JEE ISSN: 2288-1220
https://doi.org/10.5141/jee.24.109
Journal of Ecology and Environment (2025) 49:03
RESEARCH

Characteristics of natural habitats of an endangered species, *Cymbidium macrorhizon*

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ARTICLE INFO
Received December 3, 2024
Revised February 3, 2025
Accepted February 3, 2025
Published on February 20, 2025

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Background: A leafless, partially mycoheterotrophic terrestrial orchid *Cymbidium macrorhizon* is legally protected as Endangered Species in Korea, but there is insufficient information on the habitat and growth conditions of this species to ensure its conservation. We conducted a survey of the occurrence and growth of *C. macrorhizon* from June to November 2024 on Mt. Noza in Geoje, and in Jeju during July and September. We also examined the vegetation, canopy coverage, soil respiration rate, and soil physicochemical parameters in *C. macrorhizon* habitats. To understand the factors influencing the survival and reproductive success of *C. macrorhizon*, we analyzed the relationships between population size and the surrounding vegetation, as well as soil physicochemical parameters.
Results: In both Geoje and Jeju, *C. macrorhizon* can be observed from late June to early November, with the highest emergence occurring in July. However, less than 3% of the fruits were continuously maintained and reached fruit maturity. *Cymbidium macrorhizon* was observed with more than 20 individuals in the *Pinus thunbergii* and *Platycarya strobilacea* communities. The results of the Principal Component Analysis indicated that the *P. thunbergii* community is associated with soil characteristics such as organic matter content, water content, and pH. The successful progression of *C. macrorhizon* through its growth stages, including flowering, fruiting, and fruit maturation, was primarily observed in areas with adequate light penetration, specifically where light levels reached up to a relative light intensity of 56% with a maximum of about 5,300 lux, rather than those excessively shaded by the canopy.
Conclusions: *Cymbidium macrorhizon* forms large populations, especially in *P. thunbergii* stands, which are characterized by well-developed organic layers and well-drained soils with approximately 40% soil moisture content. It is proposed that *C. macrorhizon* may increase its population size through vegetative propagation via rhizomes facilitated by microbial activity in environments that limit population growth through seed reproduction, such as shaded stands with high organic matter content. Understanding the specific environmental conditions, such as soil characteristics and light penetration, and vegetation community in its natural habitat, can provide crucial data for establishing effective conservation strategies to ensure the continued survival and proliferation of *C. macrorhizon*.

Keywords: *Cymbidium macrorhizon*, habitat, leafless orchid, partially mycoheterotrophic orchid, rare and endangered plant, terrestrial orchid

Introduction

Cymbidium macrorhizon Lindl., a leafless terrestrial orchid in the genus *Cymbidium*, is native to tropical and subtropical Asia and northern Australia, and inhabits dense evergreen or deciduous broadleaf forests, as well as mixed pine forests (National Institute of Biological Resources 2021; Ogura-Tsujita et al. 2012; Suetsugu et al. 2018; Thakur and Dutt 2021). Especially, terrestrial orchid distribution and population formation are influenced by various factors, including topography, vegetation, mycorrhizal viability, soil physicochemical properties, such as organic matter, pH, and nutrients, and climate (Djordjević et al. 2020; Swarts and Dixon 2009).

Orchids fully or partially depend on mycorrhizal fungi for their supply of carbon resources the carbon supplied by mycorrhizal fungi throughout their life cycle (McCormick et al. 2018; Stöckel et al. 2014). *Cymbidium macrorhizon* were often found growing near ectomycorrhizal trees like *Quercus serrata, Castanopsis cuspidata, Carpinus tschonoskii*, and *Pinus thunbergii* (Jung et al. 2020; Suetsugu 2015). In mycoheterotrophic and mixotrophic orchids, ectomycorrhiza-forming fungi, such as Sebacinales, Russulaceae and Thelephoraceae, are most often identified as mycobionts, suggesting that the photosynthates of nearby trees likely represent the final carbon sources. *Cymbidium macrorhizon* is associated mainly with ectomycorrhizal Sebacinales in the Basidiomycota (Ogura-Tsujita et al. 2012). It is crucial to identify the interactions between vegetation communities, microbes, and a target plant (Godefroid et al. 2011; Li et al. 2021; McCormick et al. 2009; McCormick and Jacquemyn 2014; Rusconi et al. 2023).

Cymbidium macrorhizon had been considered fully mycoheterotrophic (Motomura et al. 2010; Ogura-Tsujita et al. 2012), but recent studies demonstrated that this species be considered a partially mycoheterotorphic species particularly during the fruiting stage, its photosynthetic ability of stem and pericarp (Kobayashi et al. 2021; Suetsugu 2018). The establishment of association with ectomycorrhizal fungi may enable *Cymbidium* plants to occupy ecological niches in the shaded areas of evergreen broadleaf forests (Ogura-Tsujita et al. 2012). Preiss et al. (2010) demonstrated the correlations between light levels at orchid habitats and the degree of mycoheterotrophy in orchid individuals dependent on ectomycorrhizal fungi. Low light levels result in strong myco-heterotrophy while higher irradiances successively drive the orchids towards autotrophy. Drought and shade environments can both increase mycorrhizal reliance in a partially mycoheterotrophic orchid on carbon and nitrogen derived fungi (McCormick et al. 2022).

National Institute of Biological Resources (NIBR) in Korea recently classified *C. macrorhizon* as VU(B2b(iii)c(iv)) on the Red List, based on IUCN criteria. This classification is attributed to its limited area of occupancy, decline in both habitat extent and quality, and a decrease in population (National Institute of Biological Resources 2021). *Cymbidium macrorhizon* is legally protected as Endangered species Class II in Korea. However, there is insufficient information on the habitat and growth conditions of this species to ensure its conservation.

The aim of this study is to provide an information of the potential edaphic factors, topography and vegetation structure affecting the abundance and spatial distribution of *C. macrorhizon* orchid in natural environments. A better understanding of the factors on orchid population may be critical to their long-term conservation. Identifying the characteristics of individuals and the key factors influencing their population fluctuation is crucial for long-term conservation.

Materials and Methods

Study site

Cymbidium macrorhizon is native to Northern Pakistan and Eastern India, as well as temperate regions of Eastern Asia. In Korea, it has been known from the southern coast including Geoje Island, Jeju Island and some locations of Gangwon-do. *Cymbidium macrorhizon* faces several critical threats, including its restricted growth conditions within humid coastal forests, significant fluctuations in population size, and indiscriminate human activities (National Institute of Biological Resources 2021). Although the population size is limited, its habitats were found recently in Mt. Noza in Geoje lsland, Gyeongsangnam-do and Jeju Island where *C. macrorhizon* is relatively frequently observed and we selected them as the study sites. Based on the data collected in 2023, 34 sites where orchids were found at Mt. Noza of Geoje Island in 2024 were marked. In Jeju Island, 4 sites were selected by investigating the area where it previously appeared (Fig. 1).

Meteorological data

Both Geoje Island and Jeju Island are significantly influenced by a maritime climate due to their geographical characteristics of being surrounded by the sea. They experience four distinct seasons, characterized by high temperatures and humidity. The monsoon season lasts for one month from late June to late July, and during this period, heavy rainfall exceeding 50 mm per hour trigger landslide, which may deliver organic matter to downslope. The meteorological data from January to December for the two study regions, Geoje and Jeju Island, was obtained from the Korea Meteorological Administration (Table 1). In Geoje, the mean temperature was 16°C, with reaching 28.2°C in August, with the highest temperature reaching 32.4°C in August. The monthly mean temperatures from June to October, the period when *C. macrorhizon* orchids observed, were 22.2°C, 25.8°C, 28.2°C, 25.8 and 18.7°C, respectively. The monsoon season in the southern region lasted for about 31 days from 23 June to 24 July, with an average rainfall of 341.1 mm. The highest rainfall in 390.9 mm occurred in September. The mean humidity was 72.1%, dropping to 54.8% at its lowest in December. The sunshine duration from January to December was 2,038.1 hour, with the highest sunshine duration being 294.4 hour in August. The mean wind speed was 1.5 m/s and a maximum mean wind speed of 6.8 m/s.

In Jeju, the northern Jeju City and the southern Seogwipo City, where study sites were located, had the mean temperature of 18.2°C and 18.3°C, respectively. In August, mean temperature reached 29.9°C in Jeju City and 29.8°C in Seogwipo City. The highest mean temperature occurred in August, ranging from 33.0°C to 33.2°C, with the southern region being the warmest. The average temperature

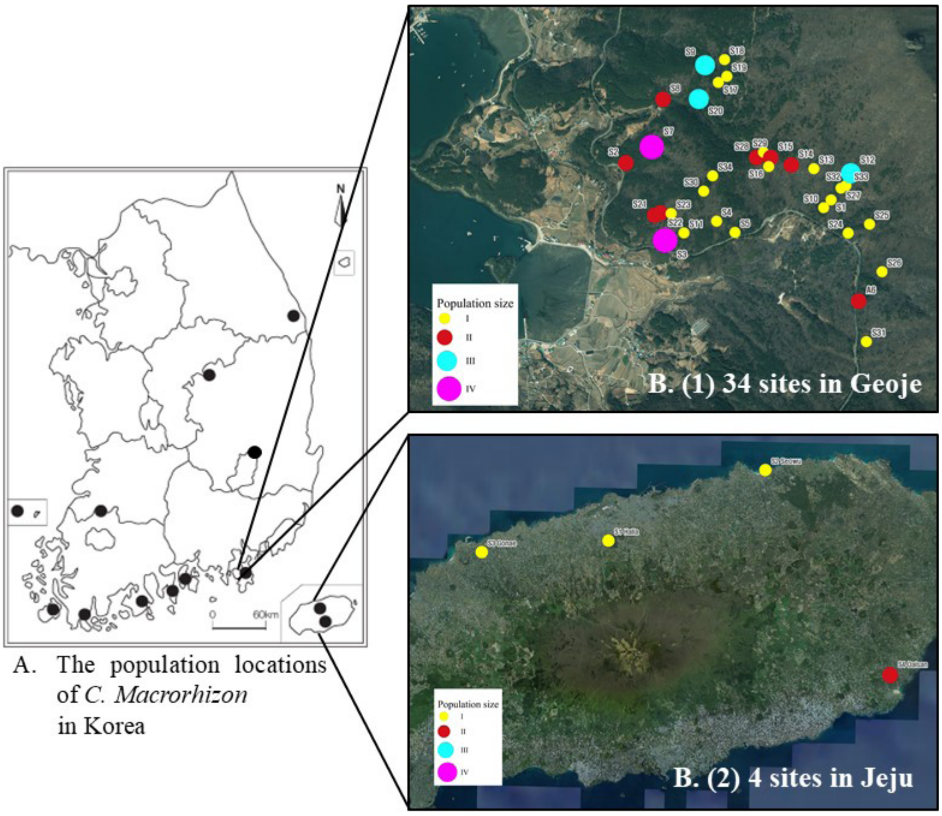

Fig. 1 (A) Map of the locations where the populations of *Cymbidium macrorhizon* were found in Korea. (B) Map of the study sites where orchids were found in Geoje and Jeju Island. Population size of *C. macrorhizon*: I: 1–10 individuals; II: 11–20 individuals; III: 21–30 individuals; IV: > 30 individuals.

Table 1 Meteorological data in Geoje and Jeju from January to December 2024

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mean temperature (°C)												
Geoje (Geoje city)	4.3	6.8	9.2	15.2	18.2	22.2	25.8	28.2	25.8	18.7	12.3	5.1
Jeju (Jeju city)	7.8	9.5	10.9	16.4	19.1	23.1	28.9	29.9	27.6	20.9	15.1	8.7
Jeju (Seogwipo city)	8.5	10.3	11.1	16.8	19.3	22.6	27.3	29.8	27.9	21.7	15.9	8.9
Duration of sunshine (h)												
Geoje (Geoje city)	166.1	92.7	190.4	122.8	267.6	196.8	110.8	246.2	166.2	137.1	148.4	193.0
Jeju (Jeju city)	77.6	60.3	159.8	152.1	265.9	155	204.9	275.2	131.5	88.0	114.7	69.8
Jeju (Seogwipo city)	162.7	108.3	193.5	143.1	244.1	133.2	102.5	249.4	210.5	146.1	161.5	191.5
Precipitation (mm)												
Geoje (Geoje city)	37.2	139.9	127.3	187.6	182.6	288.2	383.0	109.5	390.9	238.8	128.4	0.0
Jeju (Jeju city)	93.4	205.4	98.1	80.2	42.9	271.8	156	47	126.2	135.2	335.7	5.8
Jeju (Seogwipo city)	56.8	147.7	155.5	271.3	214.3	615.6	193.7	124.5	119.5	126.0	220.9	1.5
Mean relative humidity (%)												
Geoje (Geoje city)	63.8	73.4	62.7	73.1	67.3	75.3	88.1	78.2	78.6	76.5	71.5	54.8
Jeju (Jeju city)	63.9	71.4	62.0	70.9	63.2	72.6	72.9	71.4	72.7	69.2	64.6	53.9
Jeju (Seogwipo city)	65.7	74.1	66.7	74.6	66.1	78.7	88.9	74.0	74.9	71.5	67.6	56.7
Mean wind speed (m/s)												
Geoje (Geoje city)	1.3	1.4	1.7	1.2	1.6	1.4	1.7	1.4	1.4	1.4	1.3	1.6
Jeju (Jeju city)	3.9	3.6	3.7	2.7	3.1	2.8	3.5	2.9	2.9	3.2	3.7	4.4
Jeju (Seogwipo city)	1.6	2.1	1.9	1.6	2	1.5	1.9	2.0	2.3	2.4	2.2	1.8

from June to September was about 1°C higher than in Geoje. The monsoon season in the southern region lasted for about 32 days from 19 June to 20 July, with an average rainfall of 348.7 mm, with more rainfall than Geoje. The precipitation from January to December 2024 in Jeju and Seogwipo was 1,597.7 mm and 2,247.3 mm, respectively, with the southern region having the higher rainfall. The mean humidity from January to December 2024 in Jeju and Segwipo was 67.5% and 71.8%, respectively, dropping to 53.9% and 56.7% at its lowest in December. The sunshine duration ranges from 1,570.3 to 1,693.4 hour, with the higher southern region than northern region. The mean wind speed in Jeju City 3.4 m/s, while in Seogwipo, it was 1.9 m/s in Seogwipo, were higher than those recorded in Geoje.

Data collection on individual

Data on the status of *C. macrorhizon* individual were collected between late June and early November 2024. Due to the ability of *C. macrorhizon* to form more than one inflorescence from its rhizome, flower stalks emerging within 10 cm of each other were considered as originating from a single rhizome and thus regarded as a single individual (Motomura et al. 2010; Zhang et al. 2020). To examine shoot longevity or life span, during the study period, we marked the observed individuals and recorded the floral stage (early inflorescence stalk, flowering, capsule fruit, wilted inflorescence stalk) of each *C. macrorhizon* individual at the observed time, and rechecked the growth status of the marked individuals to obtain information about their longevity or lifespan in September and October. The population size of *C. macrorhizon* was expressed through a four scale: (I) 1–10 individuals, (II) 11–20 individuals, (III) 21–30 individuals and (IV) > 30 individuals.

Vegetation survey

We investigated the vegetation surrounding the marked individuals to identify the interactions between vegetation communities, the activity of microbes, and the distribution and vitality of *C. macrorhizon*. We established quadrats (10 m × 10 m) and investigated the dominant species and coverage in upper tree (T1) layer and lower tree (T2) layer. The species composition of T1 and T2 layer to analyze the vegetation type was recorded using Braun-Blanquet (1964) values, which were converted to a cover-abundance scale in each quadrat (Table 2). Light intensity around observed individuals within the habitat was measured at the apex of the plant using a portable multi-function soil moisture meter with a lux sensor (HMM 300 Pro; Han young systems, Seoul, Korea). The values were recorded when similar readings were obtained at least three times. Additionally, background light intensity was measured and recorded at a bright spot minimally affected by the canopy. We investigated the thickness of the forest floor (organic material consisting of undecomposed or partially decomposed litter, O horizon) around the areas where *C. macrorhizon* was marked, as well as the dominant species of the litter layer. O horizon thickness was categorized into five intervals based on the recorded data to represent the average thickness of the O layer at the study sites: (I) 1–3 cm, (II) 3–5 cm, (III) 5–7 cm, (IV) 7–9 cm and (V) > 9 cm. The effective soil depth was considered to be the depth to which a ruler could not be inserted in the surrounding area of the observed individual. The effective soil depth was measured three times, and to represent the average effective soil depth in site where *C. macrorhizon* is founded, the values were categorized into five intervals: (I) 1–5 cm, (II) 5–10 cm, (III) 10–15 cm, (IV) 15–20 cm and (V) > 20 cm.

Soil physiochemical analysis

After removal of decomposed litter, approximately 200 g of soil samples were collected within each quadrat, from five sample spots at the center and four corners, at a depth of 10 cm from the surface. Soil samples were collected twice: one it at the vegetation survey in July and the other is at the soil respiration measurements in September. The air-dried soil samples were sieved using a 2 mm sieve. Soil physicochemical properties were analyzed by Rural Development Administration's method (National Institute of Agricultural Science and Technology 2000). Gravimetric method was used to determine the soil water contents (WC) at 105°C for 24 hours. Soil pH and electrical conductivity (EC) were measured using pH and EC meter (Starter 3100M; OHAUS, Seoul, Korea) after extracting 5 g of soil with 25 mL of distilled water for one hour. Total organic matter (OM) was determined by loss-on-ignition at 550°C for 4 hours. Ammonium nitrogen (NH_4-N) in soil was extracted by adding 25 mL of 2 M KCl to 5 g of soil, shaking 30 minutes, and then filtered through Whatman No. 2 filter paper. The filtrate was used for analysis. NH_4-N content was determined by the indophenol blue colorimetric method, with measurements taken at 665 nm using a spectrophotometer (GeneQuant 1300; Biochrom, Cambridge, UK). Cation exchange capacity (CEC) extracted by 1N ammonium acetate (pH 7.0). The measurement method involved placing 5 g of soil sample into a container, adding 50 mL of 1N ammonium acetate solution, and shaking it for 30 minutes. After shaking, CEC was calculated by accurately measuring the pH to two decimal places using a glass electrode pH meter. Soil respiration (CO_2 emission) rates were measured by a portable infrared gas analyzer EGM-5 (PP System, Amesbury, MA, USA), the soil respiration chamber with built in temperature sensor on soil in the adjacent area of *C. macrorhizon*.

Statistical analysis

One-way ANOVA was used to test for differences in quantitative variables (the number of individuals, soil characteristics, altitude, slope, and soil respiration), and ordinal variables (effective soil depth and O horizon thickness), using the nominal variables (vegetation type, slope face, and population size of *C. macrorhizon*) as independent variables. The data were tested for normality with the Kolmogorov-Smirnov test and homogeneity of variances with Levene test. Where significant differences ($p < 0.05$) were found among the groups, we conducted a Duncan's post hoc test. Only the results showing significant differences were presented as box plots using the box-whisker plots using SPSS 18.0 (SPSS Inc., Chicago, IL, USA). Correlation analysis was conducted to determine the relationships between soil physicochemical factors, topography and leaf litter thickness. SPSS statistics was used to all statistical analyses, and significance level as set to $p < 0.05$.

Table 2 Vegetation table of upper tree (T1) and lower tree (T2) layer

Site	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38
Coverage of upper tree (T1) layer (%)	80	80	90	90	85	90	90	80	80	85	90	90	80	85	70	80	95	70	90	90	90	90	85	85	90	90	85	80	50	90	90	85	80	70	80	80	50	70
Coverage of lower tree (T2) layer (%)	25	30	40	30	20	30	35	20	20	25	15	15	20	30	70	60	80	45	35	25	20	20	35	25	30	30	45	45	50	35	35	45	30	50	20	60	-	80
Pinus thunbergii	5.5	4.4	5.5		4.4	2.2	5.5	4.4	4.4	5.5	5.5			1.1	1.1		1.1	4.4	4.4	5.5	2.2		1.1	2.3	2.2	2.2	4.4	4.4	3.3	3.3		4.4		4.4	5.5	4.4	3.3	4.4
Platycarya strobilacea		2.2		4.4				2.2	2.2	1.1		4.4		4.4	4.4	4.4			1.1	1.1	3.3	4.4	4.4		4.4			1.1	2.2	1.1		1.1						
Carpinus laxiflora	1.1					3.3			1.1			1.1	4.4		2.2		3.3		1.1	1.1				1.1			1.1			1.1	2.2			2.2				
Zelkova serrata				2.2		4.4							3.3				4.4	1.1												1.1	4.4		2.2					
Quercus serrata	2.2	2.2	2.2	1.1		1.1		1.1	1.1		2.2	3.3		3.3	4.4	3.3	1.1	3.3	2.2	2.2	4.4	3.3	1.1	4.4	1.1	4.4	2.2	2.2	3.3	4.4	2.2	2.2	4.4					
Cryptomeria japonica			3.3																																			2.3
Styrax japonicus				3.3	2.2	3.3	3.3		1.1	2.2	2.2	2.2	2.2	3.3			4.4				2.2	2.2	3.3		3.3	2.2	3.3	3.3		2.2	3.3	3.3	3.3	3.3				
Morus bombycis							1.1	2.2											1.1	2.2												1.1	1.1					
Acer pseudosieboldianum									2.2								1.1	2.2						2.2	1.1	1.1	1.1			1.1	1.1							
Meliosma myriantha								1.1									1.1	2.2	3.3	1.1						1.1					+							
Aria alnifolia																		1.1																2.2				
Celtis sinensis			1.1	1.1									1.1									1.1							2.2									
Cornus controversa					2.2																	1.1				1.1			1.1									
Chamaecyparis obtusa		2.2																																				
Prunus spachiana																																			2.2	+		
Machilus thunbergii																																			1.1	3.3		
Litsea japonica																																				3.3	2.2	
Ficus erecta																																				2.2		4.4
Cudrania tricuspidata																																					3.3	
Quercus acutissima										1.1														1.1									1.1					
Albizia julibrissin											1.1						+	1.1															r					
Prunus sargentii										1.1																	1.1											
Quercus variabilis				1.1		1.1																		1.1	1.1								1.1					
Cornus macrophylla					1.1																					1.1												
Castanea crenata		+																																				
Ulmus davidiana var. *japonica*																						+																
Kalopanax septemlobus					1.1																																	
Magnolia sieboldii					1.1																																	
Tilia amurensis								1.1																														
Styrax obassia														1.1																								
Carpinus cordata																								1.1														
Carpinus turczaninovii																					1.1													1.1				
Neoshirakia japonica												+																1.1					+					
Cinnamomum chekiangense													+										1.1															
Fatsia japonica																																						
Toxicodendron trichocarpum					r																																	
Viburnum odoratissimum var. *awabuki*																																			1.1			
Neolitsea sericea																																						1.1
Morus alba																																						1.1

Principal correspondence analysis (PCA) was used to reveal the effects of the vegetation and environmental variables using PC-ORD program for windows version 5.21 (McCune and Mefford 2006).

Results

Vegetation structure

Cymbidium macrorhizon was observed in various environments, including shaded areas with developed canopies, steep slopes with bare rock, rock crevice, around tree roots, near forest roads, hiking trails, and in areas where forest stands where forest management practices have been implemented (Fig. 2). The slope direction of the sites where the observed *C. macrorhizon* were relatively abundant was mainly such as south- and west-facing slopes (Fig. 3).

Based on the vegetation surveys, *C. macrorhizon* was distributed below 300 m above sea level in Geoje and Jeju regions. We found that *C. macrorhizon* grows in conifer, deciduous and mixed forests (Table 3). In Mt. Noza of Geoje, it is mainly distributed in *P. thunbergii* community, followed by the community dominated by *Platycarya strobilacea*, and then in the mixed forest of *P. thunbergii* and deciduous leaved trees, such as *Q. serrata*, and *P. strobilacea*. The population of *C. macrorhizon* was found in the *P. thunbergii* community at S2, S7, and S20, followed by the *P. strobilacea* community at S12. The habitat of *C. macrorhizon* in Jeju was dominated by *P. thunbergii*, and *C. macrorhizon* was more abundant in the S38.

The light intensity penetrating below the canopy was found to be influenced by the canopy structure of the constituent species and the slope. In the habitat of *C. macrorhizon* in Geoje, the light intensity reaching the ground ranged from 10 to 5,320 lux. In the deciduous forest, light intensity penetrating the forest floor was less than 1,000 lux in areas where the canopy layer was well-developed. In areas within deciduous forests where light intensity fluctu-

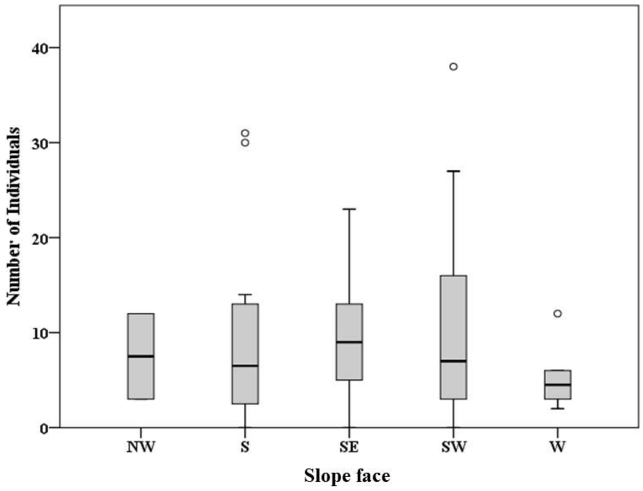

Fig. 3 The number of individual occurrences according to slope face (North-West: NW; South: S; South-East: SE; South-West: SW; West: W) of study sites during the study period from late June to early November 2024.

Fig. 2 The habitats of *Cymbidium macrorhizon* orchids in Geoje (A-E) and Jeju (F-J).

Table 3 Topography and vegetation types of *Cymbidium macrorhizon* in Mt. Noza of Geoje (S1-S34) and Jeju (S35-S38)

Site	Population size	Altitude (m)	Slope (°)	Slope face	Effective soil depth (level)	Vegetation type	O horizon thickness (level)	The ratio of conifer and deciduous litter (%)	Litter dominant species	Community	Dominant species of lower tree (T2) layer	Coverage of upper tree (T1) layer (%)	Coverage of lower tree (T2) layer (%)	Coverage of shrub (S) layer (%)	Light (lux)
S1	I	251	13	S	I	Conifer	II	80 and 20	PITH	PITH	QUSE	80	25	60	150-820
S2	II	69	15	SW	II	Conifer	I, II	90 and 10	PITH	PITH	PLST	80	30	60	30-1,210
S3	IV	92	16	S	II	Conifer	I	80 and 20	PITH	PITH	CRJA	90	40	60	10-550
S4	I	134	21	S	II	Deciduous	I	50 and 50	QUSE	PLST	STJA	90	30	40	300-1,800
S5	I	107	26	S	III	Conifer	II	90 and 10	PITH	PITH	STJA	85	20	30	50-430
S6	II	157	28	NW	IV	Deciduous	II, III, IV	20 and 80	CALA	ZESE-CALA	STJA	90	30	50	50-80
S7	IV	121	23	SW	II	Conifer	I, II, III	50 and 50	PITH	PITH	STJA	90	35	20	80-1,300
S8	II	134	26	SW	II	Conifer	III, IV	70 and 30	PITH	PITH	MOBO	80	20	35	30-990
S9	III	214	22	SE	III	Conifer	II, III	70 and 30	PITH	PITH	ACPS	80	20	35	90-460
S10	I	139	12	SW	II	Conifer	II	80 and 20	PITH	PITH	STJA	85	25	40	10-380
S11	I	96	21	SW	IV	Conifer	I, II	50 and 50	PITH	PITH	STJA	90	15	35	10-180
S12	III	200	21	SW	I	Deciduous	I	0 and 100	QUSE	PLST	STJA	90	15	60	10-1,250
S13	I	179	25	S	II	Deciduous	I, II	0 and 100	CALA	CALA-ZESE	STJA	80	20	50	10-70
S14	II	173	23	SE	III	Deciduous	II	30 and 70	QUSE	PLST-QUSE	STJA	85	30	50	10-1,130
S15	II	195	11	S	II	Deciduous	I	10 and 90	QUSE	PLST	QUSE	70	70	40	10-720
S16	I	184	22	SE	III	Deciduous	I	10 and 90	PLST	PLST	QUSE	80	60	60	20-120
S17	I	176	18	SW	II	Deciduous	I, II	30 and 70	CALA	ZESE-CALA	STJA	95	80	40	280-490
S18	I	209	10	SW	IV	Conifer	III, IV	90 and 10	PITH	PITH	ACPS	70	45	20	520-1,150
S19	I	193	19	W	I	Conifer	I	70 and 30	PITH	PITH	MEMY	90	35	50	50-360
S20	III	161	24	S	I	Conifer	I	80 and 20	PITH	PITH	MOBO	90	25	40	20-5,320
S21	II	114	15	S	III	Deciduous	II, III	80 and 20	PITH	QUSE-PLST	STJA	90	20	40	40-520
S22	II	114	19	S	III	Deciduous	I	10 and 90	PLST	PLST-QUSE	STJA	90	20	35	10-620

Table 3 Continued

Site	Population size	Altitude (m)	Slope (°)	Slope face	Effective soil depth (level)	Vegetation type	O horizon thickness (level)	The ratio of conifer and deciduous litter (%)	Litter dominant species	Community	Dominant species of lower tree (T2) layer	Coverage of upper tree (T1) layer (%)	Coverage of lower tree (T2) layer (%)	Coverage of shrub (S) layer (%)	Light (lux)
S23	I	127	22	SW	II	Deciduous	I	60 and 40	PITH	PLST	STJA	85	35	20	160-1,460
S24	I	138	14	SW	II	Mixed	I, II, III	60 and 40	PITH	QUSE-PITH	ACPS	85	25	40	10-20
S25	I	158	17	W	I	Mixed	I, II	30 and 70	PLST	PLST-PITH	STJA	90	30	45	70-250
S26	I	167	20	W	II	Mixed	II, III	20 and 80	QUSE	QUSE-PITH	STJA	90	30	50	150-160
S27	I	159	18	S	III	Conifer	I	80 and 20	PITH	PITH	STJA	85	45	30	80-830
S28	II	208	2	SE	III, IV	Mixed	I, II, III	80 and 20	PITH	PITH-QUSE	STJA	80	45	30	230-650
S29	I	198	15	SE	II	Mixed	I	80 and 20	PITH	PITH-PLST	QUSE	50	50	30	280-580
S30	I	179	18	SE	II	Mixed	I, II	60 and 40	PITH	QUSE-PITH	STJA	90	35	35	150-530
S31	I	172	22	NW	III	Deciduous	I, II	5 and 95	ZESE	ZESE-CALA	STJA	90	35	40	30-900
S32	I	159	18	S	I	Mixed	I	10 and 90	QUSE	PITH	STJA	85	45	30	20-1,340
S33	I	174	14	S	II	Deciduous	I	0 and 100	QUSE	QUSE	STJA	80	30	50	10-650
S34	I	213	22	SE	III	Conifer	IV, IV	90 and 10	PITH	PITH	STJA	70	50	20	330-1,620
S35	I	185	12	W	V	Conifer	II	95 and 5	PITH	PITH	PRSP	80	20	5	10-130
S36	I	85	10	SW	I, II, V	Conifer	I, II	60 and 40	PITH	PITH	LIJA	80	60	40	10-17,000
S37	I	155	17	W	III, V	Conifer	I	70 and 30	PITH	PITH	-	50	-	50	430-18,200
S38	II	80	25	W	V	Conifer	III, IV	90 and 10	PITH	PITH-Cj	FIER	70	80	30	40-4,500

Population size level: I: 1-10 individuals; II: 11-20 individuals; III: 21-30 individuals; IV: > 31 individuals.
Slope face: North: N; North-East: NE; East: E; South-East: SE; South: S; South-West: SW; West: W; North-West: NW.
Effective soil depth level: I: 1-5 cm; II: 5-10 cm; III: 10-15 cm; IV: 15-20 cm; V: > 20 cm.
O horizon thickness level: I: 1-3 cm; II: 3-5 cm; III: 5-7 cm; IV: 7-9 cm; V: > 9 cm.
Species: *Acer pseudosieboldianum*: ACPS; *Cryptomeria japonica*: CRJA; *Carpinus laxiflora*: CALA; *Ficus erecta*: FIER; *Litsea japonica*: LIJA; *Morus bombycis*: MOBO; *Melios mamyriantha*: MEMY; *Prunus spachiana* for. *ascendens*: PRSP; *Platycarya strobilacea*: PLST; *Pinus thunbergia*: PITH; *Quercus serrata*: QUSE; *Styrax japonicas*: STJA; *Zelkova serrata*: ZESE.

ated from below 100 to above 1,000 lux, the slope was measured to be over 20 degrees. In Jeju's S2 and S3, *C. macrorhizon* were observed near walking paths, and the light intensity was measured to be over 15,000 lux. ANOVA results showed that vegetation type was closely related to slope, which may be because deciduous broadleaf trees are distributed in steeper areas of Geoje (Fig. 4).

Soil physiochemical properties

The soil texture of the survey area was identified using the Agricultural Soil Information System (ASIS) of the National Institute of Agricultural Sciences. The soils of study sites in Mt. Noza of Geoje are Haplic Cambisols (sandy loam A horizons) or Leptic Cambisols (loam A horizons). In Jeju, the soil of S35 is Cutanic Luvisols (silt loam A horizons), S36 is Umbric Silandic Andosols (sandy loam A horizons), S37 and S38 are Aluandic Andosols (silty clay loam A horizons). These soils are well-drained, indicating that *C. macrorhizon* prefers well-drained conditions. In Geoje, the habitat of *C. macrorhizon* had bare rocks and shallow soil depth, whereas in Jeju, the habitat featured no bare rocks and had deeper soil.

Some soil characteristics considered are shown to be influenced by vegetation structure, topographic features, and slope aspect. The soil in Geoje was measured with pH 5.9 ± 0.2, EC 0.6 ± 0.2 dS m^{-1}, CEC 7.3 ± 0.8 cmol kg^{-1}, WC 30.7 ± 7.1%, OM 16.6 ± 2.6%, and NH_4-N 35.2 ± 14.1 ppm. The soil in Jeju was measured with pH 6.4 ± 0.1, EC 0.7 ± 0.1 dS m^{-1}, CEC 7.1 ± 0.6 cmol kg^{-1}, WC 46.6 ± 14.1%, OM 24.3 ± 0.9%, and NH_4-N 24.9 ± 2.3 ppm. Significant differences were observed in the pH, EC, and WC values between the two regions.

It was found that soil pH and water contents were related to vegetation types (Fig. 4). The pH value of the habitats of *C. macrorhizon* was weakly acidic, its value was higher in in coniferous forest than that in mixed forest. The WC in coniferous forests was found to be higher than in deciduous forests and mixed forests. The EC, CEC, the contents of OM and NH_4-N, and O horizon thickness did not show significant differences depending on the vegetation type. There was no significant difference in soil respiration rate according to vegetation type (Fig. 5). This indicates that microbial activity in the habitat of *C. macrorhizon* is similar at Mt. Noza of Geoje and Jeju.

An analysis of the correlations among soil characteristics revealed that OM showed a positive correlation with EC, CEC, WC, and NH_4-N contents, but a negative correlation with slope (Table 4). Soil WC had a positive correlation with EC, OM and NH_4-N contents. Soil properties were correlated to slope, altitude, slope face (direction) and O horizon thickness (Table 4). Soil respiration rate showed a negative correlation with slope. Altitude had a positive correlation with CEC, but a negative correlation with pH and EC. The soil characteristics were significant differences according to slope face, indicating that soil respiration, WC, and OM are related to the direction (Fig. 6). Specifically, soil WC and OM were significantly higher in west-facing sites compared to other orientations. Additionally, soil respiration rates were relatively high in southwest and south-facing sites. O horizon thickness had a positive correlation with NH_4-N contents.

Life cycle of *C. macrorhizon*

It was observed that the inflorescence of *C. macrorhizon* begins to emerge after the June monsoon period. The flowering period lasted for approximately 4 months from the early summer (late June) to early autumn (October), with the highest emergence occurring in July (Fig. 7). Flower longevity was rather short, about one weeks in the field, and the flowers are known to be capable autonomously self-pollinate for capsule production. While some individuals produced fruit after blooming, less than 3% of the fruits were continuously maintained and reached full maturity (Fig. 8). Additionally, individuals that maintained fruits for over three months were observed mostly in light-penetrated areas, such as along trails (from S1 to S27), near forest roads (S20), and in cleared forest regions (S28 and S38). In shaded and humid summer environments caused by canopy cover, individuals forming inflorescences frequently exhibited tilting or breaking of flower stalks.

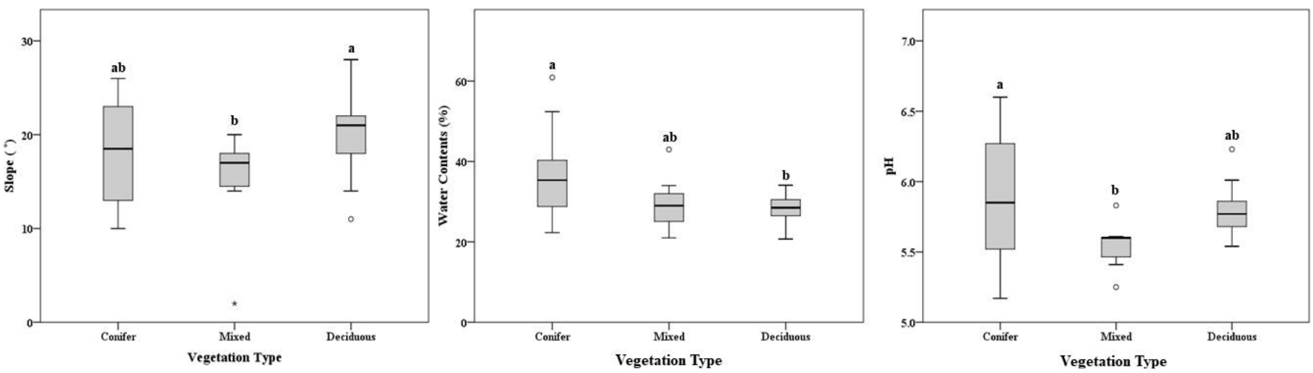

Fig. 4 Topographical and soil physicochemical properties related to vegetation type (conifer, mixed, and deciduous forest). The different letters indicate significant differences among the vegetation types, according to Duncan's test ($p < 0.05$).

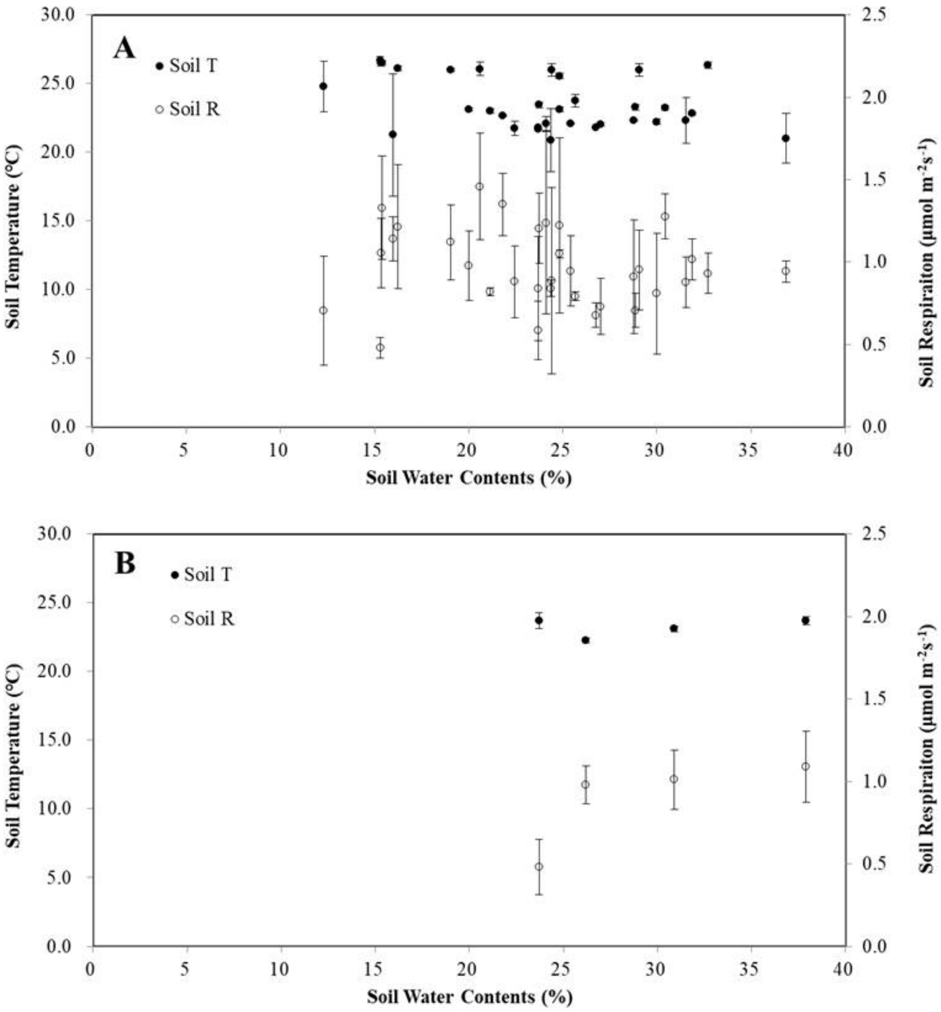

Fig. 5 Soil respiration rate at the *Cymbidium macrorhizon* habitats in (A) Geoje and (B) Jeju.

Table 4 Correlation matrix of altitude, slope and soil physicochemical properties

Pearson correlation	Altitude (m)	Slope (º)	WC (%)	pH	EC (dS m^{-1})	CEC (cmol kg^{-1})	OM (%)	NH_4-N (ppm)	Soil respiration (μmol $m^{-2}s^{-1}$)	O horizon thickness
Altitude										
Slope	0.196			-						
WC	-0.139	-0.064								
pH	-0.426**	0.182	0.258							
EC	-0.383*	-0.047	0.462**	0.335*						
CEC	0.490**	-0.3921*	0.260	-0.491**	-0.133					
OM	0.036	-0.354*	0.726**	0.255	0.469**	0.505**				
NH_4-N	-0.111	0.139	0.551**	0.055	0.195	0.039	0.388*			
Soil respiration	-0.133	-0.420*	-0.130	-0.226	0.165	0.082	0.046	0.004		
O horizon thickness	-0.007	0.114	0.225	-0.055	-0.148	-0.011	0.089	0.608**	0.124	

WC: water contents; EC: electrical conductivity; CEC: cation exchange capacity; OM: total organic matter; NH_4-N: ammonium nitrogen contents.
**Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (1-tailed).

Additionally, many of these plants stopped above-ground growth, with some turning brown and withering, or exhibiting abscission of the peduncles followed by browning. Once a peduncle or pedicel bends or breaks, the above-ground parts rapidly turn brown and start to wilt. These results indicate that the longevity or lifespan of flowers and fruits of *C. macrorhizon* in open canopy is higher than that in a densely closed canopy with high humidity and low light penetration to the forest floor. Upon further investigation of the marked individuals' growth state in September and October, it was observed that some of them formed new inflorescences. The proportion of individuals that sprouted new inflorescence from the underground rhizome, depending on environmental conditions and the

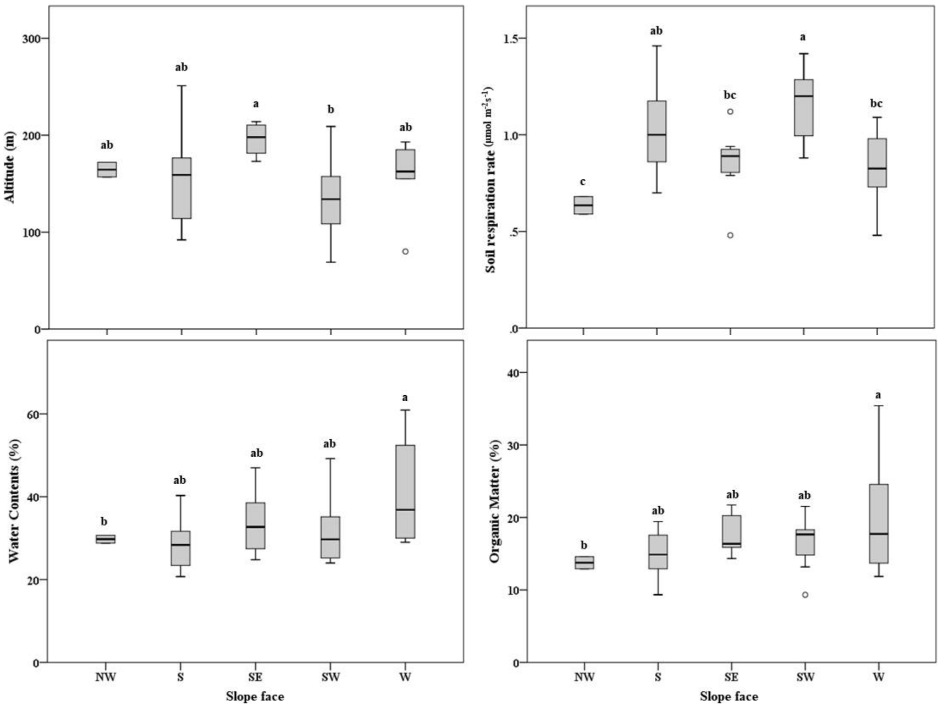

Fig. 6 Topographical and soil physicochemical properties showing significant differences according to slope face (Northwest: NW; South: S; Southeast: SE; Southwest: SW; West: W) of study sites. The different letters indicate significant differences among the vegetation types, according to Duncan's test ($p < 0.05$).

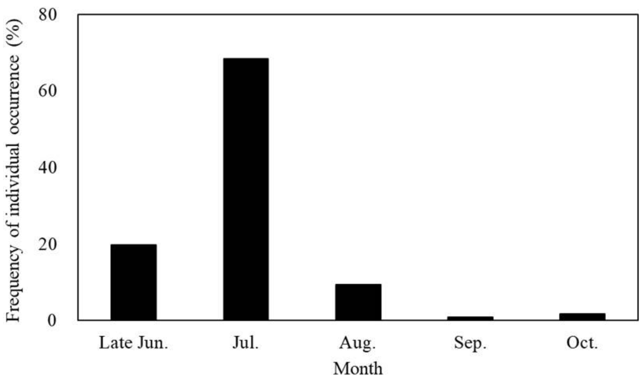

Fig. 7 Frequency of individual occurrence (%) of *Cymbidium macrorhizon* during the survey period from late June to October 2024.

state of the rhizome, was less than 3%. After 3–4 months fruit capsule ripe and dehisced longitudinally as per the locules of the capsule and dust-like seeds dispersal can be dispersed by wind and rainwater. Consequently, *C. macrorhizon* is likely to be distributed along the wind direction and water flow direction in the forest.

The relationships between soil, vegetation type and population size of *C. macrorhizon*

An analysis of the relationship between vegetation type and the population of *C. macrorhizon* revealed that relatively large populations were associated with coniferous species, *P. thunbergii*. The PCA results clearly show the key environmental factors affecting the distribution of *C. macrorhizon* in different vegetation types. PCA results indicated that the *P. thunbergii* community is associated with soil characteristics such as organic matter content, moisture content, and pH (Fig. 9). Furthermore, within the *P. thunbergii* community, higher EC and NH_4-N contents were correlated with larger population sizes of *C. macrorhizon* compared to other survey sites in Geoje and Jeju (Fig. 10). Deciduous forests were found to be associated with relatively NH_4-N and altitude (Fig. 9). In the S12, where population size III was observed in deciduous forests dominated by *P. strobilacea*, the area was characterized by a high proportion of bare rocks, steep slopes, very shallow soil depth, and an O horizon thickness of less than 3 cm. Despite these conditions, *C. macrorhizon* was observed at a relatively high rate in these areas, specifically in rock crevices and near tree roots where soil had accumulated.

Discussion

Factors influencing the population of *C. macrorhizon*: insights into habitat conditions and soil environments

The slope of the habitat is wide, from gentle to steep, and the slope direction is mainly exposed to sun for longer periods, such as southeast-, south- and west-facing slopes. The survival of orchids may be negatively affected by increasing annual mean temperatures on south-facing slopes, while terrestrial orchids may also be impacted by excessively high humidity (Fekete et al. 2023). In regions influenced by a maritime climate, such as Geoje and Jeju Island, the high rainfall and humidity during the summer can inhibit the reproductive development of *C. macrorhizon*, preventing them from successfully completing their repro-

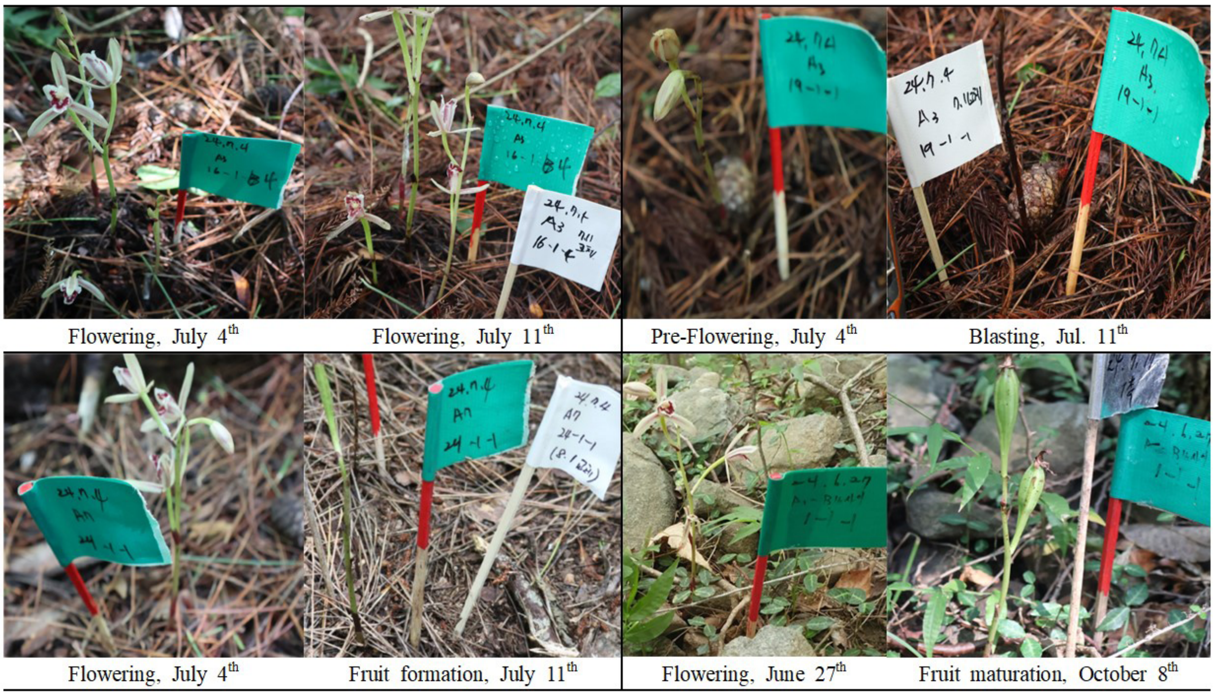

Fig. 8 The growth change of *Cymbidium macrorhizon* orchid found during the survey period in Geoje.

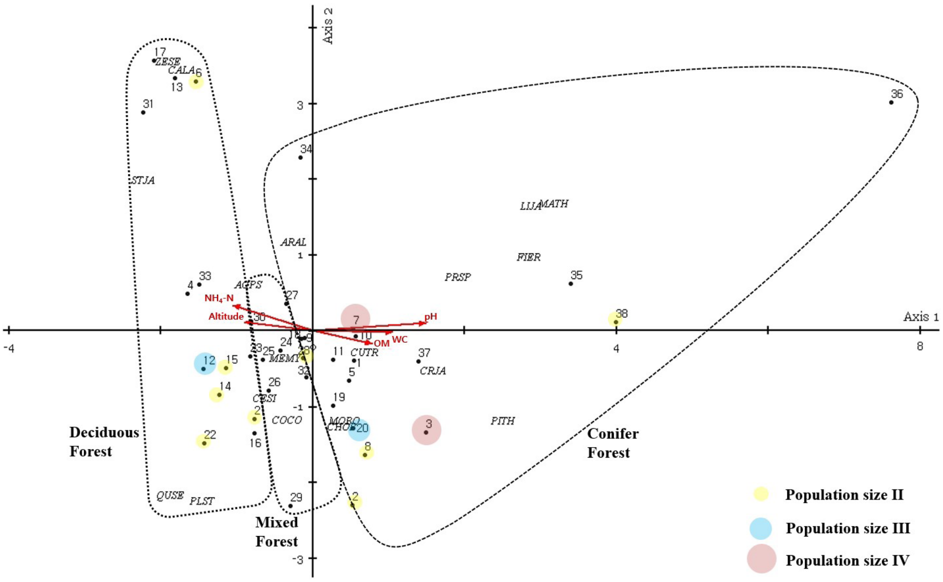

Fig. 9 Principal correspondence analysis (PCA) biplot depicting the relationships among topographical and soil physiochemical variables and the plant communities in 38 sites of *Cymbidium macrorhizon*. The numbers indicate the surveyed sites, and the italicized letters represent the community.

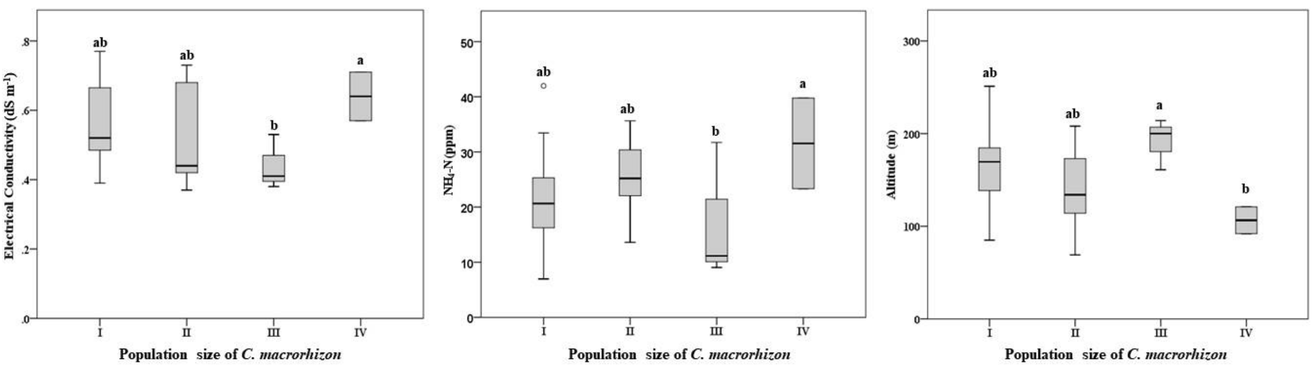

Fig. 10 Topographical and soil physicochemical properties related to population size of *Cymbidium macrorhizon*. The different letters indicate significant differences among the vegetation types, according to Duncan's test ($p < 0.05$).

ductive life cycle. Unsuitable environmental conditions, including high temperature, low temperature, and/or low light intensity, can significantly impact inflorescences or the development of young reproductive structures such as flower buds in *Cymbidium*, often resulting in their death, shedding, or reversion to vegetative growth (Ohno and Kako 1978). Orchid diseases such as soft rot, brown rot, brown spot, black rot, wilt, foliar, root rot, anthracnose, and leaf spot are associated with high temperature and humidity (Jain et al. 2020). *Cymbidium macrorhizon* individuals were observed in areas with bare rocks and shallow soil, around hiking trails or forest roads, and in cleared forests. Therefore, for *C. macrorhizon* distributed under dense canopies at lower altitudes, habitats on south-facing slopes, where increased sunlight penetration occurs during the summer, may be important for its survival and thriving, as these conditions might provide the necessary light for their growth and reproduction.

Soil formation is affected by a range of natural environmental factors, including landform, elevation, slope, climate, and vegetation (Dede et al. 2024). Shallow soils on hillslopes can be more susceptible to erosion and mass movement, while deeper soils offer better water storage capacity, affecting local water availability, plant growth, and nutrient retention (Senanayake et al. 2024). Soil formation is influenced by various natural environmental factors, including landform, elevation, slope, climate, and vegetation (Dede et al. 2024). Shallow soils on hillslopes are more prone to erosion and mass movement, whereas deeper soils provide better water storage capacity, which in turn affects local water availability, plant growth, and nutrient retention (Senanayake et al. 2024). Particularly in regions with shallow soils and steep slopes, heavy rainfall can result in soil loss at a faster rate than soil production. Consequently, the population growth of *C. macrorhizon* in such environmentally susceptible areas can be limited due to these unfavorable conditions. The soil NH_4-N contents in Geoje and Jeju was measured at 35.2 ± 14.1 and 24.9 ± 2.3 respectively, which is similar to NH_4-N 4.0–5.1 ppm in the coniferous forests within the National Arboretum (Son et al. 1995). Zhang et al. (2024) investigated the nitrogen acquisition and allocation mechanisms in *C. macrorhizon*, revealing that this orchid species utilizes very limited soil inorganic nitrogen in its natural habitat, with the root-like rhizome primarily storing nitrogen rather than absorbing its inorganic forms. This suggests a unique adaptation strategy to nutrient-poor environments, underscoring the complex interplay between the plant and its symbiotic fungi. According to the results of this study, the thickness of the O horizon positively affects NH_4-N content and plays a crucial role in soil nitrogen accumulation in the topsoil. Therefore, it can be inferred that *C. macrorhizon* has a significant relationship between nitrogen allocation and the growth and establishment of its populations.

Generally, coniferous forest litter has a higher C/N ratio and lignin content compared to broad-leaved forest and mixed forest, which leads to differences in soil respiration, abundance, composition, and activity of soil microbial communities (Han et al. 2015; Sulzman et al. 2005). The PCA results of this study indicate that coniferous forests are closely associated with soil organic matter content. Soil organic carbon stocks differ between coniferous and deciduous forests, with coniferous forests accumulating more organic material due to the slower decomposition of needle litter. In contrast, deciduous forests form shallower organic layers with higher turnover rates (Jandl et al. 2021). These findings suggest that the dynamics of soil organic carbon storage vary significantly between forest types.

Soil microbial activity is typically measured by the flux of carbon dioxide (CO_2) out of a soil, termed soil respiration, which includes both plant root and microbial respiration (Kuzyakov and Larionova 2005; Raich and Schlesinger 1992). This activity is influenced by soil temperature and moisture contents (Davidson et al. 1998), despite soil moisture also affects affecting it (Hanson et al. 2000; Lloyd and Taylor 1994; Sierra et al. 2015). In this study, the nitrogen content in the region with population size IV of *C. macrorhizon* was found to be higher than in other regions; however, microbial activity showed no significant difference. These findings suggest that the microbial activity in regions of Geoje and Jeju, where *C. macrorhizon* is found, is similar. In this study, soil respiration was relatively high on the southwest and south-facing sites. Although this study demonstrated a positive correlation between O horizon thickness and nitrogen content, it did not establish a relationship between O horizon thickness and soil respiration at the sites where *C. macrorhizon* appeared. This finding indicates that while litter input into the forest floor can enhance soil nitrogen content, the microbial activity within the habitats of *C. macrorhizon* in Geoje and Jeju is more significantly influenced by temperature variations driven by slope direction rather than by nitrogen content.

Strategies for individual reproduction of *C. macrorhizon*

Cymbidium macrorhizon bloomed for approximately one week before initiating fruit development, which took about three months to mature. During periods of high summer humidity and temperature, the frequency of *C. macrorhizon* occurrence was high in dense, low-altitude forested areas. However, despite this high occurrence, the number of individuals progressing to the fruit maturation stage after blooming was low. This suggests that while the environmental conditions are suitable for the initial growth of *C. macrorhizon*, factors inhibiting successful fruit maturation and seed reproduction may be limiting the full reproductive potential of this orchid species. During the early growth stages, the nutrient and water supply from mycorrhizal fungi is crucial for rapidly raising the peduncle from the underground rhizome. However, after pollination, the high humidity during the time required for fruit formation and maturation reduces the longevity of the fruit. The long-term survival of this species depends on frequent canopy openings (Jacquemyn et al. 2008). Additionally, since light can influence flowering, indirect light transmitted through the canopy is necessary. Bayu et al. (2017) reported that the development of the shrub layer may decrease the abundance of *Neottia cordata* in forests by increasing shade and closing the canopy.

To ensure the stable growth of the *C. macrorhizon* orchid, it is essential to maintain a well-balanced integration of microorganisms, vegetation, and soil environment. Orchid species possess the ability for vegetative propagation by rhizomes, which are the predominant pattern for population maintenance and establishes a system of reproductive reliability (Batygina et al. 2003). *Cymbidium* species without nectar, living in low-light environments and not favored by pollinators, are likely to prefer self-pollination as a reproductive assurance to compensate for pollinator limitation (Suetsugu 2015). However, *C. macrorhizon* have a high propensity for self-pollination at the early stage of flowering, and structurally, their stigmas often became covered with pollinia still attached to their anther caps, making self-pollination more likely than insect-mediated pollination (Suetsugu 2015). Despite producing enormous numbers of seeds, orchids have low pre-reproductive survival rates. Factors such as difficulties in dispersal, unsuccessful seed germination, and problems in establishment significantly limit their survival to maturity (Shefferson et al. 2020). *Cymbidium macrorhizon* can increase its population through vegetative propagation via rhizomes and seed propagation via self-pollination or cross-pollination. If the plant fails to produce fruit capsule after forming a peduncle, it can quickly wither its shoot to rapidly reclaim nutrients and, enter a process of growing its rhizome with the help of mycorrhizal fungi (Ohno and Kako 1978). Depending on the environment and the state of the rhizome, it may be able to produce a new inflorescence above ground within a year. In this study, it was observed that a few marked individuals produced new inflorescence. If the environment is suitable for fruit formation and seed production, the additional cost of ripening the fruit can be replaced by photosynthesis of the fruit pericarp (Kobayashi et al. 2021).

It takes a long time for individuals to develop and growth from seed reproduction (Rasmussen and Whigham 1998). However, individuals that growth from branched rhizomes can expect faster population growth if the environmental conditions are favorable for rhizome habitation. Těšitel et al. (2018) and McCormick et al. (2022) reported that partially mycoheterotrophic orchid could increase their dependence on carbon obtained from fungi when photosynthetic capability was encumbered, and photosynthesis contributes primarily to shoot parts of partially mycoheterotrophic plants (Lallemand et al. 2019). Chagi et al. (2023) reported that partially mycoheterotrophic orchid adjust their dependency against fungi in response to changes in the environment. Although the rhizome growth of *C. macrorhizon* is associated with the activity of mycorrhizal fungi in the soil, especially the high air temperature and humidity in a densely closed canopy during the summer period are factors that reduce the maturity and lifespan of the fruits. Consequently, individuals under shade canopy can increase their populations through vegetative propagation via the growth and branching of rhizomes, rather than through seed reproduction. This type of plant has adapted to the harsh ecological conditions by strengthening asexual reproduction and weakening sexual reproduction. This strategy enables the plants to survive in this region.

Conclusions

In conclusion, topographical aspects and vegetation structure can affect the species composition and abundance of understory vegetation, particularly herbaceous plants. We found that the endangered plant *C. macrorhizon* strategically adapts to various habitats to ensure its survival and increase its population. *Cymbidium macrorhizon* can tolerate a range of conditions and may be more widespread than previously thought, if habitat conditions are provided according to environmental factors. *Cymbidium macrorhizon* is associated with tree species such as *P. thunbergii*, *P. strobilacea*, *Carpinus laxiflora*, *Q. serrata*, and *Z. serrata*. Notably, it forms large populations, especially in *P. thunbergii* stands, which are characterized by well-developed organic layers and well-drained soils with approximately 40% soil moisture content.

Considering the rapid lifespan of the shoot of *C. macrorhizon* and the low seed reproduction rate, it is crucial to establish environmental conditions that maintain the viability of the rhizomes to sustain and increase the population. Additionally, it is preferable to have light intensity and quantity that avoid direct sunlight, rather than being in a densely closed canopy with high humidity, to form and mature seeds. Apparently, the short duration and sterility of each flower would avoid the invalid energy waste in unfavorable circumstances and save the limited energy for more valid asexual reproduction so that the opportunity of multiplication in a suitable environment condition would be increased to ensure the reproductive success.

Consequently, it is proposed that *C. macrorhizon* may increase its population size through vegetative propagation via rhizomes facilitated by microbial activity in environments that limit population growth through seed reproduction, such as shaded stands with high organic matter content. Understanding the specific environmental conditions, such as soil characteristics and light penetration, and vegetation community in its natural habitat, can provide crucial data for establishing effective conservation strategies to ensure the continued survival and proliferation of *C. macrorhizon*. Forward our research will investigate the impact of mycorrhizal fungi substances related to *C. macrorhizon* affect the growth of seeds and rhizomes, this research will provide crucial data for establishing conservation strategies for this endangered plant species.

Abbreviations

ANOVA: Analysis of variance
PCA: Principal correspondence analysis
WC: Soil water contents
CEC: Catio exchange capacity
EC: Electrical conductivity
NH_4-N: Ammonium nitrogen
OM: Total organic matter

Authors' contributions

JSH conceived the ideas, conducted the data collection and analysis, and wrote the manuscript. JHK conceived the ideas, checked the project administration, examined the manuscript. HJB conducted field study, checked the database, and examined the manuscript. DSK conceived the ideas, provided the resources, conducted the data collection, conducted field study. YSC conceived the ideas, checked the database, and reviewed the manuscript. All authors read and approved the final manuscript.

Funding

This work was supported by Kyungpook National University, Korea.

Availability of data and materials

Not applicable.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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