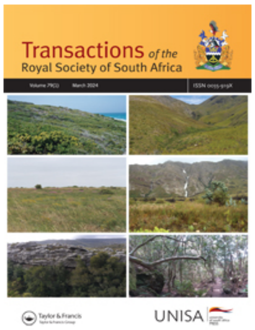


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# Assessing plant utilisation by communities bordering a protected area in Zimbabwe using utilitarian diversity metrics

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**Protected areas and their peripheries harbour biodiverse ecosystems which underpin ecosystem service provision to local communities. Understanding the relationship between the species contained within these ecosystems and the utilitarian services they provide is important. However, there is a shortage of quantitative methods for assessing species' utilitarian roles. We used a dendrogram-based method to quantify utilitarian diversity and an ordination method to determine co-occurrences in three sites at the periphery of Gonarezhou National Park, in Zimbabwe. The use categories for the plants were determined using household questionnaire surveys, and vegetation data was collected via standard plotless sampling techniques. There was higher plant diversity in the sites adjacent to the protected area, i.e. Malipati communal area (*S* = 45; Simpson's index = 0.7271) and Gonakudzingwa farms (*S* = 50; Simpson's index = 0.9351), with the lowest diversity recorded at the site far from the park, i.e. Chomupani communal area (*S* = 25; Simpson's index = 0.6305). Utilitarian diversity was also highest in the areas adjacent to the protected area, with Malipati and Gonakudzingwa having values of 22.2 and 21.4, respectively, while Chomupani attained 20.6. A principal component analysis ordination indicated which utilitarian species occurred in the same areas. Our results contribute to plant conservation by highlighting the utilitarian relationships of species at protected area peripheries. This allows planners and conservationists to set conservation priorities to avoid losing species that contribute the most to ecosystem service provision.**

**Keywords:** Gonarezhou; alpha diversity; utilitarian diversity; protected areas; ecosystem services

## INTRODUCTION

### Species diversity and ecosystem services

Local people living on the margins of protected areas mostly rely on nearby woodlands to provide their basic needs (Thondhlana *et al.*, 2012). These needs usually range from food and medicines to wood used for construction, toolmaking and fuel (Dowo *et al.*, 2018). Such tangible benefits extracted from these local ecosystems are termed provisioning ecosystem services. The Millenium Ecosystem Assessment report (2005) defines ecosystem services as the benefits provided from nature to people, with provisioning services focusing on those material goods harvested. Other ecosystem service categories include regulating, supporting and cultural. These services, especially provisioning, are directly related to the plant diversity within a given ecosystem (Quijas *et al.*, 2010). Hence, to understand the natural resource utilisation dynamics at the periphery of protected areas it is important to consider the diversity of plant species within a given area and relate it to the kind of benefits people utilise. Vegetation type has an influence on the number of species used per household, utilisation categories and quantities of material collected (Cocks *et al.*, 2008). Therefore, it is assumed that the more diverse an ecosystem is, the more different plant species are available for use by local people and the greater the ecosystem service provisioning. However, there is a shortage of tools available for conservation biologists to measure how biodiversity loss impacts ecosystem service provision (Brown *et al.*, 2011). Such quantification is important when trying to understand ecosystem services supply and demand dynamics at the periphery of a protected area. Brown *et al.* (2011) proposed a quantification framework based upon the notion of functional diversity (FD) as defined by Petchey and Gaston (2002). This framework relates plant diversity to the utilitarian properties of each species.

### Functional and utilitarian diversity

FD measures the range of functional traits of organisms prevailing within a given ecosystem and influences some aspects of ecosystem functioning, e.g. ecosystem dynamics and stability (Goswami *et al.*, 2017). It can be measured using functional richness and evenness. Functional richness quantifies the number of species occupying a given niche, while functional evenness refers to how the species are distributed (Goswami *et al.*, 2017). FD has an effect on ecosystem



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productivity, and this is explained through concepts such as the sampling effects model and niche differentiation model (Goswami *et al.*, 2017), where generally ecosystem productivity is expected to increase as species richness increases. It is, therefore, important to measure FD so as to determine how functional trait composition varies between species assemblages and to better understand the determinants of ecosystem function and how species trait diversity affects this function (Petchey and Gaston, 2007). A measure was developed, termed FD, defined as the total branch length of a functional dendrogram constructed from information about species' functional traits (Petchey and Gaston, 2002). The dendrogram serves to describe the functional relationships shared by the given species. This approach was then adopted by Brown *et al.* (2011), who instead of FD introduced the concept of utilitarian diversity as the quantification of those species traits that are of direct importance to people. While FD focuses on assessing traits such as specific leaf area, wood density and height, utilitarian diversity focuses more on economic use traits such as firewood, medicine, wood for construction, etc. (Brown *et al.*, 2011). Another, related concept is that of utilitarian redundancy defined as a measure of the degree of overlap between the utilitarian properties of given species within a community (Brown *et al.*, 2011). This study will focus on quantifying utilitarian diversity using the dendrogram approach as well as quantifying other utilitarian properties and relating them to plant diversity.

Just as FD influences ecosystem functioning, in this study we were guided by the notion that utilitarian diversity of a given ecological community will impact local livelihoods. Where there is high utilitarian diversity, local people will have more species available to meet their daily needs. However, where utilitarian diversity is low, there will be a lack of alternatives which can result in selective extraction of the given species. Several studies report preferential harvesting of certain tree species for firewood, for example (Tabuti *et al.*, 2003; Vasicek and Gaugris, 2014; Dowo *et al.*, 2018). We focused on the following objectives for this study:

(1) To compare the alpha diversity of different ecological communities located at the periphery of Gonarezhou National Park in Malipati and Chomupani communal areas and Gonakudzingwa small-scale commercial farms.
(2) To quantify the utilitarian properties of the species located in each area.
(3) To compare utilitarian diversity between the areas using functional dendrograms.
(4) To assess the spatial relationships of the utilised species.

Prior to this study, conservation efforts in the Gonarezhou National Park periphery focused primarily on protecting biodiversity within the park boundaries. This approach often prioritised species-specific conservation and habitat preservation, aiming to maintain the park's ecological integrity (Tafangenyasha, 1997; Gandiwa *et al.*, 2013; Martini *et al.*, 2016). However, this approach sometimes neglects the socioeconomic dynamics surrounding the park and the dependence of local communities on its resources. The current study reflects a shift towards a more holistic understanding of conservation. It recognises the interconnectedness between biodiversity within the park and the utilisation of plant resources by local communities living on its periphery. It examines how the diversity of plants utilised by local communities varies across different sites outside the park, and how this affects the sustainability of their livelihoods and the conservation of the park's flora and fauna.

## MATERIALS AND METHODS

### Study area

The study was conducted in areas surrounding Gonarezhou National Park (GNP) in Chiredzi District, Masvingo Province in Zimbabwe (Figure 1). Located in the south-east lowveld of Zimbabwe at latitude 21°00′– 22°15′S and longitude 30°15′–32° 30′E (Gandiwa and Kativu, 2009), it occupies an area of 5053 $km^2$ (Zimbabwe Parks and Wildlife Management Authority [ZPWMA], 2011). The mean annual rainfall for GNP is 466 mm, although this varies highly between years (Gonarezhou.org, 2019). The park experiences a short dry winter season in June and July (with temperatures below 30°C) and a hot wet summer season from November to April when temperatures may exceed 40°C. Two main vegetation types occur within GNP, which are the Mopane woodland or Mopane-dominated scrub and the dry deciduous sandveld woodland and scrub maintained by high fire frequencies and elephant densities (ZPWMA op. cit.). Sampling sites were in Malipati (Ward 15: 953 $km^2$) and Chomupani (Ward 11: 358 $km^2$) communal areas as well the Gonakudzingwa small-scale commercial farming area (Ward 12: 306 $km^2$). The sites were selected based mainly on three criteria: proximity to the park, land tenure system and land use practice. Malipati and Gonakudzingwa share a common boundary with the park. Chomupani is more than 30 km from the park boundary, with this distance providing a hindrance to direct access to the park's natural resources. Sampling was carried out in all nine villages constituting Malipati communal area, five villages constituting Chomupani communal area and 35 farms in Gonakudzingwa.

### Vegetation sampling

Vegetation data was collected between May 2016 and November 2018, covering the cool dry and hot wet seasons. A plotless sampling technique, the wandering quarter method (WCQ) (Catana, 1963), was employed. Using this method, a starting point was randomly selected and then a compass was used to decide a direction to proceed from that first point. From the first plant encountered, a 90° exclusion angle was determined forwards along the directional line (centred to form a 45° angle either side of the line). The nearest plant within this exclusion angle was identified and its distance measured and recorded. This procedure was repeated after progressing to that plant, keeping the exclusion angle at the same alignment as at the starting point. Attributes such as the species name, height, diameter at breast height, canopy cover and height to canopy were also recorded. The procedure was continued until about 30–50 individuals had been counted. Each WQ transect was considered a single sampling unit. Several transects were repeated at random points and the number of transects was determined by recording the number of new species encountered on each new transect until no new species were encountered after further efforts. A local guide was also present to identify tree species using vernacular names. All plant samples collected were then taken to the National Herbarium in Harare, Zimbabwe, for verification of taxonomic names.

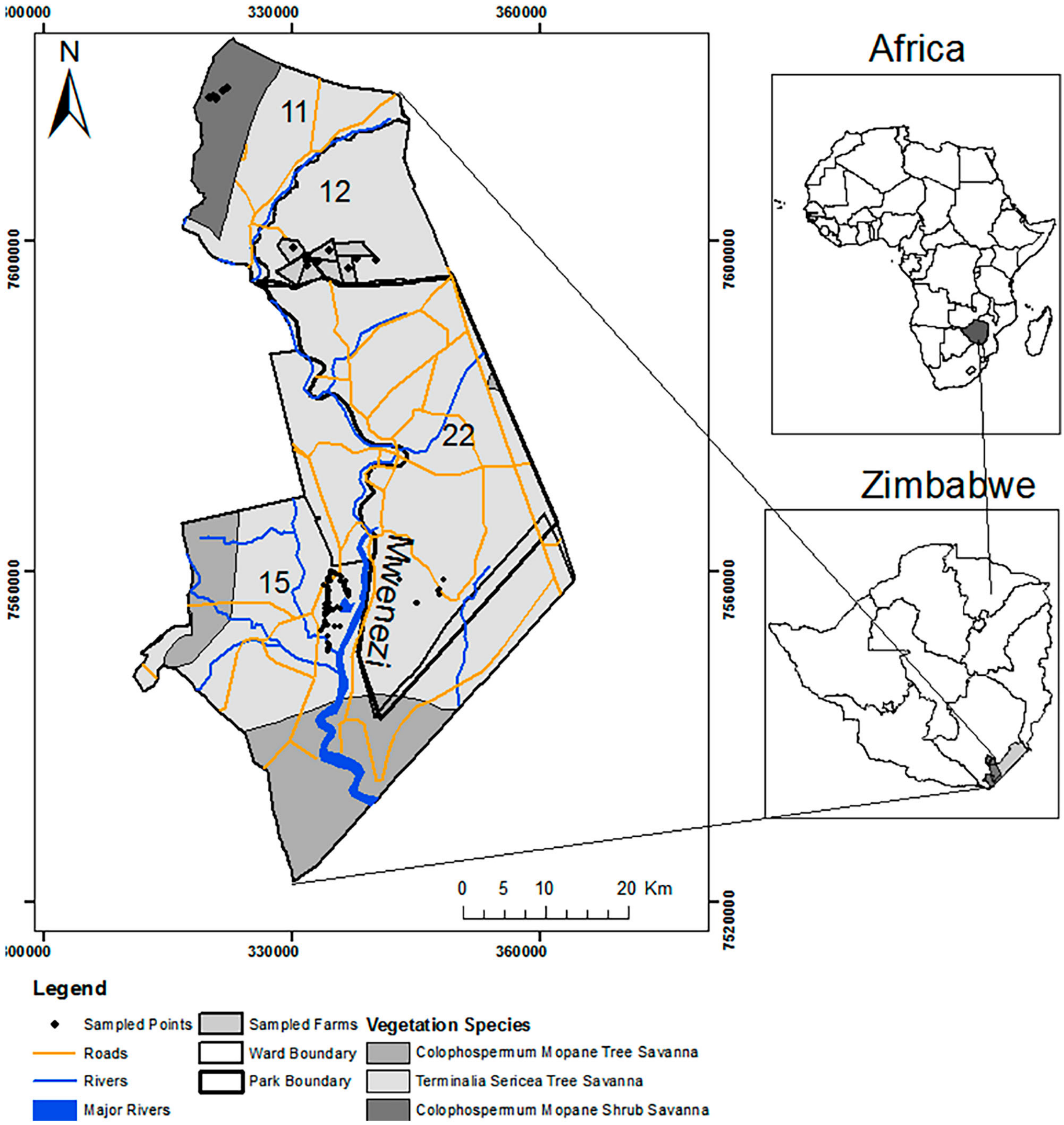


**Figure 1.** A map of the study area showing the sampled wards, i.e. 15, 12 and 11, in Chiredzi District. Source: Dowo *et al.* (2018).

### Utilitarian properties

Utilitarian properties for the plants recorded during the vegetation survey were determined by two main methods, i.e. questionnaires and focus group discussions, following the methods outlined in Dowo *et al.* (2018). A total of 247 individual surveys were administered between June and November 2014. The survey sampled 137 households in Malipati from an estimated total of about 450 households, achieving a sampling intensity of 30%; 75 households in Chomupani among about 150 households (50% sampling intensity); and within the Gonakudzingwa farms 35 households belonging to the farm owners were sampled which amounted to 100% of the occupied farms. In Malipati and Chomupani communal areas, systematic stratified sampling was employed in the selection of households. Stratification was based on village, such that in Malipati the following nine villages were sampled – Manzini, Mafunjwa, Mhlekwani, Ngwenyeni, Samuel, Bhazela, Jackson, Hlengani and Adama – whereas in Chomupani five villages were sampled, namely Panganai, Zvokureva, Sibezwile, Mashawi and Matsvati villages. Within each village, the village head provided a list of all households. From the numbered list, every third member of the list was selected from a random starting point. A village had an average of 50 households. In Gonakudzingwa, convenience sampling was employed as the number of farms was small, hence all occupied farms were sampled to achieve a statistically acceptable sample size (>30). The survey was carried out following guidelines by Liswanti *et al.* (2012), whereby it was implemented in the form of an interview with the head of household. Where the head of household was absent, the oldest next of kin present was interviewed. Focus group discussions were then held to cross-check information gathered from the surveys and to validate the community consensus knowledge. Between six and 13 people participated in the meetings, as recommended by Liswanti *et al.* (2012), and meetings lasted for an hour and a half.

### Utilitarian diversity

The Petchey and Gaston (2002) FD dendrogram-based approach was adopted and used as the measure of utilitarian diversity. In this study, "utilitarian diversity" refers to the diversity of utilitarian properties of the species that were recorded in the ecological communities studied. The Euclidean distance and unweighted pair-group method with arithmetic mean (UPGMA) were used to calculate multivariate distances between species. These methods resulted in the highest cophenetic correlations. Utilitarian properties of interest were as follows: human remedies, veterinary remedies, livestock feed, firewood, timber and fruits. The same methods were used to produce all dendrograms for Malipati, Chomupani and Gonakudzingwa. The phylogenetic method of total branch length was used as a measure of utilitarian diversity following the way Petchey and Gaston (2002) calculated FD. Each branch of the dendrogram was numbered and its length recorded. The utilitarian diversity was then obtained through summation of all branch lengths. A principal component analysis (PCA) was employed to deduce the spatial relationships between the species. Dendrograms and PCA outputs were constructed using PAST® (Hammer *et al.*, 2001) and CANOCO® software.

### Data analyses

The vegetation data was also analysed using PAST® software. Alpha diversity indices were first calculated using the Diversity Indices module. The indices were then compared using the diversity t-tests which are modified Hutcheson's t-tests. Student's t-tests were used to compare numbers of utilitarian properties.

## RESULTS

### Alpha diversity

The alpha diversity, which is the mean species diversity at the local scale or within-community diversity (Whittaker, 1972), of the three sites was compared. There was higher species richness in the sites adjacent to the park, which were Malipati Communal area and Gonakudzingwa small-scale commercial farms. Even though the Gonakudzingwa farms were richer in species composition than Malipati (Table 1), this difference was not statistically significant ($p > 0.05$), as indicated by the overlap in the standard error bars (Figure 1). However, there was a significant difference ($p < 0.05$) for both these sites when compared with the species richness of Chomupani communal area, which was only 25 species (Table 1).

Other indices of diversity for the three sites were then compared. There was a significant difference ($p < 0.05$) for the dominance index (D). Gonakudzingwa small-scale commercial farms had the lowest dominance value (Table 1). The highest value for the dominance index was recorded in Chomupani communal land mainly because on this site *Colophospermum mopane* achieved a relative density value of 59% (Table 2). Related is the evenness index, which in Gonakudzingwa small-scale commercial farms had the highest value because of the absence of a dominant species. However, the evenness indices for Malipati and Chomupani communal areas were both low due to the occurrence of *C. mopane* at high densities in those areas. In terms of the Simpson index, there were significant differences ($p < 0.05$) among the three sites (Table 1). The Gonakudzingwa farms had the highest value, followed by Malipati communal area. This means both these areas had higher plant biodiversity when both species richness and evenness were considered. Chomupani communal area, however, had lower diversity according to the Simpson's index, due to its low species richness and evenness values (Table 1).

**Table 1.** Diversity indices for Malipati communal area, Gonakudzingwa small-scale farms and Chomupani communal area. Different letters indicate significant differences ($p < 0.05$) in the relevant diversity index.

| | Malipati | Gonakudzingwa | Chomupani |
|---|---|---|---|
| Individuals | 584 | 532 | 325 |
| Species richness (S) | 45[a] | 50[a] | 25[b] |
| Dominance (D) | 0.2361[a] | 0.0641[b] | 0.3695[c] |
| Simpson (1 – D) | 0.7271[a] | 0.9351[b] | 0.6305[c] |
| Evenness (H) | 0.2164[a] | 0.4919[b] | 0.2242[a] |

### Relative density

Relative density values for the plants sampled in the three study sites showed that *C. mopane* was the most dominant species. The dominance of the species was most profound in Chomupani communal area, where its relative density reached almost 60% of the plants sampled. In Malipati the density was close to 50% (Table 2). However, in the Gonakudzingwa farms, while *C. mopane* was still the most abundant species it only achieved a relative density value of almost 17%. Apart from the dominant *C. mopane*, only *Grewia monticola* sampled in Chomupani achieved a relative density above 10%. The rest of the species in all three sites had relative densities below 10%. Table 2 below provides a list of species recorded that had relative density values of at least 1%.

### Utilitarian diversity

#### *Utilitarian properties*

The plant species sampled were then classified according to their utilitarian properties, i.e. how the local people used them based on the categories of economic importance of Dowo *et al.* (2018). In general, Chomupani communal area, due to its relatively low species richness and diversity (Table 1), also had the lowest number of species in each category. The most significant differences ($p < 0.05$) between Chomupani and the other two areas adjacent to the protected area were recorded in the human remedies and fruits categories (Figure 2). This also meant that Chomupani communal area had the lowest utilitarian redundancy in these categories. There was no significant difference ($p > 0.05$) for Malipati communal area

**Table 2.** Relative density values for plant species recorded in Malipati communal area, Gonakudzingwa small-scale farms and Chomupani communal area. Only those species that achieved a relative density value of at least 1% are shown. (Refer to the Supplementary data for the full list.)

| Malipati (*N* = 584) | | Gonakudzingwa (*N* = 532) | | Chomupani (*N* = 325) | |
|---|---|---|---|---|---|
| Species | Relative density (%) | Species | Relative density (%) | Species | Relative density (%) |
| *Colophospermum mopane* | 46.13 | *Colophospermum mopane* | 16.73 | *Colophospermum mopane* | 59.08 |
| *Dichrostachys cinerea* | 9.81 | *Combretum apiculatum* | 9.74 | *Grewia monticola* | 11.38 |
| *Combretum apiculatum* | 7.57 | *Grewia monticola* | 9.19 | *Combretum imberbe* | 4.62 |
| *Acacia tortilis* | 7.23 | *Dalbergia melanoxylon* | 5.15 | *Dichrostachys cinerea* | 4.00 |
| *Grewia bicolor* | 4.65 | *Androstachys johnsonii* | 4.23 | *Maytenus senegalensis* | 3.39 |
| *Hippocratea crenata* | 3.27 | *Acacia tortilis* | 4.04 | *Combretum mossambicense* | 3.08 |
| *Maerua parvifolia* | 2.24 | *Fluggea virosa* | 4.04 | *Dalbergia melanoxylon* | 2.46 |
| *Terminalia prunioides* | 1.55 | *Dichrostachys cinerea* | 3.31 | *Sclerocaryea birrea* | 1.54 |
| *Acacia nigrescens* | 1.37 | *Senna singueana* | 2.94 | *Combretum hereroense* | 1.54 |
| *Fluggea virosa* | 1.20 | *Commiphora mossambicensis* | 2.94 | *Commiphora marlothii* | 1.23 |
| *Salvadora australis* | 1.20 | *Grewia flavescens* | 2.76 | | |
| *Ximenia caffra* | 1.03 | *Grewia occidentalis* | 2.57 | | |
| | | *Combretum imberbe* | 2.21 | | |
| | | *Acacia nigrescens* | 2.02 | | |
| | | *Combretum mossambicense* | 2.02 | | |
| | | *Albizia amara* | 2.02 | | |
| | | *Lonchocarpus capassa* | 1.65 | | |
| | | *Markhamia zanzibarica* | 1.47 | | |
| | | *Gibourtia conjugata* | 1.47 | | |
| | | *Hippocratea indica* | 1.28 | | |
| | | *Xeroderris stuhlmanni* | 1.28 | | |
| | | *Boscia albitrunca* | 1.10 | | |
| | | *Euclia divinorum* | 1.10 | | |

and Gonakudzingwa small-scale commercial farms in utilitarian diversity for all categories (Figure 2). The highest utilitarian diversity for all three study sites was to be found in the human remedies, firewood and timber categories, where at least 10 species were sampled that are used by locals. In the fruits category, only Malipati and Gonakudzingwa, areas close to the protected area, had more than 10 species recorded. The lowest utilitarian diversity among all categories was to be found in the ethnoveterinary remedies and livestock feed categories, where fewer than 10 species were recorded, although with no significant differences ($p > 0.05$) among the sites (Figure 2).

### Utilitarian relationships among plant species

To ascertain the relationships between these species in terms of their utilitarian functions in the different areas, a dendrogram approach was used. This was because quantification of functions alone was not exhaustive as the specific functions may differ even for species with equal utilitarian values. Figure 3 is a dendrogram for Malipati communal area (cophenetic correlation coefficient = 0.816). A similarity distance of 0.0 was used as the grouping distance as this was the distance that could ultimately produce groups of species with the same utilitarian functions. Species at opposite ends of the dendrogram have the greatest degree of dissimilarity whereas species adjacent to each other are more similar. A total of 17 groups were produced in the Malipati classification (Figure 3), with an observed utilitarian diversity of 22.2. The utilitarian properties were based on use values for the species as mentioned by Dowo *et al.* (2018). The first group produced under this classification (i.e. from top to bottom of the dendrogram) was a single species group which contained *Cissus cornifolia*, a species only used as an ethnoveterinary remedy. The second group contained two species, i.e. *Salvadora australis* and *Strychnos madagascariensis*. These two species are valued only for their fruits. The next two groups were also composed of single species, which were *Terminalia prunioides* and *Salvadora persica*, respectively. The former is valued for both firewood and timber and the latter is used as livestock feed. *Hyphaene petersiana* and *Hippocratea crenata* were clustered in one group. Both are valued for their fruits and as a livestock feed. Three species, i.e. *Zanthoxylum humile*, *Euclia divinorum* and *Acacia xanthophloea*, formed a separate group. These species are only used in traditional medicine. *Berchemia discolor* is unique in having three uses which are traditional medicine, timber and fruits, whereas *Fluggea virosa* and *Ximenia caffra* are used for traditional medicine and fruits only. *Grewia flavescens* and *Xanthocercis zambesia* were grouped together because they are both used for traditional medicines, ethnoveterinary remedies and fruits. *Maytenus senegalensis* is valued in traditional medicines and ethnoveterinary remedies; hence, it is closer to *Spirostachys africana*, which in addition to those two utilities is also highly valued for its timber. *Sclerocaryea birrea* and *Colophospermum mopane* are

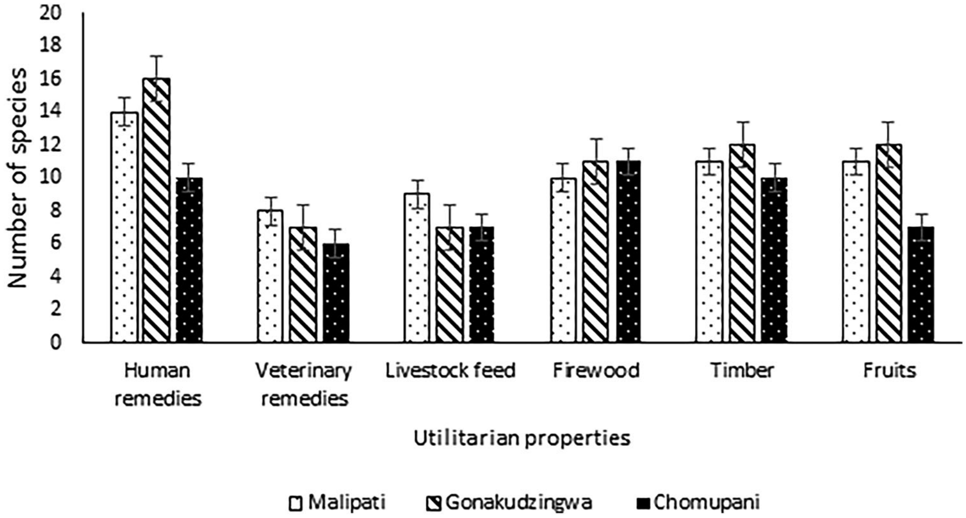


**Figure 2.** Number of species recorded within each category of use (utilitarian property) for the plants which occurred in the three study sites.

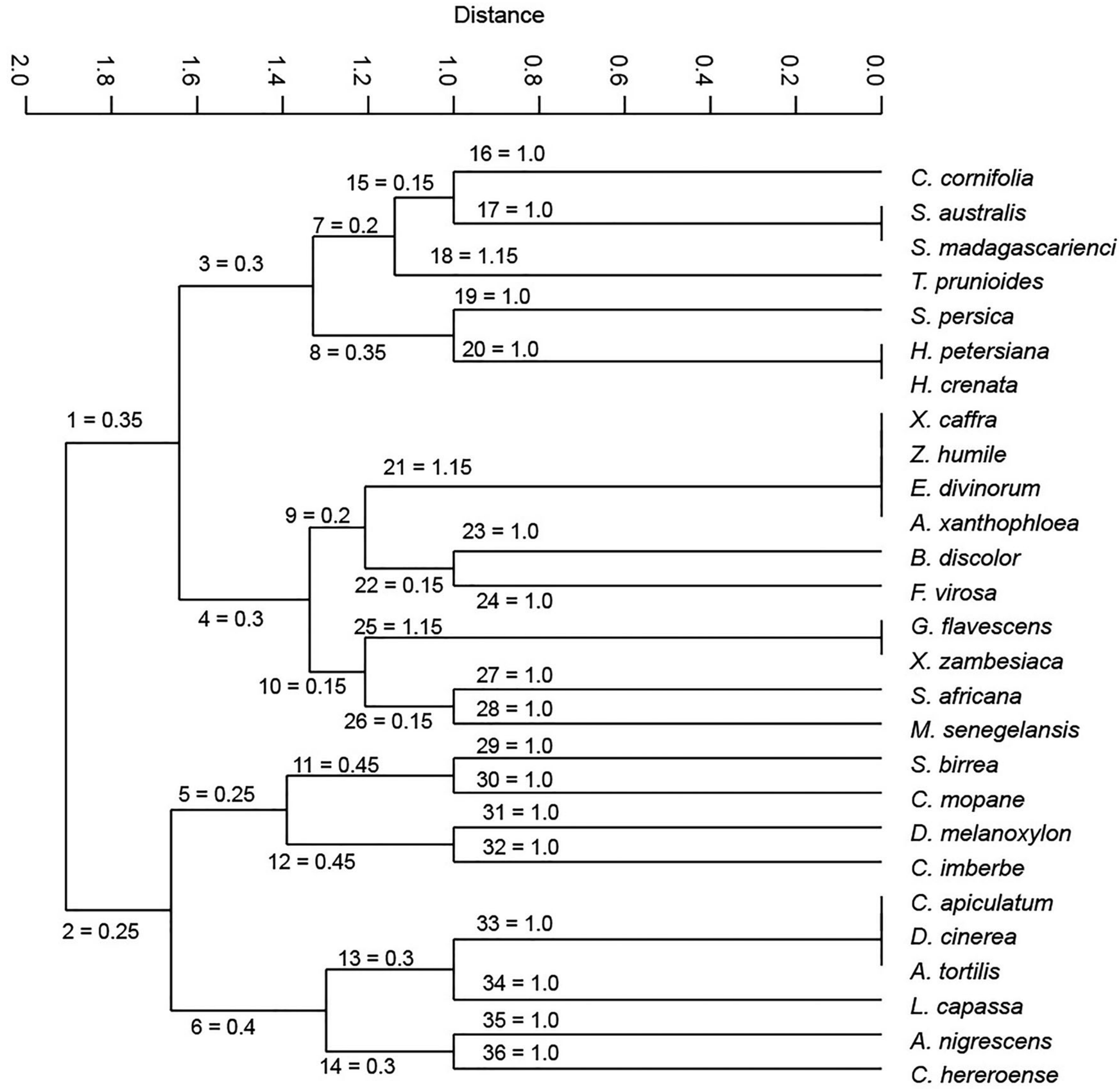


**Figure 3.** A dendrogram showing the utilitarian relationships of plants occurring in Malipati communal area. The branches are numbered 1–36 and the respective branch lengths based on the scale are indicated.

related to each other in having the highest utility values. *Sclerocaryea birrea* is used in all categories, i.e. traditional medicines, ethnoveterinary remedies, livestock feed, firewood, timber and fruits. *Colophospermum mopane*, however, lacks fruits. Another set of related species is that of *Dalbergia melanoxylon* and *Combretum imberbe*; they are highly valued for their timber and firewood but are used in traditional medicine as well. Additionally, *C. imberbe* is also used as an ethnoveterinary remedy. *Combretum apiculatum*, *Acacia tortilis* and *Dichrostachys cinerea* form a separate group. These are the species used as firewood and timber as well as livestock feed. Functionally, these species are also related to *Lonchocarpus capassa* which is utilised for firewood and as livestock feed but not timber. Finally, the bottom two species on the Malipati dendrogram (Figure 3), *Acacia nigrescens* and *Combretum hereroense*, are both valued for their wood, with *A. nigrescens* being used for timber only while *C. hereroense* is used for both timber and firewood.

The Gonakudzingwa farms dendrogram (cophenetic correlation coefficient = 0.8744) produced similar clusters to those of Malipati at a similarity distance of 0.0 (Figure 4). Just like in Malipati, the dendrogram produced 17 groups at distance 0.0 but with a lower observed utilitarian diversity of 21.4. However, there were some species present that were not recorded in Malipati, and the groups produced also contained some unique assemblages of species. For instance, in Gonakudzingwa, *S. africana*, used in traditional medicine, veterinary remedies and timber, was closely related to two other species, i.e. *Cassia abbreviata* and *Terminalia sericea*, which are both important only in traditional and ethnoveterinary medicine. Other related clusters included that which contained *Albizia amara*, a species which in addition to traditional medicine is also used for livestock feed, whereas the group containing *Xeroderris stuhlmanni*, *Euclia divinorum*, *Combretum collinum*, *Acacia xanthophloea* and *Kirkia acuminata* consisted of species exclusively utilised in traditional medicinal remedies. The next group contained *Senna singueana*, *Grewia occidentalis*, *Strychnos spinosa*, *Ziziphus mucronata*, *Flacourtia indica* and *Strychnos madagascariensis*. These are the species exclusively valued for their fruits. Hence, they are closer to *T. prunioides* which in addition to providing fruits is also used for firewood. In terms of species in the timber group, in Gonakudzingwa a highly valued species, *Androstachys johnsonii*, was recorded. The dendrogram for Chomupani communal area (Figure 5) also showed similar patterns to the previous two in terms of clustering, producing 16 groups. All utilitarian species found in Chomupani communal area also occurred in the two other study sites previously discussed. However, due to the lower species richness ($n = 25$), Chomupani also had the lowest observed utilitarian diversity, of 20.55.

Gonakudzingwa small-scale commercial farming area had the highest total of utilitarian species with 30 species, while Malipati had 27 species. Chomupani communal area had the lowest number with only 20 species. When compared to the actual species richness, both Malipati and Gonakudzingwa had a 60% proportion of species that were utilitarian species. On the other hand, Chomupani communal area, due to its relatively low species richness (Table 1), had 80% of recorded species being utilitarian species. Since the number of species which are useful was lower than the total species richness, this also meant a decreased redundancy for most of the use categories. Hence, in most categories only one species was available although most species had multiple uses (Figures 3–5). Table 3 summarises the species available in each use category in the three different sites. The categories with the highest utilitarian redundancy were the fruits and human remedies category, e.g. in Gonakudzingwa there were six species available for fruits and five species used as human remedies. In Malipati three species were recorded that are used as human remedies. However, there was a general low utilitarian redundancy for most categories, in which only one or at most two species were recorded (Table 3). Other categories had one species located only in one study site, e.g. *Cissus cornifolia* is the only species used for both veterinary remedies and fruits and *Salvadora persica* is the only species valued specifically for livestock feed, and both were recorded only in Malipati. While Malipati had the highest utilitarian diversity, it had no species in the livestock feed and human remedies category (Table 3). Gonakudzingwa had the highest species richness but it had about four categories without a species while Chomupani had five such categories.

### Spatial relationships among plant species

Of importance to the utility of a given species is where it is located. A PCA was carried out to examine the spatial relationships among the species to deduce their occurrence and co-occurrence. The PCA produced seven groups of related species (Figure 6). Group 1 had species like *X. zambesiaca* and *B. discolor*, which were recorded only in Malipati. In Group 2 were found those species which were recorded in both Malipati and Gonakudzingwa exclusively, e.g. *A. xanthophloea*, *S. africana* and *S. madagascariensis*. Group 3 contained *M. senegalensis* which was the only species found exclusively in Malipati and Chomupani. The common species located in all three areas, such as *C. mopane*, *C. imberbe* and *S. birrea*, were in Group 4. Group 5 comprised *A. garckeana* and *A. karoo*, species recorded in Chomupani only. Some species were only recorded in Gonakudzingwa and Chomupani, such as *G. monticola* and *C. abbreviata*, and these were in Group 6. Finally, species located in Gonakudzingwa only, such as *A. amara* and *T. sericea*, formed Group 7.

## DISCUSSION

### Alpha diversity

Given the role of protected areas in biodiversity conservation and sustaining local livelihoods (Naughton-Treves *et al.*, 2005), the aim of this study was to compare biodiversity levels in areas at the periphery of a protected area and relate them to utilitarian diversity. There was significantly higher richness and diversity of tree species in Malipati communal area and the Gonakudzingwa farms, both adjacent to GNP. Interestingly, there was no significant difference in species richness between these two areas even with their different land uses. Malipati is a relatively densely populated communal area while Gonakudzingwa farms are sparsely populated, with large tracts of undisturbed land. This agrees with Shackleton (2000) who observed that high disturbance in communal areas next to a protected area did not mean lower species richness and diversity. In this study, lower richness and diversity were observed farther away from the park in the densely populated Chomupani communal area, located approximately 40 km away from GNP. There is more intense agricultural activity in this area far from a protected area. Chapungu *et al.* (2007) reported significant habitat fragmentation

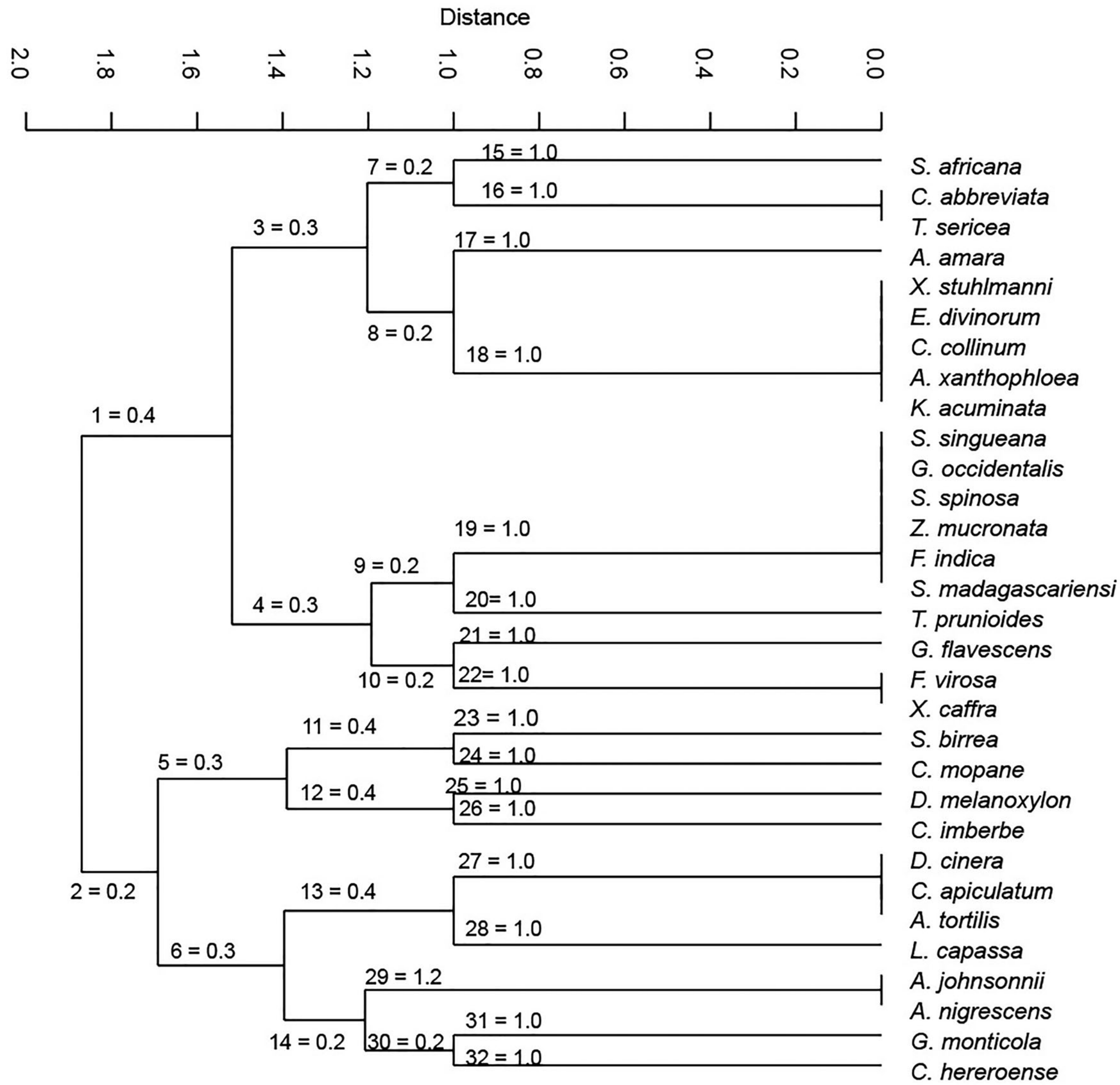


**Figure 4.** A dendrogram showing the utilitarian relationships of plants occurring in Gonakudzingwa small-scale commercial farming area. The branches are numbered 1–32 and the respective branch lengths based on the scale are indicated.

and loss in Ward 11 of Chikombedzi District where Chomupani is located and attributed this to human settlement, agriculture and infrastructural development. They also noted frequent droughts as contributing to species loss in this area.

Dominance–diversity relationships in vascular plant communities are complex and the occurrence of a particular dominant species in a plant community will not necessarily lead to the extinction of the others in a Gaussian competition manner (Whittaker, 1965). Mopane woodlands are dominated by *Colophospermum mopane*, as noted in this study, where dominance of the species was high in the communal areas. It reached almost 60% in Chomupani. The name "Chomupani" itself is a reference to the widespread occurrence of the species in the area, known locally as "Mupani." It is a species normally found in low-altitude (400–700 m), low-rainfall areas (200–800 mm per annum), which are often associated with high temperatures. It usually forms pure stands where it occurs (Mapaure, 1994). In the Gonakudzingwa farms, though within the same climatic region, *C. mopane* achieved a relative density value of only 17% although it remained the dominant species. Mapaure (1994) notes that *C. mopane* stands usually suppress grass growth, which results in a loss of nutrient-rich topsoil due to erosion. Hence, livestock farmers in the Gonakudzingwa farms are incentivised to keep *C. mopane* under control to promote the establishment of grass for cattle fodder. Wessels (n.d.) discussed the ecology and management of *C. mopane* and reported that its clearance resulted in the highest grass dry matter yields. High fire frequencies, however, tend to increase woody densities of *C. mopane* due to its multi-stemmed habit and coppicing strategy (Gandiwa and Kativu, 2009). Hence, farmers need to manage fire wisely to maximise grass production. Apart from *C. mopane*, the only other species to achieve a relative density above 10% was *Grewia monticola*, which may be due to its fire tolerance (Nefabas and Gambiza, 2007) and unpalatability to browsers (Owen-Smith and Cooper, 1987).

## Utilitarian diversity

### *Utilitarian properties*

Utilitarian properties of species are those that make them useful to people, e.g. for medicinal, firewood and construction uses (Brown *et al.*, 2011). Due to its low species richness,

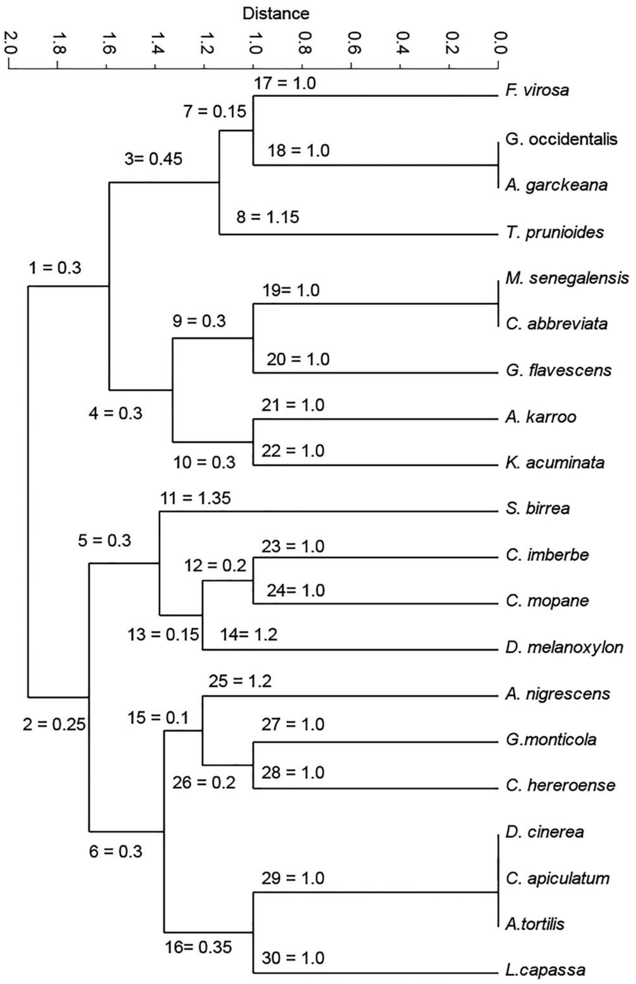


**Figure 5.** A dendrogram showing the utilitarian relationships of plants occurring in Chomupani communal area. The branches are numbered 1–30 and the respective branch lengths based on the scale are indicated.

Chomupani communal area recorded the least number of species in most of the utilisation categories. This was statistically significant in the human remedies and fruits categories where fewer than 10 species were recorded for each category. This indicates that if species loss were to occur it is those kinds of utilities which become vulnerable. Hence, for low-diversity systems like Chomupani, categories like fruits and human remedies deserve closer attention due to their high specificity. A fruit that is favoured for beer-brewing, like *Sclerocaryea birrea* (mupfura), cannot be replaced by one valued for its sweetness and palatability, e.g. *Azanza garckeana* (mutohwe). The same applies to human remedies, whereby a species used as an antidote for snakebite poison such as *Cissus quadrangularis* cannot be replaced by *C. mopane*, which is used to treat diarrhoea (Dowo *et al.*, 2018). This is also the case with species utilised for livestock feed in all three areas. Another observation was that in the firewood and timber categories, even Chomupani achieved utilitarian diversity levels that were similar to those of the other two areas with higher species richness. Even though there are preferred species like *C. mopane*, *C. apiculatum* and *C. imberbe* (Dowo *et al.*, 2018), when it comes to timber and firewood, people are more flexible in their selection and can use any other species for that same purpose. Physical properties of species – important for fuelwood and timber – are more easily substitutable than chemical properties used in food and medicine (Gueze *et al.*, 2014).

Of the species that have the most functions, only *C. mopane* was found to occur abundantly in all three areas. The extensive use of *C. mopane* is in line with the 'ecological apparency' hypothesis which states that the most apparent species i.e. most abundant, available and visible, are often the most utilised, with greater use value (Phillips and Gentry, 1993). Mashabane *et al.* (2001) also reported multiple uses of *C. mopane* by the VaTsonga people in the Gazankulu region of South Africa, although they did not provide its abundance values. A question which then arises is: Why do species with low relative densities, like *Sclerocaryea birrea* and *Combretum imberbe*, have multiple uses, the same number as or even more than *C. mopane*? Firstly, in accordance with the 'ecological apparency' hypothesis, it can be deduced that these species (*S. birrea* and *C. imberbe*) might have occurred in large quantities in the past, hence their widespread use. Perhaps, due to overharvesting over the years, their quantities declined. Published data on the historical distribution of these species in the study area could not be obtained. However, Shepherd (n.d.) reported extensive felling of *C. imberbe* for fence posts and the clearance of *S. birrea* for infrastructural development in the then Southern Rhodesia. Another explanation could be that offered by Gueze *et al.* (2014), who state that 'ecological apparency' has to be approached with caution when it comes to humans, as they have a more complex relationship with plant species which makes the association between ecological importance and usefulness of a species quite unpredictable. Loss of biodiversity is generally understood to have a negative impact on ecosystem function (Schmid *et al.*, 2009), hence this utilitarian approach is an important step in understanding the likely impacts of biodiversity loss on ecosystem services.

### Utilitarian relationships among plant species

The advantage of considering utilitarian relationships between species is that it allows a more detailed look at utilitarian diversity. Instead of relying on just the number of species in a given category, this approach is more specific in that it allows those species utilised for similar multiple purposes to be grouped. This is important in the resolution of trade-offs in conservation decision making where similar species with the same uses can be compared and their abundances taken into consideration such that decisions can be made regarding which of the species might be more suitable to harvest. Such multiple and sometimes conflicting uses were summarised in Table 3. For example, both *Dichrostachys cinerea* and *Acacia tortilis* are important for livestock feed, firewood and timber. These are conflicting uses. However, for firewood and timber, uses which are destructive, *D. cinerea* can be selected, while *A. tortilis*, whose pods and leaves are a favourite of goats (Scholte, 1992; Komwihangilo *et al.*, 1995), is reserved for livestock feed. *Dichrostachys cinerea* is invasive and can reduce herbaceous species diversity while changing soil nutrient composition (Mudzengi *et al.*, 2014). It was also ranked as the fourteenth most invasive species with significant impact on the Island of Reunion (Tassin *et al.*, 2006).

The dendrograms produced in this study provide a visual representation of relationships among plant species. Where

**Table 3.** A summary of available species in each use category. The more species in each category the higher the utilitarian redundancy.

| Use category | Species | | |
|---|---|---|---|
| | Malipati | Gonakudzingwa | Chomupani |
| Veterinary remedies and fruits | *Cissus cornifolia* | | |
| Fruits only | *Salvadora australis, Strychnos madagascariensis* | *Senna singueana, Grewia occidentalis, Strychnos spinosa, Ziziphus mucronata, Flacourtia indica, Strychnos madagascariensis* | *Grewia occidentalis, Azanza garckeana* |
| Firewood and fruits | *Terminalia prunioides* | *Terminalia prunioides* | *Terminalia prunioides* |
| Livestock feed only | *Salvadora persica* | | |
| Livestock feed and fruits | *Hyphaene petersiana, Hippocratea crenata* | | |
| Human medicinal remedies only | *Zanthoxylum humile, Euclia divinorum, Acacia xanthophloea* | *Xeroderris stuhlmanni, Euclia divinorum, Combretum collinum, Acacia xanthophloea, Kirkia acuminata* | *Kirkia acuminata* |
| Human medicinal remedies, timber and fruits | *Berchemia discolor* | | |
| Human medicinal remedies and fruits | *Ximenia caffra, Fluggea virosa* | *Ximenia caffra, Fluggea virosa* | *Fluggea virosa* |
| Human medicinal remedies, ethnoveterinary remedies and fruits | *Grewia flavescens, Xanthocercis zambesiaca* | *Grewia flavescens* | *Grewia flavescens* |
| Human medicinal remedies, ethnoveterinary remedies and timber | *Spirostachys africana* | *Spirostachys africana* | |
| Human medicinal remedies and ethnoveterinary remedies | *Maytenus senegalensis* | *Cassia abbreviata, Terminalia sericea* | *Maytenus senegalensis, Cassia abbreviata* |
| Human medicinal remedies, ethnoveterinary remedies, livestock feed, firewood, timber and fruits | *Sclerocarya birrea* | *Sclerocarya birrea* | *Sclerocaryea birrea* |
| Human medicinal remedies, ethnoveterinary remedies, livestock feed, firewood and timber | *Colophospermum mopane* | *Colophospermum mopane* | *Colophospermum mopane* |
| Human medicinal remedies, firewood and timber | *Dalbergia melanoxylon* | *Dalbergia melanoxylon* | *Dalbergia melanoxylon* |
| Human medicinal remedies, ethnoveterinary remedies, firewood and timber | *Combretum imberbe* | *Combretum imberbe* | *Combretum imberbe* |
| Human medicinal remedies and livestock feed | | *Albizia amara* | *Acacia karoo* |
| Livestock feed, firewood and timber | *Combretum apiculatum, Dichrostachys cinerea, Acacia tortilis* | *Combretum apiculatum, Dichrostachys cinerea Acacia tortilis* | *Combretum apiculatum, Dichrostachys cinerea, Acacia tortilis* |
| Livestock feed and firewood | *Lonchocarpus capassa* | *Lonchocarpus capassa* | *Lonchocarpus capassa* |
| Timber only | *Acacia nigrescens* | *Androstachys johnsonii, Acacia nigrescens* | *Acacia nigrescens* |
| Firewood and timber | *Combretum hereroense* | *Combretum hereroense* | *Combretum hereroense* |
| Firewood, timber and fruits | | *Grewia monticola* | *Grewia monticola* |

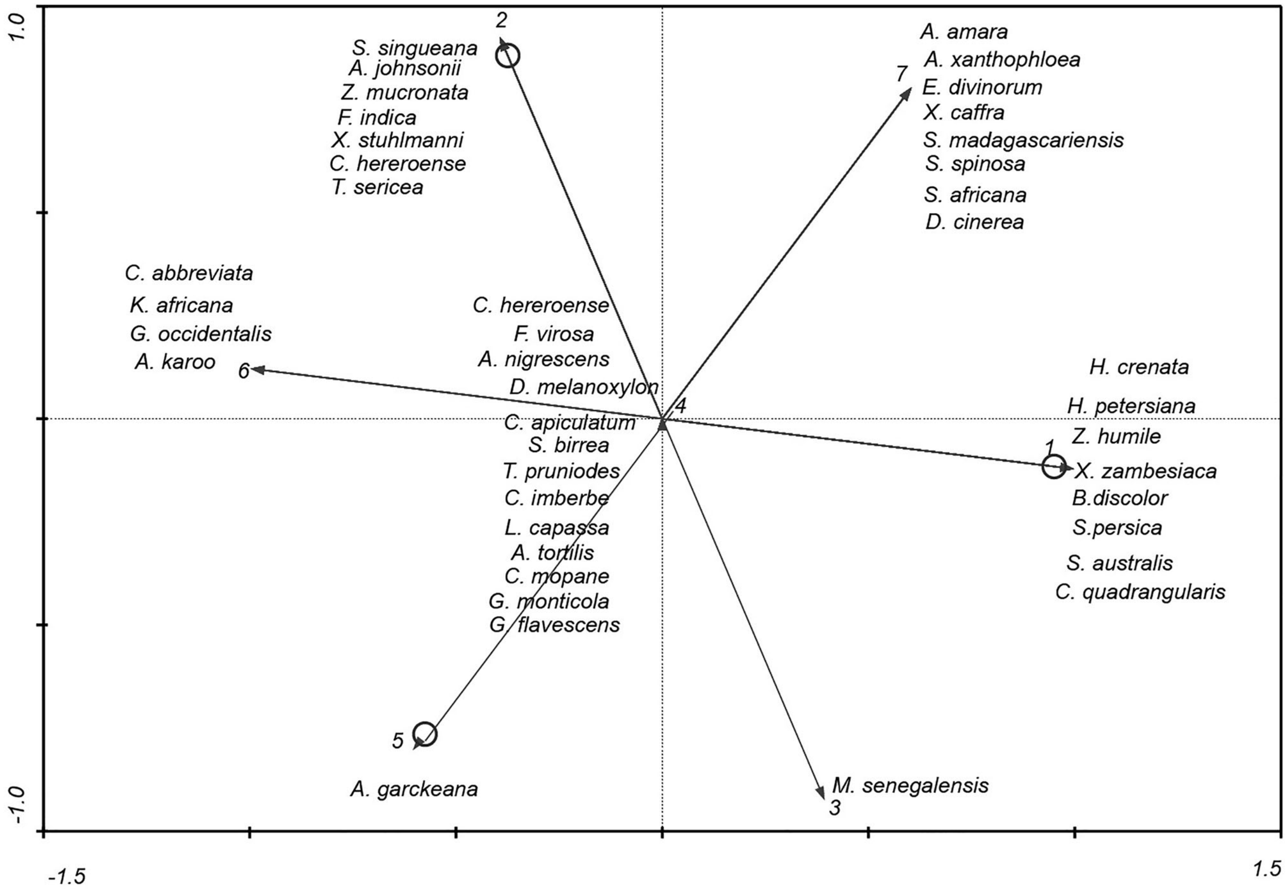


**Figure 6.** Principal component analysis (PCA) output showing groups of spatially related species.

redundancy exists, it can be easily deciphered from the vertical line of clustered species. The longer the line is, the higher the redundancy (e.g. the cluster from *S. singueana* to *S. madagascariensis* in Figure 3 which contains species utilised only for their fruits). The low redundancy in the Chomupani dendrogram is quite evident due to the scarcity of these vertical lines (Figure 5). The advantage of analysing utilitarian diversity is that areas at risk of losing utilitarian species can be identified and prioritised in conservation programmes (Brown *et al.*, 2011). It is also emphasised by Brown *et al.* (2011) that one of the goals of conservation is to maintain high levels of functional redundancy within ecosystem service providers. In this case, Chomupani communal area is most at risk due to its low utilitarian diversity and should be targeted for community reforestation programmes focusing on utilitarian native species.

### Spatial relationships among plant species

The location of a given species is important to its utility. Within transfrontier conservation areas (TFCAs) this is important as natural resource gradients exist which cause movement. While this movement is mainly by animals searching for better forage resources, such as cattle straying into protected areas (Murwira *et al.*, 2013), such movements may also involve people as they search for utilitarian species. Our results showed some plants that were exclusively located in particular areas. If such species have an important function, people travel in search of them even if they are located within a protected area. An example is *Spirostachys africana*, a species important for human medicinal remedies, ethnoveterinary remedies and timber. It was recorded only in Gonakudzingwa and Malipati, areas adjacent to the protected area. This attracts people to such areas in search of the species, which inevitably leads to harvesting from protected areas as there is no clear boundary on the ground. Livelihoods of poor households are highly dependent on protected areas even when harvesting is done illegally (Tumusiime *et al.*, 2011). In a survey, some respondents admitted to illegally harvesting some resources from GNP within the Great Limpopo TFCA (Dowo *et al.*, 2018). The weakness of our method, however, was that it relied on random sampling. Therefore, it does not follow that species which were not recorded absolutely did not occur in those areas; rather, it means only that the probability of encountering them was low.

### Limitations of the study

The study mainly focused on the utility of trees and shrubs. This is because in an earlier study (Dowo *et al.*, 2018) the majority of respondents expressed greater knowledge of these plant forms. While the study acknowledged differences in plant biodiversity in the different areas around a protected area, it did not explicitly study the major determinants such as vegetation types, soils and previous disturbance patterns. This study also focused more on utilitarian diversity itself rather than utilitarian redundancy.

## Conclusions

Low-diversity systems like Chomupani communal area have low utilitarian diversity, especially in utilitarian categories like fruits and human remedies. *Colophospermum mopane* is the dominant species in all three study sites due to the species' ecological attributes. Consideration of spatial and utilitarian relationships between species allows for an understanding of utilisation patterns and resolution of trade-offs. Utilitarian diversity metrics are thus useful in TFCAs to identify those areas at risk of losing utilitarian species and prioritise them in conservation programmes.

## Management and conservation implications

Protected areas and their peripheries are rich in biodiversity. Managers should work to conserve and preserve such natural endowments. The importance of *C. mopane* in the study region is indisputable. However, managers should devise strategies to promote the growth of other key utilitarian species also. Utilitarian diversity is an important concept that managers should take note of. Where there is low diversity, there is a greater risk of loss of key ecosystem services if certain species are lost. Managers should be aware of such ecologically apparent species like *C. mopane* and the implications of their future loss. The multiple uses of species should be considered and any trade-offs present carefully analysed. Dendrograms should be used in management to rapidly identify areas most at risk of ecosystem service loss due to low utilitarian diversity. Finally, managers should be aware of the locations of key species to avoid illegal harvesting in protected areas and to properly prioritise reforestation measures.

The study's findings will inform the development of more effective conservation strategies for the Gonarezhou National Park and its surroundings. These strategies could include more integrated conservation approaches that balance the needs of both biodiversity and local communities, sustainable resource utilisation programmes that promote responsible harvesting and alternative livelihoods, and improved protected area management that enhances park security and community participation.

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## DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

## SUPPLEMENTAL DATA

Supplemental data for this article can be accessed online at https://doi.org/10.1080/0035919X.2024.2326101.

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