**Journal of Plant Sciences**
2023; 11(3): 39-53
http://www.sciencepublishinggroup.com/j/jps
doi: 10.11648/j.jps.20231103.11
ISSN: 2331-0723 (Print); ISSN: 2331-0731 (Online)

# Distribution and Regeneration Status of *Guibourtia copallifera* Benn. in Sierra Leone

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## To cite this article:
Jonathan Johnny, Aiah Lebbie, Richard Wadsworth. Distribution and Regeneration Status of *Guibourtia copallifera* Benn. in Sierra Leone. *Journal of Plant Sciences*. Vol. 11, No. 3, 2023, pp. 39-53. doi: 10.11648/j.jps.20231103.11

**Received**: April 15, 2023; **Accepted**: May 15, 2023; **Published**: May 29, 2023

**Abstract:** This study was conducted to assess the species distributional range, structure, and regeneration status of *G. copallifera* Benn. A distributional survey was conducted in over 30 villages and communities where claims were made about the presence of this species. At four locations, pairs of large plots measuring 500m x 20m were laid out 400m apart and each subdivided into ten (10) subplots (50m x 20m). For the regeneration studies (Seeds, seedlings and saplings), four quadrats of 5m x 5m were established in each subplot (giving a total of 320 quadrats). A total of 1,294 live individuals from 74 tree species and 12 lianas were recorded, representing 61 genera in 27 families. *Guibourtia copallifera* has the highest dominance, followed by *Nesogordonia papaveriefera* (A. Chev.) Capuron ex N. Hallé., *Memecylon normandii* Jacq.-Fél. and *Gmelina arborea Roxb*. Species such as *Homalium africanum* (Hook. f.) Benth. *Lindackeria dentata* (Oliv.) Gilg, *Pentadesma butyracea* Sabine. and *Santiria trimera* (Oliv.) Aubrév. were recorded at low levels. Regarding family dominance, the Leguminosae - Caesalpiniaceae scores the highest, followed by Sterculiaceae, Euphorbiaceae, Melastomataceae and Verbenaceae. The density of regenerating individuals varied significantly between subplots based on the amount of degradation. The regeneration and spatial patterns of the species examined in this study exhibited clear relationships with disturbance intensity. Urgent action is needed to conserve this species, together with other ecologically and economically important tree species, before they are locally exterminated.

**Keywords:** Regeneration, Distribution, Management, Status, Density, Guibourtia

## 1. Introduction

The spatial distribution of trees is mainly a result of their dispersal processes and establishment patterns, although factors such as environmental changes, competition and chance events can also determine the distribution of trees. In the case of juveniles, their spatial arrangement results from a combination of seed dispersal modes, distribution of regeneration niches and seedling–sapling survival [1-3]. Patterns of forest regeneration following natural or anthropogenic disturbances are also determined by interactions between regimes of disturbance (intensity, frequency, scale, and type) and species biology, such as life history and behaviour [4, 5]. The density, composition of species and regeneration drive the future of the forest, which is in need of replacement. However, the forest can face several regeneration stressors, including invasive alien species, insects and diseases, herbivory, lack of appropriate management and climate change [6]. The patterns of regeneration are important because they will ultimately determine the floristic composition of the remnant [7]. The density value of seedling and saplings are considered an indicator of the regeneration potential of the species [8], in which the presence of good regeneration indicates the suitability of a species to the environment, although this can be affected by climatic factors and biotic interference [9].

Threat to forest reserves arises due to the need to provide for the food, fiber requirement and housing needs of an increasing population. A major threat in Sierra Leone is uncontrolled firewood and charcoal production to provide for the needs of the urban poor [10]. The sustainability of these resources depends on the conservation of other management techniques employed.

Sierra Leone is home to two species of trees from the genus *Guibourtia,* namely G. *copallifera* Benn. and G. *leonensis* J. Léonard. *G. leonensis* is the more widely distributed of the two, but neither is common, and knowledge of the distribution, density, population data, and threats regarding these species is deficient. *G. copallifera* Benn. is found in the Sudano-Zambezian and Sudano-Guinean zones of Africa. In West Africa, it is found in Senegal, Sierra Leone, Guinea, Mali, Côte d'Ivoire, Nigeria, Benin, Burkina Faso, Congo and the Democratic Republic of Congo in Central Africa [11]. It colonizes dry forests, Sudanian and Guinean riparian forests, rough slopes and the banks of streams [12]. In the 19th and early 20th Centuries, sap from *C. copallifera* was called Gum copal, and it was exported to Europe and America mostly as an ingredient for varnish. In the 1920's, demand was so great that the species was overexploited, resulting in the 1929 Government prohibition on its export [13–15]. In recent decades, the management of this species in its natural habitat has been largely neglected by the forestry authorities. As the timber is hard and mature trees are large, it was mostly ignored by charcoal burners until the introduction of power saws (chain saws). It is now specifically targeted as it produces high-quality charcoal, as demand for charcoal is on the increase in all urban centres. Regeneration patterns of forest patches in Sierra Leone, with particular regard to the Kasewe forest reserve, have not been thoroughly studied, and a better understanding of this topic and species may be helpful in assessing many other parameters of forest ecosystems.

Kasewe forest reserve faces many problems ranging from improper management, farming, harvesting of timber and charcoal burning, where these products represent the main sources of income for local people. These activities can alter the natural regeneration, tree species distributions and eventually, the natural dynamics of this reserve.

Long-term monitoring of the forest stands and species composition on a regular basis is useful to document the vegetation dynamics satisfactorily, which is a grey area in Sierra Leone. Hence population trends and the status of species cannot be predicted. Yet exploitation of these species is on the increase by communities. Moreover, the population of this species is small due to its restricted range and the increasing levels of anthropogenic pressures placed on it. These gaps need urgent attention if the conservation of the species should improve at the local level.

Therefore, this study aimed to investigate the distribution and regeneration status of *G. copallifera*. Specific objectives included identifying the national distributional range of the species and determining the density of seeds, seedlings and saplings of the species in relation to the land use pattern in the forest reserve.

# 2. Materials and Methods

## *2.1. Study Area*

The study was conducted in and around the Kasewe Forest Reserve, which borders the Tonkolili and Moyamba districts in the south-central portion of Sierra Leone. This lowland forest gives way to a medium-altitude forest on the slopes and peaks of the Kasewe hill ridges, which has an of up to 500m. Kasewe Forest Reserve has center GPS coordinates of 8°18′53″N and 12°15′43″W, it is approximately 2,331 ha in size [16]. The dominant vegetation is tropical forest, but the Reserve contains a mosaic of moist semi-deciduous forests, evergreen forests and savanna [16]. The hills are made up of volcanic intrusion, and its high elevation above the surrounding plains serves as an important water catchment area for all communities around the reserve [17, 18].

## *2.2. Species Distribution Sampling*

In gaining an in-depth knowledge of the species nationally, we reviewed the existing literature, including published journals, project documents, EIA (Environmental Impact Assessment) and botanical survey reports. These reports confirmed that the species had a very limited geographic range. So, a distributional survey was conducted in over 30 villages in the area around the Reserve (the furthest village from Kasewe is about 15 miles), where claims were made about the presence of this species. The survey was carried out during the first four months of the study, between January and April 2019, to determine the areas inhabited by the species. Claims of species presence in communities were also verified after the distributional survey. This was carried out through visits and enquiries, interviews and opportunistic surveys. In enquires and informal interviews, the following set of informants was targeted: community authorities, farmers, hunters, wood and pole harvesters, charcoal burners and sellers. In an opportunistic method, information about the presence of the species is gathered by chance or coincidence. Collected data from the various methods were collated so that the communities referred to could be located on the map, with each village visited to verify the presence of the species. In these communities, after the introduction and purpose of visits to the communities were made, informal interviews were conducted. Relevant questions included the presence of the species, its location, historical and traditional uses, threats to the species, and current uses of this species in their community. Informants were also questioned to determine their attitude towards this species and whether it had been utilized in the past, and if there are any present uses for the species. Locations or villages cited by informants were visited, and the presence of plants was confirmed through direct sightings. All verified locations were positioned by GPS and then mapped to illustrate the distributional range of this species. Photographs of the species were taken, and specimens were collected for later verification at the National

Herbarium of Sierra Leone located in the Department of Biological Sciences, Njala University.

### *2.3. Site Selection and Establishment of Transects*

A reconnaissance survey of the study area was undertaken in 2019, with basic information on the study site obtained and representative sampling sites identified. Four representative sampling sites were selected based on land use patterns and vegetation diversity. These sites were chosen because they represented the various human activities ongoing in the reserve, as well as areas of the reserve that remained protected or minimally impacted by human activity.

At each of the four sites, pairs of plots covering one hectare and measuring 500m x 20m were laid out 400 m apart. Each plot was subdivided into ten (10) subplots, each measuring 50m x 20m and giving a total of 80 subplots (each 50 m x 20 m). All woody species (trees, shrubs and lianas) were identified and documented. For the regeneration studies (Seeds, seedlings and saplings), four 5m x 5m quadrats were established within each subplot (giving a total of 320 quadrats).

### *2.4. Vegetation Sampling and Measurement*

For vegetation sampling and measurement, rectangular plots are chosen as they tend to include more of the within-plot heterogeneity and thus be more representative than square or circular plots of the same area [19]. Following the methods suggested by Gebrewahid et al.; Molla and Kewessa [20, 21], all trees ≥ 10 cm DBH (diameter at breast height) were identified and recorded. For species with buttresses or stilt roots like *G. copallifera*, DBH was taken above the top of the buttresses or stilt roots. Plant species presence/absence, coverage, density, abundance and height were estimated in each plot and sub-plot. Nested within each subplot, 5 m x 5 m quadrats were inventoried for saplings and seedlings by counting and recording the species. In the quadrats, seeds of all species were collected and counted, and those of *G. copallifera were* separated out. For this study, large trees are defined as those with a DBH >25 cm, small poles with DBH of 5-25cm, saplings DBH 2-5cm and seedlings were those with DBH < 2cm [22]. In each of the quadrats, seeds, seedling and sapling identification and the count were made to determine the composition of the subplot and sites.

### *2.5. Plant Identification*

Collected plants were authenticated at the National Herbarium of Sierra Leone located in the Department of Biological Sciences, Njala University, where voucher specimens were deposited. The conservation status of the collected plants was verified according to the International Union for Conservation of Nature (IUCN).

### *2.6. Statistical Analysis*

The majority of the analyses were done in R version 3.6.2 (R Core 2020). In order to determine the assemblages/communities that exist in such a collection of data, multi-dimensional scaling (MDS) using the cmdscale package in R was used to visualize the relationship between plants. The plot level data involving the average value of DBH, seeds, seedlings and saplings were calculated by averaging or totaling the individuals in the plot. The frequencies of tree size (DBH), seed, seedling and sapling are presented in histograms with median values for the four sites. The regeneration of *G. copallifera* was analyzed using a graphical representation of seedling, sapling, and tree frequencies in histograms. The average values of DBH, seed numbers, seedling numbers, tree numbers, and sapling numbers were compared for the sites. The species and family importance values were calculated. The SIV (Importance value Index) was calculated for all species by summing Relative frequency, Relative density and Relative dominance, each expressed as a percentage leading the IVI to have a value between 0 and 300. While the FIV is calculated by summing_Relative Dominance (RDo)+ Relative Density (RD) +Relative Diversity (RDi) [23, 24].

## 3. Results

### *3.1. Social Data of Respondents*

The "typical" respondent is therefore a married Muslim male of early adulthood (18-30 years) with relatively little formal education (none or primary school) who was born in the area and is most likely to be a farmer or charcoal burner (Table 1 and Figure 1).

***Table 1.*** *Social characteristics of respondents.*

| Respondents Status | Variables | Frequency | % Frequency |
|---|---|---|---|
| *Sex of respondents* | Male | 396 | 56.57 |
| | Female | 304 | 43.43 |
| | Total | 700 | 100.00 |
| *Religion of respondents* | Muslim | 474 | 67.71 |
| | Christian | 226 | 32.29 |
| | Total | 700 | 100.00 |
| *Marital status of respondents* | Single | 195 | 27.86 |
| | Married | 315 | 45.00 |
| | Engaged | 58 | 8.29 |
| | Widowed/Widower | 72 | 10.29 |
| | Co-habitant | 60 | 8.57 |
| | Total | 700 | 100.00 |

| Respondents Status | Variables | Frequency | % Frequency |
|---|---|---|---|
| *Occupation of respondents* | Local authorities | 41 | 5.87 |
| | Hunters | 63 | 9.00 |
| | Farmer | 120 | 17.14 |
| | Wood harvesters | 95 | 13.57 |
| | Pole harvesters | 78 | 11.14 |
| | Charcoal burners | 162 | 23.14 |
| | Charcoal sellers | 106 | 15.14 |
| | Teacher | 35 | 5.00 |
| | Total | 700 | 100.00 |
| *Level of education of respondents* | Primary | 230 | 32.86 |
| | Secondary | 73 | 10.43 |
| | Tertiary | 21 | 3.00 |
| | Informal | 51 | 7.29 |
| | Illiterate | 325 | 46.43 |
| | Total | 700 | 100.01 |
| *Age category of respondents* | 18 – 30 | 384 | 54.86 |
| | 30 - 50 | 245 | 35.00 |
| | 50 above | 71 | 10.14 |
| | Total | 700 | 100.00 |
| *Ethnic group of respondents* | Mende | 407 | 58.14 |
| | Temne | 235 | 33.57 |
| | Limba | 58 | 8.29 |
| | Total | 700 | 100.00 |
| *Origin of respondents* | Indigenes | 524 | 74.86 |
| | Migrants | 176 | 25.14 |
| | Total | 700 | 100.00 |

### *3.2. Frequency of Respondents in the Districts*

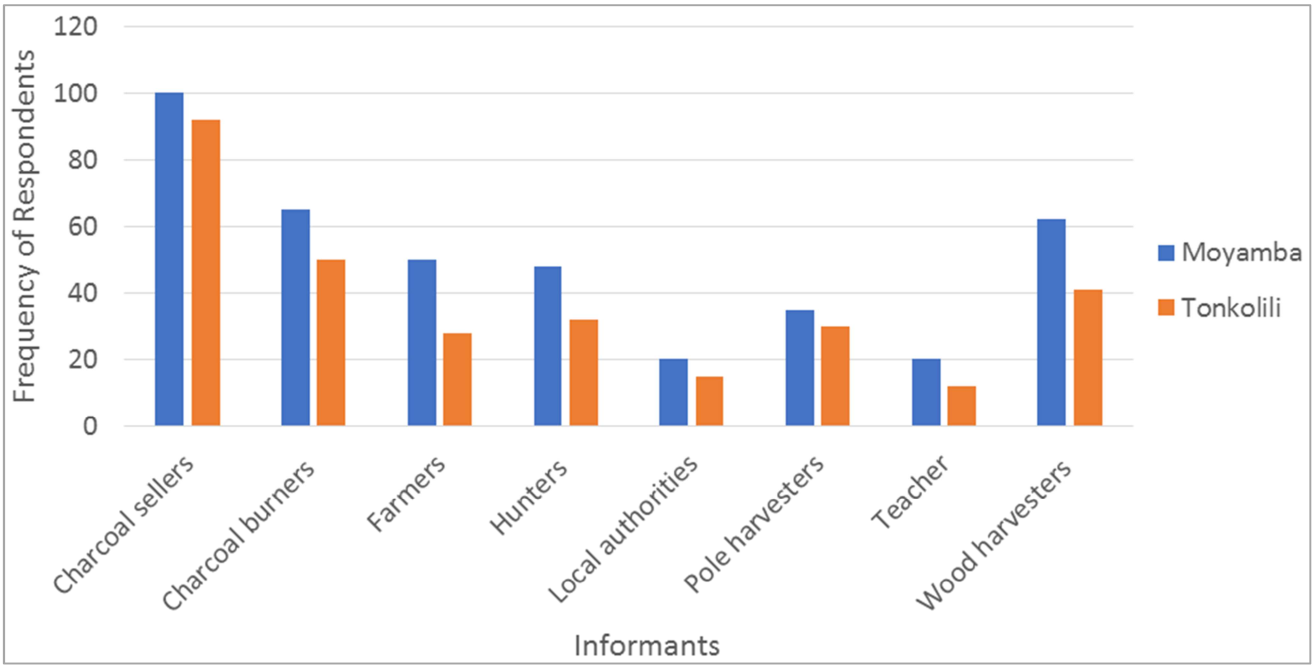


***Figure 1.*** *Informant frequency across the districts.*

Moyamba District had more respondents than Tonkolili District, which accounts for 57.14% of the total number of respondents. In all of the various informants interviewed, Tonkolili District registered the least numbers, but charcoal sellers were in the highest, followed by charcoal burners and teachers the least. It was observed from the data that gender variations exist in terms of participation, with Tonkolili District having more female (26%) respondents than in the Moyamba District (17.14%), while 22.57% males responded in Tonkolili District and 34% male responded in the Moyamba District.

### *3.3. Distributional Range of G. copallifera in Sierra Leone*

From Figure 2, it is clear that the species is recorded in only 5 of over 100 Chiefdoms in the country and two of the 18 districts (Tonkolili and Moyamba). In the mid-20th Century, it was planted along road sides in towns in the south and east, notably Kenema, Blama and Mano. These have, however, been harvested for charcoal, with a few plantings in three smaller towns that have survived but are not regenerating. Kaiyamba (Moyamba town) and Dasse (Mano town) have a few remaining roadside trees but the majority having been harvested for charcoal, at Taiama town (Kori chiefdom), with a small area of less than 1 acre under further threat of being harvested for charcoal production.

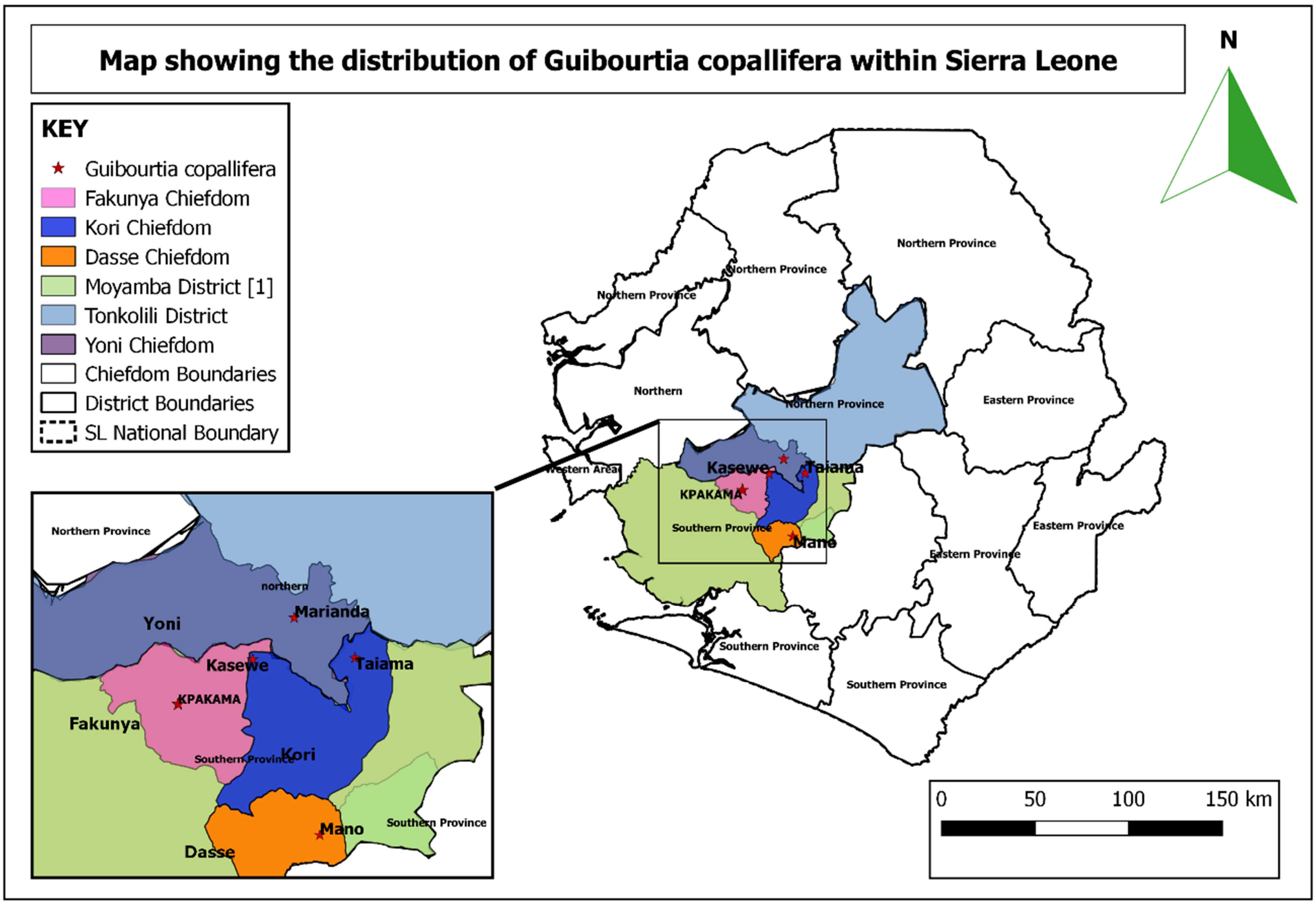


*Figure 2. Locations within Moyamba and Tonkolili Districts where G. copallifera has been reported.*

*G. copallifera* has been recorded in five chiefdoms; Kori, Fakunya, Kaiyamba and Dasse in Moyamba District and the adjacent Yoni chiefdom in Tonkolili District. Regarding the population density of the species, Kori holds the largest population density (Kasewe Forest Reserve), followed by Yoni (Marianda village) and Fakunya (Gbanba village).

### *3.4. Vegetation Communities*

A total of 1,294 individual trees distributed across 74 species were recorded within the 4 ha plots, representing 61 genera in 27 families, exclusive of 12 lianas and some dead stems, which were unidentified. It is difficult to manually determine what persistent mixtures ("assemblages", "communities") exist in such a collection of data; MDS (multi-dimensional scaling) using the cmdscale package in R was used to visualize the relationship between plants. Some species are regularly found together at similar levels of abundance, forming positive associations, e.g., *Carapa procera* DC. with *Homalium letestui* Pellegr; *Blighia sapida* König with *Anisophyllea laurina* R Br. or *Bridelia micrantha* (Hochst.), *Fagara macrophylla* Engl. *and Entandorgphragma cylindricum* (Sprague) Sprague. Species appearing near the edges of the Dendrogram tend to be infrequent, e.g., *Afzelia africana, Ficus mucuso, Pterocarpus santalinioides,* and *Albizia zygia* (Figure 3).

*Guibourtia copallifera* has the highest SIV (112.16), followed by *Nesogordonia papaveriefera* (32.9), *Memecylon normandii* (24.7) and *Gmelina arborea* (6.3). Some species such as; *Homalium africanum, Lindackeria dentata,* and *Bersama abyssinica* recorded SIV of less than 1. A total of 27 families were encountered in the plots. Taxonomically well represented families are; Leguminosae-Caesalpiniaceae (9 species), Euphorbiaceae (8), Annonaceae (6) and Sterculiaceae, Guttiferae and Rubiaceae, each with four species, with sixteen families represented by a single species.

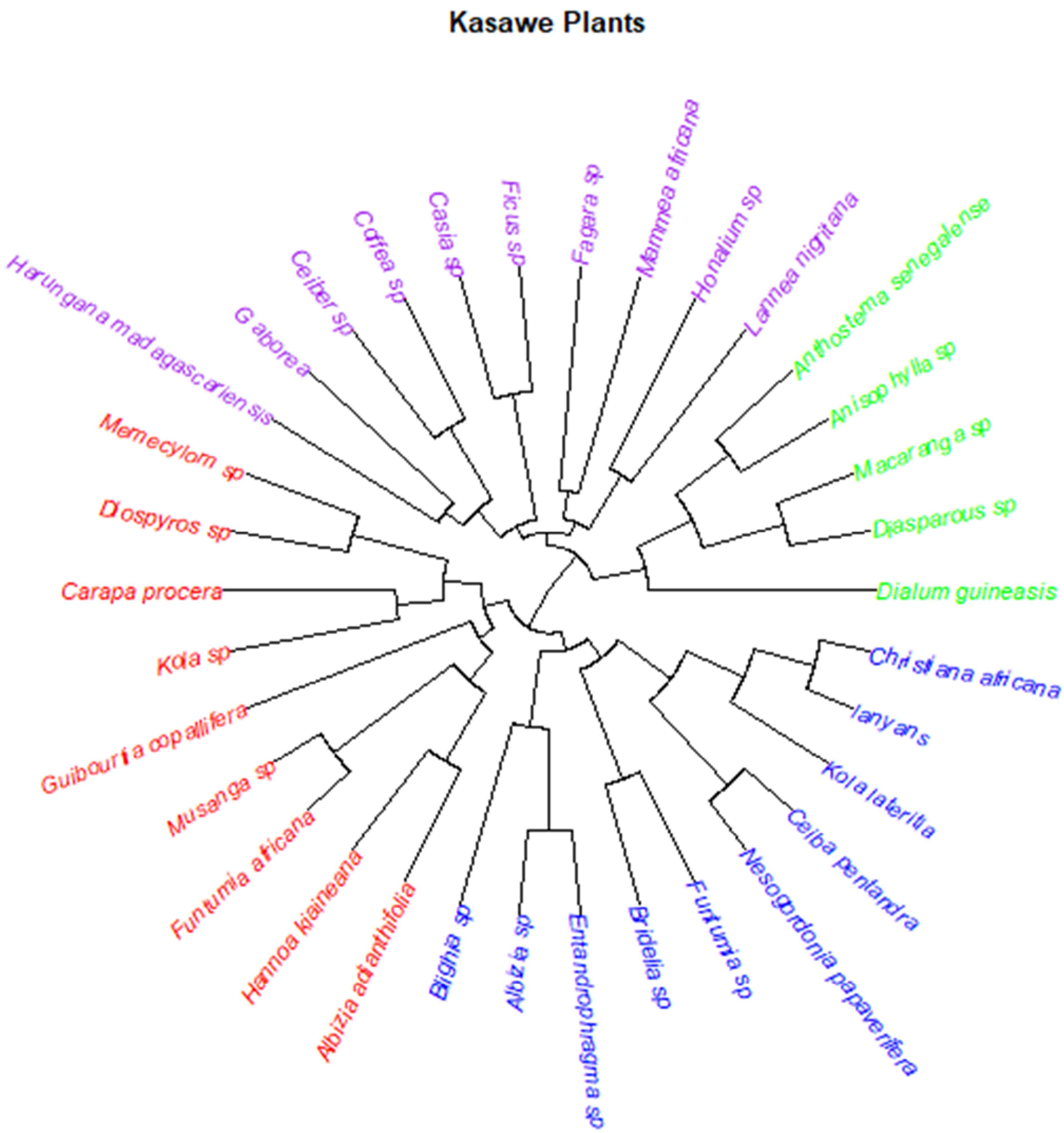


***Figure 3.*** *Dendrogram of species associations by site.*

### *3.5. Distribution of DBH Classes*

The distribution of dbh classes indicates that the reserve has relatively many smaller stems in the less degraded patches than in the degraded areas. This demonstrates regeneration in less disturbed areas and that a few large trees remain in the degraded areas, perhaps being too difficult to fell by hand or of species with little value (Figure 4). Selective logging in the less disturbed areas may also reduce the number of stems in the larger size classes. However, the largest size classes (greater than 341 cm dbh) are only recorded (in very small numbers) in the patches with little or no human interference. The presence of buttress roots was not consistent within species. The majority of the buttress trees were of the stilt–buttress type (i.e., with at least some of the roots arching from the tree, leaving a gap beneath). There was an obvious increase in buttressing with increasing tree diameter, with few buttressed trees less than 40 cm DBH. Species which regularly produce buttresses or stilt roots include; *Guibourtia copallifera, Uapaca guineensis, Amphimas pterocarpoides, Antiiaris africana, Musanga cecropioides*.

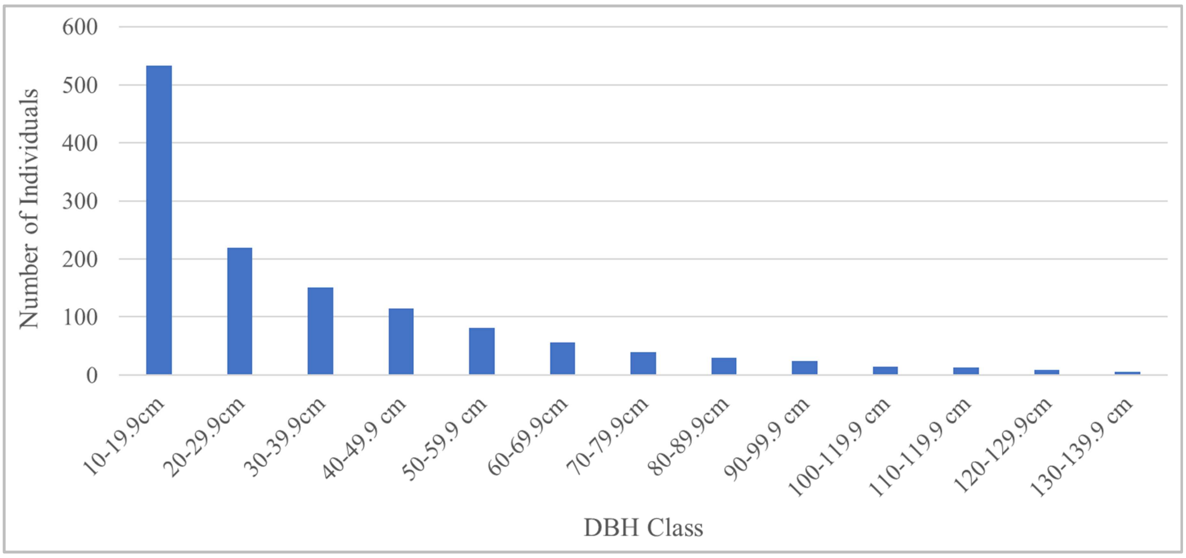


***Figure 4.*** *DBH distribution of the trees in the Forest.*

***Table 2.*** *Species Importance Value Index.*

| Species | R. frequency | R. Density | R. dominance | R. Abundance | S I V I |
|---|---|---|---|---|---|
| *Guibourtia copallifera* Benn. | 6.93 | 25.45 | 79.78 | 8.46 | 112.16 |
| *Nesogordonia papaveriefera* (A.Chev.) Capuron ex N.Hallé. | 6.37 | 16.51 | 10 | 5.93 | 32.88 |
| *Memecylon normandii* Jacq.-Fél. | 5.99 | 12.05 | 6.63 | 4.63 | 24.67 |
| *Gmelina arborea* Roxb. | 1.5 | 3.88 | 0.97 | 5.96 | 6.35 |
| *Diospyros heudelotii* Hiern | 4.12 | 2 | 0.11 | 1.12 | 6.23 |
| *Anisophyllea laurina* R Br. | 4.12 | 1.77 | 0.2 | 0.99 | 6.09 |
| *Parinari excelsa* Sabine | 3.18 | 2.42 | 0.22 | 1.75 | 5.82 |
| *Amphimas pterocarpoides* Harms | 3 | 1.73 | 0.12 | 1.33 | 4.85 |
| *Tabernaemontana crassa* Benth. | 2.25 | 2.18 | 0.17 | 2.24 | 4.6 |
| *Milicia excelsa* (Welw.) C.C. Berg | 2.44 | 1.94 | 0.18 | 1.84 | 4.56 |
| *Trema guineensis* (Schumach. & Thonn.) Ficalho. | 1.31 | 2.87 | 0.15 | 5.05 | 4.33 |
| *Phyllocosmus africanus* (Hook.f.) Klotzsch | 2.81 | 1.28 | 0.05 | 1.05 | 4.14 |
| *Fagara macrophylla* (Oliv.) Engl. | 2.06 | 1.59 | 0.27 | 1.78 | 3.92 |
| *Margaritaria discoideus* (Baill.) G.L. Webster | 2.62 | 1.07 | 0.05 | 0.94 | 3.74 |
| *Dialium guineense* Willd. | 2.25 | 0.8 | 0.02 | 0.82 | 3.07 |
| *Baphia nitida* G.Lodd. | 1.69 | 1.28 | 0.09 | 1.75 | 3.06 |
| *Spathodea campanulate* P.Beauv. | 1.69 | 1.18 | 0.08 | 1.61 | 2.95 |
| *Afzelia africana* Sm. ex Pers. | 1.69 | 1.21 | 0 | 1.66 | 2.9 |
| *Ceiba pentandra* L. Gaertn. | 2.25 | 0.55 | 0.04 | 0.57 | 2.84 |
| *Blighia unijugata* Baker. | 1.69 | 1.07 | 0.04 | 1.47 | 2.8 |
| *Daniella thurifrea* Benn. | 1.31 | 1 | 0.05 | 1.76 | 2.36 |
| *Pycnanthus angolensis* (Welw.) Warb. | 1.5 | 0.73 | 0.04 | 1.12 | 2.27 |
| *Christiana africana* DC | 1.5 | 0.66 | 0.06 | 1.01 | 2.22 |
| *Xylopia acutiflora* (Dunal) A.Rich. | 1.69 | 0.45 | 0.04 | 0.61 | 2.18 |
| *Carapa procera* DC. | 1.5 | 0.55 | 0.01 | 0.85 | 2.06 |
| *Harungana madagascarisensis* Lam. ex Poir. | 1.31 | 0.69 | 0.02 | 1.22 | 2.02 |
| *Vitex micrantha* Gürke | 1.5 | 0.45 | 0.03 | 0.69 | 1.98 |
| *Cola lateritia* K Schum. | 1.5 | 0.45 | 0.02 | 0.69 | 1.97 |
| *Lannea nigritana* (Scott-Elliot) Keay | 1.12 | 0.59 | 0.04 | 1.21 | 1.75 |
| *Mareya micrantha* (Benth.) Müll.Arg. | 1.12 | 0.62 | 0.01 | 1.28 | 1.75 |
| *Garcinia cola* Heckel | 1.12 | 0.55 | 0.06 | 1.14 | 1.73 |
| *Hannoa klaineana* Pierre ex Engl. | 1.31 | 0.35 | 0 | 0.43 | 1.66 |
| *Sterculia tragacantha* Lindley | 1.12 | 0.49 | 0.02 | 0.99 | 1.63 |
| *Mammea africana* Sabine | 0.94 | 0.66 | 0.01 | 1.62 | 1.61 |
| *Oxyanthus speciosus* DC. | 0.94 | 0.59 | 0.01 | 1.45 | 1.54 |
| *Strombosia glaucescens* Engl. | 0.75 | 0.62 | 0.02 | 1.92 | 1.39 |
| *Landolphia micrantha* (A.Chev.) Pichon. | 0.75 | 0.62 | 0.01 | 1.92 | 1.38 |
| *Berlinia confuse* Hoyle | 0.94 | 0.42 | 0 | 1.02 | 1.36 |
| *Uapaca guineensis* Müll. Arg. | 0.94 | 0.31 | 0.02 | 0.77 | 1.27 |
| *Anthostema senegalenses* A.Juss. | 0.75 | 0.38 | 0.02 | 1.09 | 1.15 |
| *Nauclea diderrichii* De Wild. & Th.Dur.) Merrill | 0.75 | 0.35 | 0.01 | 1.06 | 1.11 |
| *Musanga cecropoides* R.Br. | 0.75 | 0.31 | 0.01 | 0.96 | 1.07 |

| Species | R. frequency | R. Density | R. dominance | R. Abundance | S I V I |
|---|---|---|---|---|---|
| *Xylopia aethiopica* (Dunal) A. Rich. | 0.75 | 0.28 | 0 | 0.85 | 1.03 |
| *Entandorgphragma cylindricum* (Sprague) Sprague. | 0.65 | 0.35 | 0.02 | 1.42 | 1.02 |
| *Macaranga barteri* Müll. Arg. | 0.65 | 0.35 | 0.01 | 1.42 | 1.01 |
| *Diospyros thomasii* Hutch & Dalz. | 0.65 | 0.21 | 0 | 0.85 | 0.86 |
| *Ficus mucuso* Welw. ex Ficalho | 0.65 | 0.21 | 0 | 0.85 | 0.86 |
| *Funtumia africana* (Benth.) Stapf | 0.65 | 0.14 | 0.01 | 0.57 | 0.8 |
| *Albizia adianthifolia* (Schum.) W Wight | 0.65 | 0.1 | 0.01 | 0.43 | 0.76 |
| *Cassia sieberiana* DC. | 0.56 | 0.17 | 0 | 0.71 | 0.73 |
| *Morinda germinate* DC. | 0.38 | 0.24 | 0 | 1.49 | 0.62 |
| *Hymenocardia lyrate* Tul. | 0.38 | 0.17 | 0 | 1.06 | 0.55 |
| *Napoleona heudelotti* A.Juss. | 0.38 | 0.17 | 0 | 1.06 | 0.55 |
| *Terminalia ivorensis* A. Chev. | 0.38 | 0.17 | 0 | 1.06 | 0.55 |
| *Didelotia afzelii* Taub. | 0.38 | 0.14 | 0 | 0.85 | 0.52 |
| *Pterocarpus santalinioides* L' Herit | 0.38 | 0.14 | 0 | 0.85 | 0.52 |
| *Albizia zygia* (D.C.) Macbr | 0.38 | 0.07 | 0 | 0.43 | 0.45 |
| *Cola chlamydantha* K. Schum. | 0.38 | 0.07 | 0 | 0.43 | 0.45 |
| *Rauvolfia vomitoria* Afzel. | 0.38 | 0.07 | 0 | 0.43 | 0.45 |
| *Voacanga africana* Stapf | 0.38 | 0.07 | 0 | 0.43 | 0.45 |
| *Terminalia superba* Engl. & Diels | 0.19 | 0.17 | 0 | 2.13 | 0.36 |
| *Uvaria chamae* P. Beauv. | 0.19 | 0.07 | 0 | 0.85 | 0.26 |
| *Bersama abyssinica* Fresen. | 0.19 | 0.04 | 0 | 0.43 | 0.23 |
| *Blighia sapida* König | 0.19 | 0.04 | 0 | 0.43 | 0.23 |
| *Bridelia grandis* Pierre ex Hutch. | 0.19 | 0.04 | 0 | 0.43 | 0.23 |
| *Bridelia micrantha* Hochst. Baill. | 0.19 | 0.04 | 0 | 0.43 | 0.23 |
| *Didelotia idea* De Wit. & Leon. | 0.19 | 0.04 | 0 | 0.43 | 0.23 |
| *Fiscus sur* Forssk. | 0.19 | 0.04 | 0 | 0.43 | 0.23 |
| *Homalium africanum* (Hook. f.) Benth | 0.19 | 0.04 | 0 | 0.43 | 0.23 |
| *Khaya anthotheca* C.DC. | 0.19 | 0.04 | 0 | 0.43 | 0.23 |
| *Lindackeria dentata* (Oliv.) Gilg | 0.19 | 0.04 | 0 | 0.43 | 0.23 |
| *Pentadesma butyracea* Sabine. | 0.19 | 0.04 | 0 | 0.43 | 0.23 |
| *Santiria trimera* (Oliv.) Aubrév. | 0.19 | 0.04 | 0 | 0.43 | 0.23 |

***Table 3.*** *Familial Importance Value for Plant Families.*

| Family | No. of species | FIVI |
|---|---|---|
| Leguminosae Caesalpiniaceae | 9 | 125.28 |
| Sterculiaceae | 4 | 36.93 |
| Melastomataceae | 1 | 24.67 |
| Euphorbiaceae | 8 | 12.92 |
| Apocynaceae | 6 | 8.83 |
| Leguminosae Papilionaceae | 3 | 8.43 |
| Verbenaceae | 2 | 8.33 |
| Ebenaceae | 2 | 7.09 |
| Rhizophoraceae | 1 | 6.09 |
| Chrysobalanaceae | 1 | 5.82 |
| Moraceae | 3 | 5.65 |
| Guttiferae | 4 | 5.59 |
| Ixonanthaceae | 1 | 4.84 |
| Rubiaceae | 4 | 4.67 |
| Ulmaceae | 1 | 4.33 |
| Rutaceae | 1 | 3.92 |
| Annonaceae | 3 | 3.47 |
| Meliaceae | 3 | 3.31 |
| Sapindaceae | 2 | 3.03 |
| Bombacaceae | 1 | 2.84 |
| Myristicaceae | 1 | 2.27 |
| Tiliaceae | 1 | 2.22 |
| Anacardiaceae | 1 | 1.75 |
| Simbarounceae | 1 | 1.66 |
| Olacaceae | 1 | 1.39 |
| Leguminosae Mimosaceae | 2 | 1.21 |
| Cecropiaceae | 1 | 1.07 |
| Combretaceae | 2 | 0.91 |
| Lecythidaceae | 1 | 0.55 |
| Flacourtiaceae | 2 | 0.46 |
| Burseraceae | 1 | 0.23 |
| Melianthaceae | 1 | 0.23 |

### *3.6. Regenerating Capacity of the Species and Sites*

Large-size trees were fewer in all of the degraded sites, particularly in sites 1 and 2, while there were many in the non-degraded patches. The density of regenerating individuals (including seeds, seedlings and saplings) was very low across the degraded sites. More seeds, seedlings and saplings were recorded from the undegraded sites compared to degraded sites. It is also evident that all the sites have sapling height classes between 2 and 4 m, but exceptionally tall saplings were recorded in the non-degraded sites. Average sapling height was lower in degraded (2.9 m) compared to undegraded sites (4.2 m), with significant variations (Kruskal-Wallis $\chi 2 = 28.75$, df = 2, $p < 0.001$).

### *3.7. Seed Count on the Forest Floor*

A total of 80,781,310 Seeds were recorded from the forest floor, representing 65 genera and 46 families. *G. copallifera* made up 85.6% of the seeds collected from the forest floor, while the rest is a combination of various other species (Table 4 and figure 5).

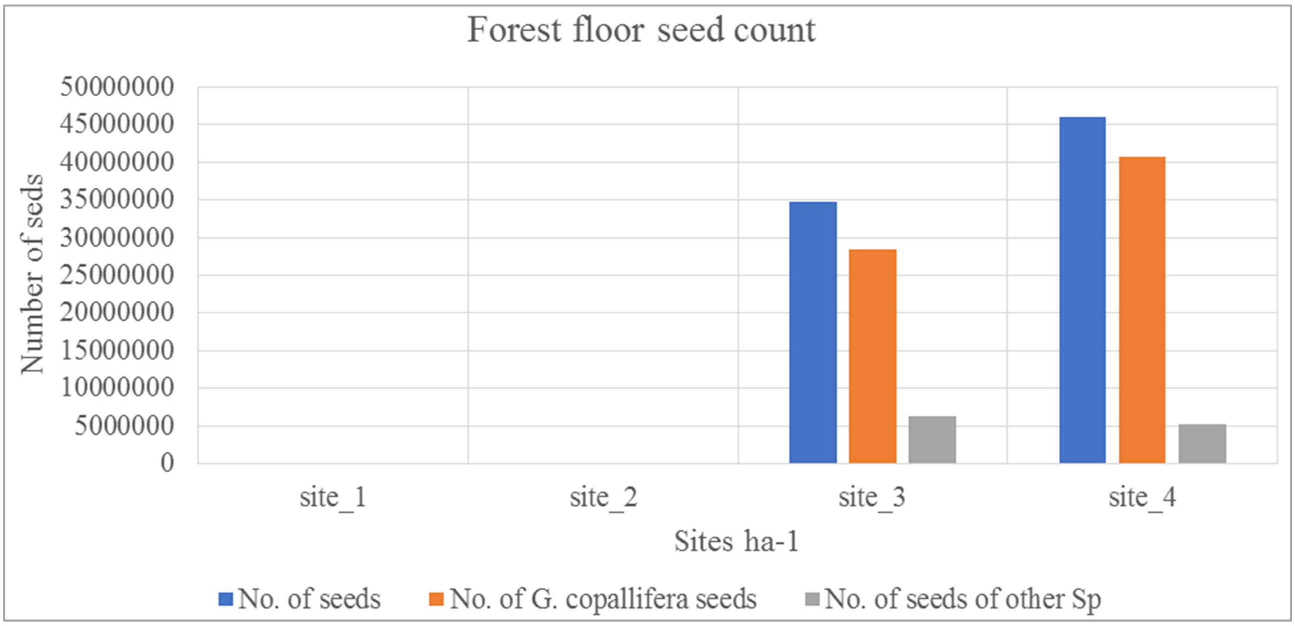


***Figure 5.*** *Seed numbers found on the forest floor.*

***Table 4.*** *Plant seeds recorded on the forest floor.*

| Site | No. of seeds per ha$^{-1}$ | No. of *G. copallifera* seeds per ha-1 | No. of seeds of other species per ha-1 |
|---|---|---|---|
| site_1 | 3,250 | 1,474 | 1,776 |
| site_2 | 4,293 | 1,690 | 2,603 |
| site_3 | 34,789,315 | 28,463,874 | 6,325,441 |
| site_4 | 45,984,452 | 40,678,345 | 5,306,107 |

Seed count on the forest floor of the sampling sites indicates low numbers on the disturbed sites (1 and 2) and much higher numbers on the less disturbed sites 3 and 4 (Table 4 and figure 5).

### *3.8. Seedling Survey of the Sites*

Across the 320 seedling plots established at four sites, we recorded 67,269,884 seedlings representing 71 genera and 52 families (Table 5 and figure 6). *G. copallifera* seedlings comprised over a third of the total (59,985, 645 / 89.17%). *G. copallifera* was dominant on sites 3 and 4, but less on sites 1 and 2, where other species like *Tabernaemontana crassa, Bridelia grandis, Terminalia ivorensis, Carapa procera, Gmelina arborea, Cassia sieberiana, Strombosia glaucescens, Ceiba pentandra, Funtumia africana*, *Bridelia micrantha, Garcinia cola, Combretum grandiflorum*, *Pennisetum purpureum, Ctenium newtonii* and_*Chromolaena odorata* were recorded (Table 5 and figure 6).

***Table 5.*** *Number of seedlings recorded.*

| Sites | No. of Seedlings per ha-1 | No. of G. copallifera per ha-1 | No. of other species per ha-1 |
|---|---|---|---|
| Site_1 | 5,621 | 1,352 | 4,269 |
| Site_2 | 5,376 | 1,195 | 4,181 |
| Site_3 | 30,677,324 | 27,841,675 | 2,835,649 |
| Site_4 | 36,581,563 | 32.141,423 | 4,440,140 |

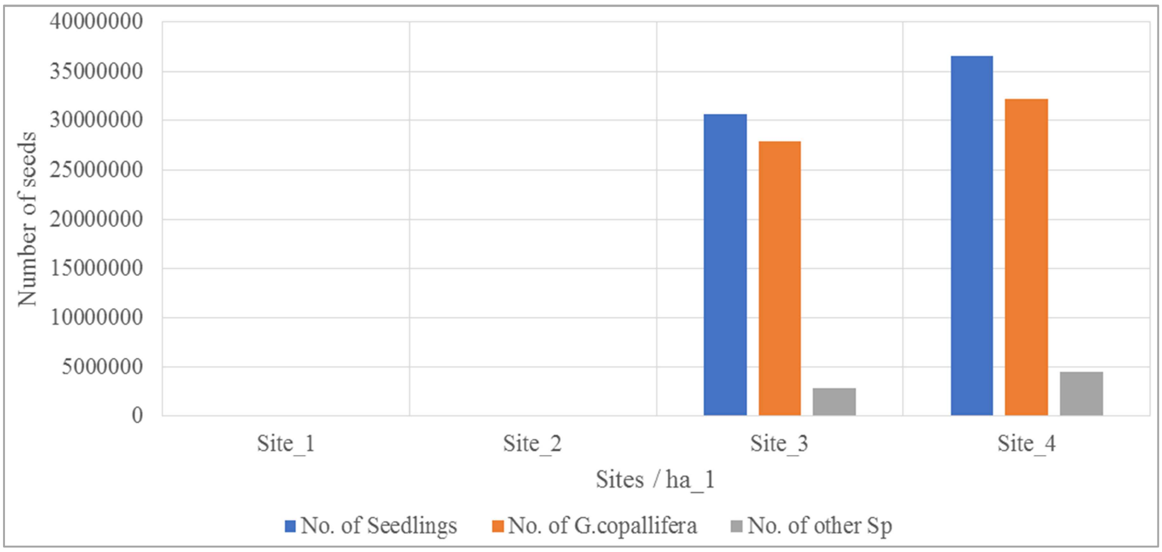


***Figure 6.*** *Seedlings recorded in the four sites.*

### *3.9. Sapling Survey of the Sites*

A total of 46,258,858 individual saplings representing 60 genera and 42 families were recorded. Saplings were highest at the less disturbed sites 3 and 4 (Table 6). *G. copallifera* accounted for well over a third of saplings (79.35%; 36,704,394). This trend is expected because *G. copallifera* is about one-fourth of the seedlings (89.17%), but it did constitute nearly two-thirds of the seeds (61%), indicating lower-than-average germination (Table 6 and Figure 7).

***Table 6.*** *Number of Saplings in each site.*

| Sites | No. of Saplings per ha-1 | No. of G. copallifera per ha-1 | No. of other species per ha-1 |
|---|---|---|---|
| Site_1 | 4,588 | 1,843 | 2,745 |
| Site_2 | 5,689 | 2,361 | 3,328 |
| Site_3 | 20,457,228 | 16,857,491 | 3,599,737 |
| Site_4 | 25,791,353 | 19,842,699 | 5,948,654 |

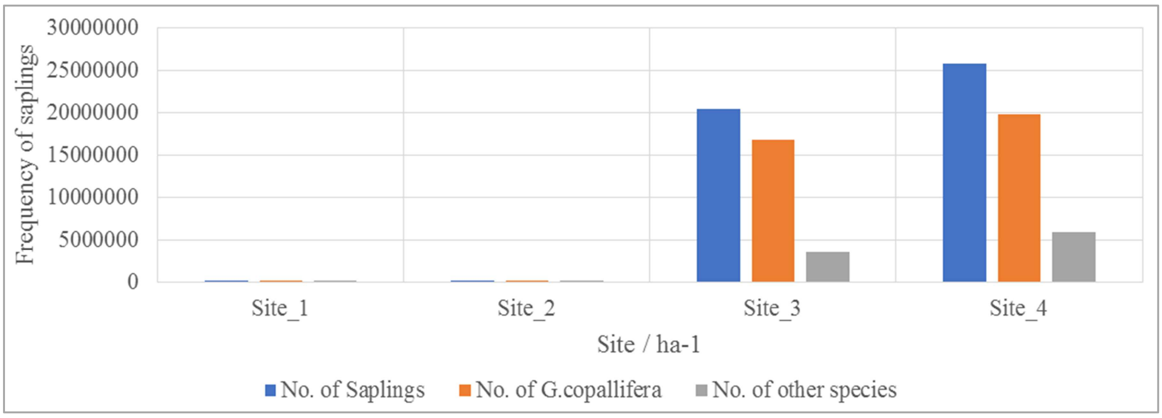


***Figure 7.*** *Number of saplings recorded.*

### *3.10. Tree Fall Gaps / Natural Disturbance Regime in the Site*

In total, 269 gap makers (fallen trees) are recorded in the plots; 41% and 37% of gap makers are in the 1st, and the 2nd degree of decomposition, whilst the rest are in the 3rd and 4th degree of decomposition. Large ratios of gap makers with a low degree of decomposition can be considered as additional evidence that the majority of gaps have originated in the more recent past. The most frequent species among gap makers are *G. copallifera* and *X. aethiopica*. Taking into account only the numbers of identified gap makers, the proportion of *G. copallifera* in the past species composition is approximately 50%, and the proportion of *X. aethiopica* is approximately 25%.

The numbers of trees in a single gap (gap makers) range from 1 to 5, accounting on average for seven trees. Almost 50% of gaps originated from the fall of fewer than five trees approximately one-third of gaps were created by one or four trees falling down. Based on the field survey and mapping of the study area, we identified 68 gaps, representing, on average, 16 gaps per hectare. Almost 40% of the sampling area is covered by gaps (open canopy gaps—62.8%, and expanded gaps—37.2%). These were mostly recorded in the non-degraded areas of the reserve, with limited numbers in the degraded areas of the reserve.

# 4. Discussion

### *4.1. Current Distribution of G. copallifera*

The most comprehensive guide to the economic trees of Sierra Leone remains by Savill and Fox [13], which described the natural habitat of this tree as; "well-drained rocky ridges or flat land overlying lateritic pan". *G. copallifera* is indigenous to Sierra Leone, from Kasewe westwards. During the early 1920s, the Forestry Department made a number of plantations at Blama, Kenema, Mano and elsewhere, as, at that time, the demand for copal was great, with demand for it making the establishment of roadside tree plantations at Moyamba and Kenema necessary.

Historically, Kobo grew naturally across a few chiefdoms in only one district in Sierra Leone. However, the current distribution has changed from the historic areas in terms of densities. The distribution of the species, as recorded in the historical records, floras, herbarium specimens and government reports, was limited to Moyamba town, Taiama, Mano, Blama town, Kenema town, and Moyamba. When compared to the distribution of current remnant populations of the species, it is now recorded (sighted) in Yoni in Tonkolili District (one village) and several villages in Moyamba District.

Taiama and Mano have fewer trees remaining on what used to be plantation sites, with the remaining trees largely used for charcoal making. Plantations in Blama and the environs of Kenema are no longer in existence. Despite the fact that the species was recorded in the district of Tonkolili, which seems like an extension of its original range, its population density is under serious threat. In all of the sightings observed in various communities, it is used for charcoal production irrespective of its density and population growth trends. Overexploitation of this species for charcoal production is on the increase in every community where it was recorded.

### *4.2. Vegetation Communities*

The findings of the present study showed a more diverse species composition compared to other studies where between 38-64 tree species were recorded [25, 26]. However, other studies have recorded relatively higher numbers of tree species (between 86-163) in other parts of the globe than the present study [27, 28]. Moraceae was the dominant family (5 species) with naturally growing fruit species, like *Artocarpus chaplasha*, *Artocarpus lacucha*, *Ficus hispida*, *Ficus pyriformis*, and *Ficus racemosa*. Leguminosae was the most dominant plant family due to the phenomenal dispersal of their seeds and pollen grains by wind, water, birds, mammals, and humans. Comparable investigations by Semenya and Maroyi [29] recorded the highest number of species from the family Leguminosae, followed by Moraceae and Myrtaceae. Furthermore, Komolafe and Ige [30] reported that Leguminosae contains a higher number of species than Bignoniaceae, followed by Moraceae, Sapindaceae, and Myrtaceae. Also, Gnoumou et al., [31] reported that the two kinds of areas studied had just *G. copallifera* as a common species, and it was the main species with the highest SIV recorded in both the protected and unprotected area.

### *4.3. Population Density*

There are striking variations between the densities of seeds, seedlings and saplings of the species in the study area. For certain species, it was difficult to register seedlings and saplings even with the presence of mature plants (*G. kola* and *C. acuminata)* in the sampling sites. The seed density of *G. copallifera* was extremely high compared to the density of other species due to the fact that it was in its fruiting season at the time the study was conducted. The establishment, survival and growth of seedlings are governed by several biotic and abiotic factors [32]. The arrival of viable seeds in regeneration sites and the subsequent germination and establishment of seedlings are vital determinants of the efficacy of natural regeneration [33-35]. Similar studies on *G. americanus* found it to be a species with abundant regeneration and a large number of mature trees, which in turn can serve as seed sources. *G. americanus* is one of the most abundant species in Chacocente [36].

Brandt et al., [37] analyzed the impacts of experimental controls of vegetation cover on recruitment, mortality and density of seedlings (20-100 cm tall) and saplings (≥100 cm tall) of woody growth forms over a 2.5-year period. They noticed expanded first-year recruitment and density, as well as mortality of seedlings. Saplings experienced lower mortality and more delayed gap-enhanced recruitment and density than seedlings., The expulsion of understory vegetation significantly affected tree seedling and sapling elements [37].

Our study found that the overall pattern of natural regeneration of the *G. copallifera* is similar to the findings of studies done in the dry deciduous forests of Chacocente and Nandarola in Nicaragua for *G. americanus* [38, 39]. However, the density of recruits in our study was comparably lower than that reported by Archer et al. [40].

In terms of land use areas of the forest, it was observed that degraded areas bear less of *G. copallifera* and more of either exotic species or grasses. Non-degraded areas are observed to hold high densities of seedlings and saplings of *G. copallifera* than other species, whilst densities of seedlings and saplings of other species are high in the degraded areas with low density of *G. copallifera.*

It was also observed that some plots along transects were dominated by farm bushes, grasses, and farmed areas which might have a negative impact on the density of *G. copallifera* recruits due to competition. Human disturbance clearly has a negative effect on the potential for regeneration. Seed numbers in the degraded areas are observed to be so low that the regeneration ability of the species in this habitat could be compromised.

Farming is an ongoing activity in the reserve which actually affects the adult trees and the juveniles of this species through the use of fire. The low density of seeds, seedlings and saplings of the species studied in the degraded areas of the reserve might also be attributed to uncontrolled fires, which are regular occurrences and the use of fire in charcoal production within the reserve, particularly during the dry season. Sabogal and Valerio [38] observed a very low density of seedlings and saplings of *G. americanus* in the Chacocente dry forest and attributed that to uncontrolled fires and grazing or browsing, particularly during the dry season.

Young seedlings of *G. copallifera* are vulnerable to several biotic and abiotic factors. Predation, herbivory and pathogens are the major biotic factors that affect seedling survival and seedling population densities [41, 42]. Among the abiotic factors, heavy rains and runoffs add to the causes of seedling mortality in reserve, as well as tree falls and natural disturbances. Similar research undertaken by Ray and Brown [43] and others [44, 45] made similar assertions. Seeds and seedlings are also killed by low-intensity ground fires [46] and physical damage from litter falls [47], although this is also variable among species [48].

### *4.4. Spatial Pattern*

The density of recruits varied considerably in relation to exposure to direct sunlight, human interventions and natural disturbances. For instance, the density of *G. copallifera* seedlings and saplings that were partially or fully exposed to direct sunlight was much lower than for fully shaded areas of the reserve. On the other hand, the density of *G. copallifera* seedlings and saplings was much higher in full shade. González-Rivas et al., [49] recorded lower numbers of seedlings and saplings for *G. americanus* in studies done in the dry forest of the Chacocente National Wildlife Refuge in the province of Carazo, Nicaragua. NdangalasiI et al., [50] recorded a total of 2800 seedling recruits, and there were 38 and 47 species represented under exotic and native legacy trees, respectively. Gnoumou et al., [31] examined the variety and the elements of *G. copallifera* communities in two distinct kinds of land use history, a protected area (forest of Comoé-Leraba) and an unprotected area (the forests of Tourni and Timba). In the two distinct kinds of land use, the threats of *G. copallifera* communities were great, and the varieties were comparable and low with high β variety [31].

Oluwole and Okusanya [51] did ecological assessments on the seedling improvement of the African walnut, *Tetracarpidium conophorum*. They saw that seedlings addressed the effect of full daylight and shade in a comparative manner to the extent that all credits were assessed. There was altogether better improvement under the drenched soil condition than in the dry condition [51]. The level of human use of the land reduces the density of the recruits in the areas. Sites that were under intense human activities recorded the least number of recruits and adult trees. Plots that coincided with farmed areas and charcoal production activities were devoid of *G. copallifera* recruits since most of these areas experienced a high intensity of the fire. Natural disturbances like tree fall, soil erosion, wind action, runoff and flooding, depending on the intensity, reduce recruits' numbers, subsequently affecting the density of trees in reserve [52, 53].

### *4.5. Tree Fall / Disturbance Regime in the Site*

The distribution of natural regeneration corresponds with the distribution of gaps, which agrees with gap-recruitment studies [54]. Our results suggest that wind disturbances creating successively expanding large gaps do allow for maintaining of mid- and late-successional tree species but are not sufficient to favour pioneer and early-successional ones or for ground vegetation to hamper the regeneration process. Initially, gap partitioning speculation accepts that the assortment of miniature ecological circumstances along the slope concealed understory — canopy gap empowers conjunction of a few tree species partly in light of higher stem density in gaps [55].

At another seasonal tropical forest site, [56] showed that low-intensity fires can generate a landscape-scale pulse of canopy gap formation. The percentage of *G. copallifera* seems to be the highest gap maker in the reserves, especially in areas surveyed. This observed trend might be a result of it being the dominant species in the reserve. Moreover, the root system of this species does not penetrate deep into the soil as the underlying soil is a hard pan. The roots of *G. copallifera* lack a tap root structure which goes deep into the soil; rather, the roots spread like fibrous roots on the available soil. This species is observed to grow in very difficult environmental conditions, which most species cannot stand as a result of the fact that the roots are shallowly spread on thin soils spread over rocks and depth is lacking, so heavy winds in the reserve affect this species more than other plant species. Hence the dominance of this species in the numbers of gap makers in the reserve.

## 5. Conclusion

The regeneration and spatial patterns of the species examined in this study exhibited clear relationships with disturbance intensity. Tree population and recruitment numbers decline as natural and anthropogenic disturbances increases over time. This is evident in the land use pattern operating in the reserve, where degraded and non-degraded areas show significant differences in the numbers of seeds, seedlings and saplings. Moreover, the total stem density of advanced regeneration and trees increased as the disturbance intensity decreased to a certain level. The overall population density of recruits is very low, especially for sites that are highly degraded, and mortality rates are high, with recruitment rates being slightly higher for non-degraded areas. Due to limited regeneration ability, the smaller population of *G. copallifera* in degraded areas of Kasewe may experience severe impacts from anthropogenic disturbances. Similarly, the absence of seedlings and the low number of saplings of *G. copallifera* in sampled plots of Kasewe indicate that the area may experience population declines in the near future.

These small patches of *G. copallifera* stands are more vulnerable to ongoing global climate change necessitating careful planning and management strategies. Regeneration is spatially heterogeneous and clumped in certain areas, and this suggests that regeneration dynamics are changing due to activities that cause disturbance (e.g., logging, farming, fire, charcoal burning, etc.) in the forests. Over-exploitation of tree species for timber, charcoal, fuel-wood and non-timber forest products by local people may lower their regeneration ability in heavily disturbed sites. Special attention should be paid to the extraction intensity of this species and forest products since we have found heavy disturbance to be detrimental to the composition and structure of the forests. Our results propose that incessant and fluctuating disturbances, acting all the while with different effects, were responsible for striking contrasts in the number of species among sampling sites and the significantly higher stem density in forest patches with less degradation. Recurrent human intervention for the collection of fuel-wood, fruit, litter, and minor forest items, as well as logging, charcoal burning, pole harvesting, farming and trampling, can significantly adjust the species' environment [57]. Therefore, the species richness of a site subject to disturbance relies upon the differential reactions of species to such unsettling influences; some species may endure the disturbances, while others might turn out to be locally extinct [58]. This is the current state of *G. copallifera* species in this reserve if urgent attention is not given to its management in its most populated habitat in Sierra Leone. In the most degraded sites, the recruitment stages of this species are halted as human activities increase. Diameter class distributions indicated the harvesting potential of some of the tree species in the non-degraded areas of the reserve.

The regeneration potential of this tree species was observed to decline and exhibited poor regeneration or no regeneration in farmland and charcoal production sites where fire intensity was high, which could affect its populations and its diversity. These results indicate the urgent need for the development and implementation of a strong forest management plan to rehabilitate and sustain the degraded areas of this forest in the hope of saving this species from extirpation. Therefore, an urgent priority is needed to conserve this species, in addition to supporting ecologically and economically important plant species, the prevent their loss and support local livelihoods. Since this forest holds 128 medicinal plant species belonging to 71 genera and 46 families, which are used to treat 42 human ailments [59]. Further research is required to investigate the regenerative status and capacity of important tree species which are data deficient in the studied forest reserve.

## Acknowledgements

The authors appreciate the communities and their authorities who participated in the study and are also grateful to the Ministry of Forestry and Food Security for granting permission to conduct this research in Kasewe Forest Reserve. The staff of the National Herbarium of Sierra Leone (SL) in the Department of Biological Sciences at Njala University are acknowledged for their technical support. We express our thanks to Mr. Jonathan Musa, Mr Kinnie Jarawallay, Mr. Josephus Jauna and Mr. Andrew Kamanda for their roles in collecting field data.

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