land

MDPI

Article

Phytosociological Investigations on the Afroalpine Vegetation of the Ruwenzori Mountains (Uganda)

Salvatore Cambria [1], Pietro Minissale [1,*] and Gianmarco Tavilla [2]

[1] Department of Biological, Geological and Environmental Sciences, University of Catania, 95125 Catania, Italy; cambria_salvatore@yahoo.it
[2] National Research Council of Italy, Institute of Atmospheric Pollution Research (CNR-IIA), c/o Interateneo Physics Department, 70125 Bari, Italy; gianmarcotavilla@cnr.it
* Correspondence: p.minissale@unict.it

Abstract: This paper presents the results of a phytosociological study on the Afroalpine vegetation of the Ruwenzori Mountains, one of the most prominent mountain ranges in Africa. This study marks the pioneering comprehensive investigation into the plant communities of this region, which holds significant phytogeographic importance. Through statistical analyses, eight distinct plant communities, three new alliances, two new orders, and one new class were identified within the altitudinal range of 3500 to 4600 m above sea level. These communities are well-defined from both floristic and ecological perspectives. Hierarchical classification was conducted using the quantitative Sørensen (Bray-Curtis) distance measure and the beta flexible linkage method. Furthermore, indicator species for each group were determined by calculating fidelity and constancy (occurrence frequency) within the classified dataset. To assess the validity of the classification results, non-metric multidimensional scaling (NMDS) was carried out. These analyses provide the first phytosociological arrangement of the Afroalpine vegetation of the Ruwenzori Mountains, providing a solid framework and valuable insights into its floristic and ecological characteristics.

Keywords: Africa; alpine; ecology; mountain vegetation; plant diversity

check for updates

Citation: Cambria, S.; Minissale, P.; Tavilla, G. Phytosociological Investigations on the Afroalpine Vegetation of the Ruwenzori Mountains (Uganda). *Land* **2024**, *13*, 1752. https://doi.org/10.3390/land13111752

Academic Editor: Eusebio Cano Carmona

Received: 10 October 2024
Revised: 21 October 2024
Accepted: 24 October 2024
Published: 25 October 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The Ruwenzori Mountains, located along the border between Uganda and the Democratic Republic of Congo, are one of the main high-altitude areas of Africa. In fact, this mountain range reaches an altitude of 5109 m above sea level (ASL) at the top of Mount Stanley (Cima Margherita), making it the third-highest peak on the African continent, after Kilimanjaro (5895 m) and Mount Kenya (5199 m). The vegetation of this area was first documented by European explorers [1], who noted the presence of distinct altitudinal belts with very characteristic plant communities. The upper limit of the montane rainforest generally occurs between 2400 and 2700 m [2,3], followed by a bamboo-dominated belt and ericaceous forests and scrublands extending up to 3000–3100 m. At higher elevations, a woodland dominated by *Rapanea rhododendroides* (Gilg) Mez and *Hagenia abyssinica* (Bruce) J.F.Gmel becomes prevalent, while, above 3600–3800 m, the Afroalpine belt begins, extending nearly to the highest peaks, which are characterized by the presence of glaciers. From a phytogeographic point of view, the upper areas of the Ruwenzori Mountains hold significant importance due to their distinctive Afroalpine flora, with a high presence of local endemics [4]. In fact, the Afroalpine region consists of isolated areas surrounded by a vast expanse of tropical and subtropical climate zones [5]. This flora likely originated in the cold-temperate areas of Eurasia and spread southwards over the past 5 million years through several colonization events [6,7]. The flora of the Afroalpine areas shows numerous examples of evolutionary convergence, particularly within genera such as *Dendrosenecio* (Hauman ex Hedberg) B. Nord. and *Lobelia* L., which are notable for unusual phenomena of gigantism, contributing to the unique physiognomy of Afroalpine vegetation [4,8]. The

first studies specifically addressing the alpine vegetation of the Ruwenzori were carried out by Woosnam [9], followed by Engler [10] and Ross [2,3], who provided initial data on the main life zones and altitudinal belts. More detailed and in-depth surveys of plant communities were later carried out by Hedberg [4] in his extensive review of the Afroalpine flora and vegetation. Additional local data have been reported by Loveridge [11] for the Nyamagasani Valley, Schmidt & Beck [12] for the Butawu Valley, and Fishlock & Hancock for the Bujuku Valley [13]. Raimànkovà & Rejmànek [14] also provide limited information on the vegetation with *Carex runssoroensis* K. Schum. However, these studies are largely ecological and physiognomic, typically presenting lists of species and rarely vegetation relevés. Similar data on Afroalpine vegetation have been reported by various authors for other areas, such as Kilimanjaro [15,16] and Mount Kenya [17,18]. To date, no phytosociological studies have been conducted in the Ruwenzori Mountains or other mountain regions with Afroalpine vegetation. The phytosociological method has been widely applied to the study of alpine vegetation in temperate regions of Europe and Asia [19–22], and it has also proven efficient in studying mountain vegetation in tropical regions, particularly in the Andes [23,24]. Therefore, the aim of this study is to propose a phytosociological classification of the plant communities occurring in the Ruwenzori Mountains between 3500 and 4600 m. The proposed phytosociological framework is based on multivariate analysis, utilizing a hierarchical classification of vegetation. The identified communities were characterized from a floristic, ecological, structural, and distributive point of view. This study, therefore, aims to identify and analyze, using a well-known and tested method, the main types of vegetation present in the area. It will also allow the identification of an altitudinal gradient of the different communities.

This paper may represent a starting point for further studies in other mountain areas of Africa with similar vegetation, which may provide a more extensive phytosociological classification of Afroalpine plant communities.

2. Materials and Methods

2.1. Study Area

The research was carried out on the south-eastern side of the Ruwenzori mountains, within the territory of Uganda (Western Region), near its border with the Democratic Republic of Congo. On the Ugandan side, the mountains lie within the Ruwenzori Mountains National Park (UNESCO World Heritage site). The surveyed area covers approximately 3000 km^2, at an altitudinal range of 3500 to 4600 m above sea level. The study area is situated at 0°19′4.58″ N and 29°52′54.14″ E (Figure 1). Due to the lack of long-term climate data, statistically significant trends could not be determined. However, data from the Fresh Field Pass meteorological station (4200 m) recorded over a four-year period (2009 to 2012) indicate an average temperature of −1.3 °C and an average annual precipitation of 535.8 mm. Additionally, data from the Bujuku Hut station (3900 m) collected over a two-year period (2011–2012) show an average temperature of 3.9 °C and average annual precipitation of 526.1 mm [25]. Precipitation is primarily concentrated in two rainy seasons (March–May and September–December), during which fog, rain, and snow at the highest elevations persist for long periods. Frosts are frequent throughout most of the year at altitudes above 4000 m [26]. However, it must be highlighted that the lack of long-term climate data limits our ability to understand the ecology of the studied communities, and it is hoped that this gap can be filled in the future.

Geologically, the Ruwenzori Mountains form a narrow mountain range, exceeding 5000 m in elevation, within the western branch of the East African Rift System. Unlike the volcanic origins of Kilimanjaro and Mount Kenya, the Ruwenzori Mountains consist of Precambrian metamorphic rocks [27].

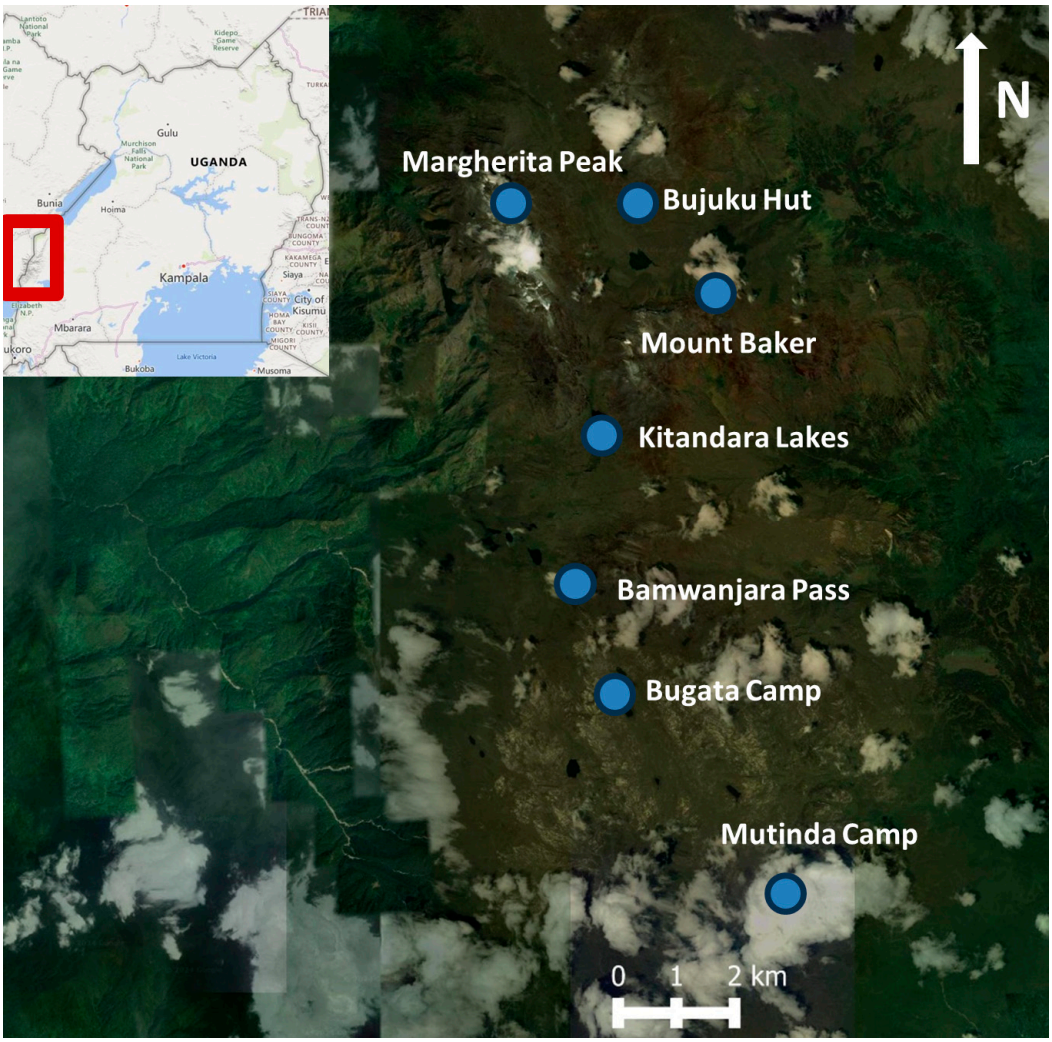

Figure 1. Ruwenzori Mountains, with indications of the locations where the surveys were carried out (blue dots), Uganda, maps from ESRI base map imagery, and OpenStreetMap (modified).

2.2. Data Collection

The plant species were identified and photographed directly in the field. Species identification, as well as other data on taxonomy and distribution, were obtained from the literature. The nomenclature of the taxa follows Flora of Tropical East Africa [28] and Flore du Rwanda [29]. Additional information on the taxonomy and species distribution was sourced from various references [30,31]. Fieldwork was conducted over a two-year period (2016–2017) during the months of December and January.

According to the Braun-Blanquet methodology [32], a total of 27 relevés were conducted in 12 sites within an altitudinal range of 3500–4600 m ASL. Plot size varied from 50 to 100 m^2. Vegetation relevés were sampled in different biotopes, which were randomly selected and positioned according to the principle of homogeneity. For each relevé, species presence was recorded. The coverage was obtained by a rough estimate of the percentage of surface covered by vegetation.

Due to insufficient expertise, the species of bryophytes and lichens were not identified.

2.3. Data Analysis and Vegetation Classification

All statistical analyses were performed using R 4.2.3 software [33]. According to van der Maarel [34], we converted the combined cover-abundance data into an ordinal scale (1–9). In particular, the hierarchical classification was carried out using the "vegan" package [35]. The phytosociological relevés were analyzed using the Bray-Curtis distance

and beta flexible method (beta = −0.25). The Bray-Curtis distance was chosen as it is widely recognized as one of the most effective metrics for analyzing ecological communities. It minimizes the impact of outliers and maintains sensitivity even when dealing with heterogeneous datasets [36]. The beta flexible method was employed as the linkage criterion due to its compatibility with Bray-Curtis distance and its property of conserving spatial relationships. This method preserves the integrity of the original dissimilarity matrix throughout the clustering process. In contrast, space-distorting methods may introduce issues like excessive chaining, where individual items are incrementally added to existing clusters [36,37]. The optimal number of clusters was determined using the silhouette index, calculated with the "cluster" package [38]. The indicator species analysis was carried out utilizing the "multipatt" function of the "indicspecies" package [39]. We calculated Pearson's phi coefficient [40] in order to identify the vegetation type-specific species for the different cluster groups [37,41]. Non-metric multidimensional scaling (NMDS), using Bray-Curtis dissimilarity, was applied to depict the main trends in the floristic differences. This iterative approach is particularly suitable for ecological data as it performs well with non-normal distributions, supports non-Euclidean distance measures, and does not assume linear or unimodal species responses to environmental gradients [36]. The nomenclature of the new syntaxa proposed (listed in Appendix A) follows the 4th edition of the *International Code of Phytosociological Nomenclature* [42]. The nomenclature and chorotype of the taxa recorded (listed in Appendix B) are in accordance with POWO [43].

3. Results and Discussion

Figure 2 presents a dendrogram derived from the classification of phytosociological relevés, which were divided into two primary groups (Cluster A and B). According to the silhouette width, 8 different plant communities were identified (Figure 3A). At each fusion level, the average silhouette width can be used as a measure of the quality of the partition (Rousseeuw quality index), and the best partition turns out to be exactly 8 clusters (Figure 3B).

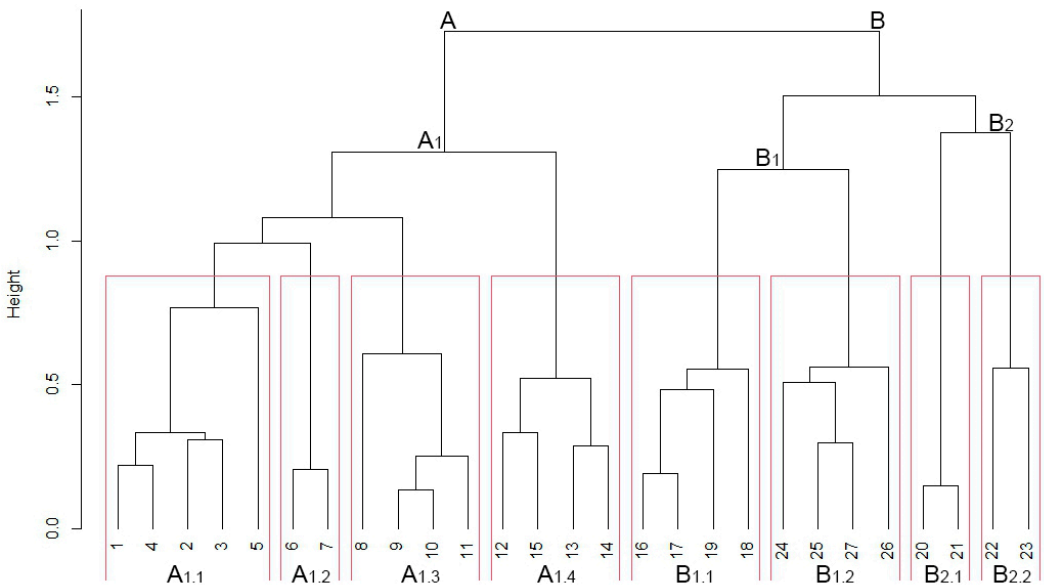

Figure 2. Hierarchical clustering of phytosociological relevés from the Ruwenzori Mountains (Uganda). The cophenetic correlation coefficient was 0.734. **A**. *Dendrosenecionetalia erici-rosenii*; $\mathbf{A_1}$. *Dendrosenecionion erici-rosenii*; $\mathbf{A_{1.1}}$. *Galio ruwenzoriensis-Dendrosenecionetum erici-rosenii*; $\mathbf{A_{1.2}}$. *Alchemilletum argyphyllae*; $\mathbf{A_{1.3}}$. *Helichrysetum stuhlmannii*; $\mathbf{A_{1.4}}$. *Erico trimerae-Hypericetum bequaertii*; **B**. *Dendrosenecionetalia adnivalis*; $\mathbf{B_1}$. *Dendrosenecionion adnivalis*; $\mathbf{B_{1.1}}$. *Lobelio wollastonii-Dendrosenecionetum adnivalis*; $\mathbf{B_{1.2}}$. *Caricetum runssoroensis*; $\mathbf{B_2}$. *Alchemillion stuhlmannii*; $\mathbf{B_{2.1}}$. *Alchemilletum subnivalis*; $\mathbf{B_{2.2}}$. *Senecio mattirolii-Sedetum ruwenzoriensis*.

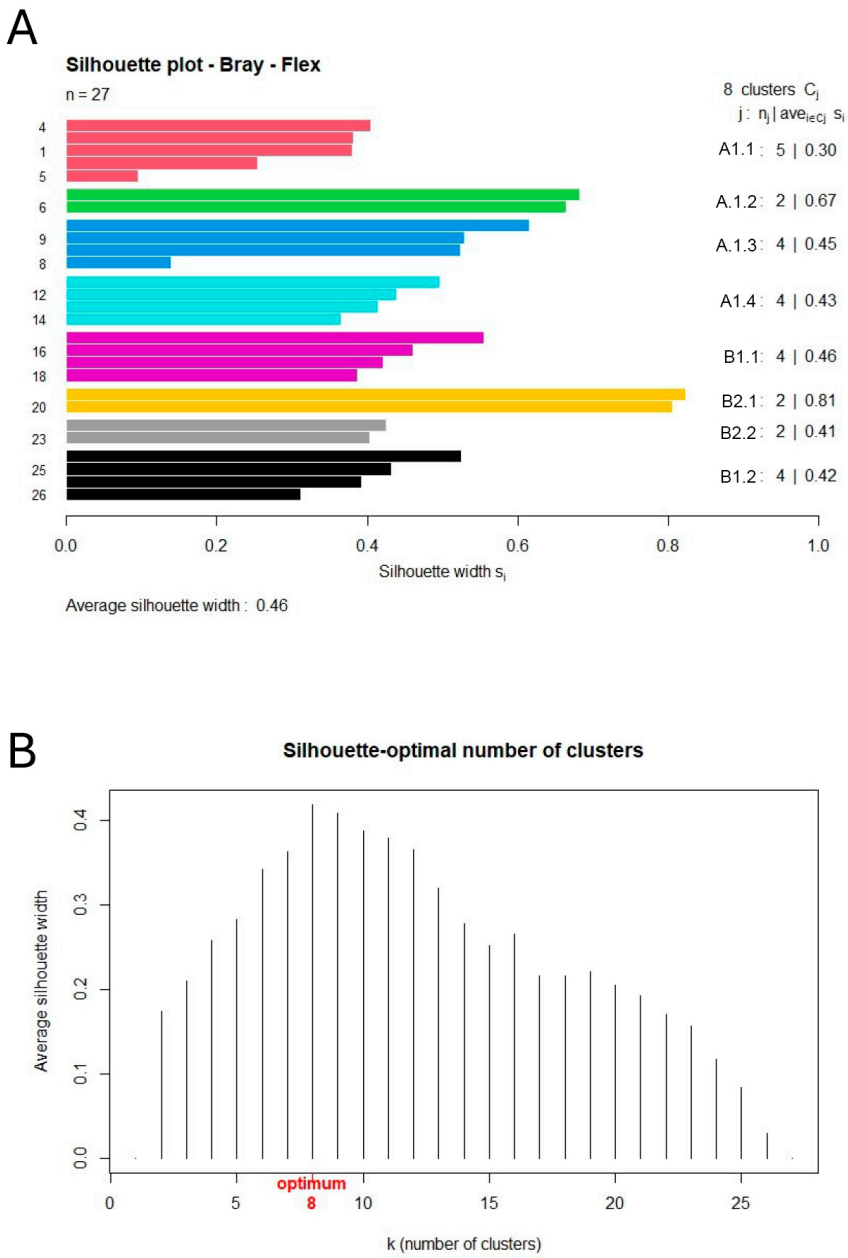

Figure 3. Average silhouette widths. (**A**). Silhouette plot of the clustering. (**B**). Bar plot showing the average silhouette widths for k = 2 to 29 groups. The best partition by this criterion is highlighted in red.

The non-metric multidimensional scaling (NMDS) analysis of the entire vegetation using species abundance confirmed the separation of the clusters of the dendrogram for each syntaxa (Figure 4). From a phytosociological viewpoint, a total of 8 associations, 3 alliances, 2 orders, and 1 class are presented. These represent new proposed syntaxa for the Ruwenzori Mountains, considering the lack of previous phytosociological studies for the area. Based on our phytosociological reléves, a reduction in species richness and vegetation cover with increasing elevation was noted. In fact, the communities occurring in the lower belt of the Afroalpine area (below 4000 m) show a floristic richness of up to 9–11 species for a 50 m^2 plot, while on the surfaces of equal size above 4000 m, no more than 7 species were detected, with a minimum of 5 species at around 4300 m. Furthermore, the vegetation of the Ruwenzori Mountains is significantly affected by the steep slopes, limited availability of substrate, and the harshest weather conditions being at higher altitudes. These data are consistent with the findings of Ssali et al. [44].

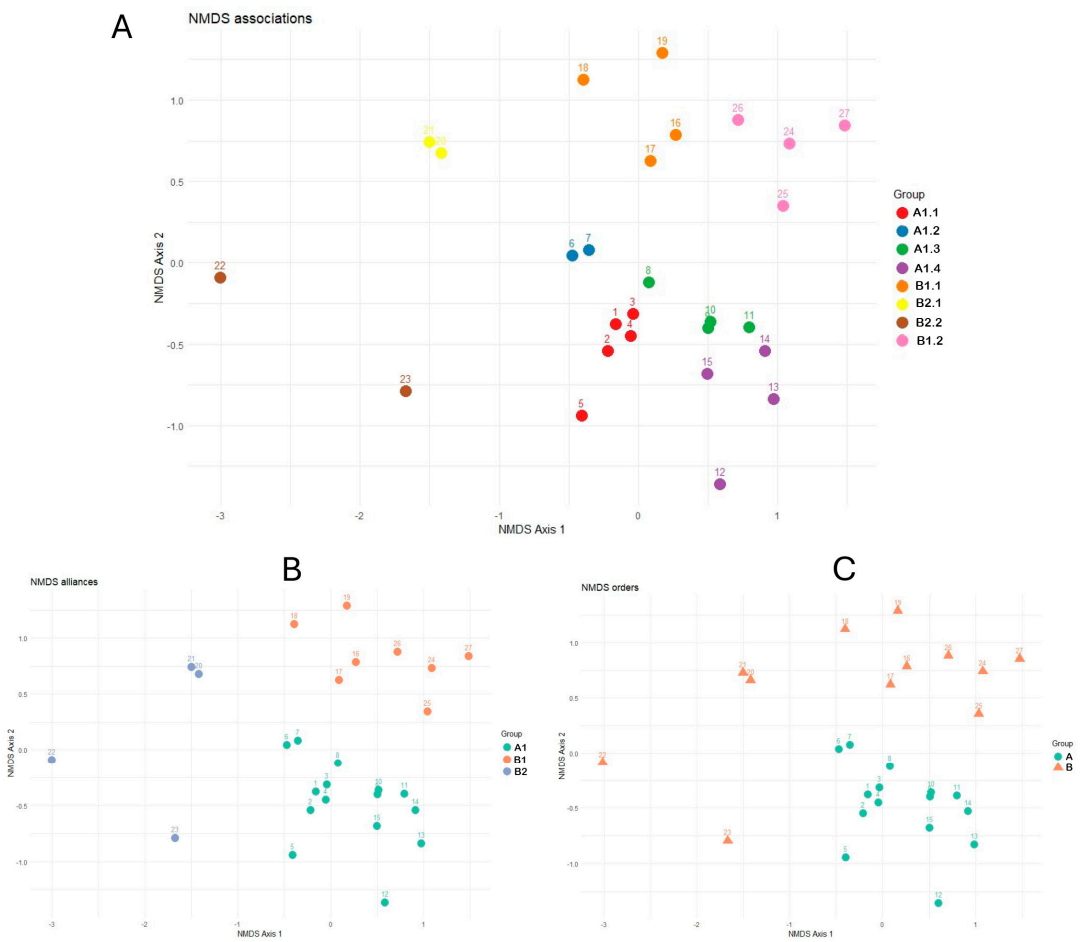

Figure 4. Non−metric multidimensional scaling (NMDS) of the phytosociological relevés (stress value = 0.14). (**A**). Associations; (**B**). alliances; (**C**). orders. For the legend of the syntaxa, see Figure 2.

Below is provided an overview of these vegetation units, with information about the floristic set, structure, composition, ecology, and distribution. After comparison with the literature [2,3,10–13], all these vegetation units could be described as new syntaxa.

3.1. Description of Vegetation Units

Helichrysetea stuhlmannii class nov. hoc loco
Holotypus: *Dendrosenecionetalia erici-rosenii* ord. nov.

Physiognomy and ecology: This class includes all Afroalpine vegetation communities found in the Ruwenzori Mountains. Similar vicariant syntaxa are likely present in the other central-eastern Africa mountains ranges, such as Kilimanjaro, Mount Elgon, Mount Kenya, etc. Floristically, this vegetation is characterized by the consistent presence and often dominance of *Helichrysum stuhlmannii.*

Indicator species: *Hypericum bequartii, Helichrysum stuhlmannii, Senecio transmarinus, Poa ruwenzoriensis*.

Distribution: This vegetation is widely distributed across the Afroalpine region of the Ruwenzori Mountains, occurring between 3000 (more typically 3500) and 4600 m above sea level.

A. ***Dendrosenecionetalia erici-rosenii*** ord. nov. hoc loco

Holotypus: ***Dendrosenecionion erici-rosenii*** all. nov. hoc loco

Physiognomy and ecology: This order includes plant communities linked to the lowest altitudinal zone of the Afroalpine belt. This vegetation is characterized by a dense

structure and dominated by tall woody species, such as *Dendrosenecio erici-rosenii*, *Erica trimera* subsp. *Trimera*, and *Hypericum bequartii*.

Indicator species: *Alchemilla argyrophylla subsp. argyrophylloides, Dendrosenecio erici-rosenii, Erica trimera* subsp. *trimera, Hypericum bequartii*.

Distribution: This vegetation is widespread in the Afroalpine region of the Ruwenzori mountains between (3000) 3500 and 4000 m ASL.

A1. ***Dendrosenecion erici-rosenii*** all. nov. hoc loco

Holotypus: *Galio ruwenzoriensis-Dendrosenecionetum erici-rosenii* ass. nov. hoc loco

Physiognomy and ecology: See order.

Indicator species: *Hypericum bequartii, Dendrosenecio erici-rosenii, Alchemilla argyrophylla* subsp. *argyrophylla, Erica trimera* subsp. *trimera*.

Distribution: See order.

A1.1. ***Galio ruwenzoriensis-Dendrosenecionetum erici-rosenii*** ass. nov. hoc loco (Table 1, Figure 2—Cluster $A_{1.1}$, Figure 5A)

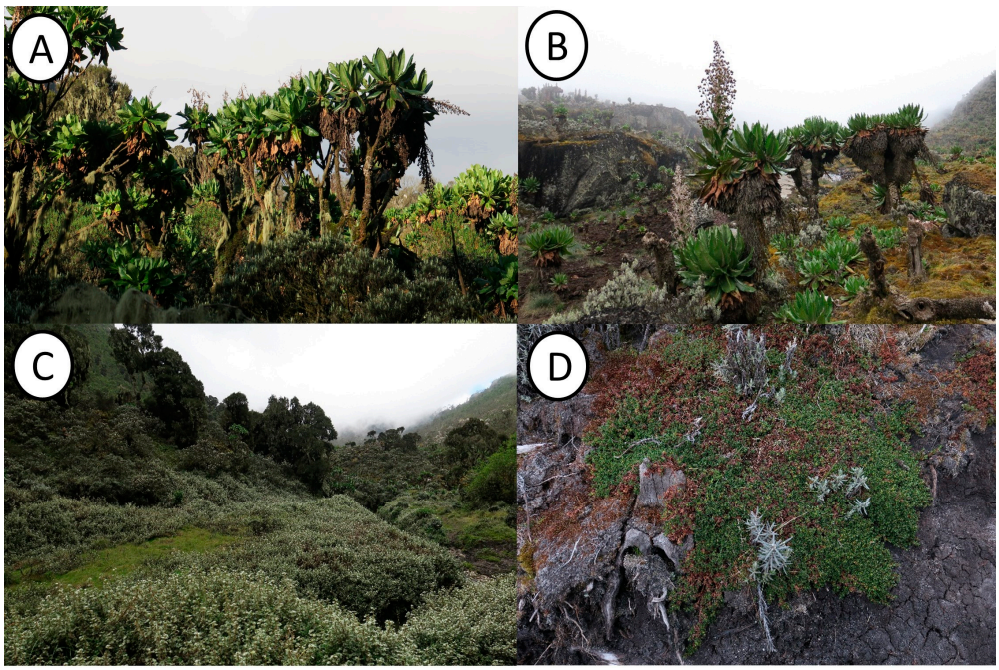

Figure 5. Afroalpine communities of Ruwenzori: (**A**) *Galio ruwenzoriensis-Dendrosenecionetum erici-rosenii*; (**B**) *Lobelio wollastonii-Dendrosenecionetum adnivalis*; (**C**) *Alchemilletum argyphyllae*; (**D**) *Alchemilletum subnivalis*. Photos by Salvatore Cambria.

Holotypus: Rel. 5, Table 1

Physiognomy and ecology: This vegetation type consists of tall woody species, reaching up to 8 m in height, and is associated with slightly sloping and moderately humid surfaces between 3600 and 4000 m. This plant community partly corresponds to the "*Dendrosenecio* woodland" quoted by Hedberg [4] and represents one of the most distinctive vegetation types of the Afroalpine areas. It is present in all the major mountains of central-eastern Africa, featuring various vicariant species of the genus *Dendrosenecio*. In the Ruwenzori Mountains, the dominant species is the local endemic *D. erici-rosenii*, which constitutes dense arboreal-shrub formations with high degrees of coverage, contrasting with similar vegetation on Mount Kenya and Kilimanjaro. Other species commonly found in this vegetation type are *Galium ruwenzoriense*, *Afrosciadium kerstenii*, *Helichrysum stuhlmannii*, *Lobelia stuhlmannii*, and *Alchemilla argyrophylla*. At higher altitudes (above 4000 m), *D. erici rosenii* becomes less frequent, being replaced by *D. adnivalis*, which prefers more humid and deeper soils.

Indicator species: *Dendrosenecio erici-rosenii, Galium ruwenzoriense, Lobelia stuhlmannii.*

Distribution: This vegetation was widely detected in various locations of the lower Afroalpine belt below 4000 m.

Table 1. *Galio ruwenzoriensis-Dendrosenecionetum erici-rosenii* ass. nov. hoc loco.

Relevés	**1**	**2**	**3**	**4**	**5**
Altitude (m)	3600	3600	3700	3700	4000
Surface (m^2)	100	100	50	50	100
Coverage (%)	90	80	90	90	90
Inclination (°)	60	60	70	70	70
Exposure	SO	SO	NO	NO	NE
Char. Ass.					
Dendrosenecio erici-rosenii	4	4	4	3	3
Lobelia stuhlmannii	2	+	+	1	.
Galium ruwenzoriense	.	+	.	+	1
Char. Ord. and All.					
Alchemilla argyrophylla subsp. *argyrophylloides*	+	1	1	1	.
Afrosciadium kerstenii	1	.	1	+	.
Hypericum bequaertii	.	.	1	+	1
Erica trimera subsp. *trimera*	+	+	+	.	.
Char. Class					
Helichrysum stuhlmannii	2	1	3	2	.
Senecio transmarinus	+	.	.	+	.
Other species					
Cardamine obliqua	.	+	+	.	+
Senecio sp.	+	+	.	+	.
Alchemilla johnstonii	.	+	.	.	.
Luzula johnstonii	+	.	.	.	.
Poa ruwenzoriensis	.	.	+	.	.
Lobelia wollastonii	.	.	.	.	1
Arabis alpina	.	.	.	.	+
Poa annua	.	.	.	.	+

A1.2. *Alchemilletum argyphyllae* ass. nov. hoc loco (Table 2, Figure 2—Cluster $A_{1.2}$, Figure 5C)

Holotypus: Rel. 6, Table 2

Physiognomy and ecology: This vegetation represents a typical community referred to as the "*Alchemilla* scrublands", which was previously investigated by Hauman [32] and Hedberg [4] and represents one of the most widespread vegetation types in all Afroalpine areas. From a phytogeographical point of view, it is notable for the presence of some genera commonly found in temperate areas of Europe and Asia, such as *Alchemilla*, *Cardamine*, *Poa*, *Deschampsia*, *Senecio*, *Hypericum*, etc. This community colonizes flat and humid surfaces, often on slightly raised areas above marshes, between 3600 and 4000 m. It is dominated by *A. argyrophylla* subsp. *argyrophylloides*, which, especially at lower altitudes, grows with *A. johnstonii*. The herbaceous layer frequently includes *Cardamine obliqua*, *Poa ruwenzoriensis*, and *Senecio transmarinus*.

Indicator species: *Afrosciadium kerstenii, Alchemilla argyrophylla* subsp. *argyrophylloides, A. johnstonii, Poa schimperana.*

Distribution: This vegetation is very frequent on the eastern slopes of the Ruwenzori Mountains.

Table 2. *Alchemilletum argyphyllae* ass. nov. hoc loco.

Relevés	**6**	**7**
Altitude (m)	3700	3800
Surface (m^2)	50	50
Coverage (%)	90	90
Inclination (°)	50	60
Exposure	NE	NE
Char. Ass.		
Alchemilla argyrophylla subsp. *argyrophylloides*	4	3
Alchemilla johnstonii	1	1
Afrosciadium kerstenii	1	+
Poa schimperana	.	+
Char. Ord. and All.		
Dendrosenecio erici-rosenii	+	.
Hypericum bequaertii	.	+
Char. Class		
Helichrysum stuhlmannii	+	1
Senecio trasmarinus	+	+
Poa ruwenzoriensis	+	+
Other species		
Cardamine obliqua	1	1
Alchemilla triphylla	.	+

A1.3. ***Helichrysetum stuhlmannii*** ass. nov. hoc loco (Table 3, Figure 2—Cluster $A_{1.3}$, Figure 6A)

Figure 6. Afroalpine communities of Ruwenzori: (**A**) *Helichrysetum stuhlmannii*; (**B**) *Erico trimerae-Hypericetum bequaertii*; (**C**) *Caricetum runssoroensis*; (**D**) *Senecio mattirolii-Sedetum ruwenzoriensis*. Photos by Salvatore Cambria.

Holotypus: Rel. 10, Table 3

Physiognomy and ecology: This scrub community generally represents secondary vegetation, originating from the degradation of *Dendrosenecio* woodlands. In particular, it

primarily colonizes recently burned areas up to 4400 m and constitutes one of the initial stages of plant recolonization after a fire [45].

The plant community is dense but floristically poor, dominated by *Helichrysum stuhlmannii*, a large shrub reaching up to 2 m in height, often associated with *Erica trimera* subsp. *trimera*, *Helichrysum guilelmi*, *Lobelia bequaertii*, etc. This vegetation likely plays a primary role in gently sloping, rocky areas with thin soil layers.. At altitudes above 4000 m, this vegetation tends to become shorter and sparser.

Indicator species: *Helichrysum stuhlmannii*, *Helichrysum guilelmi*, *Lobelia bequaertii*.

Distribution: This community represents one of the most typical vegetations of the Ruwenzori Mountains, particularly in the most disturbed areas of the Afroalpine zone.

Table 3. *Helichrysetum stuhlmannii* ass. nov. hoc loco.

Relevés	**8**	**9**	**10**	**11**
Altitude (m)	3900	4000	4000	3900
Surface (m^2)	50	100	100	100
Coverage (%)	70	80	80	90
Inclination (°)	60	70	70	60
Exposure	NO	SE	SE	NO
Char. Ass.				
Helichrysum stuhlmannii	3	3	4	4
Lobelia bequaertii	.	+	+	1
Helichrysum guilelmi	+	.	+	+
Char. Ord. and All.				
Alchemilla argyrophylla subsp. *argyrophylloides*	1	1	1	.
Erica trimera subsp. *trimera*	.	1	+	+
Hypericum bequaertii	.	+	1	+
Dendrosenecio erici-rosenii	+	.	.	.
Char. Class				
Senecio trasmarinus	1	.	.	.
Other species				
Alchemilla johnstonii	+	.	.	.
Senecio sp.	+	.	.	.
Hedbergia longiflora subsp. *macrophylla*	.	.	.	+

A1.4. *Erico trimerae-Hypericetum bequaertii* ass. nov. hoc loco (Table 4, Figure 2—Cluster $A_{1.4}$, Figure 6B)

Holotypus: Rel. 14, Table 4

Physiognomy and ecology: This association is characterized by a very peculiar woodland dominated by *Hypericum bequaertii*, an endemic species of Ruwenzori and Elgon Mt. It was first identified in the Ruwenzori Mountains by Schmitt & Beck [12]. This community occurs on steep, wet slopes in the lower belt of the Afroalpine zone, between 3300 and 4000 m. Usually, it forms a dense and tall vegetation reaching up to 12 m in height. The shrubby layer is mainly composed of *Erica trimera* subsp. *trimera*. From the floristic point of view, the occurrence of *Galium ruwenzoriense* is particularly noteworthy.

Indicator species: *Hypericum bequartii*.

Distribution: This community is quite rare in the western and eastern slopes of the Ruwenzori Mountains.

Table 4. *Erico trimerae-Hypericetum bequaertii* ass. nov. hoc loco.

Relevés	**12**	**13**	**14**	**15**
Altitude (m)	3600	4000	4000	4000
Surface (m^2)	50	100	100	50
Coverage (%)	90	80	80	70

Table 4. *Cont.*

Relevés	**12**	**13**	**14**	**15**
Inclination (°)	80	70	70	70
Exposure	NO	SE	SE	NE
Char. Ass.				
Hypericum bequaertii	4	3	4	3
Crassocephalum ducis-apruti	.	+	+	.
Char. Ord. and All.				
Erica trimera subsp. *trimera*	2	+	+	.
Dendrosenecio erici-rosenii	+	+	.	+
Lobelia bequaertii	.	+	+	.
Galium ruwenzoriense	.	+	.	.
Char. Class				
Helichrysum stuhlmannii	.	.	+	1
Senecio trasmarinus	.	.	+	.
Other species				
Lobelia wollastonii	.	1	1	+
Senecio sp.	+	.	.	+
Helichrysum forskahlii	.	.	+	.
Luzula johanstonii	.	.	+	.

B. ***Dendrosenecionetalia adnivalis*** ord. nov. hoc loco

Holotypus: *Dendrosenecion adnivalis* all. nov.

Physiognomy and ecology: This syntaxon includes the communities found in the upper altitudinal zone of the Afroalpine belt. This vegetation generally shows a loose structure and is floristically dominated by woody shrubs such as *Dendrosenecio adnivalis* and *Helichrysum stuhlmannii*. Additionally, various herbaceous plants are prominent, including *Carex runssoroensis*, *Deschampsia flexuosa*, *Festuca abyssinica*, and *Senecio transmarinus*.

Indicator species: *Dendrosenecio adnivalis, Carex runssoroensis, Alchemilla subnivalis.*

Distribution: This vegetation is widespread in the Afroalpine region of the Ruwenzori mountains between 4000 and 4600 m ASL.

B1. ***Dendrosenecionion adnivalis*** all. nov. hoc loco

Holotypus: *Lobelio wollastonii-Dendrosenecionetum adnivalis* ass. nov. hoc

Physiognomy and ecology: This alliance includes woody or herbaceous plant communities found on moderately moist, deep soils, typically on flat or slightly sloping surfaces. This vegetation occurs at elevations between 4000 and 4500 m ASL.

Diagnostic species: *Dendrosenecio adnivalis, Carex runssoroensis, Lobelia wollastonii.*

Distribution: See order.

B1.1. ***Lobelio wollastonii-Dendrosenecionetum adnivalis*** ass. nov. hoc loco (Table 5, Figure 2—Cluster $B_{1.1}$, Figure 5B)

Holotypus: Rel. 16, Table 5

Physiognomy and ecology: This community replaces the previous one in wet and deep soils, within the altitudinal range of 4000–4500 m. It consists of relatively tall vegetation, reaching up to 6–8 m in height, dominated by *Dendrosenecio adnivalis*, which constitutes a dense tree layer. Floristically, the physiognomy of this vegetation is characterized by the regular presence of *Lobelia wollastonii*, typically intermixed with *D. adnivalis* as individual plants or small groups. The herbaceous layer is sparse and composed of a few species, such as *Poa ruwezoriensis, Festuca abyssinica, Alchemilla* sp. pl., etc. A continuous moss carpet covers both the soil and the stems of *Dendrosenecio*.

Indicator species: *Dendrosenecio adnivalis, Alchemilla adnivalis, Lobelia wollastonii.*

Distribution: This vegetation is quite spread in the upper Afroalpine belt, particularly near the Bamwanjara Pass.

Table 5. *Lobelio wollastonii-Dendrosenecionetum adnivalis* ass. nov. hoc loco.

Relevés	**16**	**17**	**18**	**19**
Altitude (m)	4300	4300	4500	4200
Surface (m^2)	100	100	50	50
Coverage (%)	60	50	40	50
Inclination (°)	10	10	30	20
Exposure	NE	NE	NE	NE
Char. Ass.				
Dendrosenecio adnivalis	4	3	2	3
Char, All. and Ord.				
Lobelia wollastonii	2	1	.	+
Carex runssoroensis	+	.	.	+
Char. Class				
Helichrysum stuhlmannii	2	2	+	.
Alchemilla subnivalis	+	+	1	.
Afrosciadium kerstenii	+	+	.	.
Poa ruwenzoriensis	.	+	1	.
Festuca abyssinica	.	.	+	.
Other species				
Alchemilla triphylla	+	.	.	.
Lobelia stuhlmannii	.	.	.	+

B1.2. *Caricetum runssoroensis* ass. nov. hoc loco (Table 6, Figure 2—Cluster $B_{1.2}$, Figure 6C)

Holotypus: Rel. 24, Table 6

Physiognomy and ecology: The flat or gently sloping surfaces with poor drainage and waterlogging are colonized by herbaceous vegetation dominated by *Carex runssoroensis*, a species spread in all Afroalpine areas. This bog vegetation occurs between 3300 and 4200 m and is characterized by a taller layer of sedges and grasses, mainly including *C. runssoroensis*, *Deschampsia cespitosa*, and *Agrostis gracilifolia*, along with a lower moss carpet composed of *Sphagnum* sp.pl. and other herbaceous plants such as *Subularia monticola, Cerastium afromontanum, Ranunculus oreophytus, R. volkensii, Huperzia saururus*, etc. The tussocks of *C. runssoroensis* constitute a thick peat layer (up to 1 m), determining low values of pH [4]. This vegetation is often found in the outer belt of alpine lakes, transitioning inward to highly hygrophilous herbaceous communities dominated by *Subularia monticola.* Outwardly, this vegetation forms catenal contact with *Alchemilletum argyphyllae*, occurring on the dryer raised surfaces.

Indicator species: *Carex runssoroensis, Huperzia saururus, Ranunculus oreophytus, Subularia monticola.*

Distribution: This vegetation is very frequent in the Ruwenzori Mountains, particularly along the eastern slopes. Similar communities probably occur in the other Afroalpine areas.

Table 6. *Caricetum runssoroensis* ass. nov. hoc loco.

Relevés	**24**	**25**	**26**	**27**
Altitude (m)	3800	4100	4000	3900
Surface (m^2)	50	50	100	50
Coverage (%)	90	80	90	90
Inclination (°)	0	10	0	0
Exposure	SO	SO	NE	NE
Char. Ass.				
Carex runssoroensis	4	4	1	4
Huperzia saururus	.	+	+	+
Subularia monticola	.	+	1	+

Table 6. *Cont.*

Relevés	24	25	26	27
Ranunculus oreophytus	+	.	+	+
Cerastium afromontanum			+	+
Deschampsia cespitosa	+	.	3	.
Char. All.				
Lobelia wollastonii	1	+	+	.
Char. Ord.				
Dendrosenecio adnivalis			+	.
Char. Class				
Helichrysum stuhlmannii	+	+	+	+
Senecio trasmarinus	.	+	.	.
Other species				
Alchemilla subnivalis	+	.	+	.
Crassocephalum ducis-aprutii.	+	.	.	.
Erica trimera subsp. *trimera*	.	+	.	.
Helichrysum guilelmii	+	.	.	.
Agrostis gracilifolia	+	.	.	.
Alchemilla argyrophylla subsp. *argyrophylloides*	.	.	1	.
Ranunculus volkensii	.	.	.	+

B2. ***Alchemillion stuhlmannii*** all. nov. hoc loco

Holotypus: *Alchemilletum subnivalis* ass. nov. hoc loco

Physiognomy and ecology: This syntaxon includes low shrubby or herbaceous plant communities. This vegetation occurs on shallow soils, often with rocky outcrops, at elevations ranging from 4000 m to the upper limit of vegetation.

Indicator species: *Alchemilla stuhlmannii, A. triphylla, Arabis alpina, Festuca abyssinica.*

Distribution: See order.

B2.1. ***Alchemilletum subnivalis*** ass. nov. hoc loco (Table 7, Figure 2—Cluster $B_{1.2}$, Figure 5D)

Holotypus: Rel. 20, Table 7

Physiognomy and ecology: This community replaces the *Alchemilletum argyphyllae* at higher altitudes, occurring between 4000 and 4750 m, often on fresh moraines near the upper vegetation limit below glaciers. Floristically, it is a rather species-poor community with low coverage. In fact, *Alchemilla subnivalis* is associated with only a few other herbaceous species, including *A. triphylla, A. stuhlmannii, Arabis alpina, Poa ruwenzoriensis*, and *Cardamine obliqua*.

Indicator species: *Alchemilla subnivalis, Arabis alpina*.

Distribution: This vegetation is sparsely distributed across the upper slopes of the Ruwenzori Mountains.

B2.2. ***Senecio mattirolii-Sedetum ruwenzoriensis*** ass. nov. hoc loco (Table 8, Figure 2—Cluster $B_{2.2}$, Figure 6D)

Holotypus: Rel. 22, Table 8

Physiognomy and ecology: This is a chasmophilous community linked to rocky outcrops or stony slopes with very shallow soils, occurring between 3300 and 4500 m. It is characterized by the dominance of *Sedum ruwenzoriensis*, often with low coverage values. Floristically, this community shows very low species richness. Among the few other species present are *Senecio mattirolii*, *S.* x *pirottae*, *S. trasmarinus*, and *Festuca abyssinica.*

Indicator species: *Sedum ruzeworiense, Senecio mattirolii, S. x pirottae*.

Distribution: This vegetation is relatively uncommon and covers only small surfaces in the Ruwenzori Mountains.

Table 7. *Alchemilletum subnivalis* ass. nov. hoc loco.

Relevés	**20**	**21**
Altitude (m)	4300	4300
Surface (m^2)	50	50
Coverage (%)	90	90
Inclination (°)	40	30
Exposure	NO	NO
Char. Ass.		
Alchemilla subnivalis	3	2
Char. All., Ord. and Class		
Alchemilla stuhlmannii	+	1
Arabis alpina	+	+
Poa ruwenzoriensis	+	.
Other species		
Alchemilla triphylla	1	1
Cardamine obliqua	+	+

Table 8. *Senecio mattirolii-Sedetum ruwenzoriensis ass*. nov. hoc loco.

Relevés	**22**	**23**
Altitude (m)	4000	4000
Surface (m^2)	50	50
Coverage (%)	40	40
Inclination (°)	80	90
Exposure	NE	NE
Char. Ass.		
Sedum ruwenzoriense	2	2
Senecio mattirolii	1	1
Senecio x pirottae	+	+
Char. Ord. and All.		
Arabis alpina	+	+
Char. Class.		
Festuca abyssinica	1	+
Senecio trasmarinus	.	+
Other species		
Avenella flexuosa subsp. *flexuosa*	+	.

3.2. Floristic Remarks

A total of 39 vascular species (Appendix C, Figure 7) belonging to 21 genera and 15 families were recorded. The flora of the total relevé dataset is dominated by Asteraceae (10 taxa), Poaceae (7 taxa), Rosaceae (6 taxa), and Campanulaceae and Brassicaceae (3 taxa). These results concerning plant diversity are also in line with those observed, for example, in the study conducted by Ssali et al. [44]. Such a low number of recorded species is in agreement with the hypothesis proposed by [7]: that the Afroalpine flora is isolated, young, and unsaturated because the habitat disturbance caused by the Pleistocene climate oscillations likely induced cycles of colonization, speciation, extinction, and recolonization, probably not yet finished. A low number of species and a high rate of endemism are also observed in the high-altitude areas of mountains in other territories, which are also subject to Pleistocene climatic oscillations [45,46].

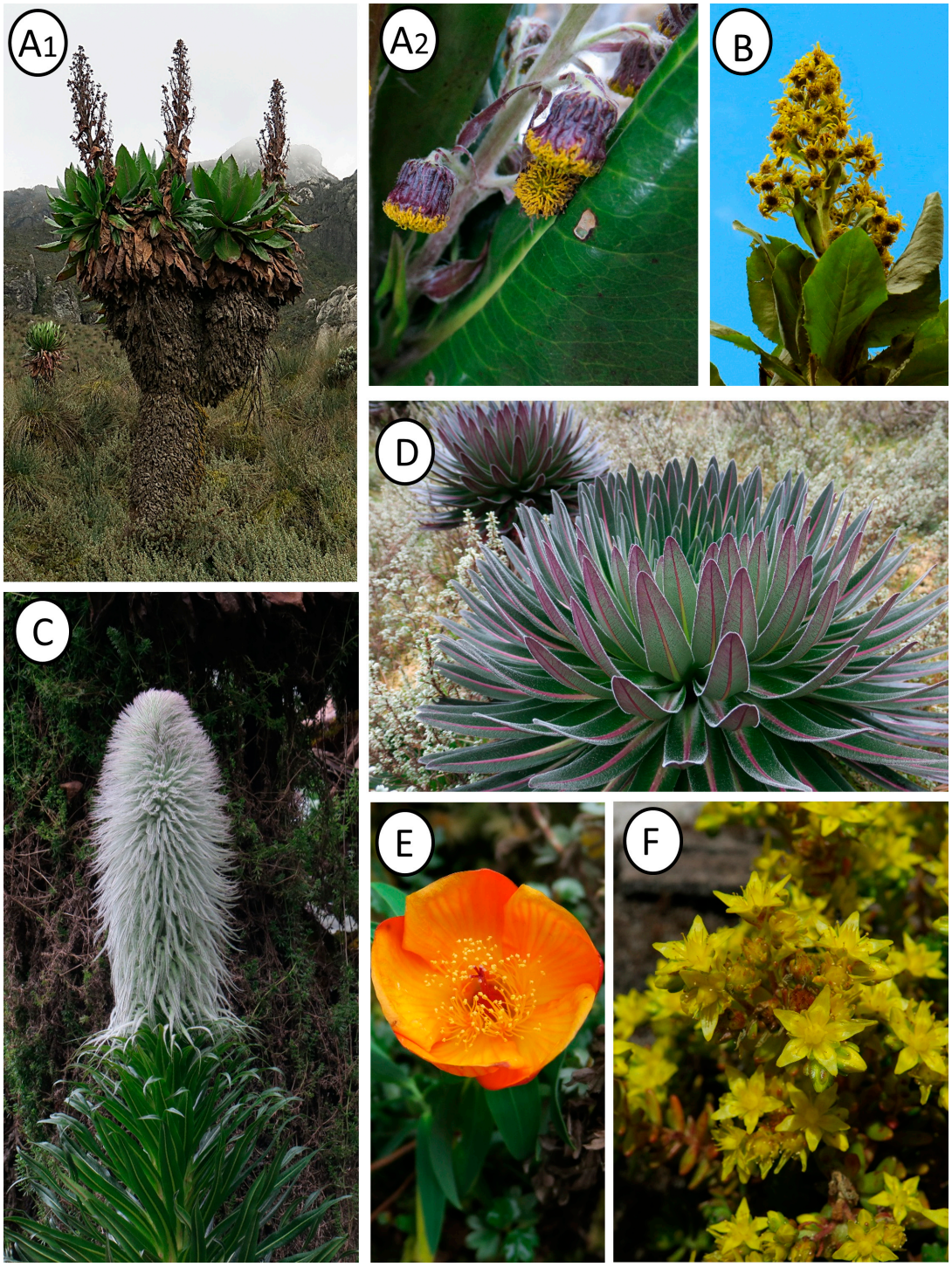

Figure 7. Endemic species and of phytogeographical interest in the Ruwenzori flora: (**A**) *Dendrosenecio adnivalis*: A1. habitus; A2. flower detail (**B**) *Dendrosenecio erici-rosenii*; (**C**) *Lobelia wollastonii*; (**D**) *Lobelia bequaertii*; (**E**) *Hypericum bequaertii*; (**F**) *Sedum ruwenzoriense*. Photos by Salvatore Cambria.

In terms of life forms (Figure 8), hemicryptophytes are the most represented (59%), followed by phanerophytes (16%), chamaephytes (15%), geophytes, and therophytes (2%). From a chorological perspective (Figure 9), the narrow endemics of the Ruwenzori mountains are represented by 11 taxa (28%), while 17 species (44%) are shared with other mountain areas of Central and Eastern Africa. A significant contingent consists of species mainly distributed in the temperate regions of Europe and Asia (5%). Furthermore, the vegetation

and flora of the Ruwenzori Mountains, including many endemic species identified during our phytosociological surveys, may be at high risk of extinction due to ongoing climate change [47]. This phenomenon is becoming increasingly apparent in East Africa's high mountain regions, as evidenced by the rapidly receding glaciers [48]. The difference in plant species between the lowest and highest summits of the Ruwenzori Mountains highlights the restricted elevation ranges of many species. Several studies have demonstrated that plant species growing in tropical alpine zones are predominantly dispersed by birds and wind, which enables them to overcome topographical barriers [49–51].

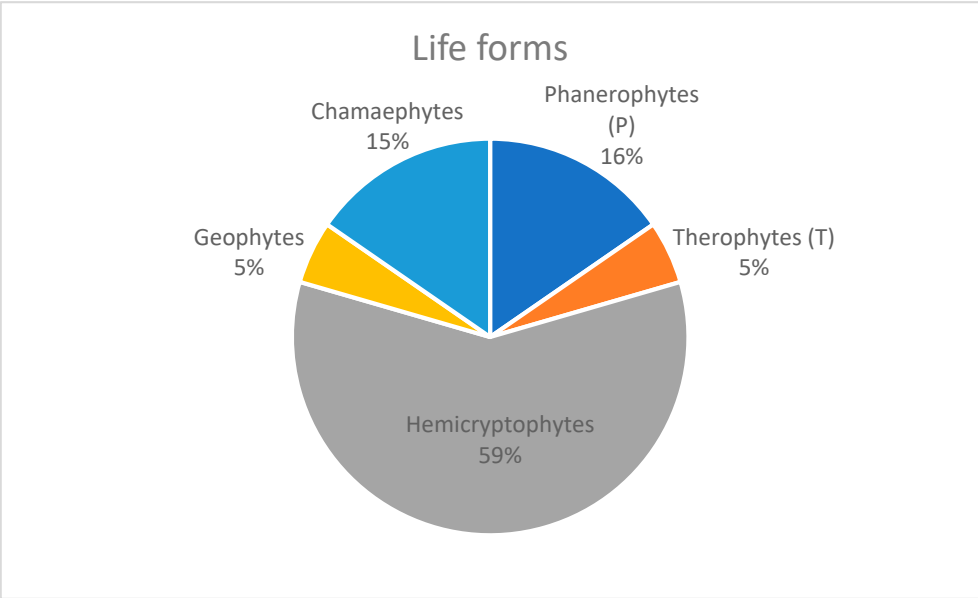

Figure 8. Life forms of the species recorded in the study area.

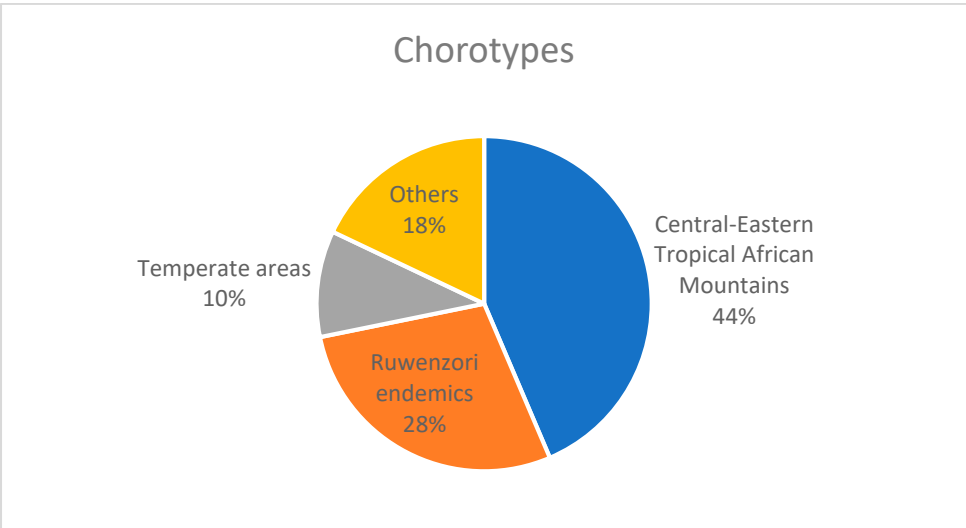

Figure 9. Chorotypes of the species investigated from the Ruwenzori mountains (Uganda).

4. Conclusions

The results of this study represent the first comprehensive classification of the Afroalpine vegetation of the Ruwenzori Mountains. The dominance of hemicryptophytes (59%) in the flora, followed by phanerophytes (16%) and chamaephytes (15%), reflects the significant adaptation of these life forms to the harsh climatic conditions at elevations above 3500 m. These adaptations, including frost tolerance and wind resistance, are critical for

survival in extreme environments. The vegetation communities display distinct vertical zoning in correspondence with altitudinal gradients (Figure 10). Identifying new plant groups, including new associations and alliances, contributes significantly to understanding Afroalpine vegetation.

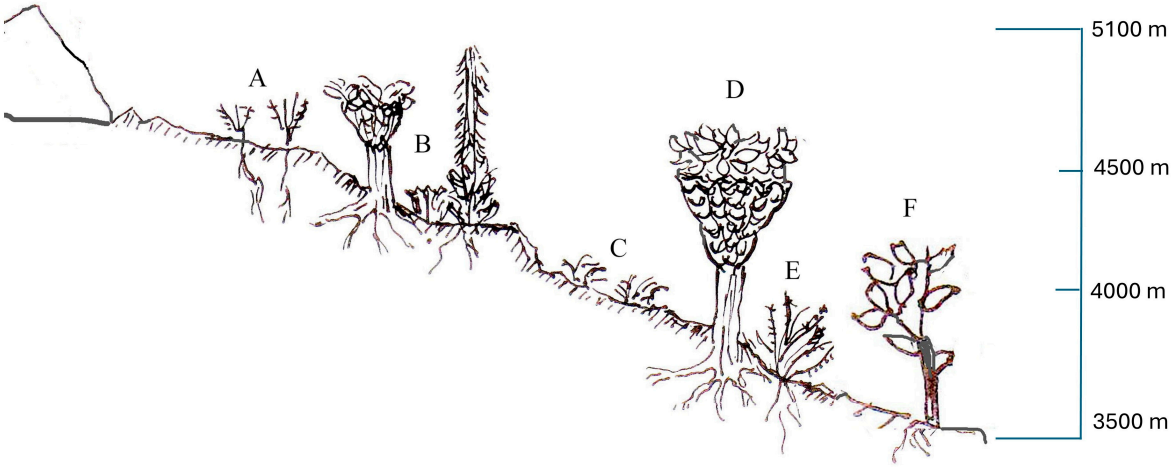

Figure 10. Altitudinal zonation of Afroalpine plant communities in the Ruwenzori Mountains. The summit area devoid of vegetation represents the zones devoid of vascular flora and coincides largely with the surface occupied by glaciers. It is followed towards lower altitudes by various communities: (**A**). *Alchemilletum subnivalis*: a low and floristically poor vegetation linked to the highest altitudes of the Afroalpine belt, developing up to 4750 m on fairly steep stands; (**B**). *Lobelio wollastonii-Dendrosenecionetum adnivalis*: a sparse scrub growing above 4000 m on deep, moist soils; (**C**). *Caricetum runssoroensis*: a grassland linked to humid stations on flat surfaces; (**D**). *Galio ruwenzoriensis-Dendrosenecionetum erici-rosenii*: a dense woodland occurring below 4000 m; (**E**). *Alchemilletum argyphyllae*: a low, shrubby vegetation linked to dry ridges; (**F**). *Erico trimerae-Hypericetum bequaertii*: a tall woodland occurring in the lower belt of the Afroalpine area. Drawing by Rosaria Di Cicca.

The presence of unique and vicariant species in the Ruwenzori Mountains, such as *Dendrosenecio erici-rosenii* and *Helichrysum stuhlmannii*, supports previous findings on the evolutionary significance of these isolated mountain ecosystems. Based on our results, the number of unique species highlights the biogeographical importance of the Ruwenzori Mountains as a center for endemism and a potential refuge during historical climatic shifts. The flora likely represents a mix of ancient lineages that survived past climatic fluctuations. The ecological significance of the identified plant communities is reflected in their roles in ecosystem function, particularly in water regulation and soil stabilization. The bog vegetation dominated by *Carex runssoroensis*, which occurs in poorly drained areas between 3300 and 4200 m, is crucial for peat formation and water retention. Despite the limitations of this study, including the sample size, constraints of the investigation period, and potential long-term effects of environmental changes, our findings provide a baseline for future research on Afroalpine vegetation.

Further investigations are needed to monitor the dynamics of these plant communities in response to environmental changes, particularly those driven by climate change. In conclusion, this study represents a significant step forward in the classification of the Afroalpine vegetation of the Ruwenzori Mountains. The identification of new plant communities and their ecological roles underscores the importance of these ecosystems for biodiversity conservation. Immediate conservation actions, combined with continued research, will be essential to preserve the unique flora of this remarkable mountain range.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land13111752/s1.

Author Contributions: Conceptualization, S.C. and G.T.; methodology, S.C., P.M. and G.T.; software, G.T.; validation, G.T. and S.C.; formal analysis, G.T.; investigation, S.C.; resources, P.M.; data curation, S.C.; writing—original draft preparation, S.C., G.T. and P.M.; writing—review and editing, S.C. and G.T.; visualization, G.T.; supervision, P.M.; project administration, P.M.; funding acquisition, P.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by the research program of University of Catania (PIA.CE.RI. 2020–2022) Line 2 cod. 22722132189.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request. The geographical coordinates of all the relevés are available in the Supplementary Materials.

Acknowledgments: We thank Rosaria Di Cicca for the illustration and Rwenzori Trekking Services for the support in the field activities.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Conspectus of the Syntaxa

HELICHRYSETEA STUHLMANNII Cambria, Minissale & Tavilla
- *DENDROSENECIONETALIA ERICI-ROSENII* Cambria, Minissale & Tavilla
  - *DENDROSENECIONION ERICI-ROSENII* Cambria, Minissale & Tavilla
    - *Galio ruwenzoriensis-Dendrosenecionetum erici-rosenii* Cambria, Minissale & Tavilla
    - *Alchemilletum argyphyllae* Cambria, Minissale & Tavilla
    - *Helichrysetum bequaertii* Cambria, Minissale & Tavilla
    - *Erico trimerae-Hypericetum bequaertii* Cambria, Minissale & Tavilla
- *DENDROSENECIONETALIA ADNIVALIS* Cambria, Minissale & Tavilla
  - *DENDROSENECIONION ADNIVALIS* Cambria, Minissale & Tavilla
    - *Lobelio wollastonii-Dendrosenecionetum adnivalis* Cambria, Minissale & Tavilla
    - *Caricetum runssoroensis* Cambria, Minissale & Tavilla
  - *ALCHEMILLION STUHLMANNII* Cambria, Minissale & Tavilla
    - *Alchemilletum subnivalis* Cambria, Minissale & Tavilla
    - *Senecio mattirolii-Sedetum ruwenzoriensis* Cambria, Minissale & Tavilla

Appendix B

Localities and dates of relevés. Table 1—Rels 1–2: 23 December 2016, Mutinda Camp (Uganda); Rels 3–4: 23 December 2016, sampling between Mutinda Camp and Bugata (Uganda); Rel 5: 26 December 2016, above Kachope Lakes (Uganda), Table 2—Rels 6–7: 23 December 2016, between Mutinda Camp and Bugata (Uganda). Table 3—Rel 8: 23 December 2016, between Mutinda Camp and Bugata (Uganda); Rels 9–10: 27 December 2016, near Butawu Camp (Uganda); Rel 11: 27 December 2016, near Kachope Lakes (Uganda). Table 4—Rel 12: 23 December 2016, above Mutinda Camp (Uganda); Rels 13–14: 27 December 2016, near Kachope Lakes (Uganda); Rel 15: 27 December 2016, near Kitandara Lake (Uganda). Table 5—Rels 16–17: 26 December 2016, near Bamwanjara Pass (Uganda); Rel 18: 27 December 2016, near Bamwanjara Pass (Uganda); Rel 19: 27 December 2016, between Bugata and Bamwanjara (Uganda). Table 6—Rels 24–25: 24 December 2016, near Bugata Camp (Uganda); Rel 26: 24 December 2016, valley above Kachope Lakes (Uganda); Rel 27: 27 December 2016, near Butawu Camp (Uganda). Table 7—Rels 20–21: 26 December 2016, near Bamwanjara Pass (Uganda). Table 8—Rels 22–23: 23 December 2016, near Bugata Camp (Uganda).

Appendix C

Species	Family	Life Forms	Chorotypes
Afrosciadium kerstenii (Engl.) P.J.D.Winter	Apiaceae	G	Central-Eastern Tropical African Mountains
Agrostis gracilifolia C.E.Hubb.	Poaceae	H	Central-Eastern Tropical African Mountains
Alchemilla argyrophylla Oliv. subsp. *argyrophylloides* (Baker f.) Rothm.	Rosaceae	Ch	Endemic Ruwenzori
Alchemilla johnstonii Oliv.	Rosaceae	H	Central-Eastern Tropical African Mountains
Alchemilla stuhlmannii Engl.	Rosaceae	Ch	Endemic Ruwenzori
Alchemilla subnivalis Baker f.	Rosaceae	Ch	Endemic Ruwenzori
Alchemilla triphylla Rothm.	Rosaceae	Ch	Endemic Ruwenzori
Arabis alpina L.	Brassicaceae	H	Temperate areas of Old World
Avenella flexuosa (L.) Drejer subsp. *Flexuosa*	Poaceae	H	Temperate areas
Cardamine obliqua Hochst. ex A.Rich.	Brassicaceae	H	Tropical mountains of America and Africa
Carex runssoroensis K.Schum.	Cyperaceae	H	Central-Eastern Tropical African Mountains
Crassocephalum ducis-apruti S. Moore	Asteraceae	H	Central-Eastern Tropical African Mountains
Dendrosenecio adnivalis (Stapf) E.B.Knox	Asteraceae	P	Endemic Ruwenzori
Dendrosenecio erici-rosenii (R.E.Fr. & T.C.E.Fr.) E.B.Knox	Asteraceae	P	Endemic Ruwenzori
Deschampsia cespitosa (L.) P. Beauv.	Poaceae	H	Temperate areas
Erica trimera (Engl.) Beentje subsp. *trimera*	Ericaceae	P	Endemic Ruwenzori
Festuca abyssinica A. Rich	Poaceae	H	Africa
Galium ruwenzoriense (Cortesi) Ehrend.	Rubiaceae	H	Central-Eastern Tropical African Mountains
Hedbergia longiflora (Hochst. ex Benth.) A.Fleischm. & Heubl subsp. *macrophylla* (Hedberg) A.Fleischm. & Heubl	Orobanchaceae	G	Central-Eastern Tropical African Mountains
Helichrysum forskahlii (J.F.Gmel.) Hilliard & B.L.Burtt	Asteraceae	Ch	Africa and SW Asia
Helichrysum guilelmi Engl.	Asteraceae	P	Central-Eastern Tropical African Mountains
Helichrysum stuhlmannii O.Hoffm.	Asteraceae	P	Endemic Ruwenzori
Huperzia saururus (Lam.) Trevis.	Lycopodiaceae	H	Tropical areas of Africa and America
Hypericum bequaertii De Wild.	Hypericaceae	P	Central-Eastern Tropical African Mountains

Species	Family	Life Forms	Chorotypes
Lobelia bequaertii De Wild.	Campanulaceae	H	Endemic Ruwenzori
Lobelia stuhlmannii Schweinf. ex Stuhlmann	Campanulaceae	H	Central-Eastern Tropical African Mountains
Lobelia wollastonii Baker f.	Campanulaceae	H	Central-Eastern Tropical African Mountains
Luzula johnstonii Buchenau	Juncaceae	H	Eastern and Central Africa
Poa annua L.	Poaceae	T	Temperate areas
Poa ruwenzoriensis Robyns & Tournay	Poaceae	H	Central-Eastern Tropical African Mountains
Poa schimperiana Hochst. ex A.Rich.	Poaceae	H	Tropical Africa and SW Asia
Ranunculus oreophytus Delile	Ranunculaceae	H	Central-Eastern Tropical African Mountains
Ranunculus volkensii Engl.	Ranunculaceae	H	Central-Eastern Tropical African Mountains
Sedum ruwenzoriense Baker f.	Crassulaceae	Ch	Central-Eastern Tropical African Mountains
Senecio mattirolii Chiov.	Asteraceae	H	Endemic Ruwenzori
Senecio sp.	Asteraceae	H	-
Senecio transmarinus S. Moore	Asteraceae	H	Central-Eastern Tropical African Mountains
Senecio x *pirottae* Chiov.	Asteraceae	H	Endemic Ruwenzori
Subularia monticola A.Braun ex Schweinf.	Brassicaceae	T	Central-Eastern Tropical African Mountains

List of taxa surveyed in the phytosociological study. The following abbreviations are used for life forms: G = Geophyte; H = Hemicryptophyte; Ch = Chamaephyte; P = Phanerophyte; T = Phanerophyte.

References

1. Bere, R.M. The exploration of Ruwenzori. *Alp. J.* **1952**, *285*, 483–495.
2. Ross, R. Some aspects of the vegetation of the sub-alpine zone on Ruwenzori. *Proc. Linn. Soc. Lond.* **1953**, *165*, 136–140. [CrossRef]
3. Ross, R. Some aspects of the vegetation of the Ruwenzori. *Webbia* **1955**, *11*, 451–457. [CrossRef]
4. Hedberg, O. *Features of Afroalpine Plant Ecology*; Swedish Science Press: Stockholm, Sweden, 1964; pp. 1–144.
5. Hedberg, O. Evolution and speciation in tropical high mountain flora. *Biol. J. Linn. Soc.* **1969**, *1*, 135–149. [CrossRef]
6. Brochmann, C.; Gizaw, A.; Chala, D.; Kandziora, M.; Eilu, G.; Popp, M.; Pirie, M.B.; Gehrke, B. History and evolution of the afroalpine flora: In the footsteps of Olov Hedberg. *Alp. Bot.* **2022**, *132*, 65–87. [CrossRef]
7. Kandziora, M.; Gehrke, B.; Popp, M.; Gizaw, A.; Brochmann, C.; Pirie, M.D. The enigmatic tropical alpine flora on the African sky islands is young, disturbed, and unsaturated. *Proc. Natl. Acad. Sci. USA* **2022**, *119*, e2112737119. [CrossRef]
8. Hedberg, O. The phytogeographical position of the afroalpine flora. *Rec. Adv. Bot.* **1961**, *1*, 914–919.
9. Woosnam, R.B. Ruwenzori and its life Zones. *Geogr. J.* **1907**, *30*, 616–629. [CrossRef]
10. Engler, A. *Die Pflanzenwelt Afrikas, Part 5*; W. Engelmann: Leipzig, Germany, 1925; pp. 1–341.
11. Loveridge, J.P. Plant ecological investigations in the Nyamagasani Valley, Ruwenzori Mountains, Uganda. *Kirkia* **1968**, *6*, 153–168.
12. Schmitt, K.; Beck, E. On the Afroalpine vegetation of the Ruwenzori Mountain, Uganda. *Phytocoenologia* **1992**, *21*, 313–332. [CrossRef]
13. Fishlock, C.W.L.; Hancock, G.L.R. Notes on the flora and fauna of Ruwenzori with special reference to the Bujuku valley. *J. East Afr. Nat. Hist. Soc.* **1932**, *44*, 205–229.
14. Rejmànkovà, E.; Rejmànek, M.A. Comparison of *Carex runssoroensis* Fens on Ruwenzori Mountains and Mount Elgon, Uganda. *Biotropica* **1995**, *27*, 37–46. [CrossRef]
15. Beck, E. Plant Life on Top of Mt. Kilimanjaro (Tanzania). *Flora* **1988**, *181*, 379–381. [CrossRef]
16. Hemp, A. Vegetation of Kilimanjaro: Hidden Endemics and Missing Bamboo. *Afr. J. Ecol.* **2006**, *44*, 305–328. [CrossRef]
17. Kokwaro, J.O. Vegetation analysis of the upper Teleki valley (Mount Kenya) and adjacent areas. *J. East Afr. Nat. Hist.* **1981**, *171*, 1–8.
18. Young, T.P.; Peacock, M.M. Giant Senecios and Alpine Vegetation of Mount Kenya. *J. Ecol.* **1992**, *80*, 141–148. [CrossRef]
19. Kaul, V.; Sarin, Y.K. The phytosociology of some alpine meadows in N.W. Himalayas. *Vegetatio* **1971**, *23*, 361–368. [CrossRef]

20. Parolly, G. The High Mountain Vegetation of Turkey—A State of the Art Report, Including a First Annotated Conspectus of the Major Syntaxa. *Turk. J. Bot.* **2004**, *28*, 39–63.
21. Noroozi, J.; Hülber, K.; Willner, W. Phytosociological and ecological description of the high alpine vegetation of NW Iran. *Phytocoenologia* **2004**, *47*, 233–259. [CrossRef]
22. Malfasi, F.; Cannone, N. Phytosociology of the vegetation communities of the Stelvio Pass area. *J. Maps* **2021**, *17*, 367–375. [CrossRef]
23. Zarate, N. The database on high Andean páramo vegetation in Colombia. *Biodivers. Ecol.* **2012**, *4*, 275–286.
24. Montesinos-Tubée, D.B.; Cleef, A.M.; Sýkora, K.V. The Subnival Vegetation of Moquegua, South Peru: Chasmophytes, Grasslands and Cushion Communities. *Ecologies* **2021**, *2*, 71–111. [CrossRef]
25. Eilu, G.; Galabuzi, C.; Waiswa, D.; Oriekot, J.; Kakuri, W.; Mwavu, E.N.; Orikiriza, L.B.; Turyahabwe, N.; Shofuna, A.; Kasangaki, A.; et al. *Impact of Climate Change on the Species of Restricted Range in RMNP. Final Report November 2013*; Makerere University: Kampala, Uganda, 2013; pp. 1–61.
26. Eggermont, H.; van Damme, K.; Russell, J.M. Rwenzori Mountains (Mountains of the Moon): Headwaters of the White Nile. In *The Nile: Origin, Environments, Limology and Human Use*; Dumont, H.J., Ed.; Springer Science + Business Media B.V.: Berlin, Germany, 2009; pp. 243–261.
27. Bauer, F.U.; Karl, M.; Glasmacher, U.A.; Nagudi, B.; Schumann, A.; Mroszewski, L. The Rwenzori Mountains of western Uganda—Aspects on the evolution of their remarkable morphology within the Albertine Rift. *J. Afr. Earth Sci.* **2012**, *73–74*, 44–56. [CrossRef]
28. Milne-Redhead, E.; Bertram Turrill, W.; Hubbard, C.E.; Polhill, R.M.; Beentje, H.; Ghazanfar, S.A. (Eds.) *Flora of Tropical East Africa*; 263 parts; Crown Agents for Overseas Governments and Administration & Rotterdam: London, UK, 1952–2012.
29. Troupin, G. (Ed.) *Flore du Rwanda. Spermatophytes*; Koninklijk Mseum voor Midden-Afrika: Tervuren, Belgium, 1978–1987.
30. König, P. *Field Guide to the Upland Plants of Uganda*; Meise Botanic Garden: Greifswald, Germany, 2023; pp. 4–511.
31. Braun-Blanquet, J. *Pflanzensoziologie*; Grundzüge der Vegetationskunde: Berlin, Germany, 1928; pp. 1–888.
32. Hauman, L. Esquisse de la vegetation des hautes altitudes sur le Ruwenzori. *Bull. Acad. Belg. Cl. Sci. V* **1933**, *19*, 301–368.
33. R Core Team. R: A Language and Environment for Statistical Computing. 2022. Available online: https://www.R-project.org/ (accessed on 26 July 2024).
34. van der Maarel, E. Transformation of cover-abundance values in phytosociology and its effects on community similarity. *Vegetatio* **1979**, *39*, 97–114.
35. Oksanen, J. Multivariate Analysis of Ecological Communities in R: Vegan Tutorial. 2015. Available online: https://john-quensen.com/wp-content/uploads/2018/10/Oksanen-Jari-vegantutor.pdf (accessed on 23 September 2024).
36. McCune, B.; Grace, J.B. *Analysis of Ecological Communities*; MjM Software Design: Gleneden Beach, OR, USA, 2002.
37. Legendre, P.; Legendre, L. *Numerical Ecology*; Elsevier: Salt Lake City, UT, USA, 2012.
38. Maechler, M.; Rousseeuw, P.; Struyf, A.; Hubert, M.; Hornik, K.; Studer, M.; Roudier, P.; Gonzalez, J.; Kozlowski, K.; Schubert, E.; et al. Cluster: Cluster Analysis Basics and Extensions. R Package Version 2.1.1. Available online: https://CRAN.R-project.org/package=cluster (accessed on 23 September 2024).
39. De Cáceres, M. indicspecies: Relationship Between Species and Groups of Sites. Available online: https://cran.r-project.org/web/packages/indicspecies/index.html (accessed on 23 September 2024).
40. Chytrý, M.; Tichý, L.; Holt, J.; Botta-Dukát, Z. Determination of diagnostic species with statistical fidelity measures. *J. Veg. Sci.* **2002**, *13*, 79–90. [CrossRef]
41. De Cáceres, M.; Legendre, P. Associations between species and groups of sites: Indices and statistical inference. *Ecology* **2009**, *90*, 3566–3574. [CrossRef]
42. Theurillat, J.P.; Willner, W.; Fernández-González, F.; Bültmann, H.; Čarni, A.; Gigante, D.; Mucina, L.; Weber, H. International code of phytosociological nomenclature. *Appl. Veg. Sci.* **2021**, *24*, e12491. [CrossRef]
43. POWO (Plants of the World Online). Facilitated by the Royal Botanic Gardens, Kew. Available online: https://powo.science.kew.org/ (accessed on 27 September 2024).
44. Ssali, F.; Mugerwa, B.; van Heist, M.; Nkurunziza, V.; Mutabazi, M.; Arinaitwe, H.; Bitariho, R.; Uwimana, A.; Oryem-Origa, H.; Gilbert, G. Plant diversity and composition vary with elevation on two equatorial high mountains in Uganda: Baselines for assessing the influence of climate change. *Alp. Bot.* **2023**, *133*, 149–161. [CrossRef]
45. Sciandrello, S.; Minissale, P.; Giusso del Galdo, G. Vascular plant species diversity of Mt. Etna (Sicily): Endemicity, insularity and spatial patterns along the altitudinal gradient of the highest active volcano in Europe. *PeerJ* **2020**, *8*, e9875. [CrossRef]
46. Raduła, M.; Świerszcz, S.; Nobis, M.; Nowak, S.; Nobis, A.; Nowak, A. Palaeoclimate has a major effect on the diversity of endemic species in the hotspot of mountain biodiversity in Tajikistan. *Sci. Rep.* **2021**, *11*, 18684. [CrossRef] [PubMed]
47. Eltringham, S.K. The frequency and extent of uncontrolled grass fires in the Rwenzori National Park, Uganda. *Afr. J. Ecol.* **1976**, *14*, 215–222. [CrossRef]
48. Chala, D.; Brochmann, C.; Psomas, A.; Ehrich, D.; Gizaw, A.; Masao, C.A.; Bakkestuen, V.; Zimmermann, N.E. Good-bye to tropical alpine plant giants under warmer climates? Loss of range and genetic diversity in *Lobelia rhynchopetalum*. *Ecol. Evol.* **2016**, *6*, 8931–8941. [CrossRef] [PubMed]
49. Tovar, C.; Melcher, I.; Kusumoto, B.; Cuesta, F.; Cleef, A.M.; Meneses, R.I.; Halloy, S.; Llambí, L.D.; Beck, S.; Muriel, P.; et al. Plant dispersal strategies of high tropical alpine communities across the Andes. *J. Ecol.* **2020**, *108*, 1910–1922. [CrossRef]

50. Tovar, C.; Hudson, L.; Cuesta, F.; Meneses, R.I.; Muriel, P.; Hidalgo, O.; Palazzesi, L.; Suárez Ballesteros, C.; Hammond Hunt, E.; Diazgranados, M.; et al. Strategies of diaspore dispersal investment in Compositae: The case of the Andean highlands. *Ann. Bot.* **2023**, *132*, 255–267. [CrossRef]
51. Wang, X.; Zhou, X.; Zhang, M.; Donohue, K.; Hou, M.; Li, J.; Ge, W.; Zhou, H.; Ma, L.; Yang, L.; et al. Climate and plant traits alter the relationship between seed dispersal and seed dormancy in alpine environment. *Environ. Exp. Bot.* **2024**, *219*, 105660. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.