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Research Article

Propagation and community perspective of the climber species *Smilax nageliana* A.DC. endemic to Java Island

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Abstract

A conservation approach for *Smilax nageliana* A.DC. was implemented by integrating ex-situ propagation, habitat suitability modeling, and SWOT analysis. The propagation of *S. nageliana* has proven successful in rescuing and preserving this threatened species, resulting in 0.55 shoots per cutting, with an average shoot length of 3.51 cm and 1.05 leaves per shoot. Approximately 66.7% of the forest-adjacent community engages in field cultivation activities, resulting in minimal disturbance to *S. nageliana* habitats. Conservation strategy development for *S. nageliana* employed Partial Least Squares (PLS) analysis, which identified slope as a significant factor influencing habitat suitability, which influences the growth of *S. nageliana*, particularly stem diameter. SWOT analysis revealed that *S. nageliana*'s strengths include its status as an East Java endemic species, coupled with limited knowledge about this plant. The primary weakness of *S. nageliana* is its critically endangered status on the IUCN Red List. External factors presenting opportunities for *S. nageliana* conservation include community interest in utilizing the plant as livestock feed and support for exploring its medicinal potential. The main external threat is the prevalence of farming and forest product harvesting among survey respondents. A recommended conservation strategy model for *S. nageliana* involves all stakeholders' increasing knowledge and sustainable plant utilization.

Keywords: community perspective; conservation; endemic; propagation; *Smilax nageliana*; threatened species

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Introduction

Java, one of the world's most densely populated islands, is a biodiversity hotspot facing significant environmental challenges due to its high population density and associated human activities. The escalating demands for resources and land conversion have substantially reduced forest cover, jeopardizing the island's rich biodiversity, particularly its endemic plant species. Endemic plants, characterized by their restricted geographic range and limited distribution, are more susceptible to anthropogenic threats, such as habitat loss, pollution, overexploitation, and environmental changes, including climate change and habitat fragmentation. Their vulnerability stems from their inability to disperse and adapt to new environments as rapidly as more widespread species (Rinandio *et al.*, 2022). The conservation of these species is a major concern on a global scale, and relying solely on *in situ* protection is inadequate to ensure their long-term conservation. Therefore, ex-situ conservation efforts must be implemented to complement *in situ* measures and enhance the conservation of these species (Coelho *et al.*, 2020).

The field of botany has evolved into a dynamic interdisciplinary science that integrates traditional research methodologies with cutting-edge technologies and contemporary knowledge. This synergistic approach empowers us to delve deeper into the intricate evolutionary history of plants (Puttick *et al.*, 2018; Ramírez-Barahona *et al.*, 2020; Carta *et al.*, 2022) and serves as the foundation for effective conservation practices (Westwood *et al.*, 2021: Heywood and Iriondo, 2003; Edwards and Jackson, 2019), particularly for endemic plant species that hold immense evolutionary significance within their respective regions (Thompson *et al.*, 2005; Lavergne *et al.*, 2004; Peruzzi *et al.*, 2014). Due to their restricted geographical distribution and limited dispersal abilities, endemic taxa are often more susceptible to extinction threats, making them a critical focus of conservation efforts across regional and local scales (Orsenigo *et al.*, 2018; Salles *et al.*, 2019). Consequently, safeguarding these unique plants remains at risk without a comprehensive scientific understanding of their systematics, distribution, ecology, and well-defined conservation priorities (Orsenigo *et al.*, 2018; Isik, 2011). To address these pressing issues and further enhance the study and conservation of endemic plants, collaboration among institutions with expertise in botany is essential. Botanical gardens and other plant science research centers are pivotal in this endeavor.

Endemic species are organisms that naturally occur only in a specific geographic region and are highly adapted to the environmental conditions of that area (Isik, 2011; Anderson, 1994; Burlakova *et al.*, 2011; Foggi *et al.*, 2014). Based on the size and boundaries of their range, endemic species can be categorized into "local endemics" (restricted to a small area), "provincial endemics" (restricted to the boundaries of a province), "national endemics" (restricted to the boundaries of a country), "regional endemics" (restricted to a geographic region), and "continental endemics" (restricted to a continent) (Foggi *et al.*, 2014; Ladle and Whittaker, 2019). A proportion of endemic species display a variety of characteristics, either individually or in combination. Their vulnerability to anthropogenic threats and natural changes is heightened when they exhibit a combination of characteristics, including narrow distribution, small population size, declining population size, human overexploitation, low reproductive capacity, unique habitat requirements, and stable environments (Coelho *et al.*, 2020).

Given the inherent vulnerability of endemic plants, conservation efforts are crucial, despite the limitations of ex-situ conservation methods, such as propagation through cuttings, in ensuring their survival compared to their natural habitats. Alterations in the ex-situ environment can potentially diminish these plants' reproductive capacity, competitive abilities, and fundamental phenotypic traits. Studies investigating ecological adaptation within ex-situ conservation frameworks are still under-explored, necessitating further research. This study delves into ex-situ conservation strategies employing the conventional approach of plant propagation through cuttings.

The ex-situ management of endemic plant species is initiated with collecting propagules (seeds or planting materials). Following a period of short-term conservation, these propagules undergo a regeneration and multiplication phase. Subsequent conditioning, harvesting, and cultivation stages provide opportunities to assess the viability, vigor, vitality, and health of the germplasm and evaluate the success of the implemented ex-situ conservation methods (Kovács Zs. *et al.*, 2021). Conservation efforts extend beyond the plants themselves, encompassing the support of various stakeholders, including local communities and governing authorities. Ex-situ conservation practices play a crucial role in raising public awareness about the existence and significance of endemic plants. By bringing these unique and often endangered species into the public eye, ex-situ conservation efforts foster a deeper understanding and appreciation of biodiversity. This investigation establishes an integrated conservation framework for East Java's endemic flora, particularly *Smilax nageliana* A.DC. (Smilacaceae), a critically significant taxon due to its restricted distribution and minimal recognition. The species' exceptional vulnerability stems from its highly localized occurrence in Mt. Kawi and Ranu Darungan (Sulistyaningsih *et al.*, 2021; Sofiah *et al.*, 2025), compounded by insufficient public awareness, factors collectively threatening its persistence. The species' vulnerable status necessitates a multifaceted conservation strategy consisting of habitat protection, public awareness campaigns, research into its potential uses, and community engagement. This study aims to describe the community perspective and propagation value as part of ex-situ conservation of *S. nageliana*.

Materials and Methods

Study area

The research was conducted at Ranu Darungan (Ranu Lingga Rekisi) in Bromo Tengger Semeru National Park (BTSNP), Pronojiwo District, Lumajang Regency, East Java Province. The geographical location of BTSNP is S 08°10'26.5" E 112°55'26.6". Ranu Darungan is one of the management resorts in BTSNP, a national park under the management of the Indonesian Ministry of Environment and Forestry. Additional research was conducted in Mt. Kawi, Wonosari Village, Wonosari District, Malang Regency, East Java Province. Mt. Kawi's natural forest falls under the primary management of Perhutani, an Indonesian state forestry agency responsible for resource utilization. Plantations within the area are predominantly controlled by Perhutani, with a limited portion belonging to the local community. Notably, Mt. Kawi serves as a designated site for religious ceremonies, attracting significant visitor influx, particularly during periods of cultural significance to the local population.

Species descriptions

Smilax nageliana A.DC. is a woody climber with vine-like stems and stipules. The stem has a round cross-section, while the branches are somewhat four-angled, sparsely armed with triangular prickles (1-2 mm long). Internodes are terete, measuring 2-4 cm in length and 1-2 mm in thickness. Leaves are alternate, with petioles 9-20 mm long, featuring a narrow basal sheath that extends approximately 4 mm from the base. Leaf blades are generally oblong to lanceolate, with a subacute to attenuate apex and a rounded-truncate base, measuring 6-8 × 4-6.5 cm. The margins are entire, and the abaxial surface is pruinose. Both adaxial and abaxial surfaces are green, with 5 to 7 prominent veins.

The inflorescences are solitary umbels, 3-3.5 cm long, borne on a 0.5 cm stalk. Each umbel contains 21-23 staminate flowers with green perianths. The tepals are free, with outer tepals oblong and rounded at the apex (4-5 mm long), while the inner tepals are linear-oblong, obtuse, and narrower (0.2-0.4 mm wide), both recurved at anthesis. Pistillate flowers are arranged in umbels of 20 and have rounded ovaries measuring 6-8 mm in diameter. The pistillate perianth is approximately 4 mm long, with outer tepals elliptical (about 1 mm wide) and inner tepals oval (0.5 mm wide) with a blunt tip. The ovary is ellipsoid (1.5 mm long, 1 mm thick), with a stigma of about 1 mm and three needle-like staminodes (1 mm long). Fruits are round to obovoid berries, 6-8 mm in diameter, dark green. Seeds are one or two per fruit, green.

Community perspective and habitat suitability of Smilax nageliana A.DC.

A simple modeling was developed to support the conservation of *S. nageliana*, particularly for future development plans such as reintroduction. The modeling was conducted by combining two methods: a habitat suitability model using several independent variables, including microclimate, soil pH, elevation, slope, slope direction, surface temperature, and vegetative plant variables. This modeling was constructed using Partial Least Squares through the smartPLS 15 program.

The conservation analysis for *S. nageliana* was further supported by a SWOT analysis based on a survey of local communities. Semi-structured interviews were conducted with various community members, including government officials, residents, and key stakeholders. The SWOT analysis matrix was processed using Microsoft Office 365. SWOT analysis, employing a matrix to assess internal (Strengths and Weaknesses) and external (Opportunities and Threats) factors, is utilized to quantify and analyze conservation strategies for *S. nageliana*. The SWOT matrix serves as a tool for strategic planning and decision-making to maximize strengths and opportunities while minimizing weaknesses and threats to *S. nageliana* plants in their habitat.

Propagation of Smilax nageliana A.DC.

Vegetative propagation is a crucial stage in plant conservation efforts. Vegetative propagation of *S. nageliana* was conducted using stem cuttings with three different mediatreatments: soil, sand, and a mixture of cocopeat and rice hulls . The soil utilized for stem cuttings propagation was andosol soil sourced from the native habitat of *S. nageliana*, specifically from Mount Kawi, located in Sumbersuko Village, Wagir Subdistrict. The sand employed was derived from katel sand. This katel sand substrate exhibits a non-compacted structure, thereby facilitating optimal root development for plant propagation (Muthahara *et al.*, 2018). Stem cuttings were obtained from *S. nageliana* individuals in their natural habitat. The stem cuttings used contained a single node and were approximately 5 cm long (Figure 1). Each media treatment consisted of ten (10) experimental units. The parameters measured were leaf count and shoot length. Vegetative propagation of *S. nageliana* was conducted under plastic dome conditions within a screen house. Growth parameters observed were shoot length and leaf count. Plant growth observations were performed weekly until 4 months after planting (MAP). Environmental parameters monitored included microclimate temperature, humidity, and light intensity. Data analysis for vegetative propagation was conducted using an experimental design in Minitab with ANOVA analysis and followed by Duncan's multiple range test.

Figure 1. Stem propagation of *S. nageliana*; a) stem internode of 5 cm; b) rice hulls and cocopeat mix planting medium; c) soil planting medium; d) sand planting medium

Results

Propagation of *Smilax nageliana* A.DC.

Smilax nageliana A.DC. exhibited optimal growing conditions under the hood application in the screen house (Sofiah *et al.*, 2022). Controlled relative humidity, air temperature, and light intensity proved more favorable for cutting growth. Under-hood application in screen house, the emergence of new shoot was observed approximately twice a week, with peak growth occurring within the first two weeks. During this study soil as growing medium proved to be optimal for the successful propagation of *S. nageliana*, because soil provides optimal nutrition for the growth of *S. nageliana*'s propagation.

Table 1. Propagation results of *S. nageliana*

Experimental treatments	Shoot number (shoots)	Length shoot (cm)	Number of leaves (leaves)
Sand	**0.35**^{ab}	**0.37**^{a}	**0.62**^{ab}
Soil	**0.55**^{bc}	**3.51**^{c}	**1.07**^{bc}
The mixture of cocopeat and rice hulls	**0.1**^{a}	**0.42**^{ab}	**0.18**^{a}

Note: Letters following the numbers indicate significant differences according to Duncan's Multiple Range Test (DMRT)

Treatment of sand, soil, and cocopeat husk mixture has shown statistically significant results in two-way ANOVA analysis. Duncan's post-hoc test revealed that soil media significantly optimal than both rice hulls/cocopeat mix and sand media for *S. nageliana* stem cutting propagation, producing superior results in shoot number (0.55 shoots; F=6.04, p=0.05), shoot length (3.51 cm; F=3.34, p=0.05), and leaf count (1.05 leaves; F=3.34, p=0.05). The results of this study also indicated successful vegetative propagation of *S. nageliana*, whereas previous research had stated that vegetative propagation of Smilax plants was notably difficult to achieve (Martins *et al.*, 2011). Eigen value of environmental factor of *S. nageliana*'s propagation showed in Table 2. In this study, the first factor that mostly influenced stem cutting of *S. nageliana* was light intencity. The second factor that influenced the stem cutting of *S. nageliana* was temperature.

Table 2. Eigen value of the environmental factor of *S. nageliana*'s propagation

Parameter	PC1	PC2	PC3
Eigenvalue	1.8408	0.6014	0.5578
Proportion	0.614	0.200	0.186
Cumulative	0.614	0.814	1.000
Temperature	0.572	0.713	0.405
Humidity	-0.573	0.701	-0.426
Light intensity	0.587	-0.012	-0.809

Community perspectives of Smilax nageliana A.DC.

Most adult residents (over 40 years old) living near the forest area possess limited in-depth knowledge about *S. nageliana* despite their relatively frequent plant utilization (Figure 2). Based on these findings, there is a need to enhance awareness and understanding of *S. nageliana*'s potential value among local communities. Increased knowledge may foster community engagement in conservation efforts for this species. Some respondents, particularly in Ranu Darungan area, reported using *S. nageliana* as animal fodder. Interestingly, while these individuals frequently employ the plant for this purpose, they generally lack specific knowledge about *S. nageliana* as a species.

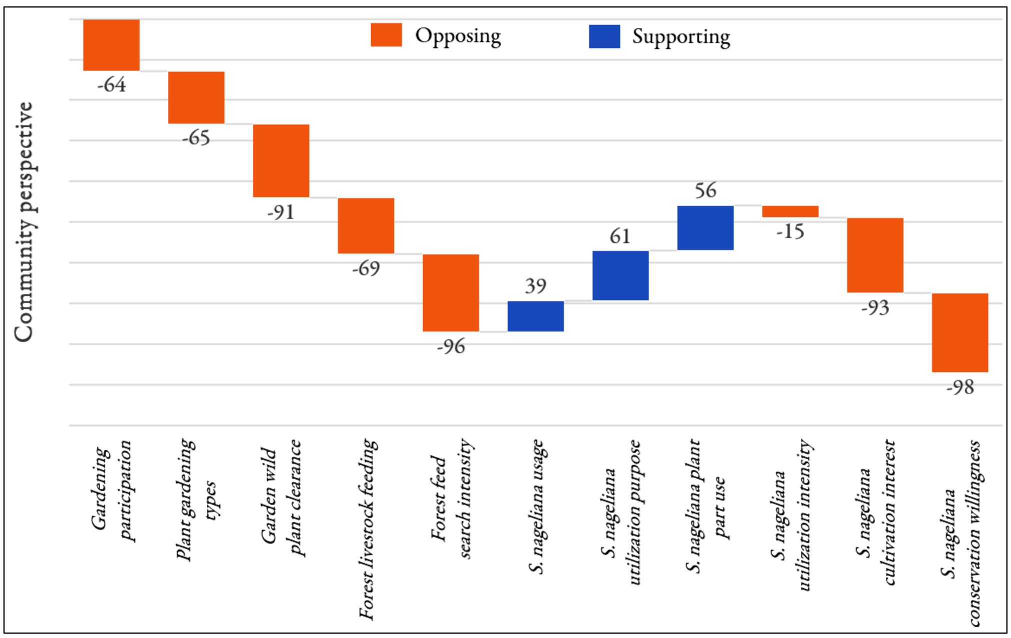

Figure 2. Graphs depicting the results of a community survey on knowledge and utilization of plants about the conservation of *S. nageliana* at Ranu Darungan and Mt. Kawi

Figure 2 illustration demonstrates that local community knowledge regarding *S. nageliana* remains substantially limited, necessitating more comprehensive efforts in implementing conservation strategies. One conservation pillar already being progressively implemented by the community involves the utilization of this species, wherein such strategic exploitation enables community participation in preserving the presence and ecological significance of *S. nageliana*. Based on the SWOT analysis (Table 3; Figure 3), according to local communities, fundamental aspects related to *S. nageliana* include their general lack of knowledge about this endemic plant. However, some use it for livestock feed. This aspect could become a focus for the conservation and development of *S. nageliana*. The effort to elaborate on the strengths and opportunities in the conservation of *S. nageliana* aims to integrate the sustainable utilization of *S. nageliana* with conservation efforts to ensure the long-term viability of the species while minimizing its exploitation.

Table 3. Internal and external factors of SWOT analysis for *S. nageliana*

No.	SWOT Analysis Parameters	Score	Factors
1	Comprehensive knowledge of *S. nageliana*	0.58	Opportunity/Threat
2	Utilization potential of *S. nageliana*	0.71	Strength/weakness
3	Community engagement with *S. nageliana*	0.54	Opportunity/Threat
4	Respondent agricultural profile	-0.09	Opportunity/Threat
5	Critically endangered of *S. nageliana*	-1.00	Strength/weakness
6	*S. nageliana* is an endemic plant of East Java	1.00	Strength/weakness
7	The presence of *S. nageliana*	0.92	Strength/weakness
8	Sources of information about pharmaceutical ingredients	0.09	Strength/weakness
9	The desire to uncover the benefits of Indonesian plants	1.00	Opportunity/Threat

STRENGTHS	OPPORTUNITIES
S. nageliana is a plant species endemic to East Java Utilization potential of *S. nageliana* The presence of *S. nageliana*	Comprehensive knowledge of *S. nageliana* Community engagement with *S. nageliana*
WEAKNESSES	**THREATS**
S. nageliana is classified as Critically Endangered on the IUCN Red List Sources of information about pharmaceutical ingredients	-

Figure 3. SWOT analysis of *S. nageliana*

One approach is through ex-situ conservation, for example, at the BRIN Botanical Gardens, one of the conservation authorities. Research in botany, particularly regarding the conservation of *S. nageliana*, has been structured into a conservation program workflow incorporating various aspects, including conservation principles encompassing study, save, and use approaches (Figure 4).

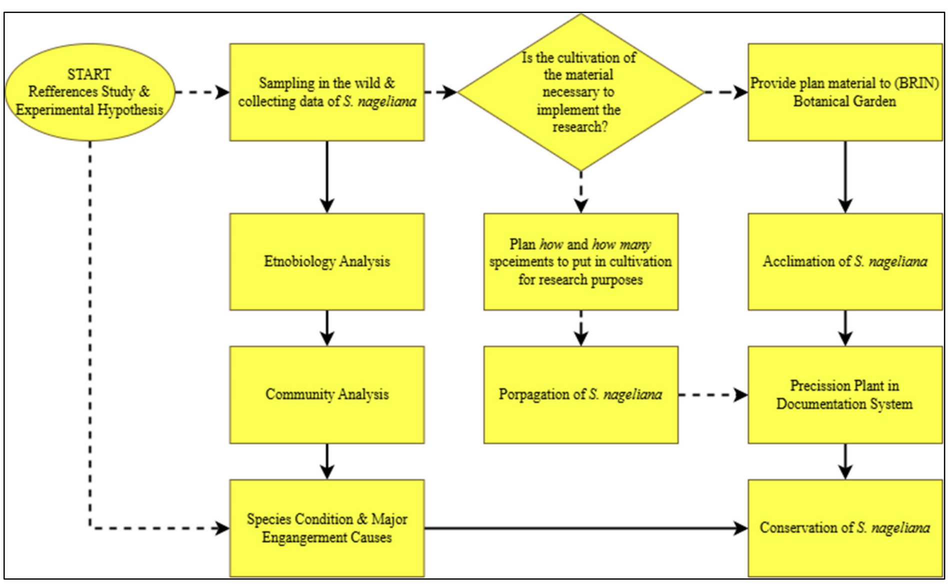

Figure 4. A flowchart of *S. nageliana*'s conservation

This program workflow consists of stages implemented in *S. nageliana* conservation efforts. The initial point originates from specific experimental hypotheses, culminating in outputs of conservation practices across various stakeholder elements to prevent *S. nageliana* from extinction. Based on the analysis using Partial Least Squares modeling, results depict a significant factor influencing the habitat suitability of *S. nageliana*, namely slope. This is evidenced by the T-statistic value exceeding 1.96, specifically 1.99 (Table 4).

Table 4. T-values, p-values *S. nageliana*

Variables of habitat suitability modelling	T statistic	P values
Fruiting <- Suitability	0.902	0.367
Flowering <- Suitability	0.921	0.357
Mature leaf <- Suitability	0.437	0.662
Young leaf <- Suitability	0.552	0.581
Diameter of stem <- Suitability	2.139	0.033
Elevation <- Geography	0.536	0.592
Light intensity <- Climate	1.745	0.081
Air humidity <- Climate	0.421	0.674
Slope <- Geography	1.990	0.047
Length of stem <- Suitability	1.031	0.303
Temperature <- Climate	1.253	0.210
pH <- Soil	0.000	0.000

Note: T statistic >1.96 -> significantly influential factor
T statistic <1.96 -> not significantly influential factor

This factor significantly affects the vegetative growth of *S. nageliana*, particularly stem diameter, with a T-statistic value of 2.139. Environmental factors had a greater influence on stem diameter, but not on the growth of stems, flowers, growth of young and mature leaves and fruits. Climate and soil factors did not significantly affect *S. nageliana*. Sofiah *et al.*, (2024) stated that the highest population density (65.71%) was observed in areas with a slope gradient of 15-25%, followed by 25.71% in steeper regions with 25-40% gradients, and the remaining 8.57% in very steep areas exceeding 40% inclination. Thus, the optimal slope gradient for *S. nageliana* populations is 15-25%, with population density decreasing as the gradient increases beyond this range.

Discussion

Propagation of S. nageliana

The propagation of critically endangered endemic plants presents numerous distinct challenges, particularly when conducted *ex situ*, due to potential climatic conditions that differ from their native habitats. One significant challenge relates to the varying levels of adaptive capacity during the acclimatization process (Cristea *et al.*, 2013). *S. nageliana* specimens were positioned in open shaded areas referring to its natural habitat (Sofiah *et al.*, 2022). In these areas, *S. nageliana* wildling exhibited dynamic growth, with optimal development observed during the early weeks, specifically in the fourth and sixth weeks. This indicates that optimal initial acclimation for *S. nageliana* wildling is achieved under plastic hood conditions within a screen house environment. Subsequent optimal growth of *S. nageliana* individuals is best facilitated in open yet shaded areas. The findings indicate that wildling growth proceeded slowly and remained dynamic during acclimation under the plastic hood in the screen house.

The propagation or multiplication phase is a critical stage in conservation efforts, particularly in ex-situ conservation, following plant acclimation or adaptation. The alternative propagation methods for *S. nageliana* are implemented considering scientific rationales regarding the availability of propagation materials. The observed adaptation is deemed particularly important for plants that are scarce in their natural habitats. In this research, the generative propagation of *S. nageliana* has not been feasible due to insufficient fruit seed production to meet the required quantity. *S. nageliana* flowers annually, typically in August/September. Observations in its natural habitat revealed that fruit development from flowers yields a low number of seeds, approximately fewer than 10 per fruit. Mature *S. nageliana* plants capable of producing flowers and fruits were scarce, with only about two individuals identified and distributed in Mt. Kawi, where flowers with both sexes present naturally produce fruits and seeds. *S. nageliana* is a monoecious plant in which most *Smilax* species are dioecious (Martins *et al.*, 2012; Li *et al.*, 2011; Martins *et al.*, 2013; Sulistyaningsih *et al.*, 2021; Holm, 1890; Andreata, 1980; Pogge & Bearce, 1989; Andreata & Pereira, 1990; Barnea et al., 1991; Andreata & Menezes, 1999; Rosa & Ferreira, 1999; D'Antuono and Lovato, 2003; Santos *et al.*, 2003; Palhares *et al.*, 2009).

Longitudinal observations spanning four years of transplanted endemic and endangered Dianthus taxa (*D. callizonu*s, *D. glacialis* ssp. gelidus, and *D. spiculifoliu*s) at the "Alexandru Borza" Botanical Garden of Cluj-Napoca (Romania) revealed that among specimens collected from natural habitats and subsequently replanted *ex situ*, only *D. spiculifolius* demonstrated successful acclimatization and long-term survival (Cristea *et al.*, 2013). In contrast, plantlets derived through in vitro propagation protocols exhibited significantly enhanced adaptation capacity and survival rates when transferred to outdoor environmental conditions. Based on observations in its natural habitat, *S. nageliana* does not reproduce vegetatively, showing any characteristics of vegetative propagation, such as the absence of adventitious shoots arising from stem nodes or stolons. Several studies have indicated that *Smilax* spp. are insect-pollinated species (Pellet, 1976; Kevan *et al.*, 1991). The population of *S. nageliana* in its habitat is largely composed of juvenile plants, exhibiting an inverted J-shaped distribution. Previous research has indicated that *Smilax* species, such as *Smilax rotundifolia*, are classified as insect-pollinated plants (Kevan *et al.*, 1991). Its pollen grains are connected by viscin threads, which are known to prevent wind dispersal effectively. According to Kevan *et al.* (1991), in most locations of *Smilax rotundifolia*'s habitat, populations do not reproduce sexually, are unisexual, and do not spread vegetatively. Based on *S. nageliana*'s natural reproduction patterns in its habitat, vegetative propagation methods could be implemented for its multiplication.

The propagation of *S. nageliana* has proved successful in rescuing and preserving it as a threatened species. The propagation of *S. nageliana* conducted in this study utilized stem cuttings. Previous research has reported that vegetative propagation of *Smilax* spp has proven to be highly challenging (Palhares & Silveira, 2005). Research conducted by Pogge *et al.* (1974) demonstrated low success rates in rooting cuttings. They tested two common *Smilax* species found in North America, namely *S. rotundifolia* and *S. glauca*, but the success rate only reached less than 30%. According to these results, Pogge *et al.* (1974) stated that the addition of substrates such as 0.8-percent IBA mixture (talc) provides more optimal results for the propagation growth of *S. rotundifolia* using stem cuttings, with Smilax growth rates reaching 70%. However, these results differ when Smilax cutting propagation is conducted during summer and fall seasons, with plant survival rates of 30% and 65% respectively. The possible differences in air humidity likely influence the growth of Smilax Furthermore, attempts at vegetative propagation using rhizome cuttings in the species *S. goyazana* also failed to yield positive results.

S. nageliana demonstrated a favorable response to controlled growth environments. Microenvironment control significantly influenced the success of propagation of *S. nageliana*. Table 2 showed that temperature was the highest proportional (71,3%) influenced of *S. nageliana*'s stem cuttings. The propagated in a greenhouse with average controlled air temperature <30°C with automatic water fog sprinkle, light intensity reduced using shadenet to about 60 %. Watering was done in the beginning of planting and later when required, about twice a week to ensure the seedlings received enough water during the initial growing stage. Screen house cultivation of *S. nageliana* wildlings with supplementary plastic shading functions as a CO_2 enrichment system, potentially enhancing non-structural carbohydrate accumulation in woody tissues, though this mechanism remains contentious (Grossnickle and Ivetic, 2022). Elevated CO_2 concentrations within these controlled environments, particularly when enhanced with plastic hoods, promote robust root system development, conferring superior post-transplantation establishment capacity. The acclimatization protocol utilizing plastic coverings represents an adaptive strategy for optimizing transplant success. Comparative studies, particularly in arid regions, demonstrate that pre-planting acclimatization of wildlings yields significantly higher establishment rates compared to direct seeding approaches (Bailey *et al.*, 2024).

Relative humidity significantly influences plant growth through its impact on photosynthetic rates by modulating water vapor pressure deficit and enhancing stomatal conductance, directly affecting CO_2 assimilation and photosynthate production (Sofiah *et al.*, 2022). In *S. nageliana* wildlings, leaf chlorophyll content development proceeded unimpeded from initial planting through controlled temperature and humidity conditions within plastic-covered screen houses, with this positive trend continuing after transfer to open areas. Growth parameters including new shoot formation and leaf production showed more substantial improvement once plants were relocated to open environments, indicating successful acclimatization. The shaded conditions and stable humidity within the plastic-covered screen house provided optimal conditions for initial leaf development in the wildlings. Under reduced light conditions, *S. nageliana* demonstrated adaptation through induced light compensation point and reduced dark respiration rate, indicating capacity to minimize photosynthate consumption while maximizing efficiency under low irradiance (Sui *et al.*, 2012). Screen house humidity management requires precise monitoring through relative humidity measurements, expressed as the percentage ratio between actual water vapor pressure and saturated vapor pressure at specific temperatures. Internal screen house temperature regulation is crucial given its direct influence on photosynthetic and transpiration mechanisms (Singh and Chandra, 2018). A notable limitation of this ex-situ conservation approach was insufficient genetic factor control among wildling specimens collected from natural habitats for cultivation in the Botanic Gardens.

Community perspective analysis on the utilization of S. nageliana

Conservation efforts for *S. nageliana* require a holistic approach encompassing both in-situ and ex-situ conservation and increased public awareness. *In situ* conservation through national parks and nature reserves protects natural habitats, allowing *S. nageliana* to thrive in its native ecosystem, namely BTSNP and Mt. Kawi. The populations surrounding Ranu Darungan and Mt. Kawi do not exhibit significant dependence on the forest where *S. nageliana* occurs. Approximately 66.7% of residents adjacent to the forest engage in agricultural activities, which suggests that the habitat of *S. nageliana* remains relatively undisturbed. Most people choose to farm as their livelihood. This agricultural focus results in a selective approach to crop cultivation. Consequently, non-cultivated plants may be cleared for agricultural commodities, including *S. nageliana*, often regarded as wild liana. A minor subset of the community residing near *S. nageliana*'s habitat maintains some forest dependence. These individuals typically harvest forest products such as fuelwood and animal fodder, with some utilizing *S. nageliana* as livestock feed. The leaves of *S. nageliana* are the primary part harvested for this purpose. Notably, harvesting generally involves partial defoliation rather than complete plant removal, leaving the roots intact. This practice allows for the regeneration and survival of the utilized *S. nageliana*.

S. nageliana is an endemic plant of East Java and is classified as critically endangered based on the IUCN Red List. Geographical slope emerges as the sole factor significantly influencing *S. nageliana*'s habitat suitability. Slope inclination is crucial to growth, especially for endemic plant species. Hubbell (1979) hypothesized that maintaining highly clustered populations is one strategy by which rare species can persist, as it ensures effective pollination and increases the likelihood of seeds falling in suitable habitats. Slope inclination/geographical gradient is a significant factor influencing *S. nageliana* populations in their habitat, with the species exhibiting a clustered distribution predominantly in sloped. Both in Ranu Darungan and Mt. Kawi, *S. nageliana* primarily grows on sloped terrain. In addition, the forests in *S. nageliana* habitats have varied topography. Previous research showed that herbaceous plant communities showing an increase in species richness (Cirimwami *et al.*, 2019), so these could be hypothesized that *S. nageliana* demonstrates a higher population density in regions characterized by significant topographic elevation.

In the internal factor analysis, the highest-scoring strength factor is *S. nageliana*'s status as an East Java endemic species, with a score of 1. Given its limited distribution, *S. nageliana* warrants higher conservation priority than other species. Conservation efforts for this species would also enhance motivation to preserve the entire ecosystem in Ranu Darungan-BTSNP and Mt. Kawi. However, *S. nageliana*'s classification as Critically Endangered on the IUCN Red List is a significant weakness, scoring -1. This condition necessitates immediate conservation action to prevent extinction. The total internal factor score is 9.2, indicating a very strong position. The external factors with the most significant influence as opportunities for *S. nageliana* conservation are the community's intensity in seeking *S. nageliana* for livestock feed (score 1) and community support for exploring medicinal plant potential (score 1). These two external factors have equal strength in supporting *S. nageliana* conservation, with a total score of 2, categorized as low level. External factors classified as threats include the community's use of *S. nageliana* as a livestock feed commodity (-0.74), respondents' occupations primarily involving gardening and forest product extraction (-0.27), and the intensity of clearing garden areas (removing plants considered weeds) with a score of -0.7. The total external factor value is 0.56, falling into the low category. Consequently, the combination of internal and external factors for *S. nageliana* conservation in Ranu Darungan and Mount Kawi has a ratio of 16.43:1.

Habitat suitability outside the native range of *S. nageliana* is crucial. Thus, efforts in acclimation and development in ex-situ conservation areas to suit its growth requirements constitute one of the key factors for the successful conservation of this plant species. Another approach to elaborating on the strengths and opportunities for the conservation of *S. nageliana* is to develop *S. nageliana* plants in-situ with the involvement of local communities. This objective seeks to promote the cultivation of *S. nageliana* within its natural habitat (in-situ) by engaging local communities in sustainable harvesting and management practices. This approach aims to empower local communities and ensure the sustainable utilization of the species.

The SWOT analysis results for mitigating weaknesses and enhancing opportunities in *S. nageliana* conservation suggest: 1) Improving conservation responsibility through enhanced interpretation to increase public knowledge, awareness, and participation in *S. nageliana* conservation in Mt. Kawi and BTSNP. This aims to enhance public understanding and engagement in *S. nageliana* conservation efforts by developing and implementing effective interpretation strategies, consisting of providing educational materials, organizing outreach programs, and engaging local communities in conservation activities; 2) Implementing both ex-situ conservation, such as in BRIN Botanical Gardens, and in-situ conservation. This objective underscores the critical nature of implementing both ex-situ and in-situ conservation approaches for *S. nageliana*. ex-situ methods safeguard against extinction by maintaining populations outside their natural range, whereas in-situ strategies focus on preserving the species' genetic variability and ecological functions within its native ecosystem. The synergistic application of these complementary conservation paradigms aims to maximize the long-term viability and evolutionary potential of *S. nageliana.*

The SWOT analysis matrix for conserving *S. nageliana*, focusing on enhancing strength and mitigating weakness and threats, involves the following approaches: 1) The objective is to facilitate multi-stakeholder collaboration for effective management of *S. nageliana* habitat. It addresses habitat conversion by identifying and implementing sustainable land-use strategies that mitigate anthropogenic impacts on the species' ecological niche; (2) Enhancing knowledge about *S. nageliana* as an endemic plant species requiring protection. Additionally, the objective seeks to enhance public awareness regarding the conservation significance of *S. nageliana* as an endemic taxon. This objective encompasses educational initiatives, community engagement programs, and integration of *S. nageliana*-focused content into local educational curricula; (3) Preserving local wisdom and traditional practices of the indigenous communities. The objective emphasizes integrating indigenous knowledge and traditional ecological practices into conservation strategies. This integration involves engaging local communities in participatory decision-making processes, acknowledging their role in environmental stewardship, and ensuring that conservation interventions align with their cultural values and socioeconomic needs.

A strategy to enhance public knowledge and perception of *S. nageliana* is establishing it as a flagship species in its habitat regions, particularly given that both habitat areas are tourist destinations for religious and mountain climbing purposes. Promoting *S. nageliana* (locally known as Riwono in Ranu Darungan or Grunggung in Mt. Kawi) as a flagship species involves conservation actions supported through various tourism activities. These actions include education to increase tourist awareness about plant conservation. For instance, implementing programs to enhance public understanding of ecology, which aligns with ecotourism goals supporting conservation (Walpole and Leader-Williams, 2002). Applying *S. nageliana* conservation pillars in Ranu Darungan and Mt. Kawi can operate synergistically, especially if conservation efforts can improve the local economy. Supporting *S. nageliana* conservation as a flagship species in these areas can be achieved through local souvenirs like t-shirts or other tourist merchandise. Involving communities in ecotourism activities within national park management systems (Ranu Darungan-BTSNP) and Mt. Kawi will fundamentally increase local awareness of the ecosystem and its supporting aspects.

The SWOT analysis also revealed external factors threatening *S. nageliana*, primarily related to community activities such as gardening and forest product extraction. Efforts are needed to maintain Ranu Darungan and Mt. Kawi as habitats for the endemic *S. nageliana* while considering the ecosystem dynamics in the surrounding areas. For instance, regulating land use in areas bordering *S. nageliana* habitats in Mt. Kawi, which are agricultural and plantation zones, is crucial for maintaining favorable habitat conditions. The proposed conservation strategy model for *S. nageliana* integrates all factors between strengths and opportunities while mitigating weaknesses and threats. This model incorporates support for sustainability determinants of the *S. nageliana* population to ensure its conservation and prevent extinction in its natural habitat. The conservation strategy model is based on the conservation pillars: Study, Save, and Use. In conclusion, the recommended conservation strategy model for *S. nageliana* involves increasing all stakeholders' knowledge and utilization of the plant, grounded in both ex-situ and in-situ conservation principles. This approach is supported by measures to ensure species and habitat continuity while considering ecosystem dynamics in surrounding areas.

Workflow of S. nageliana conservation

Optimal efforts are conducted to ensure mutual benefits for all involved parties. The conservation hypothesis for *S. nageliana* serves as the fundamental basis for subsequent required phases. Botanical gardens typically function as plant conservation facilities that provide dedicated space and cultivation infrastructure for species under development, facilitating access to well-documented and systematically organized specimens for observation and morphometric analysis of the species. The outcomes of these practices can be disseminated through scientific research publications and other stakeholders who can contribute to popularizing the research activities to the broader community, thus promoting the significance of *S. nageliana* and contributing to its conservation from extinction.

The conservation phases for *S. nageliana* are founded on two fundamental queries: reference studies and conservation hypotheses. Based on reference studies and secondary data collection, *S. nageliana* has been documented to be endemic to Ranu Darungan and Mt. Kawi, with currently insufficient data regarding its population dynamics, ecological parameters, and conservation status. Furthermore, ethnobotanical information concerning its utilization within local communities still needs to be updated. By investigating these two major aspects, it has been determined that *S. nageliana* is critically threatened in its natural habitat, emphasizing the significance of acclimatization and propagation protocols for species development. Despite its limited anthropogenic utilization, the extremely restricted natural population necessitates immediate conservation measures to prevent extinction. *S. nageliana* has been registered at Purwodadi Botanical Gardens (National Research and Innovation Agency, Republic of Indonesia) under accession numbers P2022040001, P2022040003, P2022020004, P2022020005, P2022020006, P2022020007, and P2022020008.

Vegetative propagation with stem cuttings of *S. nageliana* represents an initial phase in developing a conservation strategy for this critically endangered, endemic species that is extinct in the wild. Although the quantity of new individuals produced through this effort remains limited, these specimens are invaluable as material for subsequent propagation refinement efforts. They serve as a precious resource supporting ex-situ conservation initiatives, particularly as a safeguard for the living collection maintained at the BRIN Botanic Gardens. Simultaneously, this work bolsters in-situ conservation through both reintroduction programs and enhancement of populations within their natural habitat.

Conclusions

According to the findings of this research, a conservation strategy model for *S. nageliana* can be recommended, emphasizing the enhancement of knowledge and utilization among all stakeholders through both ex-situ and in-situ conservation approaches. This model should be supported by carrying capacity assessments for species sustainability and habitat conservation, considering the ecosystem dynamics of surrounding areas. Therefore, to maintain Ranu Darungan and Mt. Kawi as endemic habitats of *S. nageliana*, enhanced management efforts are essential, with particular attention to the ecological dynamics of adjacent regions. The community perception of *S. nageliana* was positive in supporting the existence of this species to prevent its extinction. However, awareness needs to be enhanced regarding the importance of habitat conservation for the survival of *S. nageliana*. Forest managers of *S. nageliana* habitats must also support conservation efforts for this species by implementing land-use regulations and protecting *S. nageliana* forest habitats to ensure their sustainability.

Author's contribution

Conceptualization (SS, LH, RA, IR); Data curation (SS, IY, DU); Formal analysis (SS, LH, RA, IR); Funding acquisition (SS); Investigation (SS, RA, IR); Methodology (SS, LH, RA, IR, LS, DU); Project administration (SS); Resources (SS, LS); Software (SS); Supervision (SS, LH, RA, IR); Validation (SS, LH, RA, IR); Visualization (SS, LH, IR); Writing- original draft (SS, LH, RA, IR); Writing - review and editing (SS, ER, LS, T).

All authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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