STRUCTURE AND REGENERATION STATUS OF WOODY SEED OIL SPECIES IN NORTHERN BOTSWANA

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ABSTRACT

Concerns about energy security and environmental risks have sparked interest in edible and non-edible seed oils as potential renewable feedstocks for biodiesel production. A study was conducted to investigate the population structure and regeneration status of woody seed oil species in the districts of Chobe and Ngamiland. The population structure and regeneration condition of woody seed oil species were studied in 20 × 20 m (400 m^2) quadrats spaced 50 m apart along a parallel line transect. Data on the identity of all woody species, the number of all live individuals, and the diameter at breast height (DBH) of individuals with DBH > 2 cm of each woody species were collected in each quadrat. The diversity (H') and evenness (J') of woody seed oil species were 1.53, 1.42 and 0.71, and 0.85, 0.73 and 0.51 in Parakarungu, Seronga and Shorobe, respectively. *Ximenia caffra* was the dominant woody seed oil plant in Shorobe and Seronga, and exhibited an inverted *J*-shaped curve with continuous diameter classes distribution. *Trichilia emetica* was only found in Parakarungu, where it was the second dominant species and demonstrated excellent recruitment and regeneration. In Shorobe and Seronga, *Croton megalobotrys* was the second most dominant species. It had low recruitment, which was most likely due to herbivory and predation on seeds and seedlings. The least prevalent species (*Sclerocarya birrea*, *Schinziophyton rautanenii* and *Guibourtia coleosperma*) had no representation in the intermediate diameter-classes, which might be attributed to the selective removal in these diameter-classes. The examination of the population structure of woody seed oil species indicated variations in patterns of diameter-class distribution, indicating differences in the population dynamics of the species across the study areas. The least dominant species experienced hindered recruitment and regeneration due to herbivory and anthropogenic influences.

Keywords: Biodiesel; recruitment; feedstock; district; Chobe; Ngamiland

INTRODUCTION

The world is experiencing a surge in demand for energy due to an increase in population growth, industrialisation, rapid urbanisation and the large-scale transportation sector (Brahma *et al*., 2022; Liu *et al*., 2022). To meet this ever-increasing energy demand, more than 80% of global energy is generated from non-renewable and fossil fuel sources such as petroleum, coal and natural gas (Etim *et al*., 2022). However, these energy resources are limited and expected to diminish with the current upsurge in demand (Jamil *et al*., 2020). Moreover, high consumption of non-renewable fossil fuels presents the world with the twin problems of fossil fuel depletion and climate change (Khanam *et al*., 2021). This is because the combustion of fossil fuels emits a significant amount of greenhouse gases, which are the major causes of air pollution (Liu *et al*., 2022). Carbon dioxide is the main cause of global warming and is mainly emitted from the burning of fossil fuels (Khan *et al*., 2018). In response to the energy security and environmental risk posed by the intensive use of fossil fuels, 'green' renewable energy sources have been proposed as a strategy to mitigate climate change and ensure energy security. Biodiesel has emerged as one potential alternative. In addition, the production and use of biodiesel will also contribute to the attainment of United Nations (UN) Sustainable Development Goal 7; affordable and clean energy.

Biodiesel is also known as fatty acid methyl ester (FAME), and is produced from a variety of feedstocks, both edible and non-edible seed oils (Niazi *et al*., 2022). Examples of edible oils that have been used are rapeseed oil, soybean oil, sunflower oil, palm oil and hazelnut oil (Martinez *et al*., 2014; Qasim, 2019). However, the use of edible oils led to an increase in their prices and raised ethical issues about the use of edible oils in biodiesel production (the food vs. fuel debate). Thus, non-edible oils such as waste animal fats, wild mustard oil, *Ricinus communis* oil, waste cooking oil and *Jatropha curcas* seed oil were proposed as alternative feedstocks to edible oils for biodiesel production (Ahmed *et al*., 2015; Outili *et al*., 2020; Silitonga *et al*., 2015). Moreover, biodiesel is environmentally friendly, renewable and biodegradable (Rozina *et al*., 2022), and can be used directly in engines without blending or modification of the engine (Anwar *et al*., 2019). It is compatible with petroleum diesel in the engine (Etim *et al*., 2022).

Biodiesel development in Botswana was initiated by the then Ministry of Minerals, Energy and Water Resources through a feasibility study conducted in 2007. The study recommended *Jatropha curcas* as a potential feedstock for the production of biodiesel in Botswana (EECG, 2007). This led to biodiesel research in Botswana. In Phase 1 of the Biodiesel Research Project, the Government of Botswana collaborated with the Japanese International Cooperation Agency to evaluate the non-edible seeds of Jatropha for biodiesel production in Botswana (Republic of Botswana, 2017). However, research on the sustainability of Jatropha cultivation projects for biodiesel production in southern Africa found that Jatropha projects in the region are not economically viable due to low seed yield and high costs of production (von Maltiz *et al*., 2014; Kgathi *et al*., 2017). Furthermore, there were concerns about the invasiveness risk of Jatropha and its cultivation was prohibited in Australia, South Africa and the USA (GISP, 2008; von Maltitz *et al*., 2014). After concerns about the non-viability of the Jatropha biodiesel project, the Government of Botswana moved to Phase 2, of the Biodiesel Project. In Phase 2 the government is funding research to assess the potential of woody seed oil species for biodiesel production. This current research project on the population structure and regeneration status of woody seed oil species is part of Phase 2 of the Biodiesel Research Project.

The population structure of woody plant species is defined by the distribution of individuals in different height or diameter classes. It is used to determine the species' ability for regeneration, which is demonstrated by the existence of seedlings, saplings and trees in a particular location (Buragohain *et al*., 2023). Therefore, a species' potential for regeneration can be determined by the number of seedlings present at a given site. Understanding the population structure and regeneration status of woody seed oil species is an important measure taken to assess the ability of woodlands to provide seed yield for the production of biodiesel. Plant population structure indicates whether or not the population has a healthy regeneration that allows continuous regeneration (Balemlay & Siraj, 2021). Continuous regeneration will result in sustainable seed yields for biodiesel production. In addition, an analysis of the population structure and regeneration status of woody seed oil species is a pre-requisite for designing conservation programmes and also highlights threatened and economically important species that need to be prioritised for conservation (Dutta & Devi, 2013; Maua *et al*., 2020). Lack of information on the population structure of woody seed oil species limits the planning of sustainable conservation and rehabilitation strategies (Lokonon *et al*., 2022). Against this background, this study aims to examine the population structure and regeneration status of woody seed oil species using diameter-class distributions in Ngamiland and Chobe districts. Such a study provides baseline data for ensuring ecological management practices, conservation and sustainable use of woody seed oil species for biodiesel production.

MATERIALS AND METHODS

Study Areas

The study was conducted in Chobe district in the village of Parakarungu and in the villages of Seronga and Shorobe in Ngamiland district (Fig. 1). These sites were chosen because they are endowed with flora and fauna, due to their close proximity to the wetlands of the Okavango Delta and Chobe River Systems.

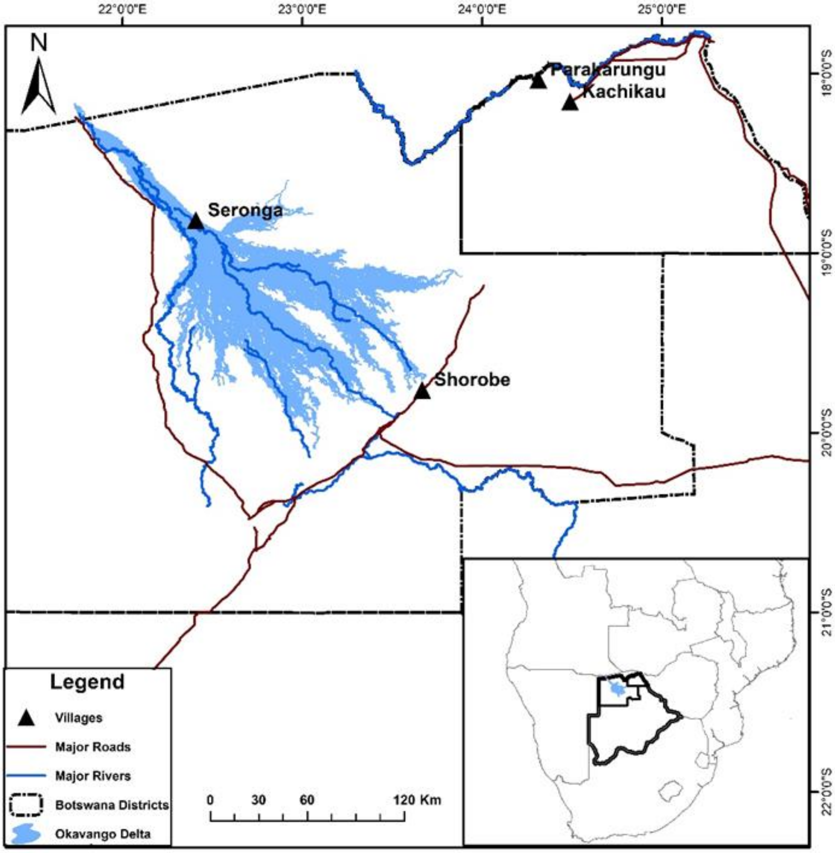
Chobe District receives an annual rainfall of about 640 mm, occurring in the hot summer months from October to April (Botswana Meteorological Service Department unpublished data). October is usually the hottest month, with a mean daily temperature of 35 ^{o}C and a mean daily minimum of 14 ^{o}C. The winter season is from May to July and is dry, with a mean monthly temperature range of 8 ^{o}C. Deciduous trees start to drop their leaves in July (Masunga *et al*., 2016).

The vegetation of Chobe District varies with distance from the Chobe River. The riparian woodland is dominated by *Garcinia livingstonei* T. Anders, *Croton megalobotrys* Müll.Arg., *Trichilia emetica* Vahl, *Kigelia africana* (Lam.) Benth. and *Senegalia nigrescens* Oliv. In the Kalahari sands away from the river, mixed shrub and woodland are dominated by *Baikiaea plurijuga* Harms, *Burkea africana* Hook., *Terminalia sericea* Burch. Ex DC., *Bauhinia petersiana* Bolle, *Combretum elaeagnoides* Klotzsch and *Baphia massaiensis* Taub. (Mosugelo *et al*., 2002; Skarpe *et al*., 2004). The vegetation structure and composition show varying degrees of herbivory impact by elephants (*Loxodonta africana*), buffalo (*Syncerus caffer*) and other mammalian herbivores (Mosugelo *et al*., 2002).

Shorobe village is situated on the southern fringe of the Okavango Delta, 30 km east of Maun, the capital of Ngamiland District. It is located on a 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). The sandveld is dominated by mopane woodlands and the dominant tree species is *Colospermum mopane* (Makhado *et al*., 2012). Riparian woodland species such as *Croton megalobotrys* Müll. Arg., *Diospyros mespiliformis* Hochst.ex A.DC, *Kigelia africana* (Lam.) Benth, *Philenoptera violacea* (Klotzch) Schrire and *Garcinia livingstonei* T. Anderson start to dominate with distance towards the river.

Seronga is situated about 100 km in the north-western side of the town of Shakawe, near the apex of the Delta (the lower Panhandle region) and had the highest population of 2 674 among the four study areas. Soils in Seronga are sandy (> 90 % sand) with low clay content (0.4–2.8 %) content (Gwatidzo, 2014). The village is surrounded by dense woodlands such as *C. mopane* (mopane), *Terminalia sericea* (silver terminalia) and *Ximenia caffra* (sour plum) (Mubyana-John & Masamba, 2014).

Fig.1: Map of the study area



Data collection

To determine the population structure and regeneration status of the woody seed oil species, 26, 28 and 35 quadrats were used in Shorobe, Parakarungu and Seronga, respectively. Quadrats measuring 20 m x 20 m (400 m^2) were laid down along a parallel line transect at 50 m intervals. In each of the quadrats, the data on the identity of all woody species, the number of all live individuals and the diameter at breast height (DBH) of individuals with DBH > 2 cm of each woody species were recorded. In the case of juveniles (seedlings and coppices < 1.5 m in height), the total number of individuals of each woody seed oil species was counted and recorded in each quadrat. A calliper and graduated measuring stick were used to measure DBH and height, respectively. The woody seed oil species were identified directly at the sites using books published on the flora of Botswana

(Heath & Heath, 2010; 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, tree species nomenclature follows that of Setshogo &Venter (2003) and Setshogo (2005). This study adopted the following definitions of seedling, sapling and tree by Teketay (1997) and Setshogo & Venter (2003): seedlings are defined as plants with the heights < 1.5 m; saplings as plants with the height range between 1.5 and 3 m; and trees as those with a height > 3 m.

Data analysis

The diversity of woody seed oil species was analysed using the Shannon Diversity Index (*H'*). It is also referred to as the Shannon-Weiner or Weaver Diversity Index (Magurran 2004). The woody seed oil species diversity was determined by using the following formula:

$$H' = -\sum_{i=1}^{S} P_i \ln P_i$$

where, H' = Shannon index, S = woody seed oil species richness, P_i = proportion of S made up of the i^{th} species (relative abundance).

Evenness or equitability measures the similarity of the abundances of the different woody species in the different habitats and was analysed using Shannon's Evenness index. Its value ranges from 0 to 1, with 1 being complete evenness. It was calculated by using the following formula:

$$J' = \frac{H'}{\ln(S)},$$

where, J' = evenness and S = woody seed oil species richness.

The population structure of each woody species in the three habitats was assessed using the frequency distribution of diameter classes. Histograms were constructed by using the density of individuals of each species categorised into 10 diameter classes for tall trees, i.e., 1 = 0–5 cm; 2 = 5–10 cm; 3 = 10–15 cm; 4 = 15–20 cm; 5 = 20–25 cm; 6 = 25–30 cm; 30–35 cm; 7 = 35–40 cm; 9 = 40–45 and 10 = > 45 and 5 diameter classes for shrubs, i.e., 1= < 2; 2 = 2–4; 3 = 4–6; 4 = 6–8 and 5 = 8–10 cm. The woody species were then grouped into different groups based on the pattern of the histograms. The number of groups was determined by the number of patterns in the histograms.

RESULTS

Diversity and evenness

The diversity (*H'*) and evenness (*J'*) of woody seed oil species were highest in Parakarungu. The opposite is true for Shorobe which recorded the lowest diversity and evenness of woody seed oil species (Table 1). Of the total number of woody seed oil species Seronga recorded the highest number of species (7), followed by Parakarungu (6) and lastly Shorobe (4).

Table 1: Diversity indices of woody seed oil species in the study area

Study areas	*H'*	*J'*	*S*
Parakarungu	1.53	0.85	6
Seronga	1.42	0.73	7
Shorobe	0.71	0.51	4

Density, species and family richness of woody oil species

The total mean densities of woody seed oil species were 1089, 2565 and 1957 individuals ha^{-1} in Parakarungu, Shorobe and Seronga, respectively (Table 2). The total density of woody seed oil species was about two times higher in Shorobe and Seronga compared with Parakarungu. The three densiest woody species were *Croton megalobotrys*, *Trichilia emetica* and *Ximenia caffra* in Parakarungu, *X. caffra*, *C. megalobotrys* and *Sclerocarya birrea* in Shorobe and *X. caffra*, *C. megalobotrys* and *Schinziophyton rautanenii* in Seronga.

Euphobiaceae exhibited the highest richness in woody oil species with four species. The other families were represented by only one woody oil species (Table 2).

Table 2: Mean density (± SE) of woody seed oil species in the study areas

Species	Life form	Family	Density (Individuals ha^{-1})		
			Parakarungu	Shorobe	Seronga
Ximenia caffra Sond.	Shrub	Olacaceae	185 ± 35	1,805 ±345	920 ± 161
Croton megalobotrys	Tree	Euphorbiaceae	420 ± 48	692 ± 219	516 ± 84
Schinziophyton rautanenii Schinz	Tree	Euphorbiaceae	0	0	127 ± 42
Garcinia livingstonei T.Anderson	Tree	Guttiferae	45 ±13	0	68 ± 29
Sclerocarya birrea (A.Rich.)	Tree	Anacardiaceae	110 ±28	55 ± 18	46 ± 31
Guibourtia coleosperma (Benth.) J.Léonard	Tree	Fabaceae	0	0	248 ± 36
Ricinus communis L.	Shrub	Euphorbiaceae	53 ±11	13 ± 7	32 ± 13
Trichilia emetica Vahl	Tree	Meliaceae	276 ±63	0	0
Total			1,089 ± 42	2,565± 103	1,957 ± 78

Regeneration

Overall, regeneration of woody seed oil species varied across the study areas (Fig. 2). Healthy regeneration was exhibited in Shorobe {(seedlings > saplings > trees) Fig. 2a}. *Ximenia caffra* and *S. birrea* had a higher number of individuals in the seedling stage, while *C. megalobotrys* and *R. communis* were abundant in the sapling stage. Regeneration was fair in Seronga and Parakarungu {(seedlings < saplings > trees) (Figs. 2b and c)}. In Seronga, *G. coleosperma*, *S. birrea*, *S. rautanenii* and *G. livingstonei* dominated the seedling stage while *X. caffra*, *C. megalobotrys* and *R. communis* were abundant in the sapling stage. *Trichilia emetica*, *S. birrea* and *G. livingstonei* were abundant in the seedling stage while *X. caffra* and *C. megalobotrys* dominated the sapling stage in Parakarungu. Some species did not have individuals in the juvenile stage. For instance, *G. coleosperma* and *G. livingstonei* had absent individuals in the sapling stage in Seronga, seedlings of *R. communis* and saplings of *S. birrea* were missing in Shorobe, no saplings of *S. birrea* and *G. livingstonei*, and no juveniles of *R. communis* were encountered in Parakarungu.

Population structure

The population structure of seven woody seed oil species was analysed using their density at various diameter classes. Different representative patterns were detected across the three study areas (Figs. 3, 4 and 5). The analysis of the population structure revealed four general patterns. The first pattern was formed by species with a reverse J-curve. This species had the highest densities in the lower diameter classes and a gradual decline in density with increasing diameter classes, indicating good reproduction and healthy regeneration. This pattern was demonstrated by *X. caffra* in Seronga (Fig. 3a) and Shorobe (Fig. 4a), and *T. emetica* in Parakarungu (Fig. 5d). The second pattern exhibited by *R. communis* (Fig. 3b) and *C. megalobotrys* (Fig. 3c) in Seronga, *C. megalobotrys* in Shorobe (Fig. 4c), *X. caffra* (Fig. 5a), *R. communis* (Fig. 5b) and *C. megalobotrys* (Fig. 5c) in Parakarungu indicated absence or very few number of individuals in the first diameter classes followed by a high number of individuals in the middle classes and absence or few number of individuals in the higher diameter classes. Such a pattern indicates hampered regeneration. The third pattern was formed by species having irregular distributions of diameter-classes. It shows the representation of individuals in the lower and higher diameter-classes, with few or no individuals in the middle diameter-classes. This pattern was exemplified by *S. birrea* (Fig. 3d), *G. coleosperma* (Fig. 3e), *S. rautanenii* (Fig. 3f) and *G. livingstonei* (Fig. 3g) in Seronga, *S. birrea* in Shorobe (Fig. 4d) and Parakarungu (Fig. 5e). The fourth pattern was formed by species with individuals in the first or second diameter classes, followed by the absence of individuals in the subsequent diameter classes. This pattern was well represented by *R. communis* in Shorobe (Fig. 4b) and *G. livingstonei* in Parakarungu (Fig. 5f).

Fig. 2: Density of seedling, sapling and adult trees in Shorobe (a), Seronga (b) and Parakarungu (c)

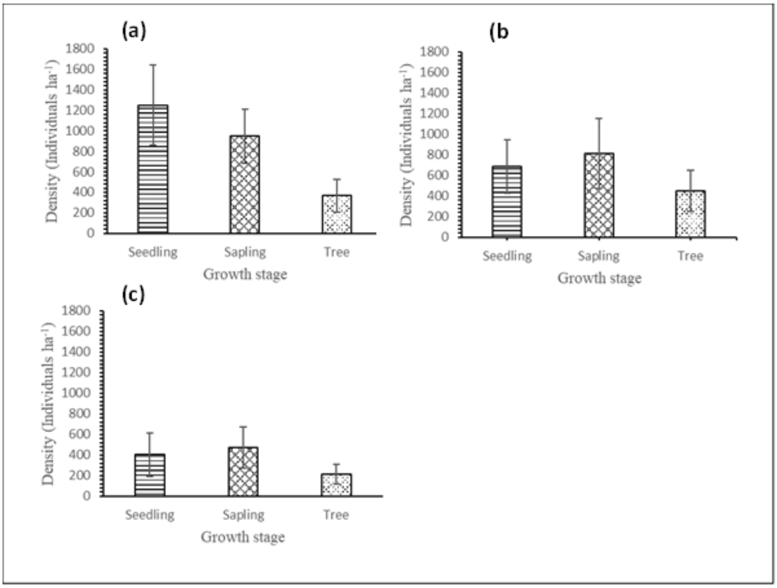


Fig. 3: Population structure of woody seed oil species in Seronga

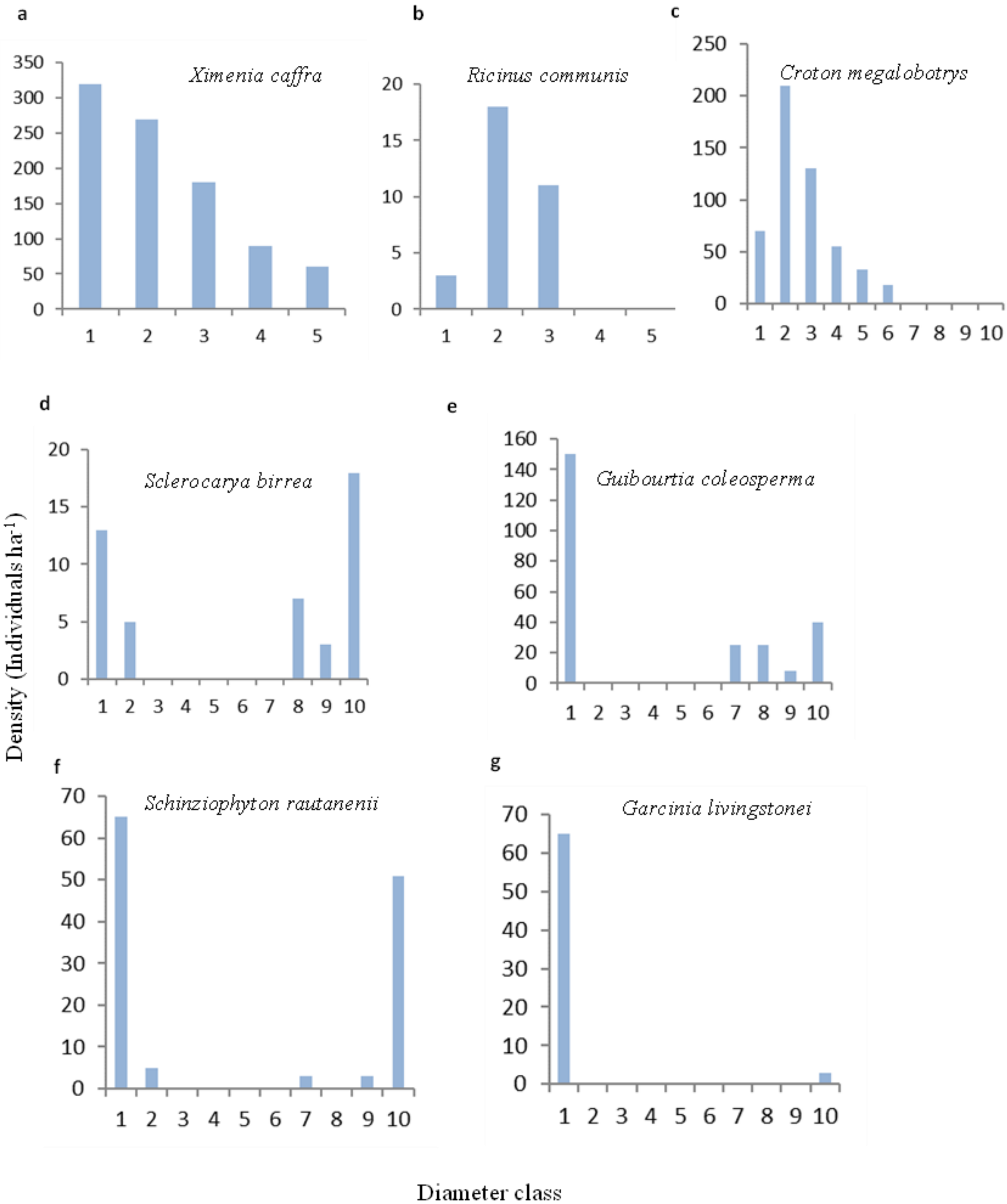


Fig. 4: Population structure of woody seed oil species in Shorobe

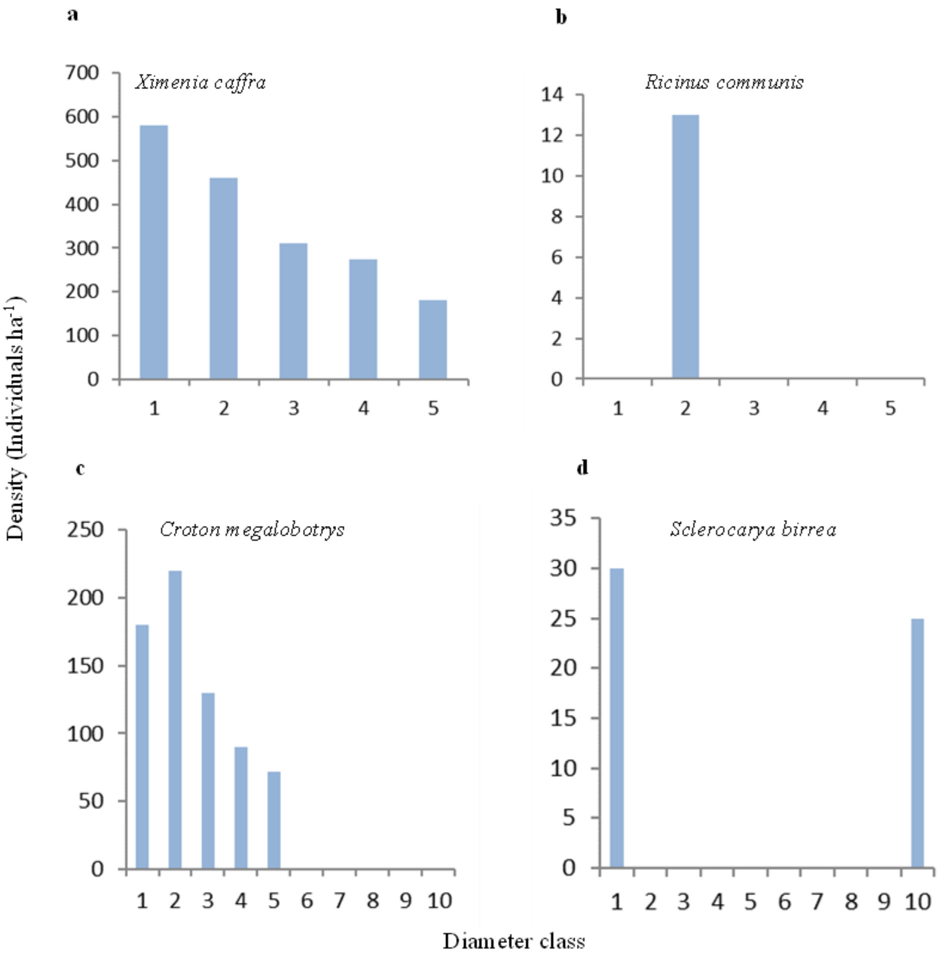
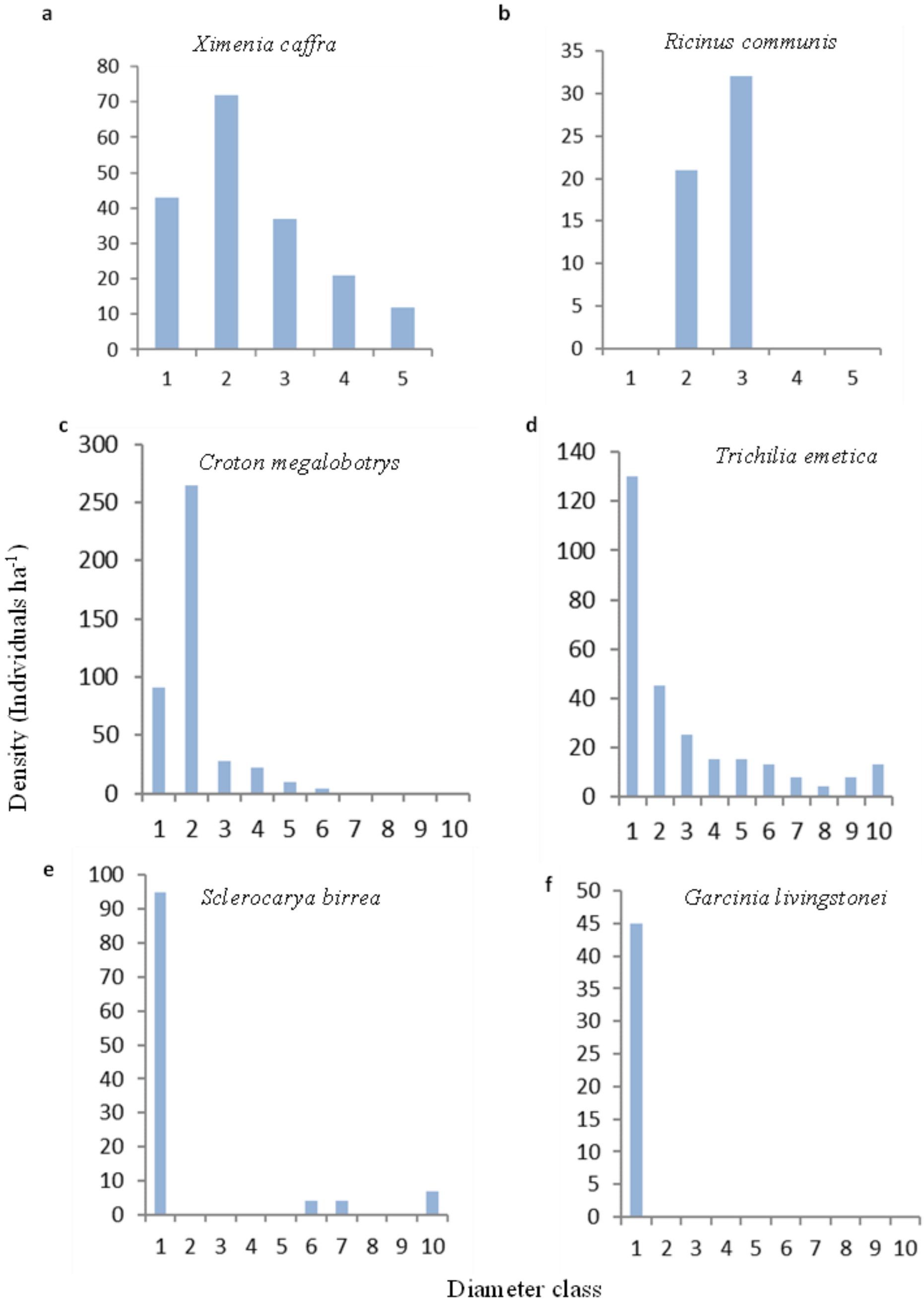


Fig. 5: Population structure of woody seed oil species in Parakarungu



DISCUSSION

Species diversity is determined by the amount and distribution of species at a site (Palit & Chanda, 2012). The results revealed that the diversity and evenness values for Parakarungu (H' = 1.53 and J' = 0.85) and Seronga (H' = 1.42 and J' = 0.73) were much higher than those recorded for Shorobe (H' = 0.71 and J' = 0.51). This pattern was also evident for species richness. However, the reverse trend was observed for the density of woody seed oil species. The highest total density in Shorobe was attributed to high proportion of *X. caffra* which contributed 70% to the total density of woody seed oil species. As a result, the diversity and evenness were lowest, indicating an unequitable distribution of individuals of different woody seed oil species in Shorobe. The lesser species diversity also indicates that woodland ecosystems are heavily disturbed (Hughes, 2012). Furthermore, the high demand for woody seed oil species for commercial and medicinal purposes possibly leads to their over-utilisation, which results in a reduction in species richness and diversity (Buragohain *et al*., 2023). The diversity in the three study sites is significantly lower than in previous studies in northern Botswana (Neelo *et al*., 2013; 2015; Teketay *et al*., 2018). This variance can be explained in part by the fact that only woody seed oil species were investigated in this study, but all woody species, including non-seed oil, were considered in the other investigations.

The plant juvenile stage has been identified as a key stage in natural regeneration but can be easily impacted by natural and anthropogenic disturbances that impede natural regeneration's success (Du *et al*., 2007). The woody seed oil species investigated revealed variations in seedling and sapling densities. Although Shorobe exhibited good regeneration status largely due to the high proportion of *X. caffra* (83.2 %) at the seedling stage, some species in other study areas also showed good regeneration. *Guibourtia coleosperma*, *S. rautanenii* and *G. livingstonei* in Seronga, *T. emetica, S. birrea* and *G. livingstonei* in Parakarungu displayed good regeneration, with more individuals in the seedling stage. The dominance of these species in the seedling stage implies that the seedling bank is their primary regeneration mechanism (Teketay, 1997). It also suggests that their seeds have little or no dormancy and readily germinate after dispersal, with biotic and abiotic restrictions limiting their growth rate (Gurmessa *et al*., 2023). *Ricinus communis* is the only species that is completely absent in the seedling stage in Parakarungu and Shorobe, indicating that it is facing extinction on a local scale. This is an encouraging ecological development because this species is a poisonous invading alien that has been rejected as a potential feedstock for biodiesel production in the United States and the Caribbean (Gordon *et al*., 2011).

Assessment of patterns of species population structure yields insights into their recruitment and regeneration status, as well as the viability status of the different species that could inform conservation and management strategies (Teketay, 2005; Tesfaye *et al*., 2010). Different patterns of species population structure have been reported for various species in other woodlands in northern Botswana (Neelo *et al*., 2015; Tsheboeng *et al*., 2017; Teketay *et al*., 2018; Kashe *et al*., 2021). In the current study, the woody seed oil species assessed exhibited significant variations in their diameter-class distributions, implying differences in the overall regeneration status among species. It also suggests variations in reproductive capacities among the different woody seed oil species and therefore calls for further studies on the reproductive biology of the species.

The dominant woody seed oil species in Shorobe and Seronga was *Ximenia caffra*. This species exhibited an inverted *J*-shaped curve with continuous diameter–classes distribution, implying good recruitment and healthy regeneration (Yineger *et al*., 2008; Teketay *et al*., 2018). However, it was the third dominant species in Parakarungu, and it revealed hampered recruitment and healthy regeneration in the subsequent diameter–classes. Such a population structure indicates that seedlings may be under pressure from seed predation, grazing and browsing (Gurmessa *et al*., 2012). Botswana is home to the highest population of elephants (*Loxodonta africana*) in Africa (Lori, 2022), at about 207, 545 elephants distributed in Ngamiland and Chobe districts (DWNP, 2012; Lindsay *et al*., 2017). Chobe National Park hosts the largest portion of the population (Lori 2022), and therefore were partly responsible for the hampered regeneration observed in *X. caffra* and other species in Chobe district (Parakarungu). Elephants can change the vegetation structure through browsing (Ferry *et al*., 2020). They ring-bark woody vegetation, resulting in high levels of mortality (Watson *et al*., 2020). *Trichilia emetica* was recorded only in Parakarungu and was the second dominant species. It revealed good recruitment and healthy regeneration mostly along the river banks and floodplain, implying its adaptability to these habitats (Heath & Heath, 2009).

Croton megalobotrys was likewise, the second most dominant species in Shorobe and Seronga. This species exhibited poor recruitment, probably due to herbivory and predation on seeds and seedlings by invertebrates and rodents (Kashe *et al*., 2021). A similar pattern was reported by Neelo *et al*. (2015), Tsheboeng *et al*. (2017) and Teketay *et al.* (2018). Despite hampered recruitment, *C. megalobotrys* had mature individuals in medium sized diameter–classes that were mature enough to produce seeds. This non-edible oil woody species is an ideal biodiesel feedstock owing to its high seed oil content. A study in Botswana by Paphane *et al*. (2021) reported its seed oil content to be ranging from 45–54 %. The least dominant species (*Sclerocarya birrea*, *Guibourtia coleosperma*, *Schinziophyton rautanenii* and *Garcinia livingstonei*) exhibited a U-shaped curve, which may be associated with selective removal of intermediate diameter–classes. For example, *S. rautanenii* and *G. livingstonei* are used to make dug-out canoes (Heath & Heath, 2009). *Sclerocarya birrea* is used for woodcarving, medicinal purposes and its leaves are browsed by several herbivores (Mocheki *et al*., 2018). *Guibourtia coleosperma* is exploited for food (fruits and oil), fuelwood and commercial timber (Heita *et al*. 2019). The invasive *Ricinus communis* had a low density across the study areas and was only found in disturbed sites (roadsides, dumping sites and livestock kraals). The species exhibited hampered recruitment and poor regeneration in all the study areas. However, *R. communis* is a non-edible oil woody species that can produce a seed yield of about 902 kg ha^{-1} in marginal areas (Berman *et al*., 2011). Its seeds contain 54 % oil (Herawati *et al*., 2022). It is against this background that *R. communis* should be explored for biodiesel production in Botswana, considering its invasiveness risk.

CONCLUSIONS AND RECOMMENDATIONS

Edible-oil woody species, *Ximenia caffra* in Ngamiland and *T. emetica* in Chobe district exhibited healthy regeneration. These species should be explored for biodiesel production in northern Botswana. Their promotion as biodiesel feedstocks should be coupled with community-based forest restoration programmes so that they both yield the seed needed for biodiesel production and also provide other ecosystem services for household needs. This will address the ethical issues that normally arise in the food vs fuel debate. The local communities should also be capacitated through participatory forest management programmes to plant seedlings of the feedstocks to sustained recruitment and regeneration of woody seed oil species. Other edible oil woody species, *Sclerocarya birrea*, *Guibourtia coleosperma*, *Schinziophyton rautanenii* and *Garcinia livingstonei* showed absence of individuals in the intermediate diameter-classes, indicating excessive selective logging for firewood, poles for fencing farms and the construction of livestock kraals. These species should not be considered for biodiesel production. Moreover, they are edible and contribute to dietary needs. Their use as biodiesel feedstock would compromise food security. The study highly recommends that the species be prioritised for conservation. The few mature individuals should serve as seed sources for conservation programmes.

Non-edible oil woody species, *J. curcas*, *C. megalobotrys* and *R. communis* exhibited hampered regeneration. However, they have mature individuals that can produce seeds and therefore should be promoted for biodiesel production. Higher seed oil producing varieties of these species should be developed to yield sufficient seeds for biodiesel production. *Ricinus communis* and *J. curcas* are invasive and should be subjected to Weed Risk Assessment to determine their invasiveness risk before their promotion for biodiesel production.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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