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RESEARCH

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Vegetation structure and distribution characteristics of *Symplocos prunifolia*, a rare evergreen broad-leaved tree in Korea

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Abstract

Background: In Korea, *Symplocos prunifolia* Siebold. & Zucc. is only found on Jeju Island. Conservation of the species is difficult because little is known about its distribution and natural habitat. The lack of research and survey data on the characteristics of native vegetation and distribution of this species means that there is insufficient information to guide the management and conservation of this species and related vegetation. Therefore, this study aims to identify the distribution and vegetation associated with *S. prunifolia*.

Results: As a result of field investigations, it was confirmed that the native *S. prunifolia* communities were distributed in 4 areas located on the southern side of Mt. Halla and within the evergreen broad-leaved forest zones. Furthermore, these evergreen broad-leaved forest zones are themselves located in the warm temperate zone which are distributed along the valley sides at elevations between 318 and 461 m. *S. prunifolia* was only found on the south side of Mt. Halla, and mainly on south-facing slopes; however, small communities were found to be growing on northwest-facing slopes. It has been confirmed that *S. prunifolia* trees are rare but an important constituent species in the evergreen broad-leaved forest of Jeju. The mean importance percentage of *S. prunifolia* community was 48.84 for *Castanopsis sieboldii*, 17.79 for *Quercus acuta*, and 12.12 for *Pinus thunbergii*; *S. prunifolia* was the ninth most important species (2.6).

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Conclusions: *S. prunifolia* can be found growing along the natural streams of Jeju, where there is little anthropogenic influence and where the streams have caused soil disturbance through natural processes of erosion and deposition of sediments. Currently, the native area of *S. prunifolia* is about 3300 m^2, which contains a confirmed population of 180 individual plants. As a result of these low population sizes, it places it in the category of an extremely endangered plant in Korea. In some native sites, the canopy of evergreen broad-leaved forest formed, but the frequency and coverage of species were not high. Negative factors that contributed to the low distribution of this species were factors such as lacking in shade tolerance, low fruiting rates, small native areas, and special habitats as well as requiring adequate stream disturbance. Presently, due to changes in climate, it is unclear whether this species will see an increase in its population and habitat area or whether it will remain as an endangered species within Korea. What is clear, however, is that the preservation of the present native habitats and population is extremely important if the population is to be maintained and expanded. It is also meaningful in terms of the stable conservation of biodiversity in Korea. Therefore, based on the results of this study, it is judged that a systematic evaluation for the preservation and conservation of the habitat and vegetation management method of *S. prunifolia* should be conducted.

Keywords: Endangered species, *Symplocos prunifolia*, Syngeography, Vegetation classification

Background

Symplocos prunifolia Siebold. & Zucc. is the only evergreen tree belonging to native Symplocaceae in Korea. This species is found only on Jeju Island in Korea. In 2010, the Korean Forest Service designated *S. prunifolia* as a vulnerable species (Kim et al. 2008; Korean National Arboretum 2009). However, due to the lack of information on the distribution and habitat characteristics of this species, it was not evaluated as an object of legal protection (GBIF 2020).

Studies of *S. prunifolia* were undertaken on several occasions during field surveys on Jeju Island and were conducted by universities and arboretums (KBIS 2020; NIBR 2020). In addition, comparative studies of warm temperate zones in Korea and the western regions of Japan found that this species is distributed in two regions that have a high plant geography connection (Kim and Itow 1996, Choi and Lee 2015). Kim and Itow (1996) defined *S. prunifolia* trees as well as *Michelia compressa*, *Myrica rubra*, and *Marsdenia tomentosa* as the phytogeographic link between the two regions. However, in a study comparing evergreen broad-leaved forest vegetation in warm temperate zones of both Korea and Japan, it is suggested that the species characterizes Japanese forests (Yoon et al. 2011). In fact, studies on evergreen broad-leaved forests in Korea, *S. prunifolia*, have not been recorded or suggested as a major diagnostic species of vegetation, and little is known about the habitat environment (Choi 2013). There are still insufficient data on the natural distribution of *S. prunifolia* trees in Korea, and basic studies on the natural habitat of the species have not been conducted.

As well as Korea, *S. prunifolia* can also be found growing in two other regions of East Asian—China and Japan. In China, *S. prunifolia* has been documented as an important component of mature evergreen broad-leaved forests and mixed forests in the subtropical monsoon climate region of southeastern China (Song 1988; Song and Wang 1995). However, it is not to be found growing in the semi-moist evergreen broad-leaved forest of the west which are located inland around Yunnan (SW China), but only in the eastern regions adjacent to the sea (Wang et al. 2007; Tang and Ohsawa 2009). In Japan, an island country, this species is distributed in almost all regions of the temperate climate zone. In Japan, *S. prunifolia* was recorded as a character species of Symploco-Shiietum cuspidatae, Cleyero-Castanopsietum cuspidatae etc., a type of evergreen broad-leaved forest found in the Kanto region of Honshu, Shikoku, Kyushu, and the Ryukyu Islands (Miyawaki et al. 1994; Hattori et al. 2012). These syntaxa is known to represent the evergreen broad-leaved forests along the Pacific Ocean coast of Japan, and *S. prunifolia*, *Castanopsis sieboldii*, *Photinia glabra*, and *Meliosma rigida* are composed of important species. These syntaxa have never been reported in Korea (Miyawaki et al. 1994).

Unlike China and Japan, the distribution of *S. prunifolia* is limited in Korea, and information on natural vegetation including the distribution of native places is insufficient. The lack of research on species distribution and vegetation characteristics in native habitats means that there is a lack of information on the conservation of species and sustainable management of native habitats. In particular, the limited area of distribution, small population size, and low understanding of the mechanisms for maintaining native habitats are obviously a threat to the conservation of this species in Korea. Therefore, this study aims to find out the distribution and vegetation characteristics of the *S. prunifolia* community. Based on this, we intend to prepare a management plan to manage and preserve the native habitat of *S. prunifolia*.

Methods

Investigation of native environment

To increase our understanding of the distribution of *Symplocos prunifolia* Siebold. & Zucc. on Jeju Island and to confirm the characteristics of their appearance in vegetation, field surveys were conducted on all areas of Jeju Island (Fig. 1). Field surveys were conducted from March to October 2019, and vegetation, population size, and environmental factors were recorded for native habitats. In order to analyze the vegetation characteristics of native habitats, we surveyed through a 20 m × 20 m (400 m^2) quadrat considering the vegetation height and closely recording environmental factors such as GPS location information, slope aspect, rock exposure, and microtopography in the survey site.

Vegetation analysis

Vegetation surveys were made based on Braun-Blanquet's phytosociological methods. All constituent species appearing in the quadrats were recorded, and the vegetation stratification structure, and the height, diameter at breast height (DBH), crown width, vegetation coverage, and the number of each species were also recorded. Relative density, relative coverage, and relative frequency for each layer were calculated based on the number of species in the community. In addition to vegetation surveys, it was important to compare the relative abundance of each species and relative importance percentage (IP) was analyzed for each vegetation layer (Curtis and McIntosh 1951; Brower et al. 1998). The IP was calculated by calculating the mean importance percentage weighted by the vegetation layer of the individual species layer (Yi et al. 2010; Shin and Yi 2011). Diversity Index (H'), Maximum H', evenness, and dominance were calculated using DBH for tree and subtree layers, crown width for shrubs, and ground coverage for herbaceous layers to show diversity and homogeneity of constituent species for each (Shannon and Weaver 1963; Pielou 1975). Furthermore, to compare the phytosociological classification between the *S. prunifolia* vegetation surveyed in the current study and previous studies of the evergreen broad-leaved forests of Jeju Island, all vegetation data was converted to combined cover-abundance degree and analyzed (Westhoff and Maarel 1973).

For comparison with the evergreen broad-leaved forests of Jeju Island, Kim (2000)'s vegetation relevés were

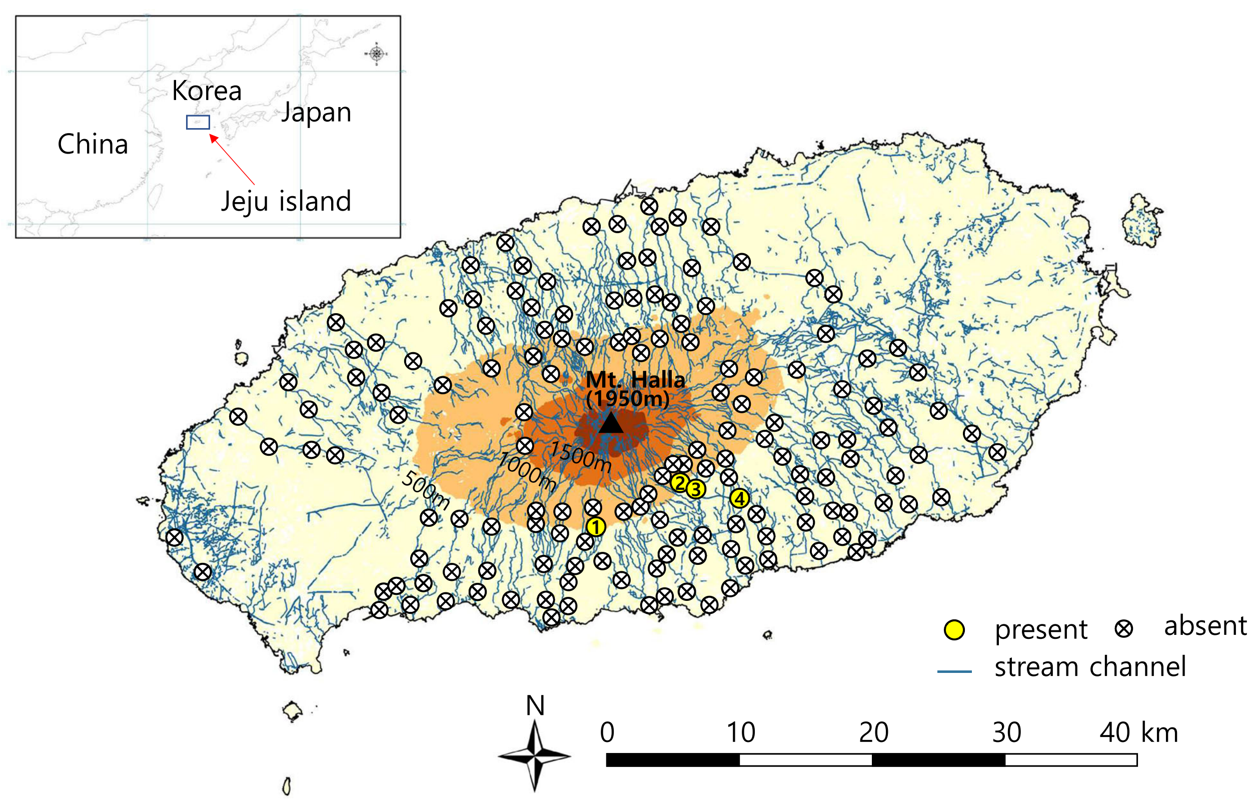

Fig. 1 Map showing the location of the study areas which are shown by the cross circle or the open circle. Open circles are native habitat and cross circles are investigation points where *S. prunifolia* is not distributed. The numerals in the map correspond to the locality number in Table 1

used. The vegetation data is divided into 6 sytaxa and consists of 59 relevés and 185 taxa. For qualitative and quantitative correlation and significance analysis among vegetation units, ordination and cluster analysis were performed using SYNTAX's nonmetric multidimensional scaling (NMDS) technique (Podani 2001). For ordination and cluster analysis, the NMDS (non-metric multidimentional scaling) method was analyzed in consideration of the ordinal scale characteristics of the coverage degree, and Kendal's tau and Goodman-Kruskal lambda were used as coefficients. The synecological and syngeographical characteristics were discussed with respect to the relative differences derived from species composition.

Plants were identified through Lee (2003a, 2003b), Lee (1996), and KNA (2009), and when it was difficult to determine tree species, information such as photos, bark, and leaves were obtained and used to identify the tree species. The collected specimens were kept in the herbarium of Warm Temperate and Subtropical Forest Research Center. Names of syntaxon followed the International Code of Phytosociological Nomenclature (Weber et al. 2000).

Results

Natural environment characteristics

As a result of the field survey, four regions of *S. prunifolia* native communities were identified in Seogwipo City, which is located to the south of Mt. Halla (Table 1). These communities are in the evergreen broad-leaved forests of the warm temperate zone which are all located along the valley sides at elevations between 318 and 461 m. Most of the native habitats of *S. prunifolia* were found on south facing slopes, but in some areas, communities existed on northwest facing slopes according to the microtopography of the location. The average rock exposure rate of these habitats is 30% (range 5 to 60%), and the range of slope was 25° to 30°. In terms of the structure of Jeju's streams, *S. prunifolia* are distributed along the floodplain areas (Fig. 2).

Located within the riparian forest, these areas are relatively wet with steep slopes and shallow soil where the possibility and frequency of disturbance remains high. In particular, the geographic location of these native habitats is prone to erosion and the deposition of sedimentation due to the constantly changing direction of the water flow. The habitat of *S. prunifolia* on Jeju Island shows similar characteristics to the result of being an intermediate successional sere species leading to the development of the forests into mature forests, while *S. prunifolia* are a pioneer species in Japan (Naka and Yoneda 1984; Miyawaki et al. 1994; Ito 2009). Moisture levels within the soil are constantly maintained, and the microtopography mainly consists of irregularities. The main lithosphere of native sites consists of trachybasalts (Baekrokdam trachybasalt, Boriak trachybasalt, and Siohreum trachybasalt) and trachyte (Hallasan trachyte) formed in the Quaternary period (KIGAM 2020). The soil is built up from large amounts of eroded sediment being deposited by the streams, and the humus layer was poorly developed at less than 5 cm in all locations. The topographical structure and soil characteristics of this environment are being constantly replenished and reformed by the constant occurrence of flooding which takes place around 10 times a year in Jeju Island (Moon et al. 2005).

Native vegetation characteristics

Vegetation structure and relative importance percentage

It has been confirmed that *S. prunifolia* trees are a rare but important constituent species of the evergreen broad-leaved forest of Jeju Island's warm temperate zone. The native vegetation structure formed four layers (canopy, subcanopy, shrubs, ground vegetation). The canopy, subcanopy, and shrub layers were greater than 30% coverage, but the herbaceous layer had a lower coverage. The average height of the trees was 14 m, the average coverage was 75%, the average height of the subtree and shrub layers were 8.8 and 3.3 m, respectively, and the average coverage was 45.3 and 31.3%, respectively. The average vegetation height of the herbaceous layer was 0.7 m, and the average coverage was found to be 18.6% (Table 1). This is because the canopy layer is composed of evergreen broad-leaved tree species with high crown density, which is considered to limit vegetation development by allowing only a small amount of light to understory vegetation (Manabe et al. 2000). In particular, the evergreen broad-leaved forest limits the distribution of photophilous species and maintains a community centered on shade-tolerant species by maintaining a high crown density throughout the year, including in winter (Miura et al. 2001). Furthermore, the development of the herbaceous layer was difficult because of the widespread flooding on the slopes adjacent to the valley floor (Kang et al. 2018).

Analysis of the IP of each layer indicated that *Castanopsis sieboldii* was the most important component of the canopy tree layer (IP = 48.84), followed by *Quercus acuta* (IP = 17.79), *Pinus thunbergii* (IP = 12.12), and then *Carpinus laxiflora* (IP = 8.45). In the subtree layer, *Castanopsis sieboldii* was the most important species (IP = 18.50), followed by *Distylium racemosum* (IP = 16.76), *Eurya japonica* (IP = 13.42), and *Q. acuta* (IP = 12.20). The order of the most important species in the shrub layer was *E. japonica* (IP = 31.18), *Castanopsis sieboldii* (IP = 21.90), and *Camellia japonica* (IP = 18.61), and in the herbaceous layer, the most important species were

Table 1 General descriptions of physical character and vegetation in *S. prunifolia* habitats

Site no.		1	2	3	4
Location		Seohodong	Sanghyodong	Sanghyodong	Namwoneup
GPS*	Latitude	33°17′--″	33°19′--″	33°19′--″	33°19′--″
	Longitude	126°30′--″	126°35′--″	126°35′--″	126°37′--″
Major direction		SSE	NW	SSW	SSE
Altitude (m)		461	350	446	318
Rock coverage (%)		60	10	5	45
Slop (°)		25	30	25	25
Land form		Valley	Valley	Valley	Valley
Microtopography		Irregularity	Irregularity	Irregularity	Irregularity
Soil texture		Brown forest soil	Brown forest soil	Brown forest soil	Brown forest soil
Soil character		Sandy loam	Silt loam	Loam	Sandy loam
Soil moisture		Moist	Wet	Wet	Wet
Bedrock		Trachyte	Trachybasalt	Trachybasalt	Trachybasalt
Humus layer (cm)		< 5	< 5	< 5	< 5
Vegetation structure					
Tree	Height (m)	13.0	13.0	16.0	14.0
	Coverage (%)	75	60	80	85
Subtree	Height (m)	8.0	8.0	10.0	9.0
	Coverage (%)	55	55	45	30
Shrub	Height (m)	3.5	3.0	3.5	3.0
	Coverage (%)	25	45	40	15
Herb	Height (m)	0.6	0.8	0.9	0.5
	Coverage (%)	5	45	10	15

*GPS coordinates are confidential to prevent illegal harvesting

Vaccinium japonicum (IP = 16.66), *Castanopsis sieboldii* (IP = 16.09), and *Camellia japonica* (IP = 7.38) (Table 2).

Overall, *S. prunifolia* was ranked the 9th (IP = 2.6) when the mean importance percentage of all species across all four layers was calculated; it was ranked 5th (IP = 4.8) in the tree layer and 6th (IP = 3.3) in the shrub layer. The quadrats (20 m × 20 m) contained between 1 and 3 *S. prunifolia* individuals; the total coverage was not high in any of the quadrats. Although a small number of young individuals were identified in the

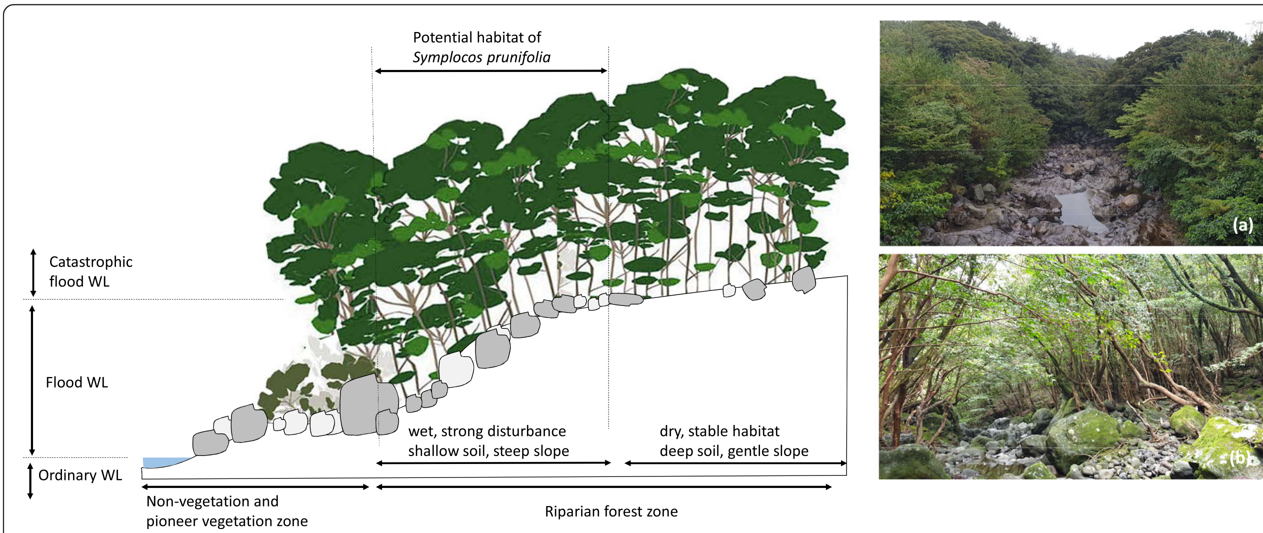

Fig. 2 Vegetation structure and stream cross-section of riverine forest in Jeju. The range of *S. prunifolia* is located at the edge of a multi-layered forest. Photo: **a** Main forest landscape in natural habitat. **b** Representative vegetation structure and soil environment. WL water level

Table 2 Importance percentage (IP) and mean importance percentage (MIP) of all species in *S. prunifolia* community

Scientific name	IP				MIP
	Tree	Subtree	Shrub	Herb	
Castanopsis sieboldii (Makino) Hatus.	48.8	18.5	21.9	16.1	31.1
Quercus acuta Thunb.	17.8	12.2	5.2	1.2	11.9
Eurya japonica Thunb.	–	13.4	31.2	7.2	11.0
Camellia japonica L.	–	8.9	18.6	7.4	7.1
Distylium racemosum Siebold & Zucc.	–	16.8	5.4	0.9	6.2
Pinus thunbergii Parl.	12.1	–	–	–	4.8
Carpinus laxiflora (Siebold & Zucc.) Blume	8.4	1.6	–	0.9	3.9
Cleyera japonica Thunb.	–	10.2	2.0	0.8	3.5
Symplocos prunifolia Siebold & Zucc.	4.8	–	3.3	–	2.6
Styrax japonicus Siebold & Zucc.	2.3	3.4	–	–	1.9
Vaccinium japonicum Miq.	–	–	–	16.7	1.7
Rhododendron weyrichii Maxim.	–	3.3	2.5	1.1	1.6
Dendropanax morbiferus H.Lév.	–	2.9	1.5	0.7	1.2
Prunus sargentii Rehder	2.9	–	–	–	1.2
Ilex integra Thunb.	2.9	–	–	–	1.1
Cinnamomum japonicum Siebold ex Nees	–	1.8	2.3	0.7	1.1
Quercus salicina Blume	–	2.3	1.5	–	1.0
Smilax china L.	–	1.5	1.5	1.5	0.9
Ardisia crenata Sims	–	–	–	5.3	0.5
Cryptomeria japonica (L.f.) D.Don	–	–	1.8	1.6	0.5
Maackia fauriei (H.Lév.) Takeda	–	1.7	–	–	0.5
Lemmaphyllum microphyllum C.Presl	–	–	–	4.8	0.5
Sapium japonicum (Siebold & Zucc.) Pax & Hoffm.	–	1.5	–	–	0.5
Deparia japonica (Thunb.) M.Kato	–	–	–	4.1	0.4
Ardisia japonica (Thunb.) Blume	–	–	–	4.0	0.4
Damnacanthus indicus C.F.Gaertn.	–	–	–	4.0	0.4
Trachelospermum asiaticum (Siebold &Zucc.) Nakai	–	–	–	3.4	0.3
Callicarpa mollis Siebold & Zucc.	–	–	1.4	–	0.3
Daphniphyllum macropodum Miq.	–	–	–	1.8	0.2
Pyrrosia lingua (Thunb.) Farw.	–	–	–	1.8	0.2
Lepisorus thunbergianus (Kaulf.) Ching	–	–	–	1.5	0.2
Pteridium aquilinum var. *latiusculum* Underw. ex Hell.	–	–	–	1.5	0.2
Stauntonia hexaphylla (Thunb.) Decne.	–	–	–	1.4	0.1
Dryopteris varia (L.) Kuntze	–	–	–	1.4	0.1
Neolitsea aciculata (Blume) Koidz.	–	–	–	1.2	0.1
Parthenocissus tricuspidata (Siebold & Zucc.) Planch.	–	–	–	1.1	0.1
Osmunda japonica Thunb.	–	–	–	1.0	0.1
Ainsliaea apiculata Sch.Bip.	–	–	–	0.9	0.1
Lindera erythrocarpa Makino	–	–	–	0.9	0.1
Hedera rhombea (Miq.) Bean	–	–	–	0.8	0.1
Polystichum polyblepharum var. *polyblepharum* Presl	–	–	–	0.7	0.1
Clerodendrum trichotomum Thunb.	–	–	–	0.7	0.1
Viburnum erosum Thunb.	–	–	–	0.7	0.1
Total	100.0	100.0	100.0	100.0	100.0

upper and lower streams adjacent to the survey point, the distribution area was considered small along with the total population (Kim et al. 2008; Korean National Arboretum 2009).

Based on the results of the survey, it is estimated that the total number of *S. prunifolia* trees in the tree and subtree layers is about 30 and the number of individuals in the shrub and herb layer is about 150. Site 1 and Site 4 have relatively large populations which are distributed as mature individuals in the tree and subtree layers with relatively stable structures. In comparison to sites 1 and 4, sites 2 and 3, it appeared that the distribution of species is found only in the shrub and herbaceous layers, and where young individuals dominate. The area and population size of each native site is about 1200 m^2, 36 in site 4, about 800 m^2, 18 in site 1, about 700 m^2, 78 in site 3, about 600 m^2, 45 in site 2 were distributed. All individuals showed band distribution along the stream's floodplain area. Past records which were collected in the Andeok Valley area by some researchers, but this was the result of misidentification of the species, and the distribution of the species could not be confirmed at the site.

Species diversity analysis

The species diversity index was highest in the herbaceous layer (1.141), followed by the subtree layer (0.952), the tree layer (0.548), and the shrub layer (0.204) (Table 3). The maximum species diversity calculated by the number of emergent species was highest in the herbaceous layer (1.531) followed by the subtree layer (1.176), and lowest in the tree layer (0.903). The tree layer, subtree layer, and herbaceous layer of the community species composition were all relatively stable in the range of 0.607 to 0.809, but the shrub layer was 0.178, which was confirmed to show severe heterogeneous species composition. When considering the ratio of the dominance of each species, the dominance by layer was 0.822 for the shrub layer, and *E. japonica* and *Castanopsis sieboldii* for the tree layer, and 0.393 for the tree layer. It was found that several taxa dominated rather than being dominated by one specific taxa. Considering the ratio of dominance of each species, it was found that the shrub layer was 0.822, *E. japonica* and *C. sieboldii*, and the tree layer was 0.393, *C. sieboldii* and *Q. acuta* dominated, and the subtree and herbaceous layers were 0.191 and 0.255, respectively. Several species were mixed together without being a single species being dominate (Whittaker 1956; Sung et al. 2013).

Discussion

Phytosociological comparison of the *S. prunifolia* community

C. sieboldii was the dominant species in all vegetation in the *S. prunifolia* community; *Q. acuta*, *D. racemosum*, and *E. japonica* were also present. This forest belongs to the Hosto minor-Castanopsietum sieboldii, according to the characteristics of phytosociological constituent species, and shares important diagnostic species such as *Q. acuta*, *Dendropanax morbiferus*, *Distylium racemosum*, and *Ainsliaea apiculata* (Kim 2000). This association of an evergreen broad-leaved forest in the stream valleys of Jeju Island is known as a forest that contributes greatly to the diversity of warm temperate and subtropical organisms in Korea. The reason that the existence of *S. prunifolia* was not confirmed in previous phytosociological studies is considered to be due to the fact that the population size is very limited and so its appearance is relatively low in mature evergreen broad-leaved forests, so it was omitted from the investigation.

This vegetation found at the site is representation of the usual evergreen broad-leaved forests that are usually found along the stream valleys of Jeju Island, and it is one of the vegetation units that contributes greatly to the diversity of species in the warm temperate and subtropical zones of Korea. In the previously reported vegetation studies, it was judged that the *S. prunifolia* did not appear as a constituent species, the population size was insignificant, and so it was not included in the vegetation survey of typical evergreen broad-leaved forests (Oh 1995; Kim 2000; Choi 2013; Yoon et al. 2014).

As a result of ordination analysis, the species characteristics of the *S. pruniolia* community were also identified as a type of *Castanopsis*-dominated community of Jeju Island, which showed high similarity with the Hosto minor-Castanopsietum sieboldii (Fig. 3). The Hosto minor-Castanopsietum sieboldii is reported to be one of the unique evergreen broad-leaved forests of Jeju Island and is distinct from vegetation associated with the species in Japan and China (Choi 2013). In the cluster analysis results, a small group was formed that was distinguished from the existing Jeju Island evergreen broad-

Table 3 Species diversity indices for all species in *S. prunifolia* community

Layer	No. of species	H′(Species diversity)	H′max	J′(evenness)	D(dominance)
Tree	8	0.548	0.903	0.607	0.393
Subtree	15	0.952	1.176	0.809	0.191
Shrub	14	0.204	1.146	0.178	0.822
Herb	34	1.141	1.531	0.745	0.255

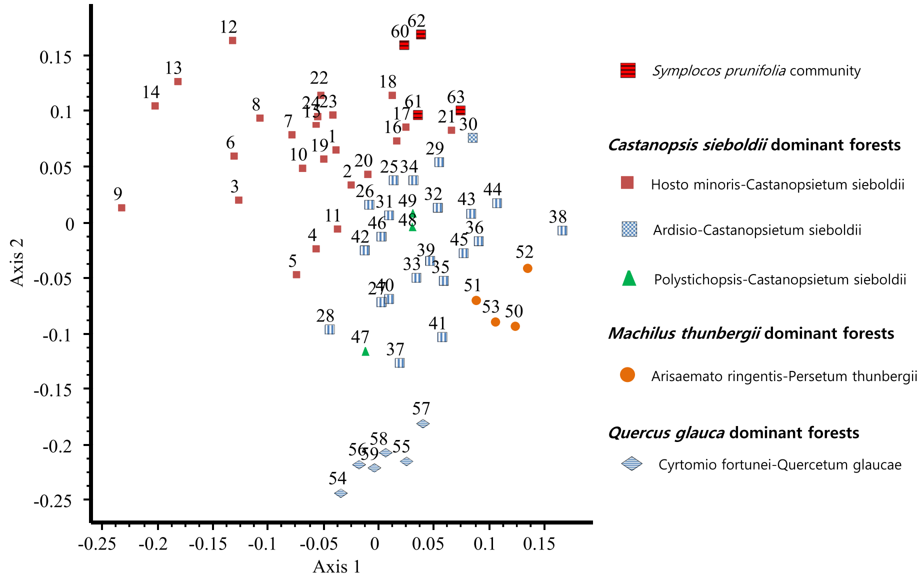

Fig. 3 NMDS ordination of warm temperate evergreen broad-leaved forests and *S. prunifolia* community in Jeju. The data sources for warm temperate evergreen broad-leaved forest of Jeju are Kim (2000). (no. 1~24: Hosto minoris-Castanopsietum sieboldii Kim, Hukusima et Hoshino 1994, no. 25~46: Ardisio-Castanopsietum sieboldii Suz..-Tok. 1952, no. 47~49: Polystichopsis-Castanopsietum sieboldii Miyawaki et al. 1971, no. 50~53: Arisaemato ringensis-Perseetum thunbergii Miyawaki et al. 1971, no. 54~59: Cyrtomio fortunei-Quercetum glaucae Kim, Hukusima et Hoshino, 1994, no. 60~63: *S. prunifolia* community)

leaved forest, which was a result of differences in constituent species such as *Vaccinium japonicum*, *Carpinus laxiflora*, *Callicarpa mollis*, *Deparia japonica*, and *Cryptomeria japonica* (Fig. 4). However, the difference between these species is not too different to the extent that the association is newly defined, and most were widely distributed species, cold-temperate species, pioneer species, and accidental species.

Therefore, *S. prunifolia* is a character species and an important diagnostic species in such forests as Hosto minor-Castanopsietum sieboldii in Korea, *Pinus massoniana-Schima superba* community in China Symploco glaucae-Castanopsietum sieboldii, Symploco glaucae-Castanopsietum sieboldii, and Cleyero-Castanopsis cuspidatae in Japan (Miyawaki et al. 1994; Wang et al. 2007). The distribution of these syntaxa is considered to be closely related to the influence of the Oceanic climate and the Kuroshio warm current (111°01′E–139°54′E, 22°20′N–36°00′N) (Fig. 5). The Kuroshio warm current, which existed even during the ice age in East Asia, has maintained evergreen broad-leaved forests in the Kagoshima region of southern Japan, making it the longest documented warm temperate vegetation history in all of East Asia (Tsukada 1985; Miyoshi et al. 1999). After the ice age, evergreen broad-leaved forests in East Asia gradually expanded to the north due to continuous temperature rises and sea level expansion (Zheng et al. 2014). The expansion of the sphere of influence of the Kuroshio current is deeply linked to the movement of these species (Miyawaki et al. 1994; Tang 2015). The expansion of Korea's evergreen broad-leaved forest is also highly linked to the expansion of species centered around these regions. In particular, the expansion of warm maritime currents in these regions is considered as an important factor which has had a significate influence on the expansion of vegetation. This is reflected in part by the lack of migration inland of Korea's evergreen broad-leaved forests and why they are located only in coastal areas (Yim and Kira 1975; Choi 2013). Among them, the distribution of *S. prunifolia*, particularly in the maritime climate region, is judged to be determined by the expansion of the Kuroshio warm current and its sphere of influence (Kawahata and Ohshima 2004).

The evergreen broad-leaved forests of Jeju Island have a long history in the warm temperate zone of Korea. As mentioned above, it is the first region that the species settled after the ice age in East Asia. As a result, it shows the largest diversity of evergreen broad-leaved trees in the warm temperate zone of Korea, and why the species is only found on Jeju Island. However, the continental climate still has an indirect influence on Jeju Island. This is evident in the characteristics of the intermediate climate zone and a marine climate, as only partial vegetation is formed (Kim 1992; Eom 2019). Among these, *S. prunifolia* and some evergreen broad-leaved tree species

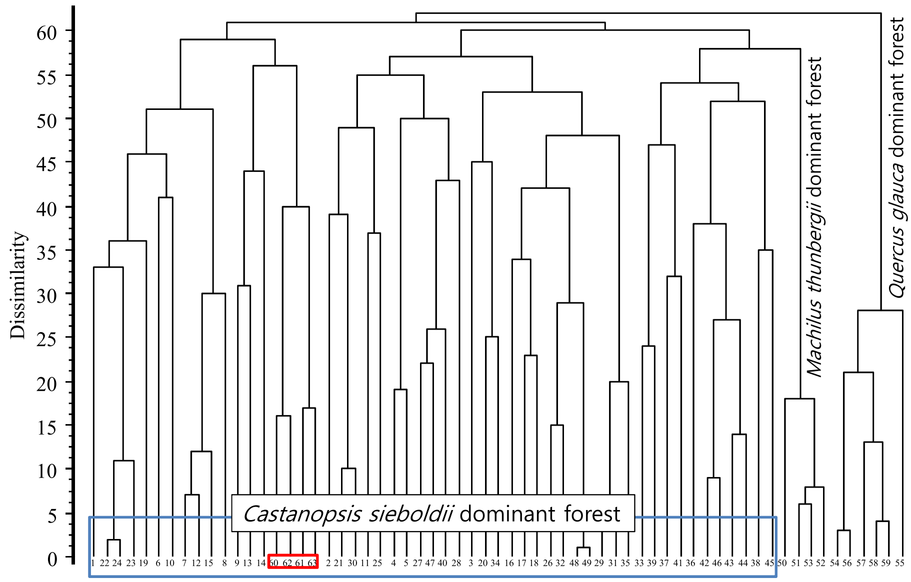

Fig. 4 Dendrogram showing floristic similarity. NMDS clustering of evergreen broad-leaved forests and *S. prunifolia* community in Jeju. Numbers are same as Fig. 3

are thought to be distribution-dependent on the forests adjacent to the stream with minimal continental climate (Kim 2000).

Species, including *S. prunifolia*, have a relatively short migration history in Korea when compared to Chinese and Japanese vegetation, which are at the centers of warm temperate and subtropical forest regions of East Asia, and where diversity of species is greater (Chinzei et al. 1987; Chung 2007). Nevertheless, the *S. prunifolia* community of Jeju Island is one of the northernmost distribution areas in Northeast Asia, and it can be considered as a significant indicator of the change in forest vegetation expansion in warm temperate zones (Harrison et al. 2001, Corlett 2009) (Fig. 5).

However, it has been confirmed that species of *S. prunifolia* on Jeju Island are vulnerable to various threats. As revealed in the results of this study, there are only 4 native areas which sustain the 180 individual plants. Fortunately, two of these native sites form a relatively stable population structure, but others do not. Among the native vegetation, it appears in fewer numbers than other species in the tree layer (*Castanopsis sieboldii*, *Quercus*

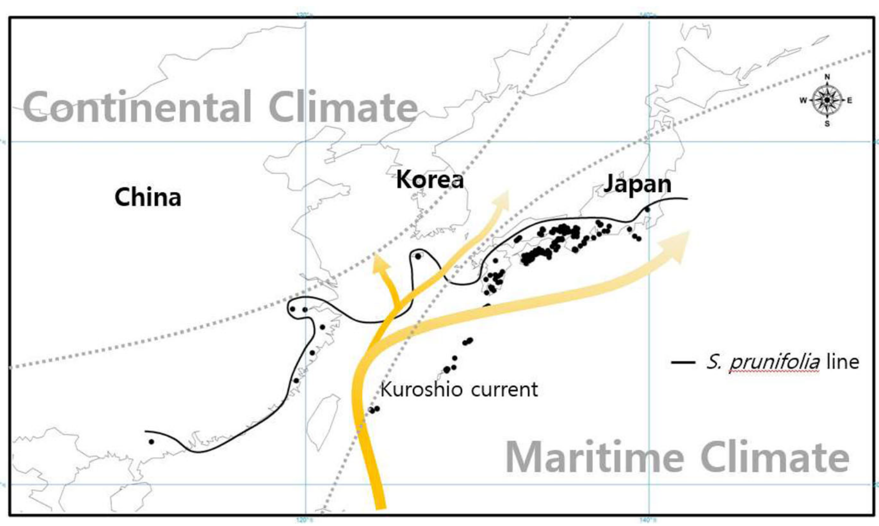

Fig. 5 Phytogeography of *S. prunifolia* and high correlation with Kuroshio current in East Asia. The data sources for phytogeography of *S. prunifolia* community in East Asia are GBIF (2020), Miyawaki et al. (1994), Tang (2015) and this study

acuta, *Pinus thunbergii*, *Carpinus laxiflora*, etc.), and its growth is relatively slow, which is disadvantageous to competition (Hong et al. 2019). In particular, even in the vegetation succession process, it is difficult to secure the stability of the population because *S. prunifolia* seedlings have relatively weak shade tolerance in the evergreen broad-leaved forest at the late seral stage have poor regeneration (Oh and Choi 1993). Furthermore, the low-fruiting and irregular rates of the observed *S. prunifolia* in the field make it difficult to ascertain which physiological and ecological factors this phenomenon is due to, but it is considered to act as a negative factor for maintaining a healthy community and the spread of species.

In particular, it is feared that excessive development of Jeju Island's streams will reduce the area of Jeju's riverine forest, which is the only native habitat of *S. prunifolia*, which will in turn will lead to a decline in species numbers. It is feared that excessive development of Jeju Island's streams will also reduce the area of Jeju's riverine forest, leading to a loss of native habitat of *S. prunifolia* and causing a decline of both habitat and species (Song et al. 2019). Therefore, in terms of conservation of national biodiversity, there is a need for more extensive ecological studies on species and to prepare a conservation management plan for these native sites.

Conclusion

S. prunifolia is found along the natural streams of Jeju Island, where there is little anthropogenic influence, and where the streams cause soil disturbance through the process of erosion and deposition of sediments. Currently, the area of the site where the native growth of *S. prunifolia* is confirmed at about 3300 m^2, which is relatively small, and is home to 180 individual plants which places it among other rare species in Korea. The vegetation in which they appear has been identified as one of Jeju's unique vegetation types the Hosto minoris-Castanopsietum sieboldii. This syntaxa contains a large number of the endemic species of vegetation along with the warm temperate species which represent the warm temperate riverine forest of Jeju Island. It is accepted that *S. prunifolia* is distributed as a constituent species at the edge of this vegetation. It appears in the canopy layer according to its location and was a major constituent of evergreen broad-leaved forests, but the frequency and coverage of the species were still not high. Unfortunately, due to its specific characteristics of weak shade tolerance, low-fruiting rate, and irregular alternate fruit bearing cycles, along with external factors such as a reduction of potential habitats and the natural processes of soils disturbance, it continues to demonstrate rare distribution characteristics on Jeju Island.

It is thought that S. *prunifolia* is in the process of adapting and migrating to new areas on Jeju Island, which is located along the transition point between the continental and marine climates of East Asia. It is a species that is thought to have difficulty settling in Korea's evergreen broad-leaved forest. Furthermore, it is a significant marker and evidence that the number of marine species, including *S. prunifolia*, are gradually appearing in the country. The protection of this species is urgent given its circumstances of limited habitats. In the future, it is unclear whether this species will gradually see an increase in its population and an expansion of its native habitats given the difficulties many species face with climate change. What is clear, however, is that the survival and health of the current native habitat is paramount to the future survival of the species. In addition, the stable preservation of this species is important in terms of biodiversity of plant life in Korea.

In conclusion, there is an urgently need to prepare a conservation management plan for the protection of this species and its native habitat areas, as well as to re-evaluate the species' conservation level. Active protection efforts are urgently required with continuous monitoring of mature individuals, along with additional studies on additional native sites, and potential distribution sites are also required.

Abbreviations

GBIF: Global Biodiversity Information Facility; KBIS: Korea Biodiversity Information System; KIGAM: Korea Institute of Geoscience and Mineral Resources; NIBR: National Institute of Biological Resources

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Authors' contributions

YJK, KMS, and BKC wrote the manuscript; KMS and BKC made the figures; YJK and KMS made the tables; BKC, YOS, and HSC modified the language; YJK, EYY, and BKC collected the literature; KMS and BKC provided the ideas. All the authors agreed on the contents of the paper and post no conflicting interest. The authors read and approved the final manuscript.

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Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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