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Effect of altitude on Mistletoe's distribution in Bwindi Impenetrable National Park (BNIP), Uganda

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Abstract

This study examined mistletoes in the Bwindi Impenetrable National Park in South Western Uganda. In 6.4 ha, comprising 64 plots, divided between disturbed and less disturbed forests, spanning on an elevation range of 1160 to 2607 m a.s.l. 1,496 mistletoes counts were recorded, comprising of 21 species in seven genera and two families. These were hosted on 542 host trees comprising of 45 species in 18 unique mistletoes – host families. These mistletoes showed a preference for stems growing in open conditions with the mean density of 356 ha⁻¹ versus 129 ha⁻¹ in denser forest. The most abundant mistletoe species were found in the altitudinal range of a1000.5-1500m and 1500.5-2000.5m a.s.l with minimum numbers of counts dominated by *Englerina woodfordiodes* (with a count of 151 contributing to 23.18 %.) and *Phragamentera usuiensis* (with 155 counts contributing to 42.8% of mistletoes in Bwindi forest). Mistletoe abundance differed significantly between altitude ranges ($P < 0.001$) although it was similar between the forest edge and interior sites ($P = 0.565$). Nevertheless, six mistletoe species were recorded over one hundred times each and another six species were recorded only once implying that the species list is incomplete. Application of Chao's estimator indicated that mistletoe species richness is likely to exceed 40 species suggesting that mistletoes represent a significant component of the forest's botanical diversity.

Keywords: Distribution; Altitude range; Mistletoes; Host; Disturbed forest; Less disturbed forest

1. Introduction

The mistletoes are members of the family Loranthaceae which includes about 36 genera with some 1,300 species within the order Santales [1, 2]. Most of these are perennial evergreens parasitic on the stems and branches of trees or shrubs [3]. They comprise over 4100 known taxa and occur in most biomes [4,5]. They are woody evergreen hemi parasites, they photosynthesize but are dependent on their hosts for water and nutrients requiring them to maintain lower water potentials than their hosts which require well-lit locations [6].

They are termed hemi-parasites because although most mistletoe species photosynthesize, they obtain all water and minerals from their host via a specialized vascular attachment called a haustorium [1]. The root tip, instead of growing into the ground, forms an attachment point called a haustorium which functions as an umbilical cord with the host tree. The tree provides the parasite with the water and mineral nutrients it needs, but the mistletoe does its own photosynthesis.

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While such plants almost certainly influence the productivity, viability and reproduction of their hosts, influence community competition, and also provide food resources for other species with some viewing them as keystone species [5], [7], [8] their diversity and abundance have seldom been studied in the tropics. Notably, evaluations of mistletoe diversity and distributions in African mountain forests are lacking. The aim of this study was to provide an initial characterization of mistletoes and their distribution along altitudes in the Bwindi Impenetrable National Park in south western Uganda.

2. Methodology

Bwindi, a UNESCO World Heritage site, covers 331 km², and is one of the few forests in East Africa which combines lowland and montane vegetation (1,200 m and 2,600 m above sea level a.s.l.). It is believed to have continuity with forest cover that persisted through the last glacial, making it among the region's richest forests [9], [10]. There are two annual peaks in rainfall (March to May and September to November) with long-term annual rainfall ranging from 1,392 mm (elevation 1890 m) to 1,826 mm (elevation 1494 m), and mean annual temperature range from 16.4 C (elevation 2,300 m) to 21.7 C (elevation 1,433 m) (Institute of Tropical Forest Conservation (ITFC) <http://www.itfc.org> 9/7/2017).

We purposively placed plots along transects divided equally among track edges and interior forests, (Figure 1) following [11],[12] sampling methods. These locations were selected for accessibility and to span elevations from 1160 to 2607 m above sea level. At every 50 m, trees with diameter (DBH) ≥ 10 cm at 1.3 m height within 10 m to either side were examined for mistletoes. Mistletoes' species, locations, host name, tree diameters, and heights were recorded. A total of 64 plots were assessed which comprised 6.4 ha equally distributed between "forest-edge" and "interior forest" (i.e. the disturbed and less disturbed forests). A reference collect of all the species encountered was made. All collected materials were matched to herbarium material held at the Institute of Tropical Forest Conservation (ITFC). When in doubt, we sought additional guidance from experienced botanists based at the Institute of Tropical Forest Conservation herbarium who helped in referencing majority species especially the woody trees. For the unknown mistletoes, specimens collected, batched and taken to Makerere University tree herbarium for clear identification. In some cases, due to lack of flourishing material, we had to group certain mistletoes species into morph types. All collections are deposited at ITFC and Makerere Herbaria.

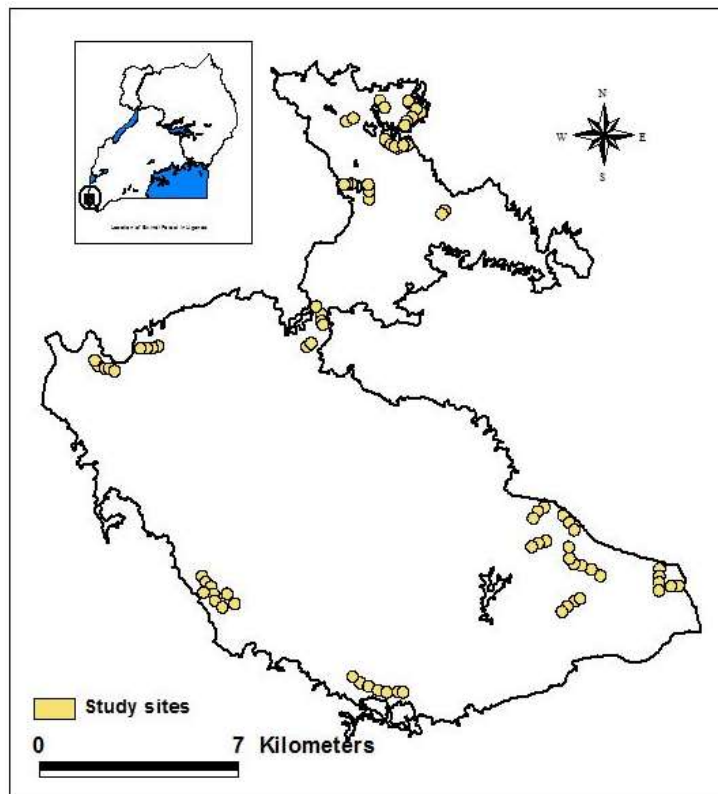


Figure 1 Location of Bwindi Impenetrable Forest with specific study sites

3. Results and discussion

Only 1,452 mistletoes were recorded comprising 21 species from seven genera and two families (Loranthaceae and Viscaceae) respectively in 6.4 ha which were divided over 64 plots (Table 1). These mistletoes occurred on 542 individual trees comprising 45 host species in 18 families (Table 2). Overall mistletoes densities in edge habitat were 2.7 times greater than in comparable interior forest, i.e. 1138 versus 414 individuals respectively or 356 ha⁻¹ versus 129 ha⁻¹. Of the 21 species recorded, 10 appeared only in disturbed forests and four only in less forest while seven occurred in both. Chao's estimator for the lower-bound of overall richness ([13], [14] indicated that the forest wide species richness is likely double what has already been observed (38.5 for the total data, but 44.5 for only the more open vegetation). And values for the less open vegetation alone were generally few and countable in all situations and could easily be computed.

Table 1 Mistletoe species recorded in more and less open conditions

Hemi-parasitic species	Family	More open	Less open	Total
<i>Englerina woodfordiodes</i> (Schweinf) Balle	Loranthaceae	187	141	328
<i>Viscum fischeri</i> (Engl)	Viscaceae	306	10	316
<i>Phragmanthera usuiensis</i> (Oliv) M. Gulb	Loranthaceae	184	59	243
<i>Viscum triflorum</i> (DC)	Viscaceae	215	12	227
<i>Agelanthus entebbensis</i> (Sprague) Polhil & Wiens	Loranthaceae	107	0	107
<i>Englerina schubotziana</i> (Engl & K. Krause)	Loranthaceae	56	48	104
<i>Tapinanthus brunneus</i> (Engl. Ball& Halle)	Loranthaceae	0	82	82
<i>Tapinanthus constrictiflorus</i> (Engl.) Danse	Loranthaceae	33	8	41
<i>Englerina</i> sp 11	Loranthaceae	0	21	21
<i>Phragamanthera</i> sp	Loranthaceae	18	0	18
<i>Agelanthus djurensis</i> (Engl.Polhill and Wiens)	Loranthaceae	1	15	16
<i>Viscum combreticola</i> (Engl. LC)	Viscaceae	15	0	15
<i>Globimetula anguliflora</i> (Engl.) Danser	Loranthaceae	0	10	10
<i>Tapinanthus bangwensis</i> (Engl) (Denser	Loranthaceae	10	0	10
<i>Englerina</i> sp1	Loranthaceae	0	8	8
<i>Viscum congolense</i> (Zenker)(Winkler)	Viscaceae	1	0	1
<i>Tapinanthus erianthus</i> [Sprague] Dans	Loranthaceae	1	0	1
<i>Phragmanthera</i> sp 11	Loranthaceae	1	0	1
<i>Phragmanthera</i> sp 1	Loranthaceae	1	0	1
<i>Phragmanthera</i> sp 111	Loranthaceae	1	0	1
<i>Olirella trildebrandtii</i>	Loranthaceae	1	0	1

The distribution of these species spans the whole elevation range where majority mistletoes of thirteen mistletoe plant species were found in the altitudinal range of 1500.5-2000.5 m a.s.l with minimum numbers of 151 counts and these were dominated by *Englerina woodfordiodes* with a minimum record of 35 counts in this altitude range making a total occupancy of 23.18 %. This is in conformity to Rahbek (1995) who described four patterns of the relationships between species richness and elevation. These were followed by 1000.5-1500.5 altitude range where a record of 11 mistletoes was made with 155 counts and these were dominated by *Phragamanthera usuiensis* with 66 counts making total percentage occupancies of 42.8%. And a reasonable amount of 7 mistletoes with a minimum number of 121 counts was recorded in the altitude range of 2000.5-2500.5 m a.s.l dominated by *Englerina woodfordiodes* with 38 stem counts

making a total of 31.4% occupancy. From the data collected and analyzed, the study revealed that parasites were common in mid elevation than in upper and lower elevations. It was clear that mistletoes were placed indiscriminately /regardless of host size or in terms of diameter classes along the altitude between 1000.5-2500.5 m a.s.l (Fig 1 and Table 2) with the few outliers in the highest altitude and in the lowest altitudes. This agrees with what Clark (1986) found out, that species richness in tropical forests are repeatable in mid-elevation peak along elevation gradients.

In Bwindi forest, by far, the most common parasite distribution was the 'hump-shaped' pattern, which was reported from 80% of the sites that covered complete gradients and trend and reported a positive monotonic increase in parasite richness with elevation. The complex environmental variable 'altitude' explains the variation of 21 mistletoes' data than 'height of host trees. (Hanley et al., 2005), adds, that topography has a strong influence on the local climate through associated wind patterns. This axis range accommodates parasite generalists that have a high tolerance in respect of altitude and were confined in the mid-elevation belt of Bwindi forest. Many vascular plants fall in this category, observed by (Hanley et al., 2005). He also unfolds that vegetation distribution pattern probably reflects the occasional occurrence of tree species in shaded habitats. The slope angle had less significant effect on parasite distribution and diversity. Only minimum influences were recorded within steep slope with the P = 0.024.

Table 2 Distribution of hemi-parasitic plants at different elevations in BINP

Elevation (masl)	0-1000.5	1000.5-1500.5	1500.5-2000.5	2000.5-2500.5	2500.5-3000.5
Hemi-parasitic plant (abundance)	<i>Englerina schubotziana</i> (1)	<i>Phragmenthera Usuiensis</i> (66)	<i>Englerina woodfordiodes</i> (35)	<i>Englerina woodfordiodes</i> (38)	<i>Viscum fischeri</i> (5)
		<i>Agelanthus entebbensis</i> (58)	<i>Phragmenthera Usuiensis</i> (32)	<i>Viscum fischeri</i> (38)	
		<i>Viscum triflorum</i> (13)	<i>Viscum triflorum</i> (26)	<i>Viscum triflorum</i> (30)	
		<i>Globimatula braunii</i> (5)	<i>Agelanthus brnneus</i> (25)	<i>Englerina schubotziana</i> (10)	
		<i>Phragmanthera Sp.</i> (5)	<i>Englerina SP 111</i> (11)	<i>Tapinathus constrictifoides</i> (3)	
		<i>Tapinathus constrictifoides</i> (2)	<i>Englerina schubotziana</i> (9)	<i>Olirella trildebrandtii</i> (1)	
		<i>Viscum combreticolla</i> (2)	<i>Viscum combreticolla</i> (5)	<i>Phragmenthera Usuiensis</i> (1)	
		<i>Phragmanthera Sp 1</i> (1)	<i>Tapinathus constrictifoides</i> (3)		
		<i>Phragmanthera Sp 11</i> (1)	<i>Agelanthus djurensis</i> (1)		
		<i>Tapinathus buvumea</i> (1)	<i>EnglerinaSp1</i> (1)		
		<i>Viscum congolensis</i> (1)	<i>Tapinathus constrictus</i> (1)		
			<i>Viscum fischeri</i> (1)		
			<i>Phragmanthera Sp 111</i> (1)		
Total No. of species	1(1)	11(155)	13(151)	7(121)	1(5)

On the other hand, *Phragmanthera usuiensis* was clearly found to appear nearly in the altitudinal range from 1000 to 2500 m a.s.l, with the number of mistletoes stems decreasing as the elevation increased and decrease. Also *Englerina schubotziana* was found to prefer lower and mid altitudes i.e. between 0-2500.5 m a.s.l as compared to *Viscum fischeri* which preferred upper altitudes ranging from 2000.5-3000.5 m.a.s.l and appearing as a single species at 2500-3000 m.a.s.l (Table 2 and Fig1).Species greatly decreased as one moves either up or down along the altitude gradient. Also mistletoes were seen infecting nearly all common tree species within the range between 1000.5-2000.5 m a.s.l. Specifically, host tree species including *Macaranga kilimandscharica* Pax, *Maesa lanceolata* Voigt, and *Millettia dura* Dunn regardless of their sizes (Table 3).

This is thought to have been influenced by the mistletoes seeds distribution agents that frequently perch and or appear in theses altitude ranges. It was thought that, mistletoes appearance followed the disperser’s movements within the altitude ranges depending on their avian movements. For example, if dispersers prefer a particular tree species for perching, feeding or nesting, it is most likely to receive more mistletoe seeds than none preferred tree species. Bird’s movements among potential host trees are unlikely to be random [15]. As a result of any disperser preferences, whether for foraging or nesting or other reasons, therefore, not all trees would equally and likely receive mistletoe seeds.

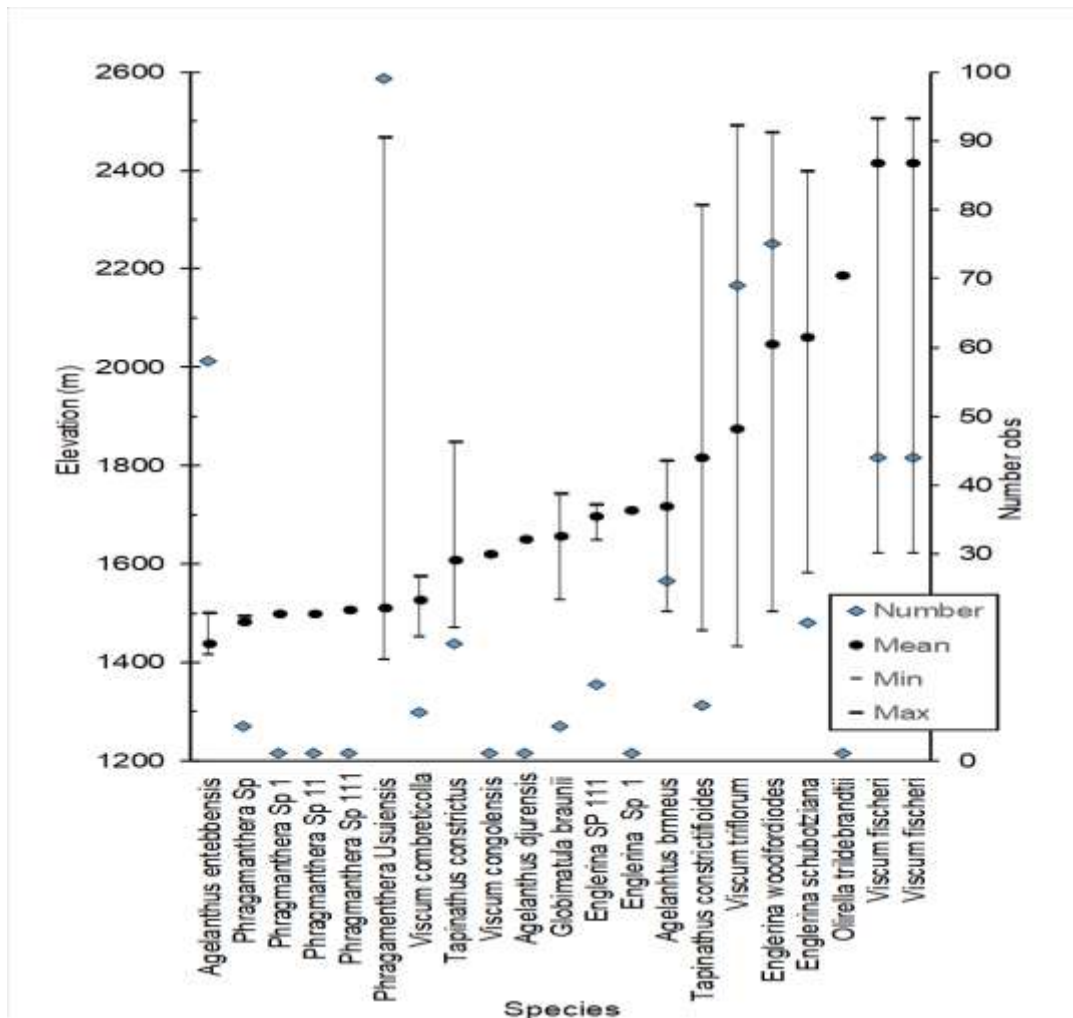


Figure 2 Number of observations versus elevation range

One way ANOVA showed a significant ($P < 0.05$) variation in the distribution of mistletoes and elevation within Bwindi Impenetrable National Park forest (Figure 2 and Table2) meaning that the abundance of mistletoes increased with the increase of elevation up to about 2500 m a.s.l when numbers and spices started to decrease. In addition, a trend line with an R-square value of 0.0028 imply that 0.28% of mistletoes abundance in Bwindi forest can be attributed to changes in the altitudinal gradient while the other variables that this study did not consider would have attributed 99.72%.

The study revealed that the individual 95% CIs with the Mean Based on Pooled StDev of 0.02828 accumulated, meaning that altitude alone could not contribute to the appearance of many types of mistletoe within an altitude range. Study results also explained by the Simultaneous Confidence Intervals of Tukey 95% with the Individual confidence level of 99.35% in all pair wise comparisons among Levels of study sites in Bwindi forest still unfolds that altitude location ranging from 1000.5- 2500.5 attracted mistletoes as well as host trees preferred by specific mistletoes.

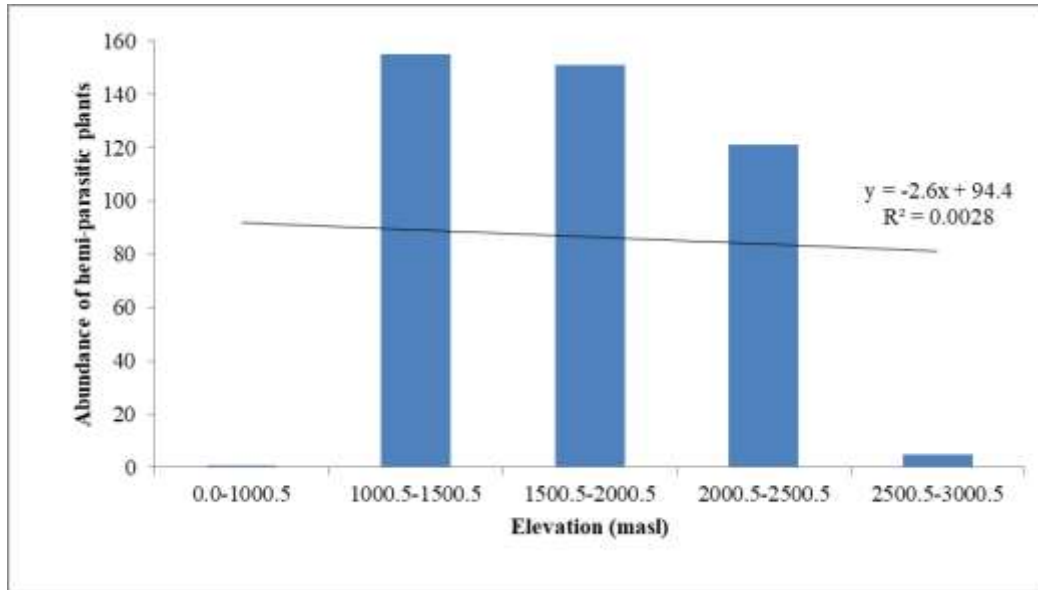


Figure 3 Variation in mistletoes' abundance with elevation

3.1. Host trees

In this study, mistletoes occurred on 542 different host trees (mean 85 host stems over 10 cm dbh ha⁻¹) comprising 45 tree species. These host species included 28 families of Euphorbiaceae, Leguminosae, and Moraceae being the majority tree host species (Table 3).

Host species were dominated by fast growing pioneer tree species including *Macaranga kilimandscharica* Pax which alone hosted over 30 % of total individuals mistletoe, *Maesa lanceolata* Voigt, and *Millettia dura* Dunn (Table 3) hosting about 58.29% of mistletoes. Unsurprisingly our observations show that per unit area more mistletoe occurred on smaller sized common tree hosts than on scarcer larger trees, but also larger trees were more likely to host mistletoes.

3.2. Host associations with mistletoe species

In this study, numbers indicate how many of the parasites were recorded on each host tree species. Many types of mistletoe could simultaneously parasitize many host species-but many of our species occurred at too low an abundance to evaluate this appropriately. *Phragamentera usuiensis* showed 241 occurrences on different host tree species in the study and recording 18 positive associations and twenty seven (27) negative associations with all host species. *Englerina woodfordiodes* showed 240 occurrences in the study areas with 12 positive associations and thirty three (33) negative associations with all host tree species. The rest of the mistletoe species showed positive association with a few of the tree species; most of the associations were negative. The major hosts for mistletoes in Bwindi forest (study areas) was *Macaranga kilimandscharica* hosting about 31.36 % of total individual mistletoe through the study area. This was followed by *Maesa lanceolata* hosting about 10.5% of the total individual mistletoes, meaning that major host species had a positive association with more than one mistletoe species (Table 3).

The interaction between host species and site was significant ($P < 0.001$). *Phragamentera usuiensis* was the most common species, infesting more host species (i.e. 40 %) than any of the other species (Table 1). This was followed by *Englerina woodfordiodes*, which infested 27% of the all host species. The remaining mistletoe species occurred on only a few tree species. Mistletoe distribution on trees was non-random in the studied plots ($\chi^2 = 1145.94$, $df = 28$, $P = 0.001$)

Our general impression was that, larger trees found in open areas were more likely to support many types of mistletoe than smaller trees in denser forest. As it has been assessed elsewhere the probability that tree infected tends to increase with tree size [16], Nonetheless, in Bwindi, as in most forests, stem-densities in typical old-growth forest, typically

halved with every 10 cm increase in the lower-diameter size limit. So the number of stems in the 10-20 cm dbh class are generally about twice as abundant as those in the 20-30 cm dbh class, which are in turn twice as abundant as those in the 30-40 cm dbh classes indicated by [17], Martijena and Bullock, 1994. Thus while individual large trees may support more parasites than do individual small trees, such trees are relatively rare and the greater density of the latter means that most mistletoes are supported by smaller trees commonly found in the mid altitudes. This showed that the proportional distribution of individuals among DBH classes differs strikingly between sites host species and their sizes in host diameters.

Table 3 Host tree distributions and abundance

Host tree species	Family	Disturbed	Lightly disturbed
<i>Albizia gummifera</i> C.A.Sm.	Leguminosae	5	0
<i>Alchornea hirtella</i> Benth.	Euphorbiaceae	1	0
<i>Aningeria altissima</i> (A.Chev) Aubrév. & Pellegr	Sapotaceae	0	1
<i>Allangium chinense</i> Rehder.	Alangiaceae	11	2
<i>Allophylus abyssinicus</i> (Hochst.) Radlk.	Sapindaceae	1	2
<i>Bridelia micrantha</i> Baill.	Euphorbiaceae	2	4
<i>Carapa grandiflora</i> Sprague	Meliaceae	0	2
<i>Clerodendrum</i> Sp	Lamiaceae	1	0
<i>Faurea saligna</i> Harv.	Proteaceae	0	2
<i>Ficalhoa laurifolia</i> Hiern.	Theaceae	0	2
<i>Ficus capensis</i> Hort.Berol. ex Kunth & C.D.Bouché	Moraceae	5	0
<i>Ficus</i> sp	Moraceae	0	6
<i>Ficus</i> sur Forssk.	Moraceae	1	0
<i>Hagenia abyssinica</i> J.F.Gmel.	Rosaceae	0	2
<i>Harungana madagascariensis</i> Poir.	Clusiaceae	8	25
<i>Ilex mitis</i> Radlk.	Aquifoliaceae	1	0
<i>Pellaea</i> sp	Pteridaceae	2	0
<i>Lindackeria bukobensis</i> Gilg.	Flacourtiaceae	0	1
<i>Macaranga barteri</i> Müll.Arg.	Euphorbiaceae	17	1
<i>Macaranga kilimandscharica</i> Pax.	Euphorbiaceae	33	137
<i>Maesa lanceolata</i> Voigt.	Myrsinaceae	19	60
<i>Maesopsis eminii</i> Engl.	Rhamnaceae	3	2
<i>Markhamia lutea</i> K.Schum	Bignoniaceae	3	0
<i>Millettia dura</i> Dunn	Leguminosae	66	1
<i>Myrianthus holstii</i> Engl.	Cecropiaceae	1	0
<i>Mystroxydon aethiopicum</i> (Thunb.) Loes	Celastraceae	0	2
<i>Neoboutonia macrocalyx</i> Pax	Euphorbiaceae	0	7
<i>Neoboutonia</i> sp	Euphorbiaceae	0	17
<i>Newtonia buchananii</i> (Baker) G.C.C.Gilbert & Boutique	Leguminosae	5	0
<i>Nuxia congesta</i> R.Br.	Buddlejaceae	0	1

<i>Persia americana</i> Mill.	Lauraceae	3	0
<i>Pinus patula</i> Schiede & Deppe ex Schldtl.	Pinaceae	2	0
<i>Pinus taeda</i> Blanco	Pinaceae	1	10
<i>Prunus africana</i> (Hook.f.) Kalkman	Rosaceae	0	5
<i>Psychotria mahonii</i> C.H.Wright	Rubiaceae	0	4
<i>Rapanea melanophloeos</i> Mez	Myrsinaceae	0	2
<i>Sapium ellipticum</i> (Krauss) Pax.	Euphorbiaceae	35	0
<i>Strombosia scheffleri</i> Engl.	Olacaceae	1	1
<i>Tabernaemontana orientalis</i> R.Br.	Apocynaceae	1	0
<i>Camellia sinensis</i> (L.) Kuntze	Theaceae	0	1
<i>Teclea nobilis</i> Delile	Rutaceae	0	8
<i>Tetrorchidium didymonstemon</i>	Euphorbiaceae	1	0
<i>Trema orientalis</i> (L.) Blume	Ulmaceae	2	0
<i>Trichilia rubescens</i> Oliv.	Meliaceae	2	0
<i>Vernonia</i> sp	Asteraceae	0	1

4. Conclusion

We have provided an initial characterization of mistletoes in the Bwindi Impenetrable National Park in Uganda. In conclusion therefore, this study reveals that there are a number of mistletoes present in Bwindi forest and are hosted by different host trees along the diverse altitude ranges. The study puts it clear that mistletoes prefer rather mid altitude and majority of the hosts were medium to large sizes. The mistletoes i.e. the canopy hemi-parasitic woody species are typical of natural forests, in these areas are more abundant at the edge, in gapes, and along the paths while in the inner areas there are a few and specialized in tolerating large fluctuations in physical variables including altitude. In disturbed forest types, it is been recognized that the increasing levels of stress caused by human activity have sometimes homogenized areas of the forest and increased mistletoes' abundance due to the forest cover loss and the terrestrial influence. Therefore conservation of hosts in Bwindi will directly lead to conservation of mistletoes in general.

Our limited sampling of through the whole forest and their host species precludes confident evaluations but Chao's estimator indicates that the forest wide mistletoe species richness is likely to be more than 40 species suggesting that this group of species represents a significant component of the forest's botanical diversity.

Compliance with ethical standards

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Disclosure of conflict of interest

Emilly Kamusiime declares that she has no conflict of interest; Denis [Byabashejja](#) Mujuni declares that he has no conflict of interest; Grace Abigaba declares that she has no conflict of interest; Scovia Mudondo declares that she has no conflict of interest.

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