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Liana Proliferation Threatens Chimpanzee (*Pan troglodytes schweinfurthii*) Food Trees Abundance in Gombe National Park, Tanzania

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Abstract

Lianas plant species are abundant, diverse and essential component in tropical forests with impacts in the forest dynamics, through competitions for resources with attacked trees. Although lianas species are essential to chimpanzees, presence in chimpanzee habitats can negatively distress the availability and accessibility of tree food resources by inhibiting tree growth and fruiting capacity. However, the impacts of lianas to chimpanzee food trees abundance in Gombe National Park, western Tanzania remains unstudied. To investigate the impacts of liana infestation on chimpanzee food trees in Gombe national park, GIS and remotely sensed maps helped us to identify liana-infested areas. We randomized 50 grids each with 1-ha size distributed in liana range. We collected data on; names, DBH of all killed, affected and unaffected chimpanzee food trees, identified names and DBH of all lianas associated with chimpanzee food trees in main plot. Identified and counted all lianas and chimpanzee food trees seedlings in each 1 m × 1 m subplot at every diagonal corner. *Landolphia lucida* was the most dominant killer liana species in both Kasekela and Mitumba. Mitumba had a higher liana individuals/ha than Kasekela. Killed and affected chimpanzee food trees were generally larger in mean DBH than unaffected chimpanzee food trees. The regeneration potential of chimpanzee food trees was significantly lower than lianas in both ranges. Liana infestation poses a significant threat to larger chimpanzee food trees in Gombe National Park, western Tanzania. Undertaking ecological restoration strategies to preserve chimpanzee food trees providing larger food patches is essential for long-term chimpanzee survival.

Subject Areas

Plant Science

Keywords

Chimpanzee Food Trees, Lianas, Liana Infestation, Gombe National Park, Western Tanzania

1. Introduction

Lianas (non-self-supporting parasitic climbers) plant species are abundant, diverse, essential components of tropical forests and impacts forest dynamics (Li *et al.*, 2018 [1]; Kaçamak *et al.*, 2022 [2]). They can cover up to 20% of the woody plant diversity and about 40% of the stem density in tropical forests (Li *et al.*, 2018) [1]. These plant species do not capitalize on structural support at adult age, use the trees to climb to forest canopy and can exhibit a large leaf area-stem diameter ratio compared to trees (Hegarty and Caballé, 1991) [3]. Lianas have ability to invade more than half of canopy tree crowns (Ingwell *et al.*, 2010) [4], resulting into a monolayer of leaves on top of trees affecting the ability of supporting trees to capture light (Avalos *et al.*, 1999 [5]; Visser *et al.*, 2018 [6]). These plant species have the ability to explore and capture soil resources than large trees (Smith-Martin *et al.*, 2019) [7]. They have ability to cause direct competition with trees for both below and above ground resources (Avalos *et al.*, 1999 [5]; De Deurwaerder *et al.*, 2018 [8]), diminishing tree diversity, growth and intensely limiting forest resilience (Schnitzer & Carson, 2010 [9]; van der Heijden *et al.*, 2015 [10];). Although chimpanzees have long been studied in Gombe national park, western Tanzania (Pusey *et al.*, 2007 [11]; Wilson *et al.*, 2020 [12]), no study has assessed the impacts of lianas infestations on chimpanzee food trees abundance. Large chimpanzee food trees produce more patches for chimpanzees; decline in chimpanzee food trees will have significant implications to the endangered chimpanzees ecologically.

Despite of negative impacts that liana can cause in the forests, yet they are essential vegetation types that can influence species composition, canopy cover density, modified habitat and chimpanzees use some lianas species as fallback food when fruit availability from trees is scarce (Arroyo-Rodríguez *et al.*, 2015) [13].

Liana infestation is listed among the factors that can change species composition thus influence structure and carbon stocks in tropical forests (van der Heijden *et al.*, 2015) [10]. Increasing lianas density and biomass is suggested as leading contributors to changes in the tropical forest structure (van der Heijden *et al.*, 2015) [10]. To achieve effective environmental monitoring program in the tropical forests, accurate evaluation of the impacts of lianas infestation and associated infested trees in most lianas affected priority areas is essential (Li *et al.*, 2018) [1], though in tropical forest of Africa this field is poorly understood.

In tropical forests, liana infestation can significantly affect the basal area of dead trees (Van Der Heijden & Phillips, 2009) [14]. Speaking of Basal area, this refers to the cross-sectional area of a tree trunk occupying land surface, measured at breast height (1.3 meters or 4½ feet above the ground) (Elledge & Barlow, 2010 [15]; Schnitzer *et al.*, 2008 [16], 2011 [17]). Lianas as a woody vines climbing on trees and hence compete with trees for resources and space leading to their death or suppression of growth and hence resulting in a reduction in the basal area of affected trees (Van Der Heijden & Phillips, 2009) [14]. Studies have demonstrated the effects of liana infestation on basal area in tropical forests, showing how lianas compete with trees for light, water, and nutrients (Van Der Heijden & Phillips, 2009) [14]. They can wrap around tree trunks, branches, and leaves, shading the host tree and reducing its photosynthetic capacity. This competition hinders tree growth, leading to slower diameter increment and reduced basal area (Phillips *et al.*, 2002 [18]; Schnitzer *et al.*, 2006 [19]). Lianas can also exert mechanical stress on host trees, particularly during wind events or when the lianas become heavy with foliage (McDowell *et al.*, 2018) [20]. This stress can cause structural damage, such as breakage or uprooting, which further reduces the basal area of affected trees (Van Der Heijden & Phillips, 2009) [14].

Moreover, in severe cases of liana infestation, where the number and density of lianas are excessive, trees can succumb to the competition and mechanical stress imposed by the lianas. As these trees die and decompose, their basal area contribution to the forest decreases (Putz, 1984 [21]; Schnitzer & Bongers, 2011 [17]). The selective removal of infested trees from a forest can also have implications for the overall basal area. This reduction occurs due to the removal of both the tree itself and the lianas attached to it (Putz & Chai, 1987 [22]; Sist *et al.*, 2003 [23]).

Food abundance and distribution are by far the determinants of animal species abundance, population size, density and distribution (Foerster *et al.*, 2016) [24], Thus larger trees provide a significant huge amount of food, making them essential for studying how they are impacted by lianas. This is because conserving healthy tree populations that provide chimpanzee with abundant foods, controlling liana growth in specific areas, and promoting diverse forest habitats can help maintain a sustainable and abundant supply of tree food resources for chimpanzees and other sympatric wildlife species; Ashy red colobus, baboons, blue monkeys in Gombe national park. Monitoring liana infestation and its impact on basal area and considering targeted liana control or removal methods when necessary are essential steps in managing lianas' effects on basal area in African tropical forests (Putz & Chai, 1987 [22]; Schnitzer *et al.*, 2012 [25], 2015 [26]; Sist *et al.*, 2003 [23]).

In Gombe National Park, challenges caused by lianas have been escalating necessitating for this study, which aimed at identifying and estimating basal area of killed chimpanzee food trees species. This study forms the first of a kind following lianas proliferations in this park from imageries of 1972 and 2020 combined with field observations, which shows that chimpanzee food trees are dying from liana infestations. More death of chimpanzee food trees is likely to influence changes in chimpanzee feeding ecology in this small national park, western part of Tanzania. This study focused on: 1) identifying all killed chimpanzee food trees and the associated lianas to species level, 2) measured the size as diameter at breast height (DBH) of killed, unaffected and affected chimpanzee food tree species, and lianas, 3) compared Kasekela and Mitumba on killer liana dominance and structure, tree size structure and within sites difference, and 4) studied regeneration potential of lianas and chimpanzee food trees in Gombe national park. The purpose of the study was to investigate the impacts of lianas infestation to chimpanzee food trees to provide recommendations for the need to undertake restoration strategy in Gombe national park, western Tanzania.

2. Methodology

2.1. Study Site

Gombe National Park is the second smallest park in Tanzania covering an area of 56.2 km^2 of which 22.6 km^2 equivalent to 40% is part of Lake Tanganyika waters and 33.6 km^2 (60%) is terrestrial- **Figure 1** (Gombe GMP, 2016) [27]. It extends from low land along lakeshore, in the west at elevation 766 m to high mountainous terrain rising between 1300 to 1623 m in crests of a series of mountains in the east (Foerster *et al.*, 2016 [24]; M. L. Wilson *et al.*, 2020 [12]).

The study area comprises evergreen forests, vines and thickets along streams and semi- deciduous forest along slopes (Pusey *et al.*, 2007) [11]. >50% of its major streams around the park flows throughout the year while other streams flow depending on seasonality (Wilson, 2013 [28]; Wilson *et al.*, 2020 [12]). The Park has a clear set of wet and dry seasonality, light rains start from late September to December and heavy rains start from February to April while the dry season covers May to early September. Vegetation composition varies from

Figure 1. Study area location.

southern part to the northern part of the park with more forest in northern part and drier part in the southern part dominated by woodland forests. The suppression of wildfire since 1968 has resulted in increased shrubs and vines proliferation contributing a large percent of the Park's greener area especially in the northern part of the park (Wilson, 2013) [28].

2.2. Data Collection

Landsat MSS and ETM^+ imagery and GIS helped us to create lianas affected range in Kasekela and Mitumba chimpanzee community ranges. With the aid of QGIS, we generated 50 random plots each with 100 m × 100 m dimensions (1-ha) size (Kasekela = 30, Mitumba = 20) within lianas ranges (**Figure 2**). Each grid was assigned a unique label or number to facilitate further analysis. Using Microsoft Excel, we randomly selected 50 grid numbers, using RAND function (see **Figure 2**).

To obtain precise GPS coordinates for the randomly selected plots, we used QGIS. Using research tool in QGIS, we generated regular points at the corners of each plot within the identified grids. Additionally, we incorporated Coordinate Reference System (CRS) geometry attributes to define the spatial coordinates of the developed random plots. The CRS geometry data were transferred to Garmin GPS 64s to facilitate efficient navigation to plots. During data collection process, we specifically identified and measured the size as diameter at breast height

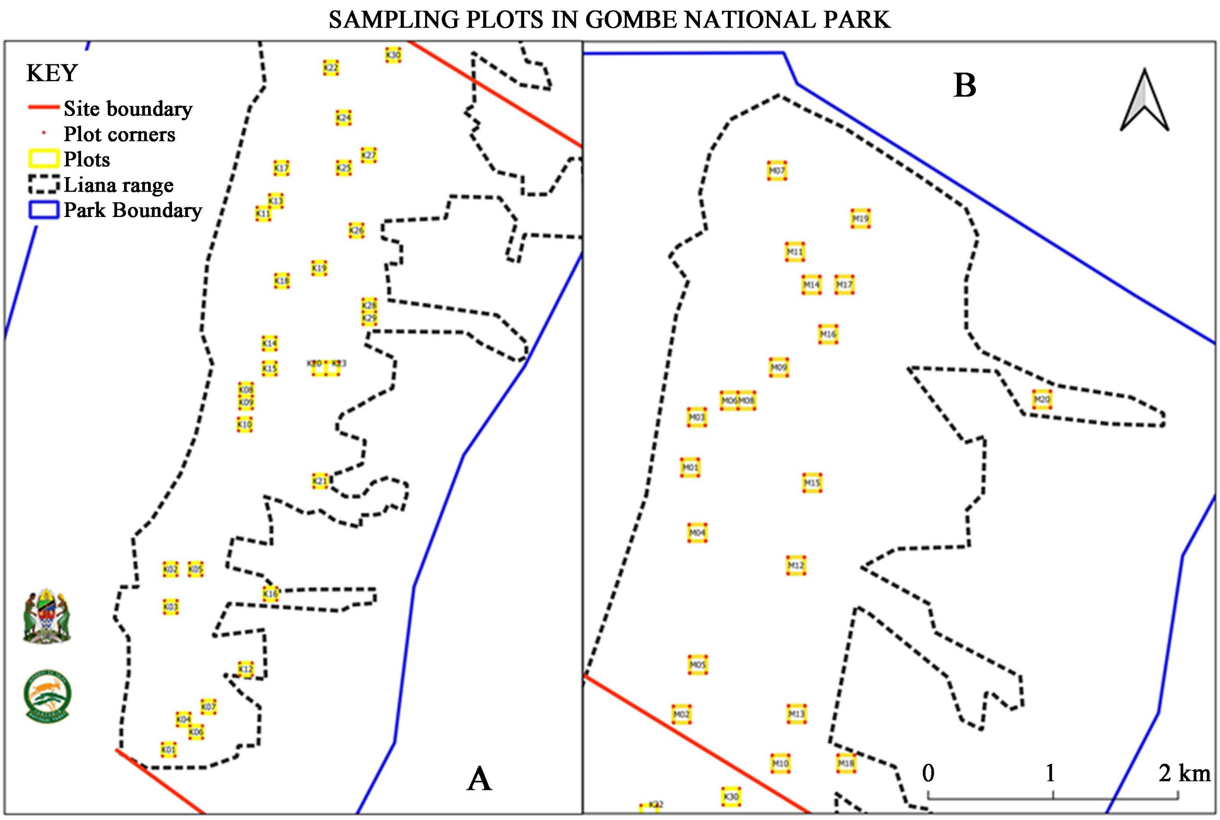

Figure 2. Liana random plots distribution in Kasekela (A) and Mitumba (B).

(DBH) of lianas that originated outside the plot but entered the plot and infested chimpanzee food tree rooted inside the plot. Conversely, we disregarded lianas rooted inside the plot but infesting trees located outside the plot. We also identified and measured the size of chimpanzee food trees size as DBH (killed, affected and unaffected trees). Finally, identified and counted all lianas and tree species in 1 m × 1 m subplot located at each South-west corner of the main plot.

2.3. Data Analysis

Data were analyzed using past software and Excel. Past software allows exploring relationships, conducting regression analyses and assessing the significance of observed patterns in the data. Statistical tests, such as t-tests and analysis of variance (ANOVA) and its extension of Turkey's Q test where difference among groups existed, helped to compare groups in the two chimpanzee ranges. The Importance Value Index-IVI (Curtis and McIntosh, 1951) [29] helped to understand the most; killer liana species, killed food tree species, affected and unaffected chimpanzee food tree species calculated as IVI = relative density + relative frequency + relative dominance of a species/3. The extent of liana species similarity between chimpanzee ranges were calculated using Jaccard similarity Index (J) (Jaccard 1912) [30] using a formula $J = A/(A + B + C) \times 100$, where; A refers to species in community 1 (Kasekela), B species in community 2 (Mitumba) and C refers to species shared by 1 and 2. The value of J ranges between 0 and 1 (or 0 - 100%) such that values closer to 1% or 100% indicates high overlap in species composition.

3. Results

3.1. Killer Liana Composition and Abundance

We enumerated 21 killer liana species from 10 families at Kasekela while we recorded 17 killer liana species from 12 families in Mitumba. Apocynaceae family had higher number of species responsible in killing chimpanzee food trees at both Kasekela and Mitumba. Importance Value Index (IVI), ranked 6 killer liana species from 4 families in Kasekela and only 4 killer liana species from 3 families in Mitumba. *Landolphia lucida* was the most dominant killer liana in both Kasekela and Mitumba representing with IVI = 28.9 and 50.9 in Kasekela and Mitumba respectively (Table 1).

3.2. Killer Liana Structure

We enumerated killer liana mean DBH of 2.76 ± 2.76 cm and 2.32 ± 1.69 cm (N = 457, N = 299) in Kasekela and Mitumba respectively, which statistically varied (t-test, $t = 2.7256$, $p = 0.0066$). We recorded 139 and 255 stem/ha of Killer liana species in Kasekela and Mitumba respectively (Table 2).

3.3. Similarity between Sites

According to Jaccard similarity index (J), killer liana species in Kasekela and

Table 1. Killer liana species importance value index in Kasekela and Mitumba (RF = relative frequency of a species, RBA = relative abundance, RD = relative density).

Kasekela						Mitumba					
Name of killer liana species	Family	RF	RBA	RD	IVI	Name of Killer Liana	Family	RF	RBA	RD	IVI
Landolphia lucida	Apocynaceae	37.36	12.11	37.36	28.94	*Landolphia lucida*	Apocynaceae	57.79	37.28	57.79	50.95
Uvaria angolensis	Annonaceae	18.91	16.78	18.91	18.2	*Saba comorensis var. florida*	Apocynaceae	6.79	23.53	6.79	12.37
Saba comorensis var. florida	Apocynaceae	8.4	20.97	8.4	12.59	*Uvaria angolensis*	Annonaceae	8.46	10.25	8.46	9.06
Saba comorensis var. comorensis	Apocynaceae	9.05	17.11	9.05	11.73	*Canthium hispidum/venosum*	Rubiaceae	6.4	5.92	6.4	6.24
Canthium hispidum/venosum	Rubiaceae	7.4	8.61	7.4	7.8	*Grewia platyclada*	Tiliaceae	2.3	7.33	2.3	3.97
Grewia platyclada	Tiliaceae	1.58	14.13	1.58	5.76	*Cissus verticillata*	Vitaceae	3	5.52	3	3.84
Dioscorea odoratissima	Dioscoreaceae	4.81	1.12	4.81	3.58	Unidentified (Mdalila)	Unknown	2.75	4.43	2.75	3.31
Cissus verticillata	Vitaceae	2.47	4.11	2.47	3.01	*Salacia leptoclada*	Celastraceae	3.53	1.69	3.53	2.92
Sabicea orientalis	Rubiaceae	4.12	0.69	4.12	2.97	*Sabicea orientalis*	Rubiaceae	1.98	0.7	1.98	1.56
Salacia leptoclada	Celastraceae	1.84	1.74	1.84	1.81	*Dioscorea odoratissima*	Dioscoreaceae	1.96	0.5	1.96	1.48
Ampelocissus cavicaulis	Vitaceae	1.2	0.65	1.2	1.02	*Smilax kraussiana/ anceps*	Smilacaceae	2.08	0.23	2.08	1.46
Smilax kraussiana/ anceps	Smilacaceae	1.2	0.1	1.2	0.83	*Saba comorensis var. comorensis*	Apocynaceae	1.33	1.58	1.33	1.42
Strychnos nux-vomica	Loganiaceae	0.43	0.63	0.43	0.5	Unidentified (Rufyetanyi)	Unknown	0.53	0.38	0.53	0.48
Tiliacora funifera	Menispermaceae	0.45	0.5	0.45	0.47	*Baphia capparidifolia*	Fabaceae	0.31	0.35	0.31	0.33
Baphia capparidifolia	Fabaceae	0.45	0.34	0.45	0.42	*Strychnos nux-vomica*	Loganiaceae	0.31	0.05	0.31	0.23
Oncinotis tenuiloba	Apocynaceae	0.07	0.22	0.07	0.12	*Dioscorea dumentorum*	Dioscoreaceae	0.27	0.1	0.27	0.22
Clematis brachiata	Ranunculaceae	0.12	0.1	0.12	0.11	*Tylophora spp*	Asclepiadaceae	0.18	0.15	0.18	0.17
Unidentified (local rufyetanyi)	Unknown	0.05	0.06	0.05	0.05						
Tylophora spp	Asclepiadaceae	0.05	0.02	0.05	0.04						
Tinospora caffra	Ranunculaceae	0.02	0	0.02	0.02						
Dioscorea dumentorum	Dioscoreaceae	0.02	0	0.02	0.02						

Table 2. Killer Liana Density (individuals/ha) in Kasekela and Mitumba.

Name of Liana killed tree	Family	Kasekela Density (stems/ha)	Mitumba Density (stems/ha)
Landolphia lucida	Apocynaceae	52.03	147.2
Uvaria angolensis	Annonaceae	26.33	21.55
Saba comorensis var. florida	Apocynaceae	11.7	17.3
Saba comorensis var. comorensis	Apocynaceae	12.6	3.4
Canthium hispidum/venosum	Rubiaceae	10.3	16.3
Grewia platyclada	Tiliaceae	2.2	5.85
Cissus verticillata	Vitaceae	3.43	7.65
Dioscorea odoratissima	Dioscoreaceae	6.7	5
Unidentified (local name Mdalila)	Unknown	0	7
Salacia leptoclada	Celastraceae	2.57	9
Sabicea orientalis	Rubiaceae	5.73	5.05
Ampelocissus cavicaulis	Vitaceae	1.67	0
Smilax kraussiana/anceps	Smilacaceae	1.67	5.3
Strychnos nux-vomica	Loganiaceae	0.6	0.8
Unknown (locally Rufyetanyi)	Unknown	0.07	1.35
Tiliacora funifera	Menispermaceae	0.63	0
Baphia capparidifolia	Fabaceae	0.63	0.8
Dioscorea dumentorum	Dioscoreaceae	0.03	0.7
Oncinotis tenuiloba	Apocynaceae	0.1	0
Tylophora spp	Asclepiadaceae	0.07	0.45
Clematis brachiata	Ranunculaceae	0.17	0
Tinospora caffra	Ranunculaceae	0.03	0
		139	**255**

Table 3. Similarity index for killer Liana species across the sites.

Site	Unique species	Shared species	Jaccard Similarity index (%)
Kasekela	5	15	71.4
Mitumba	1		

Mitumba had higher species overlap between them (J = 71.4%) (Table 3). However, Kasekela had 5 unique species not found in Mitumba.

3.4. Chimpanzee Food Tree Structure

3.4.1. Unaffected Chimpanzee Food Trees

We enumerated 42 and 36 unaffected chimpanzee food tree species in Kasekela and Mitumba respectively (Table 4). The most dominant unaffected chimpanzee

Table 4. Unaffected chimpanzee food trees in Kasekela and Mitumba.

SN	Unaffected food tree species	Kasekela Stems/ha	Mitumba Stems/ha
1	*Diplorhynchus condylocarpon*	32.33	37.25
2	*Annona senegalensis*	24.93	24.05
3	*Uapaca nitida*	15.73	3.2
4	*Hymenocardia acida*	1.97	24.6
5	*Anisophyllea boehmii/pomifera*	2.93	11.8
6	*Brachystegia sp.*	10	0.5
7	*Parinari curatellifolia*	8.17	4.65
8	*Pterocarpus angolensis*	5.57	5
9	*Albizia glabberima*	0.97	1.45
10	*Pseudospondias microcarpa*	2.03	1.45
11	*Antidesma venosum*	4.23	4.65
12	*Elaies guineensis*	2.63	1.9
13	*Pterocarpus tinctorius*	2.7	0.7
14	*Tabernaemontana holstii*	1.87	3.2
15	*Sterculia quinqueloba*	0.2	0.9
16	*Vitex fischeri*	2	1.75
17	*Uapaca kirkiana*	1.17	1.5
18	*Syzygium guineense*	1.83	0.7
19	*Stychnos madagascariensis*	1.53	1.7
20	*Milicia excelsa*	0.2	0.25
21	*Pycnanthus angolensis*	0.67	0.5
22	*Garcinia huillensis*	0.9	0.75
23	*Rothmannia englerana*	0.07	1.35
24	*Piliostigma thonningi*	0	0.9
25	*Mangifera indica*	0.03	0
26	*Vitex mombassae*	0.37	0
27	*Multidentia crassa*	0.5	0.65
28	*Ficus sycomorus*	0.4	0.15
29	*Harungana madagascariensis*	0.2	0.65
30	*Ficus trichopoda*	0.07	0.15
31	*Afrosersalisia cerasifera*	0.27	0.05
32	*Antiaris toxicaria*	0.1	0.15
33	*Ficus vallis-choudae*	0.27	0
34	*Flacourtia indica*	0.27	0.3

Continued

35	*Myrianthus arboreus*	0	0.35
36	*Ficus strangler*	0.17	0
37	*Dalbergia nitidula*	0.23	0.15
38	*Ficus exasperata*	0.03	0.1
39	*Cordia africana*	0.1	0
40	*Psychotria riparia*	0	0.05
41	*Strychnos spp.*	0.03	0.05
42	*Sorindeia submontana*	0.1	0
43	*Sterculia tragacantha*	0.03	0
44	*Combretum molle*	0.03	0
45	*Protea welwitschii*	0.03	0
		128	**138**

food tree species in Kasekela were; *Diplorhynchus condylocarpon* (21.7), *Annona senegalensis* (15.6), *Uapaca nitida* (11), *Brachystegia sp.* (10.3), *Parinari curatellifolia* (8.61) and *Pterocarpus angolensis* (5.65) whereas in Mitumba were; *Diplorhynchus condylocarpon* (24.84), *Annona senegalensis* (15.21), *Hymenocardia acida* (14.12), *Anisophyllea boehmii/pomifera* (8.48), *Pterocarpus angolensis* (5.85) and *Parinari curatellifolia* (5.16) (**Table 5**). These chimpanzee food trees had a mean size of 17.37 ± 12.65 cm and 14.73 ± 10.38 cm in Kasekela and Mitumba respectively, which statistically varied (N = 3836, N = 2750; unequal samples: t test, t = 9.296, p = 1.9547E−20). These unaffected chimpanzee food trees had 128 and 138 stems/ha in Kasekela and Mitumba respectively (**Table 4**).

3.4.2. Affected Chimpanzee Food Trees

We enumerated 36 and 39 species of affected chimpanzee food tree species in Kasekela and Mitumba respectively (**Table 6**). The most dominant affected chimpanzee food trees in Kasekela were; *Pseudospondias microcarpa* (21.33), *Annona senegalensis* (17.79), *Diplorhynchus condylocarpon* (13.16), *Vitex fischeri* (8.23) *Parinari curatellifolia* (5.74) and *Albizia glabberima* (5.64) while in Mitumba were; *Annona senegalensis* (7.3) and *Diplorhynchus condylocarpon* (5.4) (**Table 5**). Mean size DBH of the affected chimpanzee food trees was 19.3 ± 15.5 cm and 19.2 ± 13.9 cm in Kasekela and Mitumba respectively which were comparable (N = 1861, N = 1653) (Unequal samples t test, t = 0.041393, p = 0.9669). These affected chimpanzee food trees had 62 and 83 stems/ha in Kasekela and Mitumba respectively (**Table 6**).

3.4.3. Killed Chimpanzee Food Trees

We enumerated 23 and 14 killed chimpanzee food tree species in Kasekela and Mitumba respectively (**Table 7**). The most killed tree species in Kasekela were; *Albizia glabberima* (14.7), *Diplorhynchus condylocarpon* (13.68), *Annona senegalensis*

(9.69), *Parinari curatellifolia* (9.46), *Syzygium guineense* (7.48), *Vitex fischeri* (6.69) and *Anisophyllea boehmii/pomifera* (6.6), while in Mitumba the most killed chimpanzee food tree species were; *Annona senegalensis* (21.95), *Albizia glabberima* (15.74), *Anisophyllea boehmii/pomifera* (13.8), *Diplorhynchus condylocarpon* (8.41), *Hymenocardia acida* (7.89), *Pterocarpus angolensis* (7.11), *Parinari*

Table 5. Importance Value Index (IVI) of unaffected, affected and killed tree species in Kasekela and Mitumba (RF = relative frequency, RBA = relative basal area and RD = relative density).

Kasekela					Mitumba				
Unaffected trees									
Tree names	**RF**	**RBA**	**RD**	**IVI**	**Tree names**	**RF**	**RBA**	**RD**	**IVI**
Diplorhynchus condylocarpon	25.3	14.5	25.3	21.7	*Diplorhynchus condylocarpon*	27.09	20.34	27.09	24.84
Annona senegalensis	19.5	7.9	19.5	15.6	*Annona senegalensis*	17.49	10.64	17.49	15.21
Uapaca nitida	12.3	8.6	12.3	11.1	*Hymenocardia acida*	17.89	6.58	17.89	14.12
Brachystegia sp.	7.8	15.2	7.8	10.3	*Anisophyllea boehmii/pomifera*	8.58	8.27	8.58	8.48
Parinari curatellifolia	6.4	13.1	6.4	8.6	*Pterocarpus angolensis*	3.64	10.29	3.64	5.85
Pterocarpus angolensis	4.4	8.2	4.4	5.6	*Parinari curatellifolia*	3.38	8.72	3.38	5.16
Affected trees									
Pseudospondias macrocarpa	14.42	35.17	14.42	21.33	Annona senegalensis	0.22	0.11	21.72	7.35
Annona senegalensis	22.00	9.36	22.00	17.79	*Diplorhynchus condylocarpon*	0.16	0.10	16.03	5.43
Diplorhynchus condylocarpon	15.92	7.64	15.92	13.16	*Vitex fischeri*	0.13	0.16	12.70	4.33
Vitex fischeri	8.50	7.68	8.50	8.23					
Parinari curatellifolia	5.22	6.77	5.22	5.74					
Albizia glabberima	1.94	13.04	1.94	5.64					
Killed trees									
Albizia glabberima	8.15	27.81	8.15	14.70	*Annona senegalensis*	28.38	9.10	28.38	21.95
Diplorhynchus condylocarpon	16.30	8.46	16.30	13.68	*Albizia glabberima*	6.76	33.72	6.76	15.74
Annona senegalensis	11.11	6.84	11.11	9.69	*Anisophyllea boehmii/pomifera*	14.86	11.67	14.86	13.80
Parinari curatellifolia	8.15	12.09	8.15	9.46	*Diplorhynchus condylocarpon*	10.81	3.61	10.81	8.41
Syzygium guineense	8.89	4.67	8.89	7.48	*Hymenocardia acida*	10.81	2.04	10.81	7.89
Vitex fischeri	7.41	5.24	7.41	6.69	*Pterocarpus angolensis*	5.41	10.51	5.41	7.11
Anisophyllea boehmii/pomifera	8.15	3.49	8.15	6.60	*Parinari curatellifolia*	4.05	11.77	4.05	6.63
					Antidesma venosum	6.76	2.19	6.76	5.23
					Vitex fischeri	4.05	5.56	4.05	4.56

Table 6. Affected chimpanzee food trees in Kasekela and Mitumba.

Sn	Trees infected standing	Kasekela Stems/ha	Mkitumba Stems/ha
1	*Afrosersalisia cerasifera*	0.13	0.4
2	*Albizia glabberima*	1.2	1.1
3	*Anisophyllea boehmii/pomifera*	1.13	2.75
4	*Annona senegalensis*	13.63	17.95
5	*Antiaris toxicaria*	0.3	0.2
6	*Antidesma venosum*	2.97	6.3
7	*Bridelia atroviridis*	0.03	0.05
8	*Combretum molle*	0.1	13.25
9	*Diplorhynchus condylocarpon*	9.87	0.25
10	*Elaies guineensis*	0.63	0.15
11	*Ficus exasperata*	0.03	0.05
12	*Ficus strangler*	0.17	0.2
13	*Ficus sycomorus*	0.23	0.15
14	*Ficus trichopoda*	0.07	0.3
15	*Ficus vallis-choudae*	0.67	0.1
16	*Flacourtia indica*	0.8	1.05
17	*Garcinia huillensis*	2.27	0.75
18	*Harrisonia abyssinica*	0.13	0.05
19	*Harungana madagascariensis*	0.13	0.15
20	*Hymenocardia acida*	0.5	1.05
21	*Milicia excelsa*	0.07	0.45
22	*Multidentia crassa*	0.2	0.15
23	*Myrianthus arboreus*	0.23	1.55
24	*Parinari curatellifolia*	3.23	1.9
25	*Pseudospondias microcarpa*	8.93	8.35
26	*Piliostigma thonningi*	0	0.9
27	*Pterocarpus angolensis*	0.4	0.6
28	*Pterocarpus tinctorius*	0.57	0.8
29	*Pycnanthus angolensis*	1.03	0.9
30	*Sorindeia submontana*	0.6	0.25
31	*Sterculia quinqueloba*	0.1	0.3
32	*Rothmannia englerana*	0	0.5
33	*Sterculia tragacantha*	0.07	0
34	*Stychnos madagascariensis*	0.67	0.25

Continued

35	*Syzygium guineense*	2.7	2.5
36	*Tabernaemontana holstii*	2.8	6.25
37	*Vitex fischeri*	5.27	10.5
38	*Vitex mombassae*	0.1	0.05
39	*Uapaca nitida*	0	0.15
40	*Vitex doniana*	0	0.05
		62	**83**

Table 7. Killed chimpanzee food trees number of stems/ha in Kasekela and Mitumba.

Sn	Name of Tree Species killed	Kasekela Stems/ha	Mitumba Stems/ha
1	*Afrosersalisia cerasifera*	0.07	0.25
2	*Anisophyllea boehmii/pomifera*	0.37	0.55
3	*Albizia glabberima*	0.37	0
4	*Annona senegalensis*	0.5	1.05
5	*Antidesma venosum*	0.3	0.25
6	*Diplorhynchus condylocarpon*	0.73	0.4
7	*Bridelia atroviridis*	0.07	0
8	*Ficus trichopoda*	0	0.05
9	*Ficus vallis-choudae*	0.13	0.1
10	*Elaies guineensis*	0.07	0
11	*Ficus sycomorus*	0.03	0
12	*Parinari curatellifolia*	0.37	0.15
13	*Piliostigma thonningi*	0	0.05
14	*Garcinia huillensis*	0.03	0
15	*Pseudospondias microcarpa*	0.13	0.05
16	*Harungana madagascariensis*	0.03	0
17	*Pterocarpus angolensis*	0.07	0.2
18	*Pycnanthus angolensis*	0.13	0.05
19	*Hymenocardia acida*	0.17	0.4
20	*Vitex fischeri*	0.33	0.15
21	*Milicia excelsa*	0.03	0
22	*Multidentia crassa*	0.03	0
23	*Pterocarpus tinctorius*	0.1	0
24	*Sorindeia submontana*	0.03	0
25	*Syzygium guineense*	0.4	0
		4.5	**3.7**

curatellifolia (6.63), *Antidesma venosum* (5.23) and *Vitex fischeri* (4.56) (Table 5). We calculated killed chimpanzee food tree stems/ha of 4.5 and 3.7 in Kasekela and Mitumba respectively (Table 7). The mean DBH of trees killed by Liana was 22 ± 16.5 and 20.4 ± 13.1 cm in Kasekela and Mitumba respectively which was not different (N = 135, N = 74, Mann-Whitn U = 4762, z = −0.55608, p = 0.5781).

3.5. Size Comparison of Chimpanzee Food Trees within Sites

At Kasekela, chimpanzee food trees had mean DBH of; unaffected (17.37 ± 12.65 cm), affected (19.27 ± 15.50 cm) and killed (20.39 ± 13.14 cm), these chimpanzee food tree size indicated a significant difference in mean sizes (ANOVA-test, df = 2, MS = 2637.91, F = 14.18, p < 7.17E−07). Turkeys' Q test further showed that Killed chimpanzee food trees size were statistically different from unaffected (p = 0.0076) but not with the affected food trees DBH (p = 0.503).

At Mitumba, chimpanzee food tree size of the three groups had mean DBH of; unaffected (14.7 ± 10.4 cm), affected (19.2 ± 13.9 cm) and killed (22 ± 16.5 cm), which were significantly different in mean size (ANOVA-test, df = 2, MS = 11,680.9, F = 82.1, p < 9.592E−36). Turkeys' Q test further showed that killed and affected chimpanzee food trees DBH were statistically different from unaffected (p = 2.175E-05 and p = 0.0004) respectively, but had no significant difference between them (p = 0.0499) and p = 3.32).

3.6. Liana and Chimpanzee Food Tree Seedlings Regeneration

We enumerated 16 species of liana seedlings and 12 species of tree seedlings in Kasekela, while in Mitumba we enumerated 16 liana and 8 species of tree seedlings (Table 8). Liana seedlings had the total density of 2,515,000 and 2,530,000 stems/ha in Kasekela and Mitumba respectively. We enumerated tree seedlings density of 115,000.00 and 47,500.00 stems/ha equivalent to 4.6% and 1.9% of liana seedlings in Kasekela and Mitumba respectively (Table 8). *Landolphia lucida* was by far the most abundant lianas species in both sites. In Kasekela *Landolphia lucida* had 48.7% density of all liana seedlings followed by *Monanthotaxis poggei* (9.7%), *Dioscorea odoratissima* (7.5%) *and Cissus verticillata* (5.4%) while in Mitumba *Landolphia lucida* had 52.7% density of all liana seedlings followed by *Dioscorea odoratissima* (11.%), *Monanthotaxis poggei* (4.7%), and *Cissus verticillata* (4%). The species of tree seedling with the highest density in Kasekela was *Garcinia huillensis* (32.6%) followed by *Parinari curatellifolia* (21.7%), while in Mitumba tree seedlings with the highest density was *Rothmannia englerana* (36.8%) followed by *Hymenocardia acida* (15.8%).

4. Discussion

4.1. Killer Liana Composition and Abundance

We recorded large number of species in Kasekela than Mitumba due to the fact that Mitumba was the most affected area than Kasekela and most of the plots

Table 8. Liana and tree species seedlings density/ha in Kasekela and Mitumba.

Kasekela				Mitumba			
Liana seedlings	**Density/ ha**	**Tree seedlings**	**Density/ ha**	**Liana seedlings**	**Density/ ha**	**Tree seedlings**	**Density/ ha**
Landolphia lucida	1,225,000	*Garcinia huillensis*	37,500	*Landolphia lucida*	1,337,500	*Rothmannia englerana*	17500
Monanthotaxis poggei	245,000	*Parinari curatellifolia*	25,000	*Dioscorea odoratissima*	295,000	*Hymenocardia acida*	7500
Dioscorea odoratissima	190,000	*Ampelocissus cavicaulis*	10,000	*Monanthotaxis poggei*	120,000	*Dalbergia malangensis*	5000
Cissus verticillata	137,500	*Antidesma venosum*	7500	*Cissus verticillata*	102,500	*Garcinia huillensis*	5000
Dioscorea dumentorum	125,000	*Brachystegia sp.*	7500	*Saba comorensis var. comorensis*	95,000	*Parinari curatellifolia*	5000
Saba comorensis var. comorensis	122,500	*Rothmannia englerana*	7500	*Sabicea orientalis*	95,000	*Antidesma venosum*	2500
Baphia capparidifolia	92,500	*Harungana madagascariensis*	5000	*Saba comorensis var. florida*	87,500	*Diplorhynchus condylocarpon*	2500
Salacia leptoclada	87,500	*Vitex fischeri*	5000	*Baphia capparidifolia*	70,000	*Multidentia crassa*	2500
Canthium hispidum/venosum	82,500	*Afrosersalisia cerasifera*	2500	*Canthium hispidum/venosum*	70,000		
Saba comorensis var. florida	70,000	*Albizia glabberima*	2500	*Salacia leptoclada*	67,500		
Sabicea orientalis	70,000	*Bridelia atroviridis*	2500	*Dioscorea dumentorum*	65,000		
Smilax kraussiana/anceps	30,000	*Uapaca nitida*	2500	*Tylophora spp*	50,000		
Uvaria angolensis	22,500			*Strychnos nux-vomica*	27,500		
Oncinotis tenuiloba	7500			*Uvaria angolensis*	27,500		
Grewia platyclada	5000			*Smilax kraussiana/anceps*	12,500		
Unidentified liana (local name Mdalila)	2500			*Oncinotis tenuiloba*	7500		
TOTAL	**2,515,000**		**115,000**		**2,530,000**		**47,500.00**

had lianas as dominant species and very few trees were recorded in plots. Since we regarded killer liana only under presence of killed trees, therefore Kasekela ranked high in number of killer liana species recorded due to availability of many killed trees in this site compared to Mitumba.

The most important killer liana species were many in Kasekela than Mitumba and in both sites (Table 1), *Landolphia lucida* was by far the highest important species. In Kasekela and Mitumba, *Landolphia lucida* occupied 28.9% and 50.9% respectively.

Kasekela had large killer liana mean DBH than Mitumba but with low stem counts/ha (**Table 2**), implying that liana that kill trees in Kasekela are larger but they are fewer in number/ha. In Mitumba, killer liana species had small mean DBH but many individuals per hectare (**Table 2**). Other studies have highlighted liana abundance as a factor for tree mortality in most tropical forests and have discussed mechanism on which liana kill trees. Among other mechanism mentioned were promoting carbon starvation on trees, breaking branches and expose fresh part of trees to bacterial actions, and reducing water availability (McDowell *et al.*, 2018) [20].

We found high species similarity between sites among killer lianas (**Table 3**). This high overlap suggests that both community ranges have comparable environmental conditions. Although Kasekela had 5 unique liana species not found in Mitumba. Mitumba had only one unique liana species not found in Kasekela. It raises a question to why such pattern exists in unique lianas in this small park, worth future studies on factors limiting the establishment of these unique liana species across sites.

4.2. Chimpanzee Food Trees Structures across Sites

Kasekela had many tree species of unaffected food trees than Mitumba and the size of unaffected food trees was larger in Kasekela than in Mitumba. Nevertheless, the density of unaffected food trees was higher in Mitumba than in Kasekela (**Table 4**). This indicates that Mitumba has suffered the long-term impact of Liana than Kasekela and this has been revealed by Fadrique & Homeier, (2016) [31] who showed that Liana spread slowly from different topography. For this case it is likely that Mitumba was the first to be colonized by Liana. Another study by Wilson (2013) [28] have shown that after suppression of fire vines and shrubs had colonized most of northern part of the park (Mitumba). In Mitumba, chimpanzee food trees have reduced their DBH size as many areas are recently regenerants finding their way to canopy and some of the species may have been completely removed by liana- because had fewer killed food trees (**Table 5**). Having unaffected food trees have no promising future in an area with infecting liana, this is because a study of lianas in Barro Colorado found 21% of trees without liana that died in just 11 years period since 1996 to 2007 (Ingwell *et al.*, 2010) [4]. Likely, in Gombe, unaffected food trees are also open to invasion by lianas to death.

Kasekela had fewer affected food trees species than Mitumba and density of affected trees was smaller (**Table 5**). Affected food trees size was similar between sites. From field observation and satellite imaginary we speculate that liana colonize area regarded as evergreen forest in Kasekela and Mitumba and there is possibility of the southern part of the park (Bwavi) which is not colonized yet to be affected by liana as well (Zhong, 2015) [32]. Affected food trees are more vulnerable to death, the similar case recorded in Barro Colorado where 75% of crown infested by liana died in a period of 10 years (Ingwell *et al.*, 2010) [4]. Kasekela had many killed food tree species compared to Mitumba (**Table 6**), but size of killed food trees were similar between sites and the density of killed food trees differed (**Table 7**).

Generally, *Pseudospondias microcarpa* ranked high in species affected by liana in Kasekela but did not appear to be in the list of the unaffected species (**Table 5**). Same case was similar to *Albizia glabberima* which appeared as high rank of the most killed tree in both Kasekela and Mitumba but was not high in neither unaffected trees nor affected trees (**Table 5**). This may be due to lack of successful regeneration in both sites. Other species such as *Diplorhynchus condylocarpon, Annona senegalensis and Parinari curatellifolia* appeared in high IVI rank in all three food tree categories (**Table 5**). Our findings are similar to Ingwell *et al.* (2010) [4] who found that liana do compete intensively with trees and the competition covers both the belowground and aboveground resources.

4.3. Chimpanzee Food Trees Structures within Sites

Our results show that, most of killed chimpanzee food trees are larger compared to affected and unaffected individual food trees. This highlights that, most killed chimpanzee food trees are larger in size DBH and the affected food individuals too with relatively marginal difference in DBH suggesting potential death from lianas.

However, unaffected food trees were smaller in DBH, which is likely that, these are regenerates, which probably not yet infected as lianas continue to proliferate. Also, several studies have demonstrated that smaller tree species have relatively low level of liana infestation (Ingwell *et al.*, 2010) [4], suggesting that our findings are similar to other sites. Furthermore, other variables such as liana wood density, DBH, growth rate and crown illumination were discussed and mentioned as the important factors related to tree mortality in tropical forests (Rodríguez *et al.*, 2020) [33]. It was further observed that trees with high toughness in branches have higher ability to absorb liana load without breaking and can maintain a full crown and support a larger weight of liana stems and leaves (Rodríguez *et al.*, 2020) [33]. These studies likely corroborate with our study in Gombe where the killed food trees had larger DBH followed by affected and unaffected food trees. The study conducted using Unmanned Aerial Vehicle system shown significant difference in multispectral data between unaffected trees and affected trees (Li *et al.*, 2018) [1]. In addition, these results show that larger chimpanzee food trees are in danger of liana infections and death in Gombe national park.

4.4. Regeneration Potential

Our results show that lianas recruitment is by far faster than the chimpanzee food trees in both ranges. Very few tree saplings/seedlings were recorded in both sites, and Mitumba had very low tree recruitment (**Table 8**), suggesting that the liana impact is higher than in Kasekela. We suggest a similar case might be observed in Kasekela over time while in Mitumba the possibility of losing all chimpanzee food tree species is very likely. Similar case was reported by Garcia Leon *et al.*, (2018) [34] who found a significant reduction of canopy tree community level reproduction which is vital in maintaining tropical forest diversity. Furthermore, liana removal experiment has shown an increase of up to 75% of tree seedlings in the liana removal areas than in control plots (Marshall *et al.*, 2016 [35]; Zquierdo *et al.*, 2016 [36]). This has proved that liana proliferations limit tree regeneration, which is the case in our study area.

5. Conclusions

Liana infestation to large trees have detrimental effect and can alter the structure of ecosystem. Some researchers have observed different scenarios as liana infestation are dynamic trees with severe infestation, which tend to shade the entire crown over time. In the absence of long-term monitoring data on liana infestation, this hope for Gombe to achieve dynamics while protecting chimpanzee food trees remain uncertain.

The study reveals that much infected and killed chimpanzee food trees are larger in size to unaffected, suggesting the impact is huge to chimpanzee large food patches, which provide more chimpanzee food supply. The smaller unaffected chimpanzee food trees are not free to invasion in this habitat. Looking forward in the future how to control lianas infestation need more studies. Regeneration potential suggest that lianas are fast growing compared to chimpanzee food trees, as some chimpanzee food species did not even appear in the regenerants, which may both relate to lianas cover because they need light and also failures of tree seeds to grow as condition, competition on the ground increase. Investing in the understanding, the implication to chimpanzee food tree species in this small park is vital for long-term conservation.

6. Recommendations

When planning intervention, considering the presence of lianas and their impact on basal area particularly of chimpanzee food trees is crucial. Implementing selective cutting of lianas techniques that minimize damage to healthy chimpanzee food trees and account for liana-infested trees can help maintain the basal area of the forest (Putz and Chai, 1987 [22]; Sist *et al.*, 2003 [23]).

In specific cases where lianas are excessively abundant and pose a threat to tree growth such as in Gombe national park, targeted liana control or removal may be necessary to reduce chimpanzee food trees biomass from declining. This can help reduce competition and mechanical stress on chimpanzee food trees and potentially allow for basal area recovery (Schnitzer *et al.*, 2015) [26]. In Gombe, such actions are essential if we consider the impacts posed by the decline in chimpanzee food trees biomass that provide larger food amount to chimpanzees annually as may cause changes in their behavioral ecology (Foerster *et al.*, 2016) [24], which will in the future impact tourism activities and hence affect national income generation. Investing in studying the rate of liana regeneration and expansion in Gombe is urgent to ensure long-term chimpanzee conservation in this small park. Furthermore, establishing permanent liana monitoring plots to study the dynamics of regeneration and expansion in the park is commended to understand how much its effect is proliferating.

Finally, prior to undertaking control measures against lianas in Gombe, may need to study the contribution of lianas to chimpanzee diet and time spent feeding on such food type. This step would help in selecting areas for controls and removal exercise. The declining trees from lianas infestation suggest that restoration of chimpanzee food tree species is undertaken to increase the number of trees species, using careful steps such as indigenous tree species, use of modern technology to enhance tree growth other than using natural regeneration to meet demand for food supply to this endangered species.

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Data Availability

All data have been included here to provide the picture of the study.

Conflicts of Interest

The authors declare no conflicts of interest.

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