Taiwania 67(4): 497–509, **2022**
DOI: 10.6165/tai.2022.67.497

Taxonomic and ecological notes on *Gaultheria cumingiana* S.Vidal (Ericaceae) from the Cordillera Central Range, Northern Philippines

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(Manuscript received 29 June 2022; Accepted 29 August 2022; Online published 14 September 2022)

ABSTRACT: *Gaultheria leucocarpa* var. *cumingiana* (S.Vidal) T.Z.Hsu was long been treated as a variety but recent evidences on its matK analysis and pollen structure showed a distinct species. To verify this, we revisited its taxonomic treatment using field data on its morpho-anatomical and ecological characters. The taxon is distinct from *G. leucocarpa* and its varieties with its smaller leaves, larger calyx and corolla, red to purple or blackish fruit at maturity, distinct pollen structures and distinct in matK analysis; hence, we are proposing the alteration as *Gaultheria cumingiana* Vidal to be recognized as a distinct species and not just a variety of *G. leucocarpa*. Additionally, we presented its detailed anatomical features that shows a typical dicot shade leaf with well-defined air spaces and unusually high abaxial stomatal density, eustele stem and protostele root anatomy. The ecological characters of the plant are also presented in terms of edaphic factors, biodiversity indices and surrounding floral species. Elevation and shading emerged as the major factors contributing to the distribution of the taxon showing a narrow elevation range at high altitude and preference for shading particularly at lower elevation populations but higher elevated populations can tolerate full sunlight. These information are important baseline for conservation and better understanding of the unique but understudied flora of the Cordillera Central Range.

KEY WORDS: Canonical correspondence analysis, edaphic factors, elevation, Ericaceae, *Gaultheria cumingiana*.

INTRODUCTION

The genus *Gaultheria* of the family Ericaceae had been circumscribed quite extensively by Sleumer (1957; 1967), Middleton (1991, 1993) and Fang and Stevens (2005) using morphological, distribution, chromosome and anatomical characters. In these studies, *G. cumingiana*, originally published by Vidal in 1885, was treated as a variety under *G. leucocarpa* - namely as *G. leucocarpa* var. *cumingiana* (S.Vidal) T.Z.Hsu. However, some more recent studies had shown *G. leucocarpa* var. *cumingiana* to be distinct with *G. leucocarpa* complex; e.g. by Powell and Kron (2001) in the matK analysis and by Lu *et al*. (2009) in terms of their pollen structures. Amidst these, several taxonomic sites (e.g. Co's Digital Flora, World Flora Online, Plants of the World Online) still list *Gaultheria leucocarpa* var. *cumingiana* as the accepted name and *G. cumingiana* as the synonym. In light of recent evidences, there is a need to revisit its taxonomic classification.

Currently, eight varieties under *G. leucocarpa* are accepted namely var. *leucocarpa*, *crenulata, cumingiana*, *hirta, melanocarpa*, *psilocarpa, seminuda,* and *yunnanensis*. The latest accepted treatment of *G. leucocarpa* var. *cumingiana* is based on the work of Hsu (1981). It was listed distinct from other varieties in terms of its blue-black fruit, glabrous pedicel and 3-6 flowered inflorescence. This shows that its treatment is primarily morphology-based and with new taxonomic evidences arising (e.g. genetics, pollination biology), there is a need to incorporate these in the species-level treatment of some, if not all, of the *G. leucocarpa* varieties.

Another issue on this taxon is the lack of field studies on its populations. It may had been subjected to several studies as mentioned above, but often herbarium samples were the one examined. Field studies on *G. leucocarpa* var. *cumingiana* may shield light on the controversy of its taxonomic classification. This study presents a detailed morpho-anatomical and ecological characterization using several populations in the Cordillera Central Range (CCR), Northern Philippines.

From a conservation perspective, it is important to understand many aspects of plant biology, including the ecological and physiological ends of the spectrum (Volis, 2015). In the Philippines, very few studies were conducted to shed understanding on the ecology of its vast floral diversity, amidst its high endemism (Pelser *et al*., 2011–). These few studies would include the study of Guron and Napaldet (2020) on the distribution and reproductive pattern of *Coriaria intermedia*; Balangcod *et al*. (2011) on *Lilium philippinense*; Chauhan and Johnson (2009) on *Cyperus difformis*, *Cyperus iria* and *Fimbristylis miliacea*; and, Codilla and Metillo (2011) on *Chromolaena odorata*. These support the claim of Baoanan *et al*. (2020) that ecological studies on plants in the CCR and in the country are wanting. The study aims to contribute to this by also presenting some ecological aspect of *G. leucocarpa* var. *cumingiana*.

Locally, the study is part of the on-going effort to properly characterize the many indigenous and endemic plants in the CCR. This area is both culturally and biologically important as it is the home to several groups of indigenous people and harbors a unique set of floral species not found in other parts of the country (Balangcod

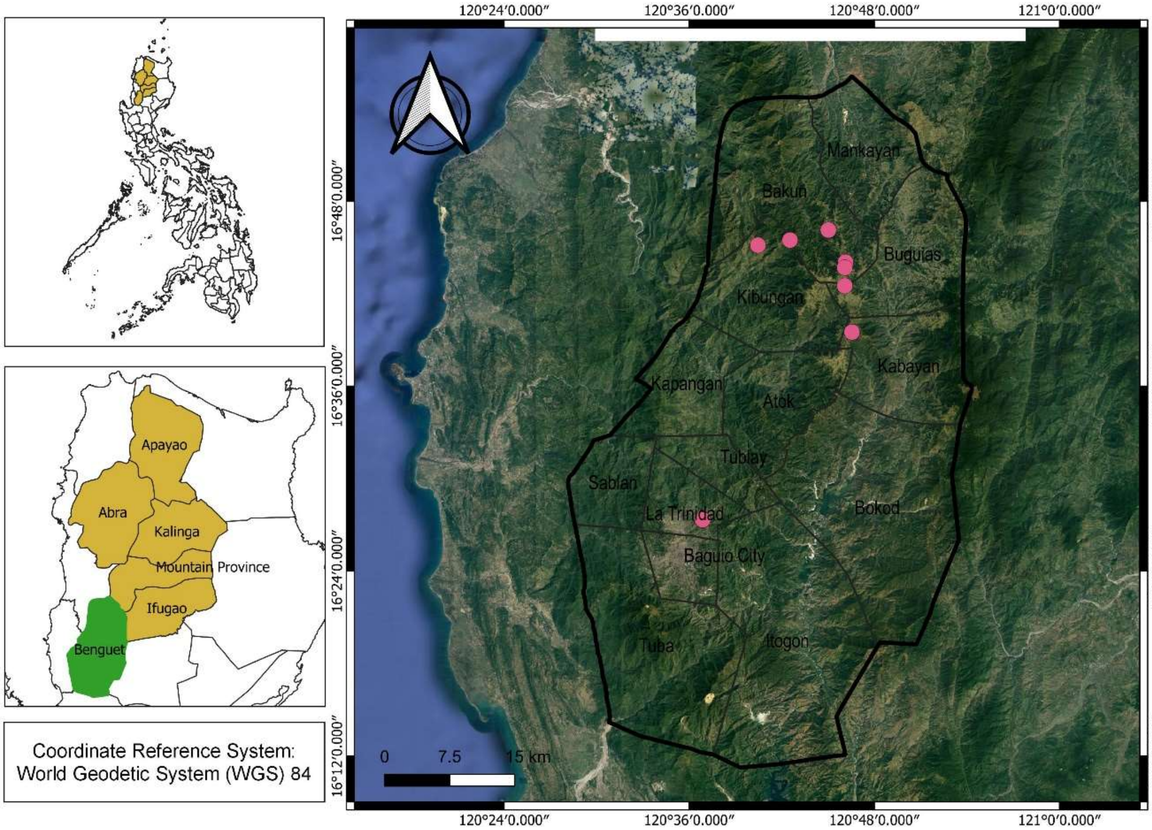

Fig. 1. Map of Benguet Province showing the location of the sampled populations of ***Gautheria cumingiana***

et al., 2011; Jacobs, 1972; Merrill and Merrit, 1910). However, it has become evident in the recent years that studies on plant diversity in the region has declined and have received less support from concerned agencies perhaps due to the lack of appreciation for taxonomy and biodiversity at the local level. Likewise, the acculturation of the local communities and the diminishing emphasis on their indigenous knowledge system (IKS) towards environment protection have led to habitat degradation as they integrate into a cash-crop economy. Navarro and Saldo (2000) noted the intensifying pressures that drive species extinction in the area such as forest conversion, mining activities, pollution and hunting. With these, baseline studies on the biodiversity of the CCR are imperative towards conservation.

In summary, the study revisited the taxonomic classification of *G. leucocarpa* var. *cumingiana*, presented the morpho-anatomical characters based from field data, and some ecological aspect (surrounding flora and edaphic factors) - as part of the baseline studies on the biodiversity of the CCR towards conservation.

MATERIALS AND METHODS

Taxonomic review of *Gaultheria cumingiana*

We revisited the long nomenclatural history of *Gaultheria cumingiana* from its first publication by Vidal in 1885 up to its recent molecular treatment by Powell and Kron (2001) and Lu *et al*. (2009). These include literature review on the works of Sleumer (1957), Middleton (1991), Fang (1999), and Fang and Stevens (2005). The treatment of the taxon as the variety *Gaultheria leucocarpa* var. *cumingiana* has been long established and used in literature. However, with new evidence arising, there is a need to revisit the taxonomic treatment of this taxon.

Sampling and morpho-anatomical description

We conducted several field visits from 2020-2021 to document the taxon but we were only able to spot and sample seven (7) populations of *Gaultheria cumingiana* in Benguet, Northern Philippines (Figure 1). The province is one of the six provinces that consist the Cordillera Central Range (CCR), which is the one of 15 biogeographical zones in the Philippines (Guron and Napaldet, 2020; Ong *et al*. 2002). Benguet Province is considered as the "ceiling of Luzon" because of its generally high elevation and the presence of famous mountains such as Mt. Sto. Tomas and Mt. Pulag with elevations of 2258 and 2924 m asl, respectively. The province falls under Climate Type I of the Coronas Classification System, with rainy days from May to October followed by the dry spells from November to April (Balangcod *et al*. 2011).

Table 1. Historical nomenclature of ***Gaultheria cumingiana***.

Year	Name used	Details	Reference
1885	*Gaultheria cumingiana*	Publication as a new species	Vidal, 1885
1957	*G. leucocarpa* forma *cumingiana*	Fruit color as the only difference with the typical *G. leucocarpa*	Sleumer, 1957
1981	*G. leucocarpa* var. *cumingiana*	*G. leucocarpa* var. *cumingiana* is listed distinct from other varieties in terms of its blue-black fruit, glabrous pedicel and 3-6 flowered inflorescence	Hsu, 1981
1991	*G. leucocarpa* var. *cumingiana*	Contend that *G. cumingiana* is a variety under *G. leucocarpa* because of the widespread distribution of the latter taxon thus having several morphological variations like the former.	Middleton, 1991
1999	*G. leucocarpa* var. *cumingiana*	*G. leucocarpa* var. *cumingiana* is distinct from other varieties by its stems with glandular bristles, rachis and pedicels glabrous, leaf blade margin spinulate-serrulate or calloso-serrulate, glabrous; Philippines endemic distribution	Fang, 1999
2001	*G. cumingiana*	*Gaultheria cumingiana* is not closely related with *G. leucocarpa* (sample from China) in matK analysis; cladogram shows both are close to other Gaultheria species	Powell & Kron, 2001
2009	*G. leucocarpa* var. *cumingiana*	*Gaultheria leucocarpa* var. *cumingiana* is very much related with *G. leucocarpa* (sample from Malaysia) in matK analysis; cladogram shows both are separated from other Gaultheria species	Bush *et al*., 2009
2009	*G. cumingiana*	*Gaultheria cumingiana* has a distinctly smaller pollen with granulate opoculpium and psilate-granulate mesocolpium vs larger pollen with regulate opoculpium and regulate mesocolpium in *G. leucocarpa*	Lu *et al*., 2009
2022	*G. cumingiana*	*Gaultheria cumingiana* is distinct from *G. leucocarpa* and its varieties with its smaller leaves, larger calyx and corolla, red to purple or blackish fruit at maturity, distinct pollen structures and distinct in matK analysis	This study

From each population, 20 individuals were sampled randomly for morphological measurements to account for the possible variations that the taxon exhibits. The samples were characterized phytographically to come up with a complete morphological description and morphometrics of the plant's vegetative and reproductive organs. Additional samples were derived for light microscopy to document the anatomical features of the roots, stem and leaves. Morphological and anatomical description of the plant follows Haupt (1953), Fahn (1982), Bell (2008) and Shipunov (2018). Lastly, descriptive statistics such as mean, range and standard deviation were used to present and analyze the morphometrics of the plant.

Ecological characterization

The habitat of *G. cumingiana* were characterized in terms of their soil conditions, slope and related floral species. Soil parameters that were measured include pH using standard soil pH meter and soil texture using feel method. The slope of the populations was determined using clinometer. The general conditions of the populations' habitat were also described qualitatively. On the other hand, the surrounding flora were inventoried using quadrat method. In each population sites, three quadrats measuring 1 m × 1 m were established. The flora within the plots were identified and counted. These data were used to compute for the population counts and diversity indices like Shannon-Wiener, Simpson, Margalef and Jaccard Index of Similarity. These ecological parameters were analyzed vis-à-vis the population sampled using Canonical Correspondence Analysis to determine the interplay of these factors.

RESULTS

Taxonomic treatment.

Gaultheria cumingiana has a rather interesting nomenclature history (Table 1). It was first published as *Gaultheria cumingiana* by Vidal in 1885 but was later downgraded as *G. leucocarpa* forma *cumingiana* by Sleumer in 1957, citing fruit color as the only difference with the typical *G. leucocarpa.* Later in 1981, T.Z. Hsu treated the taxon as *G. leucocarpa* var. *cumingiana*, which is now its accepted scientific name in several taxonomic sites such as Co's Digital Flora and the Flora of the World. Consequently, several studies that circumscribed the genus *Gaultheria* (e.g. Sleumer, 1957; Middleton, 1991, 1993; Fang, 1999; Fang and Stevens, 2005) listed the taxon as *G. leucocarpa* var. *cumingiana*. Recently, the taxon was included in molecular and pollen structure studies. Powell and Kron (2001) found *G. cumingiana* to be not closely related with *G. leucocarpa* var. *leucocarpa* in the matK analysis; and thus, they recommended for a thorough study on the taxonomic limits of *G. leucocarpa* complex. Later, Bush *et al*. (2009) refuted this claim stating that the *G. leucocarpa* var. *cumingiana* is very closely related to *G. leucocarpa* var. *leucocarpa* but the difference could be due to the samples used in the analysis. Powell and Kron (2001) used samples of *G. leucocarpa* var. *leucocarpa* from China while Bush *et al*. (2009) used samples from Malaysia. Moreover, Lu *et al*. (2009) showed that the pollen structure of *G. cumingiana* is very different from *G. leucocarpa* which is a strong evidence for the two being reproductively isolated and thus, being distinct species (Wang *et al*., 2015).

Table 2. Biological measurements of *Gaultheria cumingiana*.

Characters	Mean	Min.	Max.	SD
Plant height (cm)	73.72	25.50	144.00	±31.13
Stem diameter (cm)	0.33	0.15	0.80	±0.17
Leaf characters				
Petiole length (cm)	0.44	0.20	0.70	±0.15
Leaf width (cm)	2.86	1.90	4.60	±0.15
Leaf length (cm)	5.00	3.30	6.90	±0.83
Pedicel length (cm)	0.89	0.10	1.80	±0.17
Number of floral bract	1.00	1.00	1.00	±0.00
Number of floral bracteoles	2.00	2.00	2.00	±0.00
Length of floral bracteoles	0.10	0.10	0.10	±0.00
Sepal characters				
Number of sepals	5.00	5.00	5.00	±0.00
Sepal length (cm)	0.33	0.30	0.40	±0.05
Petal characters				
Number of petals	5.00	5.00	5.00	±0.00
Petal length (total) (cm)	0.74	0.50	1.00	±0.14
Corolla lobe length (cm)	0.65	0.50	0.80	±0.12
Corolla lobe width (cm)	0.78	0.70	0.80	±0.04
Number of stamen	9.87	9.00	10.00	±0.34
Style length (cm)	0.40	0.30	0.50	±0.06
Ovary diameter (cm)	0.27	0.20	0.30	±0.04
Fruit length (cm)	0.62	0.30	0.90	±0.15
Fruit diameter (cm)	0.61	0.30	1.80	±0.17
Stomatal characters				
Stomatal Density (stomata/mm^2)	422.93	317.62	558.57	±62.58
Stomatal Index (%)	33.60	25.00	40.00	±5.90
Stomata length (um)	3.82	3.52	4.47	±0.24
Stomatal width (um)	2.82	2.52	3.49	±0.27
Leaf Anatomy				
Midrib Width (um)	482.90	461.64	493.03	±8.99
Lamina width (um)	376.47	346.36	411.12	±23.89
Palisade layer width (um)	136.57	113.23	172.73	±20.11
Spongy layer width (um)	192.27	125.33	231.29	±31.08

Morphological description and morphometrics

Plant habit. *Gaultheria cumingiana* is a small procumbent, climbing to erect shrub, usually less than a meter tall (mean: 0.73 m). Some individuals in thickets, though, can reach 1.4 m climbing but not twining on taller plants such as *Miscanthus floridulus*, *Vaccinium* spp., *Rhododendron* spp. and *Rubus* spp. On exposed ridges, the plant is usually procumbent with woody stem all the way through the terminal leaves. The stem is terete and distinctly red. Young stems have minute white trichomes and exhibit a subtle zigzag pattern with leaves arising from the zigzag point.

Leaves. The leaf is aromatic, simple, alternate, ovate, with short reddish petiole (2–7 mm), adaxial surface is dark green in shaded condition to yellow-reddish on young or sun-exposed leaves, abaxial surface is light green, generally glabrous, pinnate-netted, secondary veins melastomataceous and slightly raised on abaxial surface, 1.9–4.6 cm in width and 3.3–6.9 cm in length (see Figure 2 and Table 2). The base is widely obtuse, apex is acuminate and margin is serrate to serrate-crenulate with few short, white trichomes.

Flowers. The inflorescence is glabrous, axillary generally few terminal, few-flowered (2–5 flowers) sometimes solitary, racemose but dropping. Flower complete, small, actinomorphic, borne on pedicel with highly variable length (0.10–1.80 cm); bract 1, at the base of pedicel, narrowly ovate; bracteoles 2, widely ovate, opposite; calyx 5, about 0.33 cm long, ovate, green, persistent; corolla small though showy, pure white to white with pink tinge on tips to reddish with white interlude, campanulate with 5 triangular lobes, lobes rolled outward, not persistent; stamens 9 to 10, inserted, epipetalous, clustered around the ovary, not persistent, filament very short, anther longer than filament, thecae 2-awned; gynoecium syncarpous, ovary superior covered with minute white hairs, stigma truncate, style protruding, persistent. Figure 2C shows the flower development from buds to full bloom to fertilized ovary without corolla.

Fruits and seeds. The fruit is accessory with persistent sepals becoming fleshy, appended by a persistent, protruding style. The fruit is globose to campanulate with the persistent sepal lobes protruding outward, enclosing a fleshy capsule and also the protruding style. The fruit develops from green to red to black, about as long as it is wide. Inside are several minute seeds, yellow. Figure 2D shows the fruit development from green to red to ripe purplish black.

Phenology and distribution

During the field survey, the flowering and fruiting of *Gaultheria cumingiana* is observed throughout the year. In its pendulous inflorescence, the upper flowers are the first to bloom and develop into fruits before the lower ones. Its flowers are most likely pollinated by ants as these were observed to regularly visit the plant.

There are contrasting report on the distribution of *G. cumingiana*. Fang and Stevens (2005) mentioned that this variety is endemic in the Philippines (Luzon) but Sleumer (1957) earlier reported this to occur in Upper Burma, Southwest to South China, Siam, Indochina, Formosa, Malay Peninsula, Sumatra and East Java. This needs further study and the morpho-anatomical characters of this taxon presented in the study could help as source of comparison with supposed populations of *G. cumingiana* in other locations or other *G. leucocarpa* varieties.

In the study site, the CCR particularly in Benguet, *G. cumingiana* occurs at high elevation range of 1592–2423 m asl. At its lower elevation range, the taxon is usually found at forest edge or forest openings that include near road and farm clearing where there is partial to moderate shading. But at higher elevation, the taxon tolerates full sunlight. The taxon exhibits a narrow distribution range generally at higher elevations but is fragmented by the massive conversion of its forest habitat into agricultural farms.

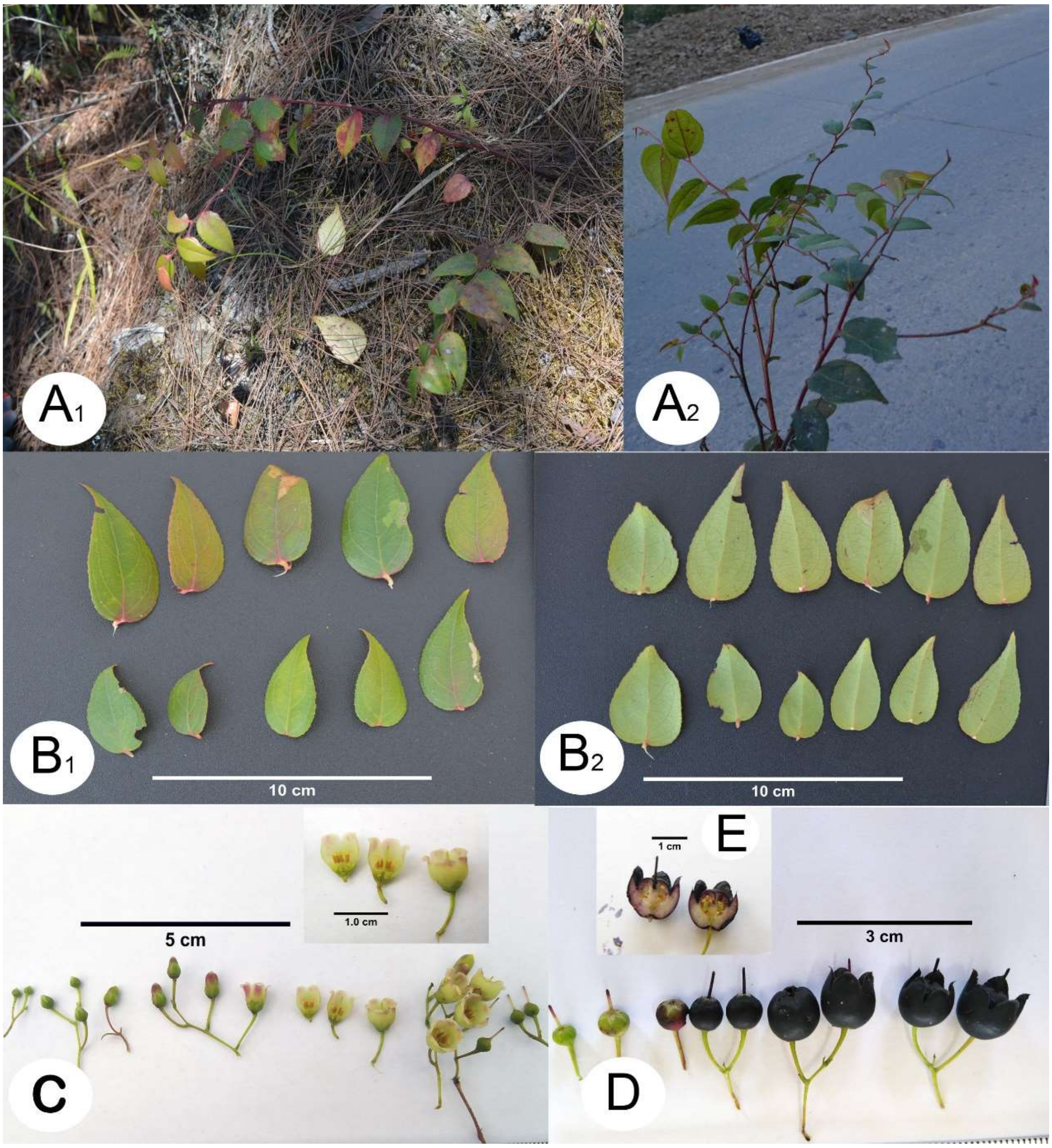

Fig. 2. Morphological traits of ***Gaultheria cumingiana*** (**A** – plant habit variation from prostrate $\mathbf{A_1}$ to erect $\mathbf{A_2}$; **B** – leaf variation and surfaces, adaxial $\mathbf{B_1}$ and abaxial $\mathbf{B_2}$; **C** – flower, urceolate; **D** – fruit, accessory; and, **E** – fruit with seeds, numerous, miniscule)

Anatomical characterization

The leaf. The cross section of the leaf (Figure 3) shows a uniseriate upper and lower epidermis enclosing the mesophyll. The upper epidermis (Figure 3A$_1$) is composed of transparent, irregularly shaped cells without any stomata or hypodermis. Under the upper epidermis, three to four layers of adaxial sclerenchyma are noted above the midrib. Few scattered trichomes were observed on the upper epidermis particulary above or near the midrib but, in general, the adaxial surface of the leaf is glabrous. The cuticle is distinctly thick on the upper epidermis. The stomata are only found in the lower epidermis (Figure 3A$_2$) and are of paracytic type. Stomatal density is high ranging from 318 to 559 per mm^2 while stomatal index is at 34% (Table 1). Like a typical dicot, the division of the mesophyll (Figure 3B$_1$) is distinct with palisade layer above and spongy layer below. The palisade layer (Figure 3B$_2$) is 113.23–172.73 um thick, consists of a one to three rows of elongated tighly-packed cells while the spongy layer is wider (125.33–231.29 um thick), and is composed of cuboidal cells with well-developed air spaces. The midrib (Figure 3B$_3$) is slightly thicker (461.64–493.03 um) than the lamina (346.36–411.12 um) with the vascular bundle (xylem and phloem) enclosed by 3–5 layers of schlerenchyma cells. The short petiole (Figure 3C) has a unilacunar vascular bundle covered by several layers of parenchyma cells and few collenchyma layers.

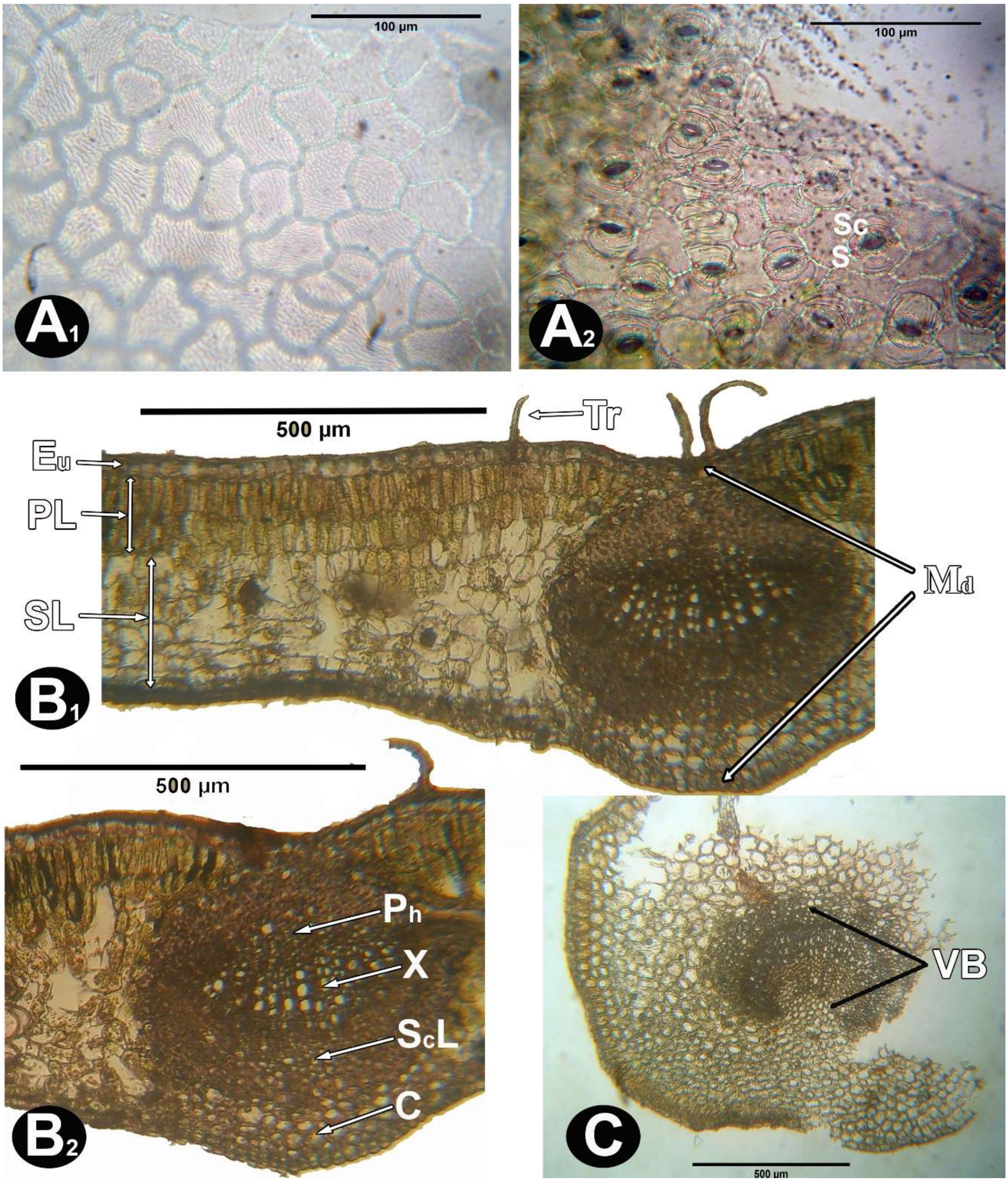

Fig. 3. The anatomy of the leaf of ***Gaultheria cumingiana*** (**A_1** – upper epidermis; **A_2** – lower epidermis, Sc – subsidiary cells, S - stomata; **B_1** – the cross-section of the leaf, SL – spongy layer, Mb - midrib, **C** – cuticle, Eu – upper epidermis, PL – palisade layer; **B_2** – midrib, X – xylem, Ph – phloem, ScL – sclerenchyma layers; C – cross-section of petiole; VB – vascular bundle)

The stem. The stem is woody all the way up to the terminal leaves; thus, the primary tissues were not observed in the cross-section. In the sectioned stem (Figure $4A_1$ and 4_2), the periderm is still starting to form with few layers only. After these is the remnant of the cortex intermix with the primary phloem. The secondary phloem appears as distinct band of small, tightly packed cells. This is followed by the vascular cambium, several layers of secondary xylem, primary xylem and the still wide pith. Pith type is Type B or heterogeneous type according to the classification by Middleton (1993) where there is marked difference in cell size and wall thickness between cells intermixed in the pith. The vessel elements and xylem rays are distinct in the secondary xylem. Vessel elements appear as the larger circles while xylem rays appear as dark lines.

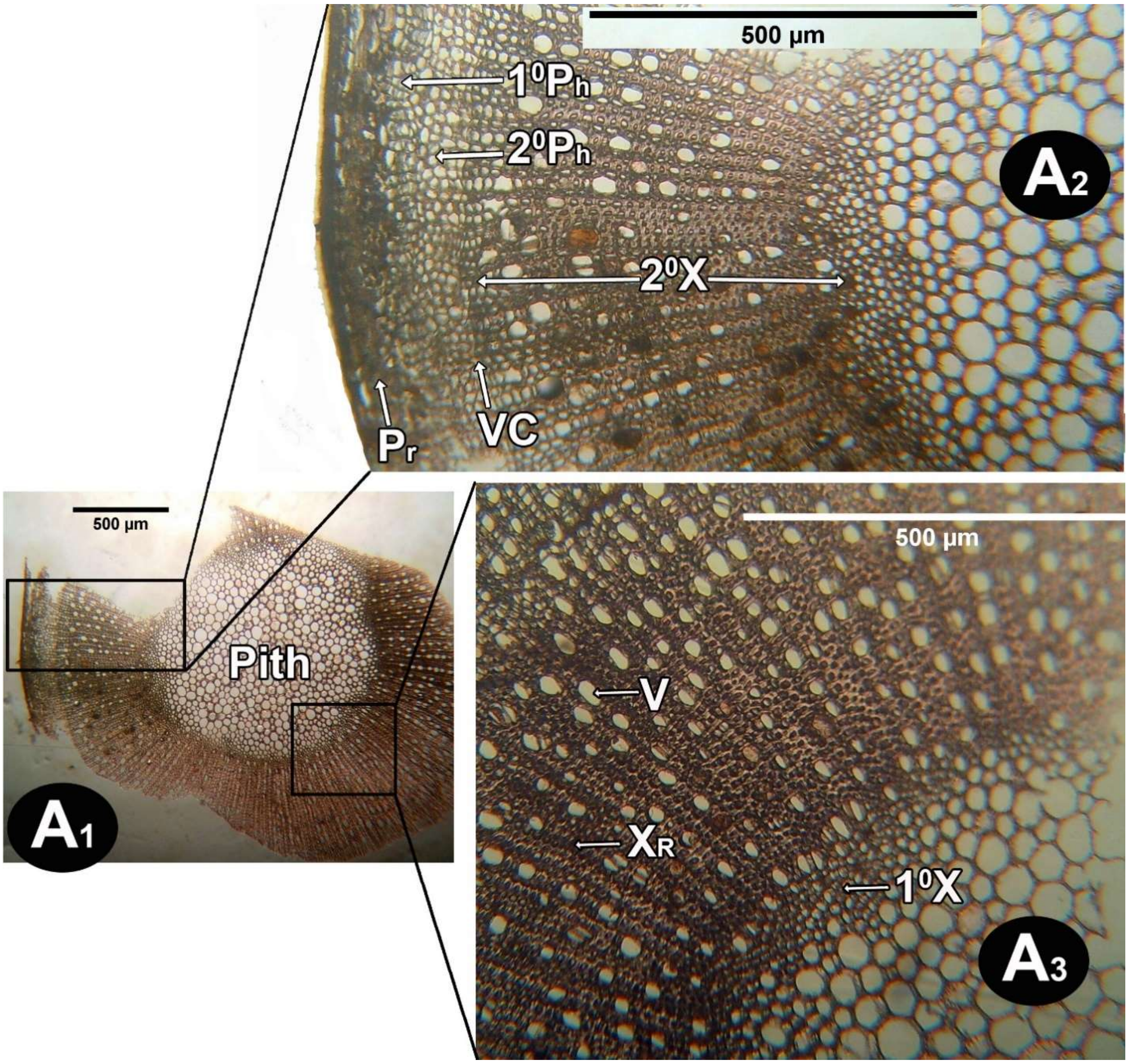

Fig. 4. The anatomy of the stem (**A_1**, **A_2** and **A_3**) of ***Gaultheria cumingiana*** (1^0X – primary xylem; 2^0X – secondary xylem; 1^0Ph – primary phloem; 2^0Ph – secondary phloem; VC – vascular cambium; V – vessel element; X_R – xylem ray; Pr - periderm)

The root. Only the woody roots (Figure $5A_1$ and $5A_2$) were documented in the study. The peridem forms the outermost covering of the roots, which consists of phellem, phelloderm and phellogen. After the periderm are the primary and secondary phloem which appears as a band of cells smaller than the other layers. The secondary xylem occupies the central portion with distinct xylem ray and vessel elements. Similar in the stem, vessel elements appear as the larger circles while xylem rays appear as dark lines. Sandwiched between the secondary xylem and secondary phloem is the vascular cambium.

Habitat characterization in terms of soil parameters and surrounding flora

Tables 3 and 4 present the habitat characters of the sampled population of *G. cumingiana*. Elevation of the populations ranges from 1592 to 2423 m asl showing that the taxon has a narrow elevation range at high altitude. The plant is usually found at forest edge or forest openings that include near road and farm clearing where there is partial to moderate shading. The plant requires more shading at lower elevation but can thrive at full sunlight in higher elevation. The soil pH is slightly acidic at 5.8 to 6.8. Results show that the taxon can tolerate varied soil conditions from red oxide soil, loamy soil to shallow gravelly soil. It is also observed overhanging at soil-stripped road walls even at rock crevices which strongly indicate it being a successional shrub.

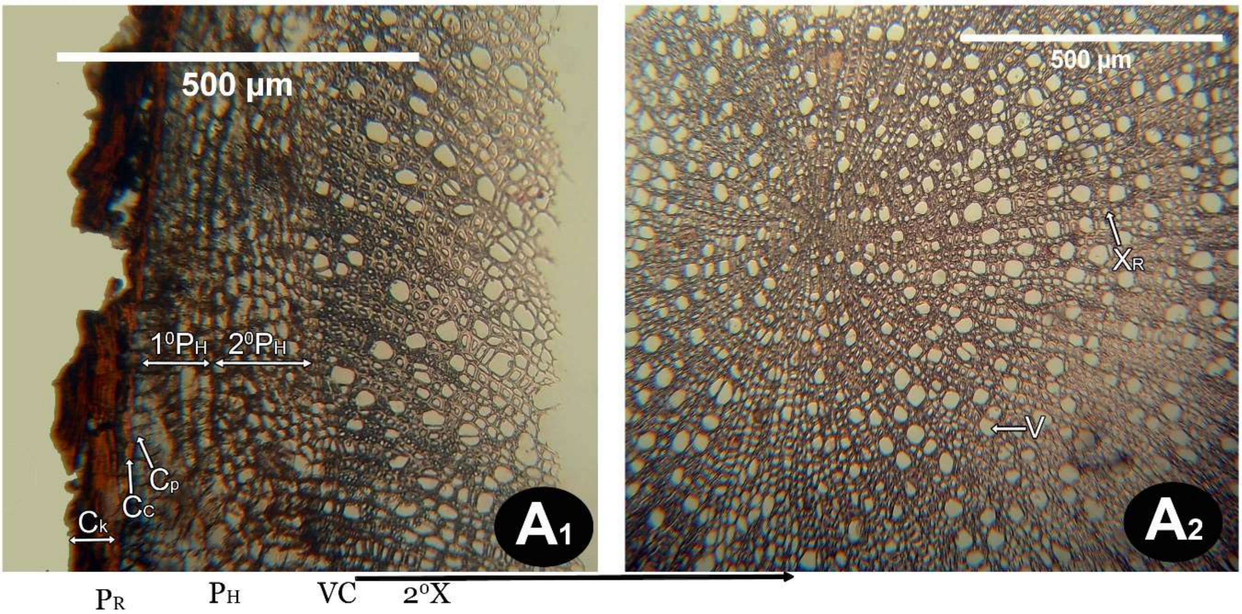

Fig. 5. The anatomy of the root of ***Gaultheria cumingiana*** (**A_1**- periphery of the root cross section, P_R – periderm, P_H – phloem, VC- vascular cambium, Ck – cork cells, Cc – cork cambium, Cp – cork parenchyma, 1^0P_H – primary phloem, 2^0P_H – secondary phloem; **A_2** – center of the root cross section, 2^0X – secondary xylem, V – vessel element; X_R)

Table 3. Biological and edaphic parameters in the habitat of the sampled population of ***G. cumingiana***.

Parameters	Palina, Kibungan	Tabbak, Kibungan	Amposungan, Bakun	Bagtangan, Bakun	Bagtangan Site 2	Atok site 1	Atok Site 2	Tawang
Slope (°)	62.00	87.00	85.00	89.00	75.00	75.00	59.00	81.00
pH	6.20	6.40	6.40	6.67	6.67	6.07	5.97	6.10
Northing	16.75222	16.75778	16.76861	16.73389	16.72806	16.70833	16.65833	16.45556
Easting	120.67417	120.70889	120.75028	120.76889	120.76806	120.76806	120.77583	120.61444
Elevation (m)	1689	1686	1609	2178	2238	2423	2301	1592
Species Richness	28	15	15	26	16	24	19	24
No. of *G. cumingiana*	3	9	13	14	16	7	7	8
Shannon Index	2.97	2.36	2.83	2.83	2.34	2.79	2.47	2.82
Evenness	0.67	0.55	0.59	0.62	0.51	0.61	0.55	0.63
Simpson	0.94	0.90	0.93	0.93	0.89	0.92	0.89	0.93
Margalefs	6.06	3.25	5.22	5.46	3.29	5.02	4.04	5.10

Table 4. General description of the habitat of the sampled population of ***G. cumingiana***.

Population Name	General description of the soil substrate and shade condition of the population's habitat
Palina, Kibungan	Red oxide soil under shade with *Pinus kesiya* as the main over story plant
Tabbak, Kibungan	As vegetation overhanging on a road cut wall, under shade with *Alnus japonica* as the main over story plant
Amposungan, Bakun	Shallow sandy soil over rocky substrate, under shade with *Pinus kesiya* as the main over story plant
Bagtangan, Bakun	Shallow loam over a rocky substrate, less shading
Bagtangan Site 2	Gravelly soil over rocky substrates, sun-exposed
Atok Site 1	Sandy soil on loose gravel, sun-exposed
Atok Site 2	Sandy soil on loose gravel, under *Pinus kesiya* shade
Tawang	Red oxide soil on vegetable garden edge adjacent to a forest site, overhanging vegetation provide shade

The species richness in the habitat of *G. cumingiana* ranges from 15 to 28 species with low to moderate diversity (Shannon-Wiener at 2.34 to 2.97). This indicates that the taxon is associated with a particular set of floral species since the plant is purposively sampled during the inventory. The taxon is associated with other 74 floral species of which 31 species are herb/ low lying plants and 46 species are overstory/ overhanging vegetation (see Table 5 and 6). Common underlying plants associated with the taxon are *Pteridium aquilinum*, *Odontosoria chinensis*, *Oplismenus hirtellus*, *Imperata cylindrica*, *Ageratina adenophora* and *Ageratina riparia* while the common overstory plants are *Miscanthus floridulus*, *Pinus kesiya*, *Alnus japonica*, *Rhododendron*

Table 5. The related understory species with ***Gaultheria cumingiana*** in Cordillera Central Range, Philippines.

Plant Species	ni	Ji	Di	Fi	Rdi	Rfi	IV
Ageratina adenophora (Spreng.) R.M.King & H.Rob.	35	6	1.46	25.00	7.97	4.11	6.04
Ageratina riparia (Regel) R.M.King & H.Rob.	51	6	2.13	25.00	11.62	4.11	7.86
Anaphalis morrisonicola Hayata	11	2	0.46	8.33	2.51	1.37	1.94
Arisaema polyphyllum (Blanco) Merr.	1	1	0.04	4.17	0.23	0.68	0.46
Blechnopsis orientalis (L.) C.Presl	8	2	0.33	8.33	1.82	1.37	1.60
Bolbitis rhizophylla (Kaulf.) Hennipman	1	1	0.04	4.17	0.23	0.68	0.46
Calanthe furcata Bateman ex Lindl.	2	1	0.08	4.17	0.46	0.68	0.57
Calochlaena javanica (Blume) M.D. Turner & R.A. White	9	3	0.38	12.50	2.05	2.05	2.05
Carex indica L.	1	1	0.04	4.17	0.23	0.68	0.46
Centratherum punctatum Cass.	1	1	0.04	4.17	0.23	0.68	0.46
Chingia ferox (Blume) Holttum	2	2	0.08	8.33	0.46	1.37	0.91
Clinopodium umbrosum (M.Bieb.) K.Koch	12	2	0.50	8.33	2.73	1.37	2.05
Crassocephalum crepidioides (Benth.) S.Moore	1	1	0.04	4.17	0.23	0.68	0.46
Desmodium velutinum (Willd.) DC.	6	4	0.25	16.67	1.37	2.74	2.05
Dianella ensifolia (L.) Redouté	11	5	0.46	20.83	2.51	3.42	2.97
Dicranopteris curranii Copel.	3	2	0.13	8.33	0.68	1.37	1.03
Dicranopteris linearis (Burm.) Underw.	6	4	0.25	16.67	1.37	2.74	2.05
Dipteris conjugata Reinw.	13	4	0.54	16.67	2.96	2.74	2.85
Emilia sonchifolia var. *javanica* (Burm.f.) Mattf.	4	1	0.17	4.17	0.91	0.68	0.80
Erigeron sumatrensis Retz.	2	2	0.08	8.33	0.46	1.37	0.91
Gaultheria borneensis Stapf	16	4	0.67	16.67	3.64	2.74	3.19
Gaultheria cumingiana S.Vidal	77	22	3.21	91.67	17.54	15.07	16.30
Gonostegia triandra (Blume) Miq.	5	4	0.21	16.67	1.14	2.74	1.94
Gunnera macrophylla Blume	13	4	0.54	16.67	2.96	2.74	2.85
Imperata cylindrica (L.) P.Beauv.	23	7	0.96	29.17	5.24	4.79	5.02
Lilium formosanum A.Wallace	6	3	0.25	12.50	1.37	2.05	1.71
Lycopodiella cernua (L.) Pic.Serm.	1	1	0.04	4.17	0.23	0.68	0.46
Lycopodium clavatum L.	17	5	0.71	20.83	3.87	3.42	3.65
Mazus pumilus (Burm.f.) Steenis	1	1	0.04	4.17	0.23	0.68	0.46
Melastoma malabathricum L.	1	1	0.04	4.17	0.23	0.68	0.46
Miscanthus floridulus (Labill.) Warb. ex K.Schum. & Lauterb.	1	1	0.04	4.17	0.23	0.68	0.46
Nepenthes alata Blanco	1	1	0.04	4.17	0.23	0.68	0.46
Nertera granadensis (Mutis ex L.f.) Druce	5	2	0.21	8.33	1.14	1.37	1.25
Oberonia cylindrica Lindl.	1	1	0.04	4.17	0.23	0.68	0.46
Odontosoria chinensis (L.) J.Sm.	16	7	0.67	29.17	3.64	4.79	4.22
Oplismenus hirtellus (L.) P.Beauv.	25	6	1.04	25.00	5.69	4.11	4.90
Persicaria chinensis (L.) H.Gross	2	2	0.08	8.33	0.46	1.37	0.91
Pogonatherum crinitum (Thunb.) Kunth	11	2	0.46	8.33	2.51	1.37	1.94
Pteridium aquilinum (L.) Kuhn	10	6	0.42	25.00	2.28	4.11	3.19
Rubus benguetensis Elmer	4	3	0.17	12.50	0.91	2.05	1.48
Rubus fraxinifolius Poir.	6	2	0.25	8.33	1.37	1.37	1.37
Rubus luzoniensis Merr.	1	1	0.04	4.17	0.23	0.68	0.46
Setaria palmifolia (J.Koenig) Stapf	1	1	0.04	4.17	0.23	0.68	0.46
Smilax china L.	4	2	0.17	8.33	0.91	1.37	1.14
Themeda triandra Forssk.	3	1	0.13	4.17	0.68	0.68	0.68
Vaccinium myrtoides (Blume) Miq.	8	5	0.33	20.83	1.82	3.42	2.62

spp and *Rubus* spp. Several of the low lying species are weeds that can tolerate the denuded nature of the sampled habitat; several also are indigenous species that are characteristics of high elevated areas; and, few are conservation important species such as the vulnerable *Rhododendron kochii* and *Rhododendron subsessile*.

On the other hand, Figure 6 presents the result of the Canonical Correspondence Analyses on the interplay of the environmental and biological parameters in the sampled populations of *G. cumingiana*. It can be readily seen in the figure that the biodiversity indices are closely associated which is expected due to their close values and the interrelated nature of these indices. The elevation and coordinates are also closely related while soil pH, species richness and slope are not related with other factors which would indicate that these do not affect the *G. cumingiana* populations. Moreover, the populations aggregated into three groups which could be equated as distinct subpopulations.

Table 6. The related overstory species with ***Gaultheria cumingiana*** in Cordillera Central Range, Philippines.

Plant Species	ni	Ji	Di	Fi	Rdi	Rfi	IV
Alnus japonica (Thunb.) Steud.	29	11	0.134	45.83	9.39	8.40	8.89
Aralia bipinnata Blanco	1	1	0.005	4.17	0.32	0.76	0.54
Clethra canescens var. *luzonica* (Merr.) Sleumer	5	3	0.023	12.50	1.62	2.29	1.95
Coriaria intermedia Matsum.	10	7	0.046	29.17	3.24	5.34	4.29
Deutzia pulchra S.Vidal	4	3	0.019	12.50	1.29	2.29	1.79
Eurya coriacea Merr.	9	5	0.042	20.83	2.91	3.82	3.36
Ficus benguetensis Merr.	4	2	0.019	8.33	1.29	1.53	1.41
Ficus septica Burm.f.	3	1	0.014	4.17	0.97	0.76	0.87
Ficus ulmifolia Lam.	1	1	0.005	4.17	0.32	0.76	0.54
Helicia robusta (Roxb.) R.Br. ex Blume	2	2	0.009	8.33	0.65	1.53	1.09
Homalanthus populneus (Geiseler) Pax	3	2	0.014	8.33	0.97	1.53	1.25
Leucosyke benguetensis Unruh	8	2	0.037	8.33	2.59	1.53	2.06
Maesa indica (Roxb.) Sweet	5	2	0.023	8.33	1.62	1.53	1.57
Maoutia setosa Wedd.	2	2	0.009	8.33	0.65	1.53	1.09
Melastoma malabathricum L.	22	8	0.102	33.33	7.12	6.11	6.61
Miscanthus floridulus (Labill.) Warb. ex K.Schum. & Lauterb.	89	21	0.412	87.50	28.80	16.03	22.42
Mussaenda benguetensis Elmer	1	1	0.005	4.17	0.32	0.76	0.54
Neonauclea reticulata (Havil.) Merr.	1	1	0.005	4.17	0.32	0.76	0.54
Pinus kesiya Royle ex Gordon	40	16	0.185	66.67	12.94	12.21	12.58
Pittosporum resiniferum Hemsl.	3	2	0.014	8.33	0.97	1.53	1.25
Rhododendron kochii Stein	10	7	0.046	29.17	3.24	5.34	4.29
Rhododendron quadrasianum var. *rosmarinifolium* (S.Vidal) H.F.Copel.	23	6	0.106	25.00	7.44	4.58	6.01
Rhododendron subsessile Rendle	7	6	0.032	25.00	2.27	4.58	3.42
Rubus copelandii Merr.	3	3	0.014	12.50	0.97	2.29	1.63
Rubus fraxinifolius Poir.	7	3	0.032	12.50	2.27	2.29	2.28
Saurauia elegans (Choisy) Fern.-Vill.	3	2	0.014	8.33	0.97	1.53	1.25
Sphaeropteris glauca (Blume) R.M.Tryon	2	1	0.009	4.17	0.65	0.76	0.71
Symplocos whitfordii Brand	3	2	0.014	8.33	0.97	1.53	1.25
Vaccinium indutum S.Vidal	5	5	0.023	20.83	1.62	3.82	2.72
Viburnum luzonicum Rolfe	2	1	0.009	4.17	0.65	0.76	0.71
Weinmannia luzoniensis S.Vidal	2	2	0.009	8.33	0.65	1.53	1.09

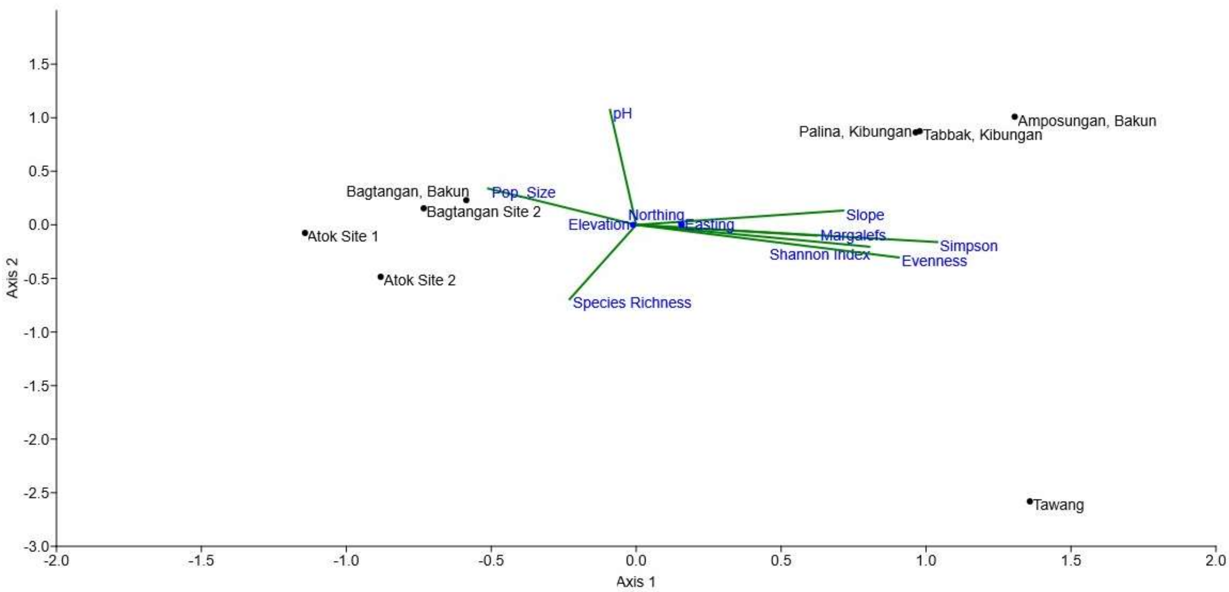

Fig. 6. Result of Canonical Corresponding Analysis showing the interplay of environmental factors with the sampled population of ***Gaultheria cumingiana***

Bagtangan and Atok populations are closely related with population size and elevation as these have larger greater population size of *G. cumingiana* and occur in higher elevation. Kibungan and Ampusongan populations will form the 2nd subpopulation which could attributed to their proximity and the Tawang population is the 3rd representing the lowest elevation range of the taxon.

DISCUSSIONS

The morphological characters of the taxon based on sampled populations are consistent with the original description of *G. cumingiana* given by Vidal (Elmer, 1911) but the description in this present study is more detailed. It is generally consistent with the descriptions for *G. leucocarpa* and its varieties given in Sleumer (1957), Fang and Stevens (2005) and Fritsch *et al*. (2008) but with some distinctions. The leaves of our specimen are smaller (3.3–6.9 × 1.9–4.6 cm) compared to 4–14.5 × 2–6.5 cm in the earlier descriptions. Leaf variations, nonetheless, are expected as plastic characters to be significantly affected by environmental factors (Pancho, 1983; Buot and Okitsu, 1999). However, some variations on the reproductive organs were also noted. Plants in this study are solitary to few-flowered (2-5) while 4–12-flowered in Fang and Stevens' and Fritsch *et al*.'s description. In addition, the corolla in this study is predominantly greenish white or pink to reddish with white interludes, which is different from Fang and Stevens' and Fritsch *et al*.'s white description but is consistent with Sleumer's. Calyx and corolla are larger in this study compared to previous descriptions (calyx: 3–4 mm long vs 2.5 mm in Sleumer and 1.5 in Fang and Stevens; corolla: 5–8 × 7–8 mm vs 3.5–4 × 3–4 mm in Sleumer and 6–7 mm in Fang and Stevens). Lastly, the fruit diameter recorded in this study is more variable (3–18 mm, smaller and larger) than the previous descriptions (9–11 mm in Sleumer and 4–7 mm in Fang and Stevens, 2005 and Fritsch *et al*., 2008). The differences of *G. cumingiana* documented in this study compared with the earlier descriptions of *G. leucocarpa* support the results of Powell and Kron (2001) which found samples of *G. cumingiana* to be not closely *related* with *G. leucocarpa* in the matK analysis; and, the distinct pollen structures of *G. cumingiana* compared to *G. leucocarpa* in Lu *et al*. (2009). To summarize, *G. cumingiana* has smaller leaves, larger calyx and corolla, red to purple or blackish fruit at maturity, distinct pollen structures (see Lu *et al*., 2009) and distinct in matK analysis (see Powell and Kron 2001) compared to *G. leucocarpa* and its varieties. With these evidences and the careful consideration of the suggestions of Helbig *et al*. (2002) that "a combination of two or three functionally independent characters can distinguish a species from other closely related species", we are proposing the alteration of *Gaultheria cumingiana* Vidal to be recognized as a distinct species and not a variety of *G. leucocarpa*.

Sleumer (1957) noted that *G. leucocarpa,* in a broad sense, is a species widely distributed beyond Malesia into East Asia. In this immense area, several varieties or forms can be distinguished based on certain characters of the indument and the color of the fruit with each of these varieties or forms having its peculiar geographical range. This assumption led him to assign *G. cumingiana* as variety under *G. leucocarpa* by being distinct from other varieties in its glabrous inflorescence, densely pubescent ovary and dark red to purplish blackish fruit. But with the recent evidences that arise, as mentioned above, it is now imperative that we recognize *G. cumingiana* as a distinct species.

The anatomical characteristics of *G. cumingiana* show a typical dicot anatomy with dorsiventral leaves, woody stem and roots with the usual arrangement of periderm followed by secondary phloem, vascular cambium, secondary xylem with vessel elements, and pith (in the case of the stem). The leaf anatomical characters of the taxon are consistent with the characterization given by Middleton (1993), but as *G. leucocarpa* var. *cumingiana*, except in lamina thickness. Lamina thickness in this study ranges from 346–411 um, much thicker than the 190 um reported by Middleton. Nonetheless, this difference is a leaf character and is most likely a plastic character that could be influenced by environmental conditions, particularly by sun or shading conditions (Poole *et al*., 1996).

The leaf anatomy of this taxon is typical of a shade plant. The palisade layer consists of 1 to 3 cell layers but the spongy layer is generally thicker and with prominent air spaces. Shade leaves are green but sun-exposed leaves are generally with red tinge, indicative of the presence of colored pigments to protect the photosynthetic layer from photo-damage of excessive radiation. Its anatomy contrast well with *Rhododendron subsessile*, a sun-plant and a similar Ericaceae species occupying the same area in the CCR (Bitayan *et al*., 2020). *Rhododendron subsessile* leaf is covered with trichomes particularly the younger leaf and in lower epidermis, with biseriate epidermis or could be a uniseriate epidermis plus hypodermis, and a much thicker palisade layer than spongy layer. These differences between the two species, but of the same family, provide a good comparison between the anatomy of shade and a sun plant occupying the same area. Moreover, these differences are attributed predominantly to the difference in sun or shade conditions (Poole *et al*., 1996; Ivanova *et al*., 2006).

The stomatal density in the sampled populations of *G. cumingiana* is interestingly very high (318–559 stomata/mm^2). It is much higher than those documented in *Lilium philippinense* at 31–124 (Napaldet, 2017) and in *Coriaria intermedia* at 172–376 stomata/mm^2 (Guron and Napaldet, 2020) that also occur in the CCR. The high stomatal density in this taxon coupled with the prominent air spaces in spongy layer correlate well with the prevailing environmental factors in its common habitat. This taxon was observed growing in eroded slopes with overhanging vegetation, in red oxide soils and commonly competing with fast growing *Miscanthus floridulus* and other grasses. The high stomatal density coupled with the prominent air spaces in the spongy layer allow the maximum absorption of CO_2 for photosynthesis to enable the taxon to compete with fast growing grasses in the area. Also, this high stomatal density may help the plant lose water during rainy season when the area is practically oversaturated. Moreover, the small stomatal size that contributes to the high stomatal density allows the plant to have faster aperture response with changing weather, opening during wet condition and closing during dry season. The stomata is of paracytic type, defined by Metcalfe and Chalk (1950) as "with two subsidiary cells running parallel the guard cells. Paracytic type is usually common on monocot such as Cyperaceae and Poaceae (Zarinkamar, 2006) and its occurrence in *G. cumingiana* is interesting. Middleton (1993) also documented paracytic to be the prominent stomatal type in *Gaultheria* and related groups.

The stem and root anatomies of this taxon were first presented in this study. Middleton (1993) in his systematic review of the leaf and stem of *Gaultheria* was only able to note the pith in the stem anatomy. The stem and root anatomy of this taxon are generally comparable with other dicot plants already documented in the same CCR biogeographic zone like *Rhododendron subsessile* (Bitayan *et al*., 2020) and *Coriaria intermedia* (Guron and Napaldet, 2020).

Elevation and shading were the major factors affecting the population of *Gaultheria cumingiana* while edaphic factors did not contribute much. The taxon has a narrow elevation range at high altitude which is similar with those of *C. intermedia* (Guron and Napaldet, 2020). Shading also affects the taxon as it is usually found in forest edge and forest clearings. At lower elevation, it generally requires more shading but at higher elevation, it tolerates full sunlight. These findings support the claim of various studies that various factors affect the distribution patterns of plants and rarely does a factor work in isolation (Magcale-Macandog and Whalley, 1994; Buot and Okitsu, 1998; Hijmans and Spooner, 2001; Schnitzer, 2006).

From a conservation perspective, the appreciation of both morphology and ecology is fundamental to understand the many aspects of plant biology of unique plants, including the ecological and physiological. Aside from being a source of characters for taxonomic classification and phylogeny reconstruction, plant morphology and anatomy elucidate the relationship of these structures to their functions or physiology (Pancho and Gruezo, 2012). This is true in the case of *G. cumingiana.* As an indigenous and ethno-medicinal species, the morpho-anatomical and ecological characters documented in this study could serve as baseline information for its conservation (Volis, 2015). In addition, documenting the morpho-anatomical and ecological characters of the local plants in CCR could help elucidate how these unique assemblages of vegetation thrive in the area, a phenomenon that puzzled the first Americans who visited the area and is still not fully understood to date.

ACKNOWLEDGMENTS

This study is part of the research project titled "Documentation and Re-description of Floral Diversity in Cordillera Central Range, Northern Philippines" funded by SEARCA (Southeast Asian Regional Center for Graduate Study and Research in Agriculture) through the Seed Fund for Research and Training. The study was also provided with travel fund support from Benguet State University through the Office of the Vice President for Research and Extension headed by Romeo A. Gomez Jr. Further, the authors are indebted to the indigenous people and LGU officials of Benguet for allowing us to conduct the study; Eugene Logatoc for the helpful insights; and the reviewers for their valuable comments and suggestions for the improvement of the manuscript. Thanks to all and to God be the glory!

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