Biodiversity and Conservation (2023) 32:3397–3421
https://doi.org/10.1007/s10531-023-02671-2

ORIGINAL RESEARCH

Harvesting distance effect on tree species diversity in traditional agroforestry landscape: a case of Vhembe Biosphere Reserve in South Africa

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Received: 29 May 2022 / Revised: 14 June 2023 / Accepted: 25 June 2023 /
Published online: 2 July 2023

Abstract

Traditional agroforestry has been recognised to contribute to biodiversity conservation; however, biodiversity strategies often lack information about drivers of tree species diversity loss, which is crucial for decision-making. Anthropogenic disturbance has positive and negative effects on tree species richness and diversity. This study was conducted in Vhembe Biosphere Reserve, Limpopo Province, and used distance from the nucleus of the community to the forest as a parameter to assess tree species richness and diversity. Vegetation data were collected using three transects of 150 m in each distance level and sampled a total area of 1000 m^2 by sampling five rectangular plots of 20 $m^2 \times 10$ m^2 (200 m^2). Data analysis was conducted using Chao1, PERMANOVA, *n*MDS, PERMDISP, DISTLIM, *db*RDA and SIMPER. The findings are in consonant with distance decay of community similarity hypotheses, with estimated tree species richness of 76, 93 and 95 species in an immediate distance, intermediate distance and far distance, respectively. Moreover, the highest species variation was observed at an intermediate distance, which indicates that there is greater species composition at an intermediate distance compared to immediate and far distances. The results confirm that the distance and associated factors have major detrimental effects on tree species richness and biodiversity in traditional agroforestry landscapes. Harvesting of provisioning ecosystem services is found and known to be extremely high in the study area. Effective interventions such as planting indigenous trees and conserving the existing vegetation must be implemented to reduce and halt overexploitation.

Keywords Biodiversity · Distance · Intermediate disturbance hypothesis · Traditional agroforestry · Provisioning ecosystem services

Communicated by Daniel Sanchez Mata.

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Introduction

Over the past decades, agroforestry practice has gradually increased with over 1.2 billion people worldwide practicing agroforestry (Islam et al. 2021). Agroforestry is a system that includes traditional and modern practices integrating crops, animals, and woody plants (e.g., trees, palms, and bamboo) into the same land management unit (FAO 2019). The agroforestry practice provides cultural benefits, socio-economic benefits, and environmental benefits (Dhanya et al. 2014). In particular, traditional agroforestry has played a critical role in conserving biodiversity and sustaining rural livelihoods through the provision of multiple products and services (Tadesse et al. 2021). In South Africa, natural tree species are well integrated into traditional agroforestry landscapes due to their use value and capacity to tolerate both environmental and anthropogenic disturbances (Starke et al. 2020).

South Africa, like many developing countries, is saddled with a high population (60.6 million), high unemployment rates (34.9%) (Statistics South Africa 2021), and high levels of poverty (Shackleton 2020). Moreover, the country is enduring severe land degradation and poor land productivity, particularly in rural communities (Ayisi et al. 2018). Hence, most poor people live in rural areas and heavily depend on provisioning ecosystem services (PESs—e.g., fuelwood, medicinal plants, wild food and fruits) (Scheiter et al. 2018; Shackleton 2020). High dependence on PESs has resulted in a loss of biodiversity and forest degradation (Mensah et al. 2016). Human dependence on PESs is directly linked to human disturbance in the forest, which is considered among the main drivers of tree species loss (Ramarumo and Maroyi 2020; Rampheri et al. 2020). Natural tree species loss has a negative impact on the stability of the ecosystem services in traditional agroforestry landscapes (Rampheri et al. 2020). However, traditional agroforestry landscapes have been recognised as one of the effective ways to conserve biodiversity and improve the livelihoods of rural people (Asase and Tetteh 2016). Agroforestry is widely promoted as an effective and equitable forest biodiversity restoration strategy (Duffy et al. 2021; Lelamo 2021; Melone et al. 2021). Species diversity plays a critical role in the function of the traditional agroforestry ecosystem and productivity (Rampheri et al. 2020). Hence, planting more indigenous trees help in restoring fragmented natural forests (Gemechu et al. 2021). Specifically, multipurpose indigenous trees provide several benefits (Lelamo 2021). However, even though planting indigenous trees is effective in restoring the forest, people prefer planting exotic tree species with economic value (Gemechu et al. 2021).

Successful traditional agroforestry systems are a function of the management of the system (Islam et al. 2021), and environmental, social, and economic parameters. These parameters have been assessed in the past in villages in Bangladesh (e.g., Islam et al. 2021). Among the change variables, the distance to the forest areas was shown as a significant driver of species richness in a traditional agroforestry landscape (Yashmita-Ulman et al. 2021). According to Yashmita-Ulman et al. (2021), tree species richness increases as the distance to the forest increases, and the tree species are closely similar. Indeed, distance has a significant influence on tree species diversity because it is directly linked to human disturbances (Cicuzza et al. 2011). There have been many studies that disturbance affects species diversity by changing local species richness, mean similarity of local assemblage, variance (homogeneity of dispersion) of local assemblages or all at the same time (e.g., Bendix et al. 2017; Araia and Chirwa 2019).

As predicted by optimal foraging theory, human beings will save time and energy when searching and collecting PESs (Soldati et al. 2017; Feitosa et al. 2018). Therefore, local people are expected to intensively harvest PESs at an immediate distance, and moderate harvest at an intermediate distance, and minimal harvest at far distances in the landscape. Subsequently, because of the intermediate disturbance hypothesis, tree species diversity is expected at an intermediate distance from the traditional agroforestry landscape to indigenous forests. The intermediate disturbance hypothesis hypothesizes that the species diversity maximises when a disturbance occurs at an intermediate frequency or with intermediate intensity (Silva Pedro et al. 2016; Bendix et al. 2017). In simple terms, the absence of disturbance or low-intensity disturbance allows species succession while the high-intensity disturbance decreases trees species richness and diversity (Bendix et al. 2017); because of high-intensity disturbance, only the most resistant species persist (Silva Pedro et al. 2016; Araia and Chirwa 2019). Despite the distance being an important tree species driver, little is known in South Africa about the influence of distance on tree species diversity in traditional agroforestry systems.

The main objective of the present study was to understand the effect of distance on tree species diversity in traditional agroforestry and its contribution to tree species and biodiversity conservation. This study, therefore, tested two hypotheses; first, ***"****Tree species diversity is expected to be the highest at an intermediate distance from the villages due to the effect of the immediate disturbance hypothesis"*. Second, "*the turnover of tree species composition between distance levels increases as the distance from the community increases due to the effect of the distance decay of community similarity hypothesis*". The distance decay of community similarity hypothesis predicts that geographically close communities or habitats tend to be like those that are far apart (Soininen et al. 2007; Dias et al. 2021). This study used distance as an environmental predictor to understand species turnover. A distance to the forest is defined as the distance from the community settlements to the proximate forest within the traditional agroforestry landscape.

Materials and methods

Study area

In the Vhembe Biosphere Reserve (VBR), most of the local people depend on forest products for livelihood (Makhubele et al. 2020; Dalu et al. 2021), and the use of forest products is deeply rooted in the culture, customs and beliefs of the local people (Araia and Chirwa 2019). The prevalence of a high degree of forest biodiversity is one of the prominent characteristics of the traditional agroforestry landscape of the VBR. The VBR has tremendous potential as a forest genetic resource for the conservation and support of the local people's livelihood. However, the PESs have been overexploited by local people to maintain their livelihoods. Therefore, it will be of immense importance if the use, species diversity and human behaviour are understood to inform future strategies of biodiversity conservation in the landscape.

The present study was conducted from November to December 2020 in the Thulamela Municipality (30°27′ 38, 67″ E, 22°58′ 15, 87″ S), Vhembe District, in Limpopo Province. The study covered four (4) purposively selected communities, Damani (22°.50′ 45 S, 30°.31′38 E), Thenzheni (22°.49′ 54 S, 30°.28′ 57 E), Tshiombo (22°.48′ 30 S, 30°.30′ 53 E) and Tshipako (22°0.51′ 14 S, 30°0.28′ 59 E) (Fig. 1). This district is endowed with a rich diversity of land use activities including tea, forestry, and agriculture farming. The annual temperature ranges from 15 °C in winter to a maximum of

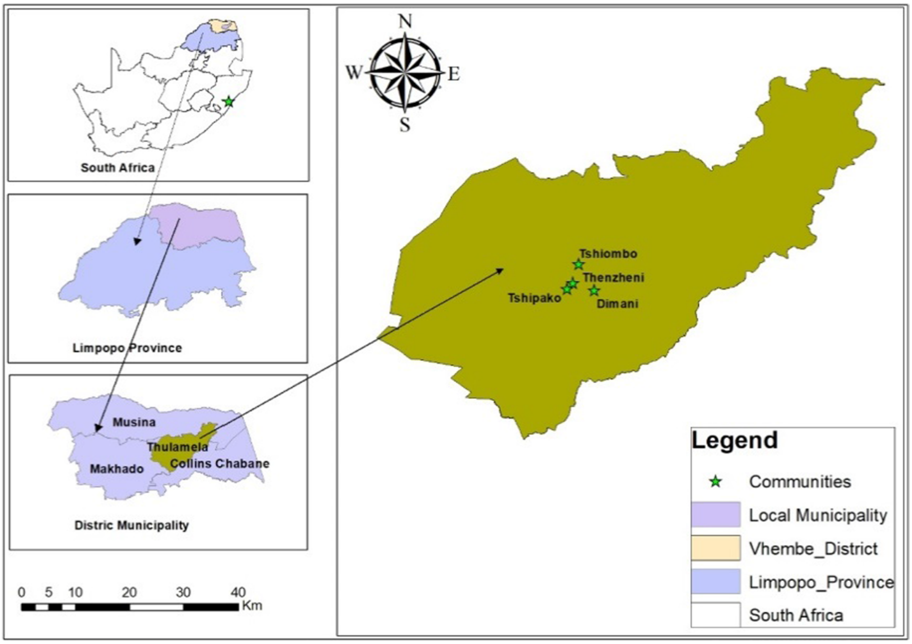

Fig. 1 Map of the study areas

45 ºC in the summer season (Constant and Tshisikhawe 2018). The area is wet and warm in summer, with annual rainfall ranging from 300 mm to above 1000 mm of which 80% occurs between October and March (Ramarumo and Maroyi 2020); it is dry and cold in the winter season. The rainfall annual threshold for both agriculture and commercial forestry is averaged at 250 and 750 mm, respectively. Though the local people in this district have a rich diversity of farming activities, the tradition of reliance on PESs persists.

The provisioning ecosystem services commonly used are wild fruits and food, medicines, firewood, building materials and livestock fodder (Constant and Tshisikhawe 2018; Araia and Chirwa 2019). The harvesting of PESs constitutes a primary source of income for most of the population (Makhubele et al. 2020), particularly the poor communities. Useful trees are retained on farms and at homesteads due to their variety of uses such as fodder, fuelwood, medicine, and timber. Thus, the landscape is characterised by traditional agroforestry practices. The VBR vegetation primarily consists of grasslands, savannahs, wetlands, and forests (Evans 2017). Dominating tree species within the Vhembe district include *Syzygium gerrardii, Xymalos monospora, Englerophytum maglismontanum, Aphloia theiformis, Podocarpus falcatus, Syzygium cordatum, Bridelia micrantha* and *Cassine eucleiformis* (Araia et al. 2019), as well as *Combretum molle*, *Ekebergia capensis*, *Pterocarpus angolensis* and *Sclerocarya birrea* (Constant and Tshisikhawe 2018). Distance acts as a natural barrier to harvesting of provisioning ecosystem services with the frequency of harvesting declining significantly as the distance from communities to the forest increases (Mensah et al. 2016; Ramarumo and Maroyi 2020). The PESs in the immediate distance (adjacent or surrounding communities) have been reported to be depleting and could disappear (Makhado et al. 2012). For this study, the inventory sites were classified based on the distance travelled to collect or harvest PESs based on information obtained

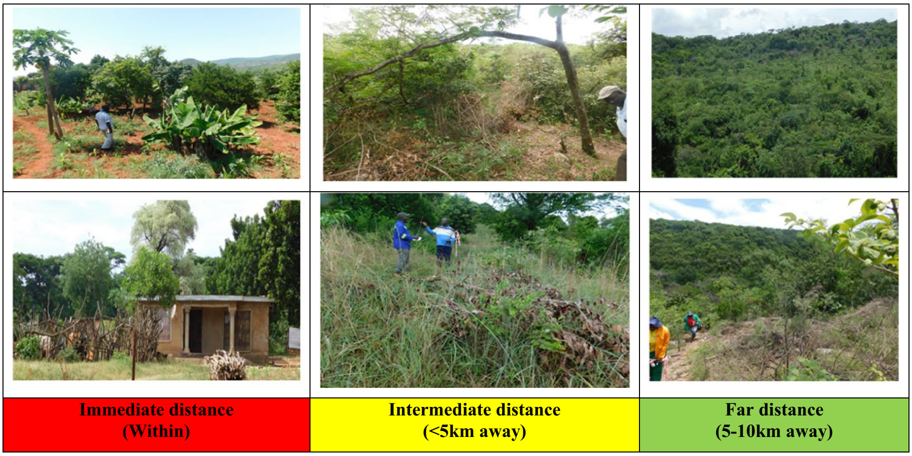

Fig. 2 Photos depicting traditional agroforestry landscapes at the immediate, intermediate and far distance level

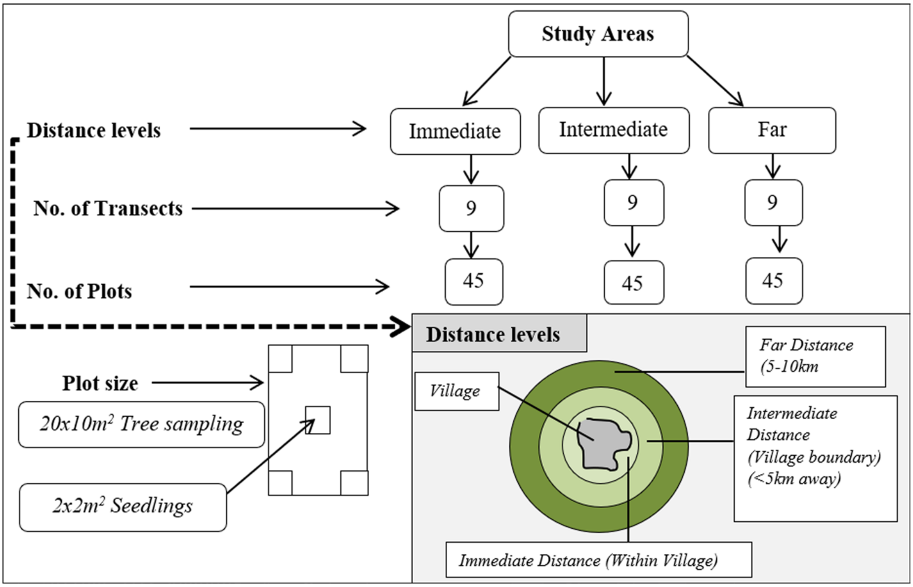

Fig. 3 Outline of sampling design for biological data collection

from local communities. The distances were thus grouped into three levels as follows (Figs. 2 and 3);

a. *Immediate distance level*: provisioning ecosystem services within the community surroundings.
b. *Intermediate distance level*: provisioning ecosystem services in the adjacent forest or forest surrounding the community (< 5 km away).

c. *Far distance level*: provisioning ecosystem services 5–10 km away from the community.

Tree species inventory

To determine the diversity of tree species existing in the traditional agroforestry landscape, a tree species inventory was conducted. The inventory sites were classified based on the distance travelled to collect or harvest PESs by communities. At each distance level, three (3) transects of 150 m each were established (Fig. 3) and sampled for a total area of 1000 m^2 by sampling five rectangular plots of $20\text{m} \times 10\text{m}\left(200\ \text{m}^2\right)$ each, separating each plot by 25 m. The rectangular plots are less vulnerable to measurement errors in the field and tend to cover a large area (Kangas and Maltamo 2006; Araia et al. 2020). The three transects were separated from each other by at least 200 m. In every 200 m^2 rectangular plots, five (5) subplots of $2\text{m} \times 2\text{m}\left(4\text{m}^2\right)$ were established at each of the four corners of the rectangle and the centre for sampling the tree seedlings (regeneration). On each plot, all individual tree species with a diameter ≥ 5 cm at breast height (DBH) were considered trees and measured using a calliper (Jegora et al. 2019; Zequeira-Larios et al. 2021). The scientific and vernacular names of the tree species were captured (Araia et al. 2020). In each subplot, tree species with a diameter ≤ 5 cm were identified and enumerated. Tree species identification was carried out using a tree identification expert and a trees field guidebook (van Wyk and van Wyk 1997). The Field guide to trees of Southern Africa was used to identify the indigenous, endemic, and exotic species (van Wyk and van Wyk 1997). The trees were classified as indigenous to South Africa, endemic to Southern Africa and exotic if originated from outside Southern Africa.

Statistical analysis

The biological data was analysed using Plymouth Routines in Multivariate Ecological Research (PRIMER) version 7.0.21 and added on PERMANOVA + 1 software. Firstly, the original abundance-based species-sample matric was prepared and followed by the analysis of Bray-Curtis similarity coefficient matrix (Clarke and Gorley 2015). This was then followed by the Jaccard similarity coefficient matrix by transforming the original abundance-based species-sample matrix into presence/absence data. Then both matrices were subjected to RELATE routine to test the correlation between the two matrices. The Spearman's rho correlation value was found to be very high ($\rho = 0.97$; $p = 0.001$) indicating the two matrices contained almost identical information. Hence, the Jaccard similarity coefficient matrix was used to test the similarity in mean local assemblage among different distance regimes (Clarke and Gorley 2015).

Sampling effectiveness and vegetation description

The sampling effort sufficiency was evaluated to observe the effectiveness of the sampling effort of observed species (Devkota et al. 2020). A sufficient sampling effort captures as many species as possible, with $\geq 80\%$ estimated species richness (Araia et al. 2020). This species richness estimate was performed using Chao 1 (Eq. 1), Chao1 is a non-parametric species richness estimator (Gotelli and Chao 2013; Chao and Chiu 2012; Clarke and Gorley 2015; Chao and Chiu 2016). Then, the species accumulation curve was computed to demonstrate the species observed and the estimated species. These indices help to compare a variety of species richness at different distance levels.

$$S_{Chao1} = S_{obs} + \frac{f_1^2}{2f_2} \tag{1}$$

where S_{obs} is the number of species in the sample, $f1$ is the number of species with only a single occurrence and $f2$ is the number of species with two occurrences in the sample (Chao and Chiu 2012; 2016). Similarities percentages analysis (SIMPER) was used to identify dominant tree species (cut off 70%) using Jaccard similarity matrix using dummy variables on original abundance data and their contribution in dissimilarity in species composition to each distance level (Anderson et al. 2008). Then, the dominance of each tree species was visualised in the shade plots. The visual impact of grey-scale intensities in a shaded plot gives a strong idea of which species are highly dominated at each distance level. White denotes the absence of that species at that distance level and full black represents the maximum abundance at the distance level (Anderson et al. 2008).

The distribution of the species similarity was calculated using the Jaccard similarity coefficient or Jaccard index in Primer-E version 7 (Clarke and Gorley 2015). The Jaccard index measured the similarity for three distance levels, ranging from 0 to 100%. The Jaccard similarity index was calculated as follows.

$$S_{jk} = 100\left[\frac{(a+d)}{(a+b+c+d)}\right] \tag{2}$$

where, S represents the probability (×100) of a single species picked at random (from the full species list) being present in both samples or absent in both samples, a = the number of species which are present in both samples; b = the number of species present in sample j but absent from sample k; c = the number of species present in sample k but absent from sample j; d = the number of species absent from both samples (Clarke et al. 2014). The species richness was determined using the Margalef index (d) of the DIVERSE index in Primer-E. Margalef index was calculated as follows.

$$d = \frac{(S-1)}{\log N} \tag{3}$$

where S = represents the number of species count, and N = represents the total number of individuals (Clarke et al. 2014). Then, the resemblance matrix of the Margalef index was developed using Euclidean distance (Araia et al. 2020). Based on the species richness data, the significant differences in species richness among different distance levels (immediate, intermediate, and far distances) were tested with permutational multivariate analysis of variance (PERMANOVA) (Anderson et al. 2008). Pairwise comparison tests with PERMANOVA 999 permutations and t statistics were conducted to investigate the significant difference in distances pairs "Immediate × Intermediate, Intermediate × Far, Immediate × Far" for species richness data.

Analysis of mean similarity of local species assemblage among different distance levels

To assess the significance of the mean similarity of local assemblages, the Jaccard coefficient matrix was subjected to non-parametric multidimensional scaling (nMDS) in

Primer-E 7. *n*MDS helps to visually inspect the mean similarities of local assemblages within a distance level and among different distance levels. This was then subjected to PERMANOVA to discriminate if the similarity is statistically significant. Pairwise comparison tests with PERMANOVA 999 permutations and *t* statistics were conducted to investigate the significant difference in species composition in distances pairs "Immediate × Intermediate, Intermediate × Far, Immediate × Far".

The variance of local species assemblages among different distance levels

To assess the significance of variance in the identity of species that are locally co-existing among the distance levels, homogeneity of dispersion (PERMDISP) was tested using the Jaccard coefficient matrix with 999 permutations (Anderson et al. 2008). A pairwise comparison of levels of distance was conducted to show variance between distance level groups. Then, SIMPER dissimilarity analysis of species was conducted to assess the species contributing to variation in the landscape.

Drivers of turnover of species composition of local assemblages among different distance levels

The inter-correlations among the change drivers were tested using the Multicollinearity test of the correlation matrix in Primer's Draftsman plot. The pairs of all variables (drivers) correlation were below the threshold ($|r| \geq 0.95$); therefore, they contain effectively different information and are not redundant (Anderson et al. 2008). Then, the link between the drivers and distance levels was tested using distance-based linear modelling (DISTLM), and visually inspected using distance-based redundancy analysis (*db*RDA) (Araia et al. 2020). The relationships between each environmental factor were analyzed separately in the marginal test. Then, the factors were subjected to a sequential test, the R^2 selection criterion which explained each factor's contribution to the changes. A *db*RDA plot obtained from PERMANOVA using DISTLM was used to visualize the patterns of the DISTLM results.

Results

Sampling effectiveness and vegetation description

Altogether, this study recorded 2578 individual trees, of which 634 are recorded at an immediate distance, 862 at an intermediate distance and 1082 at a far distance. The Chao1 species accumulation curve indicated that species sampled in the whole study area and at different distance levels captured the total number of tree species within a different number of sample plots. The tree species curve continued to increase up to 150 and 40 sample plots in the whole study area and all different distance levels, respectively (Fig. 4). The curve did not reach the asymptote which indicates that an increase in sample plots would increase the capture of the number of tree species. The Chao 1 species accumulation estimator curve slightly exceeds the observed species in the whole study and all distance levels.

The total number of tree species was 136, the number of tree species was significantly smaller at an immediate distance (66 species) than at the intermediate distance (83 species)

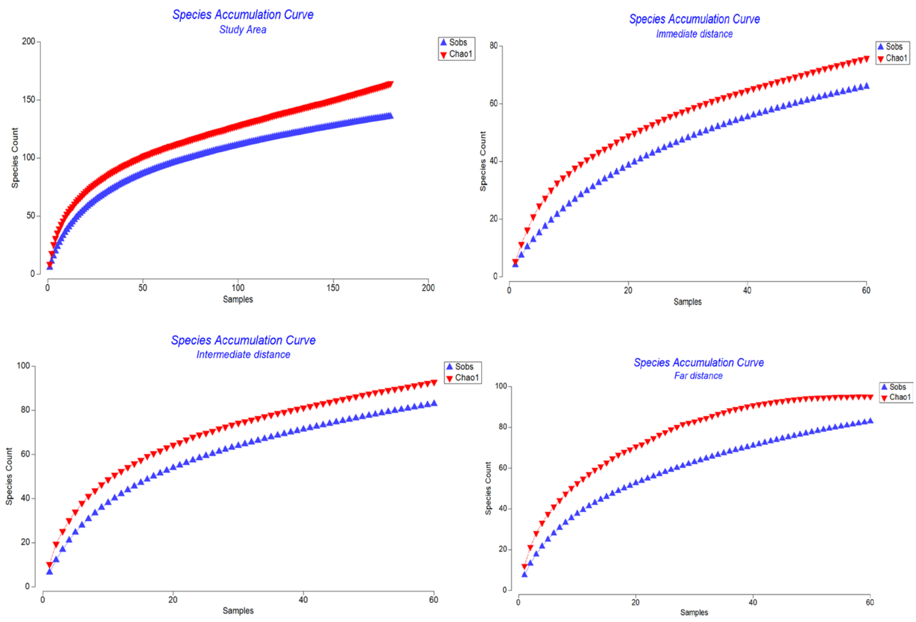

Fig. 4 Estimation of actual and estimated total species richness

Table 1 Total Species richness in different distance levels

Distance levels	Number of species		Sampling effective-ness
	S_{Ob}	S_{Chao1}	(%)
Immediate	66	75.80	87.07
Intermediate	83	92.84	89.40
Far	83	95.04	87.33
Overall	136	164.17	82.84

S_{Ob} Species observation. S_{Chao1}=Species richness estimator (Chao1)

and far distance (83 species) (Table 1). However, there was no notable difference in the number of tree species between intermediate and far distances as the number of tree species is the same. The sampling effectiveness of the whole study was 82.84% and differed slightly across distance levels, significantly higher in an intermediate distance (89.40%) followed by 87.33% in a far distance and 87.07% in an immediate distance. The Chao 1 species estimation indicated that far distance had a higher number of species (95.04 species) followed by an intermediate distance (92.84 species) and an immediate distance (75.80 species) (Table 1). Out of 136 tree species, 114 were indigenous species and 22 were endemic species to Southern Africa. This study recorded a substantive high number of exotic tree species in an immediate distance (18 species) and relatively low in both intermediate and far distances.

The SIMPER results revealed the dominating species and the contribution of each species at different distance levels (Table 2). Exotic tree species have largely dominated and contributed to the similarity of an immediate distance, *Mangifera indica* (57%) and

Table 2 SIMPER analysis of tree species abundance similarity

Immediate distance (Av.sim = 19.70)				Intermediate distance (Av.sim = 15.04)				Far distance (Av.sim = 25.5)			
Species	Av.Abund	Av.Sim	C. %	Species	Av. Abund	Av.Sim	C. %	Species	Av.Abund	Av.Sim	C.%
Mangifera indica	0.67	11.18	56.77	*Pteleopsis myrtifolia*	0.47	3.02	20.06	*Pteleopsis myrtifolia*	0.82	9.17	35.88
Persea americana	0.4	3.6	18.28	*Tabernaemontana elegans*	0.37	1.98	13.17	*Albizia adianthifolia*	0.5	3.32	13.01
				Bridelia micrantha	0.35	1.86	12.38	*Englerophytum magalismontanum*	0.37	1.79	6.99
				Pseudolachnostylis maprouneifolia	0.27	1.04	6.89	*Parinari curatellifolia*	0.37	1.71	6.7
				Combretum molle	0.27	0.91	6.03	*Tabernaemontana elegans*	0.37	1.67	6.52
				Albizia adianthifolia	0.22	0.64	4.27	*Combretum molle*	0.35	1.41	5.52
				Acacia ataxacantha	0.18	0.52	3.43				
				Afzelia quanzensis	0.18	0.42	2.82				
				Parinari curatellifolia	0.17	0.41	2.73				

Table 3 PERMANOVA results of species richness of different distance levels

Source	Df	SS	MS	Pseudo-F	P(perm)	Unique terms
Vi	3	0.33367	0.11122	0.246	0.858	997
Di	2	24.052	12.026	17.147	0.01	998
Vi x Di	6	4.2081	0.70136	1.5512	0.177	999
Res	168	75.959	0.45214			
Total	179	104.55				

Di Distance (Random factor), *Vi* Village (Fixed factor), *SS* Sum of species, *MS* Mean of species, F ratio (Pseudo-F), *P* Permuted probability values, *df* Degree of freedom'

Table 4 PERMANOVA pairwise comparison for species richness

Pairwise distance levels	T	P(perm)
(Immediate & Intermediate)	6.8345	0.027
(Immediate & Far)	5.6622	0.03
(Intermediate & Far)	0.93301	0.444

Persea americana (18.28%). The intermediate distance was dominated by a wide range of indigenous tree species including *Pteleopsis myrtifolia* (20.1%), *Tabernaemontana elegans* (13.2%), *Bridelia micrantha* (12.4%), *Pseudolachnostylis maprouneifolia* (7%), *Combretum molle* (6.03%), *Albizia adianthifolia* (4.3%), *Afzelia quanzensis* (3%) *Parinari curatellifolia* (3%) and *Acacia ataxacantha* (3.4%). Dominating species in the far distance were *Pteleopsis myrtifolia* (36%), *Albizia adianthifolia* (13%), *Tabernaemontana elegans* (7%), *Parinari curatellifolia* (7%), *Englerophytum magalismontanum* (7%), and *Combretum molle* (6%).

Local species richness among different distance levels

The PERMANOVA test for species richness found that there was a significant difference among the distance levels ($F_2 = 17.147$, $P = 0.01$) (Table 3). Then, the pairwise comparison of species richness detected significance differences between (Immediate & Intermediate) and (Immediate& Far), ($t = 6.8345$, $P = 0.027$) and ($t = 5.6622$, $P = 0.03$) respectively (Table 4). However, there was no statistical significance difference between intermediate and far distance ($t = 0.933$, $P = 0.444$).

The mean similarity of local species assemblages among different distance levels

The results of the non-metric multidimensional scaling ordination (*n*MDS) showed a greater overlap between an intermediate (2) and far distance (3), indicating no distinct species composition between the two distances (Fig. 5). The *n*MDS ordination showed a slight separation between immediate (1) and intermediate (2) distances. The results further show evidence of separation of species composition between an immediate (1) and the far distance (3), indicating a greater distinction of species composition. The results show intermediate distance as the centre of species composition.

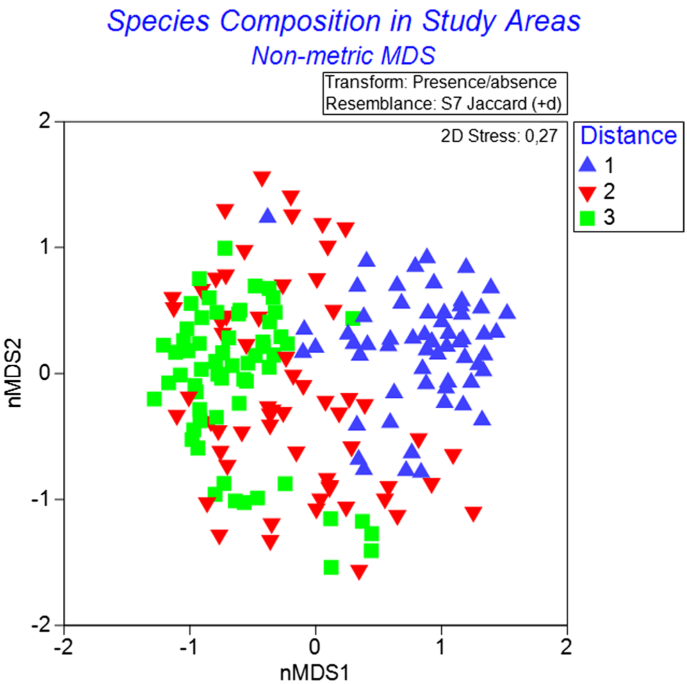

Fig. 5 Multi-dimensional scaling of the local assemblages at different distance levels

Table 5 PERMANOVA results of local species assemblage of different distance levels

Source	Df	SS	MS	Pseudo-F	P(perm)	Unique terms
Vi	3	32,025	10,675	3.5699	0.001	997
Di	2	72,256	36,128	5.8938	0.001	998
Vi x Di	6	36,779	6129.9	2.0499	0.001	998
Res	174	539,160	3098.6			
Total	179	643,440				

Di Distance (Random factor), *Vi* Village (Fixed factor), *SS* Sum of species, *MS* Mean of species, F ratio (Pseudo-F), *P* Permuted probability values, *df* Degree of freedom

The PERMANOVA test confirmed a significant effect of distance on species composition ($F_{5.8938}$;$p < 0.001$), indicating different species compositions in different distance levels (Table 5). Pairwise comparisons further supported this finding, underlining that species composition differed between the distances (Immediate & Intermediate;$t = 2.7, p < 0.05$) and (Immediate & Far;$t = 2.9, p < 0.05$), but not across all the distances (Table 6). The pairwise comparison supported the *n*MDS results of showing no significant difference in species composition between an intermediate and the far distance ($t = 1.3, p = 0.144$).

Table 6 PERMANOVA pairwise comparisons for species composition

Pairwise distance levels	T	P (perm)
(Immediate & Intermediate)	2.7025	0.031
(Immediate & Far)	2.9889	0.028
(Intermediate & Far)	1.3888	0.144

The variance of local species assemblages among different distance levels

Homogeneity of multivariate dispersion (PERMDISP) results showed a significant difference in co-existing species identity of local assemblages among the distance levels ($F = 10.771, p < 0.001$). The PERMDISP pairwise comparisons support the significant difference in the distance levels (Table 7). The species variation at an immediate distance differed significantly from the intermediate distance ($t = 4.3297, p < 0.001$). Likewise, the species variation at an intermediate distance differed significantly from the far distance ($t = 4.2181, p < 0.001$). However, species variation of an immediate distance and far distance was not statistically distinct ($t = 0.9088, p = 0.409$). The species composition variation within the distance levels was 59% at an intermediate distance, far (55%) and immediate (54%) descending.

An average dissimilarity of 95% species composition was observed between the immediate and intermediate distances (Table 8). SIMPER analysis showed that about 32 out of the 136 shared species between the immediate and intermediate distance contributed above 70% to the average dissimilarity between the two distances. The most dominating species in dissimilarity were *Mangifera indica* (7%), *Persea americana* (4%). *Pteleopsis myrtifolia* (5%), *Tabernaemontana elegans* (4%), and *Bridelia micrantha* (4%). Exotic species such as *Mangifera indica*, *Persea americana*, *Citrus sinensis*, and *Musa acuminata* were completely absent in the intermediate distance and indigenous species such as *Vitex ferruginea* and *Hexalobus monopetalus* were completely absent in the immediate distance. An average dissimilarity of 83% species composition was observed between the intermediate and far distances. About 30 out of the 136 shared species between the intermediate and far distance contributed above 70% to the average dissimilarity between the two distances. The most dominating species in dissimilarity were *Pteleopsis myrtifolia* (5%), *Tabernaemontana elegans* (4%), *Bridelia micrantha* (4%), *Combretum molle* (4%), *Albizia adianthifolia* (5%), and *Parinari curatellifolia* (4%). Indigenous species *Vitex ferruginea* was completely absent at a far distance. An average dissimilarity of 95% species composition was observed between the immediate and far distances. About 29 out of the 136 shared species between the immediate and far distance contributed above 70% to the average dissimilarity between the two distances. The most dominating species in dissimilarity were *Mangifera indica* (6%), *Persea americana* (4%), *Pteleopsis myrtifolia* (7%), *Albizia adianthifolia* (5%), and *Englerophytum magalismontanum* (4%). Indigenous species such as *Scolopia mundii, Brachylaena huillensis* and *Pavetta lanceolata* were completely absent in the immediate distance, while exotic species such as *Mangifera indica*, *Persea americana*, and *Citrus sinensis* were completely absent in the far distance. Likewise, *Trichilia emetica* was absent at a far distance. The immediate distance is predominated by exotic tree species and the far distance is predominated by indigenous and endemic species (Fig. 6). The predominance of most species shows to increase from the immediate to the far distance, for example, *Pteleopsis myrtifolia, Parinari curatellifolia, Englerophytum magalismontanum, Albizia adianthifolia* and *Bridelia,micrantha.*

Table 7 PERMDISP pairwise comparison of species composition

Pairwise distance levels	T	P(perm)
(Immediate & Intermediate)	4.3297	0.001
(Immediate & Far)	0.9088	0.409
(Intermediate & Far)	4.2181	0.001

Drivers of species turnover of local assemblages in different distance levels

The DISTLM results showed that there was a significant correlation between species composition and most of the environmental variables examined ($R^2 = 0.155, P < 0.001$). The marginal test showed a significant relationship ($p < 0.001$) between species composition (all distances) and most environmental variables (elevation, gradient, PESs harvesting and distance), except fire occurrence ($p = 0.182$) and grazing, ($p = 0.002$). The variation explained by each variable (Table 9) was as follows: distance contributed 9%, elevation (2.4%), gradient (2.2%), fire occurrence (0.6%), grazing (1.3%) and PESs harvesting (1.5%). The change of the total marginal contribution of each variable in the sequential test may indicate the dominance of variable or interaction of distance levels and other change variables in determining the species composition of a landscape. The distance (15%) explained the highest variability, followed by PESs harvesting (7%), grazing (6%), fire occurrence (5%), gradient (4%) and elevation (2%). The first two axes of *db*RDA captured 75.6% of the variability in the fitted model and 11.8% of the total variation in the data cloud (Fig. 7).

Discussion

Sampling effectiveness, vegetation description and species richness

A high species diversity is often associated with intermediate disturbance (Escobedo et al. 2021), and anthropogenic pressure resilience (Araia et al. 2019; Tadesse et al. 2019). As predicted by the intermediate disturbance hypothesis (IDH), lower species diversity is expected at a high disturbance (Araia et al. 2019; Escobedo et al. 2021). This hypothesis drives species richness in the forest ecosystem (Santos et al. 2021). This study finding confirmed the one hypothesis, the turnover of local tree species assemblages increases as the distance from the community increases as predicted by distance decay of community similarity hypothesis (Soininen et al. 2007; Dias et al. 2021). The immediate disturbance hypothesis was rejected as the species richness and diversity at intermediate and far distance were similar.

In this study, 66, 83 and 83 species were counted in an immediate distance, intermediate distance and far distance, respectively. The Choa1 predicted that 76, 93 and 95 species would be recorded for an immediate distance, intermediate distance and far distance, respectively, suggesting that an immediate distance is more likely to be lower in species richness compared to intermediate and far distances. These findings are in agreement with Escobedo et al. (2021) that large disturbance results in high dominance of disturbance-tolerant species and decreased species richness. Therefore, low species richness is expected at a high disturbed area (Araia et al. 2019). Moreover, these study findings are in agreement with Yashmita-Ulman et al. (2021) that tree species richness in agroforestry increases

Table 8 SIMPER analysis of tree species abundance dissimilarity

Average dissimilarity (Imm & Int) = 94.8%					Average dissimilarity (Int & Far) = 82.9%					Average dissimilarity (Imm & Far) = 94.5%				
	Imm	Int				Int	Far			Imm	Far			
Species	Av.A	Av.A	Av.D	C.%	Species	Av.A	Av.A	Av.D	C.%	Species	Av.A	Av.A	Av.D	C.%
Mangifera indica	0.67	0	6.72	7.08	*Pteleopsis myrtifolia*	0.47	0.82	4.07	4.91	*Pteleopsis myrtifolia*	0.13	0.82	6.64	7.02
Pteleopsis myrtifolia	0.13	0.47	4.52	4.76	*Albizia adianthifolia*	0.22	0.5	3.74	4.51	*Mangifera indica*	0.67	0	5.97	6.31
Persea americana	0.4	0	3.88	4.09	*Tabernaemontana elegans*	0.37	0.37	3.43	4.13	*Albizia adianthifolia*	0.07	0.5	4.49	4.75
Tabernaemontana elegans	0.08	0.37	3.81	4.02	*Combretum mole*	0.27	0.35	3.06	3.69	*Persea americana*	0.4	0	3.46	3.66
Bridelia micrantha	0.05	0.35	3.62	3.82	*Parinari curatellifolia*	0.17	0.37	3.03	3.66	*Englerophytum magalismontanum*	0.07	0.37	3.44	3.64
Sclerocarya birrea	0.23	0.15	3.06	3.23	*Bridelia micrantha*	0.35	0.22	3.03	3.66	*Tabernaemontana elegans*	0.08	0.37	3.37	3.56
Pseudolachnostylis maprouneifolia	0.07	0.27	2.97	3.13	*Englerophytum magalismontanum*	0.12	0.37	2.94	3.54	*Parinari curatellifolia*	0.03	0.37	3.3	3.49
Combretum molle	0.03	0.27	2.58	2.72	*Pseudolachnostylis maprouneifolia*	0.27	0.18	2.57	3.11	*Combretum molle*	0.03	0.35	2.99	3.17
Albizia adianthifolia	0.07	0.22	2.34	2.47	*Xylopia parviflora*	0.17	0.22	2.16	2.61	*Sclerocarya birrea*	0.23	0.03	2.21	2.34
Acacia ataxacantha	0.05	0.18	2.19	2.31	*Artabotrys brachypetalus*	0.17	0.2	2.13	2.57	*Hyperacanthus amoenus*	0.02	0.23	2.11	2.24
Parinari curatellifolia	0.03	0.17	1.95	2.06	*Dalbergia nitidula*	0.1	0.22	2.02	2.44	*Artabotrys brachypetalus*	0.07	0.2	2.1	2.22
Artabotrys brachypetalus	0.07	0.17	1.82	1.92	*Hyperacanthus amoenus*	0.08	0.23	2.01	2.42	*Dalbergia nitidula*	0.02	0.22	2.06	2.18
Afzelia quanzensis	0.02	0.18	1.77	1.87	*Acacia ataxacantha*	0.18	0.13	1.96	2.37	*Bridelia micrantha*	0.05	0.22	2.03	2.14
Psidium guajava	0.13	0.05	1.68	1.77	*Strychnos madagascariensis*	0.12	0.2	1.88	2.27	*Pseudolachnostylis maprouneifolia*	0.07	0.18	2	2.12
Trichilia emetica	0.15	0.03	1.64	1.73	*Syzygium cordatum*	0.1	0.17	1.69	2.04	*Xylopia parviflora*	0.02	0.22	1.9	2
Citrus sinensis	0.18	0	1.61	1.7	*Vangueria infausta*	0.13	0.13	1.63	1.96	*Strychnos madagascariensis*	0.02	0.2	1.77	1.87
Xylopia parviflora	0.02	0.17	1.49	1.57	*Peltophorum africanum*	0.13	0.1	1.5	1.81	*Syzygium cordatum*	0.05	0.17	1.71	1.81
Peltophorum africanum	0.02	0.13	1.46	1.54	*Brachylaena huillensis*	0.08	0.15	1.46	1.76	*Citrus sinensis*	0.18	0	1.46	1.54
Syzygium cordatum	0.05	0.1	1.43	1.51	*Afzelia quanzensis*	0.18	0.03	1.44	1.73	*Acacia ataxacantha*	0.05	0.13	1.43	1.51
Albizia versicolor	0.05	0.12	1.41	1.49	*Ficus sur*	0.08	0.12	1.34	1.62	*Ficus sur*	0.03	0.12	1.38	1.46

Table 8 (continued)

Average dissimilarity (Imm & Int) = 94.8%					Average dissimilarity (Int & Far) = 82.9%					Average dissimilarity (Imm & Far) = 94.5%				
	Imm	Int				Int	Far			Imm	Far			
Species	Av.A	Av.A	Av.D	C.%	Species	Av.A	Av.A	Av.D	C.%	Species	Av.A	Av.A	Av.D	C.%
Englerophytum magalismontanum	0.07	0.12	1.41	1.48	*Hexalobus monopetalus*	0.15	0.05	1.29	1.55	*Scolopia mundii*	0	0.15	1.34	1.42
Vitex ferruginea	0	0.17	1.4	1.47	*Brachylaena discolour*	0.12	0.08	1.29	1.55	*Trichilia emetica*	0.15	0	1.28	1.35
Hexalobus monopetalus	0	0.15	1.37	1.45	*Sclerocarya birrea*	0.15	0.03	1.2	1.45	*Brachylaena huillensis*	0	0.15	1.26	1.33
Dichrostachys cinerea	0.02	0.12	1.36	1.44	*Scolopia mundii*	0.02	0.15	1.19	1.44	*Vangueria infausta*	0.02	0.13	1.24	1.32
Brachylaena discolor	0.03	0.12	1.32	1.39	*Grewia microthyrsa*	0.08	0.1	1.14	1.38	*Psidium guajava*	0.13	0.02	1.24	1.31
Vangueria infausta	0.02	0.13	1.27	1.34	*Vitex ferruginea*	0.17	0	1.09	1.31	*Pavetta lanceolata*	0	0.12	1.19	1.26
Erythrina lysistemon	0.12	0.02	1.22	1.29	*Dichrostachys cinerea*	0.12	0.03	1.06	1.28	*Brachylaena discolor*	0.03	0.08	1.01	1.07
Annona senegalensis	0.05	0.1	1.22	1.28	*Pavetta lanceolata*	0.02	0.12	1.06	1.28	*Terminalia sericea*	0.05	0.08	1	1.05
Diospyros mespiliformis	0.03	0.08	1.1	1.16	*Zanthoxylum davyi*	0.08	0.07	1.01	1.21	*Croton sylvaticus*	0.02	0.1	0.99	1.05
Musa acuminata	0.12	0	1.06	1.11	*Antidesma venosum*	0.1	0.07	0.98	1.18					
Ficus sur	0.03	0.08	1.04	1.09										
Strychnos madagascariensis	0.02	0.12	1.03	1.09										

Di Distance (Random factor), *Vi* Village (Fixed factor), *SS* Sum of species, *MS* Mean of species, F ratio (Pseudo-F), *P* Permuted probability values, *df* Degree of freedom

Fig. 6 Species dominance across distance levels

with an increase in distance to the natural forest. The number of indigenous trees species is decreasing in the traditional agroforestry landscape (Lelamo 2021). The decumulation of a greater number of species in immediate distance compared to intermediate and far distances may be attributed to the extensive harvesting of provisioning ecosystem services (Banag-Moran et al. 2020) and human behaviour (e.g., harvesting area preference) (Singh et al. 2021a; Ihemezie et al. 2021), as predicted by the optimal foraging theory. Provisioning ecosystem services harvesting usually are impacted by the increase in distance to the forest, for example, fuelwood collection distance increase is perceived to reduce the collection of fuelwoods from the forest (Singh et al. 2021a). An increase in harvesting distance influences the PESs harvesters as they would prefer to harvest in proximity to save time and energy (Bahru et al. 2021). Similarly, Roy et al. (2022) found that local people harvest fuelwood in traditional agroforestry to avoid travelling a long distance to the forest.

Local people would maximise energy and time when searching and harvesting PESs. This results in a significant decline of tree species at an immediate distance as the distance from the community to the forest increases (Cicuzza et al. 2011; Tadesse et al. 2019). Studies confirmed that high species richness drives the multifunction of the ecosystem (Basile et al. 2021; Li et al. 2021), for example, the traditional agroforestry landscape. Then, low

Table 9 Results of DISTLM Marginal test and sequential test of change variables

	Marginal Test		Sequential Test	
Variable	P	Prop. (%)	P	Cum. (%)
Elevation	0.001	2.443	0.001	2.44
Gradient	0.001	2.214	0.001	4
Fire occurrence	0.182	0.620	0.188	4.6
Grazing	0.002	1.3045	0.001	5.8
PESs harvesting	0.001	1.5525	0.004	7
Distance	0.001	8.7104	0.001	15.4

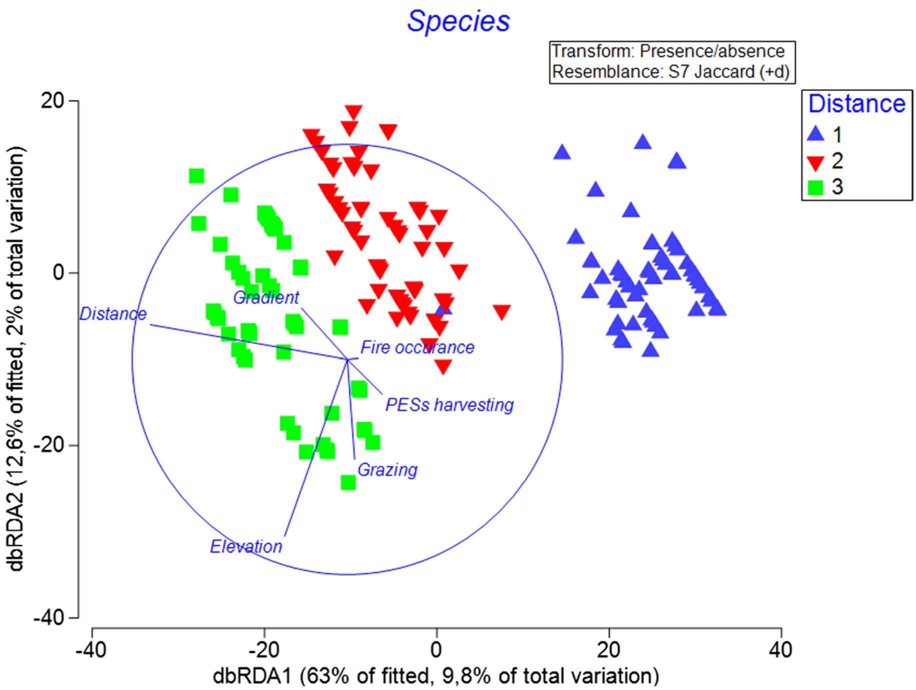

Fig. 7 *db*RDA (Distance-based redundancy analysis) on the association of distance levels and change variables

species richness in the immediate distance probably affects the proximate ecosystem functionality. Therefore, it significantly affects the products and benefits derived from a multifunctional ecosystem (Madonsela et al. 2018).

High disturbance can affect the capacity of traditional agroforestry to provide protection from natural hazards (Stritih et al. 2021). Though the immediate distance has lower tree species richness compared to intermediate and far distance, the immediate distance had 48 indigenous tree species out of 118 total indigenous species. Considerable diversity of tree species (41%) is retained and/or deliberately planted and maintained by the local people within traditional agroforestry. The higher percentage of tree species richness in the immediate distance in the present study suggests that traditional agroforestry, despite being intensively disturbed, has high potential in preserving and conserving indigenous tree species (Yashmita-Ulman et al. 2021). For example, in Indonesia and Mexico, Rendon-Sandoval et al. (2020) reported that a traditional agroforestry system contains over 50% of adjacent indigenous forests tree species and has therefore the capacity to conserve indigenous species. A study conducted in central Ethiopia found that traditional agroforestry has 64 tree species compared to the proximate forest with 31 species (Asfaw and Lemenih 2010). The high number of indigenous tree species in traditional agroforestry confirms the importance of the trees to people's livelihood (Lokonon et al. 2017); and the potential to provide a variety of resources for human livelihood (Bahru et al. 2021).

The study revealed *Mangifera indica* and *Persea americana* to be more dominant species in an immediate distance. *M. indica* and *P. americana* are exotic fruit tree species that are widely distributed in traditional agroforestry landscapes (Vibhuti and Bargali 2019).

However, these are naturalised exotic tree species in South Africa (Constant and Tshisikhawe 2018). In fact, *M. indica* and *P. americana* are home garden indicators, the occurrence of which signifies the use-value of the tree species (Gemechu et al. 2021). Along with this finding, Lokonon et al. (2017) found that *M. indica* is the dominating exotic species in Benin's traditional agroforestry. Similar to traditional agroforestry in India (Vibhuti and Bargali 2019), *M. indica* is a dominating tree species in traditional agroforestry systems. Their dominance confirms the fact that, within traditional agroforestry, many exotic trees exist due to anthropogenic disturbances (Escobedo et al. 2021). Recently, local people had a tendency of promoting exotic tree species for different uses (Lelamo 2021). This is due to the fact that most of the exotic tree species in traditional agroforestry have economic value (Gemechu et al. 2021), hence, they plant more exotic species compared to indigenous species. *Pteleopsis myrtifolia*, *Tabernaemontana elegans*, *Combretum molle*, *Albizia adianthifolia*, and *Parinari curatellifolia* are found to be dominant in both an intermediate and far distance. The dominance of indigenous tree species in the intermediate and far distance indicates that natural disturbances favour the indigenous species over exotic species because indigenous species are expected to be tolerant to historical natural disturbances (Escobedo et al. 2021). However, *Englerophytum magalismontanum* species are more dominant in the far distance and *Bridelia micrantha, Pseudolachnostylis maprouneifolia, Afzelia quanzensis*, and *Acacia ataxacantha* species are more dominant in an intermediate distance.

The most dominating species in intermediate and far distances are multiple-purpose trees, mostly used for traditional medicine; tree species such as *Combretum molle*, *Albizia adianthifolia, Parinari curatellifolia, Pseudolachnostylis maprouneifolia, Afzelia quanzensis* (Tshisikhawe et al. 2012), and *Tabernaemontana elegans* (Ndhlovu et al. 2019; Setshego et al. 2020). A recent study found that *Elaeodendron transvaalense* is a near-threatened species in a far distance area. The same species has been reported to be in high demand for bark and root medicine in Limpopo Province (Tshisikhawe et al. 2012). The *E. transvaalense* species treat sexually transmitted diseases (Semenya et al. 2013). However, the *E. transvaalense* is a protected species in South Africa (Semenya et al. 2013). Tree species such as *E. magalismontanum, C. molle* and *Bridelia micrantha* are protected from being cut by cultural rules (Constant and Tshisikhawe 2018). The dominance of fruit tree species like *E. magalismontanum* was expected in the far distance because of the high demand and use in the study areas (Araia and Chirwa 2019). Dissimilarities in species abundance in traditional agroforestry increased with increasing distance. The present study found higher species dissimilarities of 95% between an immediate and intermediate, an immediate and far distance; this could be due to human disturbances and management decisions in an immediate distance (Zequeira-Larios et al. 2021). However, all the distances shared nearly the same indigenous species. Previous studies indicated that the tree species in traditional agroforestry are nearly the same as species in the indigenous forest (Yashmita-Ulman et al. 2021).

The variability of local species assemblages among different distance levels

PERMDISP showed a narrow range of species variation among different distance levels, ranging from 54 to 59%. The species composition significantly differs among the distance levels. The highest species variation was observed at an intermediate distance, which indicates that there is greater species composition at an intermediate distance compared to immediate and far distances. These findings agree with previous studies, that tree species composition increases with an increase in distance to the natural forest and a large variation is found at an intermediate distance (Zwiener et al. 2020). Tree species composition and composition in traditional agroforestry vary based on the distance to the natural forest (Yashmita-Ulman et al. 2021). There are two potential explanations for the greater species variation in an intermediate distance. First, validation of the intermediate disturbance hypothesis, the intermediate disturbance strongly influences the species composition (Zwiener et al. 2020). The disturbance at an intermediate distance positively influences the species diversity, while the immediate distance negatively influences species diversity by encouraging dominance of certain tree species and affecting regeneration (Zwiener et al. 2020). As reported by Banag-Moran et al. (2020), disturbance can positively and negatively influence species diversity. Furthermore, anthropogenic disturbance could lead to homogeneity in species composition in the proximate areas (Banag-Moran et al. 2020; Michalet et al. 2021). This kind of disturbance also threatens biodiversity through the reduction of species composition and the introduction of exotic species (Banag-Moran et al. 2020). Secondly, the harvesting of PESs is higher in the immediate distance as the hypothesis predicted that the harvesting of PESs increases as the distance from the community to the forest increases. Yashmita-Ulman et al. (2021) indicated that tree species composition and composition variation decrease as the distance from the forest to the community decreases. This finding suggests that distance plays a very critical role in species richness and composition in local communities proximate to the forest (Yashmita-Ulman et al. 2021). Even though traditional agroforestry has rich tree species diversity through retained and planted tree species (Villanueva-Lopez et al. 2019), the number of tree species is decreasing in the traditional agroforestry landscape.

Drivers of turnover of species assemblages in different distance levels

This study confirms that there is a correlation between species composition and change variables such as elevation, gradient, distance and PESs harvesting. The drivers of species composition significantly differ among the distances. The difference could be due to human behaviour arising from change variables such as elevation, gradient, distance and PESs harvesting (Zwiener et al. 2020). These drivers are determining factors in species composition dissimilarity in traditional agroforestry landscapes in distance levels. The distance from the traditional agroforestry to the natural forest is an important parameter determining tree species composition and diversity (Cicuzza et al. 2011).

The immediate distance in close vicinity to local people had different tree species drivers compared to an intermediate and far way distance. The harvesting of PESs was found to be the driver of tree species composition at an immediate distance. The most likely reason for such a trend is that a relatively high number of local people prefer to utilize tree species at an immediate distance than an intermediate and far distance. Subsequently, this mediates the tree species in traditional agroforestry. In India, distance to the forest was shown to determine the consumption of fuelwood. Approximately 75% of the fuelwood is extracted in traditional agroforestry and was understood to save people's time travelling to the forest (Singh et al. 2021b). Moreover, an intermediate distance could be an option or alternative source for the local people to harvest the PESs. Locals could neglect to maintain tree species composition at an immediate distance since they can fulfil their demands for PESs from an immediate distance (Getachew et al. 2022). In this case, the presence of such behaviour would result in high species composition at an intermediate distance because of minimal disturbance. Consequently, the tree species composition in an immediate distance and far distance would decline due to high disturbance and succession, respectively. The distance, elevation and gradient were found to be the factors determining species composition in the far distance of the traditional agroforestry. These study results agree with the findings of the previous studies that indicated that gradient had a contribution to tree species composition (e.g., Getachew et al. 2022).

Conservation implications

Traditional agroforestry plays a critical role in reducing pressure on the natural forest for medicine, fuelwood, timber extraction, and fodder (Asase and Tetteh 2016; Phondani et al. 2020). The sustainable management of traditional agroforestry would balance the cultural, ecological, economic, and social needs of present and future generations (Phondani et al. 2020). However, this could be achieved through the direct integration of attitudes, perceptions, and preferences (Phondani et al. 2020) and the behaviour of local people. Resources preferences and use in traditional agroforestry are more likely to be influenced by many factors; harvesting distance is not an exception. It is very critical to conserve tree species in traditional agroforestry than in undisturbed forest ecosystems when conservation resources are limited (Araia et al. 2020). It has been argued that undisturbed and protected areas are not sufficient to protect all tree species (Sharma and Vetaas 2015). In addition, traditional agroforestry contributes to reducing deforestation and mitigating the loss of biodiversity (Villanueva-Lopez et al. 2019). It is crucial for traditional agroforestry management practices to have the ability to restore ecosystem structure and functions. While tree species richness has been well documented in traditional agroforestry, a decrease in tree species richness must be empirically evaluated. As far as conservation is concerned, traditional agroforestry could not be an absolute substitute for natural forests. Because some of the species are not found in traditional agroforestry landscapes, some of the species in the recent study were found to be near-threatened species in Vhembe Biosphere Reserve like e.g., *Elaeodendron transvaalense*, therefore tree species diversity must be conserved in both traditional agroforestry and indigenous forests (Asfaw and Lemenih 2010). The planting of indigenous tree species could contribute to the conservation of biodiversity. In Bangladesh, traditional agroforestry biodiversity is conserved through the local planting of indigenous trees (Baul et al. 2021). Likewise, the local people of Ethiopia plant indigenous tree species in their traditional agroforestry systems (Gemechu et al. 2021). This study found few endemic tree species in the traditional agroforestry landscape. The occurrence of some endemic tree species in traditional agroforestry makes the argument for conservation even stronger. The conservation strategies must be designed and coordinated at a local level in balance with the need of people's livelihoods. If people's livelihood is excluded from conservation strategies, no conservation intervention is likely to be effective. Multipurpose trees in traditional agroforestry should be promoted to supplement other tree species. This study confirms that traditional agroforestry integrates biodiversity with socio-economic needs and hence reduces forest degradation, deforestation, and overexploitation of natural resources. Unfortunately, the South African national agroforestry strategic framework (Agroforestry Strategic Framework 2017) currently emphasises mainly modern agroforestry systems and largely overlooks traditional agroforestry as a component of agroforestry.

Conclusion

This study's results confirm that the distance and associated factors have major detrimental effects on tree species richness and biodiversity in traditional agroforestry landscapes. The tree species richness increases as the distance from the traditional agroforestry to the natural forest increases. Contrary to expectations, species diversity at intermediate and far distances has similar higher species diversity compared to an immediate distance. The intermediate disturbance hypothesis was not applicable in this study, however, confirmed the effect of high disturbance on species richness and diversity in the immediate distance. As the tree species richness in the study area is distance-dependent, this study identifies a strong decline in tree species richness in proximity to traditional agroforestry. The provisioning ecosystem services harvesting is known to be extremely high in the study area. Effective solutions must be implemented to reduce and halt overexploitation, including planting indigenous trees and conserving the existing vegetation. Through this intervention, the immediate distance can accumulate more tree species.

Acknowledgements We thank the leadership of Damani, Thenzheni, Tshiombo and Tshipako for granting us permission to conduct the studies in their landscape. We also acknowledge their support throughout the data collection.

Author contributions LM and MGA conceptualized the research; methodology, data collection, and data analysis. LM Wrote the manuscript. MAG and PWC supervised the the manuscript writing.

Funding Open access funding provided by University of Pretoria. No funding to declare.

Data availability No data available.

Declarations

Competing interests The authors declare no competing interests.

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