SORBUS ULLEUNGENSIS, A NEW ENDEMIC SPECIES ON ULLEUNG ISLAND, KOREA

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Abstract. Plants that have been treated as *Sorbus commixta* on Ulleung Island, Korea, show morphological variability and their taxonomy is unclear. We extensively studied the morphology of wild populations of these plants and found that they can be distinguished from *S. commixta* by their larger fruits and flowers and wider inflorescences. Here we describe and illustrate them and propose them as representing a new species, *S. ulleungensis*. An updated key to the five Korean species of *Sorbus* including the new species is provided.

Keywords: new species, *Sorbus commixta, Sorbus pohuashanensis*, Ulleung rowan, Ulleung island

Sorbus L. (Rosaceae) comprises approximately 100 species of deciduous trees and shrubs widely distributed throughout northern hemisphere (Krüssmann, 1984; Ohwi, 1984; Robertson et al., 2010; Lu and Sponberg, 2003; McAllister, 2005). The main centers of diversity for the genus are in China, northern Myanmar, and the eastern Himalayas (McAllister, 2005). Recent study (McAllister, 2005) treated *Sorbus* in a narrower sense (sensu stricto) to include only the pinnate-leaved species, raising several of the simple leaved species to generic rank. As treated in its broad sense (sensu lato), *Sorbus alnifolia* (subgenus *Aria*) is included in the genus Sorbus here. Therefore, four species, *S. pohuashanensis* (Hance) Hedl., *S. commixta* Hedl., *S. sambucifolia* (Cham.& Schltdl.) M. Roem, and *S. alnifolia* (Siebold & Zucc.) K. Koch are known from the Korean peninsula (Lee, 1980; Chang et al., 2011).

Ulleung Island, a volcanic. pentagonally shaped island about 10 km in diameter, is located about 150 km from the Korean mainland. The island, formed during the late Tertiary period and surrounded by rocky cliffs, is well known for its unique flora numbering about 180 woody species, including several endemics (Lee and Joo, 1958). The one species of *Sorbus* on Ulleung Island has long been recognized as *S. commixta* Hedl. (Lee, 1980). However, Nitzelius (1989), during his expedition to Ulleung Island in 1976, first raised the question of its status due to the large size of most of its morphological characters. Nitzelius called a clone of the Ulleung rowan "Dodong" and propagated and distributed it in Europe because of its great value to landscape architecture (Nitzelius, 1989).

When field work was undertaken in Ulleung Island over several years, the larger flowers and fruits having several distinctive vegetative characters were noticed on the Ulleung rowan in comparison with the closely related *S. commixta*. An examination of herbarium material and field collections of *Sorbus* L. on Korea's Ulleung Island suggested that a description of a new taxon similar to *S. pohuashanensis* (Hance) Hedl. and *S. commixta* Hedl. was required.

Previously recognized endemic taxa, *Fagus multinervis* Nakai, *Cotoneaster wilsonii* Nakai, *Acer takesimense* Nakai, and *Acer okamotoanum* Nakai on Ulleung Island are currently treated as *F. engleriana* Seemen ex Diels, *C. multiflorus* Bunge of central China, *Acer pseudosieboldianum* (Pax) Kom., and *Acer pictum* Thunb., respectively (Chang and Jeon, 2003, Chang, 1992, Chang et al., 2011). On the other hand, *Tsuga* on Ulleung Island was shown to be more closely related to *T. diversifolia* (Maxim.) Mast. of northern Japan, rather than to *T. sieboldii* Carriere of southeastern Japan (Havill et al., 2008). Also, *Prunus takesimensis* Nakai and *Sambucus racemosa* subsp. *pendula* (Nakai) H. I. Lim and Chin S. Chang on Ulleung Island have been reported as distinctive endemic subspecies on this island (Chang, 1992; Chang et al., 2004; Lim et al., 2009). Recent studies (Koji et al. 2012, Stussey et al., 2006) showed that examination of an anagenetically derived endemic species on Ulleung Island reveals genetic variation equal or nearly equal to that of its continental progenitor.

The primary objective of this research was to define the phenetic relationships among the different morphological entities of the *S. pohuashanensis*, *S. commixta* and Ulleung island individuals. Individuals of *Sorbus* on Ulleung island were studied to determine if their morphological differentiation from the related taxa warranted specific taxonomic recognition.

Materials and Methods

Mature leaves were collected from many places in South Korea from 2010 to 2012. Three hundred and ninety one individuals were sampled for fruits, flowers and leaves from individuals from Ulleung Island (59 individuals), *S. pohuashanensis* (182), and *S. commixta* (150) were collected and measured for characters. Herbarium specimens from the material collected were stored at SNUA. In addition, herbarium specimens of *S. commixta* from Japan (48) and *S. pohuashanensis* from China (70) (from TI, MAK, TUS and PE) were selected to represent the entire geographical

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (No. 2011-0022323). We also thank Dr. Kanchi Gandhi at Harvard University Herbaria for the Latin diagnosis.

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Harvard Papers in Botany, Vol. 19, No. 2, 2014, pp. 247–255.

ISSN: 1938-2944, DOI: 10.3100/hpib.v19iss2.2014.n11, Published online: 31 December 2014

range and to reflect the morphological variability present within each taxon. Previous studies suggested that *S. pohuashanensis* in Korea is considered to be a past hybrid originating between *S. commixta* and *S. wilsoniana* in China, thus this taxon is excluded for morphological analysis here.

Characters selected for analysis included those most frequently utilized in keys and diagnoses. Criteria classically used in the literature (Lu and Sponberg, 2003; McAllister, 2005) to distinguish among taxa concerned include the length of leaflet, number of leaflets, width of inflorescence and fruit size. Since flowering or fruit specimens were not available to measure the width of floral tube, length of pistil, length of seed, and width of seed, only living collections of *S. pohuashanensis*, *S. commixta* and Ulleung individuals from Korea were selected and measured. For leaf measurements a "typical," usually the largest, measurable leaf, was selected. The initial data matrices were constructed from 19 vegetative and fruit characters including one ratio (Table 1).

Morphological variation within and among taxa was assessed using univariate statistics (mean, maximum, minimum) and multivariate morphometric analyses (principal components aanalysis: PCA). The PCAs and univariate statistics were produced with XLSTAT (version 2011.1.04) and R (version 2.15.2). A correlation matrix was generated using selected significant characters along with the univariate and analysis of variance (ANOVA). Also, bivariate scatter diagrams were performed and each characters associated with individuals of several OTUs were plotted here.

TABLE 1. Morphological characters for pomes and leaves of the *Sorbus commixta* complex used in the principal components analysis. Units of measurement are given in parentheses.

MORPHOLOGICAL CHARACTERS OF LEAVES AND POMES
1. Leaf length(mm)
2. Terminal leaflet length(mm)
3. Terminal leaflet width(mm)
4. Middle leaflet length(mm)
5. Middle leaflet width(mm)
6. Petiole length of terminal leaflet(mm)
7. Rachis length(mm)
8. Petiole length(mm)
9. Number of leaflets
10. Angle of leaflet apex, terminal leaflet (°)
11. Angle of leaflet apex, middle leaflet (°)
12. Angle of leaflet base, terminal leaflet (°)
13. Number of middle leaflet's teeth
14. Toothed length, middle leaflet (mm)
15. Length of corymb(mm)
16. Diameter of corymb(mm)
17. Length of pome (mm)
18. Diameter of pome (mm)
19. Ratio of toothed length/leaflet length, middle leaflet

RESULTS AND DISCUSSION

For fruit with leaf characters the first three PCA axes accounted only for 62.6% of the total variance: PC (principal component) 1 had the highest loadings for leaf length (character 1), terminal leaflet length (character 2), terminal leaflet width (character 3), petiole length of terminal leaflet (character 6), petiole length (character 8), toothed length of middle leaflet (character 14), length of corymb (character 15), diameter of corymb (character 16); PC2 had the highest loadings for angle of terminal leaflet apex (character 10); Angle of terminal leaflet base (character 12); PC3 had the highest loadings for ratio of toothed length/leaflet length of middle leaflet (character 19).

PC 1 vs. PC 3 provided better separation of the Chinese *S. pohuashanensis* from other taxa, while PC 1 versus PC 2 revealed separation of *S. commixta* from individuals of the Ulleung rowan. It was clear that there was minimal overlap in the clusters of individuals of the Ulleung rowan and *S. commixta*. The characters that contributed most to the separation were the leaf length, the number of leaflets (11–13 versus 13–15), corymb width, and fruit width (6–7 mm versus 9–10 mm) (Fig. 1). Also, it differs from *S. commixta* in having a wide calyx-tube, long pistil, and large seed (Fig. 1) and has more carpels (3–4 versus 4–5). This new species can be consistently distinguished from the related taxa in characters of leaf length, number of leaflets, corymb width, fruit width (Fig. 1). In general, large flowers and fruits can be considered characters of great taxonomic value to distinguish the Ulleung individuals (Table 2).

Bivariate analysis demonstrated that width of inflorescence and size of fruit between Ulleung individuals and the other related taxa emerged as the most distinct (Fig. 2). Also, its habit is more likely to be a large tree with dark gray

TABLE 2. Comparisons of three taxa, *Sorbus pohuashanensis*, *S. commixta,* and *S. ulleungensis* in terms of seven morphological characters.

	S. POHUASHANENSIS	*S. COMMIXTA*	*S. ULLEUNGENSIS*
Habits	Shrub to small tree	Shrub to small tree	Large tree
Leaf length (cm)	(11.0) 14.0–18.7 (25.0)	(10.2) 14.4–20.4 (30.3)	(16.7) 22.5–25.3 (31.3)
Inflorescence width (mm)	(63) 100–122 (160)	(50) 85–115 (154)	(90) 130–160 (235)
Flower diameter (mm)	(8) 9–11 (13)	(7) 8–10 (13)	(10) 12–14 (16)
Fruit length (mm)	(4.7) 6.0–7.1 (8.9)	(4.4) 6.2–7.1 (8.2)	(7.6) 9.0–10.5 (12.2)
Fruit width (mm)	(4.4) 6.5–7.9 (9.7)	(5.2) 6.4–7.2 (8.7)	(8.2) 9.2–10.6 (12.9)
Number of carpels	(2) 3–4 (5)	(2) 3–4 (5)	(3) 4–5 (6)

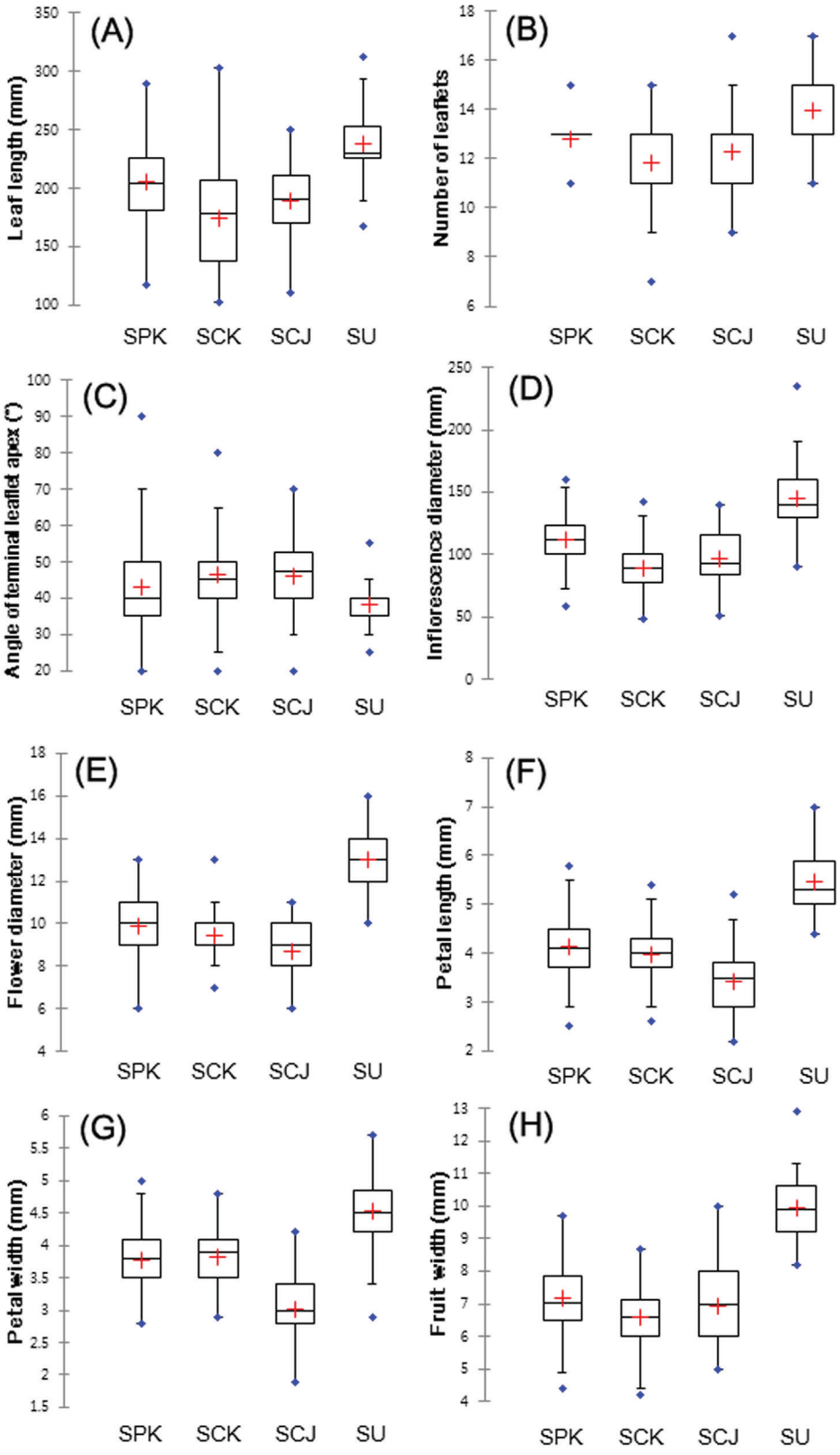

FIGURE 1. Univariate statistics with the minimum and maximum values for the discriminating characters for *Sorbus pohuashanensis* (SPK), *S. commixta* (SCK and SCJ: Korean and Japanese individuals), and *S. ulleungensis* (SU). **A**, leaf length (mm); **B**, number of leaflets; **C**, calyx tube width (mm); **D**, inflorescence diameter (mm); **E**, flower diameter (mm); **F**, fruit width (mm); **G**, petal length (mm); **H**, seed length (mm).

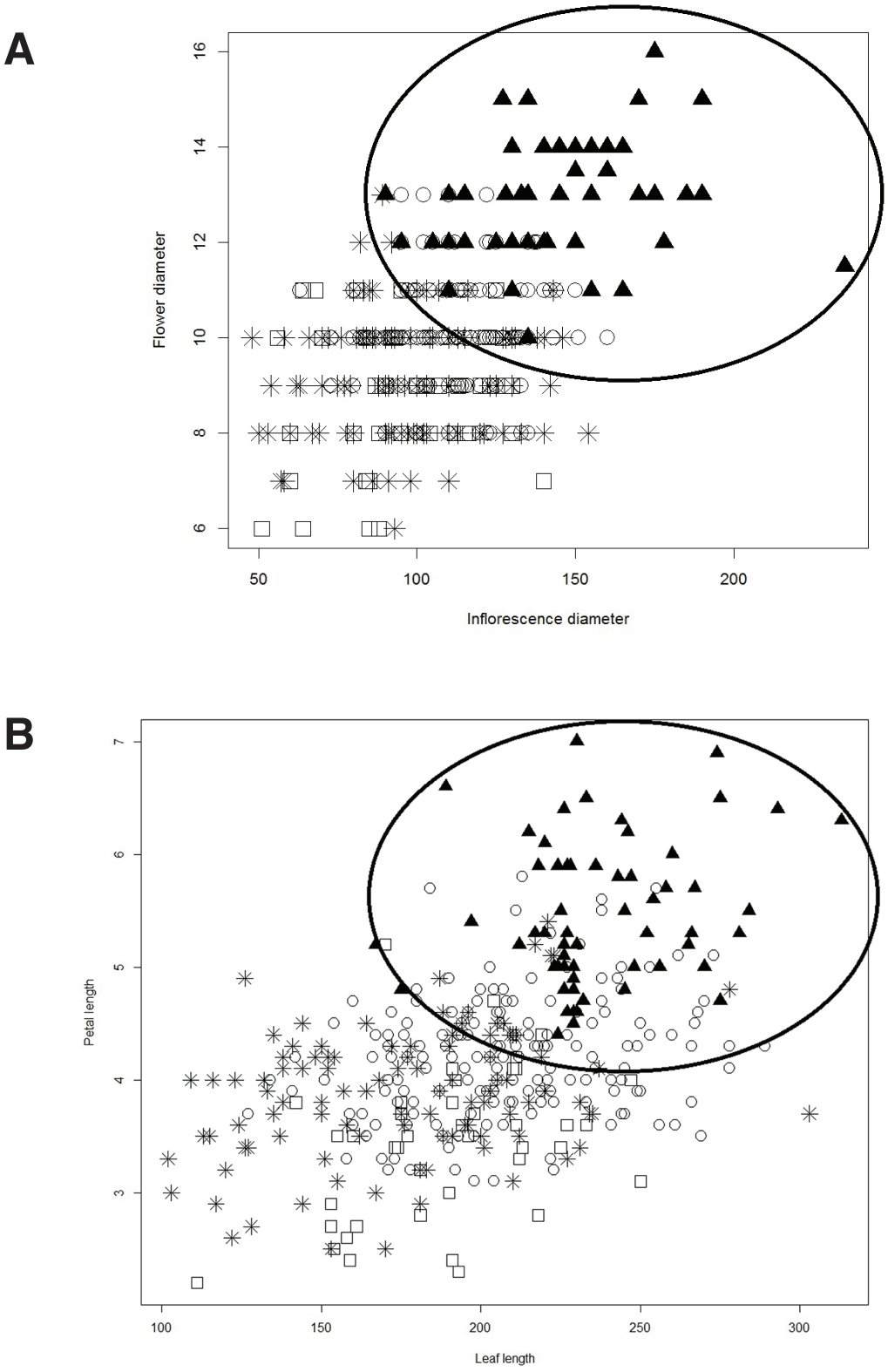

FIGURE 2. Bivariate scatter diagrams using 327 specimens for the discriminating characters for *Sorbus ulleungensis* (SU) and the other related taxa (*S. commixta* and *S. pohuashanensis*) **A**, inflorescence vs. flower diameter (mm); **B**, leaf length vs. petal length (mm).

outer bark, whereas *S. commixta* and *S. pohuashanensis* are shrubby to small but sometimes large trees with light gray bark. The results of current analysis indicate that Ulleung individuals and others were distinct in morphological aspects.

No strong discontinuities, however, existed among taxa of *S. commixta* and *S. pohuashanensis* in the Korean peninsula [In a plot of PC 1, PC 2, and PC 3, OTUs from *S. pohuashanensis* in the Korean peninsula occupied the central area of the plot and overlapped with many individuals from *S. commixta* (Fig. 3). Univariate statistics (Fig. 1), in addition to the minimum and maximum values for many characters, showed that values overlapped extensively for these taxa. These are believed to have originated by ancient hybridization between *S. commixta* from Japan and *S. wilsoniana* C.K. Schneid. from China based on flavonoids and morphology (Gil, 2013). In fact, *S. pohuashanensis* in the Korean peninsula has a very high level of morphological variation, which is more closely related to *S. commixta*. The morphological and chemical relationship between these two taxa will be presented as a separate study.

Sorbus ulleungensis grows in deciduous forest montane forests at elevations of 300–980 m with *Fagus engleriana* Seemen ex Diels, *Acer psudosieboldianum* (Pax) Kom., *Acer pictum* var. *mono* (Maxim.) Maxim. ex Franch., and *Tilia amurensis* Rupr. (Kim et al., 2003). Several hundred individuals of this species are usually found within this island. The new taxon is compared to *S. commixta* and *S. pohuashanensis* in Table 2. The specimen collected by Nakai cited under *Sorbus commixta* f. *rufohirtella* Nakai is described as a new form because of the presence of leaflet reddish hairs below on midrib unlike tufts of soft reddish hairs on leaflet midrib in other individuals. It is known that leaflets of *S. commixta* in Japan and southern Korea are glabrous to glabrate on lower surfaces, while those of *S. pohuashanensis* in Northeastern China and the putative hybrid in Korean peninsula are hairy on lower surface, which may be an important key character. *S. commixta* f. *rufohirtella,* which was not found anywhere in Island Ulleung seemed to be a unique form of this described new species. We have not found this form of this species thus far, and excluded it as a synonym of this new species.

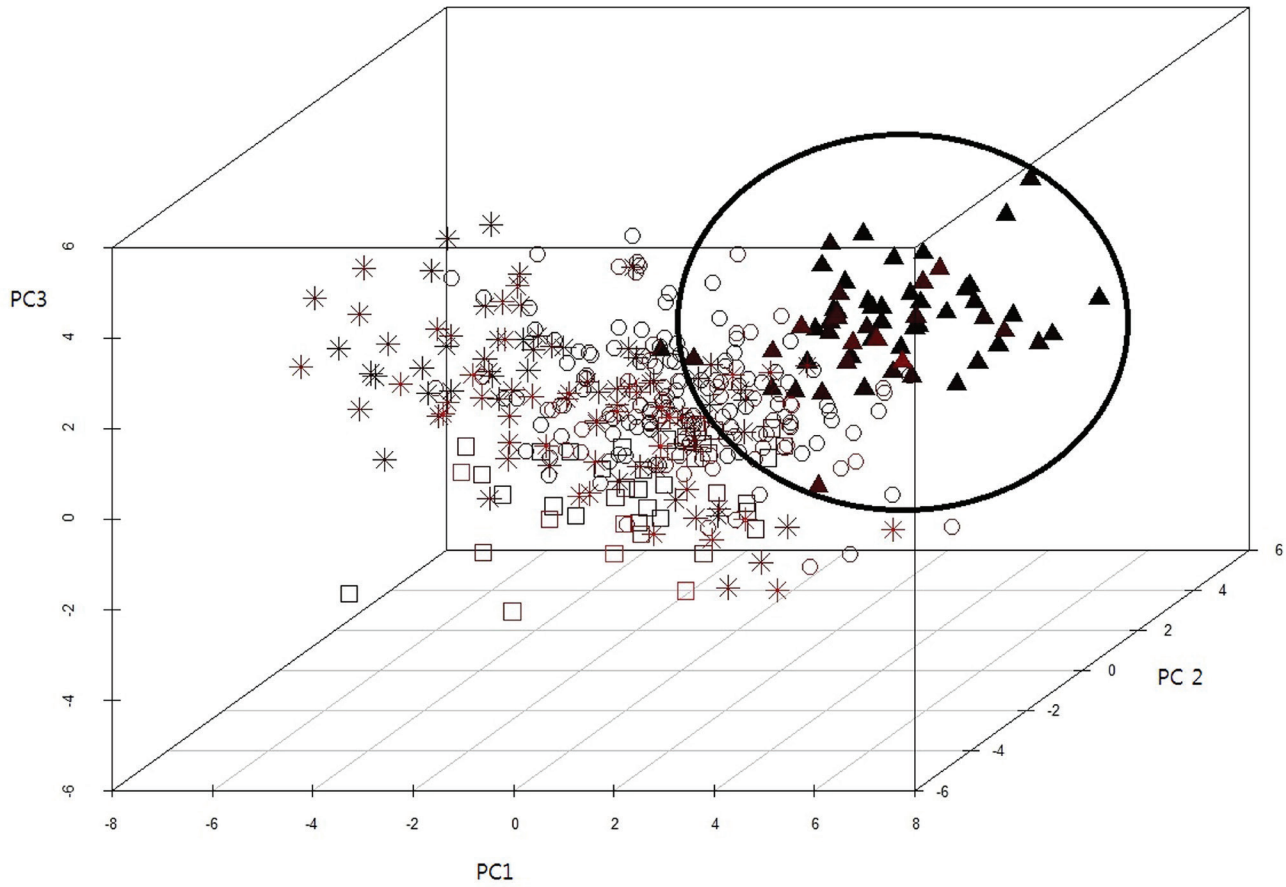

FIGURE 3. Scatter plot of the three axes of the principal component analysis (PCA) into the *Sorbus commixta* complex. *S. pohuashanensis* [Korea] (□); *S. commixta* [Korea] (○); *S. commixta* [Japan] (✳); *S. ulleungensis* (▲).

Taxonomy

Sorbus ulleungensis Chin S. Chang, *sp. nov.* TYPE: KOREA. Gyeongsangbuk-do: Ulleung-gun, Ulleung-eup, Jeodong-ri, Naesujeon observatory, along trail, mixed broadleaf forest, on roadside, natural habitat, 37˚30'45.9"N, 130˚54'29.2"E, alt. 370 m, 9 September 2011, *H.Y. Gil 736* (Holotype: SNUA [90590]; Isotype: A). Figs. 4–5.

Arbores insignes, ad 20 m altae; cortex adultus fissuris verticalibus percursus; stipulae membranaceae, deciduae; foliola 13–15; flores 12–14 mm longi, fructus 9–10.5 mm longi.

Trees up to 20 m tall; bark grayish brown, smooth when young, vertically fissured at maturity; twigs reddish brown, thick. *Buds* ovoid, red, not sticky to very sticky, glabrous to pilose at tip with yellowish brown hairs but otherwise glabrous, to 2 cm long. *Leaves* (17–)23–27(–31) cm with 6–8(–9) pairs of leaflets; petiole (30–)39–47(–53) mm; stipules caducous. Leaflets to (6.2–)7.4–8.2(–9.6) cm long, (1.5–)2.0–2.3(–2.6) cm wide, acuminate with acute apex, margin finely toothed almost to base, upper surface dark green, lower surface pale green and glabrous; lateral

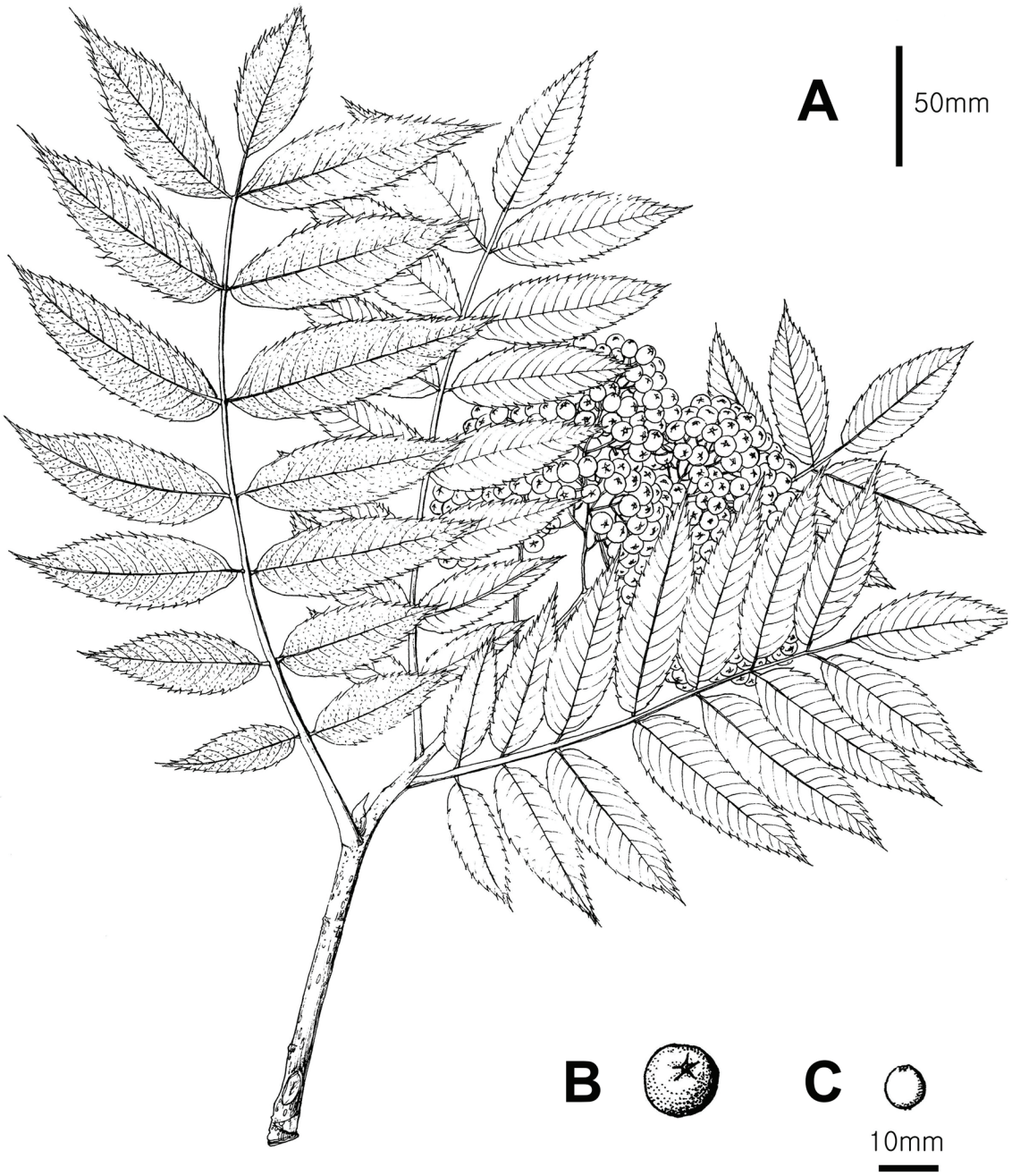

Figure 4. *Sorbus ulleungensis* Chin S. Chang. **A**, plant; **B**, fruit; **C**, seed. (Holotype: *H.Y. Gil 073,* SNUA).

FIGURE 5. A holotype of *Sorbus ulleungensis* Chin S. Chang, *sp. nov.* (SNUA).

veins 15–21 on each side of midvein. Inflorescence to (8.0–)9.8–10.6(–14.4) cm long, (9.0–)13.0–16.0(–23.5) cm wide, corymbose. *Flowers* to (1.0–)1.2–1.4 (1.6) cm diam., crowded, fragrant. Sepals triangular, green. Petals 5–6 mm long, 4–5 mm wide, broadly elliptic, white. *Fruits* glossy, yellowish-orange or orange to red, subglobose to globose, (7.5–)9.0–10.5(–12.0) mm long, (8.0–)9.2–10.6(–13.0) mm wide. *Calyx* somewhat fleshy. *Carpels* 3–5(–6), semi-inferior, white hairy. Styles (3–)4–5(–6), to 3 mm, distantly inserted. *Stamen* 20, 4 mm long; anthers yellow. *Seeds* light brown to brown, to 4.1 × 2.1 mm, up to 12 per fruit. A sexual diploid (2n = 34) species.

Additional specimens examined: KOREA. Gyeong-sangbuk-do: Ulleung-gun, Ulleung-eup: Jeodong-ri, along trail of "Naesujeon old path" (from Naesujeon to Seommok), alt. 260–420m. 17 May 2011, *H.Y. Gil 0063* (SNUA); Jeodong-ri, along trail of "Naesujeon old path" (from Naesujeon to Seommok), alt. 260–420m. 9 Sept. 2011, *H.Y. Gil 0763* (SNUA); Jeodong-ri, E slope of Mt. Seongin, along summit trail, 270–320m, ca. 500m from Bonglae waterfall entrance. 20 May 2011, *H.Y. Gil 0143* (SNUA); Jeodong-ri, E slope of Mt. Seongin, along summit trail, alt. 270–320m, ca. 500m from Bonglae waterfall entrance. 9 September 2011, *H.Y. Gil 0719* (SNUA); mountain trail (Bongrae waterfall), along the creek, eastern part of island, 28 June 1986, *C.S. Chang et al. 088* (A); Jeodong-ri, Naesujeon observatory, along trail, alt. 340–440m. 9 September 2011, *H.Y. Gil 0731* (SNUA); Dodong-ri, Mt. Seongin, from Naribunji (N slope) via summit to Dodong village (S slope), alt. 310m. 18 May 2011, *H.Y. Gil 0099* (SNUA); Dodong-ri, ridge E. of Dodong. 19 October 1989, *S. G. March et al. 338* (SNUA); Dodong-ri. 29 September 2010, *H.J. Eom 0477* (SNUA); Sadong-ri, 100m, volcanic mountain peak. 19 May 1989, *S. G. March et al. 44* (SNUA); Seo-myeon: Taeha-ri, along the trail of 'Taeharyeong'[(from Golgaegol (a stream) to Guam village, Namseo-ri], alt. 120–430m. 19 May 2011, *H.Y. Gil 0114* (SNUA); Taeha-ri, Taeha elementary school-Taeharyeong-Tsuga diversifolia community-Taeha elementary school, alt. 439m. 27 September 2010, *H.J. Eom et al. 0445* (SNUA); Buk-myeon, alt. 410m. 21 May 1989, *S. G. March et al. 63* (SNUA); Na-ri, Naribunji (basin). 28 September 2010, *H.J. Eom et al. 0450* (SNUA); Ooryong-too (Degelet Island) al t. 0-920m, 2 June, 1917, *E. H. Wilson 8553* (A); Ooryong-too (Degelet Island), al t. 0-920m, 31 May, 1917, *E. H. Wilson 8553* (A); 31 Naridong, 31 May, 1917, *T. Nakai s.n.* (TI); Ulleungdo, *K. Okamoto s.n.* (TI); Sang-bong, 2 June, 1917, *T. Nakai s.n.* (TI); Sang-bong, 23 May, 1916, alt. 900m, *T. Ishidoya s.n.* (TI); Ulleungdo, 19 August, 1938, *R. Toyama. s.n.* (KYO).

Distribution: Ulleung Island, endemic to Korea. Very common in the whole island at 300–980 m. The total number of individuals on the island was estimated at 2,000–2,500 (Fig. 6).

Habitat: On steep cliff slopes or rocks and mountain woodlands.

Korean name: U-san-ma-ga-mok.

English common name: Ulleung rowan.

Flowering: Early May to mid-June.

Etymology: The specific epithet, "*ulleungensis*," is based on the name of the location where the new species is found.

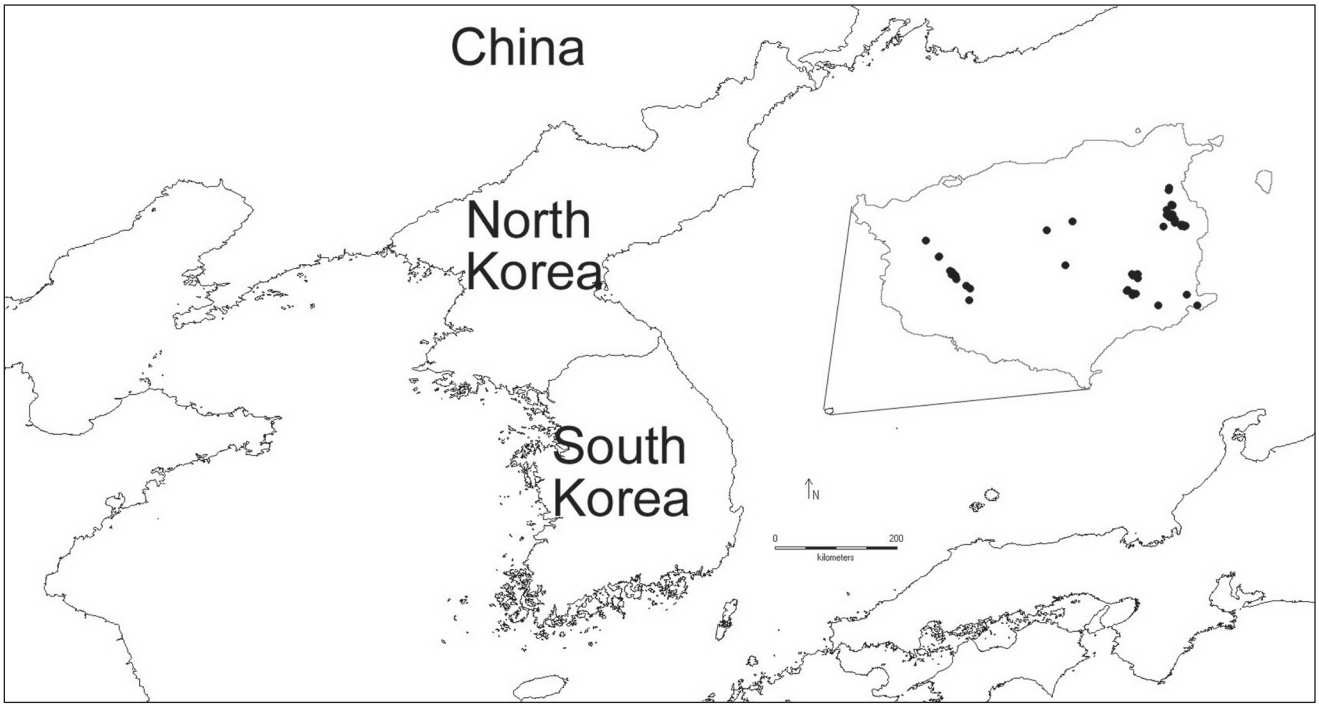

FIGURE 6. Distribution of *Sorbus ulleungensis* on Ulleung Island of Korea.

Key to *Sorbus ulleungensis* and other Sorbus taxa in Korea

1a. Leaves simple; styles 2 ..... *S. alnifolia*

1b. Leaves pinnately compound; styles 3–4 or 5 2

2a. Styles 5; leaflets 3–5(6) paired; fruit 10 mm in diameter; small shrub (< 2m); inflorescences loosely flowered (< 10) ..... *S. sambucifolia*

2b. Styles 3–4; leaflets 4–7 paired; fruit 4–7 mm in diameter; small tree(> 2m); inflorescences densely flowered (20–30) 3

3a. Winter buds densely covered with white hairs, non glutinous; leaflet lower surface pubescent with white hairs; stipules herbaceous, fan-shaped and persistent; from northeastern China, far eastern mainland Russia, and northern Korea (Mt. Baekdu) ..... *S. pohuashanensis*

3b. Winter buds glabrous or occasionally covered with brown or white hairs or glabrous, glutinous; leaflet lower surface glabrous, pubescent with yellowish brown hairs only when young; stipules membranous and deciduous; from Japan, Russia (Sachalin Island), and Korea 4

4a. Flower diameter 8–11 mm; fruit diameter 6.4–7.9 mm; leaflets 9–13; style 3–4; bark light gray; from Japan, Russia (Sachalin Island), and Korea (excluding Ulleung Island) ..... *S. commixta*

4b. Flower diameter 12–14 mm; fruit diameter 9.0–10.5 mm; leaflets 13–15; styles 3–5; bark dark brown; from Ulleung Island . *S. ulleungensis*

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