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An analysis on the response of major woody vegetation types following years of savanna elephant population decline in Sengwa Wildlife Research Area (SWRA), Zimbabwe

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Abstract
Large herbivores, particularly savanna elephants, are regarded as ecosystem engineers which shapes woody species structure in protected areas. Fluctuations in elephant populations in protected areas drives recruitment and regeneration of woody vegetation across different habitats. Savanna elephants generally exhibit a patchy foraging style, leading to heterogeneity in woody vegetation response that may be identified by analysing variation in vegetation recruitment and regeneration. In this study we sought to determine quantitatively the extent of vegetation damage and regeneration in different major woody vegetation in SWRA, and to determine seedling and sapling density in major vegetation types in SWRA. Data was collected from the 15th July, 2021 to 15th August, 2021. We ascertained and recorded woody vegetation damage levels, density of mature trees, saplings and seedlings in each plot. Data for tree, sapling and seedling density was not normally distributed therefore nonparametric test were conducted in Minitab-17. The results showed that sapling density were higher across different woody species plots followed by seedling and mature trees. Damage by elephants contributed only 0.9% of all the plants sampled. Overall good regeneration was recorded an indication of future vegetation structure change in SWRA. The study recommends long term monitoring in vegetation structure changes due to current recruitment and regeneration in SWRA and beyond.

Keywords: Recruitment, Regeneration, Damage level, Vegetation structure

1. Introduction

In most protected areas, two major factors ascribed to influence vegetation changes are fire and herbivore (Mapaure, 2013). Herbivores directly influence ecosystem structure through different interactions including direct and indirect which vary spatially and temporal (Moon *et al*., 2010) [25]. According to Staver *et al*., (2021) herbivory is a key process structuring vegetation in Savannas, especially in Africa where large mammal's herbivore communities remain relatively intact. Porensky and Veblen (2012) highlighted that large herbivore shape savanna ecosystems and they have strong impacts on wood vegetation. Changes in vegetation structure and composition can therefore be used as an indicator of herbivore density changes in the savanna ecosystems overtime as mentioned by Sankaran (2019) [31].

In many semi-arid and arid regions researches had been done to establish the impact of large herbivores, particularly elephants with findings pointing to the impacts of elephant on vegetation structure and composition (Barnes, 1983; Olff *et al*., 2002; Loarie *et al*., 2009) [4]. More impact has been recorded on nutrient rich soil with avoidance of poor and sour soils (Baxter, 1996; Eckhardt *et al*., 2000). This has been noted especially where elephant populations exceeded the carrying capacity of the protected areas.

The impacts elephants, however, are not a consequence of numbers alone, but may also result from how plant species are distributed across landscapes, elephant group sizes and composition, as well as the intensity at which patches are used within landscapes (Gordon *et al*. 2004; Young *et al*., 2008).

In areas where elephant populations below area carrying capacity, vegetation changes as a result of elephant herbivory are expected to be minimal. A decrease in large herbivore population result in a positive response by vegetation that can be accessed through determining seedling, coppicing and regeneration capacity at a given place (Barnes, 2002; Miller, 2000) [3, 24]. However, response rates vary with vegetation type as well nature of damage as a result of herbivory (Koerner *et al*., 2014; Tuomi *et al*., 2019) [18, 33]. For the past decades, elephant played a pivotal role in modifying vegetation structure in SWRA.

Researches done so far shows the greatest impacts of elephant to woody species in the area (Mapaure *et al*., 2002; Tafangenyasha *et al*., 2018) [23]. This was attributed more to high density of elephant which was above two elephants per square kilometer. According to Mapaure (2013) elephants alone at a density of 0.27 km^{-2} will convert woodland into coppice in one hundred and twenty years due to resulting massive declines of large trees. The same result is achieved in only 10 years if elephant density is at 2 km^{-2}. However, following years of disturbance, aerial elephant survey results indicate a significant population since 1996 from a density of above 2.0 elephant per square kilometer to below 1.4 elephants per square kilometer in 2020 (Dunham *et al*., 2006; Dunham *et al*., 2015 and Dunham *et al*., 2021) [12, 15, 11].

The 2014 elephant aerial survey of the Sebungwe Region showed a major decline in standing elephant populations from 13000 to 3500 (Dunham *et al*., 2015) [15]. The savanna elephant (*Loxodonta africana*) is one of the leading sources of vegetation shifts in SWRA. Research by Tafangenyasha *et al*., (2018) indicated that following elephant decline, vegetation in SWRA is on the recovery path, a result attributed to elephant decline in the area. Vegetation can recover given herbivore removal over sufficiently long-time scales (Augustine *et al*., (2019). According to Mapaure (2013) predicting the long-term impacts of herbivory on the structure and composition of different woody vegetation and how different habitats respond to given levels of impacts should be an important consideration in ecosystem management.

There have been indications that different woody species in SWRA are on a recovery path as supported by Tafangenyasha *et al*., (2018) in Sengwa. However, few quantitative studies have been conducted to substantiate this including understand the response of different woody vegetation in the aftermath of elephant population decline to the status and level of vegetation regeneration following years of drastic elephant population decline in SWRA is not adequately known. This study sought to explore impact of elephant herbivory in relation to recruitment and regeneration on different woody vegetation types. In this study one assumption was posted which assumes elephant's interaction with vegetation influence recruitment and regeneration of woody vegetation in SWRA. We postulate that the differences in vegetation response after the decline of elephant population in SWRA was caused by a differential degree of disturbance. Hence, two objectives were developed, (a). To determine quantitatively the extent of current vegetation damage by elephants in different major woody vegetation in SWRA, and (b). To determine vegetation regeneration through seedling and sapling density sampling in major vegetation types in SWRA.

2. Methodology

Study area

This study focused on determining response of different vegetation types in SWRA, Zimbabwe. SWRA is situated at the southern end of Chirisa Safari Area (18° 10″ S, 28° 14″ E) in Gokwe South District, north-western Zimbabwe (Figure 1). Covering an area of about 373 km^2, the area was set aside in the late 1960s for long term wildlife and ecological research (Tafangenyasha, *et al*., 2018).

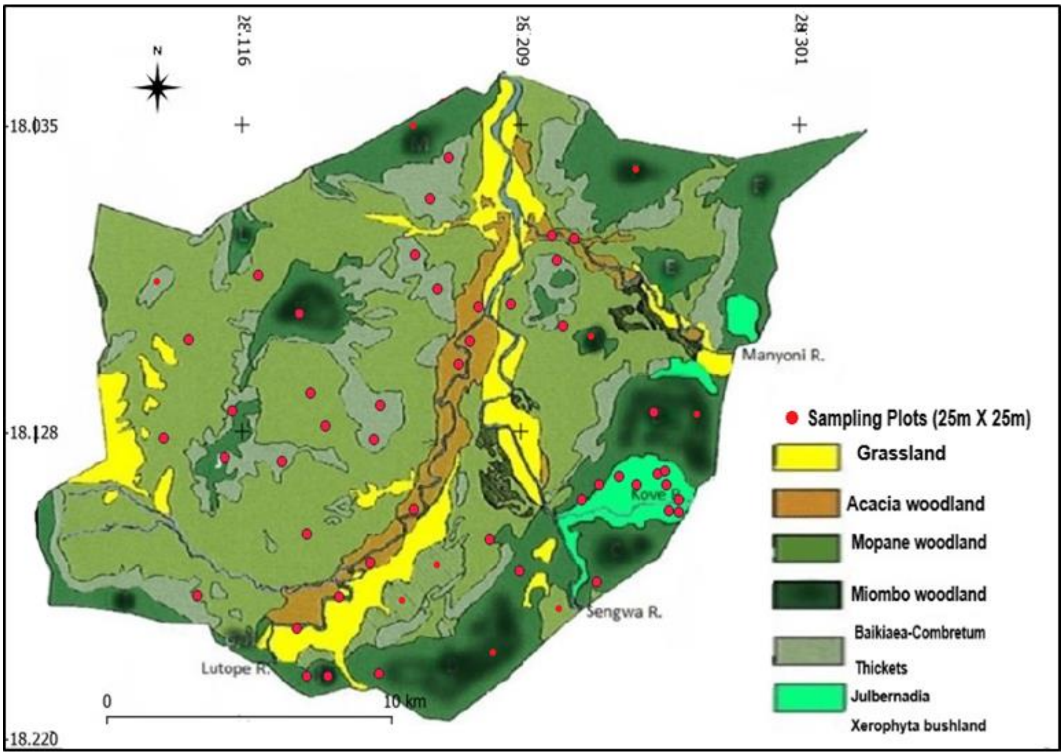

Fig 1: Location of 60 vegetation study plots (25m x 25m) sampled in six habitat types

The surface geology of the study area comprises of Lower and Upper Karoo age of escarpment grits, Madumabisa mudstone, colluvial, alluvial, rock outcrops, grit mudstone, dolerite dyke and undifferentiated red Soils (Mahakata *et al*., 2021) [21]. The Upper Karoo which overlies the mudstones gives rise to geologically and ecologically significant colluvial deposits with carbonaceous and siliceous matrices. The geological formations have been dissected by the north flowing rivers to give rise to soil and vegetation types that are an important source of water for wild animals occupying the area.

Twenty-six different vegetation types, had been described and mapped by Craig (1982) which were further grouped into five major types. According to Mapaure (2013) vegetation in SWRA is generally deciduous *Brachystegia–Julbernardia* (miombo) woodland on sandy soils and dry early deciduous woodland dominated by *Colophospermum mopane* on the lower heavier soils. Other vegetation types are riverine *Acacia* woodlands and mixed *Combretum* thickets on sands. SWRA is semi-arid ecosystem with low and irregular rainfall averaging 612mm per year (Mahakata and Mapaure, 2021) [22], high evapo transpiration and cyclical droughts (Tafangenyasha *et al*., 2018). The SWRA has a diverse large mammal community consisting of eighteen species of large herbivores with common species including elephant, buffalo, zebra, impala and waterbuck.

Data collection

A field reconnaissance survey of the woody vegetation types of SWRA was done at the beginning of June to get an overview of various vegetation types that exist in the area. A cluster random sampling procedure was used in this study. Vegetation types were grouped based on dominant vegetation in each plot. Six clusters were defined according to known broad vegetation type of SWRA (i) grassland, (ii) Miombo woodland (iii) mopane woodland (IV) Acacia woodland, (V). Baikiaea-Combretum thickets, and (VI) Julbernadia-Xerophyta bushland. Within the broad vegetation types, some small vegetation types exist.

Data collection was conducted from the 15th July, 2021 to 15th August, 2021. The estimated variables of the woody vegetation were plant height, volume dimensions, damage levels, recruitment and regeneration (Seedlings and saplings). Mature trees, saplings and seedlings were classified based on height; that is, rooted, woody, and self-supporting plants ≥ 3 m in height were classified as trees whereas rooted, woody, self-supporting, and multistemmed or single-stemmed plants greater than 1 m but < 3 m in height were classified as saplings and below one meter was classified as seedlings.

A total of sixty plots (25m × 25m) were sampled that is, ten plots in each major woody vegetation type. A six meter graduated pole was used for measuring woody plant height. A handheld Global Positioning System (GPS) was used to mark the location of each sampling plot. All seedlings, saplings and damage level was recorded. Damage level was categorised as no damage (ND) (0), low (L) ($1 \leq x \leq 25$), Moderate-light (M/L) ($26 \leq x \leq 50$), Moderate-high (M/H) ($51 \leq x \leq 75$), high (H) ($76 \leq x \leq 99$), and dead (D) (100). A quantitative method was used to record the number of trees damaged by herbivores in each class using the tally system of counting.

Analysis

Collected data were summarised and tested for normality using the Kolmogorov-Smirnov test, and data for damage level, mature tree density, sapling density, seedling density, and tree height data was not normally distributed hence non parametric test was used in data analysis. The regeneration and recruitment status of woody species was summarised based on the total count of seedlings and saplings of each species across all plots.

1. Stem density (Mature trees)

Density (e.g. stems/ha) for each plot was calculated using the formula:

$$Stem\ density = \left(\frac{number\ of\ stems}{Plot\ area\ (m^2)}\right) x\ 10.000 m^2$$

2. Seedling and sapling density

A formula was also used to calculate seedling and sapling density for each vegetation type:

$$Seedling\ and\ sapling\ density = \left(\frac{number\ of\ seedlings\ and\ saplings}{Plot\ area\ (m^2)}\right) x\ 10.000 m^2$$

3. Damage level density per hectare

$$Density\ (Damage\ per\ hactare) = \left(\frac{Number\ of\ trees\ damaged}{Plot\ area\ (m^2)}\right) x\ 10.000 m^2$$

3. Results

Six clusters were set based on known major vegetation types of SWRA, within which 10 different woody species were sampled consisting of *Senegalis*, *Mixed Baikiaea Combretum Thickets*, *mixed Colophospemum mopane*, *Colophospermum mopane Vachellia nigrescens- Ximenia*, *Colophospermum mopane* woodland, *Mixed Julbernadia Xerophyta*, *Mixed Brachystegia - Julbernadia*, *Terminalia Sericia*, *Commiphora- Combretum* woodland, *Bikiaea plurijuga* and *Combretum Imberbe* woodland. Across the habitats, a total of 1 364 woody plants were sampled. Mature trees constituted 17.8%, seedlings 23.53% and saplings dominating with 58.7%. In contrast, a total number of plants related to elephant damage were 12 across sampled plots translated to 0.9%.

1. Damage levels recorded in different woody species.

Signs of elephant disturbance were recorded in *Senegalis woodlands*, Mixed *Baikiaea-Combretum thickets*, *Commiphora-Combretum* woodlands and *Combretum Imberbe* woodlands. The remaining six vegetation types were more or less disturbed (Figure 2).

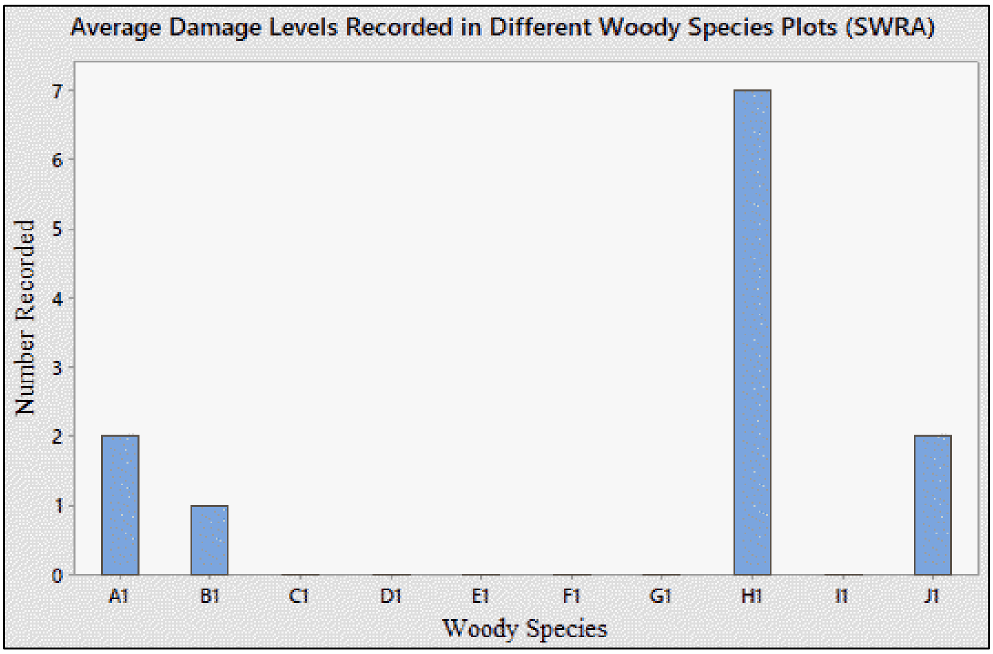

Fig 2: Number of trees damaged by elephants in different woody species sampled. (A1 = Senegalis Woodland, B1 =Mixed *Baikiaea-Combretum* Thickets, C1 =Mixed *C. mopane- Vachellia nigrescens- Ximenia* Woodlands, D1 = *C. mopane* Woodland, E1 = Mixed *Julbernadia-Xerophyta*, F1 = Mixed *Brachystegia - Julbernadia* Woodland, G1 =*Terminalia sericea*, H1 = *Commiphora-Combretum* Woodland, I1 =*B. plurijuga*, J1 =*C. Imberbe*)

2. Mature trees to recruitment levels recorded in different woody species

Number of mature trees recorded in different woody species were very low compared to level of recruitment except for C1 species where the ratio showed a 1.1. Recruitment was high in D1, E1 and F1 suggesting type of woody species respond differently to disturbance rather than number of mature trees present in a plot. For each woody species recorded number of mature trees and level of recruitment are shown in Figure 3 below.

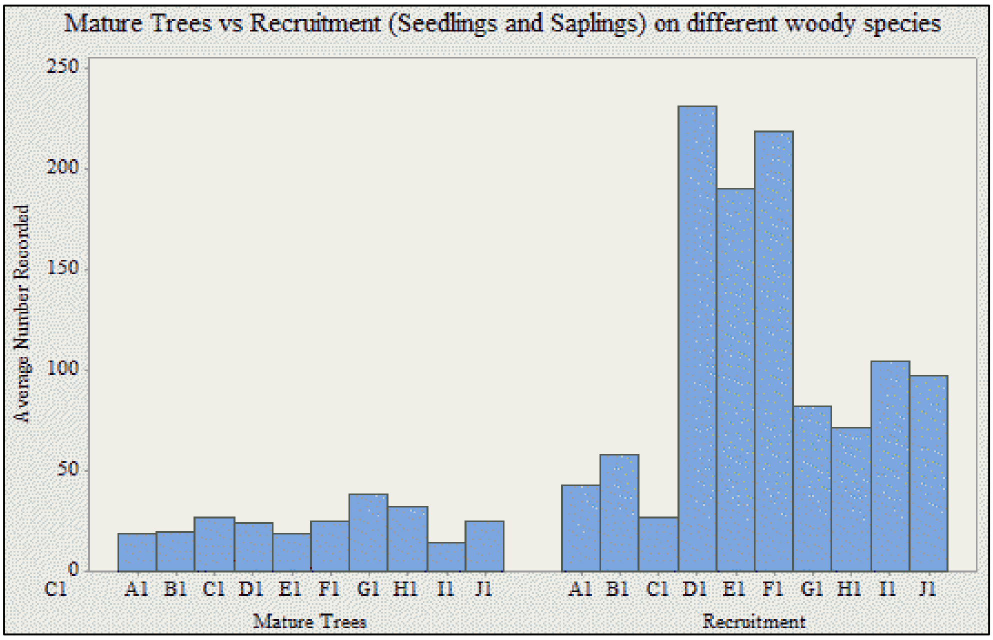

Fig 3: Comparison of mature trees to recruitment levels for each vegetation type

3. Damage level and recruitment (Seedlings and saplings)

The ratio of damage level to recruitment (Seedlings and saplings) in A1, B1, C1, D1, E1, F1, G1, H1, I1 and J1 was 1.2: 1.3: 1.1: 1.9: 1.10: 1.9: 1.3: 1.2: 1.7: and 1.9 respectively. Recruitment level in all woody species was high compared to damage (Figure 4).

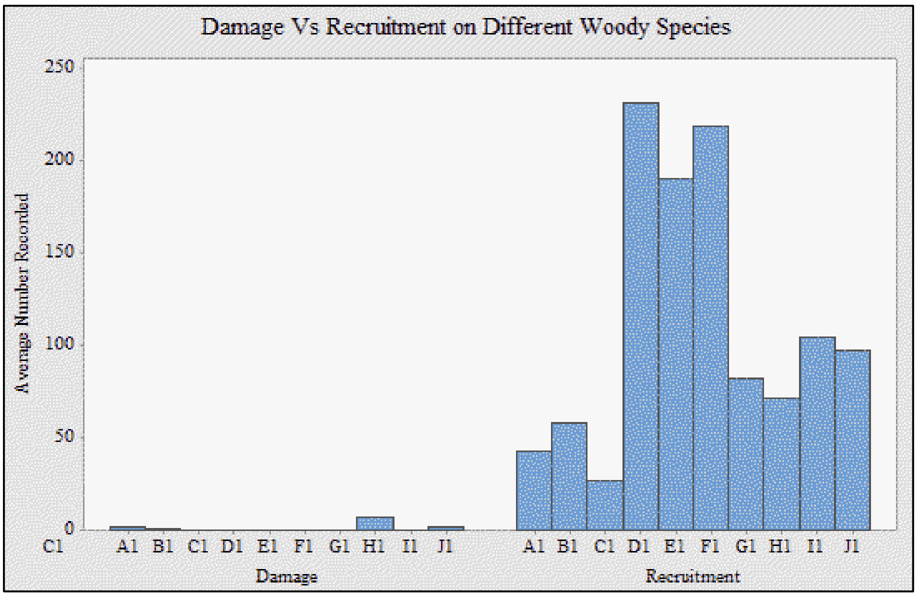

Fig 4: Comparison of damage level and recruitment in different woody vegetation types sampled

4. Density based on woody species variables measured.

Density of mature trees, saplings, seedlings and damage showed variation across different woody vegetation types. Damage levels in all woody species was very minimal compared to other variables. Saplings density dominated across different woody species (Table 1).

Table 1: Density/hectare from different vegetation types

Vegetation type	Density/ Hectare (D/Ha)			
	Mature trees	**Sapling**	**Seedlings**	**Damage**
Senegalis Woodland	304	400	288	32
Mixed Baikiaea-Combretum Thickets Mixed C. mopane-Senegalis-V.	320	720	208	16
nigrescens- Ximenia Woodlands	432	256	176	0
Mopane Woodland	384	1200	2496	0
Mixed Julbernadia-Xerophyta Mixed Brachystegia - Julbernadia	304	2080	960	0
Woodland	400	3280	208	0
T. sericea	608	1232	80	0
Commiphora-Combretum Woodland	512	992	144	112
B. plurijuga	224	1456	208	0
C. Imberbe	400	1184	368	32

4. Discussions

1. Elephant activities and woody species disturbance in SWRA.

The study showed that level of damage by elephants in different vegetation types was low constituting only 0.9% from all woody plants plots sampled. The categorised damage levels across vegetation types falls below 25% translating to low elephant disturbance across different habitats sampled. However in other protected areas for example in Hwange National Park where elephant numbers are very high, elephants are known to make a contribution in modifying the savanna wood vegetation by browsing (Childes and Walker, 1987) [7]. With a sufficient extensive browsing pressure seedlings and saplings will never get the opportunity of growing. One of the most obvious features of elephant impact on vegetation structure is the destruction and uprooting of trees and bushes that can ultimately lead to a diminution in the area of woodland and bushland (Mosugelo *et al*., 2002) [27].

Savanna elephants have been observed to cause vegetation structural change in woody species (Valeix *et al*., 2007) [34]. These changes may cause small to large scale disturbances (Morrison *et al*., 2018) [26]. This is highlighted in our study findings which recorded different levels of damage by elephants in different woody vegetation types. Previous decades of elephant disturbance may have a significantly affected on certain woody species (Mapaure and Campbell, 2002) [23] hence difference in level of recruitment as reported by the study. The study affirms the findings that low elephant disturbance is likely to be a key contributor in shaping woody vegetation communities in SWRA.

Associated to elephant density is the nature of elephant herbivory. Prolonged herbivory by elephants plays an important role in structuring savanna tree populations, irrespective of prevailing fire and rainfall conditions, according to Morrison *et al*., (2016). Chronic elephant herbivory has been observed to be a stronger predictor of tree mortality (Das *et al*., 2021) [9], as well to determine regeneration and recruitment rates in different woody vegetation types suggesting that repeated, low-intensity damage from elephants is more important to mortality than acute, but infrequent, damage (Holdo *et al*., 2016). The low elephant density in SWRA will undoubtedly result in facilitated vegetation recovery across different woody species.

2. Woody species recruitment in SWRA

Results of the study showed that recruitment and regeneration varied among different vegetation types with highest number of seedlings recorded in Mopane woodlands while *T. sericea* recorded the lowest. Plots which recorded elephant damage recorded low sapling and seedling density compared to plots with no elephant damage. This may suggest the influence of elephant to recruitment and regeneration in SWRA. However, it should be noted that utilisation of different woody vegetation types differ based on habitat preference and utilisation by elephants. This have an impact to recruitment and regeneration as a result of vegetation response to level of disturbance. However according to Clarke (2002) [8] recruitment and regeneration of woody species in an ecosystem is often episodic and disturbance driven.

The successful regeneration of a given vegetation type requires the occurrence of a sufficient number of young trees, saplings and seedlings in population (Hanief *et al*., 2016) [17]. Number of regenerating species were maximal in plots with no damage recorded compared to plots with signs of elephant damage. Plots with an apparent elephant damage had low tree densities, recruitment and regeneration levels. Low elephant disturbance could result in increased recruitment and regeneration of woody species where such as in SWRA.

3. Vegetation density

The patterns of regeneration are important because it will ultimately determine the woody structure and composition across different habitats (Laurance *et al*., 1998) [19]. The density value of seedling and saplings are considered as an indicator of regeneration potential of the species (Arya and Ram, 2011). In line with this, the ratio of seedlings and saplings to mature tree showed a significant gap, however, it was low in Mixed *C. mopane*-*V. nigrescens*- *Ximenia* woodland (Ratio 1.1); *Senegalis* woodland (Ratio 1.2) and *Commiphora*-*Combretum* woodland (Ratio1.2) In other woodland types, the ratios reveal that seedling and sapling density is greater than mature trees. The successful regeneration of a given woody vegetation type requires the occurrence of a sufficient number of young trees, saplings and seedlings in population (Hanief *et al*., 2016) [17].

The study showed that recruitment and regeneration of different woody species in SWRA is higher than number of mature trees and damage level across all habitats which translate to good regeneration. Good regeneration and recruitment occur if number of seedlings is greater than sapling density, while sapling density is greater than mature trees (Dhaulkhadi *et al*., 2008; Chauhan *et al*., 2008) [6]. The study results support the notion by Tafangenyasha *et al*., (2016) that seedling and sapling recruitment in different woody species are higher than number of mature trees in most woody species in SWRA. Tafangenyasha *et al*., (2016) highlighted that vegetation in SWRA was on the path of recovery following a major decline in elephant population over the years. This suggest a positive effect that a decline in elephant's populations has on woody vegetation regeneration.

The *Terminalia* woodland plots recorded more mature trees and saplings per hectare than other woody species sampled. The *C. imberbe* had 400 plants of mature trees with 1184 saplings. However, the two woody species had poor seedling density per hectare despite the low level of elephant. The mopane woodland plots, however, recorded low mature trees per hectare, similar to *B. plurijuga* and mixed *Julbernadia*-*Xerophyta*. In contrast, the sapling and seedling density for these three woody species was very high per hectare for mopane woodland. The low density of mature mopane trees is attributed to elephant herbivory. In the North Eastern Lake Kariba Shore, findings indicates that elephants utilisation of mopane woodland is high resulting in high elephant (Mudavanhu and Mudavanhu (2015).

In Botswana, Ben-Shahar (1998) also reported high elephant utilisation of mopane woodlands in the northern part of the country. This could be the same reason for low number of mature trees recorded in mopane plots that were sampled. Similar observations were recorded in plots with miombo woodlands where higher number of saplings and seedlings were recorded compared to the number of mature trees per hectare. The findings are comparable to those by Mapaure and Campbell (2002) [23] who also found that elephant activities in Miombo related vegetation was higher and this could have affected density of mature trees compared to the number of saplings and seedlings recorded. Higher number of seedlings and saplings compared to those of mature trees may reflects a good regeneration of vegetation in SWRA. Our findings advances that there is different response by different woody species in SWRA in responding to decline in elephant population over the years.

4. Other factors influencing vegetation recruitment and regeneration in SWRA

Woody vegetation regeneration and recruitment is a key indicator towards natural ecosystem to restoration after a period of disturbance. The nature and characteristics, of this regeneration is influenced by many factors apart from herbivory. Recruitment and regeneration levels recorded in different habitat types could have been influenced by other factors such as population decline in other mega and meso herbivores in SWRA (Dunham and Nyaguse, 2021) [11], soil type and veldfire incidence as recorded in some plots.

Fire ecological studies have alluded to different findings including; decrease in woody plant biomass, density, height and mean stem circumference while the number of stems per plant, proportion of regenerating stems increase (Shackleton and Scholes, 2000; Gandiwa and Kativu, 2009; Gandiwa, 2011) [16] elsewhere. Veldfire had been recorded in some parts of SWRA, including the central western part and northern side of the park where some sampled plots fall. Repeated burns especially in Miombo woodlands is likely affect regeneration (Ryan and Williams, 2011) [13]. Elsewhere, fire has cited as major driver of vegetation structure (Higgins *et al*., 2007; Smit *et al*., 2010). It contribute to the loss of large trees and increased shrub thickets (Levick and Asner, 2013).

The effect of fire on species richness appears to be inconsistent over several studies largely owing to soil and other factors (Shackleton and Scholes, 2000). In SWRA, a variety of soils and nutrient may have contributed to variation in recruitment in different woody vegetations. Elsewhere, in Gonarezhou, it was noted that soil type influence species diversity although there could affect structure to less extend (Gandiwa *et al*., 2014) [15]. Most woody species in SWRA occur on different soil types which could contribute to woody species regeneration rates.

Overall, the findings show that the sampled plots across different woody species have high regeneration capacity in terms of seedling and sapling but large herbivore disturbances have a long-term effect on all woody species across SWRA landscape, underlining the importance of large herbivore interaction with vegetation. The future of woody vegetation structure in SWRA depends on potential recruitment and regeneration status of trees following a disturbance.

5. Implications for Research

The information obtained in the study should influence management decisions on appropriate park ecosystem health and understanding of changes in vegetation structure as influenced by savanna elephant interactions and density in the near future. The findings of this study may be applied to other savanna elephant range areas in the country in order to understand the ecological dynamics that an increase and decline in elephant density will have on natural ecosystem informing adaptive management practices.

6. Conclusion

In sum, results of the study showed different levels of response across different woody species. Generally, recruitment was higher in all plots sampled from different woody species compared to number of mature trees recorded. This signifies good regeneration potential after years of elephant disturbance. The different woody species communities in the SWRA are on the recovery path, however, the rate of recruitment differ across woody species communities. The study provides a reference baseline for monitoring changes in woody vegetation community species and structural composition. The appropriate and timely management interventions is made possible when protected area managers understand the direction of change in vegetation communities as a result of decline or increase in savanna elephant population.

7. Future Research

Future studies should be able to model and establish time requirements and recovery rate of woody vegetation high elephant herbivory in order to ascertain biodiversity implications of different habitat types. Future research should aim to monitor changes in vegetation structure and composition as a result of other factors such as fire and rainfall. More research on plant–herbivore associations is essential at a range of both plant and animal densities to determine at what level could recruitment out compete impact of elephant damage and the diversity and density of other herbivores after decline in elephant density.

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