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# Restoration of diversity and regeneration of woody species through area exclosure: the case of Maun International Airport in northern Botswana

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**Background and objectives:** Deforested and degraded areas can be cheaply and conveniently restored through establishment of exclosures. An area exclosure excludes animals and humans from accessing an area to promote natural regeneration of plants and rehabilitate ecological condition of the area. The study was aimed at: (1) determining the diversity (species richness, diversity and evenness); (2) assessing the stand structure (densities); and (3) assessing regeneration status of woody species inside and outside exclosed Maun International Airport, northern Botswana.

**Methods:** Vegetation sampling was conducted from April to May 2018. A total of 48 and 37 quadrats of 20 × 20 m were laid down at 50 m intervals along transect lines inside and outside Maun International Airport, respectively. Identity, number of all live individuals and height of all woody species were recorded in all the quadrats. The diversity of all woody species was analysed by using the Shannon Diversity Index (H′) and regeneration status of each woody species was assessed using frequency distribution of height class.

**Results:** The diversity, evenness and species richness were significantly higher inside than outside Maun International Airport. *Colophospermum mopane* was the most abundant species both inside (75% of all woody species) and outside (96% of all woody species) Maun International Airport. More species showed more regeneration inside than outside Maun International Airport. The inside of Maun International Airport recorded more alien invasive woody species compared with the outside, owing to its original use as a residential area. The local communities might have introduced these species as ornamental trees.

**Conclusion:** This study, while limited in scale, contributes to understanding of the role of exclosures in enhancing woody species richness, diversity and evenness as well as facilitating regeneration of woody species. Degraded woodlands and other similar ecosystems could be cheaply and conveniently restored through establishment of exclosures, but more research and monitoring are required to fully understand the processes and impacts.

**Keywords:** density, evenness, population structure, regeneration.

## Introduction

Tropical dry forests and woodlands, considered as savanna in Botswana, account for about 42% of all tropical and sub-tropical forest area (Hasnat & Hossain 2020). Forests and woodlands provide a suite of valuable ecosystem services that are important livelihood activities for most rural communities (Shackleton & Shackleton 2004), particularly the poor and vulnerable communities in sub-Saharan Africa (SSA) who strongly depend on forest and non-timber forest products (NTFPs) for sustenance (Kabubo-Mariara 2013; Van Passel et al. 2020). The ecosystem services provided include provisioning services (e.g., fuelwood, timber, food) (Boy & Witt 2013), regulating services (e.g., carbon sequestration, erosion control and reduction of air pollution) (Morgenroth et al. 2016) and cultural services (spiritual, religious, cognitive effects and tree monuments) (Dallimer et al. 2012).

However, forests are being destroyed at an alarming rate worldwide (Elliot et al. 2013), with an estimated loss of about 1–4% of their current area per annum (Naidu & Kumar 2016). The destruction is attributable to increasing anthropogenic activities, deforestation and natural factors (Chow et al. 2013; Siyum 2020). The destruction of forests is largely driven by human and livestock populations, which result in land-use changes from forestry to agriculture and human settlement (Neelo et al. 2013), owing to their favourable climatic conditions (Ewel 1999). Moreover, climate change and its associated impacts on temperature and rainfall patterns are expected to affect dry woodlands and forests (IPCC 2014), and forests are overexploited for fuelwood, construction material and timber.

In Botswana unsustainable use and the ineffective management of mopane woodlands, as well as their conversion to other land-use types, are depriving the local communities of the full benefits that can be derived from the mopane woodlands (Makhado et al. 2014; Teketay et al. 2018). The reduction and degradation of forests calls for strategies to conserve and maintain the remaining forests and simultaneously restore deforested and degraded areas (Teketay et al. 2018). One such strategy that has been used recently to reverse deforestation and degradation is the establishment of area exclosures. An area exclosure is used as a fast, cheap and convenient approach to restoring degraded forest and woodland areas. The area exclosure is closed from animals and human access to promote natural regeneration of plants and to rehabilitate the ecological condition of the area (Teketay et al. 2018; Atsbha et al. 2019). Exclosures have been used in many countries across the world, e.g., China (Park et al. 2013; Liu et al. 2019), central America (Griscom & Ashton 2011), Australia (Bastin et al. 2003; Silcock & Fensham 2013), Scotland (Shaw et al. 2010), Iran (Ebrahimi et al. 2016), Ethiopia (Gebregerges et al. 2018; Ubuy et al. 2018; Atsbha et al. 2019; Asmare & Gure 2019), Kenya (Wairore et al. 2016) and South Africa (Mbatha & Ward 2010).

Various studies on the area exclosure have been conducted in Botswana, including in Mokolodi Nature Reserve (MNR) in southern Botswana (Flyman 1999; Käller 2003; Bengtsson-Sjörs 2006; Teketay et al. 2016) and also in northern (Neelo et al. 2015; Teketay et al. 2018) parts of the country. In the case of the studies in MNR, Flyman (1999) excluded herbivores to determine the fate of seedlings of woody species, Käller (2003) investigated growth pattern and reproduction of woody vegetation and Bengtsson-Sjörs (2006) studied establishment and survival of woody seedlings. Recently, Teketay et al. (2016) found that most woody species in MNR exhibited unstable population structure and hampered natural regeneration following exposure to overgrazing and other heavy anthropogenic impacts. In northern Botswana, studies on exclosure were conducted in sites close to the current study area by Neelo et al. (2015) and Teketay et al. (2018). Neelo et al. (2015) discovered that exclosure had similar diversity and density values compared with open areas and attributed such observations to heavy over-grazing and cutting of trees before establishment of the exclosure, as well as to seasonal flooding of a large portion of the exclosed area owing to its proximity to Thamalakane River. In the study reported by Teketay et al. (2018), mean density, population structure and regeneration status of woody species inside the exclosure was better than outside. All these studies on area exclosures in Botswana were conducted on formerly degraded grazing lands. Studies on the impact of exclosure on areas formerly used as residential areas or human settlement are limited in Botswana.

Therefore, this study aimed at conducting a comparative study on woody species diversity, stand structure of woodlands and regeneration status of the woody species in a ten-year area exclosure (inside Maun International Airport) and open area adjacent to Maun International Airport, northern Botswana. The specific objectives of the study were to: (1) determine the diversity (species richness, diversity and evenness); (2) assess the stand structure (densities and frequencies); and (3) assess regeneration status of woody species inside and outside the area exclosure.

# Materials and methods

## Study area

The study was conducted in Maun Village, Ngamiland District, northern Botswana (Figure 1). The village is located within the Okavango Delta, which is the distal part of the Okavango River Basin. The Delta originates in the Angolan highlands where the Cuito and Cubango river catchments receive 876 and 983 mm of rain per annum, respectively (Wolski & Murray-Hudson 2008). The Okavango River then discharges 10 $km^3$ into the alluvial fan of about 12 000 $km^2$ (McCarthy 2006). The flood wave peak discharge at the Panhandle is between April and May, and then meanders across 250 km of seasonal floodplains to arrive at Thamalakane River in Maun between July and August (McCarthy et al. 2000; Mazvimavi & Mmopelwa 2006).

The Okavango Delta is a globally renowned Wetland of International Importance and Ramsar site and was

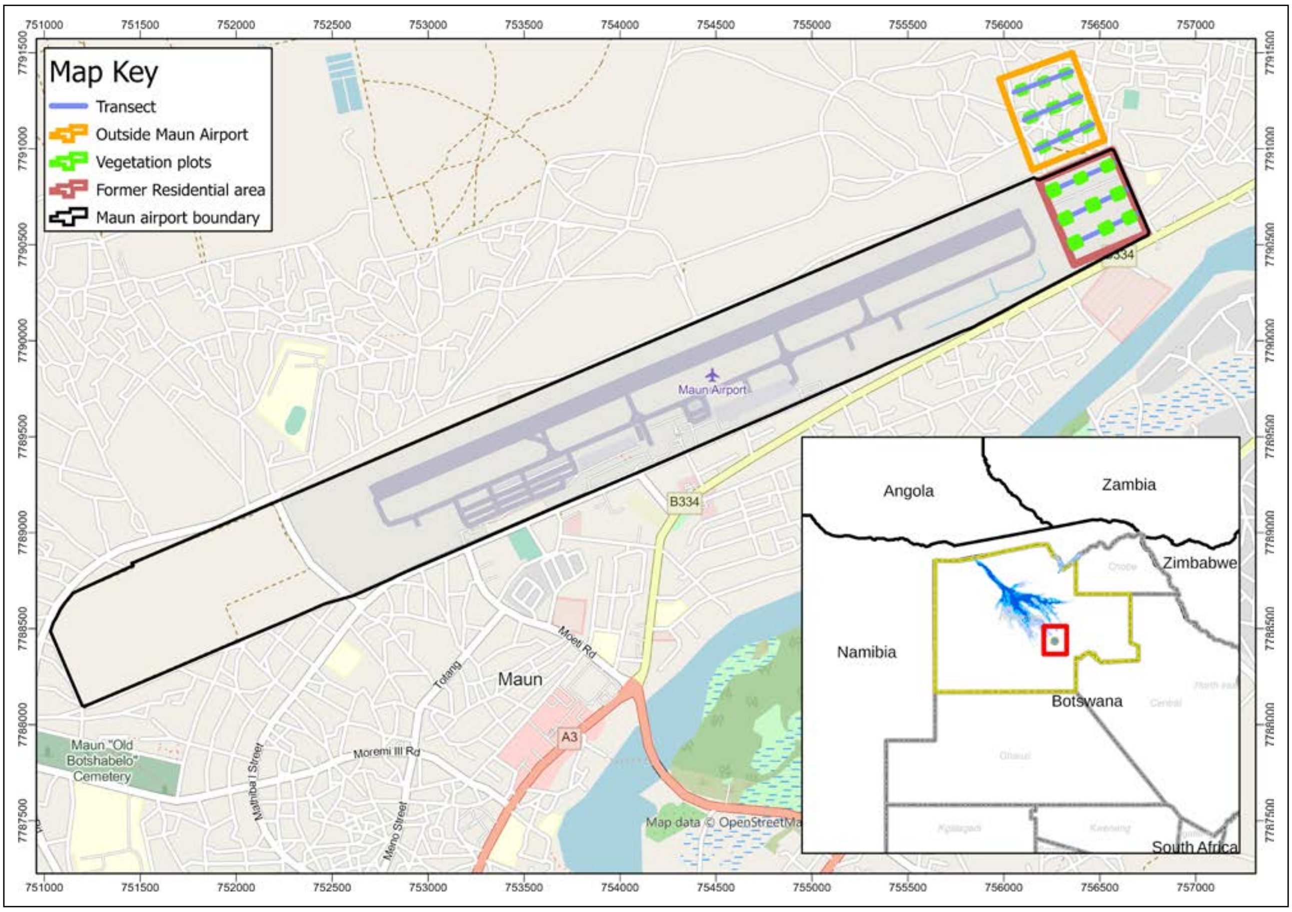


**Figure 1.** Map showing location of the study area.

inscribed as UNESCO's 1000th World Heritage Site in 2014. The stunning scenery of the Delta, characterised by an array of plant and animal life, swamps and islands, attract thousands of tourists who visit every year (Mbaiwa 2018). The tourism sector is only surpassed by mining and contributes about 4.5% to the country's Gross Domestic Product (Mbaiwa & Hambira 2020). The riparian communities depend on the Delta's ecosystem resources for their livelihoods. Common livelihood activities include dry and flood recession farming, fishing, collection of veld products, harvesting of thatching grass and reeds, basket making and tourism (Blackie & Casadevall 2019).

## Study site

The first study site was Maun International Airport (MIA) (Figure 1), located on Kalahari sandveld with > 90% sand (Veenendaal et al. 2008). Annual rainfall is quite variable, averaging between 450 and 500 mm, falling in one distinct season between November and April (Moore & Attwell 1999). Maun is the fifth largest village in Botswana with a population of 60 263 (Statistics Botswana 2014). MIA is the second busiest airport to Sir Seretse Khama International Airport (SSKIA) in terms of the number of passengers (CAAB 2019). It caters for both domestic and international flights. Owing to its proximity to the Okavango Delta, it serves as the gateway for tourists visiting the delta. MIA traffic is dominated by small single- and twin-engine aircrafts that fly daily to and from airfields in the Delta. In 2014, there were 24 864 landings, 24 870 departures and 234 896 passengers (Mmolai 2015). In response to an increase in air traffic within MIA, the Government of Botswana relocated 1 595 families within the vicinity of the airport for expansion and upgrading of the airport in 2006. The area has been a village settlement since 1985 (21 years) when it was allocated for residential use. The area was fenced in 2010, enclosing the formerly residential areas (or human settlement) to be part of MIA. The study site was therefore exclosed by a fence for ten years at the time of the current study. The inside and outside sites of MIA were adjacent and only separated by a fence. The outside of MIA was a communal area that was used for grazing and harvesting of fuelwood. At the time of the study, the exclosure (inside MIA) represents a site with low anthropogenic disturbances and outside the exclosure (outside MIA) represents the site with high anthropogenic disturbances due to open access to grazing animals and harvesting of woody species.

## Data collection

The species, genera, family, diversity (richness and evenness) and regeneration status of the woody species was

**Table 1**. Comparison of diversity indices and total density of woody species inside and outside of Maun International Airport

| Site | Density (individuals ha$^{-1}$) | H′ | E | Species richness |
|---|---|---|---|---|
| Inside | 2 642 | 1.06 | 0.43 | 26 |
| Outside | 6 435 | 0.21 | 0.07 | 12 |

determined in March 2020 by laying six and five parallel line transects, 50 m apart inside and outside MIA, respectively. The number of transect lines was informed by the size of the area and spatial heterogeneity of the vegetation. On the transect lines, quadrats measuring 20 × 20 m (400 m$^2$) were laid down at 50 m intervals, leading to a total of 48 quadrats inside and 37 quadrats outside MIA. The first quadrat was placed 20 m away from the first transect line to minimise the border effect. Following the procedure adopted by Neelo et al. (2013, 2015) and Teketay et al. (2016, 2018), the following parameters were recorded in each of the quadrats: identity of all woody species, number of all live individuals of each woody species and height of all woody species. A graduated 20 mm polyvinyl chloride (PVC) conduit was used to measure plant height.

The woody species were identified directly at the sites using books published on the flora of Botswana (Heath & Heath 2009; Setshogo 2002, 2005; Setshogo & Venter 2003) and with assistance from the forest officers and local communities familiar with the flora. Where species could not be identified, herbarium specimens were collected, and photographs were taken for later identification at the Peter Smith University of Botswana Herbarium (PSUB). In this article, woody species nomenclature follows that of Setshogo and Venter (2003) and Setshogo (2005).

## Data analysis

The diversity of woody species was analysed using the Shannon Diversity Index (*H′*). Evenness (*E*), or equitability, measures similarity of the abundance of the different woody species in the different habitats and was analysed by using Shannon's Evenness Index. Its value ranges from 0 to 1, with 1 being complete evenness.

Regeneration status of each woody species in the two sites was assessed using frequency distribution of diameter classes. Histograms were constructed by using the density of individuals of each species categorised into five height classes i.e., 0.0–0.5 m; 0.5–1.0 m; 1.0–2.0 m; 2.0–4.0 m and > 4.0 m. The woody species were then grouped according to the pattern of the histograms.

# Results

## Species diversity and density

Species accumulation curves show that all species were likely to have been sampled in both areas (Figure 2). The comparison of diversity (*H′*), evenness (*E*), species richness and density are shown in Table 1.

The four most common woody species inside MIA were *Colophospermum mopane, Leucaena leucocephala, Vachellia erioloba* and *Dodonaea angustifolia*. These four species dominated outside MIA (Table 2), and *C. mopane* was found to be the most abundant species both inside (75% of all woody species) and outside (96% of all woody species) MIA (Figure 3). Five invasive alien plant species were recorded inside MIA.

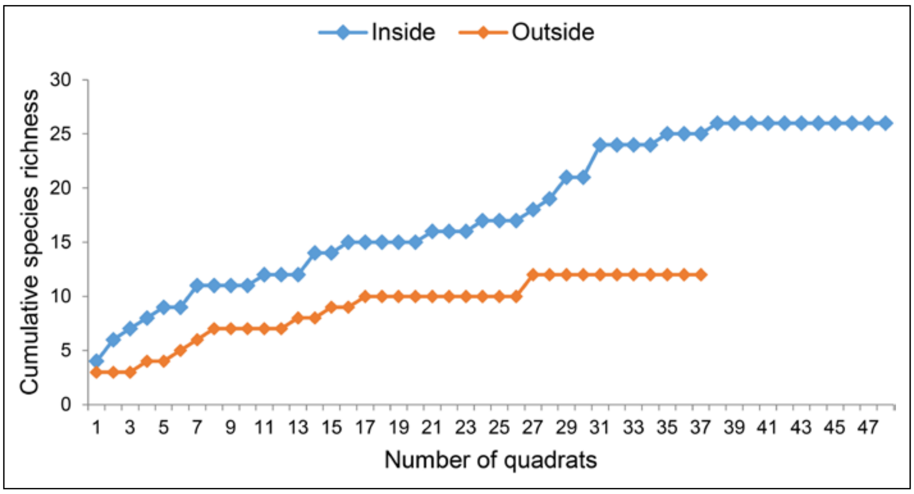


**Figure 2.** Species accumulation curves for woody species inside and outside MIA.

**Table 2.** Mean density per hectare, life form and family names of woody species recorded inside and outside MIA

| Species | Life form | Family | Density (individuals ha$^{-1}$) ± SEM | |
|---|---|---|---|---|
| | | | Inside | Outside |
| *Colophospermum mopane* | Tree | Fabaceae | 1971 ± 398 | 6201 ± 872 |
| *Leucaena leucocephala** | Shrub/small tree | Fabaceae | 266 ± 64 | 0 |
| *Vachellia erioloba* | Tree | Fabaceae | 150 ± 73 | 130 ± 41 |
| *Dodonaea angustifolia*** | Shrub | Sapindaceae | 77 ± 20 | 5 ± 4 |
| *Sclerocarya birrea* | Tree | Anacardiaceae | 56 ± 31 | 0 |
| *Vachellia tortilis* | Tree | Fabaceae | 25 ± 18 | 44 ± 32 |
| *Berchemia discolor* | Tree | Rhamnaceae | 15 ± 9 | 2 ± 2 |
| *Philenoptera nelsii* | Tree | Fabaceae | 14 ± 11 | 1 ± 1 |
| *Grewia bicolor* | Shrub | Malvaceae | 8 ± 6 | 0 |
| *Phyllanthus reticulatus* | Shrub | Phyllanthaceae | 7 ± 4 | 0 |
| *Ailanthus altissima** | Tree | Simaroubaceae | 7 ± 7 | 0 |
| *Combretum mossambicense* | Tree | Combretaceae | 6 ± 3 | 0 |
| *Combretum imberbe* | Tree | Combretaceae | 5 ± 4 | 0 |
| *Ricinus communis** | Shrub/small tree | Euphorbiaceae | 5 ± 5 | 0 |
| *Senegalia mellifera* | Tree | Fabaceae | 5 ± 5 | 2 ± 2 |
| *Boscia albitrunca* | Tree | Capparaceae | 5 ± 4 | 19 ± 13 |
| *Jatropha curcas** | Shrub/small tree | Euphorbiaceae | 4 ± 3 | 0 |
| *Ziziphus mucronata* | Shrub/small tree | Rhamnaceae | 4 ± 3 | 18 ± 12 |
| *Dichrostachys cinerea* | Tree | Fabaceae | 3 ± 3 | 6 ± 6 |
| *Philenoptera violacea* | Tree | Fabaceae | 2 ± 2 | 1 ± 1 |
| *Hyphaene petersiana* | Tree | Arecaceae | 2 ± 2 | 0 |
| *Combretum collinum* | Tree | Combretaceae | 1 ± 1 | 0 |
| *Croton megalobotrys* | Tree | Euphorbiaceae | 1 ± 1 | 0 |
| *Terminalia prunioides* | Small tree/shrub | Combretaceae | 1 ± 1 | 6 ± 5 |
| *Terminalia sericea* | Tree | Combretaceae | 1 ± 1 | 0 |
| *Jacaranda mimosifolia** | Tree | Bignoniaceae | 1 ± 1 | 0 |
| **Total** | | | 2 642 ± 281 | 6 435 ± 688 |

* = Invasive alien species; ** = Exotic species

Interestingly, the invasive woody species, *L. leucocephala* was the second most abundant species inside and was absent outside MIA. Similarly, other invasive woody species (*Ricinus communis, Jatropha curcas, Ailanthus altissima* and *Jacaranda mimosifolia*) were encountered inside, but not found outside MIA. Some indigenous fruit-bearing woody species, such as *Berchemia discolor, Boscia albitrunca* and *Ziziphus mucronata* were found both inside and outside MIA. Other indigenous fruit-bearing species (*Sclerocarya birrea, Grewia bicolor* and *Hyphaene petersiana*) were only present inside MIA.

## Regeneration status

Assessment of the regeneration structure of woody species inside MIA produced four regeneration patterns (Figure 4). The first pattern showed a high number of individuals in the shorter height classes and a gradual decline towards the tallest classes (Figure 4A, B, C and D). Such a 'reverse J-shaped' pattern was evident for *C. mopane, V. erioloba, Grewia bicolor, Phyllantus reticulatus, D. angustifolia* and *V. tortilis*. The species in the second pattern showed a lack of individuals in the shortest height class and no individuals in the tallest height classes (Figure 4E,

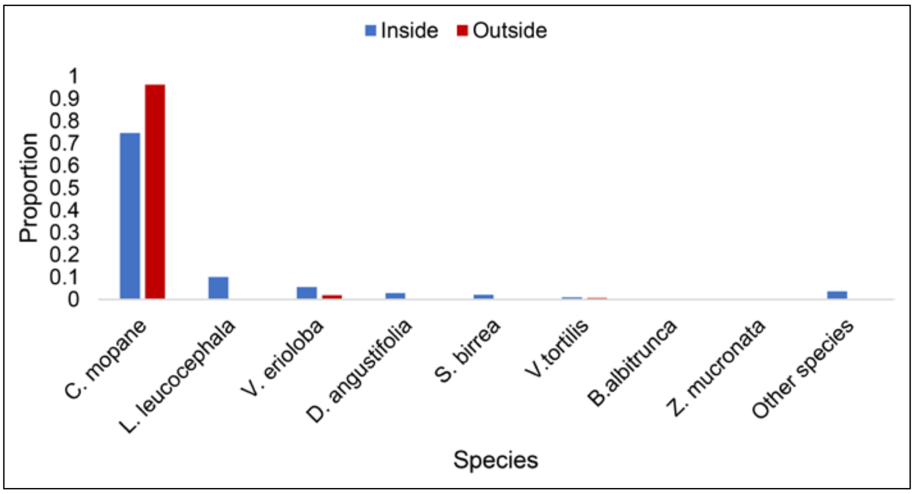


**Figure 3**. Proportion of individual woody species recorded in total across all quadrats.

and F). This pattern was illustrated by *B. albitrunca, Combretum mossambicense, J. curcas, R. communis, Ziziphus mucronata* and *Berchemia discolor*. The third pattern was composed of species that showed a high number of individuals in the short height class and a low number of individuals in the tall height class, with no individuals in the middle height class (Figure 4G and H). Species showing this pattern were *L. leucocephala* and *Sclerocarya birrea*. The fourth pattern showed hampered seedling recruitment with no individuals in the taller height classes (Figure 4I and J). This pattern was exemplified by *Philenoptera nelsii* and *Senegalia mellifera*. The fifth pattern was found in rare species, and it showed species with one middle or higher height class (Figure 4K and L). This pattern was represented by *A. altissima* and *D. cinerea*.

The distribution of the woody species outside MIA was categorised into four regeneration patterns. The first group showed high numbers of individuals in the shortest height classes and a progressive decline towards the middle and upper height classes (Figure 5A, B, C and D). This group was represented by *D. cinerea, Z. mucronata, V. erioloba* and *V. tortilis*. The second group showed interrupted 'reverse J-shaped' pattern, i.e., high numbers of individuals in the shortest height class and few or no individuals in the middle and upper height classes (Figure 5E). This pattern was only exhibited by *C. mopane*. The third group showed no individuals in the shortest height classes (i.e., seedlings) and in the taller height classes (Figure 5F, G and H). To this group belong *D. angustifolia*, *T. prunioides* and *B. albitrunca*. The species in the fourth group showed dominance of individuals in a single height class (Figure 5I, J, K and L). This group included *B. discolor, C. hereroense, P. nelsii, S. mellifera, H. petersiana* and *P. violacea*.

# Discussion

The study revealed a substantial difference between the inside and outside of MIA in terms of species diversity, evenness and regeneration status of the woody species. The Shannon Diversity Index (*H'*) of the woody species inside was five times greater than outside MIA. The difference in anthropogenic disturbances in the two areas resulted in the differences in species richness and evenness. The presence of five alien invasive plant species also partly contributed to higher richness inside MIA. There were more woody species and more even distribution of individuals of different species inside compared with outside MIA. Continuous harvesting of woody species for fuelwood and construction as well as annual fires may account for lower species richness and diversity outside MIA. The site outside the exclosure is part of communal rangelands, and therefore subjected to heavy browsing, mainly by domestic animals, but also by wild animals. Layers of grass were absent at both areas and are not likely to have influenced recruitment or regeneration. Wildfires are common in Botswana (Maabong & Mphale 2021), and therefore fire might have influenced species diversity and richness at either site.

The diversity and evenness observed inside and outside MIA are lower than those recorded from open areas in Botswana, e.g., in Shorobe (*H'* = 2.18 and *E* = 0.6) and Xobe (*H'* = 1.5 and *E* = 0.5) (Neelo et al. 2013) and also from an exclosed woodland at Island Safari Lodge (*H'* = 2.16 and *E* = 0.6) and Okavango Research Institute compound (*H'* = 2.42 and *E* = 0.75) (Teketay et al. 2018). The lower diversity recorded for MIA could be explained by its historical use for human settlement or residential purposes. It can be argued that during its time as a residential area, most woody species inside MIA were frequently harvested for fuelwood and construction. Regeneration of woody species subjected to such disturbances is influenced by several factors (Teketay et al. 2018). When a heavily harvested site is excluded from anthropogenic disturbances and herbivory impacts, as was the case with MIA, vegetation regenerates quickly through seedling recruitment from the soil seed bank and coppicing from stumps (Teketay 2005). The soil seed bank is recognised as the main pathway of regeneration of most woody species (Whitmore 1996).

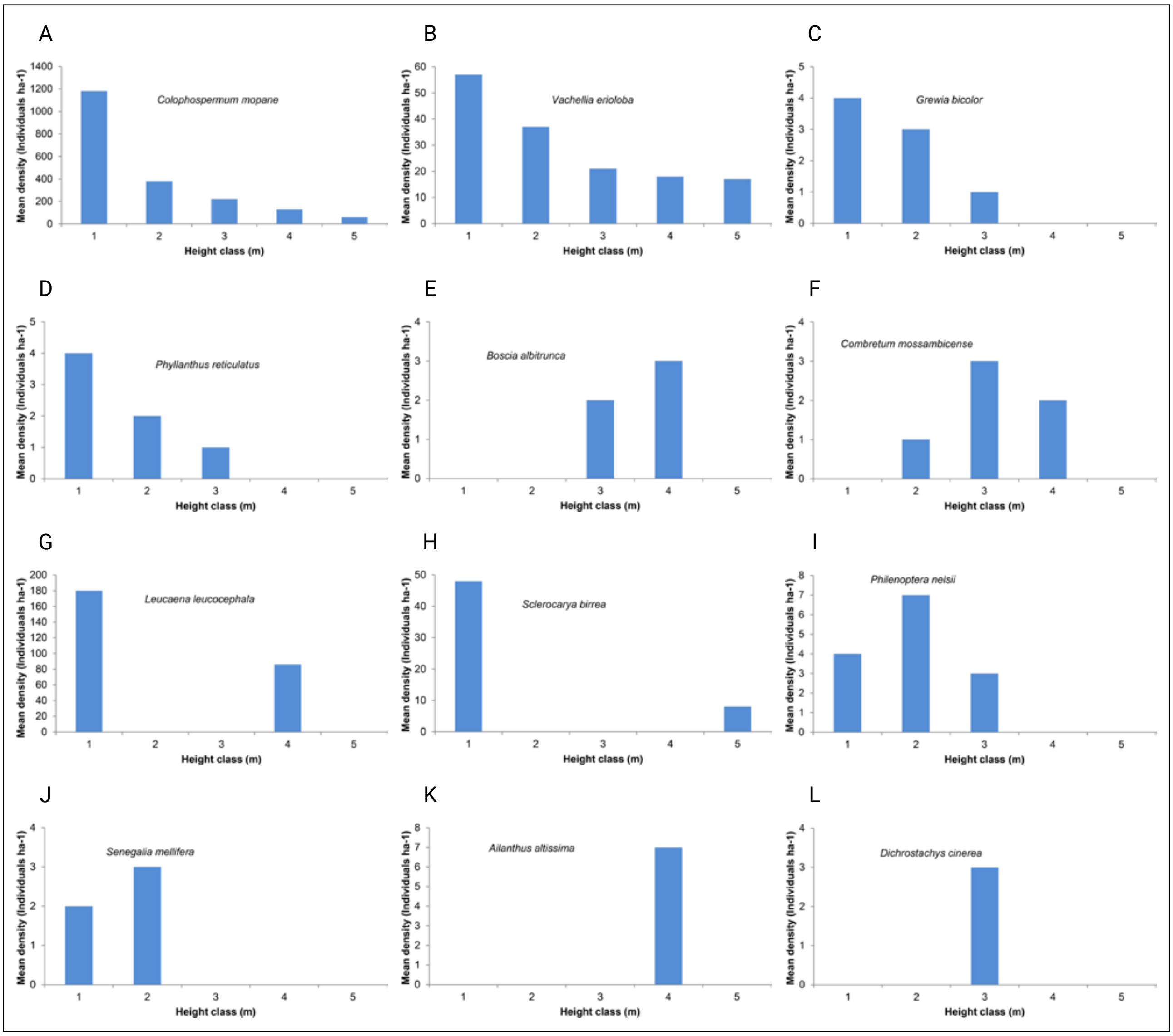


**Figure 4**. Population structure of woody species inside Maun International Airport. Height classes: 1 = 0–0.5; 2 = 0.5–1; 3 = 1–2; 4 = 2–4; and 5 = > 4 m.

In the current study, large numbers of seedlings were recorded for the dominant species (*C. mopane*) inside and outside MIA, suggesting that seed rain is the major regeneration strategy.

Woody species examined revealed substantial variations in their height class distributions, which indicates different adaptation capacity of the species to the prevailing environmental conditions and disturbances. Six and four species inside and outside MIA, respectively, exhibited a 'reverse J-shape' curve with continuous height class distributions, which implies healthy regeneration (Inoussa et al. 2017; Teketay et al. 2018; Asmare & Gure 2019). It also confirms the role of the exclosure in conservation of natural resources. However, in a mopane woodland area, exclosure may facilitate regeneration of *C. mopane*, resulting in thickets of mopane with low herbaceous productivity and diversity. This implies that the use of exclosures in rehabilitation of degraded woodlands should be used with caution.

The dominant species *C. mopane* displayed healthy regeneration inside and hampered regeneration outside MIA, even though there were very high densities of seedlings outside the exclosure area, suggesting that human impacts, such as cutting and logging, are disrupting regeneration of this species. It is commonly used as firewood because it burns slowly and produces good charcoal (Tietema et al. 1991), as well as for construction and fencing due to its resistance to rotting, termite and powderpost beetle ((https://www.wood-database.com/mopane/ accessed on 02-07-2020).

*Dichrostachys cinerea* and two species of *Vachellia*, namely *V. erioloba* and *V. tortilis*, exhibited healthy regeneration outside MIA despite pressure from anthropogenic activities and herbivory impacts. This may indicate bush encroachment due to overgrazing (Neelo et al. 2015; Teketay et al. 2016). The leaves of *V. tortilis* and *V. erioloba* are nutritious (Tolsma et al. 1987; Moleele 1998), but the presence of thorns limit browsing by herbivores

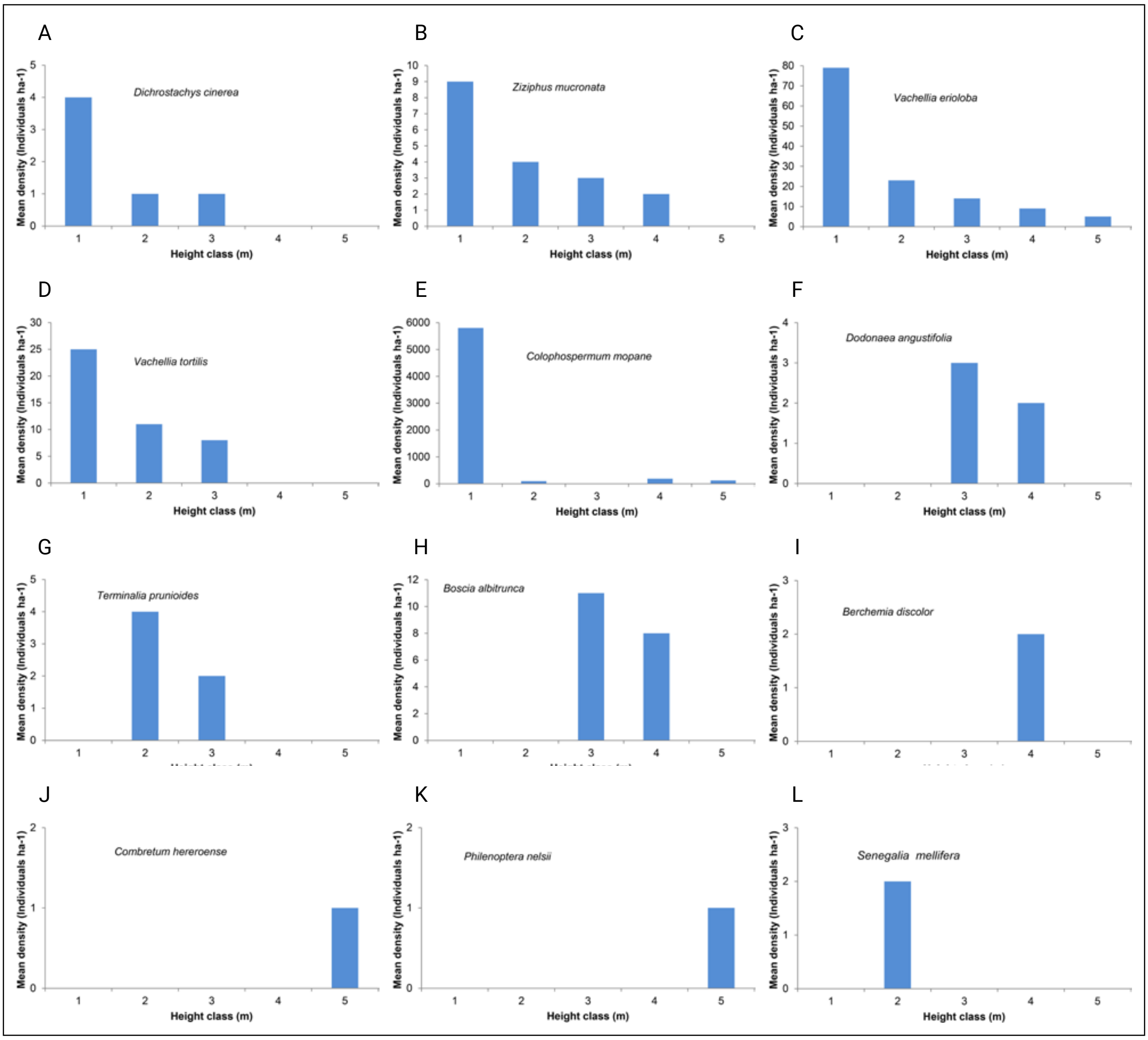


**Figure 5.** Population structure of woody species outside Maun International Airport. Height classes: 1 = 0–0.5; 2 = 0.5–1; 3 = 1–2; 4 = 2–4; and 5 = > 4 m

and, as a result, the species proliferate into trees and shrubs (Moleele & Perkins 1998). *Dichrostachys cinerea* is an aggressive invader particularly in overgrazed areas (Teketay et al. 2016). It is reported to be, most likely, stimulated by disturbances, such as fire and browsing (Wakeling & Bond 2007; Wigley et al. 2014).

Invasive woody species were only present inside MIA and showed either hampered regeneration (*L. leucocephala*) or hampered seedling recruitment (*J. curcas*, *R. communis* and *A. altissima*). The presence of invasive species is not surprising as the site was previously a residential area and local communities might have introduced them as ornamental trees, whereas the area outside the MIA was a communal area that was used for animal grazing and harvesting of fuelwood. *Ailanthus altissima* (also known as prison tree and tree-of-heaven) is planted in many countries as an ornamental tree (Iverson et al. 2019). It is an aggressive invader that spreads from root sprouts and grows rapidly to produce large quantities of seeds (Call & Nilsen 2005) that are wind dispersed (Bory & Clair-Maczulajtys 1980). *Ricinus communis* (also known as castor bean) is a fast-growing small tree that produces large quantities of toxic seeds (Kuete 2014) and has been rejected for use as biofuel crop due to its high invasive potential (Gordon et al. 2011). *Leucaena leucocephala* is a nitrogen-fixing tree-legume (Bageel et al. 2020) that grows vigorously to colonise disturbed vegetation. It has spread aggressively around the world (De Sousa Machado et al. 2020), and it is declared a Category 2 weed in South Africa (Henderson 2001). *Jatropha curcas* has spread rapidly in Asia and Africa where it is promoted as an ornamental and hedge plant (www.cabi.org/isc/data sheet). It is classified as a high-risk plant (Gordon et al. 2011; Negussie et al., 2013). Its cultivation is prohibited in Australia (PIER 2008), South Africa (GISP 2008) and Hawaii (USDA-NRCS 2008).

Edible fruit-bearing woody species displayed healthy regeneration (*G. bicolor*), hampered seedling recruitment (*B. albitrunca* and *B. discolor*) and regeneration (*S. birrea*) in the exclosure. Lack of seedlings in *B. albitrunca* and *B. discolor* may imply that fruits of these species are consumed by birds and rodents. Fruits of *B. albitrunca* and *B. discolor* are widely eaten by mammals and birds as well as by humans (Heath & Heath 2009). The fruits of *S. birrea* and *B. discolor* are rich in vitamin C, which is higher than that of exotic species (Leakey, 1999; Chivandi et al. 2012), signifying their importance as a source of food. *Sclerocarya birrea* fruits have been traditionally used to make a beer (Shackleton 2002) as well as other products (Wynberg et al. 2002).

# Conclusion

While the present study is limited in scale and requires replication, preferably where the historical use of the land inside and outside the exclosure is the same, it has demonstrated that exclosure may play a role in enhancing woody species richness, diversity and evenness as well as facilitating regeneration of woody species for this particular area. The current study may indicate that degraded woodlands and other similar ecosystems can be cheaply and conveniently restored through establishment of exclosures. However, there are many factors that could influence the results, and a larger number of similar studies are recommended to verify the findings. Based on our findings, the following recommendations are provided for sustainable management of woodlands inside MIA:

1. Develop and implement a plan for eradication of invasive woody species.
2. Study the reproductive ecology of individual trees (seed production, dispersal and germination).
3. Conduct research on herbaceous species richness, diversity, evenness and density for long-term monitoring.
4. Initiate a programme for management of bush encroachment by *D. cinerea*, *V. tortilis* and *V. erioloba*.

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## Competing interests

All the authors declare that they have no competing interests

## Authors' contributions

KK planned, designed and conducted field work. He also analysed the data and developed the first draft of the manuscript. DT revised the MS with significant contributions to all sections of the manuscript. MM and MKG were actively involved in data collection and entry. All the authors have approved the final manuscript.

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