Working Paper

State of biomass resources in refugee hosting landscapes

The case of Rhino Camp and Imvepi Refugee Settlements in West Nile, Uganda

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Lalisa Duguma, Charles Ariani, Cathy Watson, Clement A Okia, Judith Nzyoka

World Agroforestry

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Acknowledgements

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Executive Summary

Already under pressure from demands such as charcoal and tobacco curing, woody vegetation in refugee-hosting areas in West Nile region in northwestern Uganda currently faces extreme extraction pressure. A large influx of refugees from South Sudan has caused a significant loss of biomass as they have sought to meet their basic needs. The main drivers of biomass loss are energy and shelter.

This assessment focuses on the two refugee settlements in West Nile's Arua district. Imvepi and Rhino Camp Refugee Settlements are located in swathes of woody savannah that also contain some closed woodland. The refugees co-exist with the host communities, and both communities consist almost entirely of farming families that are highly natural resource-dependent.

The assessment has two main aims: 1) to understand the status of vegetation in Imvepi and Rhino Camp Refugee Settlements and in the surrounding area or buffer zone, much of which is inhabited by the host community; and 2) to estimate the biomass potential in the landscape, particularly the above-ground biomass (AGB), which is the portion of biomass that communities require for direct use.

Key findings from this assessment include:

- The average density of standing trees with a diameter at breast height (dbh) of more than 10 cm was 75, 152 and 62 trees per hectare (ha) in the buffer area, Imvepi Refugee Settlement and Rhino Camp Refugee Settlement, respectively.
- A total of 81 tree species were identified; of these, 73 were native and eight were exotic. In all three areas, the most commonly occurring tree species were indigenous.
- The two refugee settlements are dominated by *Acacia spp, Grewia spp* and *Combretum spp*. Leading species in the buffer zone include *Isoberlina doka, Pseudocedrela kotschyi*, *Combretum spp* and *Bridelia scleroneura*.
- Extraction pressure is intense. The average number of tree stumps was 33, 51 and 56 per ha in the buffer zone, Imvepi Refugee Settlement and Rhino Camp Refugee Settlement, respectively.
- Some species are under particularly intense extraction pressure. Stumps of *Acacia hockii*, *Combretum spp* and *Bridelia scleroneura* were the most common.
- In all three areas, trees with a dbh of more than 20 cm were the most likely to be cut down, leading to a sharp decline in mature trees.
- The AGB of trees was found to be 395,790 tons in the buffer zone, 368,035 tons in Imvepi Refugee Settlement, and 659,521 tons in Rhino Camp Refugee Settlement. Total tree woody biomass across the area was 1,423,345 tons.
- Largely consisting of *Harrisonia abyssinica*, *Lantana camara* and *Capsicum frutescens*, shrubs contributed 71,841 tons of AGB.
- Total woody biomass was an estimated 1,495,186 tons.

- Given the rates of use, and if refugees utilize only AGB within the two settlements, the area would be stripped bare in just 4 to 7 years.
- Drawing on AGB in areas outside the refugee settlements could extend this time period, but result in conflicts with host communities.

Urgent measures are needed to stem biomass and species diversity loss. This assessment makes multiple recommendations on the way forward, including:

1. Conduct inventories of plot content prior to plot allocation so that management options can be put in place by and for the refugees.
2. District officials, refugee and host communities, agencies and other stakeholders to build a system to enable the planting, growing, regeneration and protection of trees.
3. Ensure consensus on priority areas to plant, regenerate and protect.
4. Agree on how to control burning of biomass and contain livestock.
5. Ensure that endangered tree species are marked, and awareness is created about their importance.

Introduction

Biomass extraction due to the demand for various wood products is exerting intense pressure on woody vegetation in the tropics and subtropics. Around the globe, about one billion people depend on woody ecosystems for their livelihood and energy needs. The figure increases in dryland ecosystems where woody plants play a crucial role in reducing the adverse effects of changes in local climate and weather variability. In addition, they provide essential ecosystem services and forest products, both timber and non-timber, upon which the communities heavily depend.

The pressure that wooded ecosystems face is growing due to the increasing demand for land on which to practise agriculture and construct homes. Both are often enabled by clearing wooded land. After the creation of residential spaces, there is often limited access to modern alternatives to wood for either energy or construction. This, in turn, increases dependence on woody ecosystems for these purposes, as well as furniture making. With the growing human population, the slow pace of infrastructural expansion and limited access to alternative technologies in countries with large forests, extraction pressure on the woody ecosystem is increasing.

Woody ecosystems are also under pressure from climate change and local weather variability, which affect the evolution of the population structure of species. For instance, global warming effects may increase incidences of fire outbreaks in areas that experience long dry seasons.

Due to such diverse impacts, it is important to assess the state of vegetation in areas under extraction pressure and to design appropriate measures to sustain the vegetation for future generations.

This assessment aims to understand the state of vegetation in Imvepi and Rhino Camp Refugee Settlements. To achieve this, understanding the species-level diameter distribution of trees and estimating the biomass potential in the landscape, particularly the above-ground biomass (AGB) is essential. Such assessments are vital because the refugee settlements and their surrounding areas are experiencing a strong surge of migrants, the vast majority of whom are highly dependent on woody vegetation for cooking and other purposes.

Methods

Biomass monitoring

Biomass field data was collected to estimate stocks of biomass for different land use and land cover (LULC) classes. These classes were derived through remote sensing to map the distribution of biomass and assess changes in biomass stocks before and after the establishment of refugee settlements.

Sampling design

Since the area under assessment is large, samples were selected systematically to represent the area. Sampling based on grids of 4 km by 4 km was generated through the settlement area, including the buffer of a 5-km-width surrounding the settlement areas. At every grid junction, a cluster with nine plots was set up, each with a radius of 12.6 m, making the total area per cluster 4,489 m^2. The sampled area had 37 clusters of 9 plots, each resulting in 333 plots with an assumed total area of 16.61 ha. (166,093 m^2). Out of the data collected from 333 plots, data from 322 plots was used in this analysis. Figure 1 presents the layout of the cluster of plots at grid junctions.

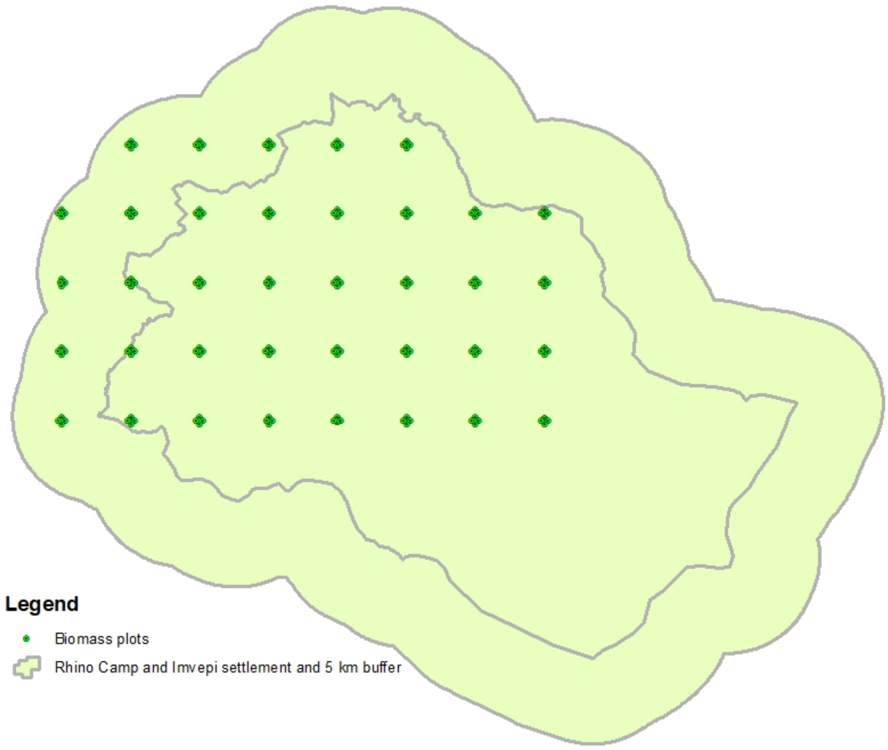


Figure 1: Biomass sample plots on a systematic grid of 4 km by 4 km

Layout of plots, plot designs and the data collection process

At every grid junction, 9 sample plots were established and enumerated. The layout of the plots and their numbering are presented in Figure 2.

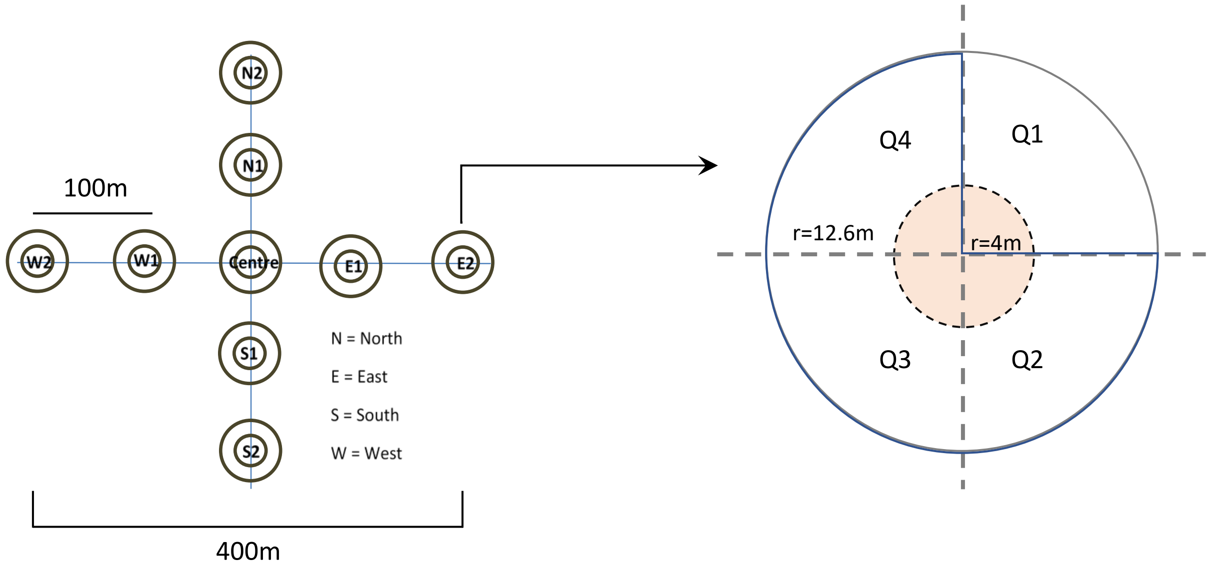


Figure 2: Layout of plots in a cluster and the specific data collection process

Figure 2 indicates the population health of the tree species that are predominant in the landscape. Circular plots of 12.6 m radius giving an area of 498 m^2 were used for the sampling process. In total, there were 162 circular plots in Rhino Camp and 81 plots each in Imvepi Refugee Settlements and the buffer zone. Two of the plots in Rhino Camp were not assessed due to inaccessibility. The circular sampling areas were selected based on the recommended sample plot design used by Uganda's National Forestry Authority (NFA) for biomass monitoring and other natural high forest inventories. A sub-plot of 4 m radius was established to count seedlings and saplings which have not attained 5 cm diameter at breast height (dbh). In the first quadrant of the main plot, all standing trees, alive or dead, of 5 cm dbh and above were enumerated. The parameters collected were species name, dbh, bole height, total height and crown diameter at shorter and longer sides. Shrubs in the plot were also captured in this quadrant (Quad. 01), taking their diameter at root collar, height and two crown diameters. In the rest of the quadrants (2, 3 & 4), trees with dbh of 10 cm and above were measured. Parameters recorded included species name, dbh, bole height, total height and crown diameters (long and short).

Tree stumps were counted and measured in the plots and parameters taken were diameter at the top, stump height and species. Identifying the stumps is usually difficult, but this was accomplished with support from local forestry experts and the community.

Measurement of tree parameters

On completion of demarcating and establishing the plot, the team then proceeded to identify tree species within each plot. For every tree within the sample plot, parameters such as diameter at breast height, tree height, bole height and crown width were measured.

Definitions are as follows:

- *Diameter at breast height*: This is the diameter of a tree located at a standard height of 1.3 m above-ground. The height at 1.3 m normally corresponds to the position of the chest or breast of an average person, hence the term 'Diameter at breast height' or dbh. It is measured by a diameter tape or caliper, which is calibrated to give readings in diameter or girth. If it is in circumference or girth, it has to be converted to diameter by dividing circumference by pi ($\pi = 3.1416$). The measurements are normally to the nearest centimetre.
- *Total tree height*: This is the height from the ground to the top of the crown or highest growing point (Avery & Burkhart, 1983). It is measured by hypsometers, which are instruments for measuring heights based on either geometric or trigonometric principles, calibrated to give readings of the height directly in metres or degrees.
- *Bole height*: This is the height of a tree from the ground up to the first branching. This part is what foresters refer to as 'merchantable or timber height'. It is measured in the same way as the total height of a tree.
- *Crown width*: This is the distance on the ground covered by the crown of a tree. It is measured by a distance-tape and readings made to the nearest metre. Since trees usually have irregular crown shapes, two diagonal readings are taken and the average mean recorded as the crown width.

In addition to the above parameters, more information from the plots such as land cover/use, percentage of bush coverage and stocking density levels were assessed and recorded on the field form. The data was collected by experienced foresters, particularly those with expertise in systematic botany.

Biomass stock estimation

The above-ground biomass (AGB) for every tree and plot was calculated using Chave et al. (2014).

$$AGB = 0.0673*(Wd * Dbh^2 * H)^{0.976}$$

AGB – Above-ground woody biomass (kg);
Wd – Wood density (gm/cm^3);
Dbh – Diameter at breast height (cm);
H – Height (m).

For total biomass, the estimate for the plots was summed up by land cover types. These values were obtained by adding and calculating averages of all the plots measured in the various LULC classes. Biomass estimation was carried out for individual trees using the wood density values and the specification given in Chave et al. (2014). Wood density for most species was obtained from the ICRAF wood density database (http://db.worldagroforestry.org/wd). For those species where the specific wood density was not available, averages of the density values given for the genus level were used. This is to avoid the bias that may be created by using the same value of 0.64 gm/cm^3 as used in the IPCC Tier 1 biomass assessment procedures. The value was used only for shrubs with no known wood density values in any database.

Findings

Analysis of vegetation characteristics: density

When all trees above 5 cm dbh were considered, the average tree densities were 244.56, 479.71 and 229.65 trees per ha in the buffer zone, Imvepi Refugee Settlement and Rhino Camp, respectively. Tree stock density per ha was highest in the Imvepi settlement, which was established more recently and has more than twice the area of Rhino Camp Refugee Settlement. The least stocked was Rhino Camp Refugee Settlement due to the pressure of long-standing refugees as well as new arrivals. The buffer zone has a considerably lower density of trees with a dbh of over 5 cm compared to Imvepi Refugee Settlement, and a slightly higher density than that of Rhino Camp Refugee Settlement. The buffer zone contains some closed woodland but extensive host community farming and grazing areas.

Analysis of vegetation characteristics: diversity

The biomass assessment included a vegetation survey that identified every tree and shrub in each sampling plot; a total of 81 tree species were identified by their botanical names and 78 by the name or names used for them by the local populations. Of the 81 species identified by their botanical names, only eight were exotics. This species composition illustrates the hitherto light use that had been made of the area. Juridically, most of it is clan land, from which firewood, grass, fruit and other non-timber forest products were typically harvested. There has also been some hunting for meat.

Among trees found were multiple species of *Acacia, Albizia, Combretum, Ficus, Gardenia, Grewia* and *Ziziphus*. Notable hardwoods included *Albezia africana, Celtis africana, Dalbergia melanoxylon, Danielllia oliveri* and *Khaya senegalensis* (mahogany). Notable indigenous fruit trees included *Borassus aethiopum, Balinites aegyptiaca, Grewia bicolor* and *G. mollis, Sclerocarya birrea, Strychnos spinosa, Vitellaria paradoxa* (shea), *Vitex doniana, Ziziphus abyssinica* and *Z. mucronata.* Trees from other parts of the world (exotics) included mango, papaya (pawpaw), moringa, eucalyptus, tamarind, *Senna siamea*, *S. spectabilis* and *Melia azedarach* (neem). The 12 most common trees in the buffer zone and both refugee settlements were all indigenous species.

Similar tree species dominate the two refugee settlements. Particularly prominent are *Acacia spp, Grewia spp* and *Combretum spp.* In the buffer zone, *Combretum spp* are also among the most common species, but diversity changes slightly to include trees such as *Isoberlina doka, Pseudocedrela kotschyi* and *Entada abyssinica.* All three areas have *Bridelia scleroneura* and *Lannea spp*, and the buffer zone and Imvepi Refugee Settlements both have *Ziziphus abyssinica*. Table 1 lists the dominant species in each of the three areas in descending order of frequency.

Table 1: Dominant tree species with dbh greater than or equal to 10 cm

Buffer zone		Imvepi Refugee Settlement		Rhino Camp refugee settlement	
Species	**Density per ha**	**Species**	**Density per ha**	**Species**	**Density per ha**
Isoberlinia doka	13.12	*Acacia hockii*	25.25	*Combretum fragrans*	10.15
Combretum fragrans	4.95	*Combretum fragrans*	20.79	*Lannea schimperi*	8.90
Pseudocedrela kotschyi	4.46	*Combretum collinum*	19.31	*Acacia hockii*	7.27
Bridelia scleroneura	3.71	*Combretum molle*	12.62	*Grewia mollis*	5.89
Combretum collinum	2.97	*Grewia mollis*	11.63	*Combretum collinum*	5.76
Entada abyssinica	2.97	*Lannea schimperi*	7.92	*Maytenus senegalensis*	5.51
Ficus sycomorus	2.97	*Bridelia scleroneura*	5.45	*Combretum molle*	4.26
Sterculia setigera	2.48	*Lannea barteri*	5.45	*Balanites aegyptiaca*	2.26
Pterocarpus lucens	2.23	*Allophylus africanus*	3.47	*Lannea barteri*	2.13
Cussonia arborea	1.98	*Acacia sieberiana*	3.22	*Bridelia scleroneura*	1.75
Ziziphus abyssinica	1.49	*Piliostigma thonningii*	2.23	*Tamarindus indica*	1.63
Stereospermum kunthianum	0.50	*Ziziphus abyssinica*	2.23	*Lonchocarpus laxiflorus*	1.13
Others	17.58	Others	32.42	Others	18.55
Total (n/ha)	**61.39**		**151.98**		**75.19**

The low tree density in the buffer region is mostly attributed to the area largely being used for agriculture and grazing where most of the trees might have been removed. On the other hand, some buffer areas of the settlements are highly degraded with very low tree density.

Smaller diameter classes exhibit greater uniformity of dominant species; all were native species. *Acacia hockii, Combretum* and *Grewia* spp are the dominant species in all three sampling areas (Table 2).

Table 2: Dominant tree species with dbh of less than 10 cm (5cm<dbh>10cm)

Buffer		Imvepi refugee settlement		Rhino Camp refugee settlement	
Species	**Density per ha**	**Species**	**Density per ha**	**Species**	**Density per ha**
Acacia hockii	30.69	*Acacia hockii*	142.58	*Acacia hockii*	42.57
Combretum fragrans	24.75	*Combretum collinum*	42.57	*Combretum collinum*	22.77
Pseudocedrela kotschyi	22.77	*Combretum fragrans*	32.67	*Combretum fragrans*	18.81

Buffer		Imvepi refugee settlement		Rhino Camp refugee settlement	
Species	**Density per ha**	**Species**	**Density per ha**	**Species**	**Density per ha**
Bridelia scleroneura	16.83	*Grewia mollis*	32.67	*Combretum molle*	8.42
Grewia mollis	13.86	*Strychnos spinosa*	14.85	*Senna siamea*	6.93
Combretum collinum	11.88	*Combretum molle*	12.87	*Grewia mollis*	6.44
Isoberlinia doka	9.90	*Piliostigma thonningii*	7.92	*Maytenus senegalensis*	5.94
Lannea fruticose	5.94	*Lonchocarpus laxiflorus*	6.93	*Rhus natalensis*	5.45
Rhus natalensis	4.95	*Bridelia scleroneura*	4.95	*Lannea schimperi*	4.95
Combretum molle	3.96	*Stereospermum kunthianum*	4.95	*Bridelia scleroneura*	3.96
Piliostigma thonningii	3.96	*Hymenocardia acida*	3.96	*Lannea barteri*	3.96
Strychnos innocua	3.96	*Maytenus senegalensis*	3.96	*Grewia bicolor*	3.47
Terminalia glaucescens	3.96	*Tamarindus indica*	1.98	*Dichrostachys cinerea*	1.98
Others	25.74	Others	14.85	Others	18.82
Total	**183.17**		**327.73**		**154.46**

The density per ha of trees with a diameter between 5 cm and 10 cm is 183 for the buffer zone, 328 for Imvepi Refugee Settlement and 154 for Rhino Camp Refugee Settlement. Again, Imvepi has the highest density of small trees, mainly because it is newer than Rhino Camp, and intense human exploitation and destruction have not yet expanded. Those who extract trees mainly seek big trees with dbh greater than 10 cm. The buffer zones are relatively highly exploited by the host communities, both for agricultural purposes and grazing. Hence, the relative damage to the smaller size trees is already high.

Harvesting of trees: Stump density as a proxy

The vegetation assessment showed tree cutting to be widespread but at scales that varied depending on location. In Imvepi and Rhino Camp Refugee Settlements, the average number of trees cut per ha was similar – 51 and 56, respectively. In the buffer zone, the rate of cutting was significantly lower at 33 trees per ha. However, the sizeable population of refugees is beginning to have a negative impact on the vegetation. Field observations revealed that the buffer zone is an increasingly key source of firewood and construction materials for refugees, as the wood resources in their settlements dwindle.

Table 3: Stump densities of main species that are harvested in the three sampling areas and overall landscape

Species (selected list only)	Stump density (No. of stumps/ha)			
	Buffer	**Imvepi refugee settlement**	**Rhino Camp refugee settlement**	**Landscape level**
Acacia hockii	**9.65**	**23.02**	**11.15**	**43.83**
Combretum fragrans	2.97	**6.44**	**12.91**	**22.31**
Combretum collinum	**5.45**	3.71	**8.27**	**17.43**
Combretum molle	1.49	3.96	**6.27**	**11.71**
Bridelia scleroneura	3.47	2.72	1.38	7.57
Grewia mollis	0.74	2.48	1.63	4.85
Terminalia glaucens	0.74	0.74	2.13	3.62
Pseudocedrala kotschyi	2.23	0.74	1.00	3.97
Rhus natalensis	0.00	0.25	2.01	2.25
Maytenus senegalensis	0.74	1.24	0.63	2.61

Note: Bold values indicate high stump density per species.

The assessment found that the species that are the most harvested are the same species that are most dominant: i.e., the three *Combretum* species together with *A. hockii* are the most commonly harvested trees in the landscape. In both refugee settlements, these species are used for firewood and construction materials. In Imvepi Refugee Settlement, however, *A. hockii* was harvested at a rate twice that in Rhino Camp. Lower harvest rates of the species were reported in the buffer zone. On the other hand, in Rhino Camp Refugee Settlement, *Combretum spp* (*C. fragrans, C. collinum* and *C. molle*) were harvested at a rate twice that in Imvepi Refugee Settlement.

Using stump diameter as an indicator, the size distribution of the cut trees revealed that for different species, different sizes are targeted. This is probably a function of the purpose for which the tree is cut. Smaller trees tended to be harvested in the buffer zone. The smallest tree harvested in the buffer zone had a diameter of 8.74 cm while the largest (excluding *Terminalia glaucens)* had a diameter of 17.42 cm. Imvepi Refugee Settlement showed a relatively wide range of diameters being harvested – from 7 cm to 18.04 cm.

In contrast, in Rhino Camp Refugee Settlement, a narrower range of diameters are seen in the harvested trees – from 10.32 cm to 16.88 cm. This is cause for concern. When harvesting focuses on a narrow range of species of a specific size, there is a risk that a selected size class of tree might vanish, creating a gap in the vegetation structure. It is, therefore, essential that harvesting in this settlement and elsewhere be managed through sustainable strategies.

Table 4: Stump diameters of cut trees in the sampling areas

Species	Mean stump diameter of cut trees		
	Buffer	Imvepi	Rhino Camp
Acacia hockii	8.74	12.41	10.32
Combretum fragrans	12.67	15.06	14.94
Combretum collinum	13.59	17.53	13.63
Combretum molle	17.42	12.53	15.43
Bridelia scleroneura	13.16	12.50	15.39
Grewia mollis	13.07	18.04	16.88
Terminalia glaucens	30.10	30.77	15.53
Pseudocedrala kotschyi	12.43	8.53	11.84
Rhus natalensis	-	7.00	11.89
Maytenus senegalensis	10.03	16.48	15.04

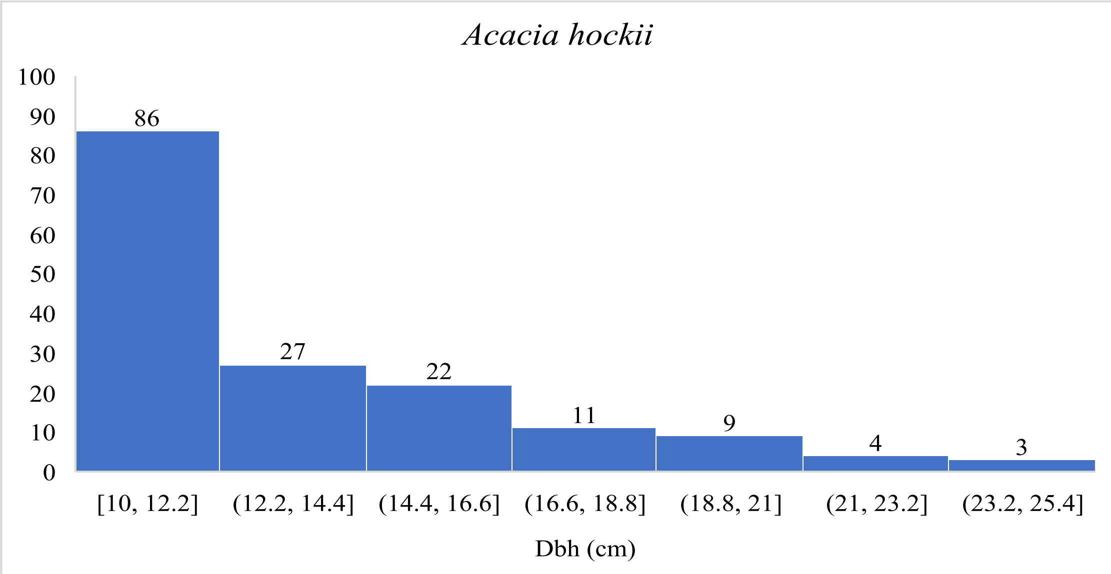
A key indicator of species health is tree size distribution with healthy populations having a greater number of younger and smaller trees than large trees in an inverted J-shape distribution. However, an in-depth look at the size of trees that had been cut revealed a serious threat to the survival of some heavily harvested species. Those that are cut tend to be mature, bearing the seeds critical for the next generation.

The problem is particularly severe for *C. fragrans* and *C. collinum*. Almost a quarter of these species that are cut have diameters of more than 20 cm. A considerable age gap is emerging in the population of this valuable tree. For all the dominant species, the abrupt decline in the number of trees as soon as they approach harvestable size is a clear signal of an unhealthy population. Management of the species needs to balance utilization and to maintain a healthy population distribution.

Table 5: Analysis of stump size distribution of heavily-used tree species that are cut often

Species	Stump diameter		
	>10 cm	>15 cm	>20cm
Acacia hockii	51%	21%	5%
Combretum fragrans	75%	45%	23%
Combretum collinum	75%	39%	20%
Combretum molle	58%	38%	24%

There is clear evidence that as the large trees become scarce, households resort to cutting any available size. Results in Table 5 indicate that communities have already commenced the harvesting of small sized trees with dbh of less than 20 cm. For many species, almost three-quarters of the cut trees are below this dbh. This creates an unhealthy population of tree species, which in case of any edaphic or climatic variation may not survive the changes.


Acacia hockii
100
90
80
70
60
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40
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[10, 12.2]
(12.2, 14.4]
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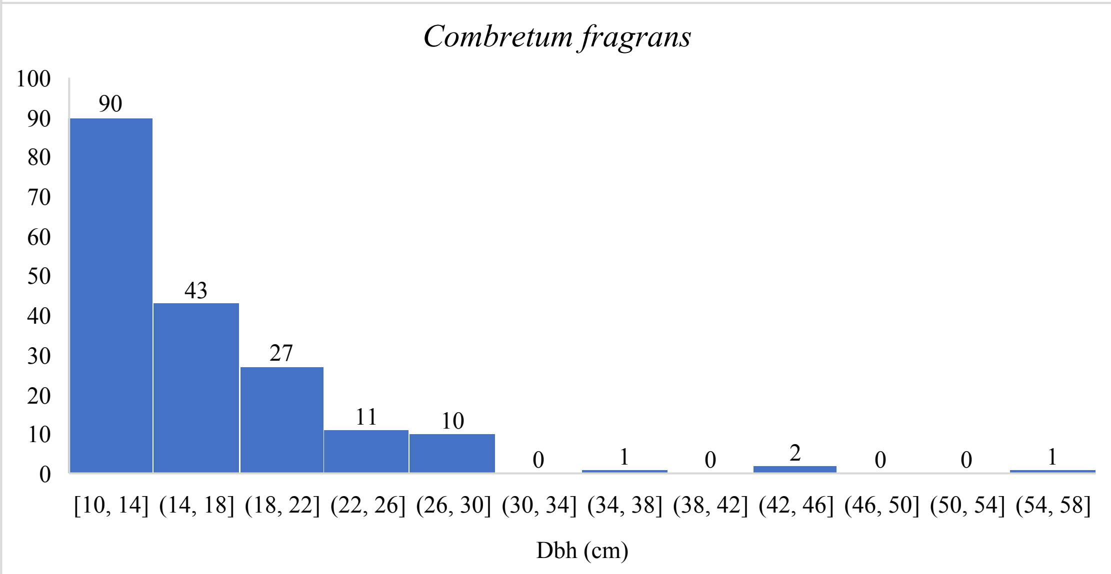
(23.2, 25.4]
Dbh (cm)


Combretum fragrans
100
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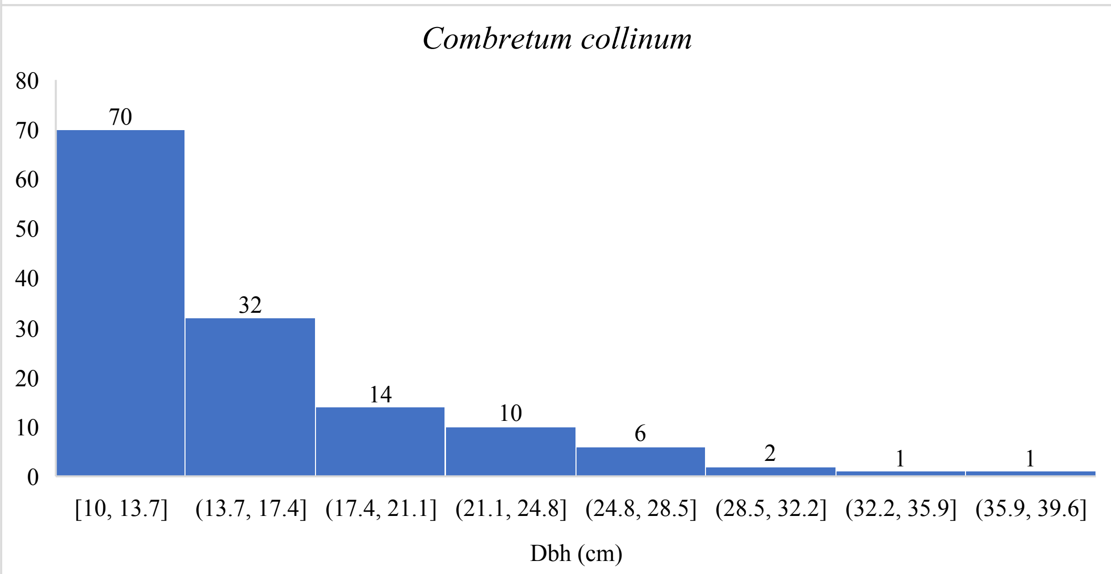
(54, 58]
Dbh (cm)


Combretum collinum
80
70
60
50
40
30
20
10
0
70
32
14
10
6
2
1
1
[10, 13.7]
(13.7, 17.4]
(17.4, 21.1]
(21.1, 24.8]
(24.8, 28.5]
(28.5, 32.2]
(32.2, 35.9]
(35.9, 39.6]
Dbh (cm)

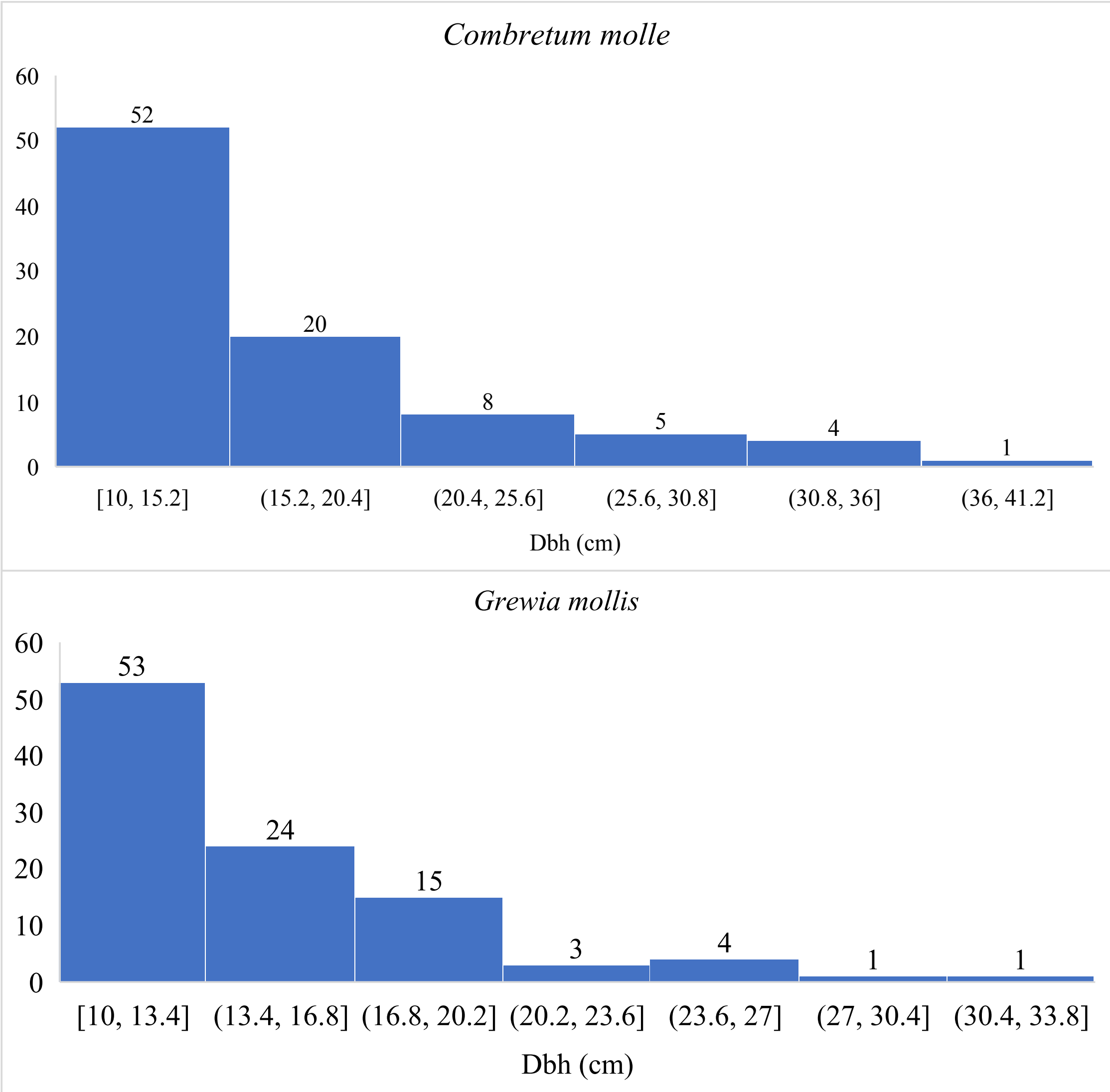


Figure 3: Size distribution of dominant tree species in the landscape. Note that the number per bar indicates the number of trees that fall within the given dbh range.

Estimating potential landscape-level tree stocking capacity

Potential tree density per hectare is the sum of standing tree density and that of the stumps of the trees cut from within the plot. The potential tree density assumed may be less than what might be there due to effects of fire and decomposition processes that may render some stumps unseen and therefore missed out during measurement. The high intensity of human activity may also lead to some stumps being removed from fields.

The 'potential tree stocking capacity' is a useful way of determining optimal tree density that could ecologically be sustainable if environmental conditions and management interventions remain similar.

Table 6: Assessment of the potential tree density per ha in the study areas

Assessment area	Standing tree density per ha	Stump density per ha	Potential tree density per ha
Buffer zone	244.56	33.40	277.96
Rhino Camp Refugee Settlement	229.65	56.39	286.04
Imvepi Refugee Settlement	479.71	50.99	530.70

Tree woody biomass assessment

Similar to tree density, woody biomass differed significantly in the three sampling areas. Table 7 summarizes the above-ground tree-based woody volume. Imvepi Refugee Settlement had almost twice the woody biomass as Rhino Camp Refugee Settlement, and almost five times that of the buffer area per unit space. The low biomass stock in the buffer is largely due to agricultural lands that often have very low tree biomass. Rhino Camp also has low woody biomass stock due to its many homes and allied buildings; only a few have shade trees or remnants of the original vegetation.

Table 7: Tree biomass estimation in different assessment areas

Assessment area	Area (ha) as at 2018	Above-ground tree biomass (>5 cm dbh) (t/ha)	Total tree ABG biomass (t/ha)
Buffer	68,570.85	5.77	395,653.80
Rhino Camp	54,625.76	12.12	662,064.21
Imvepi Refugee Settlement	15,419.36	23.68	365,130.44

From the spatial analysis, the area of the three assessment zones totalled to about 138,616 ha. The corresponding tree above-ground biomass was found to be about 1,422,848 tons.

Table 8: Average above-ground biomass from trees in different land cover types

Land cover types	Buffer	Imvepi refugee settlement	Rhino Camp refugee settlement	Overall mean (t/ha)
Bare land	0.00	6.95	2.88	3.92
Bushland	10.12	38.57	8.91	14.24
Farm land	2.20	9.36	5.29	4.31
Grassland	5.83	18.24	14.31	15.11
Open water	-	-	0.00	0.00
Wetland	-	-	9.48	9.48
Woodland	17.79	36.15	27.82	30.87
Mean AGB for sampling areas (t/ha)	**5.77**	**23.68**	**12.12**	**13.43**

Shrub biomass estimation

Three shrub species – *Harrisonia abyssinica*, *Lantana camara* and *Capsicum frutescens* – make up almost 68% of standing shrubs in the sampled areas. *H. abyssinica* alone comprises about 50% of all the standing shrubs in the entire landscape, with about 26 stems per ha: 93% of the stems of this species were recorded in Imvepi and Rhino Camp Refugee Settlements, with the former registering almost twice the stem density as the latter. *Harrisonia abyssinica* is a flowering evergreen shrub, usually about 6 m tall, that provides medicine, food and wood. *Lantana camara* is a notorious invasive. *Capsicum frutescens* is a chili species that can become woody at the base.

The average shrub AGB in the buffer zone and Imvepi and Rhino Camp Refugee Settlements was 0.21, 1.47, and 0.63 tons/ha, respectively. The total landscape level shrub AGB was found to be 14,400, 22,660 and 34,414 tons in the buffer zone and Imvepi and Rhino Camp Refugee Settlements, respectively. Hence the total landscape level shrub AGB was about 71,841 tons. Compared to the tree biomass, the shrub AGB is limited due to the small number of shrub stems in the landscape.

Total woody biomass estimation

The total woody plant AGB was about 410,054, 387,797 and 696,478 tons in the buffer zone and Imvepi and Rhino Camp Refugee Settlements, respectively. Several important conclusions can be drawn from this data:

- The total landscape AGB, or the AGB of three areas, equals approximately 1,494,329 tons.
- Out of this total landscape AGB, the above-ground biomass that is contained in the buffer zone – a total of 410,054 tons – is under the control or ownership of the host community, and therefore not readily available to refugees unless via purchase, exchange of labour or bartering for food rations.
- Only the biomass located within the two refugee settlements, a quantity that totals about 1,084,275 tons, is potentially available for use by the refugee community.
- Furthermore, some trees within the refugee settlements, largely fruit, medicinal and keystone species like *Afzelia africana,* are marked with red or yellow paint, indicating not to be cut (red) or only under certain circumstances (yellow). This further reduces biomass at the disposal of refugees.

Estimated years of woody biomass remaining

Data compiled from GIS and maps of the entire study area (buffer zone and Imvepi and Rhino Camp Refugee Settlements) indicate that AGB was 1,812,486 tons in 2010 and 1,919,302 tons in 2015. This increase is thought to be due to the establishment of broadleaved plantations, largely teak. The 2015 figure can be used as a baseline. Today, the AGB is estimated (as noted above) at 1,494,329 tons. Therefore, approximately 424,973 tons have been removed.

If this AGB is considered to have been removed over three years, then the current annual biomass loss in the area could be estimated at 141,658 tons per year. If the loss of this biomass is estimated to have occurred over two years, then the annual loss is 212,487 tons per year. If most of the loss is believed to have occurred from the end of 2016 to mid-2018 (18 months – the period of the highest refugee influx and settlement), then the annual rate of loss is 283,982 tons a year. Using those figures, at this rate, the landscape could be stripped bare of biomass in anywhere from 5 to10 years.

However, the AGB in the two refugee settlements is less than that of the total area and stands at an estimated 1,084,275 tons. Taking that as the biomass available to the refugees, then the two settlements could be stripped bare in just 4 to 7 years.

Clearly, the entire area faces a severe threat with the prospect of refugees having to walk further for natural resources, which could result in conflicts with the local population, as well as the collapse of ecosystem services and goods.

Management implications

With possibly just four years of biomass left within Imvepi and Rhino Camp Refugee Settlements, urgent measures are required to slow down its loss. The ideal would be to reach a state of equilibrium between what is removed and new growth of woody biomass each year.

However, total biomass is not the sole concern. Diversity of tree species is also important; the three areas studied have 81 identified species, which deliver a myriad of goods and services and underpin resilience.

Finally, it is also important to maintain healthy populations of individual tree species. This study found explicit threats to the dominant most harvested tree species with some beginning to disappear once their diameter exceeds 20 cm. Over 96% of individual *A. hockii,* 86% of *C. fragrans* and 91% of *G. mollis* were below the dbh of 21 cm.

Recommendations

From a broader perspective, it is evident that the relative ecological importance of sites should be taken into account in the process of allocating plots to refugees. This would entail a thorough inventory of the sites beforehand so that specific measures to preserve the existing tree species diversity can be taken. For each village or area of plots to be distributed, ecological site data should be available to accompany the decision of allocation. This seems to be missing in current practice. If such data and measures are not in place, the probability of damaging local ecological integrity is far higher, and the healthy species-level population structures may be disrupted, which on its own will lead to vegetation degradation in the landscape.

To halt further degradation, enhance woody biomass stocks, and maintain and promote diverse and healthy tree populations, the following specific actions and approaches are recommended:

- Work with refugee and host communities, district officials and other stakeholders to build a system that enables the planting, growing, regeneration and protection of trees.
- Aim for consensus on priority areas to plant, regenerate and protect.
- Agree on how to control burning and contain livestock, both of which threaten the survival of planted seedlings. Wildfires will hamper natural regeneration of woodland species.
- With different groups, deliberate and carefully curate which trees species are to be raised and planted. Building on the natural vegetation, these should aim to help meet the diverse needs of the refugees and host communities for shade, fruit, firewood and other goods and services.
- Aim to integrate trees on refugee plots and in their cultivated plots (agroforestry) so that they can meet energy needs from prunings rather than from collecting from common areas or host land. Use of woody legumes like pigeon pea can also contribute biomass.
- Encourage and support the host community to also integrate trees into their farming systems (agroforestry).
- Encourage the cutting of branches/pruning as a way to meet energy needs rather than the cutting of entire trees.
- Put in as much effort and resources into promoting natural regeneration through farmer-managed natural regeneration (FMNR) as into raising and planting trees. FMNR will likely achieve faster regreening, given that the area has 30-56 live stumps per ha.
- Develop species-level management strategies so that the ecosystem retains and regains its vigour and vegetation diversity. Focus on the top four most harvested species. In the buffer areas, focus on enrichment planting and FMNR of *A. hockii* and *C. collinum*. In Imvepi Refugee Settlement, focus on restoring the stock of *A. hockii* and *C. fragrans*. In Rhino Camp Refugee Settlement, focus on *A. hockii* and *Combretum spp.*
- Utilize the potential tree stocking capacity as an accurate indicator of how many trees may be planted where degradation is happening.
- To achieve enrichment goals, build a system of tree nurseries with the capacity to deliver seedlings.

- Work with stakeholders to control illegal harvesting of mature trees species such as *Afzelia africana* and *Khaya spp*.

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Annexes

Annex 1: Stump counts of the dominant tree species in the three sites

Species	**Stump counts in the sampling areas**			
	Buffer zone	**Imvepi**	**Rhino Camp**	**Total**
Acacia hockii	39	93	89	**221**
Combretum fragrans	12	26	103	**141**
Combretum collinum	22	15	66	**103**
Combretum molle	6	16	50	**72**
Bridelia scleroneura	14	11	11	**36**
Grewia mollis	3	10	13	**26**
Terminalia glaucens	3	3	17	**23**
Pseudocedrela kotschyi	9	3	8	**20**
Rhus natalensis		1	16	**17**
Maytenus senegalensis	3	5	5	**13**
Others	24	23	72	**119**
Aggregate	**135**	**206**	**450**	**791**

Annex 2: List of species found within the sampling plots during the large-scale vegetation survey in Rhino Camp and Imvepi Refugee Settlements and surrounding buffer zones

Species name	**Local name**	**Main uses**
1. *Acacia hockii*	Ali/Oli	Firewood, charcoal, medicine (roots), ropes (bark), fencing materials (dry branches)
2. *Acacia polyacantha*	Odumburuku	Used as a remedy for snakebites, fuelwood, repellent against snakes and crocodiles
3. *Acacia senegal*	Bina	Firewood, charcoal, poles, tool handles, food (seeds), medicine (roots), fodder (pods and leaves), nitrogen fixation, soil conservation, gum, dye (seeds), live and dry fences
4. *Acacia seyal*	Ali/Oli	Firewood, charcoal, poles, posts, medicine (bark, gum), fodder (leaves), bee forage, nitrogen fixation, soil conservation, windbreak, gum, tannin (bark), dye (bark), live fence
5. *Acacia sieberiana*	Asoro	Edible gum, forage for livestock, forage for bees, fuelwood and charcoal, timber and tool handles, medicinal purposes for variety of ailments
6. *Afzelia africana*	Meli, Buluku/Loko	Firewood, charcoal, timber, poles, posts, shade
7. *Albizia adianthifolia*	Acebi	Firewood, charcoal, timber, nitrogen fixation
8. *Albizia zygia*	Acebi	Firewood, charcoal, timber, poles, shade, ornamental, nitrogen fixation

Species name	Local name	Main uses
9. Allophylus africanus	Unknown	Fibres, fruits, fuelwood, medicinal, ornamental, timbers
10. Annona senegalensis	Elipa, lamodi	Food (fruit), medicine (bark, root, gum, fruit), fodder (leaves), dye (bark)
11. Antiaris toxicaria	Ripi	Timber (veneer, beer canoes), medicine (leaves, roots), bark cloth
12. Balanites aegyptiaca	Loba, logba	Firewood, charcoal, poles, timber (furniture), utensils, tool handles, food (fruit, leaves), medicine (roots, bark, fruit), mulch, shade, windbreak, gum, fencing (branches), oil (fruit), fish poison
13. Borassus aethiopum	Itu	Firewood, charcoal, poles, timber (roofing, door frames, etc.), tool handles, bee hives, food (fruit, seeds, young seedlings), palm wine (sap of flower shoots), medicine (roots, flowers, oil), fodder (fruit, young leaves), thatch, fiber (leaves), baskets, mats (leaf stalks, leaves), oil (fruit, pulp), brooms, drums
14. Bridelia scleroneura	Elemava/Onzuu	Dyes and tannins, fruits, fuel, and medicine
15. Carica papaya	Payipayi	Food (fruit), drink (fruit), medicine (roots, leaves), pickles, jam (fruit), meat tenderizing
16. Celtis africana	Yife	Firewood, charcoal, timber, tool handles, fodder (leaves), shade
17. Chaetacme aristata	Not known	
18. Combretum collinum	Ayi	Firewood, charcoal, medicine (leaves, roots), bee forage, fencing (cut branches), firebreaks
19. Combretum fragrans	Adu	Firewood, charcoal, medicine (leaves), bee forage
20. Combretum molle	Adu/Geleo	Firewood, charcoal, poles, posts, timber (construction), tool handles, medicine (roots, leaves, bark), bee forage, mulch
21. Craibea brownii	Not known	
22. Cussonia arborea	Osi	Food (fruits), medicinal and dyes and light duty wood requirements
23. Dalbergia melanoxylon	Poyi	Firewood, charcoal, timber (construction), carving (musical instruments, walking sticks, etc.), medicine, (bark, roots, leaves), fodder, bee forage, mulch, nitrogen fixation
24. Daniellia oliveri	Masa, Bitok	Timber (dugout canoes), mulch, bee forage, ornamental (avenue tree), windbreak, gum (resin)
25. Dichrostachys cinerea	Wasedu/Eziogati	Firewood, charcoal, poles, posts, tool handles, medicine (leaves, roots), fodder (leaves, pods), bee forage, nitrogen fixation, soil conservation, fibre (bark), live fence, dry fence
26. Diospyros mespiliformis	Olianga	Firewood, charcoal, timber (construction, furniture), carving (walking sticks), food (fruit: dry, fresh, fermented drink), medicine (bark, roots, fruit), bee forage, shade, ornamental
27. Dombeya mukole	Mvopi	Firewood, charcoal, timber, building poles
28. Dombeya sp	Mvopi	
29. Dovyalis caffra	Not Known	Fruit (jam), ornamental, bee forage, live fence

Species name	**Local name**	**Main uses**
30. *Entada abyssinica*	Mbila	Fodder, fuelwood, tannins especially from roots, timber especially for light works
31. *Eucalyptus sp*	Kalitunsi	Firewood, charcoal, poles (power lines), posts, timber (construction), bee forage, ornamental, windbreak
32. *Euphobia candelabrum*	Wari	Firewood, timber (roofing, tables, matches, boxes, carving, musical instruments), live fence
33. *Ficus glumosa*	Oua	Firewood, charcoal, food (figs), windbreak
34. *Ficus ovata*	Odulindri	Poles, shade, soil conservation and improvement, live fence, boundary demarcation, bark cloth
35. *Ficus sycomorus*	Elio/Ologo	Firewood, charcoal, carvings, food (fruit), medicine (latex), mulch, soil conservation and improvement, ornamental, shade, beehives
36. *Flueggea virosa*	Erekere	Medicinal for various ailments (e.g. heavy menstruation, headaches, migraines), dyes, forage for animals, ornamental, food (fruits) for humans
37. *Gardenia spp*	Dumu	
38. *Gardenia volkensii*	Dumu	Medicinal, utensils (cooking stirrers, sticks), shade, ornamental, ceremonial
39. *Grewia bicolor*	Enzu	Firewood, charcoal, timber, tool handles, carving (clubs, javelins, walking sticks), medicine (roots, bark), fodder (leaves, fruit)
40. *Grewia mollis*	Enzu, Onjua	Firewood, charcoal, timber, walking sticks, fodder (leaves and fruits), fibre (strings from bark)
41. *Harrisonia abyssinica*	Uliro	Medicinal (various ailments), fruits are edible, carvings and art pieces from the wood, live fence
42. *Hexalobus multiflora*	Ruta	
43. *Hexalobus sp*	Ruta	
44. *Hymenocardia acida*	Ekaraka	Food, fodder, apicultural use (flowers), fuelwood, tannins and dyes, medicinal, shade, erosion control
45. *Isoberlinia doka*	Abogo	Firewood, charcoal
46. *Khaya senegalensis*	Marigo, Mario	Firewood, charcoal, timber (heavy construction), soil conservation and improvement
47. *Kigelia africana*	Odolo, Odoloko	Firewood, timber (dugout canoes, yokes), medicine (fruit, bark), dye (boiled fruit), local honey beer (fruit)
48. *Lannea barteri*	Odikodi, Odukudu	Firewood, charcoal, utensils (durable mortars), live fence
49. *Lannea fruticosa*	Odikodi, Odukudu	Timber (construction, furniture, bed frames), hardening of earthen pots, fodder
50. *Lannea kersingii*	Odikodi, Odukudu	Firewood, charcoal, utensils (durable mortars), live fence
51. *Lannea schimperi*	Odikodi, Odukudu	Medicinal, fruits and seeds are edible, flowers are vital for apiculture, bark is used for making cordage
52. *Lonchocarpus lax iflorus*	Wowo	
53. *Mangifera indica*	Muyembe	Fruits (edible), apiculture, shade, medicinal
54. *Maytenus senegalensis*	Buruburu	
55. *Maytenus undata*	Buruburu	Firewood, charcoal, timber (local construction), farm tools, medicine (roots), live fence, ornamental

Species name	Local name	Main uses
56. *Melia azadirachta*	Lira	Firewood, charcoal, timber (tool handles), poles, posts, medicine (bark), bee forage, ornamental, shade, windbreak
57. *Moringa oleifera*	Moringa	Food (young leaves, young fruit), medicine, fodder (leaves, fruit), bee forage, soil conservation, shade, windbreak, live fence, boundary marker, fibers, spice (young roots), oil (seeds), water purification (seeds)
58. *Oncoba spinosa*	Cikinda	Fruits are edible in times of famine, edible oil is obtained from the seeds, medicinal, used for hedges, hollow dried fruits used as musical instrument
59. *Ozoroa insignis*	Rava	Firewood, charcoal, timber (furniture), carving (heartwood)
60. *Pavetta spp*	Not Known	
61. *Piliostigma thonningii*	Maza, Azaka	Firewood, charcoal, poles, timber (houses), food (pods), drink (leaves, pods), fodder (pods, shoots), bee forage, medicine (leaves, bark, roots, pods), mulch, soil conservation, ornamental, nitrogen fixation, tannin, dye (pods, seeds, bark, roots), rope (bark, root fibres)
62. *Prosopis africana*	Liso	Firewood, charcoal, timber (cabinets, railway sleepers, turnery), tool handles, tools, boat building, shade, ornamental, tannin, dye
63. *Pseudocedrela kotschyi*	Mala	Firewood, charcoal, timber (joinery), utensils (mortars, etc.), poles, shade, ornamental
64. *Pterocarpus lucens*	Nyarangilo	Fresh leaves are edible, fodder for animals, fuelwood, medicine
65. *Rhus natalensis*	Ndri-ai	Fruits and leaves are edible for humans, fodder, fuelwood, timber, medicinal
66. *Sclerocarya birrea*	Abirici, Amarula Lanyumu,	Firewood, charcoal, timber (general purpose), utensils (stools, grain mortars, beehives), carving, food (fruit, fat from seeds), drink (fruit), bee forage, fodder (leaves, fruit), medicine (bark, roots, leaves), fibre (bark)
67. *Senna siamea*	Kasia	Firewood, charcoal, poles, timber (furniture), medicine, bee forage, shade, ornamental, mulch, soil conservation, windbreak
68. *Senna spectabilis*	Kasia	Firewood, charcoal, tool handles, bee forage, shade, ornamental, mulch
69. *Sterculia setigera*	Opi	Firewood, charcoal, shade (for coffee, banana, cocoa), ornamental (avenue tree), fibres (from bark for string and ropes)
70. *Stereospermum kunthianum*	Lape, Lokobe	Firewood, charcoal, poles, tool handles, sticks, medicine (bark, fruit), ornamental
71. *Strychnos innocua*	Lomboro	Firewood, charcoal, local tools, food (fruit pulp), shade
72. *Strychnos mitis*	Lomboro	Firewood, charcoal, timber (heavy construction, rail sleepers), poles, shade (for coffee and cocoa), ornamental (avenue tree)
73. *Strychnos spinosa*	Lomboro	Firewood, charcoal, timber (furniture, boxes), fodder (leaves), food (fruit), medicine (fruit, leaves, bark, roots), musical instruments (dry fruit shell)
74. *Tamarindus indica*	Iti	Firewood, charcoal, poles, timber (furniture, boats, general purposes), food (pulp for drink, fruit, spice), fodder (leaves, fruit), medicine (bark, leaves, roots,

Species name	Local name	Main uses
		fruit), mulch, nitrogen fixation, shade, ornamental, windbreak, tannin (bark)
75. *Terminalia glaucescens*	Ongo	Firewood, charcoal, beehives
76. *Vernonia amygda lina*	Ecero, Omululisi	Firewood, food (leaves as vegetable), medicine (roots, bark, leaves), ornamental, mulch, soil conservation and improvement, live fence, toothbrushes (stems), stakes
77. *Vitellaria paradoxa*	Kumare	Fruits are edible, shea butter oil, fuelwood, timber
78. *Vitex doniana*	Odogo, Ediko	Firewood, charcoal, poles, timber (construction, furniture), food (fruit), medicine (bark, leaves, roots, fruit), fodder (leaves, fruit), bee forage, shade, dye (bark)
79. *Ximenia americana*	Ochik, Malaa	Firewood, timber (utensils), tool handles, food (fruit), medicine (roots, bark, leaves), fodder, oil (seed), live fence
80. *Ziziphus abyssinica*	Ela	Firewood, charcoal, timber (furniture, interior work, carving), poles, food (fruit pulp and seed), live fence, bee forage, dye (bark)
81. *Ziziphus mucronata*	Liria	Firewood, charcoal, timber (furniture, interior work, carving), poles, food (fruit pulp and seed), live fence, bee forage, dye (bark)

Annex 3: The mean AGB (tons per ha) for trees with less than 10cm dbh

Tree species	Buffer	Imvepi	Rhino Camp
Acacia hockii	0.2599	1.5442	0.4638
Combretum collinum	0.1793	0.4271	0.2628
Combretum fragrans	0.2185	0.2836	0.1741
Grewia mollis	0.0872	0.2417	0.0510
Combretum molle	0.0627	0.1105	0.1175
Pseudocedrela kotschyi	0.2038	0.0048	0.0067
Senna siamea	-	-	0.1036
Maytenus senegalensis	0.0110	0.0409	0.0596
Rhus natalensis	0.0338	0.0135	0.0545
Bridelia scleroneura	0.0868	0.0318	0.0176
Strychnos spinosa	-	0.1123	0.0160
Isoberlinia doka	0.1075	-	-
Lannea schimperi	0.0021	0.0183	0.0437
Terminalia glaucescens	0.0552	0.0047	0.0129
Piliostigma thonningii	0.0330	0.0472	0.0019
Lannea barteri	0.0100	0.0152	0.0251
Lonchocarpus laxiflorus	-	0.0421	0.0160
Pterocarpus lucens	0.0511	-	0.0097
Strychnos innocua	0.0611	-	-
Grewia bicolor	-	-	0.0262

Tree species	Buffer	Imvepi	Rhino Camp
Dichrostachys cinerea	-	-	0.0212
Ximenia americana	0.0188	-	0.0116
Harrisonia abyssinica	0.0009	0.0256	0.0074
Ficus sycomorus	0.0299	-	0.0051
Stereospermum kunthianum	-	0.0348	-
Lannea fruticosa	0.0239	-	0.0043
Tamarindus indica	0.0064	0.0254	-
Hymenocardia acida	-	0.0197	0.0034
Hexalobus multiflora	-	0.0087	0.0081
Acacia senegal	0.0236	-	-
Dombeya sp	-	-	0.0119
Ziziphus abyssinica	-	-	0.0102
Melia azadirachta	0.0194	-	-
Annona senegalensis	-	-	0.0097
Ziziphus mucronata	-	-	0.0095
Hexalobus sp	-	-	0.0092
Allophylus africanus	-	0.0167	-
Lannea kersingii	-	-	0.0082
Eucalyptus sp	0.0139	-	-
Senna spectabilis	-	0.0126	-
Gardenia volkensii	0.0124	-	-
Vitex doniana	-	0.0112	-
Acacia sieberiana	-	0.0108	-
Sclerocarya birrea	0.0108	-	-
Mangifera indica	0.0099	-	-
Balanites aegyptiaca	-	0.0045	0.0027
Entada abyssinica	0.0083	-	-
Daniellia oliveri	-	-	0.0041
Acacia seyal	-	-	0.0037
Moringa oleifera	0.0069	-	-
Dalbergia melanoxylon	-	0.0059	-

Annex 4: Description of land cover types used in the AGB analysis

Land cover type	Description
Bare land	Open land that has bare soil without or with minimal vegetation cover. Such areas include built-up areas, settlements and roads.
Bush land	Areas dominated by bush, thickets, shrubs and scrubs and are generally less than 4m in height.
Crop land/Subsistence farming	Mixed farmlands, small holdings in use or recently used, with or without trees.
Grassland	These are rangelands, pasturelands, open savannah; may include scattered trees, bush, shrubs, scrubs, and thickets.
Trees/Woodland	Wooded areas of trees and shrubs that are more than 4m in height. Woodlands can be dry or wet. The dry woodland is upland while wet woodland occurs along rivers/swamps.
Open water	Open water surfaces that include lakes, rivers, and ponds.

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