0.51	0.568

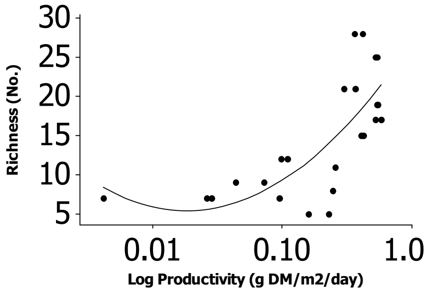

Fig. 1: Relationship between herbaceous productivity (g DM/m^2/day) and species richness of exclosures

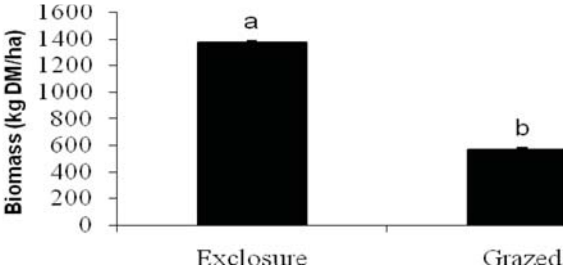

Fig. 2: Mean herbaceous biomass production (kg DM/ha) from exclosures and grazed areas. Bars with different letters significantly (P<0.05) differ from each other.

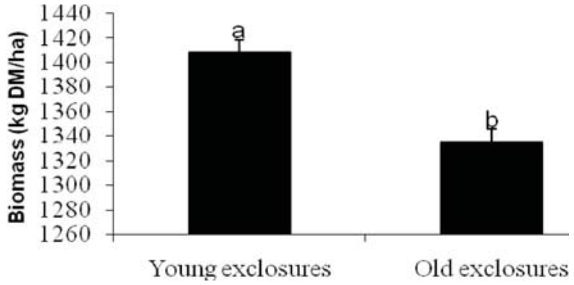

Fig. 3: Mean herbaceous biomass production (kg DM/ha) from young and old exclosures. Bars with different letters significantly (P<0.05) differ from each other.

accumulation, improved soil organic matter and other nutrients inside the exclosures that eventually lead to increased species richness [16]. However, the results contrast with other studies that reported species richness to be considerably increased under moderate grazing compared to no or heavy grazing treatments [17, 18]. The diversity of woody species was significantly (χ^2=36.8; DF=1; P<0.001) higher in the exclosures than in the adjacent grazed areas. *Acacia etbaica* and *Dichrostachys cinerea* were the most dominant woody species measured in the exclosures while in the case of the grazed areas *Euclea racemosa* was the most dominant species.

The young exclosures supported significantly (χ^2=5.34; DF=1; P=0.0208) more diverse herbaceous species than the old exclosures. The diverse herbaceous species recorded in the young exclosures might be attributed to the presence of a low density of woody species and it is acknowledged that the presence of high density of woody species suppresses growth of the understory vegetation [19]. Fallow age of exclosures did not significantly influence the diversity of woody species in a manner that was similar to the herbaceous species, although this was numerically increased in the old exclosures.

Species richness responded positively to increased productivity of the exclosures (Fig. 1).

The relationship between productivity and richness was positive, instead of the popular humpback shape [20]. Species richness increased with increased productivity without necessarily showing changes in the species composition of the herbs, a typical response reported for ecosystems characterised by lower productivity [21].

Aboveground Biomass: The mean aboveground biomass yield measured in exclosures was more than twice that of the adjacent grazed areas (Fig. 2). The ratio of biomass in the exclosures and grazed areas averaged 0.55 and the proportion of biomass consumed by livestock in the grazed areas ranged from 51 to 69%. This is within the 30-90% off-take range estimated for the larger East African savanna [22] and such level of utilization is regarded as being severe, compared to the recommended 25-35% [23]. If the current level of herbaceous aboveground biomass removal is sustained for a longer period of time, it might lead to reduction in productivity of the grazing resource [24].

The old exclosures yielded significantly (P<0.05) lower biomass than the young exclosures (Fig. 3). As expected, longer fallow age had a negative influence on herbaceous aboveground biomass production of exclosures, which is attributed to the presence of dense woody species that shifts the competitive advantages from the herbaceous understory to the woody vegetation [19].

Woody Vegetation Structure: Protection influenced the height class distribution of the three woody vegetation attributes, i.e., stem height ($F_{1,6}$=229.4, P<0.0001), canopy height ($F_{1,6}$=1023.4, P<0.0001) and canopy cover ($F_{1,6}$=7.9, P=0.03); Fallow age of exclosures significantly affected only stem height ($F_{1,6}$=10.99, P=0.02).

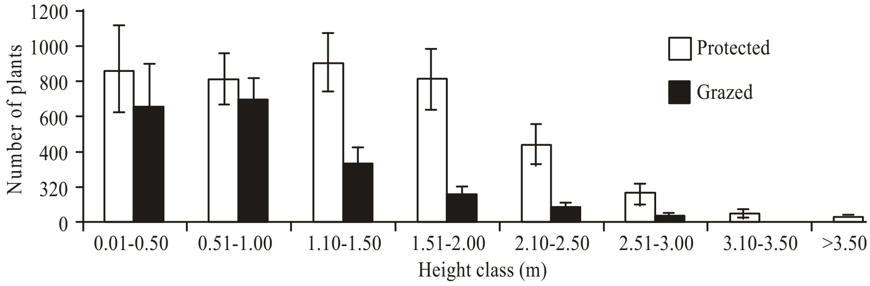

Fig. 4: Height class distribution of woody species in exclosures and grazed areas (Mean±SE)

Table 3: Woody structure attributes of exclosures and grazed areas (Mean±SE)

	Protection			Fallow Age		
Attribute	Protected	Grazed	P	Young	Old	P
Height (m) Canopy	1.27±0.02	0.89±0.02	<0.0001	1.11±0.04	1.05±0.04	0.001
height (m) Canopy	0.86±0.01	0.56±0.01	<0.0001	0.70±0.03	0.73±0.03	0.264
Cover (%)	28.01±1.81	10.45±1.28	<0.0001	16.45±1.92	22.01±2.28	0.095

The stem height class distribution in both the exclosures and grazed areas indicated that mature trees of greater than 1 m were represented in small proportions in the grazed areas (Fig. 4).

Average stem height was higher (P<0.001) in the exclosures than in the adjacent grazed areas. The stem height of the browse species sampled from the young exclosures was significantly (P<0.001) taller than those browse species sampled from the old exclosures (Table 3).

Protection led to increased woody plant height. The presence of year long grazing and browsing led to herbivore-mediated reduction in plant height. The presence of heavy browsing leads to skewed age structure, small seedlings being dominant in the grazed areas [25]. Compared to the grazed areas, woody species cover also increased in the exclosures and this is largely consistent with results reported by others [4, 5]. However, exclosures left intact for extended period of time did not linearly increase in their height and shorter fallow periods gave on average taller woody species and this may suggest the existence of above ground resource competition in the more densely populated old exclosures.

CONCLUSIONS

Exclosures established in the semi arid region of northern Ethiopia are effective in restoring species composition, diversity, biomass and key woody structural attributes of degraded communal grazing lands, factors that normally lead to improved ecosystem function and health. Extended protection may not, however, lead to beneficial increases in some attributes such as herbaceous species diversity, herbaceous biomass and the availability of foliage within browseable height for livestock. Thus, there is a need to consider alternative management strategy that allows selective and careful utilization of exclosures protected for longer period of time.

ACKNOWLEDGEMENT

I am grateful to the Norwegian Agency for Development Cooperation (NORAD) for financially supporting the research.

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