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Spatial distribution of invasive large fever berry trees (*Croton megalobotrys*) in Sengwa Wildlife Research Area: Gokwe, Zimbabwe

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Abstract

Background The invasion of rangelands by invasive plant species is a major threat to biodiversity in most parts of Zimbabwe posing not only an ecological challenge but a growing management and eradication challenge as well. However, there is sparse information relating to the spatial distribution of these species and the conditions promoting their growth and development particularly in Southern Africa. The study assessed the spatial distribution of the invasive large fever berry tree and associated soil type in Sengwa Wildlife Research Area. A mixed methods research design triangulating qualitative and quantitative methods was utilized. All known sites occupied by large fever berry trees were obtained from the Sengwa Wildlife Research Institute's records on invasive plant species. Ground truthing was done for all sites and global positioning system coordinates of occupied areas were collected. Mapping of invaded areas by the large fever berry tree was done using Quantum GIS software. Coordinates were imported to show points with the large fever berry tree. Altitude of invaded areas and soil samples were also collected for soil analysis and a soil texture triangle was used to come up with the soil type associated with the growth and spread of the large fever berry trees.

Results The results show that the large fever berry tree occupied areas along major rivers and streams on loam soils. An area of 16.5km² which is 4.4% of the Sengwa Wildlife Research Area is invaded by the large fever berry tree. Results further indicated that sandy-loam soils were associated with the growth and development of the large fever berry tree in Sengwa Wildlife Research Area. Veld fires were also identified as a factor influencing the spread of the large fever berry tree species in the Sengwa Wildlife Research Area.

Conclusion In conclusion, a holistic framework was developed to curb the invasion of the large fever berry tree in Sengwa Wildlife Research Area. It is recommended that further studies be conducted outside the protected area to establish soil characteristics and invasion rates in order to fully understand drivers of its invasion.

Keywords Invasive species, Large fever berry tree, Soil quality, Riverine vegetation, Sengwa Wildlife Research Area

Introduction

Invasive plants species are strains which have the potential to increase their spatial distribution, beyond their native range by expanding into native communities and may cause veritable harm to ecosystems they invade, the economy and human health (Pagad et al. 2018, Mworia et al. 2011; Zedler and Kercher 2004; Andersen et al. 2004). Maroyi (2017) contends that invasive plant species may be native in some countries but become invasive when introduced or when they expand to other environments and are likely to rapidly increase in numbers

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affecting resident plant species in the ecosystem they invade. Liu et al. (2023) alluded that invasive species may have a direct effect on community structure and composition causing biodiversity loss.

There are numerous causes of invasive species in a non-native environment. Pegg et al. (2022) suggested that propagation of invasive species may be caused by the global consumption of natural resources on floodplains, river channels or marshes. Globalisation may be the cause of invasive species development and spread in native environments (Mujaju et al. 2021; Pagad et al. 2018; Holmes et al. 2009). Padmanaba and Corlett (2014) pointed out that invasion in the tropical rainforests are likely to be caused by the removal of tree canopies which increase light availability on the ground, promoting the growth and development of light demanding species. Climate change has also been known to perpetuate the establishment and spread of invasive species (Ncube et al. 2020) creating conditions that promote the growth of these plant species (Milanovic et al. 2020). These invasive plants thus become aggressive and resistant to pests and diseases attack in the environments they establish themselves.

Invasive plant species have been monitored and mapped in terrestrial ecosystems in Zimbabwe and across the planet. In Zimbabwe invasive species are believed to cause poverty and threaten development as they impact on agriculture, fisheries, forestry and natural systems that sustain livelihood in the country. Majaju et al. (2021) noted that invasive plant species had an overall negative effect on the native biodiversity and are a major threat to the integrity and function of ecosystems.

Woody speciforms are one of the most common invasive plant species in the country. Invasive woody species found in Zimbabwe include the *Lantana camara* (Ntalo et al. 2022), *Acacia mearnsii* (Nyoka 2003; Ngarakana and Kativu 2018), *Pinus patula* (Nyoka 2003), *Callistris calcarata*, *Bauhinia variegata*, *Senna didymobotrya* and *homalanthus populifolius* (Timberlake and Chidumayo 2011; Feresu 2017; Nyoka 2003; Ministry of Environment and Natural Resources Management 2010). There is a growing body of work covering these invasive plant species in Zimbabwe. Nyoka (2003) conducted a study on the status of invasive forest trees in Zimbabwe concluding that *Lantana camara*, *Populus canescens* and *Acacia mearnsii* were highly invasive with an invasiveness index of 5. Several studies (Tarugara et al. 2022; Ncube et al. 2020; Nyoka 2003; Ntalo et al. 2022) have shown that *Lantana camara* is one of the most invasive ornamentals in the country. According to the Feresu (2017) and the Ministry of Environment Water and Climate (2014), the species mostly occurs in open grassland, woodlands and

riverine areas with the highest incidence being recorded in the Midlands and Mashonaland provinces.

The Highveld area of Zimbabwe is not spared from invasive plant species. Nyoka 2003 and Majaju et al. (2021) reported on the invasion and spatial distribution of the *Populus canescens*. Literature reporting on the invasive *Populus canescens* used remote sensing images and field observation to determine its pathways of invasion. The species has been mapped along river banks and riverbeds with areas affected including the Nyangombe, Odzani, Tandaai, Nyazura and Mukuvisi River systems. Like the *Lantana Camara*, *Populus canescens* can rapidly dominate natural areas and disturb the function of native communities. Other invasive plant species that have been reported extensively in literature include *Vernonathura polyanthes* (Majaju et al. 2021; Nyoka 2003), *Oponia fulgida* (Environmental Management Agency 2012).

Whilst there is extensive literature on invasive plant species as reported earlier, literature covering the spatial distribution of *Croton megaloborys* in Zimbabwe remains sparse. The Large Fever Berry tree is a non-native tree species that develops at any area and destroys other tree species in that particular area to facilitate their survival. It has invaded many areas including parts of Gokwe where the large fever berry trees are slowly dominating in Sengwa Wildlife Research Area (SWRA) especially in low lying areas and along rivers. As such there are high chances that negative environmental effects are taking place in the ecosystem. SWRA is a tourist attraction offering hunting and game which can be negatively affected by proliferation of fever berry trees in the conservancy. As such it is important to have knowledge on the distribution of this invasive species and develop a framework for the reduction and eradication of the species. This study therefore seeks to (1) determine the spatial distribution of large fever berry trees in Sengwa Wildlife Research Area using GIS (2) to establish soil types the favour the development and growth of the large fever berry tree (3) to evaluate possible routes of large fever berry trees invasion in Sengwa Wildlife Research Area.

Materials and methods

Study area

Sengwa Wildlife Research Area (SWRA) is a conservancy run by the Sengwa Wildlife Research Institute (SWRI) under the Zimbabwe Parks and Wildlife Management Authority. It is located in Gokwe South District in the Midlands Province covering an area of 373 km² (Coulson 1994). The following co-ordinates present the location of Sengwa Wildlife Research Institute: longitude 28.1948 east and latitude – 18.0778 south (Fig. 1).

The area has a cool dry season from May to July, followed by a hot dry season from August to October and a hot wet season from November to April (Tafangenyasha et al. 2016) with a mean annual rainfall of 600 mm (Mahakata et al. 2021). The mean annual temperature is 23.6°, October being the hottest month and July being the coldest month (Mahakata et al. 2021). The soils in the north-east sector of the Sengwa Wildlife Research Area comprise mostly of sandy loam, while the north-west sector is composed in part of clay loam which goes down onto the Sengwa river alluvium. The south-east end and half the south-west area is clay, while the remainder is river alluvium (Ngwarai 1976). There are three major rivers in the Sengwa Wildlife Research Areas inclusive of Sengwa River, Lutope River and Manyoni River (Sai et al. 2016). Lutope River drains into Sengwa River in the centre of the park, while Sengwa-Manyoni confluence is in the north of Sengwa Wildlife Research Area and Sengwa River drains northwards into Lake Kariba. According to Mahakata et al. (2021) there are four major types of vegetation in Sengwa Wildlife Research Area (mopane woodland, riverine dominated acacia woodland, miombo woodland and combretum bush). *Croton megalobotrys*

have recently been recorded in some sections of the park occupying mostly riverine areas. The plant has been observed to spread faster where it invades. Sengwa Wildlife Research Institute generates its revenue through research on wildlife production and habitats since the area was conserved specifically for conducting research (Coulson 1994). Other social-economic activities done in Sengwa Wildlife Research Area include sport/trophy hunting which attracts tourists. The organization also employs locals to help in maintaining the research area and in wildlife conservation activities.

Methods

The mixed methods research design was utilized for this study triangulating quantitative and qualitative data collection methods to collect detailed information about the spatial distribution of fever berry trees in the SWRA, their characteristics, behaviours and future prospects for their control. The research targeted the Sengwa Wildlife Research Area for mapping the spatial distribution of fever berry trees and soil quality assessment as well as 3 key informants from the SWRI (ecologist, the wildlife officer and the senior ranger scientific). The key

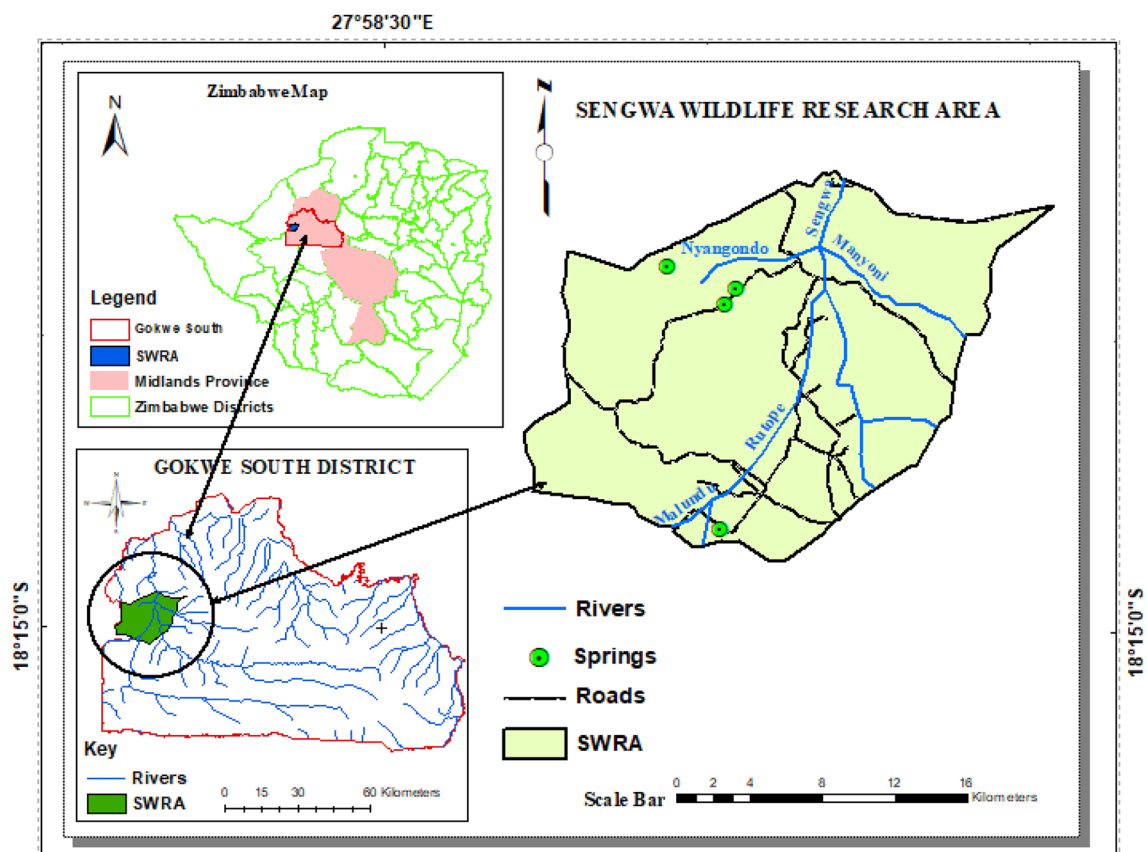


Fig. 1 Location of Sengwa Wildlife Research Area

informants were selected using purposive sampling. Data was collected using global positioning system (GPS) receivers, soil sampling methods, interviews and direct-field observations.

Prior to field visit, invasive species records from the SWRI were used to identify known areas occupied by the large fever berry in the SWRA. All known sites occupied by the Large Fever Berry trees were obtained from the SWRI records on invasive plant species. Ground truthing was done to all known sites invaded by the Large Fever berry i.e. Matekenya, Nyangondo stream, M12 along Lutope and Manyoni Rivers while searches for new sites were also done during the process. GPS coordinates of occupied areas by Large Fever Berry trees was collected. Points were marked at 500 m intervals whilst walking along the edges of the area occupied by the LFB. Polygons of invaded areas were recorded by moving along edges of areas invaded by the large fever berry trees while tracks were captured by a handheld (GPS) Global Positioning System (Etrex-40) for area calculation.

A pilot study indicated that the concentration density of the tree species was in the vicinity of rivers, this characterisation guided the transect line to follow the major water courses of Manyoni, Sengwa, Lutope and Nyangondo Rivers. The three sites were then purposively selected i.e. Matekenya (Site A), Nyangondo (Site B) and Manyoni River (Site C) on places invaded by large fever berry trees (*croton megalobotrys*) for measurements and observations based on altitude, distance from the river/stream and density of the plants at site. At each site, five plots (25 m × 25 m) were randomly placed for sampling (Tree and soil sampling). Soil quality analysis was conducted to determine the type of soils favouring the growth and spread of large fever berry trees. Direct observation in the study was done to determine the physical characteristics of the invasive species (*Croton megalobotrys*) in terms of its height and density.

Altitude and soil samples were also collected for soil analysis. Soil samples were collected randomly at two levels i.e. top soil and at 50 cm deep from the hole dug at the randomly selected site. Equal number of soil samples were collected at different altitude level which was grouped into three categories; low altitude, mid-altitude and high altitude only in areas invaded by the Large fever berry. Collected soil samples were placed into a 500 ml transparent bottle and marked with coordinates of the site for laboratory analysis to determine dominant soil types in each plot.

Soil samples collected during data collection were analysed using simple methods. A flat-bottomed clear jar was $\frac{3}{4}$ filled with the soil and water. Soil and water were then mixed so that all the soil will be broken up into individual particles (Krasner and Amy 1995; Schott 2020).

The jar was then placed for a minute which is the deposition time frame for sand particles. The deposition of silt particles occurs after an hour and the deposition of clay particles occurs after 24 h. Lines were drawn on top of each soil type layer and were measured to come up with the percentage of each soil type in the plot for which all percentages add up to 100%. Two soil types' percentages were used for analysis on the soil texture triangle which was designed by Milton Whitney (1911) and the associated soil type of each plot was obtained. The soil texture triangle was also used to determine the soil type (sand, clay or loam soil) which favours the growth and spread of large fever berry trees (*croton megalobotrys*) in SWRA and also to predict possible areas where the tree species is likely to spread to. Coordinates collected from the field surveys were also overlaid on the soil map of the SWRA to determine the specific type of soil from each category.

Mapping of invaded areas by the large fever berry was done in QGIS version 3.16. GPS coordinates collected from the field were imported into QGIS to show points with LFB in SWRA. GPS tracks recorded were also imported into QGIS software to determine total area in size invaded. The area invaded by large fever berry trees (*C. megalobotrys*) in SWRA was obtained using QGIS area measuring tool. This was done by connecting end points of large fever berry trees coordinates overlaid on the SWRA boundary map and the area size invaded. Area calculation for each site was separately calculated and later added together to estimate total number of square kilometres occupied by the LFB plant in SWRA as well as percentage area coverage of the whole SWRA.

Data was analysed using descriptive statistics using Microsoft Excel 2016. Collected data was coded using Microsoft excel and presented using graphs and charts. Coordinates of end point areas invaded by large fever berry trees in Sengwa Wildlife Research Area were converted to comma-separated values delimited files, which enabled the research to export and create a map showing the spatial distribution of the invasive tree species using geographical information system (GIS). Qualitative data from the key informant interviews was analysed using content analysis and used to support findings from the mapping and soil quality assessment.

Results and discussion

Spatial distribution of large fever berry trees in Sengwa Wildlife Research Area

Spatial distribution of large fever berry trees

Large fever berry trees were found along the three major rivers found in Sengwa Wildlife Research Area (Sengwa River, Manyoni River and Lutope River) (Fig. 2).

Large fever berry trees were also identified and mapped in the Matekenya area which is due west of

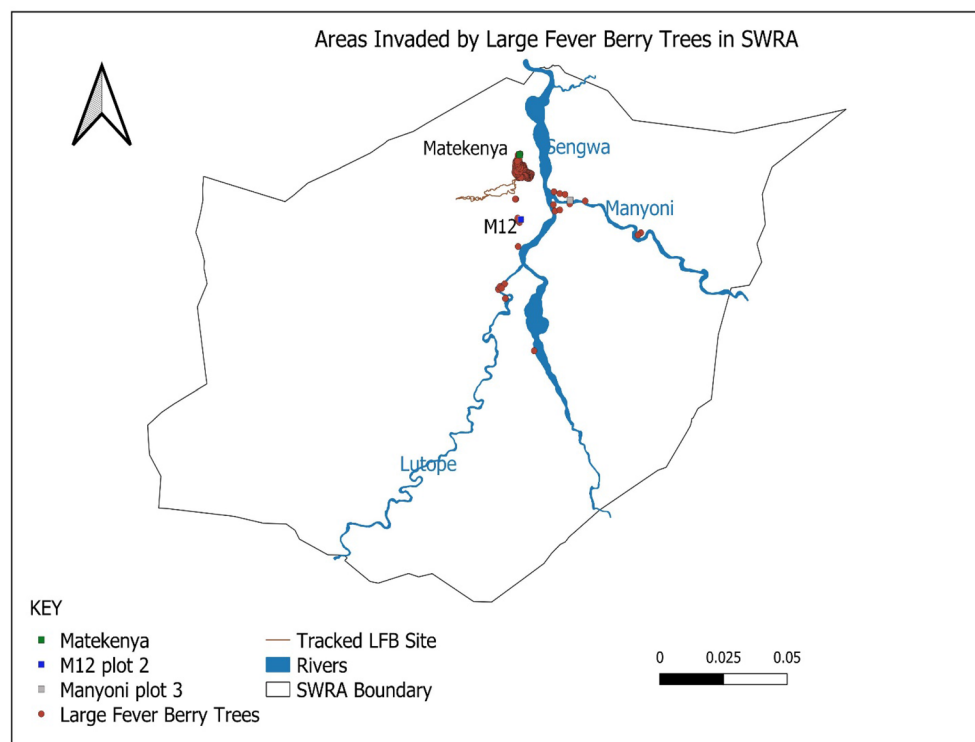


Fig. 2 Spatial distribution of large fever berry trees in Sengwa Wildlife Research Area. Source: Field data

Sengwa River. The area showed evidence of past veld fires which was corroborated by the Ecologist and the Senior Ranger Scientific at Sengwa Wildlife Research Institute. Findings indicated that large fever berry trees thrived in the Matekenya area and were densely distributed. The dense population of large fever berry trees in the Matekenya area indicates that invasion of the SWRA may have begun at Matekenya areas along Nyangondo stream that flows towards Sengwa River spreading outwardly to other areas. This is so because large fever berry trees are clustered along the area and that area is heavily invaded by the tree species. Tsheboeng et al. (2017) asserted that large fever berry trees are pioneer species that grow after human disturbances are done on vegetation. As such the frequent veld fires which occurred in the area may be the root cause of large fever berry trees invasion clustered along the Nyangondo stream.

Other invaded areas include the banks and the confluences of Manyoni, Sengwa and Lutope Rivers (Fig. 2). These findings indicate that large fever berry trees are water loving species which tend to thrive along river banks and surface water bodies. This confirms Maroyi (2017) and Oldenburg (2017) who asserted that large fever berry tree is a riverine trees species that is found along rivers.

Total area invaded by large fever berry trees in Sengwa Wildlife Research Area

The total area invaded by large fever berry trees was obtained using the measuring tool on QGIS software. The total area invaded by the tree species is 16.5 km². According to Mahakata et al. (2021) the total area of Sengwa Wildlife Research Area is 373 km². The rate of large fever berry trees invasion in the study area was calculated using the formula:

$$\text{Rate of invasion} = \frac{\text{invaded area}}{\text{total study area}} \times 100.$$

Given that the total invaded area was 16.5 km² and the area of the SWRA (373 km²) the rate of invasion was determined to be at is 4.4%.

The percentage of large fever berry trees invasion in Sengwa Wildlife Research Area is less than 50% indicating an early onset of invasion. Further, the researchers deduced that resident tree and grass species were sparse or at times nonexistent in areas with dense distribution of fever berries indicating that the invasive species was out-competing the resident woody species. This echoes with the findings of Milanovic et al. (2020) who postulated that invasive species compete with resident woody species to establish their territory and in most cases, they destroy the tree species affecting the ecosystem of the area. The invasion by large fever berry trees

could possibly be influencing land cover change around Matekenya area. If unchecked, the grassland area could be replaced by the invasive large fever berry trees posing adverse negative impacts to the ecosystem composition structure in Sengwa Wildlife Research Area.

Location of large fever berry trees in Sengwa Wildlife Research Area by altitude

Three plots were created in Sengwa Wildlife Research Area to assess vegetation variations at areas invaded by large fever berry trees. These plots were created at Matekenya (plot 1), M12 (plot 2) and Manyoni River (plot 3). At these sites, a GPS device was used to obtain the altitude of the area. Plot 1 had an altitude of 806 m, Plot 2 was found at an altitude of 811 m and lastly Plot 3 was at an altitude of 808 m. This reveals that the species is dominant in low lying areas (average altitude 808 m). Low lying areas are usually adjacent to lakes or rivers and as such have high moisture content, conditions which favour the growth of the species (Oldenburg 2017). Similarly, Maroyi (2017) revealed that large fever berry trees are found on altitudes that are below 1100 m as a result of the presence of water sources in these areas.

Vegetation variations at invaded sites in Sengwa Wildlife Research Area

Species cover at invaded sites

Large fever berry trees were the dominant/most abundant species in Plots 1 and 2 consisting of 52% and 43% of identified species in each plot, respectively (Table 1).

Resident woody species in plot 1 are outweighed by large fever berry trees since they cover 47.8% of the area revealing that area is heavily invaded and resident woody species are being affected negatively in the area. Resident woody species in plot 2 covers 56.4% of the total area but large fever berry trees have a competitive advantage over individual resident woody species such that the area may become a large fever berry woodland. Both plots show that large fever berry trees colonized the area and have managed to develop self-sustaining and self-expanding populations and are now at the establishment stage (Theoharides and Dukes 2007) where it can outcompete the

native woody species. The least invaded plot was plot 3 with large fever berry trees only covering 18% of the total areas whilst resident woody species cover the remaining area. The variations in plot 3 shows that large fever berry trees are at the transport stage of invasion (Theoharides and Dukes 2007) in the area since they have a low coverage in the area and they could possibly increase in numbers as time goes on if they remain unchecked.

Figure 3 compares large fever berry trees cover with resident woody species in Sengwa Wildlife Research Area. Large fever berry trees have the highest species cover in the area with an average coverage of 38%. Other tree species cover ranges from 6 to 26% with the acacia species having the second most abundance and the terminalia species having the least coverage in the areas.

The Ecologist at Sengwa Wildlife Research Institute indicated that large fever berry trees in the area are less than 10 years old and so are the invasive species in the area. However, Fig. 3 shows that the tree species have the highest cover in the areas of invasion compared to the other species. This means that the tree species may be fighting against resident woody species to have a large territory in the riparian areas of Sengwa Wildlife Research Area. Resident woody species thus threatened by the large fever berry trees invasion in the area. Shackleton et al. (2022) asserted that invasive plant species is the major cause of biodiversity loss and disruption of ecosystems posing negative impact on the environment. Invaded areas can be referred to as the large fever berry trees woodland area because the tree species have the highest abundance in comparison with other individual woody species. The total percentage of combined resident woody species is 62%. If large fever berry trees are unchecked, the percentage of resident woody species cover may be reduced in future, further disturbing the composition structure of the ecosystem in Sengwa Wildlife Research Area.

Table 1 Vegetation cover at invaded sites in Sengwa Wildlife Research Area

Tree species	Plot 1 (%)	Plot 2 (%)	Plot 3 (%)
Large fever berry trees	52.2	43.6	18.5
Combretum	17.4	31.3	14.8
Acacia Vachellia	30.4	18.8	29.6
Mopane	0	0	25.9
Terminalia	0	6.3	11.1

Source: Field data

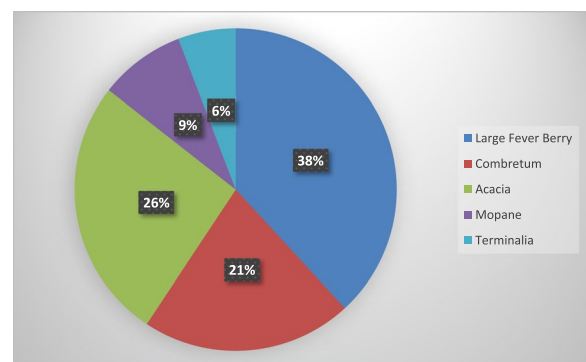


Fig. 3 Distribution of large fever berry trees in relation to other vegetation species in the area. Source: Field data

Table 3 Average tree height of trees in assessed plots

Tree species	Plot 1 (m)	Plot 2 (m)	Plot 3 (m)	Average height (m)
Large fever berry trees	5	3	3	3.7
Combretum	3	4	5	6
Acacia	4	3.5	5	4.2
Mopane	0	0	6	2
Terminalia	0	3	3	2

Source: Field data

Trees height variations at invaded area

Large fever berry trees in the mapped area had an average height of 3.7 m with plot 1 having the tallest large fever berry trees with height up to 5 m (Table 3). The dominance in height for plot 1 is likely because large fever berry trees have less competition since there are only two native woody species in the area (combretum, 3 m and the acacia, 4 m).

In plot 2, the tree heights in the area ranges from 3 to 4 m in height showing that there might be a moderate competition of all tree species in the area. Plot 3 records the mopane trees with the highest average tree height of 6 m followed by acacia and combretum species which are 5 m tall. As such, large fever berry trees are less dominant in plot 3 as they have a low average tree height compared to other tree species (Table 3). The variations in height shown in Table 3 may be attributed to variability in altitude, soil quality and moisture content within the three plots. Of the three plots, plot 1 has the lowest altitude of 806 m above sea level and has the higher moisture content compared to the two other plots given its proximity to the confluence of Sengwa and Matekenya rivers. This partially explains why the fever berry trees are dominating in terms of height in plot 1 compared to other plots. In a study done by Bonyongo (2020) they observed that soil type, the amount of phosphorous in the soil as well as the amount of moisture in the soil have a strong positive relationship with plant growth.

Soil type associated with the growth and development of large fever berry trees in Sengwa Wildlife Research Area

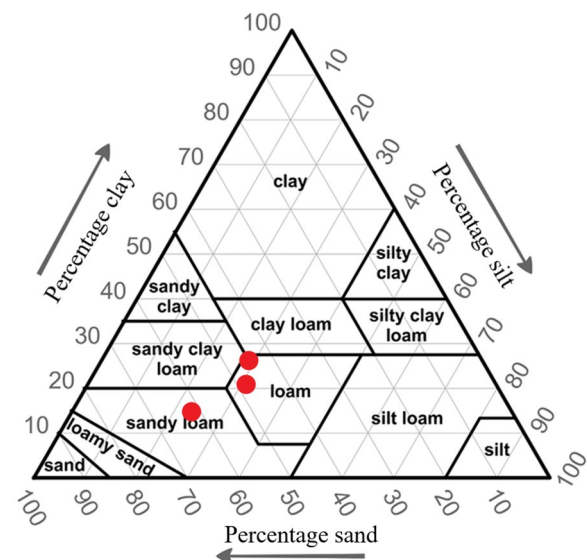
Soil type found at invaded areas in Sengwa Wildlife Research Area

Soil properties are essential to the growth of all plant species in a given area. Table 4 indicates the relative content of particles of various sizes, such as sand, silt and clay in the soil from the three sampled plots.

Table 4 Soil type associated with the growth and development of large fever berry trees

Site	Particle size distribution			Soil texture class
	Clay %	Silt %	Sand %	
Plot 1	37.5	28.6	33.9	Loam
Plot 2	47.9	31	21.1	Loam
Plot 3	27.4	28.9	43.6	Loam

Source: Field data

**Fig. 4** Soil texture triangle showing soil types found in sampled plots invaded by large fever berry trees. Source: Field data

The dominant soil texture class was sandy loam/ loamy sand revealing a high sand content in the soil. The Ecologist of Sengwa Wildlife Research Institute attested that large fever berry trees in the area grow on loam soil type. Clay and Silt values were used to come up with the actual soil type that is dominant in the three plots where large fever berry trees are most abundant. The point where clay and silt particles meet on the soil texture triangle is on the sandy loam soil (Fig. 4).

The results indicate that sandy loamy soils promote the growth and development of large fever berry trees in the SWRA. The results confirm the findings of Tsheboeng et al. (2017, 2020) who pointed out that large fever berry trees grow on alluvial soils which soils comprise mainly of sand soil particles, which are deposited by rivers over a long period. The species could have modified the soil type to its preference in an event to prevent other competing species.

Average soil type found in all areas invaded by large fever berry trees in Sengwa Wildlife Research Area

Sand soil particles are also dominant in areas invaded by large fever berry trees at all invaded areas in Sengwa Wildlife Research Area with a coverage of 44% (Fig. 5).

Clay and silt particles have 27% and 29% coverage, respectively. These values were used to determine the actual soil type dominant at invaded areas. Clay and silt values are used on the soil texture triangle and meet on the loam soil (Fig. 6). As a result, the examination reveals that the soil type that favours the growth, development and spread of large fever berry trees in Sengwa Wildlife Research Area is the loam soil.

Possible routes of invasion by large fever berry trees in Sengwa Wildlife Research Area

Riparian areas

Riparian areas are areas found along river banks and swamps (Kotze 2015). Large fever berry trees grow mostly on riparian areas (Maroyi 2017). In Sengwa Wildlife Research Area, riparian areas are found along Sengwa River, Manyoni River, Lutope River and the Nyangondo stream. These riparian areas favour the growth of large fever berry trees, making these areas vulnerable to the tree species invasion. This is because as noted by Maroyi (2017) the tree is a riverine tree, favouring low lying areas and thriving in swamps and along river banks. Thus riparian ecotones are a possible route of invasion for the large fever berry trees in the SWRA.

Grassland

Grasslands were also identified as another route of invasion by large fever berry trees in the SWRA. According to the Senior Scientific Ranger, every fire season, Matekenya grassland is affected by veld fires which destroy no less than 20 ha of grassland annually, resulting in degradation (Fig. 7). It is this disturbance that could have promoted the growth of the tree species in the area. This resonates

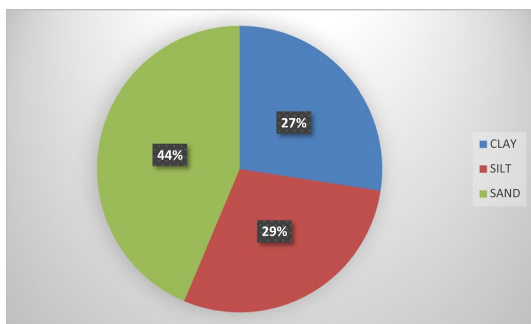


Fig. 5 Average soil texture variations found at areas invaded by large fever berry trees in Sengwa Wildlife Research Area. Source: Field data

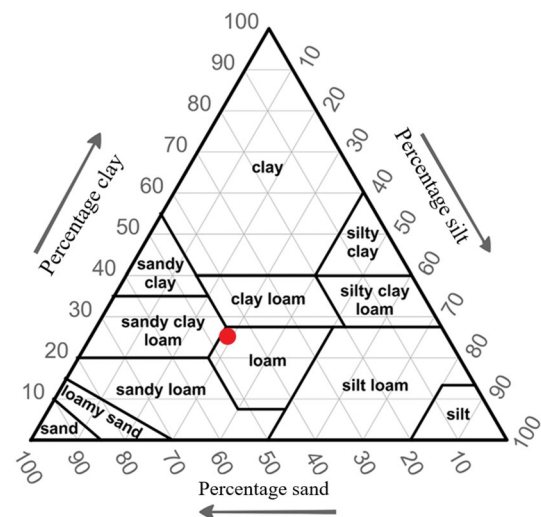


Fig. 6 Soil type favouring the growth, development and spread of large fever berry trees in Sengwa Wildlife Research Area. Source: Field data

with the findings of Tseboeng (2020) who revealed that large fever berry trees normally grow on degraded land as pioneer species after a destruction occurs. Therefore, grassland areas are vulnerable to the large fever berry trees invasion. Figure 7 shows Matekenya area burning due to a veld fire.

Loam soil

Large fever berry trees' growth is influenced by the presence of loam soils in Sengwa Wildlife Research Area (Fig. 8). This therefore, makes areas covered with loam soils vulnerable to the large fever berry trees invasion. The Ecologist and the Senior Ranger Scientific corroborated that invasive species are likely to invade areas with the same soil characteristics as those on invaded sites.

Rivers

Hydrology and stream flow were also identified as a possible route of invasion by large fever berry trees within



Fig. 7 Matekenya grassland burning due to a veld fire that occurred in July 2022. Source: Field data

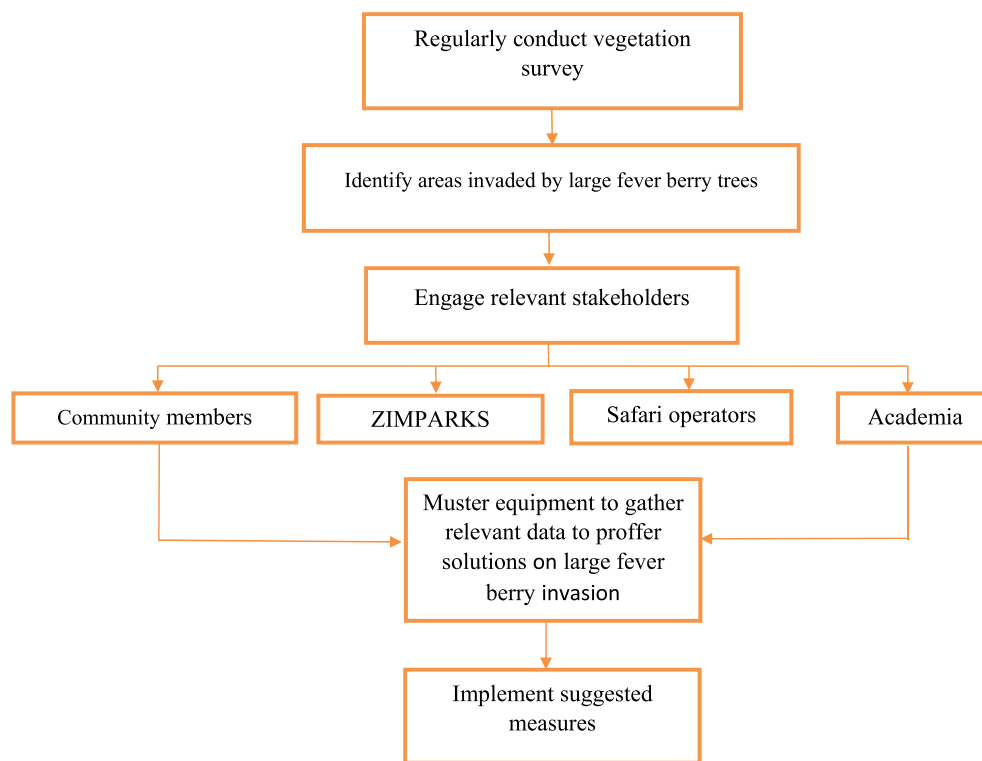


Fig. 8 Framework to reduce the invasion of large fever berry tree in Sengwa Wildlife Research Area. Source: Authors

the SWRA. There are three rivers which flow within the SWRA namely Lutope, Sengwa and Manyoni Rivers. These rivers could be a possible route of invasion by large fever berry trees withing the Sengwa Wildlife Research Area as rivers are known to be conduits for alien species invasion. The first stage of a biological invasion requires a species to be transported beyond the boundaries of its native range. The rivers in this case transport seeds and seedlings of large fever berry trees from areas upstream introducing them to the SWRA where they establish themselves, findings which ressonate with those of Ruwanzza and Mhlongo (2020). Leuven et al. (2009) also linked rivers and waterways as a highway to dispersal of invasive plant species, findings which are also in line with this study.

Framework to reduce the invasion of large fever berry tree species in Sengwa Wildlife Research Area

To successfully combat the spread of large fever berry tree, it is important to conduct a vegetation survey of the research area. This may be done using various methods like the use of transact lines, point method, grid method, stratified method and a random sampling method on selected quadrants. Figure 8 provides a framework that was developed by the researchers to reduce the invasion of large fever berry tree in

Sengwa Wildlife Research Area as informed by the findings of this study.

Vegetation survey allows researchers to obtain the large fever berry trees' structure and distribution in Sengwa Wildlife Research Area. It is also important to have surveys on large fever berry trees in Sengwa Wildlife Research Area to obtain challenges caused by the tree species because it may be a major threat to biodiversity conservation as they may cause destruction of resident woody species. Habitats of large fever berry trees should also be assessed to identify areas that are likely to be invaded in future.

Further, it is important to engage all stakeholders to accomplish the goal to reduce the invasion of large fever berry trees in the SWRA. These stakeholders assist in mustering relevant equipment, to gather relevant data to proffer solutions to curb with the spread of large fever berry trees in the protected area. Stakeholders that may be involved to address the effects of large fever berry trees include Zimparks, safari operator, academia and members of the community. These stakeholders work hand in hand to come up with solutions to address the problem caused by large fever berry trees in Sengwa Wildlife Research Area. They also provide resources needed to implement the suggested solutions to reduce the spread of large fever berry trees in Sengwa Wildlife Research Area (Fig. 8).

Conclusion

The study concluded that large fever berry trees are predominantly distributed along major rivers and streams (Sengwa, Manyoni and Lutope River Nyangondo stream) along the SWRA. Large fever berry trees tend to favour low lying riverine areas between altitudes of 800 m and 816 m above sea level. Further, it was concluded that loam soils influence the growth of large fever berry trees in Sengwa Wildlife Research Area. Because of these factors, areas along the Sengwa, Manyoni and Lutope rivers are thus prone to invasion by large fever berry trees. The successful eradication of the large fever berry trees requires a collaborative effort from all stakeholders as indicated in the proposed framework for the eradication of the invasive species in the SWRA. The framework developed in this study is innovative and groundbreaking as it can lead to the management and eradication of invasive species not only within the SWRA but in other parts of Zimbabwe and sub-Saharan Africa that are plagued by invasive species.

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All authors contributed to the production of this manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

All data will be made available on request.

Declarations

Ethics approval and consent to participate

No experiments were carried out in this research. Permission to conduct the research was granted by local leadership and the respective officers in the consulted departments. All participants participated willingly.

Consent for publication

All the authors give consent for publication.

Competing interests

The authors declare no competing interests.

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