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REPORT ON THE ECOLOGICAL STATUS AND ABUNDANCE OF AFRICAN CHERRY *Prunus africana* (Hook f.) Kalkman IN NYIKA NATIONAL PARK, MALAWI AND NYIKA NATIONAL PARK, ZAMBIA

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List of abbreviations and acronyms

GoM	Government of Malawi
FRIM	Forestry Research Institute of Malawi
DPNW	Department of National Parks and Wildlife
SABONET	Southern African Botanical Diversity Network
NNP	Nyika National Park
CITES	Convention on International Trade in Endangered Species
IUCN	International Union for the Conservation of Nature
GPS	Global Position System
LSD	Least Significant Difference
Km	Kilometre
^{o} C	Degrees Celsius
ANOVA	Analysis of Variance
US$	United States Dollar
DBH	Diameter at breadth height
BPH	Benin Prostate Hyperplasia

ABSTRACT

Prunus africana is an important medicinal plant and its population is declining in most of its natural range states because of over-exploitation. Its bark is processed by pharmaceutical companies in Europe to treat Benin Prostatic Hyperplasia (BPH). Little is known about the status of *Prunus africana* in Malawi, although it is one of the range states. It was against this background that research was conducted to investigate the population structure, species associations and soil preference of *Prunus africana* in Nyika National Park (Juniper Forest), Malawi and Nyika National Park, Zambia (Manyenjere Forest). The data was collected using belt transects. Data on species name, height (m), DBH (cm), canopy cover and soils were collected. The data was analyzed using GenStat, Mintab and PC-ORD statistical software. The study recorded 4.7 trees/ha in both study sites. The Juniper Forest had the highest mean density (14.4 trees/ha) while Manyenjere Forest recorded a lower density (3.6 trees/ha). There were more mature trees than saplings and seedlings across the study area, and Manyenjere had no seedlings at all. This was attributed to thick canopy cover in Manyenjere which hinders proper growth and development of *Prunus africana* as the species is a light demander. *Diospyros whyteana* was among the species very closely associated with *Prunus africana* at both sites. Soil analysis revealed that all essential elements (Ca, N, Mg, C) and pH were the same at both sites, except phosphorus which varied significantly ($p<0.05$) between the Juniper Forest (9.01 ±4.7 mg/kg) and Manyenjere Forest (3.83 ±3.4 mg/kg). Both sites were predominantly loamy sand which are moderately acidic. It was concluded that both sites are dominated by mature trees with very little or no recruitment at all. Additionally, *Prunus africana* thrives well in loamy sand soils which are moderately acidic. It was, therefore, recommended that cultivation or domestication of *Prunus africana* be promoted in both parks. As the Nyika Plateau is grappling with invasive species, *Prunus africana* would be a better option as the species establishes good and viable plantations and is a relatively fast-growing species (Hall *et al*, 2000).

CHAPTER 1: INTRODUCTION

1.1 Background information

Prunus africana, commonly known as the Red Stinkwood, African Cherry, or Bitter Almond, is a medicinal tree. It is known to treat Benign Prostatic Hyperplasia (BPH) a condition common in old men (Cunningham *et al*., 1997; Fashing, 2004; Jimu, 2011; Nguta, 2012). Locally it is known as dadzi in Chichewa; mzumira in Tumbuka and msisita or mkunu in Yao (Burrows & Willis, 2005).

Prunus africana has been subjected to unsustainable harvesting of its bark for the international medicinal plant trade for many decades (Cunningham & Mbenkum, 1993; Cunningham *et al*., 1997; Fashing, 2004) and was listed as a CITES Appendix-II species in 1995 (Cunningham *et al*., 1997). The high demand for bark extracts of *P. africana* has caused serious damage to wild populations in most range states (Fashing, 2004; Nyamai *et al,* 2015).

1.2 Description of *Prunus africana*

The genus name 'Prunus' is derived from a Latin word which refers to the plum family, and the scientific name *Prunus africana* refers to the species of African origin (Komakech *et al.,* 2017).

Prunus africana belongs to the subfamily *Prunoideae* within the Rosaceae family. There are around 400 species in the genus *Prunus*, divided into two sub-genera: *Padus* (deciduous) and *Laurocerasus* (evergreen). The *Laurocerasus* sub-genus includes *P. africana*, the only one found in Africa and Madagascar (Navarro-Cerrillo *et al.,* 2008; Nguta, 2012).

The genus *Prunus* comprises of over 400 species, of which only 98 are of great importance. The African Cherry is a species of the genus *Prunus*, with a mature stem diameter of up to 1 m and a height of more than 40 m with open branches and a blackish-brown bark. Leaves are simple, alternate, oval-shaped, shiny-deep green on the top side and lighter on the underside, with a conspicuous prominent midrib on the underside. Flowers are greenish or white and fruits are spherical, 7 mm long, 1.3 cm wide, pinkish-brown, and bilobed, with thin, dark red to reddish brown pulp when ripe (Komakech *et al.,* 2017).

In the Equatorial zone, there is no specific flowering season and some individuals of the species flower almost every month of the year (Munjuga *et al*., 2000). In regions north of 5ºN, flowering takes place as from November to January when the temperatures are low and there is lower rainfall (Munjuga *et al.,* 2000). In regions south of 5ºN, flowering takes place from April to October when the conditions are cool and dry. Fruiting of the species occurs 2-3 months after flowering and is associated with rainfall. In the Northern zones, fruiting takes place in the relatively wet months. In the southern regions, fruiting occurs when the rains are starting or in the second half of the dry season (Sun *et al*., 1996).

1.3 Habitat preference

Prunus africana is indigenous to the montane regions. It is a highland forest plant that grows in humid and semi-humid conditions at an altitude of about 900–3,400 m above the sea level of Sao Tome and Madagascar and Afromontane forest islands in Africa with a mean annual rainfall of 890–2,600 mm and a mean annual temperature of 18–26°C (Komakech *et al.,* 2017).

1.4 Uses of *Prunus africana*

This high-altitude species is of economic, social and scientific importance for the local people and the international community. Locally, it is a source of timber (for crafts), firewood, income and it contributes to the traditional pharmacy (Hall *et al.,* 2000). Scientifically and internationally, its bark is used by Western industries to treat benign prostate hyperplasia (Betti & Ambara, 2013; Awono *et al.,* 2016).

Prunus africana is also valued for apiculture as the flowers have sufficient nectar and pollen for good bee forage. Some communities in the range states use leaves as an inhalant for fever or are drunk as an infusion to improve appetite. Water is added to pounded bark and the red liquid is used as a remedy for stomach-ache; a bark extract may be used as a purgative for cattle (Orwa *et al.,* 2009). Additionally, other services include erosion control, shade or shelter. It is also known to improve soil fertility and ornamental as it makes an attractive garden shade tree (Orwa *et al.,* 2009).

1.5 Geographical distribution

Prunus africana is monoecious tree and is native to 21 countries in sub-Saharan Africa. It is known to occur in Africa and mostly concentrated in the eastern part of the continent (Figure 1). It is a mountain tree species of the tropical Africa including Côte d'Ivoire, Bioko, Sao Tome, Ethiopia, Kenya, Uganda, South Africa, Madagascar, Congo, the Democratic Republic of Congo, Mozambique, Tanzania, Burundi and Cameroon, Zimbabwe, Nigeria, Equatorial Guinea and Malawi (Cunningham *et al.,* 1997; Betti, 2008; Cunningham, 2005; Betti & Ambara, 2013; Awono *et al.,* 2016).

Figure 1: Distribution of *Prunus africana* in Africa (Source: Betti & Ambara 2013).

In Malawi, the distribution of *P. africana* was widespread across the country (Table 1). According to (Mphamba, 2019 *pers. comm.*) recent forest inventories have failed to locate *P. africana,* in most of the sites where it was previously sighted in the 1970s, an indication that the species has disappeared in most of the sites in Malawi and mostly attributed to deforestation, settlement and agriculture.

1.6 Statement of the problem

Prunus africana is declining over its natural range, and is even becoming locally extinct in some of its range owing to over-exploitation (Cunningham *et al.,* 1997; Ingram, 2007; Betti, 2008; Cunningham, 2005). *Ex-situ* conservation seems to be a viable option for sustaining *Prunus africana* international bark demands. However, its success is currently limited due to scanty or lack of information on population structure, species associations and soil physio-chemical properties of *P. africana* in Malawi and Zambia. Population structure of the existing population and its ecological interactions have been poorly documented in Malawi and Zambia, resulting in haphazard implementation of *ex-situ* conservation strategies.

It is against this background that a research has been initiated to investigate population structure, soil preference and species associations of *Prunus africana* in Nyika Malawi and Nyika Zambia National Parks. The information generated will assist in cultivation and domestication of *Prunus africana* in the study sites.

Table 1: Location of *Prunus africana* in Malawi in the 1970s.

PROVINCE	REGION	LOCATION	DEGREES/MINUTES
South	Thondwe, Mpita estate	edge of forest	15°26'S, 35°13'E
South	Domasi, Katsonga	near river bank	15°17'S, 35°22'E
South	Thyolo, Mchima estate	Msikidzi river banks	5km SE of Thyolo
North	Chitipa, Chisenga	Misitu forest	SE of Chisenga 1950m
North	Chitipa, Misuku hills	Wilindi forest	09°41'S, 33°28'E
Central	Dedza mountain	evergreen patches	14°20'S, 34°20'E
Central	Ntchisi	Chinthembwe Mission	13°26'S, 33°59'E
South	Mulanje mountain	Phwera waterfalls	16°04'S, 34°44'E
South	Michesi mountain	Western slopes of Napolo valley	Rocky slopes 1300m
South	Chiradzulu mountain	SE slopes above boma	36LYT3364, 1550m
South	Mt Mulanje. Likhubula valley	source of Nansato stream	
North	Rumphi	Juniper forest	10°45'S, 33°53'E
South	Thyolo	Mpeni tea estate	15°58'S, 35°05'E
Central	Ntcheu–Kalichelo hills	on top of hill	14°26'S, 37°27'E
South	Phalombe	Phalombe river	15°46'S, 16°03'E
South	Zomba mountain	south of Chingwes Hole	15°20'S, 35°16'E
Central	Dedza–Chiwamba vg 1	Msitu wa lengwe	14°10'S, 34°22'E
South	Neno primary school	Mkulumadzi river	
South	Machinga Chikala Hills	evergreen patches on top	
South	Mangochi Hills	near campsite, edge of evergreen forest patches	

Source: Department of Forestry (FRIM-Zomba)

1.7 Objectives

1.7.1 Main objective

The main objective of the study is to analyse population structure, plant species associations and soil chemistry of *Prunus africana* species in Nyika, Malawi and Zambia National Parks.

1.7.2 Specific objectives

1. To establish what is the *Prunus africana* population structure in Nyika National Parks, Malawi and Zambia;
2. To identify *Prunus africana* species associations in the study sites;
3. To examine soil physical-chemical concentrations in Nyika National Parks, Malawi and Zambia.

1.8 Justification for study

Prunus africana is threatened with extinction but can be conserved by domestication initiatives (Cunningham *et al*., 2005). Domestication and reliance of planted trees will make the pharmaceutical future of P. *africana* bark and bark extracts more secure (Cunningham *et al.,* 1997). This study was the first of its kind in Malawi and Zambia. Therefore, the study will help generate information that will assist Malawi and Zambia Governments come up with policies and strategies that will aide in conservation of *Prunus africana* through cultivation and domestication.

CHAPTER 2: MATERIALS AND METHODS

2.1 Description of the study area

The study was conducted at the Juniper and Manyenjere Forests inside Nyika National Park, Malawi and Nyika National Park, Zambia respectively.

According to GoM (2003), the Nyika National Park in Malawi occupies a tract of mountains plateau and associated hills and escarpments in northern Malawi. Its area is 3,200 km^2, and it is centered upon 10° 33'S, 33°50'E. The Park lies astride the Chitipa, Karonga, and Rumphi Districts of the Northern Region of Malawi. Part of its western boundary coincides with the Malawi-Zambia border, and a section is contiguous with the Zambia Nyika National Park (Figure 2). Zambia Nyika National Park has an area of 70 km^2 and lies in the northeast of Zambia, on the western edge of the Nyika Plateau, which is one of the highest parts of the country and most of which lies in neighbouring Malawi. The main land uses around these study areas include agriculture, settlement, logging and mining.

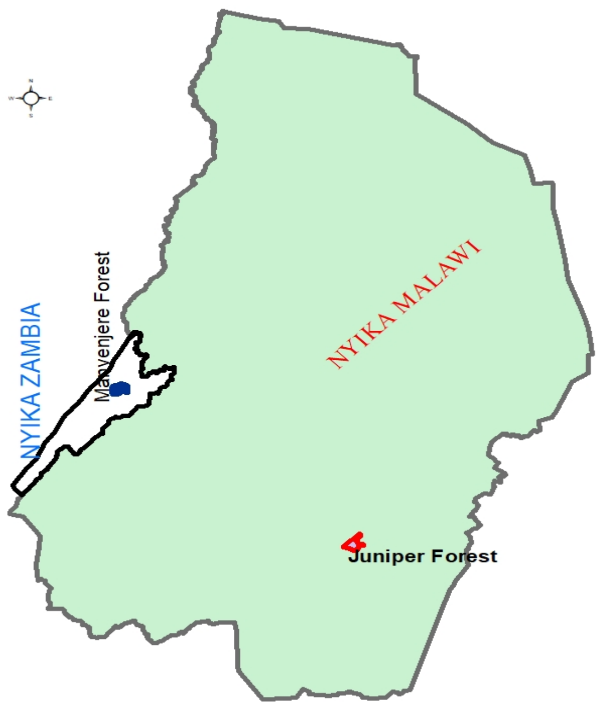

Figure 2: Nyika National Park in Malawi and Zambia showing location of Juniper and Manyenjere Forests.

The Nyika Plateau lies at an altitude of between 1800-2607m above sea level receiving an average rain of about 1000–1700 mm per annum. The Nyika National Park was established between 1948 and 1952 by the colonial Government to conserve wildlife for tourism and economic development of both Malawi and Zambia. After independence in the 1960s, management of both parks was left to Malawi and Zambia Governments. Poaching, bush fires, illegal mining, logging, and encroachment are the major problems facing the plateau at the moment.

2.2 Choice of study area and sampling methods

The sites were chosen based on the literature by Burrows & Willis (2005) who reported the presence of *Prunus africana* in these sites. A preliminary survey was undertaken to have abroad over view of the site. In the Juniper Forest, distribution of *Prunus africana* was along the stream while in Manyenjere was along forest edge. To obtain representative samples, the area was stratified into Riverine (riparian) and Non-riparian habitats. The belt transects of 50 m by 500 m divided into smaller plots of 25 m × 25 m were systematically applied and mid of the stream was taken as the mid-point of the belt (25 m left and 25 m right). Subsequent belt transects were obtained at an interval of 100 m moving away from the previous belt transect along the same baseline (Fig. 3). In non-riparian habitat, a belt transect of 50 m by 500 m started on the edge of the forest to about 50 m inside the forest (Figure 3). The initial point was randomly selected within the forests close to the forest edge.

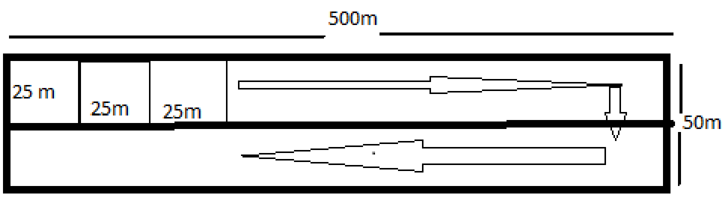

Figure 3: Belt transect showing data collection plan.

Asrat & Tesfaye (2013) reported that sampling plants especially Forest trees with a height over 3m, rectangular or square plots with a sampling area greater than or equal to 100 m^2 have commended to yield better results hence the 25 m × 25 m plots. The plot method was used because it is one of the basic and commonly accepted procedures for sampling many types of sessile organisms like plants.

A total of two belts with 40 plots were sampled in each stratum (riparian or non-riparian) representing 160 plots in both the Juniper and Manyenjere Forests. Ten hectares of the area was sampled.

2.3 Data collection

2.3.1 Trees and saplings

Within the 25 × 25 m quadrat the recordings of data regarding, name and number of tree species present, height, diameter at breast height (DBH) and crown diameter of the tree species were made. General plot canopy cover was calculated in all plots using densiometer. Heights of *P. africana* were measured using Vertex IV ultrasound instrument to have accurate and reliable measurements. DBH was measured at 1.3 m tree height using a diameter tape while crown diameter was measured using a tape measure by projecting the perpendicular distance from the ground.

2.3.2 Seedlings

Seasonal seedlings were sampled in four quadrats (l × 1 m) from two opposite sides of *P. africana* trunk base. The first side was selected as the direction the tree was encountered from while the second side was directly opposite. The first quadrat was taken immediately to the tree trunk base and each quadrat separated from each other by a distance of 5 m.

2.3.3 Soil samples

The two study sites were first evaluated before collection of soil samples. Three soil samples per plot containing *P. africana* were collected at a depth range of 0 to 15cm after removing the top organic matter under each identified study plot (Provin *et al.,* 2002). Collected soil samples from both Juniper and Manyenjere Forest plots were taken to FRIM for laboratory analyses.

2.4 Data analysis

The data collected was analysed using GenStat version 12.1, Minitab version 16.1 and PC-ORD version 6.08. ANOVA tests & T-Tests were performed to determine significant differences which was pegged at 5%. Cluster analysis, Shannon's Diversity Index analysis was applied to derive species diversity and association levels. Density was calculated by the number of individual species divided by area (ha). Abundance was found by summing up individual counts of *P. africana* in all plots and sites.

CHAPTER 3: RESULTS

3.1 Abundance of *Prunus africana* at study sites

The abundance of individual trees in the occurrence sites are presented in Table 2. A total of 47 individuals of *P. africana* were found in 26 of the 160 sample plots. Results show that abundance of trees was highly significant between study sites. Juniper forest recorded high tree abundance (38) as compared to Manyenjere Forest (9). In terms of vegetation type, the riparian forest type was highest (36) than the non-riparian (11) forest type in abundance of *P. africana*.

3.2 Stocking density of *Prunus africana* at study sites

The mean stocking density found was 4.7 trees/ha in occurrence sites. Tree stocking density was highly significant ($P<0.05$) between sites. Juniper forest had the highest, while Manyenjere forest had the lowest. The Juniper riparian habitat type (14.4 trees/ha) had the highest stocking densities followed by Manyenjere non-riparian forest (3.6 trees/ ha). The least was Manyenjere riparian (0.0 trees/ ha).

Table 2: Abundance, density, mean DBH, height and canopy cover in relation to vegetation in occurrence sites

Name of forest and forest type	Abundance	Density (trees/ha)	Mean DBH (cm)	Mean height (m)	Canopy cover (%)
Juniper riparian forest	36	14.4	30.5±18.1	15.4±7.3	55±10
Juniper non-riparian	2	0.8	24.6±3.9	12.7±2.7	48±19
Manyenjere riparian	0	0.0	0.0	0.0	92.25±8
Manyenjere non-riparian	9	3.6	28.4±18.1	21.1±11.2	87±7

3.3 Tree diameters at study sites

Tree diameters ranged between 5.5 to 66.3 cm for Juniper Forest, whereas in Manyenjere forest it ranged from 7.9- 53.5 cm. The mean DBH was highest in the Juniper Forest (27.5 cm) compared to Manyenjere (14.2 cm). Juniper riparian forest recorded the largest mean DBH (30.5 cm) followed by Manyenjere non-riparian forest, while Manyenjere riparian-forest had zero tree counts. Results of the study suggest that juniper forest has the largest tree diameters of the two sites and is found in riparian vegetation type.

3.4 Diameter-class distribution at study sites and forest types

Figure 4 shows individual tree diameter classes found in the two occurrence sites. There were no significant differences (P>0.05) in mean DBH between sites. However, the highest number of individuals recorded was in size-class 21-30.9 (6 individuals); followed by 41-50.9 cm (5 individuals) and the least in 70.9 (0 individuals). All the largest number of individuals were found in the Juniper Forest (Figure 4).

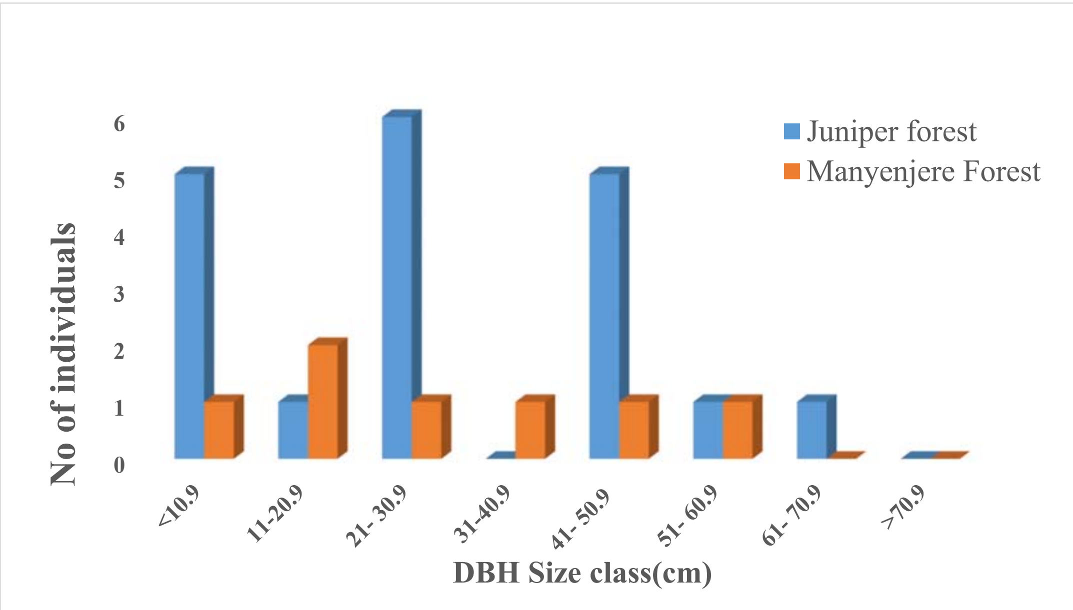

Figure 4: Tree diameter size-class distribution at the study sites.

3.5 Tree height in relation to study sites

Juniper recorded a tree mean height (m) of 15.4 ±7.3 whilst Manyenjere recorded tree mean height (m) of 21.11 ±11.17. The Juniper Forest heights ranged from 5.3 m to 26.7 m while Manyenjere Forest ranged from 7.2 m to 34.3 m. However, there was no statistically significant differences in mean height (Two Sample t-test, $t = -1.64$; $df = 23$; $p = 0.114$) between study sites.

3.6 Forest canopy cover in relation to occurrence sites

Tree canopy cover in the two study sites ranged from 7 to 95% in occurrence sites. The canopy covers for Juniper Forest ranged from 7 to 75% while Manyenjere Forest ranged from 75% to 95%. Comparatively, Juniper Forest recorded a lower mean canopy cover percent (52% ±14) whereas Manyenjere forests had the highest (94% ±5.9) average canopy cover and results were statistically significant at alpha 0.05.

3.7 Tree canopy cover in habitat types

Canopy cover percentage varied significantly ($P<0.05$) amongst the studied habitat types in Manyenjere and Juniper forests. Manyenjere riverine (riparian) forest had 94% followed by Manyenjere non-riparian forest (87.7%). Furthermore, there were significant variations between Juniper riverine forest and Manyenjere riparian forests ($p < 0.05$) with a mean canopy (%) of 55 ±10 and 92.25 ±8 respectively.

In contrast, the non-riparian habitats recorded a canopy mean (%) of 48 ±19 and 87 ±7 in Juniper and Manyenjere, respectively, which were also significant ($P<0.05$). The least was Juniper non-riparian forest (48%) (Table1).

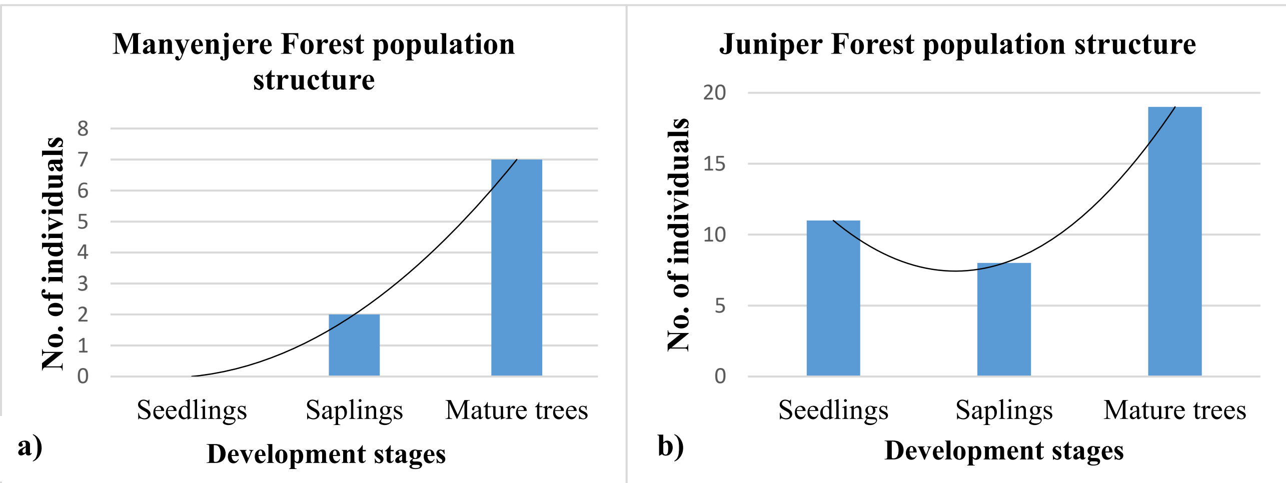

Figure 5: *Prunus africana* development states at the study sites.

3.8 *Prunus africana* population structure at study site

The main three development stages of *P. africana* found are presented in Figure 5. These were seedlings, saplings and mature trees. Results show high significant differences ($P<0.05$) in terms of individual counts of the three development stages ($F= 5$; Df 2; $P=0.007$) between sites. Comparatively, the Juniper Forest recorded a higher seedlings count (11) while Manyenjere forest had a zero count. Similarly, Juniper Forest recorded higher numbers of saplings (10) and mature trees (19) than Manyenjere forest. The observed population structure reveals exponential curves of the three development stages for *Prunus africana* and exhibited a typical J-shaped curve (Figure 5a and 5b).

3.9 Associated species

3.9.1 Species richness

A total of sixty-seven (67) associated tree species were found belonging to 43 genera in the study sites (Figure 6). Kruskal-Wallis ranking test revealed no significant variations ($H=1.62$, $DF=1$, $P=0.109$) between study sites in terms of species richness. Manyenjere forest recorded a median of 13 while Juniper Forest had 11 species (Figure 6 & Table 5). This result may indicate similarity in number of associated tree species.

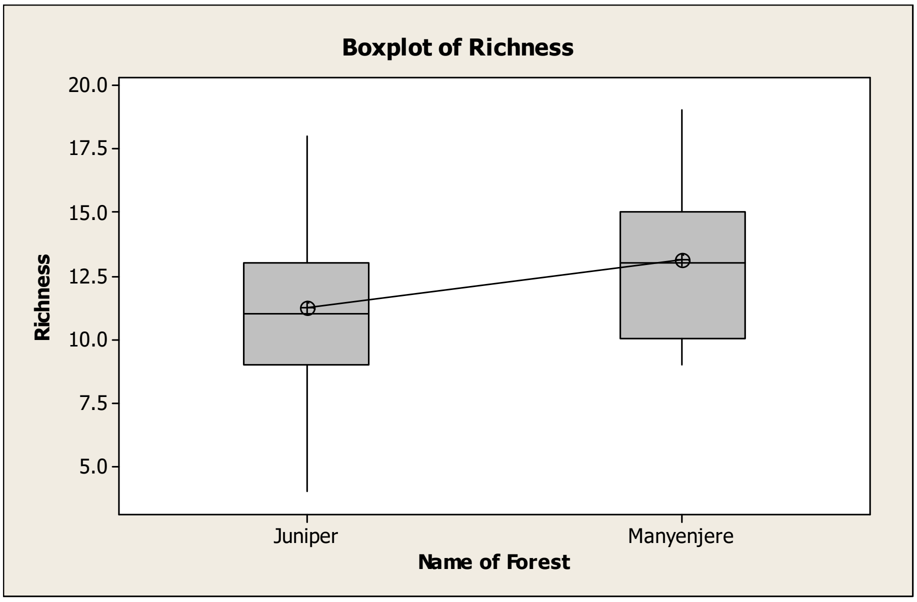

Figure 6: Boxplot of plant species richness at the study sites.

3.9.2 Species diversity

Shannon's index of diversity for the associated tree species found in the two *Prunus africana* occurrence sites revealed no significant variation found (Kruskal-Wallis analysis H= 2.01, DF=1, P=0.157) in diversity of trees species. Juniper forests recorded a median of 2.381 while Manyenjere forest had median of 2.561. The most common species found were *Diospyros whyteana*, *Teclea nobilis, Psychotria zombamontana, Parinari excelsa, Bersama abyssinica, Clausena anisata, Garcinia kingaensis, Ilex mitis, Maytenus acuminata, Rapanea melanophloeos, Agauria salicifolia, Juniperus procera, Macaraga capensis, Podocarpus milanjianus, Hagenia abyssinica* and *Tecomaria capensis*.

3.9.3 Relative abundance

The relative abundance values showed that *P. africana* tree communities were considerably dominated by *Diospyros whyteana, Teclea nobilis, Psychotria zombamontana, Parinari excelsa, Bersama abyssinica, Clausena anisata, Garcinia kingaensis, Ilex mitis, Maytenus acuminata, Rapanea melanophloeos, Agauria salicifolia, Juniperus procera, Macaraga capensis, Podocarpus milanjianus, Hagenia abyssinica* and *Tecomaria capensis*.

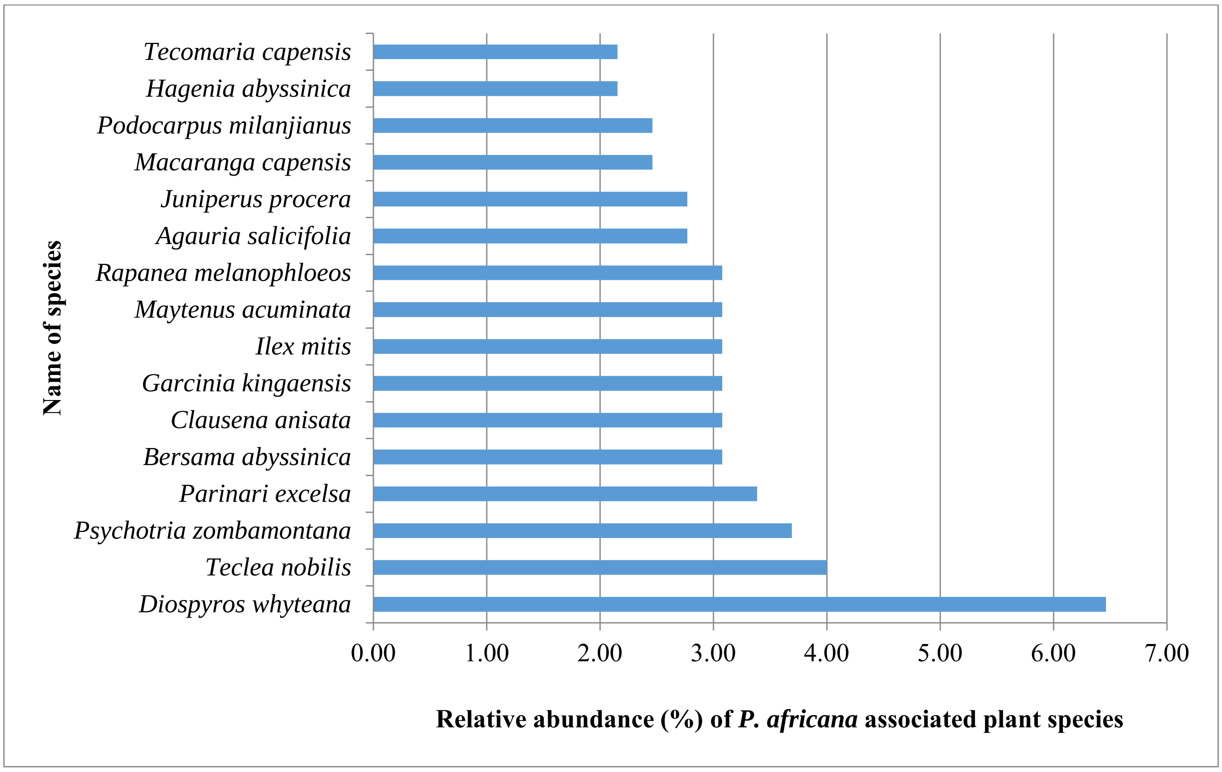

Figure 7: Relative abundance of *Prunus africana* associated plant species at the study sites.

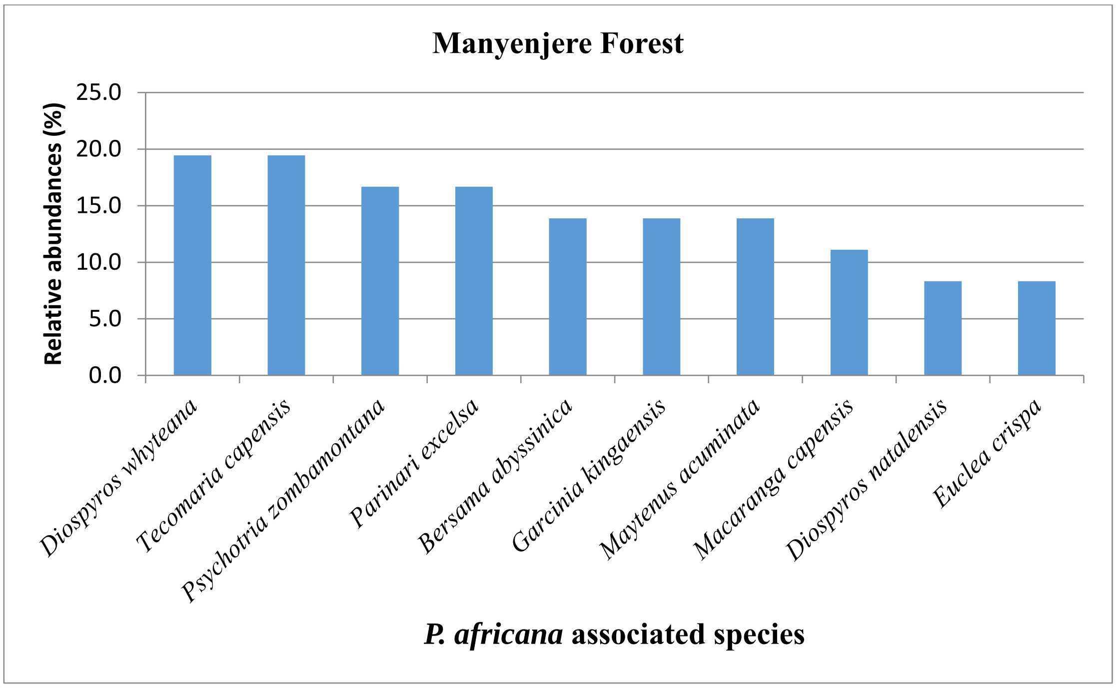

Figure 8: Common associated plant species of *Prunus africana* in Manyenjere Forest.

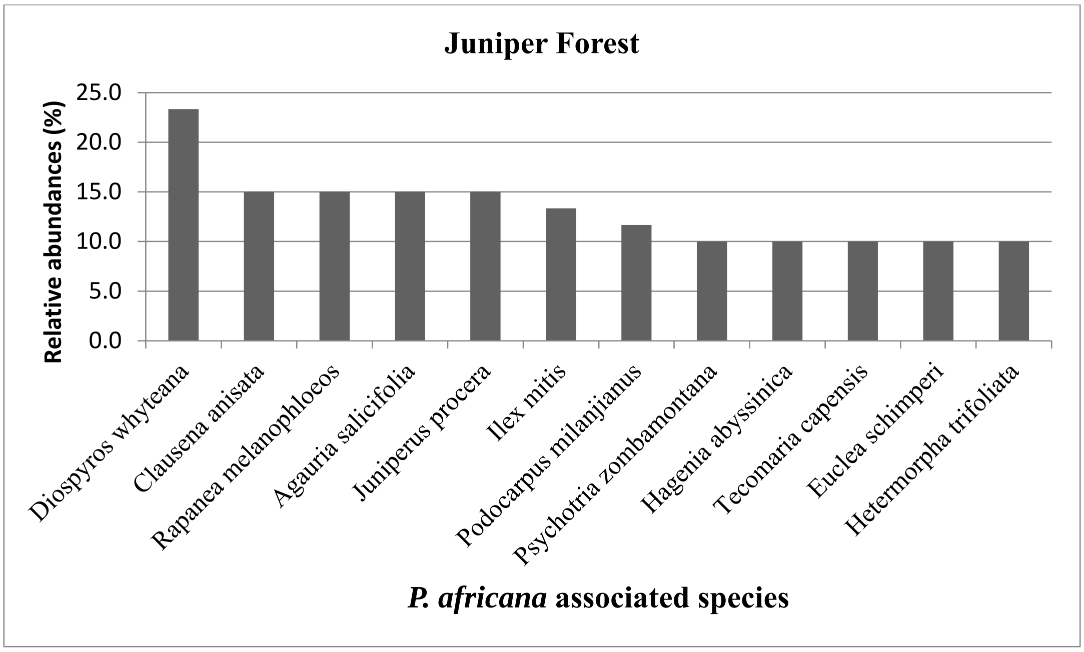

Figure 9: Common plant species associated with *Prunus africana* in Juniper Forest.

4.10. Soil texture

Table 3 below indicates the relative content of particles of various sizes, such as sand, silt and clay in the soil. There were no significant($p>0.05$) differences in particles size distribution among the plots (Table 2), soil texture for each treatment within the same plot are the same. In the Juniper forests plots, (84%) of them were loamy sand with most of the plots revealing high sand content (above 80%) and the other 16% of the plots had sand content which was below 70%. This was the same with Manyenjere plots where 84 % of the plots had above 70% sand content while the remaining plots were sandy loam (Table 3).

Table 3: Particle size distribution in plots with different soil types.

OCCURRENCE SITES	Particle size distribution			Soil texture class
	Sand%	Clay%	Silt%	
Juniper plot 01	80	6	14	Loamy sand
Juniper river bank 02	66	12	22	Sandy loam
Juniper plot 05	82	2	16	Loamy sand
Juniper plot 06	80	2	18	Loamy sand
Juniper plot 07	80	4	16	Loamy sand
Juniper plot 08	68	4	28	Sandy loam
Juniper plot 09	84	2	14	Loamy sand
Juniper plot 10	80	2	18	Loamy sand
Juniper plot 11	80	2	18	Loamy sand
Juniper plot 12	76	4	20	Loamy sand
Juniper plot 14	80	2	18	Loamy sand
Juniper plot 16	84	2	14	Loamy sand
Juniper plot 17	78	2	20	Loamy sand
Juniper plot 18	70	8	22	Loamy sand
Manyenjere plot 01	78	4	18	Loamy sand
Manyenjere plot 02	76	2	22	Loamy sand
Manyenjere plot 03	70	2	28	Loamy sand
Manyenjere plot 05	66	4	30	Sandy loam

Manyenjere plot 06	74	4	22	Loamy sand
Manyenjere plot 07	72	6	22	Loamy sand

4.11. Soil chemical properties in *Prunus africana* occurrences in the study sites

Table 4 below shows soil physiochemical properties in the two study sites. All chemicals i.e. nitrogen, calcium, magnesium, pH and carbon portrayed no significant differences($P>0.05$) except phosphorus which displayed significant differences between the sites($P<0.05$). However, the Manyenjere plots recorded a high proportional percentage of nitrogen (Table 4).

Table 4: Chemical properties of soils in *Prunus africana* occurrence sites.

SITES	N%	P(mg/kg)	Ca%	Mg%	pH	C%
Juniper	0.49±0.19	9.01±4.7	6.35±3.29	4.02±2.29	5.25±0.41	3.20±0.46
Manyenjere	0.51±0.14	3.83±3.4	5.66±2.0	3.29±2.38	5.15±0.37	3.27±0.63
P-value	0.83	0.028*	0.643	0.524	0. 589	0.787

Values are expressed as mean ± SD (n=3). (*) values less than 0.05 are significantly different.

CHAPTER 4: DISCUSSION

4.1 *Prunus africana* abundance and density in the study sites

4.1.1 Abundance and stocking density in Juniper and Manyenjere Forests

The study showed that the Juniper had a higher stocking density of *Prunus africana* than Manyenjere Forest. This could be attributed to forest canopy cover which showed significant differences (Table 2). *Prunus africana* is a light-demanding species and regeneration and establishment is difficult in areas where canopy cover is thick (Nkeng *et al.,* 2010; Nguta, 2012; Ingabire *et al.,* 2019). The other possible reason could be variability in soil phosphorus in the two study sites (Table 4) which displayed significant differences. Phosphorus is a major element in plant growth (Houghland, 1960). When phosphorus concentration in plants is sufficient, it allows plants to operate at optimum rates and growth and development of plants proceed at a normal pace. The deficiency of P in plants in general, is manifested in terms of stunted growth, reduced yield and delayed maturity (Ahemad *et al*., 2009). Coupled with the dense forest canopy cover in Manyenjere, *Prunus africana* might not compete favourably with other species, hence the disparities.

4.1.2 *Prunus africana* habitat preference in study sites

P. africana was mostly distributed along Uyaghaya River (riparian vegetation) in Juniper Forest whilst in Manyenjere the species grows along the forest edge (non-riparian). The results in Manyenjere agree with (Nguta, 2012; Nyamai *et al*. 2015; Onyango *et al.,* 2018) who also reported that *Prunus africana* in most occurrence sites prefer growing along the forest edges because it is not a shade-tolerant species. In the Juniper Forest, the growing pattern might have been influenced by flush floods. Water is one of the agents for seed disposal (Howe & Smallwood, 1982). The river might have dispersed the seeds on its banks which might have led to its linear distribution pattern of the species along Uyaghaya River.

4.1.2 Age class distribution in Juniper and Manyenjere forests

The results of the study revealed that in both cases mature trees dominated (Fig. 5). In Manyenjere Forest, no seedling was observed and Juniper Forest had few seedlings (10). There is an indication that no recruitment is taking place in Manyenjere Forest. *Prunus africana* requires light to develop

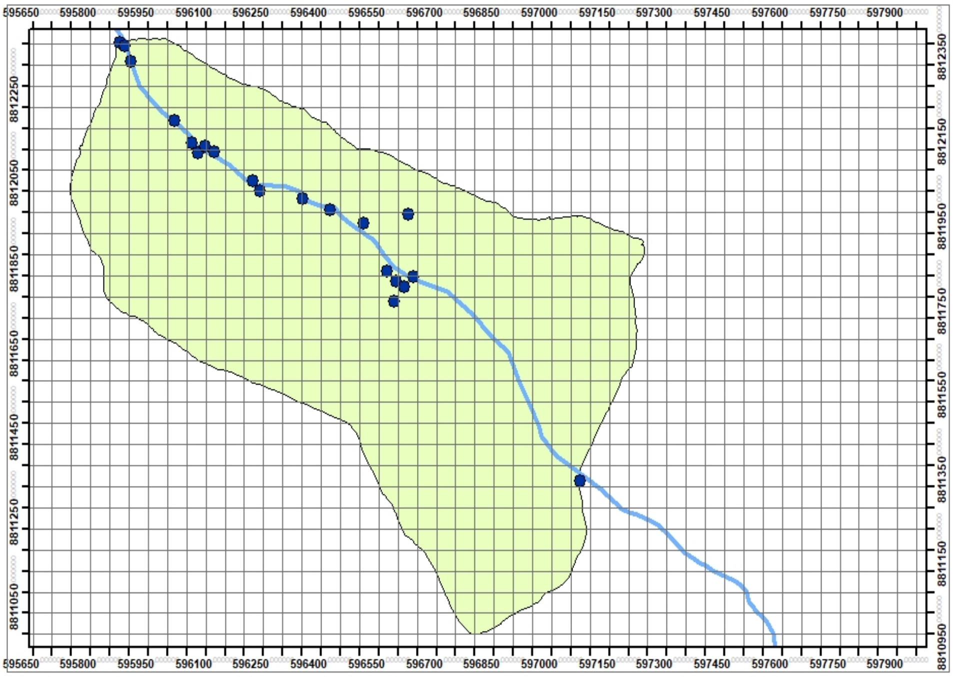

Figure 10: Linear distribution of *P. africana* along Uyaghaya River in the Juniper Forest

from seedling to saplings (Navarro-Cerrillo *et al*., 2008; Ingabire *et al.*,2019). With an average canopy cover of 94% for Manyenjere Forest (Table 2), recruitment of the *P .africana* might be difficult. Juniper Forest recorded some seedlings and saplings with more mature trees. This is possibly due to low canopy cover. In both scenarios, a typical J-shaped curve pattern was exhibited indicating an unstable population (Hall *et al*., 2000; Nguta, 2012;). Stable populations exhibit an inverse J-shaped curve, i.e. more seedlings, fewer saplings and very low mature trees (Hall *et al*., 2000; Ingabire *et al.*,2019).

4.2 Species diversity, richness and associations at study sites

The study revealed similarity in species associations in the study sites. Numerically, Manyenjere was slightly richer (13) than the Juniper Forest (11). This could be due to the fact that both sites are on almost the same altitude (GoM, 2003; Burrows & Willis, 2005). The other environmental factor attributing to the marginal difference in species diversity could be variability in the amount of soil phosphorus. In a study done by Wang *et al.* (2007) they observed that the amount of phosphorus in the soil was negatively related to plant diversity. Soil analysis (Table 4) revealed that Juniper Forest soils have significantly high levels of P which could contribute to the difference.

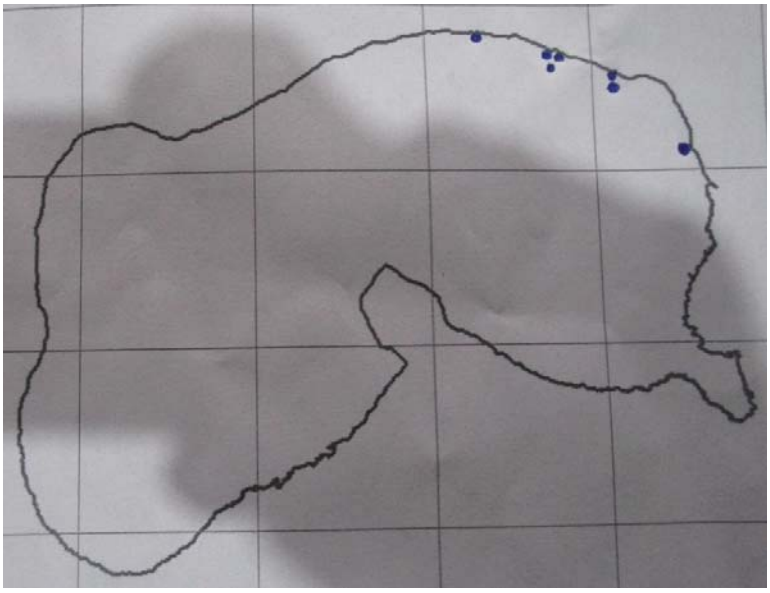

Figure 11: Map showing Manyenjere Forest and distribution of *Prunus africana*

Prunus africana was seen to be in very close association with a number of species (Figure 7). This study concurs with (Hall *et al*., 2000; Nguta, 2012), who also reported some species like *Ilex mitis, Juniperus procera* and *Podocarpus milanjianus* mostly associating with *P. africana* in most occurrence sites in Kenya and Cameroon. Chapman and White (1970) described *Ilex mitis, Juniperus procera* and *Podocarpus milanjianus* as Afromontane species found in the evergreen forest patches on Nyika Plateau.

Tree mean heights exhibited in this study were far below those reported by (Hall *et al,* 2000; Nguta, 2012) of 30 to 40 m. This could be attributed to altitude. In the study done by Hall *et al*. (2000), trees found at lower altitude were significantly taller than those found at higher altitude of more than 2100 m above sea level. Juniper Forest and Manyenjere are found at 2000 m above sea level (GoM, 2003) and this altitude could attribute to the heights observed in this study.

4.3 Soil texture in the Juniper and Manyenjere Forests

The results (Table 3) find that *Prunus africana* can thrive best in loamy sandy soils as well as in sandy loamy particle sizes. These results conform to the findings by Hall *et al.* (2000) and Nguta (2012) who reported similar results. Therefore, the similarity observed in particle size distribution between the two sites could be a consequence of vegetation structure as well vegetation types of the forests. According to Dodd *et al.* (2002), the dominance of woody plants is usually associated with course texture soils and that the ecotones between the woody and herbaceous plant functional types are associated with soil textural changes. In this study, the observed similarity in soil structure is one factor that could have influenced vegetation structure/species composition in *Prunus africana* occurrence sites. According to FAO (2011), the occurrence of a tree species on a certain soil type depends to some extent on the composition of surrounding forest cover and on the size of the soil area. In this case, *P. africana* was observed to occur on edge of grasslands both in Juniper and Manyenjere Forest. The species could have modified the soil type to its preference in an event to prevent other competing species. Furthermore, the differences observed in available phosphorus may also be used as proxy in growth rates of the species within and between the sites.

4.4 Soil chemical properties in the Juniper and Manyenjere Forests

4.4.1 Soil pH

These results indicate no differences in pH values in the study sites. This is an indication that *Prunus africana* thrive well in acidic soils. The results also support findings by Hall *et al.* (2000) who reported a similar range. Turner and Lambert (1988) reported that the effect of different tree species on soil pH is most significant in the first 10cm of the topsoil. The observed high pH values are an indication of available soil nutrients for plant uptake and use (Jensen, 2010). Plants generally acidify soils under good growing conditions in two ways: (i) Plant root respiration with soil organic matter decomposition by microorganisms can release CO_2, increasing the carbonic acid (H_2CO_3) concentration, and (ii) plants take up nutrients in the form of ions such as NO_3^-, NH_4^+, Ca_2^+, and H_2PO_4-, but often take up more cations than anions, thereby the plant roots release H^+ ions to compensate for the extra positive charge to maintain a neutral charge in the roots (Sparks *et al.,* 2003). This is an indication that cultivation of *Prunus africana* on the plateau is a feasible option.

4.4.2 Soil phosphorus (PO_4)

High significant differences ($P<0.05$) in available soil phosphorous were observed between *P. africana* occurrence sites. Juniper forest (9.01 ± 4.7 mg/kg) recorded highest phosphorus levels than Manyenjere Forest (3.83 ± 3.4 mg/kg). Phosphorus availability in the soil is largely controlled by two primary factors: soil pH, and amount of organic matter (Jensen, 2010). The potential causes for low levels of available P in these soils could be ascribed to low pH (Jensen, 2010). One influence on phosphorus availability is the soil's pH level. If soils are too acidic, phosphorus reacts with iron and aluminum. That makes it unavailable to plants. But if soils are too alkaline, phosphorus reacts with calcium and also becomes inaccessible (Jansen, 2010). The difference in the P levels could be attributed to river deposit. In Nyika, there is fire management regime which has been going on for many years (GoM, 2003). Each year, Uyaghaya River carries a lot of animal waste and other debris depositing them along the river banks. This could the source for the differences.

4.4.3 Total carbon (C)

Carbon (C) is stored in soil organic matter (Lemus & Lal, 2005). This carbon enters the soil through the decomposition of plant and material residues and other dead micro-organisms (Ontl, & Schulte, 2012). Results of the comparison have shown that, while there were no significant differences ($p>0.05$) in level of total carbon in Juniper and Manyenjere plots. There were slight differences in terms of proportional percentage as Manyenjere plots recorded slightly higher concentration of carbon (3.27 ±0.63) compared to Juniper plots (3.20 ±0.46). This could be a result of Manyenjere plots having a high dense canopy thus; higher litter fall leading to more accumulation of organic matter which positively affect the availability of carbon in the soil. The Juniper plots had more canopy spaces hence; less litter fall and less availability of carbon percentage. In addition, Juniper Forest plots were along perennial stream. According to FAO (2005), climatic conditions like temperature, moisture and rainfall also affect the rate of organic matter decomposition, whereby the decomposition is faster in areas which are warm and humid and slower in cool dry areas.

4.4.4 Total nitrogen (N)

Results of the soil analysis have shown that there were no significant differences ($P<0.05$) in the level of total nitrogen between the Juniper and Manyenjere forests plots (Table 4). However, the

Manjenyere plots recorded a high proportional percentage of nitrogen; this was because of an increase in organic matter found in Manyenjere plots which influences the availability of carbon thus; more nitrogen percentage as compared to Juniper plots which had less organic matter. This agrees with Angus *et al*. (2006), who found out that litter fall affect positively the availability of total nitrogen in the soils.

4.4.5 Calcium (Ca)

As other results show that there were no significant differences in between the plots of Juniper and Manyenjere plots, this was the same case with calcium percentage available in these plots. There were also no significant differences ($P>0.05$) in their levels. The overall proportional percentage of soil calcium levels in the Juniper and Manyenjere plots were slightly low ranging from 1.2 to 12.2. These results could be due to high percentage (above 80%) of sand level content (Table 3) compared to clay content which was below 10%. In this case, soil texture may be a factor influencing the concentration of Ca levels in the soil. Most sandy soils have low calcium concentrations, while clay soils usually have high calcium concentrations levels. Under normal circumstances the higher the calcium level in the soil, the greater the soil clay content (Bonomelli *et al*., 2019). The texture results found in this study supports Loide (2004), who found out that a rise in sand content concentration lead to a decrease in calcium levels in the soils and vice versa.

4.4.6 Magnesium (Mg)

Within each plot, there were no significant differences ($P>0.05$) in levels of magnesium between the sites. Nevertheless, comparatively, Juniper recorded a high proportional percentage (4.02 ±2.29) of magnesium level as compared to Manyenjere plots (3.29 ±2.38). In addition, magnesium deficiencies are most commonly encountered on light sand soils as it was the case with this study results where both plots recorded a high percentage of sand soils. This agrees with Chan *et al.* (1979) who reported that magnesium deficiency on soils of heavier texture appear to be increasing, particularly on strongly weathered and leached soils.

4.5 Threats to *Prunus africana* at the study sites

Besides over-exploitation, *Prunus africana* faces a number of other challenges and threats which include bushfires, diseases and pests attack, climate change and over-grazing (Hall *et al*., 2000; Fashing, 2004; Nkeng *et al.*, 2010; Nguta, 2012; Ingabire *et al.*, 2019). In this study, bushfires were observed as a major threat to *Prunus africana*, especially in the Juniper Forest (Figure 11) where a number of hectares were destroyed by wildfires.

Evidence of pests was also noted especially in fresh fruits. Manyenjere fruits had more pests than those of the Juniper. This is the area that needs more investigations. Hall *et al.* (2000) reported that disease and pests are other variables that affect crown health of *Prunus africana*, particularly coleopterous borers which often cause wood degradation. Pests found in these fruits might also contribute to the poor regeneration in the study area especially Manyenjere Forest which recorded no seedlings at all (Figure 12).

Figure 12: Part of the Juniper Forest razed down by bushfires.

Figure 13: A pest squeezed out of a *Prunus africana* ripe fruit from Manyenjere Forest.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The population of *Prunus africana* in both the Juniper and Manyenjere forests is dominated by mature trees which is an indicator of an unstable population.

This study revealed that *Diospyros whyteana*, *Teclea nobilis, Psychotria zombamontana, Parinari excelsa, Bersama abyssinica, Clausena anisata, Garcinia kingaensis, Ilex mitis, Maytenus acuminata*, *Agauria salicifolia*, *Rapanea melanophloeos*, *Juniperus procera*, *Macaraga capensis, Podocarpus milanjianus*, *Hagenia abyssinica* and *Tecomaria capensis* were commonly associated with *Prunus africana* in both the Juniper and Manyenjere Forests.

The results have shown that the two study sites are mostly comprised of loamy sand textures which are moderately acidic.

Bushfires threaten *Prunus africana* and other species in the study area.

5.2 Recommendations

- There is need to intensify *ex-situ* conservation initiatives in both areas in order to save *Prunus africana* from becoming locally extinct.
- Fire management be intensified in both parks so that *Prunus africana* is well protected. During the study, a large portion of the Juniper Forest was razed down by wild fires.
- Further research should be carried out to identify and assess the contributions of the pests found inside *Prunus africana* fruit.

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APPENDIX

Table 5: List of plant species with their frequency, relative abundances and presence/absence in the occurrence sites

No	Species name	Family name	Frequency	Relative abundance %)	Juniper Forest	Manyenjere Forest
1	*Diospyros whyteana*	Ebenaceae	21	6.46	+	+
2	*Teclea nobilis*	Rutaceae	13	4.00	+	+
3	*Psychotria zombamontana*	Rubiaceae	12	3.69	+	+
4	*Parinari excelsa*	Chrysobalanaceae	11	3.38	+	+
5	*Bersama abyssinica*	Melianthaceae	10	3.08	+	+
6	*Clausena anisata*	Rutaceae	10	3.08	+	+
7	*Garcinia kingaensis*	Clusiaceae	10	3.08	+	+
8	*Ilex mitis*	Aquifoliaceae	10	3.08	+	+
9	*Maytenus acuminata*	Celastraceae	10	3.08	+	+
10	*Rapanea melanophloeos*	Rizophoraceae	10	3.08	+	+
11	*Agauria salicifolia*	Ericaceae	9	2.77	-	+
12	*Juniperus procera*	Cupressaceae	9	2.77	-	+
13	*Macaranga capensis*	Euphorbiaceae	8	2.46	+	+
14	*Podocarpus milanjianus*	Podocarpaceae	8	2.46	+	+
15	*Hagenia abyssinica*	Rosaceae	7	2.15	+	+
16	*Tecomaria capensis*	Bignoniaceae	7	2.15	+	+
17	*Euclea schimperi*	Ebenaceae	6	1.85	-	+
18	*Heteromorpha trifoliata*	Apiaceae	6	1.85	-	+
19	*Diospyros natalensis*	Ebenaceae	5	1.54	+	+
20	*Dodonaea viscosa*	Sapindaceae	5	1.54	-	+
21	*Halleria lucida*	Stilbaceae	5	1.54	-	+
22	*Maesa lanceolata*	Myrsinaceae	5	1.54	+	+
23	*Morella pilulifera*	Myricaceae	5	1.54	-	+
24	*Rhamnus prinoides*	Rhamnaceae	5	1.54	-	+
25	*Allophyllus chaunostachys*	Sapindaceae	4	1.23	+	+
26	*Aphloia theiformis*	Flacourtiaceae	4	1.23	+	+
27	*Ekebergia capensis*	Meliaceae	4	1.23	+	+
28	*Entandrophragma excelsum*	Meliaceae	4	1.23	+	+
29	*Euclea crispa*	Ebenaceae	4	1.23	+	+
30	*Mystroxylon aethiopicum*	Celastraceae	4	1.23	-	+
31	*Syzygium cordatum*	Myrtaceae	4	1.23	+	+
32	*Tricalysia acocantheroides*	Rubiaceae	4	1.23	+	+
33	*Buddleja salviifolia*	Buddlejaceae	3	0.92	-	+
34	*Chrysophyllum bequetiodendron*?	Sapotaceae	3	0.92	-	+
35	*Croton megalobotrys*	Euphorbiaceae	3	0.92	+	+
36	*Tricalysia coriacea*	Rubiaceae	3	0.92	+	+
37	*Chrysophyllum gorungosanum*	Sapotaceae	2	0.62	+	-
38	*Cussonia spicata*	Araliaceae	2	0.62	-	+
39	*Faurea rochetiana*	Proteaceae	2	0.62	-	+
40	*Khaya anthotheca*	Meliaceae	2	0.62	+	+

41	*Lepidotrichilia volkensii*	Meliaceae	2	0.62	-	+
42	*Ochna holstii*	Ochnaceae	2	0.62	+	+
43	*Olinia rochetiana*	Oliniaceae	2	0.62	-	+
44	*Polyscias fulva*	Araliaceae	2	0.62	+	+
45	*Rhus longipes*	Anacardiaceae	2	0.62	-	+
46	*Rhus natalensis*	Anacardiaceae	2	0.62	-	+
47	*Vernonia myriantha*	Asteraceae	2	0.62	+	+
48	*Alocasia coriacea*	Araceae	1	0.31	+	-
49	*Afrocrania vokensii*	Cornaceae	1	0.31	+	-
50	*Allophylus africanus*	Sapindaceae	1	0.31	-	+
51	*Apodytes dimidiata*	metteniusaceae	1	0.31	-	+
52	*Bequatiodendron magalismotanum*?	Sapotaceae	1	0.31	-	+
53	*Carissa edulis*	Apocynaceae	1	0.31	-	+
54	*Cassipourea malosana*	Rhizophoraceae	1	0.31	-	+
55	*Cassipourea mollis*	Rhizophoraceae	1	0.31	+	-
56	*Crabbea longipes*	Acanthaceae	1	0.31	+	-
57	*Dombeya rotundifolia*	Malvaceae	1	0.31	-	+
58	*Dovyalis zeyheri*	Salicaceae	1	0.31	-	+
59	*Erica bengualensis*	Ericaceae	1	0.31	-	+
60	*Maytenus senegalensis*	Celastraceae	1	0.31	-	+
61	*Milletia dura*	Papilionoideae	1	0.31	+	-
62	*Millettia lasiantha*	Papilionoideae	1	0.31	-	+
63	*Myrsine africana*	Myrsinaceae	1	0.31	-	+
64	*Olea europaea*	Oleaceae	1	0.31	-	+
65	*Osyris lanceolata*	Santalaceae	1	0.31	-	+
66	*Pittosporum viridiflorum*	Pittosporaceae	1	0.31	-	+
67	*Pachystela brevipes*	Sapotaceae	**1**	0.31	+	-

Table 6: Location of *Prunus africana* plots in the Juniper and Manyenjere Forests.

Juniper Forest plots		**Manyenjere Forest plots**	
S 10^{0}44'46.33"	E 33^{0} 53'01.42"	S 10^{0}35'16.31"	E 33^{0} 39'48.12"
S 10^{0}44'46.30"	E 33^{0} 52'59.05"	S 10^{0}35'12.50"	E 33^{0} 39'45.08"
S 10^{0}44'52.94"	E 33^{0} 53'00.25"	S 10^{0}35'12.34"	E 33^{0} 39'45.15"
S 10^{0}44'51.11"	E 33^{0} 53'01.83"	S 10^{0}35'11.05"	E 33^{0} 39'40.90"
S 10^{0}44'51.86"	E 33^{0} 53'01.11"	S 10^{0}35'10.66"	E 33^{0} 39'40.01"
S 10^{0}44'50.66"	E 33^{0} 52'59.59"	S 10^{0}35'11.01"	E 33^{0} 39'40.80"
S 10^{0}44'46.92"	E 33^{0} 52'57.57"	S 10^{0}35'08.95"	E 33^{0}39'33.52"
S 10^{0}44'45.82"	E 33^{0} 52'54.87"		
S 10^{0}44'45.15"	E 33^{0} 52'52.36"		
S 10^{0}44'44.44"	E 33^{0} 52'48.74"		
S 10^{0}44'43.69"	E 33^{0} 52'48.08"		
S 10^{0}44'41.46"	E 33^{0} 52'44.81"		

Figure 14: *Prunus africana* sapling in the Juniper Forest.

Figure 15: Diameter measurements at the study sites.

Figure 16: Soil sample analysis at Chancellor College chemistry laboratory.

Figure 17: *Prunus africana* bending outside the forest edge in response to light demands in the Juniper Forest.