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Floristic Composition, Population Structure, and Recruitment Status of Plant Species: A Case Study of Farmer-Managed Natural Regeneration Practices in Arid and Semi-Arid Lands in Kenya

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Abstract

The technique of Farmer Managed Natural Regeneration (FMNR) is being promoted as a cost-effective approach for restoring degraded arable dry lands. Its effectiveness has been observed in many countries across the globe, where it is a traditional practice, and is now being encouraged across the African continent. This study aimed to evaluate the impact of FMNR on floristic Composition, Vegetation Structure, and Regeneration Status of woody Plant Species in the severely degraded Central Rift, Kenya. The study systematically assessed how FMNR influenced species composition, vegetation structure and regeneration status from two sample plots involved in FMNR practices. Transect lines and quadrats methods were utilized to collect data, specifically regarding the floristic composition, vegetation structure, and regeneration status of woody plant species. Quadrats and sub-quadrats of varying sizes (10 m by 10 m, 5 m by 5 m, and 1 m by 1 m) were nested along the transect lines for data collection. Furthermore, measurements of tree growth and development, including root collar diameter, diameter at breast height (D_{130}) and heights within the study blocks, were taken. The data was then analyzed using R-software. Results showed a marked progressive increase in numbers of trees, saplings, seedlings, shrubs and herbs in all FMNR sites and reductions in all non-FMNR sites. The study advocates for widespread promotion of the FMNR practice both as an environmental conservation and restoration strategy.

Keywords

Farmer Managed Natural Regeneration, FMNR, Floristic Composition, Vegetation Structure, Regeneration, Biodiversity

1. Introduction

Farmer Managed Natural Regeneration (hereafter, "FMNR") is a series of techniques that farmers employ to stimulate the growth of trees on agricultural land (Obwocha et al., 2022). FMNR involves selecting and protecting the strongest stems regrown from live stumps of felled trees, pruning off all other stems, and pollarding the chosen stems to grow into straight trunks (Chomba et al., 2020; Vergara, 1985). Globally, 1.9 billion hectares of land are experiencing significant levels of land degradation (Deutz et al., 2020; Tilahun et al., 2018) which is affecting an estimated 3.2 billion people (Fath & Fiscus, 2022). In Africa it has been established that natural regeneration is greatly influenced by factors such as human activities (Ojunga et al., 2019), land degradation, and dispersal limitation (Alanís-Rodríguez et al., 2023; Poorter et al., 2021; Lohbeck et al., 2020). In Kenya, many parts of the country are vulnerable to degradation due to factors such as climate change, deforestation, overgrazing and soil erosion (Watene et al., 2021), the loss of fertile and productive land has a direct impact on the lives and livelihoods of millions of people who rely heavily on land (Khalwale et al., 2018), soils, vegetation, woodlands and forests to survive and generate income (Watene et al., 2021; Abdel Rahman, 2023). Degradation affects the majority of the rural population, with repercussions such as water scarcity, food insecurity, and limited access to social services such as healthcare and education (Gomiero, 2016; Ngcamu & Chari, 2020). As such, there is mounting concern about the negative effects of persistent degradation. Among the notable impacts of degradation are loss of mother trees, limited or no recruitment of young plants due to deforestation, and increased disturbances—both on farms and in forests.

The increased degradation worldwide has led numerous people to participate in activities to restore degraded lands and ecosystems (Abasse & Adam, 2020). In Africa, FMNR has been utilized to revive deteriorated agricultural lands, particularly in dryland areas (Chomba et al., 2020). Studies in the continent have indicated that FMNR yields various advantages such as enhanced agricultural output due to improved soil fertility (Binam et al., 2017), increased availability of feed for livestock, greater income for farmers, and other ecological benefits (Chomba et al., 2020). Therefore, establishing trees through FMNR is often considered a key approach to restoration.

Moreover, FMNR is highly encouraged to promote the conservation of biodiversity within agricultural landscapes (Okumu et al., 2022; Garrity & Bayala, 2019). Previous findings indicate that FMNR complements *in-situ* conservation efforts, connecting isolated wild habitats, serving as intermediary pathways between networks of protected areas, and protecting the soil and biodiversity (Zinngrebe et al., 2020). Furthermore, managed natural regeneration can contribute significantly to achieving global and national restoration goals, particularly in dryland areas. Nevertheless, according to a recent comprehensive study, there are noteworthy deficiencies in the evidence supporting FMNR, such as the inadequate comprehension of local circumstances on which its expansion has been predicated (Kandel et al., 2022). Thus, it is of utmost importance to urgently prioritize the avoidance, reduction, and reversal of land degradation, as well as the restoration of degraded land. This is necessary to safeguard the biodiversity and ecosystem services that are essential for life on our planet. Therefore, this study aims to assess the Floristic Composition, Vegetation Structure, and Regeneration Status of woody Plant Species of FMNR Plots, in Central Rift, Kenya.

2. Methodology

2.1. Study Area

The FMNR study plots were selected in two separate farms each measuring approximately 2 acres in Mogotio (Baringo County) and Ngoswet within the lower part of Kerio Valley (Elgeyo Marakwet County) as indicated in **Figure 1**. Biodiversity assessments were carried at six-month intervals for a period of two years. The sites are farmlands situated in transition zones between high-potential and low-potential areas. The areas have hot and wet climates characterized by a mean temperature of 25˚C and an annual precipitation of 1500 - 2000 mm with a dry season between December and March. The farmland vegetation comprises a disturbed woodland with indigenous species in different stages of succession. The dominant but sparse woody indigenous plant species include *Vachellia*

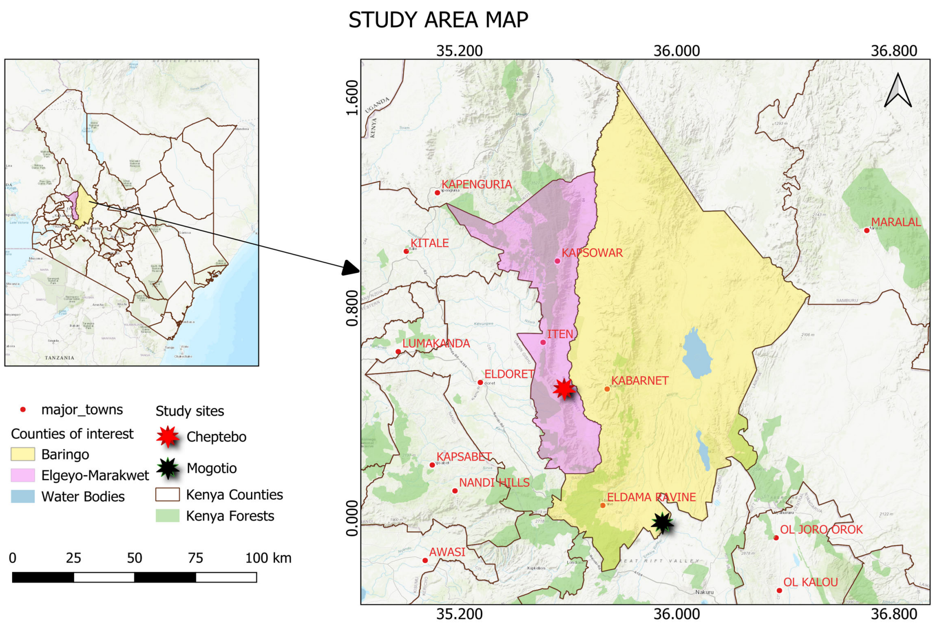

Figure 1. Map of the FMNR study sites.

tortilis, *Balanites aegyptiaca* and *Acacia seyal* while common shrubs are *Lantana camara*, *Lippia japonica* and *Indigofera errecta*. The herbaceous vegetation was dominated by *Hypoestes* species and a wide range of grass species such as *Digitaria scalarum*, *D. horizontalis*, *Cyperus rotundus* and *Cynodon dactylon*. The farmlands support the community and family members primarily for livestock grazing and supply of resources such as fuel wood, timber, construction poles, herbal medicine, fiber, indigenous fruits, traditional vegetables and bee forage for honey production.

2.2. Study Design

The study employed a nested experimental approach that incorporated both transect and quadrant methods to gather information on biodiversity. Transect lines were positioned randomly throughout each sample plot nested systematically along the transect line to examine variations in woody species richness, vegetation structure and regeneration rates. Additionally, an unprotected and unmanaged control plot was selected from the surrounding area at a close proximity to each 2-acre FMNR experimental plot. Quadrats and sub-quadrats were arranged parallel to the slope of the plot at 50 m intervals in each stratum to gather information on different forms of vegetation. The quadrats and sub-quadrats included a 10 m × 10 m main plot, 5 m × 5 m quadrats, and 1 m × 1 m sub-quadrats. The various vegetation forms recorded included mature trees, saplings, seedlings, shrubs, herbs, lianas and climbers. Plants with a diameter at breast height (DBH or D130) ≥ 2.5 cm and a height ≥ 1.5 m were considered trees (Dokata et al., 2023). Saplings were young woody plants with a root collar diameter < 2.5 cm and a height of 50 - 150 cm (Eyasu et al., 2020). Seedlings were woody plants with root collar diameter (RCD) < 2.5 cm and a height between 1 - 50 cm (Eyasu et al., 2020). Shrubs were perennial plants typically < 8m tall and characterized by many stems or branches, while herbs were annual seed plants with either erect or creeping stems that lack persistent woody tissue. Lastly, grasses were low, green plants that grow naturally over much of the earth's surface, characterized by having groups of very thin leaves that grow closely together in large numbers. All these vegetation forms in every plot were identified and recorded by local and scientific names.

2.3. Data Collection and Data Analysis

Data on floristic composition, vegetation status and distribution (structure) and regeneration status (noting subsequent new life forms) was captured in quadrats and sub-quadrats. Data on trees were captured in the entire 10 m × 10 m plot while data on saplings and shrubs were collected in the 5 m × 5 m quadrats. Information on herbs and grasses was recorded in the 1 m × 1 m quadrats. Additionally, the data collection process involved measuring various parameters of the vegetation, including tree height, stem diameter at 130 cm above ground level (D130) for trees and root collar diameter and height of saplings and seedlings.

D130 and tree height were measured using a diameter tape and a Sunto clinometer respectively. Meanwhile, vernier calipers and grid rulers were used to measure root collar diameter and the height of saplings and seedlings respectively. Variation in species composition, stem density, basal area and regeneration rates in sample plots as indicated in **Figure 2** were analyzed using R software using inferential methods. T-test was used to analyze statistical differences in the mean of species diversity of the various vegetation life forms. The comparison of the various species diversity in both FMNR and non-FMNR plots was calculated using the Shannon-Weiner diversity index. Stem density and stand basal area for each species recorded were computed by converting the data on the number of stems per plot (10 m × 10 m) and quadrats (5 m × 5 m and 1 m × 1 m) to hectare level.

(a)

(b)

Figure 2. (a) FMNR farm for enhance Tree based goods and service products (photo by M. Justus). (b) Farmer training within the sites to uptake of FMNR technology (Photo credit: M. Justus/World-Vision).

3. Results and Discussions

3.1. Richness and Diversity of Woody and Herbaceous Species

All the FMNR plots showed a marked progressive increase in numbers of trees, saplings, seedlings, shrubs and grass in each subsequent assessment period from 2020 (baseline) to 2023 (Table 1). The total numbers of the woody and herbaceous species peaked in 2023 at both Mogotio (30) and Cheptebo (31) respectively. All the control plots (non-FMNR) at both sites showed highly contrasting results with massive reduction in numbers of all forms of vegetation. For example, the control plot in Mogotio showed a reduction of floristic diversity from a total of 25 species in 2020 to only 3 species in 2023, and the Cheptebo site with very little or no vegetation (Table 1). The species diversities of woody and non-woody plants within FMNR and non-FMNR were statistically significantly different (Trees $p = 0.01 < 0.05$, Saplings $p = 0.01 < 0.05$, Seedling $p = 0.02 < 0.05$, Herbs $p = 0.02 < 0.05$, Shrubs $p = 0.02 < 0.05$ and Grass $p = 0.01 < 0.05$).

Besides the vegetation population count and observed changes in diversity over the 4-year study period, Shannon-Wiener species diversity indices provide the extent to which these changes are comparatively represented across the FMNR and non-FMNR sites. The index ranges from 0 (no diversity) to a maximum of 3.5 (highest diversity) (Table 2). The results showed that vegetation

Table 1. Species diversity of woody and non-woody species.

Site	Plot	Year	Trees	Saplings	Seedlings	Herbs	Shrubs	Grass	Total
Mogotio	FMNR	2020	3	4	1	1	2	4	15
		2021	4	4	1	4	6	6	25
		2022	4	5	2	3	6	6	26
		2023	4	5	4	4	7	6	30
	Non-FMNR	2020	3	3	1	9	4	5	25
		2021	1	0	0	1	0	2	4
		2022	0	0	0	1	0	0	1
		2023	0	0	0	1	0	2	3
Cheptebo	FMNR	2020	3	0	0	2	3	0	6
		2021	3	3	1	6	3	4	20
		2022	3	2	2	8	5	3	23
		2023	3	3	3	8	6	8	31
	Non-FMNR	2020	0	0	0	0	0	0	0
		2021	0	1	0	0	0	1	2
		2022	0	0	0	0	0	0	0
		2023	0	0	0	0	0	0	0
Statistics-t-test			$t(5) = 7$, $p = 0.01$	$t(5) = 7$, $p = 0.01$	$t(5) = 5.65$, $p = 0.02$	$t(5) = 5$, $p = 0.02$	$t(5) = 5.18$, $p = 0.02$	$t(5) = 5.27$, $p = 0.01$	

Table 2. A comparison of woody species Shannon-Wiener-diversity per plot in FMNR and Non-FMNR intervention sites.

Site	Year	Saplings DBH < 10 cm		Trees DBH > 10 cm	
		FMNR	*Non*-FMNR	FMNR	Non-FMNR
Cheptebo	2020	0.35	0.35	0.35	0.54
	2021	0.35	0	1.49	0.26
	2022	1.97	0	2.00	0
	2023	2.16	0	2.54	0
Mogotio	2020	0.35	0	1.49	0.32
	2021	0.35	0	1.43	0.11
	2022	1.35	0	2.77	0
	2023	2.26	0	3.37	0
Statistics-t-test		$t(5) = 6.6461$, $p = 0.04$		$t(5) = 5.417$, $p = 0.01$	

diversity [at FMNR sites] increased with time. For example, at the start of the experiment (baseline in 2020), the diversity index ranged from 0.35 to 0.54 for both FMNR and non-FMNR sites. Over the subsequent four years, the indices for the FMNR sites gradually increased to a peak in 2023 at 2.16 for saplings and 2.54 for trees for Cheptebo and 2.26 (saplings) and 3.37 (trees) for Mogotio respectively (Table 2). The non-FMNR sites showed little or no diversity at all, ranging from 0 to 0.54. Furthermore, the results show a statistical significantly difference of sapling (DBH < 10 cm) Shannon-Wiener-diversity between the FMNR and non-FMNR ($t(5) = 6.646$, $p = 0.04 < 0.05$) and trees ($t(5) = 5.417$, $p = 0.01 < 0.05$)

Results also demonstrated that certain plant Families responded to FMNR within the sites more than others. For example, four families of trees were found to be dominant across the two study sites. These are Zygophyllaceae (represented by *Balanites aegyptiaca*), Fabaceae (A*cacias*/ *Vachellia* sp), Burseraceae (*Commiphora* sp) and Capparaceae (*Boscia* sp) (Table 3). All of these Families are widely utilized on both domestic and commercial levels at household levels, thus underlining the socio-economic and socio-cultural importance of FMNR as a conservation and restoration practice in the arid and semi-arid landscapes (Table 3). As expected, the annual herbaceous vegetation was represented by the highest number of Families where a total of 14 were recorded against 6 Families of shrubs (Table 3). Like trees, all the herbs and shrubs recorded were found to be very useful as critical sources of livestock fodder, veterinary and human uses as herbal medicine and nutritious vegetables for human use.

Another important Family that was recorded was Poaceae (grass) where a total of 11 species were found across the two study sites (Table 3). Grass remains a critical pasture component for pastoral communities in ASALs hence the importance of FMNR as a practice that positively contributes to sustainable management of livestock fodder resources in these areas throughout the year.

Table 3. Common species of woody and non-woody species within the sites of FMNR assessed.

Type	Family	Scientific/Abundance of quadrats (%)	Status & Utilization
Trees	Zygophyllaceae	*Balanites aegyptiaca* (11.6)	Plants fixes nitrogen and improves the soil fertility, supporting grasses and harvest development, Medical values, Charcoal, poles, bee fodder & medicinal. (Belayneh et al., 2021, Goda et al., 2021, Hassan et al., 2019, Munishi et al, 2008).
	Fabaceae	*Acacia albida* (7.2)	
	Fabaceae	*Acacia seyal* (32.3)	
	Fabaceae	*Acacia hoki* (17.2)	
	Fabaceae	*Acacia tortilis* (27.9)	
	Fabaceae	*Acacia brevispica* (1.2)	
	Burseraceae	*Commiphora Spp (1.4)*	
	Capparaceae	*Boscia mossambicensis (1.2)*	
Shrubs	Malvaceae	*Grewia villosa* (29.6)	The leaves are very palatable to livestock, fodder. herbal medicine, (Etuh et al., 2021, Bhattacharjya et al., 2020, Maroyi, 2017)
	Malvaceae	*Taraxacum officinale* (9.9)	
	Verbenaceae	*Lantana camara (9.9)*	
	Lamiaceae	*Ocimum sanctum* (3.3)	
	Zamiaceae	*Encephalartos natalensis* (31.0)	
	Malvaceae	*Corchorus olitorius (13.1)*	
	Fabaceae	*Indigofera arrecta* (3.3)	
Herbs	Asteraceae	*Conzya bonariensis* (2.43)	Highly medicinal (Tan et al. 2013, Sbhatu & Abraha, 2020, Ojunga et al., 2023, Assis de Andrade et al., 2023) Food, green manure, fodder. The young fresh leaves of this plant are also high in fibre and minerals (e.g., calcium and iron) needed for good health (Rehman et al., 2015, Mutie et al., 2023)
	Asteraceae	*Notonia petraea* (29.75)	
	Acanthaceae	*Hypoestes phyllostachya* (4.87)	
	Acanthaceae	*Altenanathera sessilis* (1.36)	
	Amaranthaceae	*Achyranthes aspera* (0.27)	
	Lamiace/Labiatae	*Ocimum suave* (2.43)	
	Solanaceae	*Solanum incanum* (3.18)	
	Commelinaceae	*Cammalina benghalensis* (2.69)	
	Crassulaceae	*Kalanchoe densiflora* (16.9)	
	Cyperaceae	*Kyllinga brevifolia* (0.27)	
	Fabaceae	*Crotalaria retusa* (0.89)	
	Lamiaceae	*Leucas grandis* (4.09)	
	Malvaceae	*Corchorus olitorius* (7.63)	
	Moraceae	*Fatou villosa* (17.04)	
	Oxalidaceae	*Oxalis latifolia* (0.55)	
	Zygophyllaceae	*Tribulus terrestris* (8.07)	
Grass	Poaceae	*Digitaria sanguinities* (11.8)	These grass species are highly tolerant to drought and heavy grazing, soil binding, makes ground more stable but some invasive.
	Poaceae	*Cynodon dactylon* (13.76)	
	Poaceae	*Digitaria scalarum* (0.01)	
	Poaceae	*Eragrostis superba* (0.01)	
	Poaceae	*Eragrostis curvula* (31.05)	
	Poaceae	*Digitaria ciliaris* (8.25)	
	Poaceae	*Digitaria horizontalis* (16.06)	
	Poaceae	*Digitaria eriantha* (7.86)	
	Poaceae	*Cynodon aethiopicus* (7.86)	
	Poaceae	*Heteropogon contortus* (1.96)	

3.2. Distribution and Abundance of the Various Vegetation Types under FMNR and Non-FMNR Sites

The significant increase in numbers of all forms of vegetation types recorded in FMNR sites led to high abundance per unit area. Combination of grasses and herbs at the lower canopies showed the highest percentage vegetation cover in all the FMNR sites, rising from 10.5% in 2020 (baseline) to 91% in the 4th year of assessment while the non-FMNR sites declined from 6.25% to about 2% in the same period (Figure 3(a)). Similarly, the relative abundance of shrubs increased from 15,000 stems/ha in 2020 to 62,000 stems/ha in 2023, a four-fold increase, with non-FMNR plots decreasing from 2800 in 2020 to 1720 (Figure 3(b)).

The positive impact of FMNR practice on the abundance of tree and sapling components was also remarkably evident. For example, the recruitment of saplings in FMNR sites increased from 3911 stems/ha in 2020 to 5833 stems/ha in 2023, with a marked decrease in control sites from 2150 stems/ha to 986 stems/ha in the same period (Figure 3(c)). The characteristic slow growth of trees was demonstrated by the low levels of their relative abundance within the study period, increasing from 420 stems/ha in 2020 to 696 stems/ha in 2023 in FMNR sites (Figure 3(d)). The disturbances attributed to unprotected tree resources in the control sites can explain the observed decrease from abundance

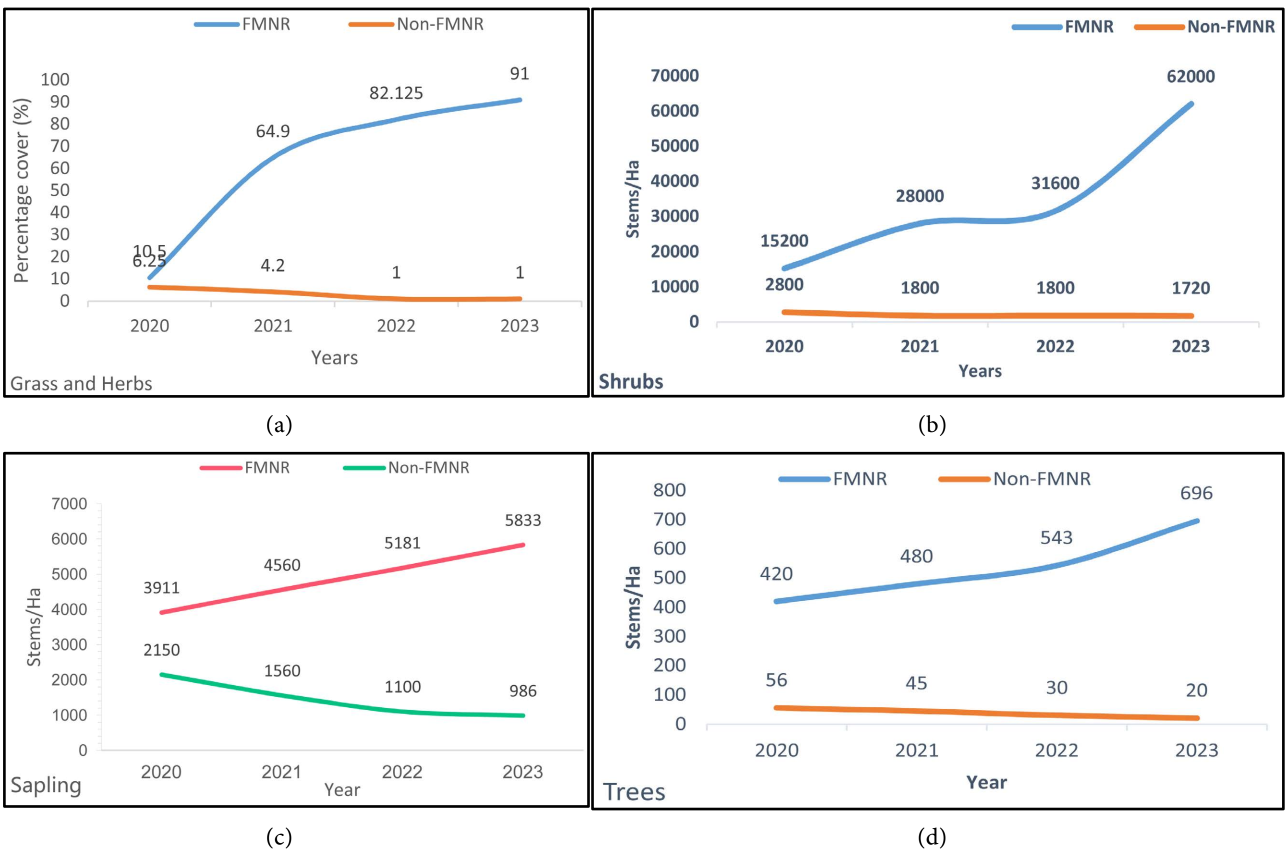

Figure 3. The diversity (a) Grass and herbs percentage cover (b) Shrubs stems/ha (c) Sapling stems/ha (d) Trees/ha between the FMNR plots and not FMNR sites.

from 56 stems/ha in 2020 to 20 stems/ha, a three-fold reduction (Figure 3(d)).

3.3. Tree Size Class Distribution and Recruitment

Results showed that all FMNR sites generally exhibited a highly positive conservation status of the woody vegetation component over the study period as demonstrated by the distribution of height and diameter at breast height (DBH) classes in both Mogotio and Cheptebo (Figure 4). In both growth parameters, their distribution in terms of relative densities across the various size classes was characterized by a typical inverse J-shaped graph (Figure 4). Although both sites indicated healthy conservation status of the woody biomass, Cheptebo showed a healthier population with higher numbers of individuals at each of the DBH and height classes compared to the Mogotio site (Figure 4).

4. Recommendation and Conclusion

4.1. Conclusion

The dominant trees, shrubs and herbs families across the study sites were noted as well as their place and importance in the plant succession continuum. Consequently, all FMNR sites showed a healthy and highly stable population structure and conservation status of the woody biomass component with increasing

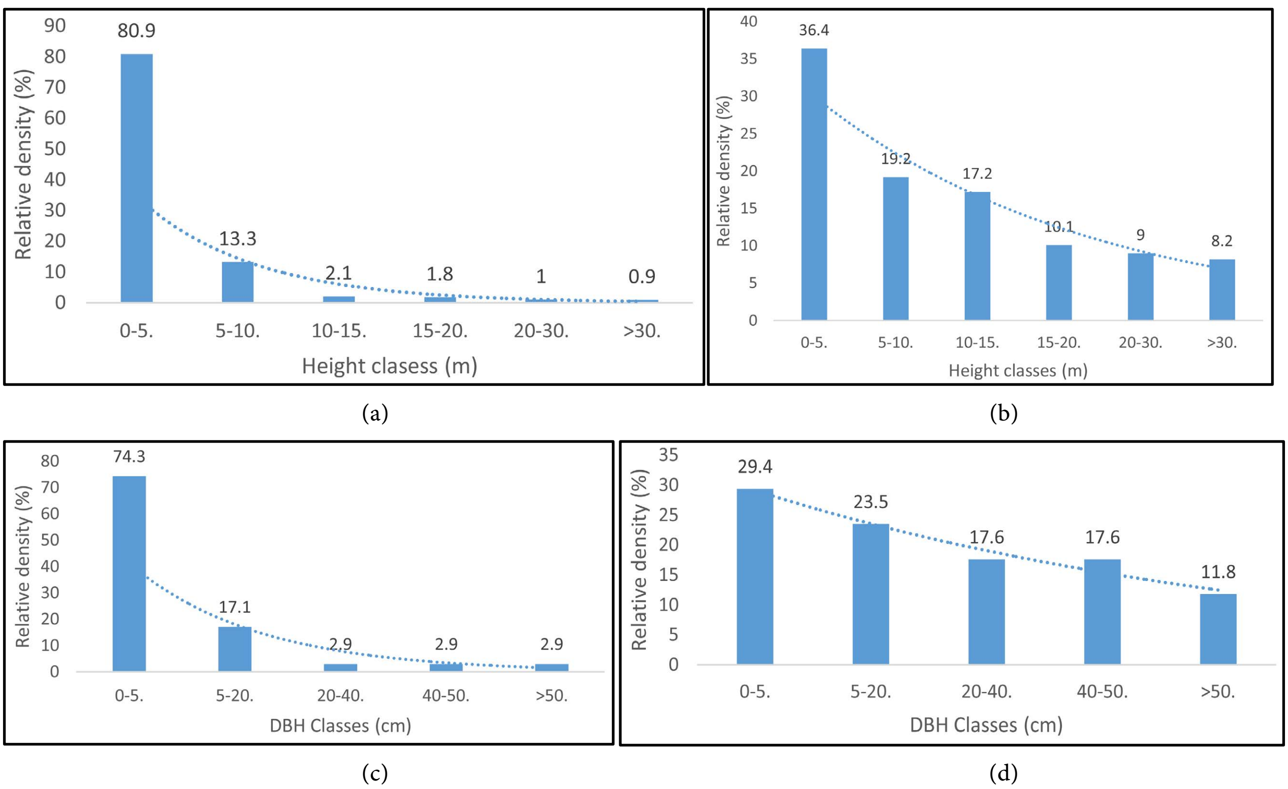

Figure 4. (a) Height class distributions of woody plant species in Baringo (Mogotio) and (b) Elgeyo-Marakwet (Cheptebo). Height class: 1 = 0 - 5 m, 2 = 5 - 10 m, 3 = 10 - 15 m, 4 = 15 - 20 m, 5 = 20 - 30 m, and 6 > 30 m. (c) The Diameter class frequency distribution of woody plants in Baringo (Mogotio) and (d) Elgeyo Marakwet (Cheptebo). Diameter at breast height (DBH) class: 1 = 0 - 5 cm, 2 = 5 - 20 cm, 3 = 20 - 40 cm, 4 = 40 - 50 cm, and 5 > 50 cm.

numbers of mature trees, saplings and seedlings respectively. The reverse is true for non-FMNR sites that are often increasingly being degraded with passage of time thus making them less and less productive. Prolonged exposure of such sites leads to continued degradation thus massive losses of underground seed banks and other sources that sustains plant regeneration.

In conclusion, the comparison between FMNR sites and non-FMNR sites highlights the remarkable advantages of FMNR in fostering greater woody species diversity, regenerating species, and maintaining stable population structures, underscoring its substantial potential in combating environmental degradation.

4.2. Recommendation

The findings of this study underscore the growing importance of Farmer-Managed Natural Regeneration (FMNR) as a critical strategy for environmental conservation and restoration. Given the evident success of FMNR sites in enhancing vegetation biomass and fostering diverse species communities, it is imperative to promote its widespread adoption within communities.

To fully capitalize on the benefits of FMNR, there is a need for extensive community outreach efforts to raise awareness about its advantages and encourage its adoption. This should include not only incentivizing more farms to embrace FMNR but also advocating for its implementation on public lands at a landscape level. Achieving widespread adoption may require reevaluating stakeholder engagement strategies within the existing FMNR framework, extending beyond private farmlands to include public spaces.

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Data Availability

The data sets used and/or analyzed in the study are available within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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