Land-use impacts on the composition and diversity of the *Baikiaea–Guibourtia–Pterocarpus* woodlands of north-western Zimbabwe

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Variation in floristic composition of recovering *Baikiaea–Guibourtia–Pterocarpus* woodlands was studied in different development stages (from early regrowth to mature woodland) under different land-use systems (protected areas, timber harvesting, pole and firewood collection, and abandoned crop fields), in the Gwayi and Tsholotsho areas in north-western Zimbabwe. A total of 150 nested circular plots were sampled representatively in four different development stages related to the land-use systems. The DBH (stem diameter at 1.3 m above ground level) and tree height were recorded by species for all stems of tree species with DBH ≥ 15 cm in a 30-m-radius plot (0.283 ha) and for trees with DBH 5.0–14.9 cm in a 11.3-m-radius plot (0.04 ha) (both centred around the same midpoint). Stems with DBH < 5 cm were counted by species in an inner sub-plot of 5.65 m (0.01 ha) radius. Tree data (stem DBH ≥ 5 cm) and regeneration data (stem DBH < 5 cm) by stem counts per species per plot, were used separately to run TWINSPAN (TWo-way INdicator SPecies ANalysis) classifications of species assemblages. Importance values were calculated for all tree species per community. Shannon–Wiener diversity indices were calculated for each community and tested for differences using one-way ANOVA in SPSS version 21. Detrended correspondence analysis (DCA) implemented in the CANOCO ordination software was used to determine the extent of variation amongst the identified communities. The classification identified 12 tree communities and 13 regeneration communities, clustering plots from different land uses together. *Baikiaea plurijuga* was the most important tree species in all tree communities, except where *Combretum collinum*, *C. apiculatum*, *Commiphora mossambicensis* and *Pterocarpus angolensis* were dominant. *Pterocarpus angolensis* showed low importance in most communities, except for communities from undisturbed sites (mostly mature trees) and abandoned fields (mostly young trees). *Baikiaea plurijuga* was most important in most regeneration communities, except in communities dominated by *Baphia massaiensis*, *C. collinum*, *C. apiculatum* and *P. angolensis.* Species diversity differed significantly ($p < 0.05$) amongst tree communities. The DCA ordination showed little variation amongst the communities. The cumulative contribution of environmental factors explaining variation in species composition was 22.6% for tree communities and 26.1% for regeneration communities, suggesting that recovery from disturbance after different land uses may explain more of such variation.

Keywords: disturbance, regeneration, species diversity, woodland

Introduction

In Africa, the majority of people live in rural areas and rely directly on natural resources for their survival. This emphasises the need for sustainable use of natural resources, a topical issue in many countries (Chidumayo 1993; Piearce and Gumbo 1993; JAFTA and Forestry Commission 2001; Mufandaedza 2002; Mapaure and Ndeinoma 2011). Poor resource-use management strategies (White 1983; Ferguson 1996; Geldenhuys 1997, 2003; Mapaure and Ndeinoma 2011), combined with pressures from increasing population densities (Mapaure and Ndeinoma 2011), have led to the decline of many African forest and woodland ecosystems. Southern Africa is endowed with woody ecosystems, such as Miombo, Undifferentiated and Mopane woodlands, semi-arid shrublands and the southern dry forests (White 1983), that sustain millions of people in rural societies. In southern Africa, the *Baikiaea–Guibourtia–Pterocarpus* woodlands, within the Undifferentiated woodlands of White (1983), cover an extensive area of approximately 265 000 km² on the Kalahari sands of north-western Zimbabwe, north-eastern Botswana, north-eastern Namibia, south-western Zambia and south-eastern Angola (King et al. 2000; Timberlake et al. 2010). In Zimbabwe, they are confined to the north-western parts of the country, in Gwayi, Mbembesi, Ngamo, Gwampa, Mzola, Tsholotsho and Fuller forests (Childes and Walker 1987; JAFTA and Forestry Commission 2001).

The demarcated forests, for example Gwayi and Mbembesi forests, are under the management of the Forestry Commission. Gondo and Mkwanda (1991) noted a decline in Zimbabwean woodlands, mainly due to clearing for agriculture, harvesting wood for fuel and construction, infrastructure development and overstocking of domestic animals. In particular, the *Baikiaea–Guibourtia–Pterocarpus* woodlands are subjected to a number of natural and human disturbances, such as fire, drought, herbivory especially by elephants, buffalo and antelope, timber logging, pole and fuel wood harvesting, other non-timber and non-wood forest products, and clearing for crop cultivation (Mutsiwegota and Mudekwe 1998). Piearce (1986) blamed the perceived decline of the *Baikiaea–Guibourtia–Pterocarpus* woodlands to disturbances by man and emphasised that extinction of the forests is imminent if intensive exploitation and devastating fires continued unchecked. Mufandaedza (2002) stated that the management of these forests is difficult because of the presence of forest settlers whose practices are against forest demarcation and protection. Different user groups harvest a variety of products from the woodlands, mainly through a permit system. Permits are issued by the Forestry Commission (state-owned land) or Rural District Councils (communally-owned land). The products include poles, fuel wood, thatch grass, grazing, timber used by rural communities for small-scale furniture industries and wood carving. Sometimes the products are harvested illegally, that is without a permit.

No harvesting operations (for commercial or subsistence purposes) are allowed in the protected areas. Timber harvesting by concession companies is conducted in the gazetted forests and also in communal areas. Timber is harvested in a single-tree selection system that is based on variable diameter limits for different species. For example, cutting diameter limits are 31 cm DBH (stem diameter at breast height 1.3 m above ground level) for *P. angolensis* and 25 cm for any other species. Trees with straight stems of good form are usually selected for harvesting, whereas deformed, damaged or diseased trees are left behind. Trees are usually cut with chain saws 15 cm above the ground. The selective cutting of individual trees leads to the creation of relatively small, open canopy gaps.

In the Tsholotsho communal area, people are allowed to harvest trees on an open-access regime for domestic and commercial use. Trees of different sizes are cut, using axes at different heights for various purposes (e.g. fuel wood, construction, fences and curios) (Matose 2002). Large canopy gaps are usually created if groups of trees are removed. Forest settlers, living inside the forest reserves, grow maize, sorghum and other crops on their fields. After the harvesting season, the debris from maize is collected and fed to cattle during the dry season; some farmers leave the debris on the field floor so as to add manure, whereas others burn the debris. The agricultural fields are usually abandoned after many years (40 years or less) of cultivation. Fields are abandoned when they are old and are not producing much yield (Mutsiwegota and Mudekwe 1998). It has been noticed that trees of different species will start growing on the abandoned fields from seed or resprouting.

Disturbances have played a major role in determining the structure and composition of ecosystems (Sousa 1984). Geldenhuys (2011) stated that the interaction between the regime (frequency, intensity, season and area of impact) of a particular disturbance and the habitat within which a suite of species live, determines how the species adapt to survive in that particular environment. This contributes to the vegetation and biodiversity patterns in ecosystems within similar landscapes. Thus, the main type of disturbance becomes the driver of the system, and changes the potential of a site based on habitat features into reality of current patterns. The deciduous woodlands are generally driven by tolerance to fire in the dry season, but adaptation to grazing/browsing is an important secondary driver (Geldenhuys 2011) in most woodland ecosystems. The species of all vegetation types therefore generally represent adaptations to different disturbance regimes and also form part of different recovery stages of the vegetation.

Childes and Walker (1987), in a study of the woody vegetation on Kalahari sand deposits in Hwange National Park, nearby to the area of this study, suggested that depth of sand and soil moisture regime determined overall vegetation structure, with well-developed, mature *Baikiaea plurijuga* woodlands on deep sands, and scrub *Terminalia sericea* and mixed woodland on soils with a higher clay content or compact layer. These authors found the central groups of stands of mixed woodlands and scrub were less easy to interpret, possibly because of previous logging disturbance, that regeneration of *B. plurijuga* may be inadequate, that elephants had only a minor effect on change in the woodlands, and that fire is a dominant feature in the scrub area and interacts with frost. Syampungani (2009) and Syampungani et al. (2010, 2016) compared Miombo woodland recovery in Zambia over >15 years in stands in close proximity to each other (to control for site differences, after cessation of disturbances from land-use practices such as charcoal production, slash and burn agriculture, and timber harvesting, with protected areas. Recovery of regeneration, plant diversity and productivity was best in charcoal production sites and slash and burn agriculture than in stands of single-tree timber harvesting and protected areas, primarily because most of the species are light demanding and require maximum exposure to sunlight to grow fast.

Five woodland stand development stages, from cessation of disturbance to mature woodland, have been identified as a basis for selective stem thinning and branch pruning in Miombo Woodland (Geldenhuys et al. 2013; Geldenhuys 2014). The stages in this development process are primarily based on stem density and stand height. Stage 0 represents the early regrowth after clearing or crop cultivation. Stage 1 is the early regrowth with short multi-stem plants (<2 m height), and develops through Stages 2 and 3, with growth focused on fewer stems associated with self-thinning of the initial many young pole-sized stems, towards mature trees with more umbrella-shaped crowns (Stage 4). Silvicultural actions (thinning and pruning in Stages 1 to 3, and clear-felling in Stage 4) and potential use of removed stems and branches vary with stand development stage. Such identification and definition of stand development stages has not been done for Undifferentiated Woodland.

We therefore need to understand how different land-use practices, including protection, affect the species composition (diversity), structure, regeneration and growth of the *Baikiaea–Guibourtia–Pterocarpus* woodland ecosystems, to develop better management strategies. The findings from such studies would contribute to the body of knowledge on woodland recovery and management under different disturbance factors, to ensure availability of the woodlands to future generations. Prudent management of the natural woodland therefore requires information on variation in the floristic and structural composition of these woodlands.

The main objective of this study was to explore the floristic variation of four stand development stages under different land-use systems (timber harvesting, pole and firewood collection, and crop fields under recovery) when compared with protected areas. The following research questions guided the data collection and analyses:

- How does species composition vary across stand development stages within the different land-use systems?
- How do species diversity patterns vary within and between communities affected by land uses and during stand development towards maturity, after cessation of land-use disturbances?
- What underlying factors influence species composition differently than disturbances caused by different land-use systems?

Materials and methods

Description of study area

The study was conducted in the Gwayi and Tsholotsho indigenous *Baikiaea–Guibourtia–Pterocarpus* woodlands of north-western Zimbabwe (Figure 1). Gwayi forest (19°16′20″ S, 27°56′36″ E) and Tsholotsho (19°46′00″ S, 27°45′00″ E) (JAFTA and Forestry Commission 2001) are both located in the Matabeleland North province at an altitude ranging between 1 010 and 1 055 m. Kalahari sands (uniform, both physically and chemically) cover the bulk of the study area. They belong to the regosol group in the amorphic soil order (Nyamapfene 1991, as cited by Gambiza 2001). The underlying geology is of sedimentary rocks overlying Karoo basalt and sedimentary deposits (JAFTA and Forestry Commission 2001). Mean monthly temperature ranges from 15 °C (June to September) and 25 °C (October to December) (Nyamapfene 1991; JAFTA and Forestry Commission 2001). A short and erratic wet season usually characterised by dry spells and sporadic droughts (Nemarundwe and Mbedzi 1999) is reported for this area.

The area is characterised by six main vegetation types (JAFTA and Forestry Commission 2001). *Baikiaea–Guibourtia–Pterocarpus* woodland mainly occurs as closed to open woodland on the Kalahari sands. *Brachystegia* woodland mainly occurs along the upper Bembesi river (shallower soils and contains more silt). *Colophospermum mopane* woodland is characterised by either stunted or multi-stemmed *C. mopane* trees. The woodland is mainly found along rivers or river valleys on alluvial soils that are poorly drained and highly erodible (JAFTA and Forestry Commission 2001). Vleis are dominated by a single layer of grasses. Trees may be absent, or occur isolated along vlei fringes (JAFTA and Forestry Commission 2001). *Pterocarpus angolensis* (in association with *Burkea africana*) belts occur as localised stands inside the *Baikiaea–Guibourtia–Pterocarpus* woodlands. *Guibourtia coleosperma*

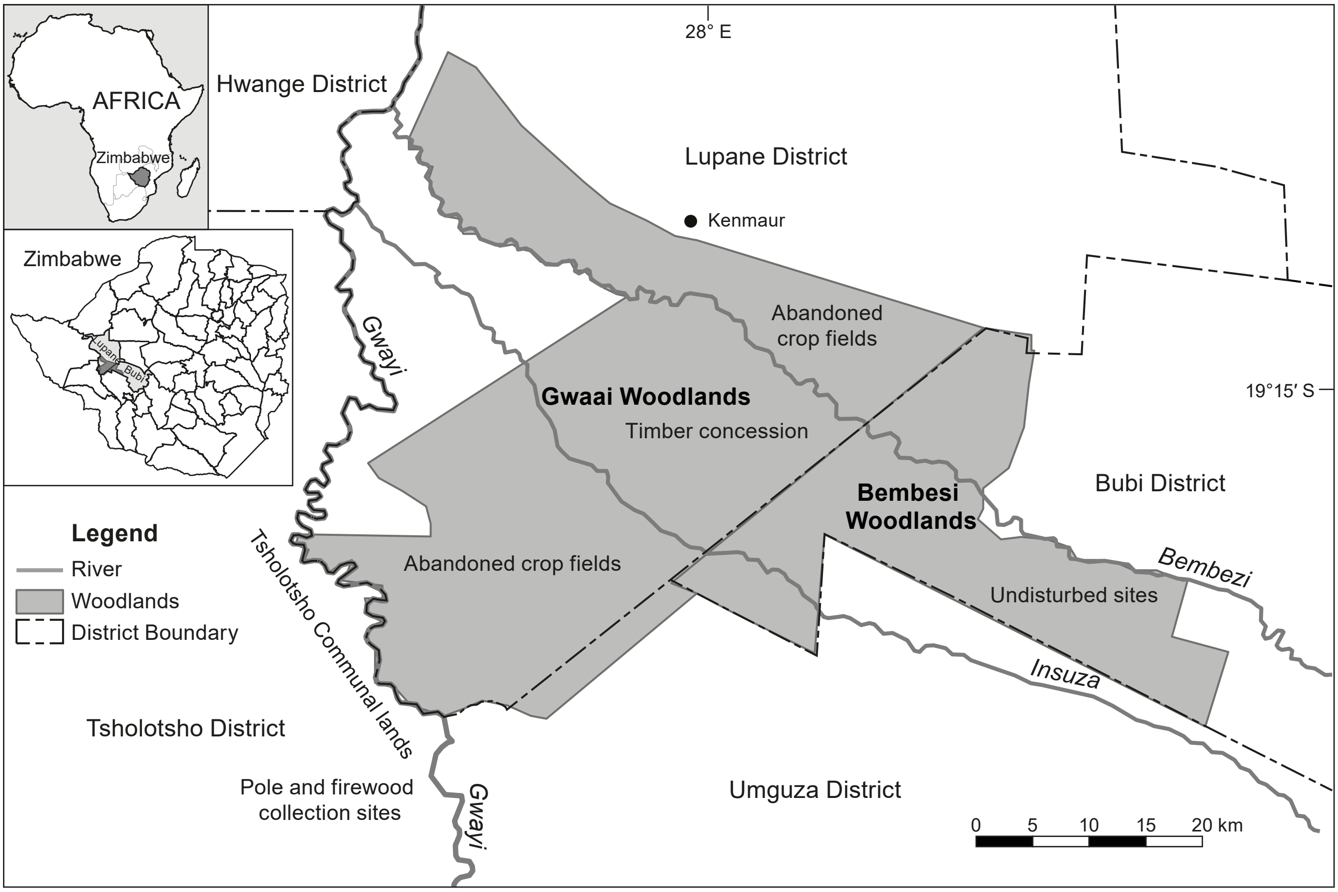

Figure 1: Location of the study area in north-western Zimbabwe

woodland is mainly characterised by the dominance of *G. coleosperma* and scattered *B. plurijuga* trees.

Data collection

Four land-use types were identified: protected area (PA), single-tree timber harvesting in concession areas (CA), pole and firewood collection (PFC), and abandoned crop fields under recovery (AF). Protected area, concession area and abandoned field sites were located in Gwayi forest, and pole and firewood collection sites were found in Tsholotsho communal forest areas. Four stand development stages were identified in each land-use type, based on the age and height of the vegetation. Stand age was based on the time since cessation of disturbance of the vegetation. The information on age was obtained from Forestry Commission records, Rural District Council offices and local communities around the forests. The development stages were predetermined using height as the main criterion. Stage 1 height was <2 m; Stage 2 height was 2.1–5 m; Stage 3 height was 5.1–8 m; and Stage 4 height was >8 m.

A total of 150 nested circular plots were sampled, with 40 plots each in abandoned crop fields, in pole and firewood collection sites and in the protected areas (which only had Stage 4 or mature stands), with 30 plots in the concession areas (which had no Stage 1 stands). In each area selected for sampling (land use × stand development stage; with four mature stands in protected areas), five points each were sampled along two parallel 500-m-long transects, with a separating distance of 100 m between the sample plot mid-points along the transects.

Four tree size categories were defined for sampling: seedling, <1 m height; sapling, 1 m height to <1 cm DBH; pole, 1–5 cm DBH; and tree, ≥5 cm DBH.

Three nested circular plots, around the same central point, were used to sample trees by size categories: a main plot of 30 m radius (0.283 ha) to record trees ≥15 cm DBH by species, DBH and height; an intermediate plot of 11.3 m radius (0.04 ha) to record trees 5.0–14.9 cm DBH by species, DBH and height; and an inner plot of 5.65 m radius (0.01 ha) to count stems of seedlings, saplings and poles by species. A caliper was used for measuring DBH and a clinometer was used for measuring tree height. Information was collected on relevant environmental variables for each plot to relate floristic and structural composition of a stand with causal factors: altitude and aspect, using a GPS; slope, using qualitative scoring (1 = flat terrain; 2 = gently sloping) and soil depth, using a soil auger. In general, the sampled sites were all in similar parts of the landscape.

Data analysis

The TWINSPAN (TWo-way INdicator SPecies ANalysis) software package of Hill (1979) was used to classify the tree (stems ≥5 cm DBH) and regeneration (stems <5 cm DBH) data by number of stems of a species in each plot. *Baikiaea plurijuga* was subdivided into three surrogate species (subsets of stems of the same species representing different diameter classes), based on stem diameter: *B. plurijuga* class 1 = 5–10 cm DBH, *B. plurijuga* class 2 = 10.1–30 cm DBH, and *B. plurijuga* class 3 = >30 cm DBH. This was done to differentiate plots with a high number of stems <5 cm DBH from plots with a low number of stems >30 cm DBH. This meant that *B. plurijuga* could be represented by three surrogate *B. plurijuga* species in a nested plot. The number of species therefore increased from 46 to 48. Within the analysis, TWINSPAN created pseudospecies, for each species in the data set, based on the abundance of a species in a plot, and in this analysis the cut levels for the different pseudospecies were 0, 3, 5, 15 and 25. The cut level defines the value that must be exceeded for a pseudospecies to be present: pseudospecies 1 = 1–3 stems plot^{-1}; pseudospecies 2 = 4–5 stems plot^{-1}; pseudospecies 3 = 6–15 stems plot^{-1}; pseudospecies 4 = 16–25 stems plot^{-1}; and pseudospecies 5 = >25 stems plot^{-1}.

Importance values of each species in each community identified in the classification (step one) were calculated using the following formulas.

For plants with DBH ≥5 cm:

$$\text{Importance Value (IV)} = (\text{R} + \text{RD} + \text{RBA})/3$$

where RF (relative frequency) = (number of plots in which a species is present) × 100 / total number of plots recorded, in a particular community; RD (relative density) = (number of stems recorded for the species) × 100 / total number of stems recorded for all species, in a particular community; and RBA (relative basal area) = (basal area of a species in a plot) × 100 / total basal area of all species in all the plots, in the particular community.

For plants <5 cm stem DBH:

$$\text{Importance Value (IV)} = (\text{RF} + \text{RD})/2$$

The Shannon–Wiener diversity index ($\hat{H}$) was calculated for each community using the formulae:

$$\hat{H} = -\sum p_i \times \log p_i$$

where p_i = the proportion of each species i.

A one-way analysis of variance (ANOVA) as implemented in IBM SPSS Statistics 21 (IBM Corporation, Armonk, NY, USA, 2012) was then performed to test for any differences in species diversity across different communities identified from the classification.

Detrended correspondence analysis (DCA) as implemented in the CANOCO software package (ter Braak 1988) is an indirect gradient analysis and was used to show the spatial distribution of plots of the identified tree and regeneration communities in ordination space. No direct gradient analysis was done with the environmental variables collected in the field because they showed little variation across the study sites.

Results

A total of 146 sampled plots, recorded in the different land-use types and stand development stages, were used in the TWINSPAN classification analyses. Four plots were excluded from the initial 150 plots; they did not aggregate with any community during the initial TWINSPAN analysis. A total of 47 species, representing 36 genera from 18 families, were recorded (Table 1). The tree data included

Table 1: List of identified tree species (stems of $\geq$5 cm DBH), species code; family; local and species occurrence (1- rare; 2- occasional; 3- common; and 4 – abundant) recorded. Species authority is indicated between brackets (based on van Wyk et al. 2011)

Species	Species code	Family	Local name	Species occurrence
Acacia ataxacantha DC.	Acac ata	Fabaceae	Uthathawu	2
Acacia erioloba E.Mey.	Acac eri	Fabaceae	isinga	1
Acacia galpinii Burtt Davy	Acac gal	Fabaceae	Umthungabayeni	1
Acacia nigrescens Oliv.	Acac nig	Fabaceae	Umkhaya, umkhayamhlophe	1
Acacia nilotica (L.) Willd. ex Delile	Acac nil	Fabaceae	Umlaladwayi	1
Afzelia quanzensis Welw.	Afze qua	Fabaceae	Umkamba	2
Albizia tanganyicensis Baker F.	Albi tan	Fabaceae	Umphaphama	1
Baikiaea plurijuga Harms	Baik plu	Fabaceae	Umkusi	4
Baphia massaiensis Taub.	Baph mas	Fabaceae	Umbhondo	2
Bauhinia petersiana Bolle	Bauh pet	Fabaceae	Imondo	3
Brachystegia spiciformis Benth.	Brac spi	Fabaceae	Igonde	2
Burkea africana Hook.	Burk afr	Fabaceae	Umnondo	2
Combretum apiculatum Sond.	Comb api	Combretaceae	Umbhondo	4
Combretum collinum Fresen.	Comb col	Combretaceae	Umkhosikazi	4
Combretum imberbe Wawra	Comb imb	Combretaceae	Umtshwili	1
Combretum molle R.Br. ex G.Don	Comb mol	Combretaceae	Umbhondo	3
Commiphora mollis (Oliv.) Engl.	Comm mol	Burseraceae	Iminyela	2
Commiphora mossambicensis (Oliv.) Engl.	Comm mos	Burseraceae	Iminyela lentaba	3
Croton gratissimus Burch.	Crot gra	Euphorbiaceae	Iboyane	2
Dalbergia melanoxylon Guill. & Perr.	Dalb mel	Fabaceae	Umbambangwe	2
Dichrostachys cinerea (L.) Wight & Arn.	Dich cin	Fabaceae	Ugagu	2
Diplorhynchus condylocarpon (Mull.Arg.) Pichon	Dipl con	Apocynaceae	Inkankamasane	2
Erythrophleum africanum (Welw. ex Benth.) Harms	Eryt afr	Fabaceae	Umsenya	2
Eucalyptus camaldulensis Dehnh	Euca cam	Myrtaceae	Umgamudeleni	1
Flacourtia indica (Burm.f.) Merr.	Flac ind	Salicaeae	Umqokolo	1
Grewia flavescens Juss.	Grew fla	Tiliaceae	Umtewa, umklampunzi, umnaba	2
Grewia monticola Sond.	Grew mon	Tiliaceae	Umhlabampunzi, umpumpulwane, umtewa	2
Guibourtia coleosperma (Benth.) J.Leonard	Guib col	Fabaceae	Umchibi	1
Julbernardia globiflora (Benth.) Troupin	Julb glo	Fabaceae	Munondo, umtshonkwe	2
Kirkia acuminata Oliv.	Kirk acu	Kirkiaceae	Umvimila	2
Ochna pulchra Hook.	Ochn pul	Ochnaceae	Umnyelenyele	2
Parinari curatellifolia Planch. ex Benth.	Pari cur	Chrysobalanaceae	Umbula, umkuna	1
Peltophorum africanum Sond.	Pelt afr	Fabaceae	Umkahla, umsehla	1
Philenoptera violacea (Klotzsch) Schrire	Phil vio	Fabaceae	Ichithamuzi, idungamuzi, iphanda	2
Pseudolachnostylis maprouneifolia Pax	Pseu map	Phyllanthaceae	Umqobampunzi	2
Pterocarpus angolensis DC.	Pter ang	Fabaceae	Umvangazi	3
Schinziophyton rautanenii (Schinz) Radel.-Sm.	Schi rau	Euphorbiaceae	Umgoma, mgonwa, umganuompobola	3
Sclerocarya birrea (A.Rich.) Hochst.	Schl bir	Anacardiaceae	Umganu	2
Searsia lancea (L.f.) F.A.Barkley	Sear lan	Anacardiaceae	Inhlokotshiyane	1
Searsia tenuinervis (Engl.) Moffett	Sear ten	Anacardiaceae	Uchane	1
Strychnos cocculoides Baker	Stry coc	Loganiaceae	Umkhemeswane	1
Strynchnos pungens Soler.	Stry pun	Loganiaceae	Umgwadi, umgwai	1
Terminalia sericea Burch. ex DC.	Term ser	Combretaceae	Umangwe	3
Vangueria infausta Burch.	Vang inf	Rubiaceae	Umthofu, umviyo	2
Vitex payos (Lour.) Merr.	Vite pay	Lamiaceae	Umtshwankela	1
Ziziphus mucronata Willd.	Ziz muc	Rhamnaceae	Umphafa, umpasamala	2

46 species and the regeneration data included 31 species. The species aggregated in different associations, as shown in the TWINSPAN classification output tables for tree communities (Table 2) and regeneration communities (Table 6).

Species associations in tree stands

Classification of tree communities

Three tree communities were identified, with subdivisions into subcommunities, to level 5 for community 2 (Figure 2), based on the TWINSPAN output table (Table 2). The eigenvalues and indicator species at each level of division are shown. Branch 1 of the first division leads to communities 1 and 2, consisting of all undisturbed site plots and most plots from advanced stages (3 and 4) from different land-use systems. The indicator species for this branch are *B. plurijuga* 3 and 2 (stems $\geq$10 cm DBH). Branch 2 (community 3) consists of plots from mostly the least developed stages 1 and 2 of different land-use systems with indicator species *B. plurijuga* 1 (stems $<$10 cm DBH) (Table 2). Both branches have communities with indicator species seemingly not related to the main groupings with *B. plurijuga*, *G. coleosperma* and *P. angolensis*. The indicator species for community 1 are

Table 2: TWINSPAN classification of trees ≥5 cm DBH based on number of stems per plot. Pseudospecies cut levels are 0, 3, 5, 15, and 25. Species with one occurrence were excluded from the table. The different land-use systems (AF = abandoned fields, PF = pole and firewood areas, CA = concession areas, PA = protected areas) in lines 1 and 2, and stages (1, 2, 3 or 4) in line 3 are shown at the top of the table

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  Land use   PPPPP PPPPPPPAAAAAAACC PAA PPPPPPPP AAPPPPPPPPPAACPPPPPPPPPPPPP AAAAACCPPP PPPPPAAACCCCCCCCCCPPPP PCCCCCCPPAPPPPPPCC ACCC PPACC PPAAAAAAAAPPPPPPPPAAAAAA PPPA
   & stage   FFFFF FFFFFFFFFFFFFFAA FFF AAAAAAAA FFAAAAAAAAAFFAAAAAAAAAAAAAA FFFFFAAAAA AFFFFFFFAAAAAAAAAAAAFF AAAAAAAAFFFAAAFFAA FAAA FFFAA FFFFFFFFFFFFFFFFFFFFFFFF FFFF
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                                        11111111   111111111   1111111111111         11 1                111    111111    111  11
             22233 1177512233576788 235 11124123 670111113445662223333333444 5756777822 4226668889999999901311 900000012362223300 7889 11688   344444444   112345 455    5
             62534 4502433456549305 777 47911169 679025687029587890123456456 8661589102 3012372380123567883819 901234529203450167 1464 08497 249012345676786788919802 1353

  Eryt  afr  ----- ---2------------ --2 -------2 --------1----------1------- ---------- ---2-2------1--------- -----------------1 ---- ----- ----------------1------- ----   0000
  Phil  vio  ----- 2--------------- --- -------- ----------------1---------- ---------- ---------------------- ------------------ ---- ----- ------------------------ ----   0000
  Dich  cin  --21- ---------------- 1-- -------- --------------------------- ---------- ---------------------- ------------------ ---- ----- ------------------------ ----   00010
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  Kirk  acu  1---1 ---------------- --- -------- -------2------------------- --1------- ---------------------- ---------1-----2-- ---- ----- ------------------------ ----   00011
  Sear  ten  ----- ---1------------ --- -------- -------------1------------- 1--------- ---1------------------ ------------------ ---- ----- ------------------------ ----   00011
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  Acac  nig  ----- ---1------------ --- -------- --------------------------- ---------- ---1------------------ ------------------ ---- ----- ------------------------ ----   00011
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  Brac  spi  ----- ---------------- --- -------- --2------2------1-2-1--2--- ---------- ---------------------- ------------------ ---- ----- ------------------------ ----   00100
  Pseu  map  ----- ----1----------- --- -----211 ------1-1------------------ ---------- ----------1----------- -----------------1 ---- ----- ------------------------ ----   001010
  Pelt  afr  ----- ---------------- --2 -------- --------------------------- ---------- -----2---------------- ------------------ ---- ----- ------------------------ ----   001011
  Pari  cur  ----- ---------------- --- -------- -------------1------------- 1--------- ---------------------- ------------------ ---- ----- ------------------------ ----   001011
  Comb  imb  ----- ---------------- --- -------- --------1------------------ ---------- ---------------------- -----------------1 ---- ----- ------------------------ ----   001011
  Pter  ang  ----- ---------------- 224 1-212323 1---21-21-233-21-1--211122- ---2------ ---2-2----1-1112-111-- --11-11---1------- ---- --1-- ------------------------ ----   001011
  Guib  col  ----- ---------------- --2 33233434 --4444322421-23222-31-12232 221-2--321 2--22-32222223323344-- --3--------------- -1-- ----- ------------------------ ----   001011
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  Dipl  con  ----- ---------------- --- -------- --------------------------- ---------- ----------------2----- --2-1------------- ---- ----- ------------------------ ----   0011
  Crot  gra  ----- ---------------- --- -------- -------------1------------- ---------- ------------2--------- 2-11121----------- ---- ----- ------------------------ ----   0011
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  Grew  mon  ----- ---------------- --- -----2-- ---2--------2-------------- ---------- -----------------22--- ------------------ ---- ----- -----------------------2 ----   010
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  Burk  afr  ----- ---------------- --- -------- -----------------1-2------- --1------- ---------------------- ------1----------- ---1 ----- ------------------------ ----   011
  Afze  qua  ----- ---------------1 --- -------1 ---2--1-------------------- ---------- ---------------------- ------------------ ---- ----- ------------------------ ----   011
  Comb  col  ----- -44315524-44233- --- -------2 221--122-22213-11-222---2-1 332223222- 2----1-1-112-222--1--- 12---11---------23 3223 ---22 ------------------------ ----   011
  Acac  ata  -1--- ------1--------- --- -------- --------------------------- ---------- ------1--2------------ ---------------2-- ---- ----2 ------------------------ ----   10
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  Flac  ind  ----- ---------------2 --- -------- --------------------------- ---------- -------------2-------- ------------------ ---- ----- ------------------------ ----   110
  Comm  mos  1---- 3------------222 --- -------- 1---1--11-1----1----------- --2---32-- ----------1-11-1----1- 221222----------1- -222 1---- -------------1------1--- ----   110
  Baph  mas  ----- ---------------- --- -------- ---1-----1----1------------ ---------- -----------1------112- 2----------------- ---- ----- ------------------1-222- ----   11100
  Bauh  pet  ----- ---------------- --- -------- 2-3------------------------ ---------- -------2----2----2---- ----------------22 --22 ----- -----------------------2 2222   11100
  Comm  mol  ----- ---------------- --- -------- --------------------------- ---------- -------1-------------- ------------------ ---- ----- ---------------------2-- ---1   11101
  Acac  eri  ----- ---------------- --- -------- --------------------------- ---------- ---------------------- ------------------ -2-- ----1 ------------------------ ----   11101
  Vang  inf  ----- ---------------- --- -------- --------------------------- ---------- ---------------------- ------------------ ---- ----- 1----------------------- -12-   11101
  Baik  pl1  ----- ----31-------233 --- ------1- ---1---1--11-----1-12--1-1- 1----432-3 --312343424434214-3--- 2211121-22121--212 4424 44443 332331223214454444455454 34-4   11101
  Schi  rau  -2--- ---------------- --1 -2-12--- ------------2-------------- --1-22-1-- -----1----1-1--------- ------------------ --1- 2---- --------------------112- ----   1111
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Communities   1.1       1.2        2.111   2.112             2.12               2.211          2.212                 2.22        3.111 3.112        3.12              3.2
```

Combretum collinum and *C. apiculatum*, for community 2 are *B. plurijuga* 2 and 3 (a mature woodland) and *G. coleosperma*, and for community 3 is *B. plurijuga* 1 (community of early regrowth stages) (Table 2).

The relationship of the 12 identified tree communities and subcommunities with the land use × development stage combinations show that plots from the more advanced development stages of different land-use systems more likely aggregate with plots from undisturbed sites to form communities (Table 3). For example, 60% to 100%, 20% to 44% and 10% to 80% of plots from concession areas, pole and firewood sites, and abandoned crop fields, respectively, aggregated with plots from undisturbed sites.

Relationship between tree communities in ordination space

The DCA ordination (indirect gradient analysis) shows the spatial distribution of tree communities, subcommunities and their plots in ordination space (Figure 3). The respective eigenvalues were 0.607 for axis 1 and 0.442 for axis 2, explaining respectively 8.4% and 5.9% of the variation, indicating a random distribution of species in the communities. The total variation explained by the first four axes was 22.6% (Table 4). The plot showed communities 1 and 2 on the positive side of axis 1, and clearly separated from community 3, on the negative side of axis 1. Community 1 is also clearly separated from community 2 along axis 2. Community 1 showed much scatter of the plots, with subcommunities clearly separated along axis 1. Community 2 plots are scattered along both axes, with subcommunities 2.111 and 2.112 separated along axis 1, also separated from the other subcommunities of community 2 in relatively close clusters along axis 2. The plots of community 3 are closely grouped, along axis 1, with a few outlier plots along axis 2, and with a separation between subcommunities 3.1 and 3.2.

Importance of tree species across tree communities

The species with the highest importance value in community 1.1 were *Combretum apiculatum* and *Dichrostachys cineria*, and in community 1.2 are *C. collinum* and *C. apiculatum*. These communities were dominated by stages 2 and 3 of different land-use systems, and had no plots from undisturbed sites. *Baikiaea plurijuga* 2 and 3, and *G. coleosperma* had high importance values in most subcommunities of communities 2 and 3. These subcommunities were dominated by plots from undisturbed sites and stages 3 and 4 from different land-use systems. *Baikiaea plurijuga* 1 had high importance values in all subcommunities of community 3, which consisted of plots from abandoned fields' and pole and firewood collection sites at stages 1 and 2. *Pterocarpus angolensis* had a high importance value in community 2.111 that mainly comprised plots from pole and firewood collection sites and abandoned crop fields at stages 1 and 3.

Species associations in tree regeneration

Classification of tree regeneration communities

Four regeneration communities were identified, with

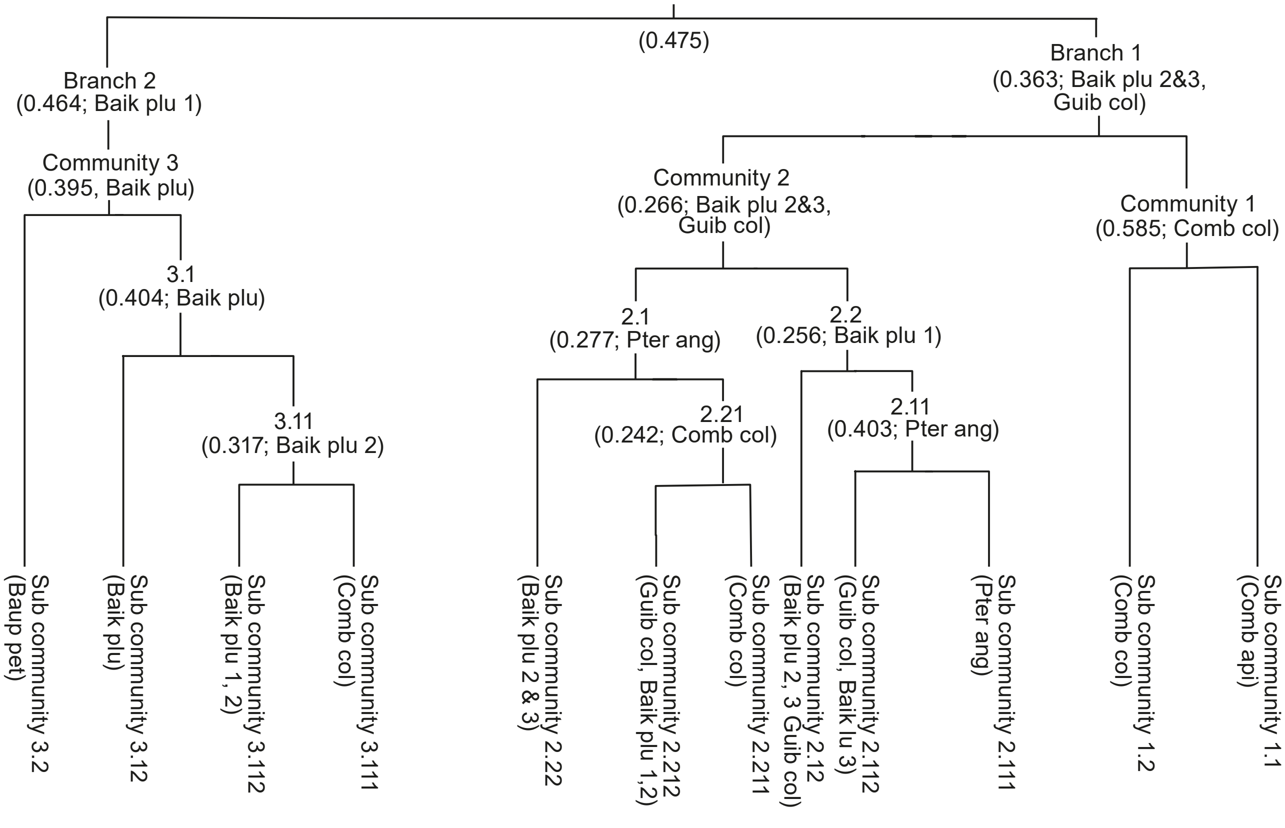

Figure 2: Schematic relationships between communities and subcommunities of tree stands in *Baikiaea–Guibourtia–Pterocarpus* woodlands based on TWINSPAN output table (Appendix 2). The eigenvalues at each subdivision and indicator species for the subcommunities are shown

Table 3: Distribution of plots in each tree community across different land use × stage combinations for trees ≥5 cm DBH

Land use × Stage combinations	Number of plots by Tree Communities												Total plots
	1.1	1.2	2.111	2.112	2.12	2.211	2.212	2.22	3.111	3.112	3.12	3.2	
Protected area	–	–	–	8	22	3	3	4	–	–	–	–	40
Concession area Stage 4	–		–	–	–	–	2	8	–	–	–	–	10
Pole-firewood Stage 4	2	2	–	–	–	–	–	4	–	–	1	–	9
Abandoned field Stage 4	–	5	–	–	1	2	1	–	1	–	–	–	10
Concession area Stage 3	–		–	–	–	–	7	–	1	2	–	–	10
Pole-firewood Stage 3	3	2	1	–	–	–	3	–	–	–	–	–	9
Abandoned field Stage 3	–	–	1	–	3	2	2	1	–	1	–	–	10
Concession area Stage 2	–	2	–	–	1	3	2	–	2	–	–	–	10
Pole-firewood Stage 2	–	3	–	–	–	–	1	1	–	2	3	–	10
Abandoned field Stage 2	–	2	–	–	–	1	–	–	–	–	6	1	10
Pole-firewood Stage 1	–	–	–	–	–	–	–	–	–	–	5	3	8
Abandoned field Stage 1	–	–	1	–	–	–	–	–	–	–	9	–	10
Total plots	5	16	3	8	27	11	21	18	4	5	24	4	146

subdivision into subcommunities, to level 6 for community 1 and level 6 for community 1 (Figure 4), based on the TWINSPAN output table (Table 6). The eigenvalues at each level of division and indicator species for subcommunities are shown. Branch 1 of the first division leads to communities 1 and 2, consisting of 30% undisturbed site plots and most plots from different land-use systems. The indicator species for Branch 1 is *B. plurijuga*. Branch 2 leads to communities 3 and 4, consisting of 63% undisturbed site plots and a few from other land-use systems. The indicator species are *Combretum* species and *P. angolensis* (stems <10 cm DBH). The indicator species for community 1 is *B. plurjuga*, for community 2 is *Baphia massaiensis*, for community 3 are *C. collinum* and *C. molle* (it had no plots from protected areas), and for community 4 is *P. angolensis* (it has only 7.5% of plots from undisturbed sites) (Table 6). Note that *B. plurijuga* regenerated well in communities that had few plots from undisturbed sites and an aggregation of plots from different land-use systems, whereas *P. angolensis* regenerated well in community 4

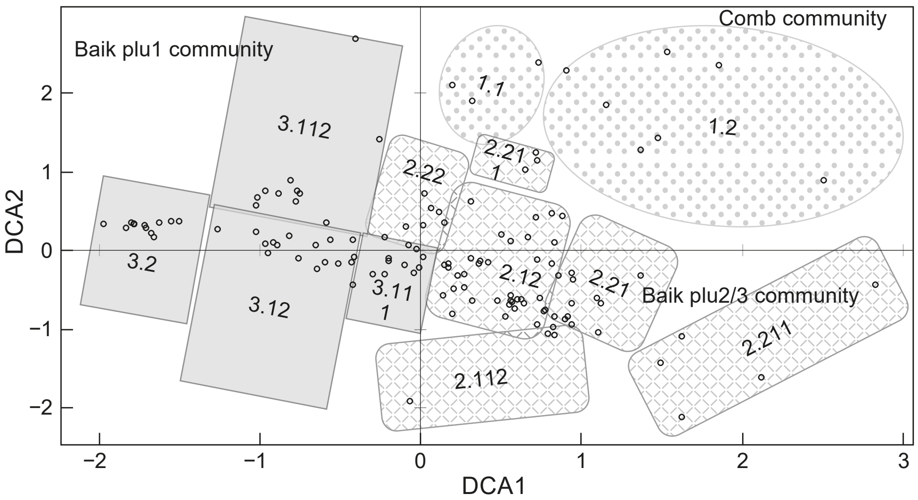

Figure 3: Detrended correspondence analysis ordination diagram of plots for the different tree communities and subcommunities. The community names and subcommunity codes are indicated within the different coloured blocks

Table 4: Principal components, loadings and percentage variance explained for tree communities

	Axis				Total inertia
	1	2	3	4	
Eigenvalues	0.607	0.422	0.378	0.218	7.205
Lengths of gradient	4.795	4.813	6.663	3.401	
Cumulative % variance explained	8.4	14.3	19.5	22.6	

that had a few plots from undisturbed sites and abandoned crop fields at stage 4 (Table 6). *Guibourtia coleosperma* showed poor regeneration in all of the identified communities.

The relationship of the 13 identified regeneration communities and subcommunities with the land-use × development stage combinations showed that plots from the more advanced development stages of different land-use systems more likely aggregate with plots from undisturbed sites to form communities (Table 7). For example, 60% to 80%, 33% to 88% and 20% to 100% of plots from concession areas, pole and firewood collection sites, and abandoned crop fields, respectively, aggregated with plots from undisturbed sites.

Relationship between regeneration communities in ordination space

The DCA ordination shows the spatial distribution of regeneration communities, subcommunities and their plots in ordination space (Figure 5). The respective eigenvalues were 0.631 for axis 1 and 0.410 for axis 2, explaining respectively 9.9% and 6.5% of the variation, and the total variation explained by the first four axes was 26.1% (Table 8). The ordination shows a gradient of plots in a relatively central band along axis 1, with communities 1 and 2 overlapping from the centre to the left, and communities 3 and 4 at the positive end, but separate from each other. Communities 1 (lower part) and 2 (upper part) are separated along axis 2. The subcommunities within communities 1 and 2 are seemingly well-separated along both axes 1 and 2.

Importance of tree species across tree regeneration communities

The species with the highest importance value in community 1.1 were *V. infausta*, *G. flavescens* and *B. plurijuga*, and in subcommunity 1.21 are *B. plurijuga* and *T. sericea*. Note that *B. plurijuga* had high importance values in most subcommunities of community 1 and 2 (a mixture of plots from all land-use systems and undisturbed sites), except 1.2221 and 2.121 and 2.22. *Combretum collinum* and *C. molle* had high importance values in community 3. This community had no plots from the undisturbed sites but abandoned fields at stages 2, 3 and 4. *Pterocarpus angolensis* and *C. apiculatum* had high importance values in community 4, a mixture of plots from undisturbed sites and stages 3 and 4 of abandoned fields.

Relationship between tree and regeneration communities

Each tree regeneration community occurred in a range of tree communities, and each tree community contained a range of tree regeneration communities (Table 10).

Species diversity across the identified tree and regeneration communities

In general, the tree communities were composed of a larger number of species than the regeneration communities, but species richness also showed much variation within these two categories between the subcommunities (Table 11).

The Shannon–Wiener species diversity index differed significantly among tree communities (Table 11; ANOVA *F* statistic = 2.462; df = 11; $p = 0.007$). However, the *post-hoc* results indicated that almost all communities had similar species diversity indices except for communities 2.111 and 3.12. Community 2.111 had the highest species diversity index, with plots from stages 1 and 3 of pole and firewood collection sites and abandoned crop fields (Tables 2

Table 5: Importance values (IV; %) for species with stems ≥5 cm DBH in the different tree communities in the *Baikiaea–Guibourtia–Pterocarpus* woodlands in north-western Zimbabwe. The IV values ≥5% in at least one community are shaded grey

Species[a]	Community											
	1.1	1.2	2.111	2.112	2.12	2.211	2.212	2.22	3.111	3.112	3.12	3.2
Comb api	42.7	12.7	–	–	6.7	1.5	–	0.5	–	–	–	–
Comb mol	7.9	4.4	7.1	–	1.6	3.4	2.4	2.0	–	2.1	3.2	–
Comm mos	4.3	4.7	–	–	1.4	4.6	0.4	3.8	9.4	1.6	2.0	
Dich cin	11.2	–	4.6	–	–	–	–	–	–	–	–	–
Kirk acu	9.8	–	–	–	0.7	1.4	–	1.2	–	–	–	–
Schl bir	9.2	1.2	–	–	–	–	–	–	–	–	1.9	–
Schi rau	5.5	–	5.5	4.6	0.4	4.6	1.2	–	5.0	6.4	3.0	–
Zizi muc	6.2	0.9	–	2.8	–	–	1.0	1.9	–	–	–	–
Comb col	–	46.9	–	1.6	5.9	15.1	4.0	3.5	18.8	6.5	–	–
Eryt afr	–	1.6	5.7	1.4	0.5	–	1.4	0.5	–	–	0.9	–
Term ser	–	6.3	5.5	–	0.5	4.9	0.3	0.7	–	7.2	–	–
Baik plu 1	–	6.4	–	1.0	8.3	9.0	11.4	8.3	22.2	24.4	77.7	45.7
Baik plu 2	–	3.5	–	2.7	9.6	17.4	31.9	21.6	22.1	45.5	–	–
Baik plu 3	–	2.6	–	35.9	25.4	13.9	13.5	44.5	10.4	–	–	–
Guib col	–	–	10.3	29.0	16.9	19.0	13.3	1.1	2.4	–	–	–
Pelt afr	–	–	6.4	–	–	–	0.4	–	–	–	–	–
Pter ang	–	–	54.9	12.7	6.1	1.5	4.3	2.3	–	2.1	–	–
Ochn pul	–	–	–	1.4	0.5	1.4	–	0.5	–	–	1.4	8.2
Pseu map	–	1.7	–	4.1	0.7	–	5.7	0.5	–	–	–	–
Bauh pet	–		–	–	0.8	–	1.3	1.2	5.0	–	1.2	20.3
Vang inf	–	–	–	–	–	–	–	–	–	–	0.9	9.5

[a] See Appendix 1 for complete names

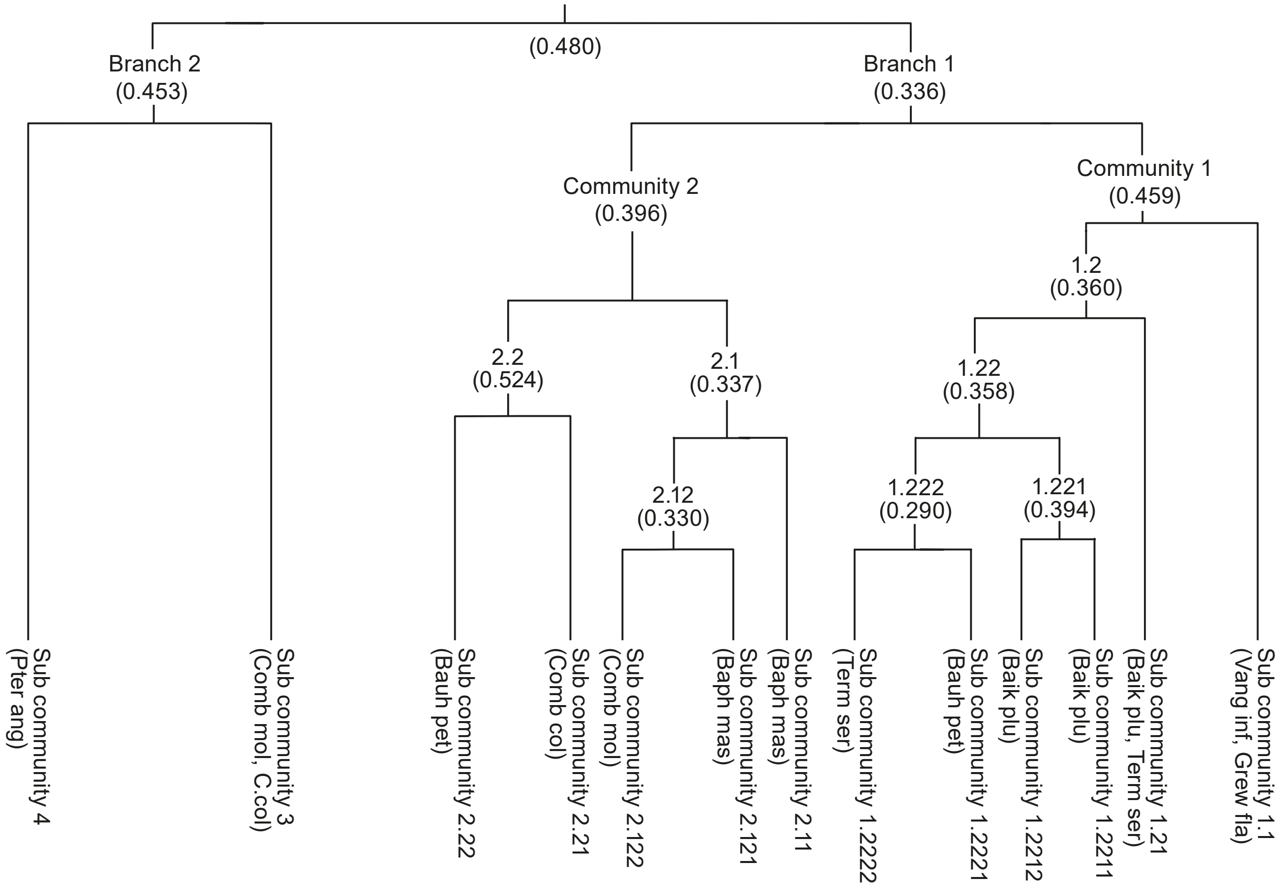

Figure 4: Schematic relationship between communities and subcommunities of tree regeneration in *Baikiaea–Guibourtia–Pterocarpus* woodlands based on TWINSPAN output table (Appendix 3). The eigenvalues at each subdivision and indicator species for the subcommunities are shown

Table 7: Distribution of plots in each regeneration community from different land uses × stage combinations for stems <5 cm DBH

Land use	Tree regeneration communities													Total
	1.1	1.21	1.2211	1.2212	1.2221	1.2222	2.11	2.121	2.122	2.21	2.22	3.0	4.0	
Protected area	–	–	–	6	3	3	5	7	6	4	3		3	40
Concession area Stage 4	–	1	1	2	3	2			1	–	–	–	–	10
Pole-firewood Stage 4	–	1	–	3	1	1	1	2		–	–	–	–	9
Abandoned field Stage 4	–	1	1	1	–	–	–	–	–	–	–	4	3	10
Concession area Stage 3	1	–	–	1	5	1		–	2	–	–	–	–	10
Pole-firewood Stage 3	2	1	3	2	–	–	–	–	–	1	–	–	–	9
Abandoned field Stage 3	–	1	1		–		–		–	–	–	6	2	10
Concession area Stage 2	–	3	1	2	–	2		1	–	1	–	–	–	10
Pole-firewood Stage 2	2	1	1	2	–	–	–	–	–	2	–	2	–	10
Abandoned field Stage 2	–	–	–	–	–	1	1	3		2	3		–	10
Pole-firewood Stage 1	–	–	4	4	–	–	–	–	–	–	–	–	–	8
Abandoned field Stage 1	–	–	–	10	–	–	–	–	–	–	–	–	–	10
Total	5	9	12	33	12	10	7	13	9	10	6	12	8	146

Table 6: TWINSPAN classification of stems <5 cm DBH based on number of stems per plot. Pseudospecies cut levels are 0, 3, 5, 15, and 25. Species with one occurrence were excluded from the table. The different land-use systems (AF = abandoned fields, PF = pole and firewood areas, CA = concession areas, PA = protected areas) in lines 1 and 2, and stages (1, 2, 3 or 4) in line 3 are shown at the top of the table

```
    Land use   CPPPP AACCPPPCC PPPPPPAACC PPPPPPPPPPPAAAAAAAAAAACCCCCPPPPPP PCCCCCCCCPPP PACCCCPPP PAPPPPPP PPAACPPPPPP PPPPPPCCC CPPAPPPA PPPAAA PPAAAAAAAAAA PAAPPAAA
     & stage   AFFFF FFAAFFFAA FFFFFFFFAA FFFFFFFFFFFFFFFFFFFFFFAAAAAAAAAAA FAAAAAAAAAAA FFAAAAAAA FFAAAAAA FFFFAAAAAAA AAAAAAAAA AFFFAAAF AAAFFF FFFFFFFFFFFF AFFAAFFF
               32233 342423222 1112333424 111122334441111111111422344       443333344    422234    42       44222             334 2232   2    222 223333334444  33  444

                                        1                           1111111       111111        11   111111     1111111 111111111 1   111  111                       1  11
               91122 5689 2377     112891   1222233333333344445678890111122 288889000224 367799913 35122342 44570011123 899003334 02344480 234455 115667566765 56736723
               21535 440680047 1239692286 456731469145678901239963591127823 846780023170 258914509 31968217 45054834547 937593483 69527817 066923 047070616135 88302251


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    Term ser   ----- 22221-13- ---------- --------------------------------- ------------ -2-22-222 -------- ----------- --------- 1111-3-3 -3-1-- -------2-2-2 11------ 011
    Grew mon   2---- 33---1--1 ---------- --------------------11------1---- ------------ -2------- -------- ----------- 3-------- 3131---2 -2---- --1-1------2 -------- 011
    Acac ata   ----- ----1--33 ------1--- --------------------------------- ------------ --------- -------1 1-121------ ---1--1-- -------- ---111 -1-222------ -------- 10
    Comb col   ----- 11322-1-- ---1-1---- --------1------------------------ ---1----1--- -1------- -------- ---1------- --------- 232333-- ------ 3122223333-1 32------ 10
    Comb mol   ----- --------1 ---1------ --------------------------------1 -----3------ -2------- -------1 11--33---13 33143-433 -1-1--1- ------ --2222333332 --33---2 10
    Acac nil   ----- --------- ---------- ---------------------2----------- ------------ --------- -------- ----------- --------- --1----- -1---- -1------1--- -------- 10
    Guib col   ----- -1------- ---------- ---------------------2----------- ------------ --------- -------- 1---------- --------- -------- ------ 1--2-------- -------- 110
    Cucu met   ----- 11------- ---------- --------------------------------- ------------ --------- -------- ----------- --------- -------- ------ -----1---1-- -1------ 11100
    Comb api   ----- --------- -----1---- --------------------------------- 1---------11 --------- -2--232- ----------- ----31-31 -------- ------ ---3-3-2123- 3331---- 11101
    Phil vio   ----- --------- ---------- --------------------------------- ------------ -1------- -------- ----------- --------- -------1 1--2-1 ------------ -------- 11101
    Eryt afr   ----- --------- ---------- --------------------------------- ------------ --------- -------- ----------- --------- -------- ------ --1-1------- -------- 11101
    Schi rau   ----- --------- ---------- --------------------------------- ------------ --------- -------- ----------- --------- -------- ------ -------3-341 333----- 11101
    Pter ang   ----- --22----- ---------- --------------------------------- ------------ --------- ---1---- ----------- -----1--3 -------- ------ ------------ 3313-133 1111
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Communities      1.1   1.21      1.2211                1.2212                  1.2221     1.2222    2.11      2.121       2.122    2.21    2.22       3.0        4.0
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and 3). Communities with plots from undisturbed sites had low species diversity. The lowest species diversity was recorded in communities 3.12 with plots from young stands under recovery (stages 1 and 2) of pole and firewood collection sites and abandoned crop fields (Table 3).

The differences in Shannon–Wiener species diversity index among regeneration communities were insignificant (Table 11; ANOVA *F* statistic = 1.681; df = 12; $p = 0.07$). The *post-hoc* results indicated that almost all communities had similar species diversity indices except for communities 1.1 and 1.2212. The highest species diversity was recorded in community 1.1, with plots from stages 3 and 4 of pole and firewood collection sites. Communities with plots from undisturbed sites had low species diversity. Lowest species diversity was recorded in community 1.2212 with a mixture of plots from different land-use systems (Tables 6 and 7).

Discussion

Vegetation classification

The study has revealed that plots from the least development stages (1 and 2) of different land-use systems aggregated into similar communities, with each community having plots from different land uses. Similarly, plots from advanced development stages (3 and 4) of concession area sites, pole and firewood collection sites, and previously cultivated fields also aggregate into communities mostly associated with undisturbed stands, but which are different

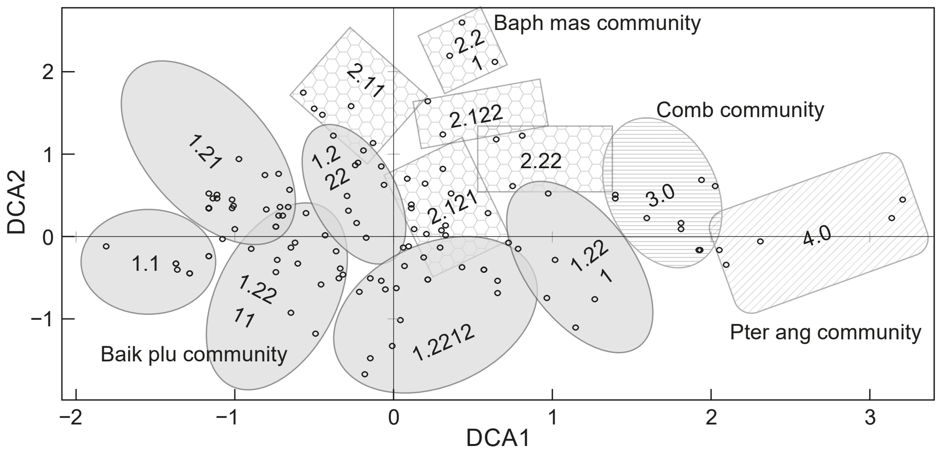

Figure 5: Detrended correspondence analysis ordination diagram of plots for the different regeneration communities and subcommunities. The community names and subcommunity codes are indicated within the different coloured blocks

Table 8: Principal components, loadings and percentage variance explained for regeneration communities

	Axis				Total inertia
	1	2	3	4	
Eigenvalues	0.631	0.410	0.351	0.269	6.358
Lengths of gradient	5.014	4.389	4.033	2.968	
Cumulative % variance explained	9.9	16.4	21.9	26.1	

from the communities of the early stages. This was shown for both tree and regeneration communities. This shows that stand development in these woodland ecosystems converge to more similar mature communities. The study showed that plots with similar intensity of disturbance tend to have similar species composition in their early recovery, with aggregation into similar communities, similar to the results presented by Childes and Walker (1987). As such stands develop without further disturbance, their species composition converges to that of undisturbed sites. Concession areas at stages 3 and 4 showed a higher percentage of plots aggregating with plots from undisturbed sites whereas pole and firewood collection sites showed a lower percentage. The intensity of disturbance in concession areas is less compared with that of pole and firewood collection sites and abandoned crop fields. This is because of the single-tree selection system that is practiced during harvesting operations. Only trees of specific species (usually *B. plurijuga*, *G. coleosperma* and *P. angolensis)* that have attained a diameter limit of >25 cm are harvested. The remainder are left to grow to maturity for the next harvesting entry. However, in pole and firewood collection sites, trees are usually harvested in groups for a variety of products by local communities. It is more likely that different species from the resident species will occupy and establish in the gaps.

Pterocarpus angolensis was able to regenerate in heavily disturbed areas and in the undisturbed sites where no timber harvesting is allowed. These findings are consistent with other studies that concluded that *P. angolensis* (a shade-intolerant species) performs well in cleared areas because of total exposure to maximum light (Boaler 1966; Werren et al. 1995; Graz 1996). In addition, reduced competition for moisture and nutrients contribute to good performance of the species in cleared areas. In a study by Syampungani (2009), *P. angolensis* performed well in charcoal production and slash and burn activities. The author further suggested that opening the forest land may also result in reduced effects of allelopathy arising from interaction between species.

Clear-felling during land preparation and length of cultivation of other crops in the abandoned crop fields might also result in variation in species composition. Imai et al. (2012) and Putz et al. (2012) suggested that woodland management strategies can accommodate low to moderate levels of utilisation whilst maintaining tree species richness, diversity and abundance. This suggests that long-term cultivation removes existing rootstocks and seed banks of key species in the soil, hence impacting on the regeneration of key species as studies have shown that fast-growing species such as *Combretum* species dominate the high utilisation sites (Backéus et al. 2006). Feldpausch et al. (2004) concluded that the rate of aboveground biomass accumulation is fastest in the first two decades of forest cultivation and declines thereafter. This suggests that long periods of intensive use or disturbance can retard biomass accumulation in secondary growth of tropical dry forests (Chidumayo and Gumbo 2013) In addition, long-term cultivation may result in soil nutrient depletion that can further retard the regeneration and growth of trees. What then must we do to recover the key species? This might imply that forest managers should consider short-term cultivation of crops in areas that have been harvested so as to allow regeneration of key species in the abandoned areas. Woodland management options in these areas should aim to create a mosaic of woodland and cultivation. A comprehensive programme is necessary to monitor the levels of cultivation and the impacts on woodland recovery.

Differences in species diversity in tree and regeneration communities

High species diversity in pole and firewood and abandoned crop fields at advanced stages could be explained by the

Table 9: Importance values (%) for species in the regeneration (stems <5 cm DBH) in the different regeneration communities in *Baikiaea–Guibourtia–Pterocarpus* woodlands in north-western Zimbabwe. The IV values ≥5% in at least one community are shaded grey

Species[a]	Community												
	1.1	1.21	1.2211	1.2212	1.2221	1.2222	2.11	2.121	2.122	2.21	2.22	3	4
Acac ata	–	8.8	1.9	–	–	–	–	6.9	2.9	4.3	–	5.4	–
Baik plu	20.7	18.4	44.3	71.2	–	35.2	34.2	21.5	25.6	12.8	14.1	2.1	–
Baph mas	–	–	–	4.6	28.8	2.8	8.1	27.4	19.0	21.2	21.4	–	3.8
Bauh pet	–	5.8	–	–	5.6	18.1	12.0	–	12.1	11.7	35.2	–	2.6
Comb api	–	–	1.9	–	24.4	4.0	–	–	7.7	–	–	11.8	12.9
Comb col	–	10.9	3.9	1.1	–	2.4	1.5	1.4	–	13.8	–	20.0	6.3
Comb mol	–	1.3	2.3	1.1	–	2.0	2.0	12.3	24.6	4.6	–	19.9	10.4
Comm mos	–	–	–	–	–	18.8	–	3.3	–	1.4	–	–	1.7
Ochn pul	–	11.0	14.2	–	13.8	4.8	–	8.6	–	–	7.4	3.4	3.4
Pter ang	–	3.7	–	–	3.1	–	–	–	4.0	–	–	–	22.7
Pseu map	–	5.3	–	–	–	–	13.6	2.6	–	–	–	–	–
Sear ten	14.7	1.3	1.9	3.7	–	–	1.5	–	–	–	–	–	–
Term ser	–	12.5	–	–	–	–	13.6	–	–	10.2	7.5	4.7	3.4
Vang inf	32.1	–	17.3	–	–	–	–	1.4	–	6.4	–	1.6	–
Grew mon	6.0	11.5		3.7	–	–	2.0	–	2.5	8.8	4.8	3.4	–
Grew fla	22.3		2.8	7.2	13.1	1.1	–	8.3	1.6	–	7.5	4.2	5.1
Stry coc	–	–	7.6	–	3.7	1.4	3.5	–	–	–	–	1.0	–
Julb glo	–	–	–	–	7.5	–	–	2.4	–	–	–	–	–
Phil vio	–	–	–	–	–	–	1.5	–	–	–	–	9.3	11.0
Eryt afr	–	–	–	–	–	–	–	–	–	–	–	2.4	5.7
Pelt afr	–	–	–	–	–	–	–	–	–	–	–	–	9.3

[a] See Appendix 1 for complete names

Table 10: Relationship between tree and regeneration communities in *Baikiaea–Guibourtia–Pterocarpus* woodlands of north-western Zimbabwe

Tree community		Regeneration communities												
		1.1	1.21	1.2211	1.2212	1.2221	1.2222	2.11	2.121	2.122	2.21	2.22	3.0	4.0
	Plots	5	9	12	33	13	10	7	13	9	10	6	11	8
1.1	5	1	2		1	1								
1.2	16	2	4	7		1					2			
2.111	3			1		2								
2.112	8						2	2	2			2		
2.12	27					4	3	4	4	1		2	6	3
2.211	11					2	3			1	1		3	1
2.212	21	2	1	3	7	1			1	1	3			2
2.22	18			1	7	1			4	2	2		1	
3.111	4						2		1				1	
3.112	6		2		2			1		1				
3.12	23				16				1	2	1	2		1
3.2	4					1				1	1			1

fact that the resource utilisation patterns at these sites resulted in the creation of large canopy gaps and many different pioneer species can occupy the created gaps and establish themselves. The findings are consistent with the conclusion that vegetation removal leads to rapid growth, which leads to increased species diversity (Kobayashi et al. 1997). Communities comprising plots from undisturbed sites and early development stages of abandoned fields, and pole and firewood collections sites showed low species diversity. The canopy tree species suppress other tree species or the woody species growing in the undisturbed sites, hence the low species diversity. There is little free space on the forest floor for other tree species to grow in undisturbed sites. It is only the large mature trees that are retained at these sites. Frequent fires in these woodlands may also keep the plants to <0.5 m height.

High species diversity for regeneration communities was in a community that mainly comprised plots from pole and firewood collection sites. However, this community was dominated by *V. infausta* and *G. flavescens.* Communities with plots from undisturbed sites also showed high species diversity. This could be a result of seedlings and saplings growing from rootstocks, lateral roots and availability of seeds from mature trees in these stands.

Relationship between communities in ordination space

The DCA results indicated that the underlying site factors explain little variation in the identified communities, suggesting that recovery from disturbance with different land uses may explain more of such variation. Differences in species composition from the identified communities are mainly driven by disturbance factors (recovery from different

Table 11: Differences in species diversity (mean ± SE) across the identified tree and regeneration communities. Values within a column followed by a different superscript differ significantly (Tukey's HSD; $p < 0.05$)

Community	Tree species diversity	Species richness	Regeneration community	Regeneration species diversity	Species richness
1.1	0.15 ± 0.02^{a}	9	1.1	0.25 ± 0.04^{ab}	6
1.2	0.08 ± 0.02^{a}	20	1.21	0.15 ± 0.02^{a}	15
2.111	0.18 ± 0.03^{ab}	8	1.2211	0.12 ± 0.03^{a}	11
2.112	0.13 ± 0.03^{a}	15	1.2212	0.06 ± 0.01^{ac}	11
2.12	0.08 ± 0.02^{a}	28	1.2221	0.21 ± 0.04^{a}	8
2.211	0.13 ± 0.03^{a}	16	1.2222	0.12 ± 0.03^{a}	13
2.212	0.07 ± 0.02^{a}	26	2.11	0.12 ± 0.03^{a}	14
2.22	0.08 ± 0.02^{a}	22	2.121	0.13 ± 0.04^{a}	14
3.111	0.17 ± 0.04^{a}	10	2.122	0.18 ± 0.04^{a}	9
3.112	0.13 ± 0.04^{a}	10	2.21	0.17 ± 0.03^{a}	12
3.12	0.05 ± 0.03^{ac}	13	2.22	0.18 ± 0.04^{a}	8
3.2	0.11 ± 0.07^{a}	7	3.0	0.12 ± 0.02^{a}	18
			4.0	0.16 ± 0.02^{a}	14
$F_{11,170} = 2.462$			$F_{12,140} = 1.68$		
p-value	0.007		*p*-value	0.07	

intensities of disturbance) and not environmental factors as seen by the aggregation of plots from different land-use systems. The nature of disturbance, and magnitude and age since disturbance cessation have a great impact on species composition. A study by Childes and Walker (1987) in Hwange National Park concluded that both the edaphic and disturbance factors influence the classification of vegetation into nine main vegetation groups. In this study, environmental and physical factors were not studied to show their influence on vegetation composition. The low variation explained by axes 1 and 2 in the DCA results did not justify further investigation of the different factors on species composition. The low percentage variation explained by axes 1 and 2 in both tree and regeneration communities suggest a random distribution of species in communities. This might be explained by the different combinations of plots from different disturbance factors, hence a clear-cut grouping of species is not possible.

Community 1 and 2 plots were grouped close together because the two communities mainly comprised plots at advanced development stages. The two communities were clearly separated from community 3 that mainly comprised least development stages. However, community 1, composed of plots at stages 2, 3 and 4 of concession areas, pole and firewood collection sites and abandoned crop fields, was clearly separated from community 2, which was composed of all plots from undisturbed sites. Community 2 had all the key species of the *Baikiaea–Guibourtia–Pterocarpus* woodlands, in contrast to community 1, which mainly comprised *Combretum* species and *Terminalia* species. This community did not have undisturbed sites' plots but was dominated by stages 2 and a few stages 3 and 4 of different land-use systems. This suggests that this community was under recovery from disturbances, in contrast to community 2, which is a mature community with fewer disturbances. In addition, community 3, which comprised the least developed stages, was dominated by *B. plurijuga* 1 and *B. petersiana.* The same pattern was observed with regeneration communities, where communities 1 and 2 mainly comprised advanced stages of development and undisturbed sites' plots, whereas communities 3 and 4 were close together and mainly comprised abandoned crop fields' plots. Community 1 comprising undisturbed sites plots had a high prevalence of *B. plurijuga*, whereas community 4 comprising stages 3 and 4 of abandoned crop fields had a high prevalence of *P. angolensis.* This finding implies that the type and intensity of disturbance had a strong influence on species assemblages and hence community aggregation.

Conclusion

We conclude that, even if the site shows potential for woodland of a specific type to develop, community aggregation is mainly influenced by utilisation systems. The intense land-use systems of clearing for crop cultivation and to a lesser extent harvesting for poles and firewood are necessary disturbances for the rejuvenation of *Baikiaea–Guibourtia–Pterocarpus* woodlands. The key commercial species, especially *B. plurijuga,* are important in most subcommunities for both tree and regeneration communities, whereas *P. angolensis* is important in heavily disturbed sites of pole and firewood collection sites and abandoned crop fields. *Guibourtia coleosperma* is important in tree communities that comprise plots from undisturbed sites and stages 3 and 4 of concession areas and abandoned fields. These sites show evidence of fire and hence negatively affect the regeneration population of the species. The species has low importance values in regeneration communities where it occurs. Results from this study suggest that the system is resilient even when severely disturbed by clearing for crops and harvesting for poles. The intense land-use systems are necessary components to rejuvenate *Baikiaea–Guibourtia–Pterorcapus* woodlands. This study suggests that recovery of resources at advanced stages of abandoned fields favour the characteristic species composition of the ideal *Baikiaea–Guibourtia–Pterocarpus* woodlands.

Acknowledgements — The authors thank the Forestry Commission for allowing us to carry out the study in their forest areas. Many thanks go to Moreblessing Dirikwe, Linda Moyo, Alford Magwizi, Forestry Commission personnel in Gwayi forest and Tsholotsho (Mr Gumbo, Mr Shoniwa, Mr Nkala and timber harvesting crew) who helped with data collection. Special thanks go to Dr HGT Ndagurwa who assisted immensely with data analysis.

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