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COMMUNICATION

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DISTRIBUTION AND HABITS OF *PAPHIOPEDILUM PFITZER* (ORCHIDACEAE) KNOWN TO OCCUR IN BHUTAN

Dhan Bahadur Gurung¹ , Nima Gyeltshen² , Kezang Tobgay³ , Stig Dalström⁴ , Jangchu Wangdi⁵ , Bhakta Bahadur Ghalley⁶ , Lekey Chaida⁷ , Phuntsho⁸ , Ngawang Gyeltshen⁹ , Kelzang Dawa¹⁰ , Tandin Wangchuk¹¹ , Rebecca Pradhan¹² , Thomas Hoijer¹³ & Choki Gyeltshen¹⁴

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PLATINUM
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Abstract: *Paphiopedilum fairrieanum*, *P. spicerianum*, and *P. venustum* (Orchidaceae: Cypripedioideae) are reported to occur in Bhutan, of which the former is known to be Critically Endangered and the latter two are Endangered. Based on numerous field trips conducted over the last decade, populations of *P. fairrieanum* and *P. venustum* were located in Bhutan. No individual of *P. spicerianum*, however, was found despite many search attempts. Its occurrence in Bhutan may have been originally erroneous. Based on the accessibility of the habitats, six 10m × 10m quadrats were defined to enumerate the plant species found in the *Paphiopedilum* habitats. Vegetation analyses and cluster dendograms of the plant species composition indicated the presence of three forest types with distinct species compositions. *Paphiopedilum fairrieanum* was found growing mainly as a lithophyte on seasonally dry limestone cliffs or on limestone outcrops with a comparatively open forest canopy. These populations were mostly located on southwest- or northwest-facing slopes with soil pH ranging from 7.1 to 7.8. *Paphiopedilum venustum*, in contrast, was a ground-dwelling species restricted to relatively dense forests with soil pH ranging from 7.1 to 7.5.

Keywords: Cluster dendrogram, eastern Himalaya, orchid, *Paphiopedilum fairrieanum*, *P. spicerianum*, *P. venustum*, vegetation analysis.

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INTRODUCTION

More than 70 species of *Paphiopedilum* Pfitzer (Orchidaceae: Cypripedioideae) are reported from southeastern Asia, India, Myanmar, southwestern China, Indonesia, the Philippines, New Guinea, and the Solomon Islands (Pearce & Cribb 2002). Distribution ranges for some species extend to the eastern Himalaya, including Bhutan, India, and Nepal. Pradhan (1976) reported the occurrence of *P. fairrieanum* (Lindl.) Stein and *P. venustum* (Wall. ex Sims) Pfitzer in Bhutan. Pearce & Cribb (2002), however, reported *P. fairrieanum* and *P. spicerianum* (Rchb. f.) Pfitzer from Bhutan, but not *P. venustum*. All these three *Paphiopedilum* species are listed in the IUCN Red List as either Endangered or Critically Endangered and are considered possibly extinct in Bhutan (Rankou & Kumar 2015a,b; Rankou & Molur 2015).

Paphiopedilum fairrieanum (Critically Endangered) is reported from Surelakha in Sarpang District (Pearce & Cribb 2002), Gomdar in Samdrup Jongkhar District (Gurung 2006), and Kalikhola in Dagana District (Dorji 2008). Recent surveys, however, indicate that *P. fairrieanum* is no more found in Surelakha. Consequently, the Bhutanese researchers, academics, foresters, and volunteers who have begun to study orchids have expanded their search for new populations of the species outside the recorded localities.

In addition to being considered possibly extinct in Bhutan (Rankou & Kumar 2015a,b; Rankou & Molur 2015), very little is known about the distribution ranges, habitat preferences, and population structures of the *Paphiopedilum* species known to occur in the country. Using the information generated from several explorations, this paper provides the current occurrence status of these *Paphiopedilum* species and the vegetation composition of their habitats.

MATERIALS AND METHODS

The team conducted a series of orchid expeditions over the last decade. Habitat information provided by researchers allowed confirmations of *Paphiopedilum* species in the reported areas. Vegetation surveys were conducted in a few selected areas in 2016, based on the accessibility of the habitats. A total of 13 quadrats of 100m² was laid out in different locations and among the 13 plots, six quadrats of 10m × 10m where the *Paphiopedilum* species occur were surveyed to assess the vegetation composition, habitat quality, and species richness of these sites: three in Zhemgang, two

in Mongar, and one in Samdrup Jongkhar. In the tree category, diameters at breast height (DBH) at 1.3m above the ground were measured to determine the basal area. On the forest ground, subplots of size 2m × 2m were laid out for herbs, and the height of the tallest of each species and their corresponding coverage were recorded. Soil pH was measured by using Takemura Digital pH meter. Species basal area (BA) was calculated from DBH data of all the tree individuals and the relative proportion of the basal area of each species was calculated in percentage (RBA). Species diversity index (H) was calculated using the Shannon & Wiener equation. The processed data were then analyzed by using PC-ORD version 5.1 program. Cluster analysis was performed using the distance measure of Sorenson (Bray-Curtis) with group linkage method to determine the forest types of the *Paphiopedilum* habitats (Ohsawa 2002; Dorji et al. 2014).

RESULTS AND DISCUSSION

Distribution range of *Paphiopedilum fairrieanum*

The occurrence of *Paphiopedilum fairrieanum* (Lindl.) Stein in Bhutan was reported by Pradhan (1976) and Pearce & Cribb (2002). Regionally, *P. fairrieanum* (Lindl.) Stein is found in Nepal (Raskoti & Ale 2011), India (Sikkim, Arunachal Pradesh, and Assam) (Raskoti & Ale 2011), and Bhutan (Pradhan 1976, 1978, 1996; Chowdhery 1998; Cribb 1998; Pearce & Cribb 2002; Rankou & Kumar 2015a). *Paphiopedilum fairrieanum* in Bhutan was reported to be widely distributed in the limestone formations and outcrops of subtropical forests. Populations were found in Leptshanangra under Mongar District (over 1,000 individuals) spread over more than 5ha at 1,200–1,400 m (Pradhan 1978); in Gomdar under Samdrup Jongkhar District (around 800 individuals); in Kalikhola (Dorji), where only a few plants remain (30 individuals); near Ngangla Trong under Zhemgang District, where *P. fairrieanum* co-occurs (60 individuals) with *P. venustum* and hence there is a potential for the existence of the natural hybrid *Paphiopedilum* × *pradhanii* Pradhan; in Gomtu under Samtse District, which is divided into two subpopulations, one spread over 1ha at 800m (80 individuals) and the other spread over 1.2ha at 1,400m (over 150 individuals); in Sarjung under Samdrup Jongkhar District (1,050 individuals); and in Kheng-Gongdu under Mongar District, of which one subpopulation is spread over more than 3ha at 978m (over 1,000 individuals) and the other is spread over 15ha at 1,044m (over 1,200 individuals according to the authors research data and distribution range, and

population dynamics).

Paphiopedilum fairrieanum was also reported from Pabji in Lamoizingkha (Dagana District) (Dorji 2008), supposedly a good habitat but highly threatened due to poaching. Twenty variously-sized individuals were observed by Gurung et al. (2016). This species co-occurred with *P. venustum*, but the latter is now known to be extinct from this site. Near Aalay in Chukha, however, six individuals of *P. fairrieanum* were observed fruiting. There is still uncertainty over the possible recovery of these two populations. Two populations of *P. fairrieanum* were known to be destroyed in 2016 during a farm road construction. Similarly, another population in Sarjung in Samdrup Jongkhar is likely to be destroyed by a farm road. No plant was recorded from Surelakha in Gelephu District during a current survey as reported by Pearce & Cribb (2002).

Since Chumbi Valley from which *P. fairrieanum* was reported (Pearce & Cribb 2002) is on the other side of the international border, Bhutanese explorers were not able to confirm the presence of the species in the area. Since the valley is connected to Bhutan through Amo Chhu River, however, it is likely that the species is distributed in the subtropical region of Amo Chhu as well.

Distribution range of *Paphiopedilum venustum*

Paphiopedilum venustum (Wall. ex Sims) Pfitzer is known to occur in Nepal (Raskoti & Ale 2011), India (Sikkim and Arunachal Pradesh) (Hooker 1894; King & Pantling 1898; Pradhan 1976; Chowdhery 1998), and China (Tibet) (Govaerts et al. 2019). While Pradhan (1976) reported the occurrence of *P. venustum* from Bhutan without any specific location, Pearce & Cribb (2002) and Gurung (2006) did not confirm its occurrence in Bhutan. *Paphiopedilum venustum* was reported from Kalikhola, Chhukha District (over 20 individuals) by Dorji (2008), from where some plants were also cultivated at the Royal Botanical Garden, Serbithang; from Bjoka and Ngangla under Zhemgang District (over 40 individuals) in 2009 at 1100m; and from Ngangla Village (over 15 individuals) in 2016 at 800m. Also, according to the author's studies/ research data and research information and data will made available soon through Bhutan Biodiversity Portal (www.biodiversiy.bt). This study site is the only habitat where both *P. fairrieanum* and *P. venustum* coexist (Image 1).

Pabji site which was known to harbour both *P. fairrieanum* and *P. venustum* (Dorji 2008) is now devoid of the latter. Similarly, a healthy population of *P. venustum*



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Image 1. *Paphiopedilum fairrieanum* and *P. venustum* growing side by side, Ngangla, Zhemgang.

near Bjoka in Zhemgang was completely wiped out by a farm road.

Paphiopedilum spicerianum—possibly extinct in Bhutan

A quote from the past adds credibility and vividly illustrates the degree of never-ending human destruction of our natural resources: “After no small amount of personal hardship this shipment [of wild collected plants of *Paphiopedilum spicerianum* in Bhutan] reached Steven’s Auction Rooms on March 9, 1884 in a quantity of 40,000 plants...” (Fowlie 1970). This depicts the intensity of threat these extraordinary plants faced in the past and hence there is a chance that the species had been present in Bhutan but was extirpated to extinction. Pearce & Cribb (2002) added this species to the flora of Bhutan based on the note by Fowlie (1970). This species was not found in the country during the rigorous surveys in the past decade. Excluding Bhutan, this species was reported from northeastern India, Myanmar, and southwestern China.

General characteristics of *Paphiopedilum* habitats

Due to the rise of the Himalaya from the Tethys Ocean (Gansser 1983), there are several limestone rock formations in Bhutan. Many of these formations seem to host *Paphiopedilum* populations. So far, 10 populations of *P. fairrieanum* and four populations of *P. venustum* were recorded in Bhutan. Survey plots were laid where *Paphiopedilum* species occurred and the vegetation composition in these sites were assessed in Zhemgang, Mongar and Samdrup Jongkhar (Table 1).

The soil pH in these habitats ranged from 7.1 to 7.8. While Pearce & Cribb (2002) mentioned that *P. fairrieanum* is found on limestone, Pradhan (1976) noted that *P. fairrieanum* occurs on gneiss ledges. There is no mention of the occurrence of *P. venustum* in association with limestone formations by Pearce & Cribb (2002) and Pradhan (1976). Except in the case of Ngangla-2, both *P. fairrieanum* and *P. venustum* were found growing

sympatrically. In the study area, *P. venustum* grows both in dense broadleaved forests with closed canopies and in limestone dominated areas with soils rich in humus (Image 2) and leaf litter, sometimes mixed with limestone gravel.

A small population of *P. fairrieanum* in Meden faces a strict northern direction. *Paphiopedilum fairrieanum* plants are predominantly found on steep slopes ranging from 65° to 95° (Table 1). The lowest gradient (45°) recorded was from Samtse. *Paphiopedilum fairrieanum* was also observed on overhanging vertical cliffs (>100°), as in the case of the remaining population near Pabji. Growing on more or less vertical cliffs protects the plants from grazing cattle and wild ungulates like Himalayan Goral and, to various degrees, from collection by people and from forest fires.

The lowest altitudinal record of a *P. fairrieanum* habitat is near Aalay at about 600m and the highest known is in Mongar at 1,400m. Pearce & Cribb (2002), however, noted the altitude range of *P. fairrieanum* to be between 1,400m and 2,200m. This suggests that the search for *P. fairrieanum* in Bhutan should extend to



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Image 2. *Paphiopedilum venustum* growing on humus rich leaf litter, Kaktong, Zhemgang.

Table 1. Plots showing important parameters of *P. fairrieanum*.

Location (Plots)	Ngangla-1	Ngangla-2	Kaktong	Gongdu	Meden	Sarjung
Altitude (m)	1052	1038	801	1044	978	981
Aspects (°)	NW 25	NW 30	SW 15	N/NE 20	NW 10	NW 25
Inclination (°)	65	70	95	75	95	85
Total BA/ha (m ² /ha)	63,317.71	63,128.08	63,929.38	32,270.58	65,521.85	70,969.68
Diversity index (H')	2.34	2.20	1.69	2.25	2.64	2.06
Species richness (SR)	41	27	25	35	35	39
Soil pH	7.8	7.1	7.5	7.7	7.8	7.5

higher elevations as well. We, however, could not locate any habitat of *P. fairrieanum* in higher elevations. For *P. venustum*, the altitude range in Bhutan varies from about 800m to 1052m (-1,100m). This is higher than the range (300–800 m) mentioned by Pradhan (1976).

Vegetation composition in *Paphiopedilum* habitats

Based on the relative basal area (RBA%) occupied by each species in each plot, the vegetation composition of the habitats were classified into evergreen trees, evergreen shrubs, deciduous trees, deciduous shrubs, and perennial herbs and shrubs (Table 2). Overall, there were 106 plant species belonging to 59 families, among which five species could not be identified. The highest plant diversity in the *Paphiopedilum* habitats was found in Meden with $H'=2.64$, followed by Ngangla-1 with $H'=2.34$. Species richness was highest (SR=41) in Ngangla-1 with 33 families and lowest (SR = 25) in Kaktong with 18 families.

Ngangla-1 primarily consisted of evergreen trees with *Phoebe lanceolata* having the highest RBA of 28.865%, *Cinnamomum impressinervium* with RBA of 12.165%, and the deciduous tree *Toxicodendron succedaneum* with RBA of 17.754%. The RBA of *P. fairrieanum* in this site was 0.022%, the lowest among all the habitats assessed. This indicates that the evergreen forest is not well-suited for *P. fairrieanum*. The presence of this orchid in this forest could have been supported by deciduous tree species like *Toxicodendron succedaneum*, *Celtis tetrandra*, *Dalbergia sericea*, and *Kydia calycina* which allowed sunlight to reach the ground. It is possible that this population together with the Ngangla-2 population represent outgroups that originated from a larger and healthier population that is locally rumoured to exist nearby.

Ngangla-2 harbours both *P. fairrieanum* and *P. venustum* (Image 1). The evergreen trees in this forest include *Rapanea capitellata* (RBA=28.998%) and *Acer oblongum* (RBA=18.112%). RBA of *P. fairrieanum* was 0.024% and that of *P. venustum* was 0.034%. The Kaktong site, however, had *P. venustum* (RBA=0.102%) population under *Kydia calycina*, a deciduous tree species with the highest RBA of 49.142% followed by *Picrasma* sp. (RBA=20.120%) and *Dysoxylum* sp. (RBA=10.855%), which are both evergreen tree species. Total RBA of evergreen tree species in Ngangla-1, Ngangla-2, and Kaktong habitats were 67.376%, 63.430%, and 47.771%, respectively. Likewise, the RBA of evergreen tree species in Meden was 47.468%. The Gongdu and Sarjung habitats, however, have higher RBA of evergreen shrubs than tree species with 31.039% and 52.443%,

respectively. The Gongdu, Meden, and Sarjung habitats have unidentified bamboo species with RBA of 41.834%, 24.419%, and 14.091%, respectively.

An analysis of the vegetation composition using PC-ORD indicated that there were three types of forests in the *Paphiopedilum* habitats assessed (Fig. 1). Ngangla-1 and Ngangla-2 had forests dominated by *Cinnamomum*, *Rapanea*, *Toxicodendron*, *Acer*, and *Phoebe* species. Gongdu, Meden, and Sarjung had a forest dominated by *Quercus*, *Acer*, *Diploknema*, *Albizia*, *Desmodium*, *Colebrookea*, and *Neyraudia*. The Kaktong habitat was dominated by *Dysoxylum*, *Picrasma*, and *Kydia* tree species.

All the *Paphiopedilum* habitats had a considerable proportion of evergreen trees or evergreen shrub species (Table 2; Fig. 2). In the lower altitudes, especially in Kaktong, there was almost an equal proportion of deciduous and evergreen species. All the tree and shrub species noted in these sites, however, are not necessarily the indicators of the presence of *Paphiopedilum* populations, yet the general forest types may give some idea of the possibility of finding *Paphiopedilum* species. Especially for *P. fairrieanum*, the presence of limestone is critical (Image 3).

Threats to *Paphiopedilum* habitats

Rankou & Kumar (2015a,b) mentioned forest fire, illegal collection for trade and horticulture, human disturbance, trampling by cattle, deforestation, climate change, and intrinsic factors as the main threats to *Paphiopedilum* species in their natural habitats. In Pabji, the local people who collected *P. fairrieanum* for the



Image 3. *Paphiopedilum fairrieanum* growing on limestone cliff, Ngangla, Zhemgang.

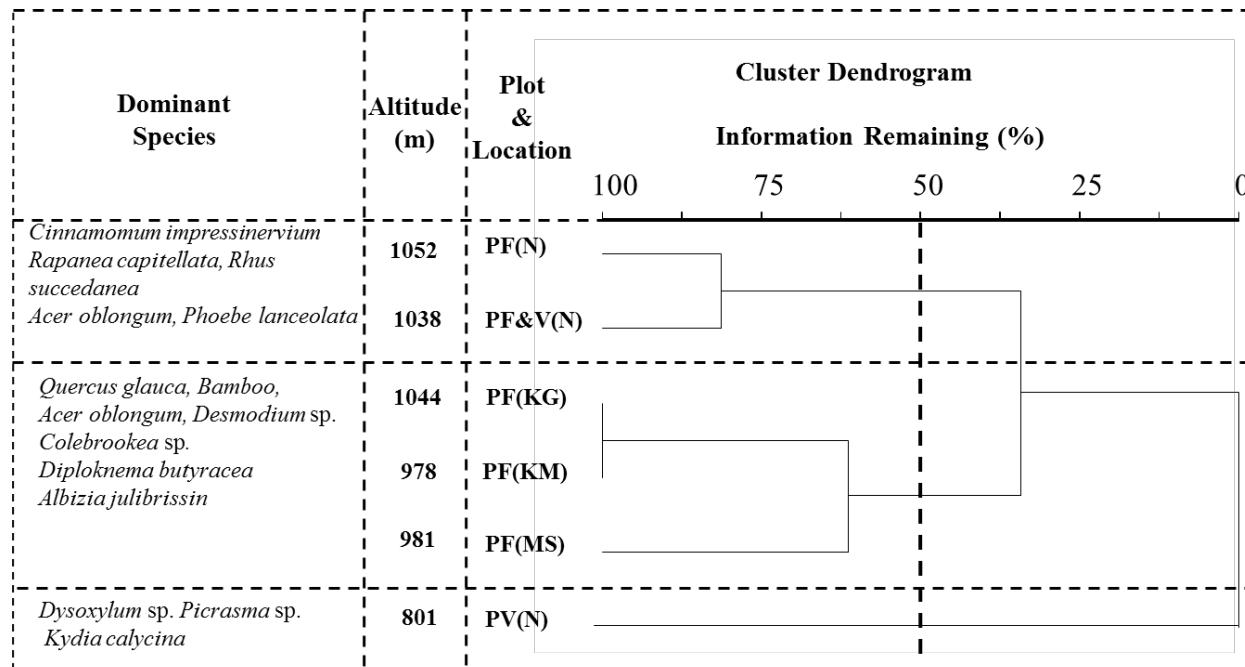


Figure 1. Dendrogram showing three forest types supporting *Paphiopedilum* populations.

Note: PF(N) = Ngangla-1 | PF&V(N) = Ngangla-2 | PF(KG) = Gongdu | PF(KM) = Meden | PF(MS) = Sarjung | PV(N) = Kaktong.

collectors in the 1960s and 1970s said that *P. fairrieanum* is grazed by wild ungulates such as the Himalayan Goral. We, however, did not observe such incidents in any *Paphiopedilum* population. There were, however, signs of forest fire damage in the upper population sites of *P. fairrieanum* in Samtse.

Since 2008, farm road construction in Bhutan has picked up very fast. Farm road construction generally follows traditional footpaths. A healthy population of *P. venustum* near Djoka was completely destroyed by a recent farm road construction. Similarly, in 2016, a farm road was constructed right through the lower population site of *P. fairrieanum* in Samtse and thus we could not locate a single remaining individual of *P. fairrieanum*. A farm road was also constructed through the *P. fairrieanum* population at Sarjung.

Paphiopedilum fairrieanum seems to prefer seasonally dry slopes prone to forest fires. Since most of the remaining populations are found on steep slopes of up to 95–100°, forest fires may not be able to destroy plants that grow on overhanging limestone cliffs. As areas warm up due to climate change and fuel loads accumulate due to forest fire control, however, any fire outbreak in *Paphiopedilum* habitats could prove disastrous to the orchid populations. Electricity transmission lines also pass through many of these habitats (Image 4). Hydropower development has also picked up in recent years in Bhutan. The *P. fairrieanum* population in

Gomdar could be in risk due to the development of the Nyera-amari Chhu hydropower project.

In general, anthropogenic activities do not seem to be a serious problem as all orchids in Bhutan are protected by the Forest and Nature Conservation Rules and Regulations 2006 (RGoB 2006). There were, however, instances of illegal collections in small quantities even in the early 2000s. Despite strict enforcement of Forest and Nature Conservation regulations to protect these rare orchid species, the risk of illegal collection is still very high as these habitats are easily accessible by roads.

Recommendations

Many of the foresters who are entrusted with the responsibility of protecting the species, however, cannot identify even the critically endangered species. Therefore, educational programs and conservation awareness campaigns may have to be carried out to protect endangered orchids such as the *Paphiopedilum* species. Further explorations and research are recommended to confirm if *P. spicerianum* is found in Bhutan. Environmental impact assessment (EIA) for all farm roads planned will have to be conducted with diligence, especially considering the threatened species. If at all possible, some of the *Paphiopedilum* habitats should be declared as protected areas—‘orchid sanctuaries’. The orchid sanctuary should be open to visitors, perhaps for a small fee that will benefit the local

Table 2. Relative basal area (RBA) in % per hectare. The green boxes indicate the dominant species.

Location (plots)	Nangla-1	Nangla-2	Kaktong	Gongdu	Meden	Sarjung
Evergreen trees						
<i>Phoebe lanceolata</i>	27.865	1.686	0.276	1.025	5.418	0.692
<i>Cinnamomum impressinervium</i>	12.165	1.524	0.266			
<i>Acer oblongum</i>	10.490	18.112			10.818	2.342
<i>Euonymus</i> sp.	5.241		1.592			
<i>Dysoxylum</i> sp.	3.354		10.855			
<i>Diploknema butyracea</i>	2.740	0.280		0.294	7.293	1.356
<i>Skimma</i> sp.	1.384		1.888			
<i>Combretum</i> sp.	0.984					
<i>Pandanus furcatus</i>	0.972	0.756	0.208			0.488
<i>Rapanea capitellata</i>	0.908	28.998			3.759	
<i>Miliusa roxburghiana</i>	0.496					
<i>Cinnamomum</i> sp.	0.474					5.269
<i>Ficus heteropileura</i>	0.179					
<i>Talauma hodgsonii</i>	0.124	0.080			2.961	2.162
<i>Wendlandia grandis</i>		11.949		0.930		0.585
<i>Hyptianthera stricta</i>		0.045				
<i>Picrasma</i> sp.			20.120			
<i>Aglaia korthalsii</i>			5.982			
<i>Sphaerosacme decandra</i>			3.716			
<i>Lithocarpus dealbatus</i>			1.294			
<i>Persea</i> sp.			1.181			0.217
<i>Elaeocarpus</i> sp.			0.393			
<i>Bridelia retusa</i>				1.073		
<i>Stereospermum colais</i>				0.585		
<i>Quercus glauca</i>					11.512	1.403
<i>Pinus roxburghii</i>					5.707	
<i>Castanopsis hystrix</i>						3.852
<i>Neocinnamomum caudatum</i>						0.585
Subtotal	67.376	63.430	47.771	3.907	47.468	18.951
Evergreen shrubs						
<i>Desmodium</i> sp.	0.126	0.634		1.394	0.916	50.303
<i>Capparis assamica</i>	0.079					
<i>Maesa chisia</i>	0.079					
<i>Leea asiatica</i>	0.031					
<i>Murraya paniculata</i>			0.595			
<i>Croton</i> sp.			0.213			
<i>Tabernaemontana divaricata</i>			0.123			
<i>Colebrookea</i> sp.				19.367	1.526	
<i>Reinwardtia indica</i>				3.099	0.740	0.240
<i>Woodfordia fruticosa</i>				1.859	0.992	0.845
<i>Daphne bholua</i>				1.549	0.238	
<i>Holmskioldia sanguinea</i>				1.549		
<i>Osyris lanceolata</i>				1.240		

Location (plots)	Nangla-1	Nangla-2	Kaktong	Gongdu	Meden	Sarjung
<i>Rhus paniculata</i>				0.477	1.386	
<i>Hypericum</i> sp.				0.279		
<i>Viburnum cylindricum</i>				0.193	0.690	
<i>Indigofera dosua</i>				0.032		
<i>Luculia gratissima</i>						1.055
Subtotal	0.316	0.634	0.930	31.039	6.488	52.443
Deciduous trees						
<i>Toxicodendron succedaneum</i>	17.754	9.412				2.826
<i>Celtis tetrandra</i>	0.126					1.279
<i>Dalbergia sericea</i>		9.417				
<i>Kydia calycina</i>			49.142			
<i>Rhus chinensis</i>				0.079	3.626	
<i>Albizia julibrissin</i>					8.948	
<i>Bauhinia purpurea</i>					2.536	0.601
<i>Engelhardia spicata</i>						3.348
Subtotal	17.881	18.829	49.142	0.079	15.111	8.054
Deciduous shrubs						
<i>Fluggea virosa</i>			0.141			
<i>Spiraea</i> sp.				6.198		
Subtotal	0.000	0.000	0.141	6.198	0.000	0.000
Perennial herbs & shrubs						
<i>Strobilanthes</i> sp.	1.421	0.348	0.034	1.240	0.687	0.557
<i>Neyraudia</i> sp.	1.406	3.168	0.267	41.834	24.419	14.091
<i>Oplesminus</i> sp.	0.711	0.396		2.324	1.221	1.071
<i>Eranthemum</i> sp.	0.671	0.260				
<i>Carex</i> sp.	0.316					0.189
<i>Hedychium</i> sp.	0.316					0.007
<i>Jasminum grandiflorum</i>	0.197	1.742				
<i>Piper</i> sp.	0.166				0.082	
<i>Smilax</i> sp.	0.152		0.250	0.341	0.229	0.220
<i>Thysanolaena latifolia</i>	0.122				0.366	0.366
<i>Menispernum</i> sp.	0.077			0.124	0.046	0.017
<i>Begonia</i> sp.	0.073	5.608			0.435	0.232
<i>Agrostemma</i> sp.	0.052					
<i>Ehretia</i> sp.	0.045					
<i>Tectaria</i> sp.	0.033		0.547			
<i>Malaxis</i> sp.	0.032					
<i>Clematis</i> sp.	0.025	0.008		1.240	0.153	0.282
<i>Paphiopedilum fairrieanum</i>	0.022	0.024		1.162	0.397	0.282
<i>Boehmeria</i> sp.		3.802				
<i>Phyllanthus</i> sp.		1.584				0.220
<i>Paphiopedilum venustum</i>		0.038	0.102			
<i>Adenostemma</i> sp.		0.025				
<i>Elatostema</i> sp.		0.025				
<i>Tetrastigma</i> sp.			0.782			

Location (plots)	Nangla-1	Nangla-2	Kaktong	Gongdu	Meden	Sarjung
<i>Pogonatherum crinitum</i>				2.324		0.273
<i>Duhaldea cappa</i>				2.014		
<i>Apluda mutica</i>				1.704		
<i>Jasminum</i> sp.				1.549	0.839	1.691
<i>Boenninghausenia albiflora</i>				0.837		
<i>Cymbopogon</i> sp.				0.697		
<i>Barleria cristata</i>				0.620	0.244	
<i>Asparagus filicinus</i>				0.583		
<i>Swertia</i> sp.				0.155		
<i>Hemidesmus</i> sp.				0.031	0.012	
<i>Drepanostachyum intermedium</i>					0.916	
<i>Senecio</i> sp.					0.511	
<i>Lindenbergia grandiflora</i>					0.238	
<i>Commelina</i> sp.					0.069	
<i>Rubus</i> sp.					0.069	
<i>Arundina graminifolia</i>						0.845
<i>Eria biflora</i>						0.068
<i>Bulbophyllum</i> sp.						0.051
<i>Spathoglottis</i> sp.						0.042
<i>Dendrobium chrysanthum</i>						0.039
<i>Goodyera</i> sp.						0.010
Subtotal	4.430	13.861	1.716	16.944	6.514	6.462
Unidentified species						
Fern 1	8.292					
Fern 2	0.221					
Unknown 1	0.079					
Unknown sp.		0.079	0.011			
Fern sp. 1			0.022			
Subtotal	9.997	3.247	0.300	41.834	24.419	14.091
Grand total	100	100	100	100	100	100

people. Local people living near *Paphiopedilum* habitats may be given the responsibility to protect the species and will hopefully benefit from the sanctuary. Such programs, however, should be fully supported and supervised by the Department of Forest and Park Services and other relevant agencies.

CONCLUSION

Three *Paphiopedilum* species have been reported from Bhutan: *P. fairrieanum*, *P. venustum*, and *P. spicerianum*. Several populations of *P. fairrieanum* and two small populations of *P. venustum* were recorded during this study. A few populations of *P. fairrieanum*

seem to extend over 15ha. While *P. fairrieanum* seems to grow in large colonies, individuals of *P. venustum* were found with fewer and scattered individuals in each site, often represented by a single growth. *Paphiopedilum fairrieanum* seems to prefer rather exposed limestone formations with open canopy forest, receiving plenty of sunshine. This species mainly prefers northwest-to southwest-facing slopes and commonly occurs on more or less vertical, sometimes overhanging cliffs. *Paphiopedilum fairrieanum* prefers soil and rocky limestone outcrops with a pH of 7.1–7.8. In contrast, *P. venustum* commonly grows among leaf litter and in shallow humus-rich soils sometimes mixed with limestone gravel and in deep forests with a closed canopy. *Paphiopedilum spicerianum* has not been documented

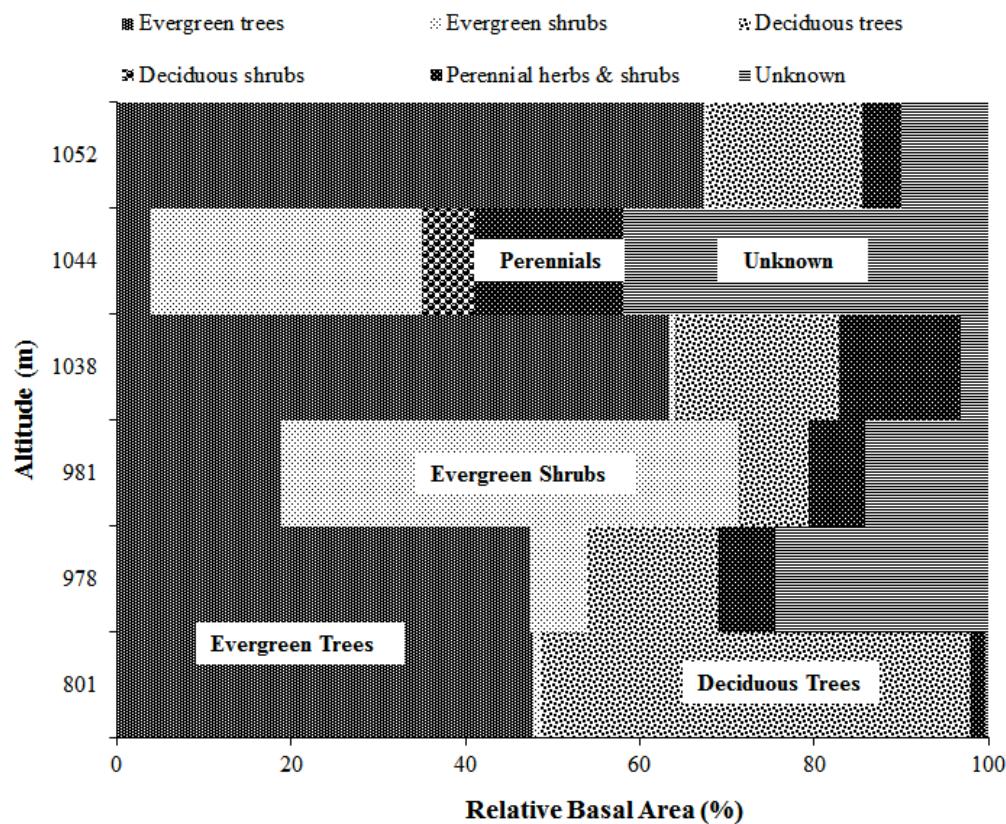


Figure 2. Various categories of vegetation composition found in the *Paphiopedilum* habitats in Bhutan.



Image 4. *Paphiopedilum fairrieanum* habitat with power lines passing over a foot path, Gongdu, Zhemgang.

so far or reported in recent times by current orchid explorers. Therefore, more efforts should be conducted to ascertain the occurrence of this species in Bhutan.

Many *Paphiopedilum* populations in Bhutan are threatened by farm road constructions. Limited collections of a few plants for research and conservation purposes also occur but deleterious collections of *Paphiopedilum* species in Bhutan seem to have occurred in the 1960s and 1970s, wiping out some populations completely. Impacts of forest fire and climate change on the species are poorly understood. Further work is required to search for potential *Paphiopedilum* habitats, especially in southeastern Bhutan. Education and conservation awareness programs for forest officials and local communities in the country may prove useful. Perhaps, a few habitats can be declared orchid sanctuaries to protect the endangered species while also benefiting the local communities.

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