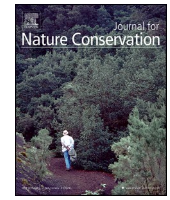
Journal for Nature Conservation 80 (2024) 126645

Contents lists available at ScienceDirect

Journal for Nature Conservation

journal homepage: www.elsevier.com/locate/jnc



Exploring a critically endangered pitcher plant *Nepenthes rigidifolia* and predicting its distribution habitat in North Sumatra, Indonesia

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A R T I C L E I N F O

Keywords:
Critically endangered plant
MaxEnt
Nepenthes rigidifolia
North Sumatra

A B S T R A C T

Nepenthes rigidifolia Akhriadi, Hernawati & Tamin is a critically endangered pitcher plant endemic to Sumatra, Indonesia. This species is at risk of extinction due to anthropogenic activities such as land use and illegal harvesting. Immediate conservation efforts are necessary to prevent the extinction of *N. rigidifolia*. This study aimed to investigate the occurrence of *N. rigidifolia* and predict its habitat as a part of conservation efforts. Several forests in four regencies of North Sumatra Province, Indonesia, namely Karo, Dairi, Pakpak Bharat, and Simalungun, were explored. The area of occupancy (AOO) and extent of occurrence (EOO) of this species were analyzed using the GeoCAT site. In addition, the prediction of habitat suitability was modeled using MaxEnt. A population of *N. rigidifolia* was found only in Lae Pondom Protected Forest, Karo Regency, which added two new records for this species. The AOO and EOO values are 12 km^2 and 4.17 km^2, respectively, located in Karo and Dairi Regencies. According to EOO value, population size, and threat level, we suggest that the new current conservation status of *N. rigidifolia* is Critically Endangered A2ad + 3d; B1ab(iv,v); C2a(i,ii); D. The AUC value of the MaxEnt model is over 0.9, indicating an excellent performance. An area of 364.18 km^2 around Lake Toba is estimated to be a highly suitable area for *N. rigidifolia*. This area, which overlaps with the EOO, is recommended as a priority area for *N. rigidifolia* conservation.

1. Introduction

Nepenthes is a monotypic genus of pitcher plants from the family Nepenthaceae, commonly known as *kantong semar* in Indonesia. It is found in the wild forests of northern Australia, Southeast Asia, and southern China (Clarke, 2006). At least 100 species of *Nepenthes* are widely spread in the Indonesian archipelago (Mansur, 2013). Sumatra, one of the main islands of Indonesia, is home to 38 species of *Nepenthes* distributed throughout the lowlands and mountains. The populations of *Nepenthes* in Sumatra are continuously declining due to various threats, such as natural system modifications, forest conversion for agriculture and aquaculture, and habitat fragmentation for transportation and service corridors (Cross et al., 2020). Furthermore, the illegal exploitation of the *Nepenthes* species by poachers for commercial purposes poses a significant threat to their population (Mansur, 2013). Hence, immediate conservation efforts are required to protect these species.

Twenty two species of *Nepenthes* were recorded in North Sumatra Province, including *Nepenthes rigidifolia* Akhriadi, Hernawati & Tamin (Mansur et al., 2022). This species is endemic to Sumatra and was discovered outside conservation areas at an altitude of 1000 to 1500 m asl around the Sidikalang area, Karo Regency, North Sumatra (Akhriadi et al., 2004). It is a critically endangered (CR) species according to the

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https://doi.org/10.1016/j.jnc.2024.126645
Received 2 January 2024; Received in revised form 16 May 2024; Accepted 16 May 2024
Available online 17 May 2024

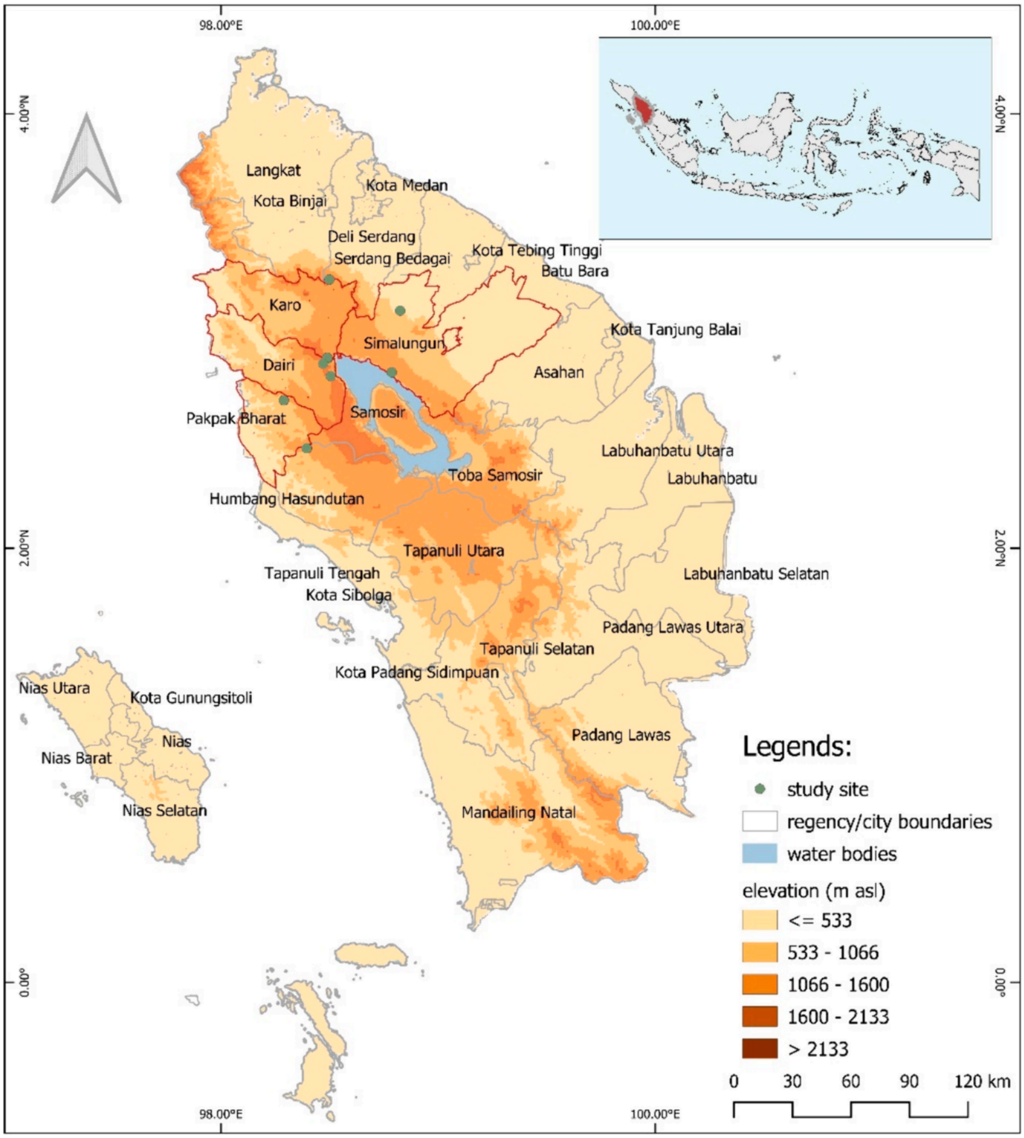

Fig. 1. Study site in exploring *Nepenthes rigidifolia* in North Sumatra Province, Indonesia.

International Union for Conservation of Nature (IUCN) red list assessment (Clarke, 2014). This species is also listed in CITES Appendix II (CITES-Secretariat & UNEP-WCMC, 2022). Additionally, it is registered as a protected species in Indonesia according to the Regulation of the Minister of Environment and Forestry Number P.106/MENLHK/SETJEN/KUM.1/12/2018.

It was initially discovered in a single population (Akhriadi et al., 2004), and subsequent assessment by Clarke (2014) was limited to one location. Its population size is likely to have changed substantially in the ten years since the assessment. Notably, the species' habitat has been significantly disturbed by road construction and logging in the surrounding forest (Clarke, 2014).

As a part of its conservation strategies, the current distribution of *N. rigidifolia* can be estimated to identify its suitable habitat. Maximum Entropy (MaxEnt) is the widely used method for modeling the species' geographic distribution based on recorded locations and environmental variables (Elith et al., 2011; Phillips et al., 2006; Smith et al., 2012). Previous studies have applied this method to predict suitable habitats for endemic and rare plant species (Qazi et al., 2022; Renjana et al., 2022; Yudaputra, 2021). However, limited occurrence records and scientific data make it challenging to construct species distribution models for *N. rigidifolia*. Therefore, this study aimed to investigate the occurrence of *N. rigidifolia* and predict its habitat distribution in North Sumatra, Indonesia.

2. Materials and methods

2.1. Study sites

The fieldwork of this study was conducted in May 2023 across several forests in the four regencies of North Sumatra Province, viz., Lae Pondom Protected Forest and Mount Sibayak in Karo Regency, secondary forests in Pegagan Julu VII and Paropo Villages in Dairi Regency, Mount Simpon and secondary forests in Kutamerah and Ulumerah Villages in Pakpak Bharat Regency, and secondary forests in Bongguran Kariahan and Parik Sabungan Villages in Simalungun Regency (Fig. 1). The study sites were selected according to discussions with the Environment and Forestry Service of North Sumatra Province, local people, and relevant literatures (Akhriadi et al., 2004; Clarke, 2001). Data were collected on *N. rigidifolia* plants including morphological characteristics, population numbers, and associated plant species. The herbarium voucher, consisting of cutting of the upper pitcher and leaves, was collected. To confirm the species, it was compared with the holotype of *N. rigidifolia* ANDA 00015422 (digital version available at https://www.

Fig. 2. Aerial observation showed that the *Nepenthes rigidifolia* population (insert) climbed on trees in a steep rocky cliff. Photograph by A. Yudaputra.

gbif.org/) and the isotype (BO 1610543) in the Herbarium Bogoriense, Bogor, Indonesia. The voucher was subsequently deposited in the Herbarium Bogoriense (BO) (voucher number: BO 1995911). The ecological and environmental data, including coordinate points, elevation, slope, aspect, air temperature, air humidity, canopy coverage, soil pH, litter thickness, and humus depth were determined. Threat factors were also recorded and supported by aerial habitat observations using an unmanned aerial vehicle.

2.2. Data preparation

The secondary data of occurrence records of *N. rigidifolia* were derived from the GBIF database (GBIF.org, 2023). Only one of the two available coordinate points was confirmed as correct after cross-referencing with Google Maps and the location data in the isotype herbarium. This study added two new occurrence records, resulting in a total of three occurrence records used for the model. The model's predictors included current bioclimatic variables, elevation, slope, and chemical soil data. The bioclimatic variables consisted of mean diurnal range, temperature seasonality, annual precipitation, precipitation of the wettest month, precipitation of the driest month, and precipitation seasonality. Chemical soil data included cation exchange capacity, nitrogen content, soil pH, and soil organic carbon. Bioclimatic data were extracted from WorldClim version 2.1, available at 30 arc s resolution (~1 km^2) (Fick & Hijmans, 2017). The elevation data was obtained from the Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) data with a 1 arc-second resolution (~30 m) (Farr et al., 2007; NASA SRTM., 2013). The slope data was derived from the elevation data. The soil data were obtained from SoilGrids with a 15–30 cm depth and a 250 m resolution (Hengl et al., 2017). All raster data layers were standardized in the same resolution (~1 km^2).

2.3. Reassessment of conservation status

The reassessment process began by analyzing the geographical range of *N. rigidifolia*'s habitat, specifically the area of occupancy (AOO) and extent of occurrence (EOO), using the Geospatial Conservation Assessment Tool (GeoCAT) site (Bachman et al., 2011). The AOO and EOO data were then used to reassess the conservation status of *N. rigidifolia* according to the IUCN Red List Categories and Criteria Version 3.1 (IUCN, 2012).

2.4. Species distribution model determination

The distribution model for *N. rigidifolia* was created using MaxEnt software version 3.4.4 (Phillips et al., 2021), which is a powerful tool for modeling species' distributions and environmental niches (Merow et al., 2013). The linear feature class was selected because of the limited occurrence records (Raes & ter Steege, 2007). The Jackknife test was used to evaluate the relative importance of predictors in the MaxEnt model. The MaxEnt settings were adjusted as follows: output cloglog, regulation multiplier 1, maximum number of background points 50, replicate 10^2, replicate run type bootstrap, random seed was selected, maximum iteration 500, convergence threshold 10^{-5}, and default prevalence 0.5. The model's performance was evaluated based on the mean of AUC value which ranges from 0.5 to 1. A model with an AUC value between 0.5 and 0.6 is considered failed, between 0.6 and 0.7 is poor, between 0.7 and 0.8 is fair, between 0.8 and 0.9 is good, and between 0.9 and 1 is excellent (Krzanowski & Hand, 2009).

2.5. Habitat suitability area determination

To predict the habitat suitability of *N. rigidifolia*, the map of average model prediction was reclassified into four categories: unsuitable ($\leq$0.10), lowly suitable (0.11–0.30), moderately suitable (0.31–0.70), and highly suitable ($\geq$0.71) (Choudhury et al., 2016; Qin et al., 2017; Yang et al., 2013). The priority areas for *N. rigidifolia* conservation were determined by intersecting the highly suitable areas, EOO value, and conservation areas.

3. Results

3.1. Population, habitat, and associated species of N. rigidifolia

During the fieldwork, *N. rigidifolia* was found solely in the Lae Pondom Protected Forest, Karo Regency. The population was small, consisting of less than three mature individuals, and located in two nearby areas. The species was observed climbing on *Pterophylla fraxinea* D.Don. and *Schima wallichii* (DC.) Korth trees in highland tropical forests at an elevation of 1700 to 1800 m asl (Fig. 2). The habitat of *N. rigidifolia* is located on rocky cliffs with a slope of 20–30 % and an aspect of 100–140°. This species was observed to grow naturally on soil humus with a depth of 10–20 cm and a litter thickness of 4–8 cm in soil with a

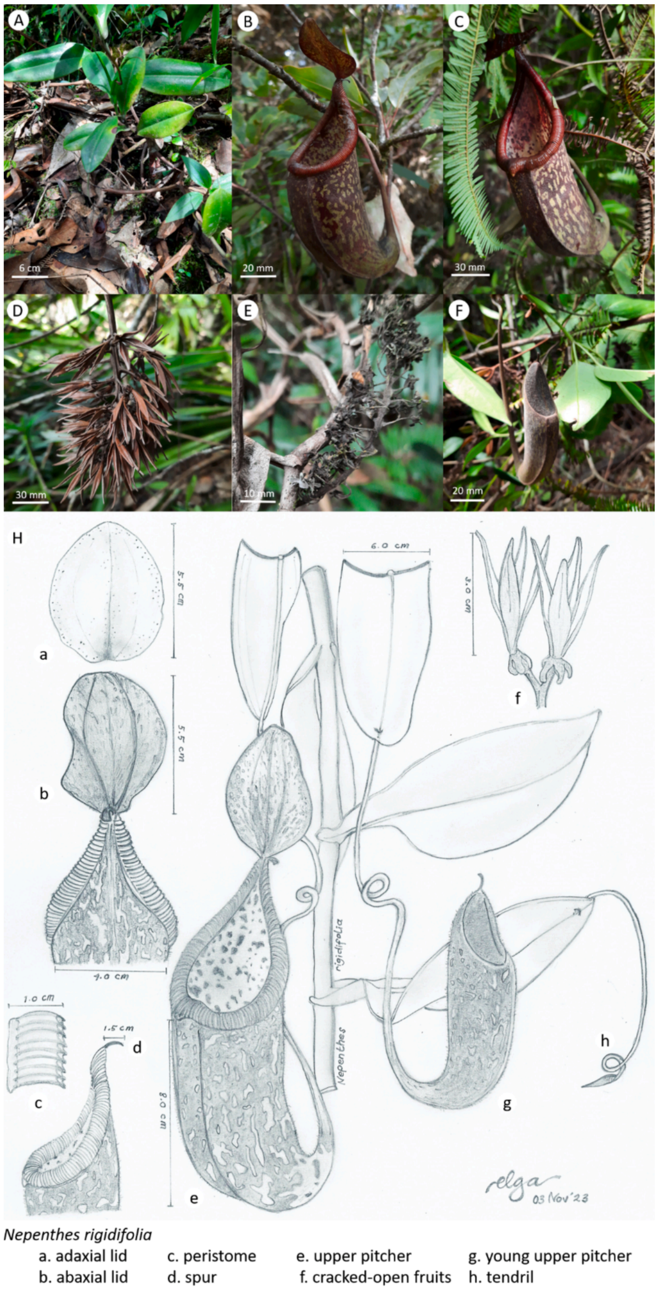

Fig. 3. Appearance of *Nepenthes rigidifolia*: (A) habitus; (B) upper pitcher on first location; (C) upper pitcher on second location; (D) fruits; (E) male inflorescence; (F) young pitcher; (H) illustration. Photographs and drawing by E. Renjana.

pH of 6–6.2. The microclimate conditions were relatively shady with a canopy coverage of 50–74 %, air temperature of 24–26 °C, and air humidity of 65–75 %. These ranges are consistent with the climate variables in North Sumatra, which have an annual air temperature range of 21.8–36.8 °C and an annual air humidity range of 37–100 % (Statistics of Sumatera Utara Province, 2023).

In this study, we observed that other *Nepenthes* species, namely *N. spectabilis* Denser and *N. tobaica* Denser, were also present around *N. rigidifolia*. Other plant species such as *Adinandra dumosa* Jack, *Alyxia reinwardtii* Blume, *Dacrycarpus imbricatus* (Blume) de Laub., *Cinnamomum sintoc* Blume, *Cryptocarya* sp., *Syzygium sumatranum* (Miq.) Widodo, *Vaccinium* sp., *Rhododendron* sp., *Pandanus* sp., and *Calamus exilis* Griff. were also observed. There were several fern species in the vicinity, including *Dicranopteris linearis* (Burm.f.) Underw., *Nephrolepis* sp., *Selaginella* sp., and the terrestrial orchid *Spathoglottis plicata* Blume.

3.2. Morphological characteristics of N. rigidifolia

During the fieldwork, we found the population of *N. rigidifolia* only with upper pitchers (Fig. 3). The stem of the upper part is green, cylindrical, over 5 m tall, and 0.8–1.1 cm in diameter, with internodes measuring 5.5–12 cm in length. The leaves on the upper part of the stem are thick and stiff, with coriaceous texture. They are sessile, ovate, or spathulate-oblong, and measure 15–16.8 cm in length and 6–6.8 cm in width. The leaves gradually taper towards the base and clap the stem. The midrib is sunken or flattened above, and there are 3–4 longitudinal veins on each side of the midrib, which are distinct above and rather distinct beneath. The apex is obtuse-acute. The tendril is 21–27 cm long and may or may not have a loop-like shape. The color of the tendril ranges from green to brownish-red. The upper pitchers have a broad ovoid and are covered in blackish-brown with greenish blotches, measuring 9.8–13 cm in height. The outer surface is covered by dense, short hairs. The glandular zone is slightly infundibular and expands to a broad ovoid shape in the middle, measuring 9–12 cm in diameter. The upper part of the pitcher is slightly ovoid and measures 7–12.7 cm in diameter. The wings are slightly reduced to ribs, measuring 9–12 cm in length and 0.1 cm in width without fringed hairs. The distance between the wings is 2–2.6 cm. The mouth of the pitcher expands outwards, measuring 6–5.2 cm in length and 2.5–4 cm in width. The peristome is brownish-red with 0.8–1.5 cm long side lobes and has a 1–1.7 cm long notch in front. The inner side of the peristome is incurved and the teeth measure 0.05 cm in length. The lid is ovate, measuring 2.5–4.5 cm in length and 1.9–3.7 cm in width, with a circular or slightly ovate nectar gland beneath. The outer side of the lid is blackish-brown with greenish blotches, while the inner side is greenish with reddish-brown blotches. The spur is unbranched, slightly curved, and is 0.5–0.6 cm long. Male flowers are in a raceme but not yet been fully characterized because they were already dry. Female flowers were not found. Fruits are capsules, cracked-open when ripe (not yet fully characterized because they were already cracked-open).

3.3. Geographical range of N. rigidifolia

The new AOO and EOO values of *N. rigidifolia* were around 12 km^2 and 4.17 km^2 respectively. These values have increased significantly compared to the previous analysis, namely AOO of 0.01 km^2 and EOO of 0.01 km^2 (Clarke, 2014), due to the addition of two new occurrence records obtained from this study. Consequently, this species now has two conservation status options, critically endangered (CR) and endangered (EN).

3.4. Distribution of N. rigidifolia

The habitat suitability model for *N. rigidifolia* has a mean AUC value of 0.936 ± 0.023 (Fig. 4A), indicating excellent predictability (Krzanowski & Hand, 2009). Elevation is the most important predictor, as demonstrated by the Jackknife test (Fig. 4) and relative contributions of variables (Table 1), compared to the other predictors in modeling the distribution map of *N. rigidifolia*.

According to the model output map (Fig. 5), the most suitable area for *N. rigidifolia* is estimated to be around Lake Toba, with an altitude range of 1241 to 2447 m asl. The total suitable area is approximately 364.18 km^2 (Table 2) located in several regencies, namely Asahan (6.85 km^2), Dairi (119.66 km^2), Humbang Hasundutan (9.26 km^2), Karo (52.09 km^2), Samosir (165.14 km^2), Simalungun (2.25 km^2), and Toba Samosir (8.93 km^2). The highly suitable area for *N. rigidifolia* is located outside the conservation areas. This increases the risk of extinction for this species.

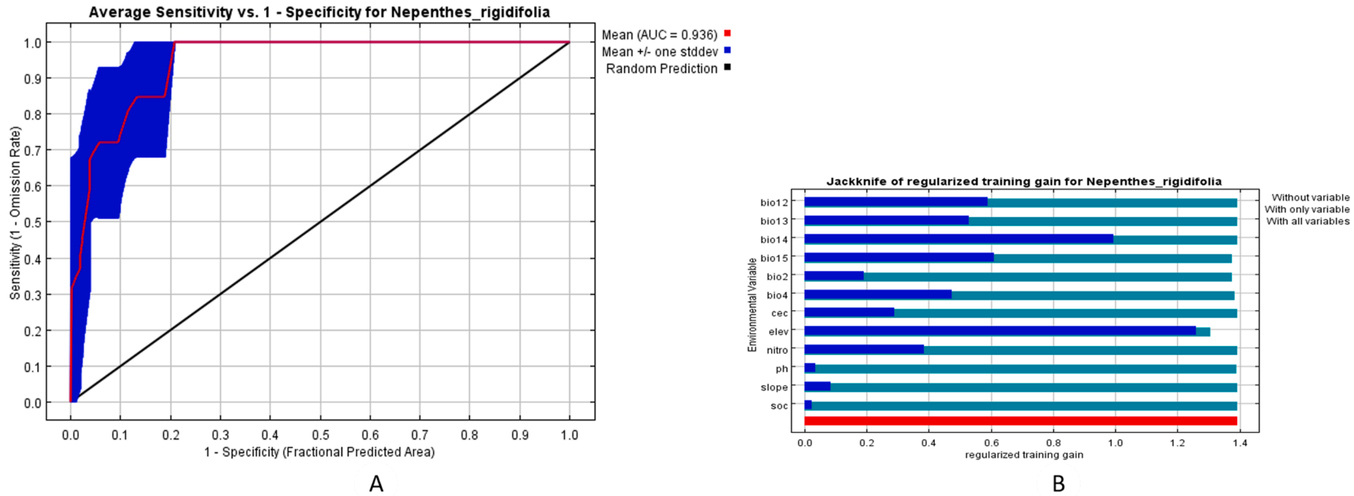

Fig. 4. The performance of habitat suitability model prediction of *Nepenthes rigidifolia* using MaxEnt: (A) the mean of AUC value; (B) the importance of bioclimatic variables based on Jackknife test. Remarks: bio2 = mean diurnal range, bio4 = temperature seasonality, bio12 = annual precipitation, bio = 13 precipitation of wettest month, bio14 = precipitation of driest month, bio15 = precipitation seasonality, cec = cation exchange capacity, elev = elevation, nitro = nitrogen content, soc = soil organic carbon.

Table 1
The variables used in MaxEnt and their contribution to the prediction of suitable habitat for *Nepenthes rigidifolia*. The contribution values presented are the average ± standard deviation over 100 replicate runs.

Variable	Description	% Contribution
bio2	Mean diurnal range (mean of monthly (max temp – min temp))	7.21 ± 18.55
bio4	Temperature seasonality (standard deviation × 100)	1.22 ± 1.75
bio12	Annual precipitation	0.08 ± 0.41
bio13	Precipitation of the wettest month	0.00 ± 0.00
bio14	Precipitation of the driest month	0.00 ± 0.00
bio15	Precipitation seasonality (coefficient of variation)	0.95 ± 0.73
elev	Elevation in meter	89.96 ± 20.62
slope	Slope in degrees	0.07 ± 0.18
cec	Cation exchange capacity (at pH 7) in mmol(c)/kg	0.00ˆ± 0.00ˆ
nitro	Nitrogen content in cg/kg	0.03 ± 0.13
ph	pH soil (pH*10)	0.48 ± 1.54
soc	Soil organic carbon	0.00 ± 0.00

ˆthe value is close to 0.

4. Discussion

4.1. Variation in N. rigidifolia

Our specimen is morphologically similar to the holotype and isotype of *N. rigidifolia*. We confirmed the species name of our specimen with the author of *N. rigidifolia*, Pitra Akhriadi. However, the spur in our specimen is unbranched, while it is branched (trifid) in the holotype and isotype. Nevertheless, *Nepenthes* species typically exhibit various spurs, as seen in *N. eustachya* (Jebb & Cheek, 1997), *N. longiptera* (Victoriano, 2021), and *N. parvula* (Wilson & Venter, 2016).

4.2. Threats to the existence of N. rigidifolia

The small population size of *N. rigidifolia* poses a threat to its natural habitats. This species is popular as an ornamental plant and expensive due to its uniqueness and rarity. It is important to take action to protect this species from further harm. However, the high enthusiasm of carnivorous plant lovers has led to an increase in illegal harvesting. According to local reports, *Nepenthes* spp. are still being targeted by many poachers in the forests of North Sumatra. Our source mentioned that in 2019, *N. rigidifolia* was also a target. During our fieldwork, it was observed that the plant saplings had been plucked. Since its habitat is a steep rocky cliff, the species' existence is further threatened by landslides. A landslide occurred in a nearby forest area during the study. This is particularly concerning as the species' habitats are located outside conservation areas.

Nepenthes rigidifolia is a perennial climber that typically grows to the tops of associated trees. This benefits the *N. rigidifolia* population by making it difficult for poachers to collect them. However, it can also render them more vulnerable to threats, as the plants are easily visible when growing on treetops, especially if the tree is located on the roadside. Aerial observation revealed that the habitat of *N. rigidifolia* is located relatively close to the main road connecting the regencies, approximately 5–50 m away (Fig. 2). As this main road is frequently congested with large vehicles, there is a possibility of road widening, which could threaten the forest areas on either side. As also mentioned by Cross et al. (2020), transportation and service corridors were identified as a threat to the sustainability of *N. rigidifolia*. Notably, anthropogenic land use has the greatest impact on biodiversity loss (Heikkinen et al., 2021).

4.3. Conservation status of N. rigidifolia

As per AOO and EOO values in this study, two conservation status options were identified for *N. rigidifolia*, critically endangered (CR) and endangered (EN). The AOO value increased to 12 km^2 with the addition of two new occurrence records from this study, resulting in a lower conservation status to EN. However, field observation revealed the population of this species to be very small, with less than three mature individuals, and facing a high risk of extinction due to illegal exploitation and forest conversion, thus, the CR option is more appropriate for this species. This suggests that *N. rigidifolia* will become extinct in the wild if conservation strategies are not implemented. Besides, new occurrence records indicate that populations of this species may exist in other locations, although not necessarily in large numbers. Therefore, we recommend that the new conservation status of *N. rigidifolia* is Critically Endangered A2ad + 3d; B1ab(iv,v); C2a(i,ii); D. We have excluded 2ab(iv,v) from the previous assessment's categorization (Critically Endangered A2ad + 3d; B1ab(iv,v) + 2ab(iv,v); C2a(i,ii); D (Clarke, 2014)) due to the AOO value exceeding 10 km^2.

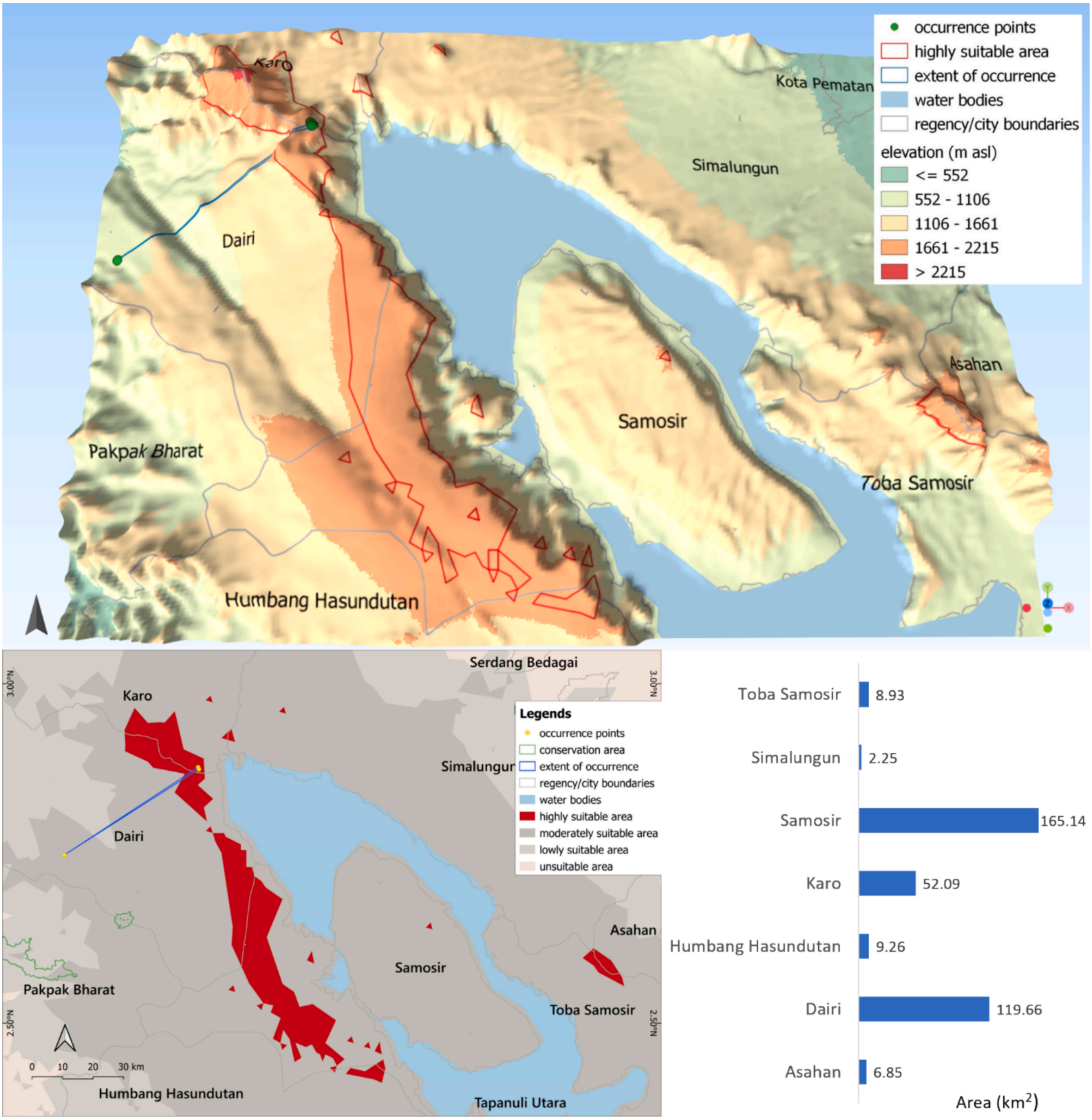

Fig. 5. Predicted distribution area of *N. rigidifolia* in North Sumatra Province.

4.4. Modeling the habitat distribution of *N. rigidifolia*

This study modeled the habitat suitability of *N. rigidifolia* using only three occurrence records. One of these was its first occurrence in 2003 (GBIF.org, 2023), while the other two were the new records obtained from this study. Despite the small sample size, MaxEnt can predict the potential distribution of rare species by applying the Jackknife test (Pearson et al., 2007). Our predicted model performs excellently with an AUC mean value of over 0.9 (Fig. 4A). It represents the habitat suitability of *N. rigidifolia* on a scale of 0 to 1, with areas scoring above 0.71 indicating high suitability for the species. These areas are primarily located in highland tropical forests around Lake Toba.

On the northern side of Lake Toba, *N. rigidifolia* is forecast to inhabit the forest areas of Mount Sibuatan (Karo Regency), Lae Pondom Protected Forest (Karo–Dairi Regencies) along the Sidikalang–Seribudolok route, Sipiso Piso Hill (Karo-Simalungun Regencies), and the forest area in Silimakuta District (Simalungun Regency). Mount Sibuatan and Lae Pondom Protected Forest are also home to *N. pectinata, N. spectabilis,* and *N. tobaica* (Mansur et al., 2022; Tarigan & Ritonga, 2020, 2021). Suitable areas on the western side of Lake Toba include the forest areas of Siadtaratas Hill, the Namartua Harangan Sihole hiking area (Dairi Regency), along the Dolok Sanggul–Sidikalang route (Dairi–Samosir Regencies), Mount Merapi Pusuk Buhit, the forest areas near Lake Sihaporas, Mount Ulu Darat Sakti, and Simangande Waterfall hiking area (Samosir Regency), as well as the forest area in Parsingguran II Village (Humbang Hasundutan Regency). On the eastern side of Lake

Table 2
The suitable area of *Nepenthes rigidifolia*.

Categories	Extent of occurrence area (km^2)	Inside conservation area (km^2)	Outside conservation area (km^2)	Total area (km^2)
Unsuitable	0.00	1285.80	39544.10	40829.90
Lowly suitable	0.29	1251.73	13770.59	15022.32
Moderately suitable	2.89	887.09	11501.32	12388.41
Highly suitable	0.97	0.00	364.18	364.18
Total area (km^2)	4.14	3424.63	65180.19	68604.82

Toba, *N. rigidifolia*'s presence is predicted in the Mount Dolok Simanukmanuk located in Asahan and Toba Samosir Regencies. The widest highly suitable areas of *N. rigidifolia* are found probably in Dairi and Samosir Regencies, covering 119.66 km^2 and 165.14 km^2 respectively. Several *Nepenthes* species including *N. pectinana, N. rhombicaulis, N. spectabilis,* and *N. tobaica* were found in Dairi Regency (Akhriadi et al., 2004; Mansur et al., 2022) while, *N. eustachya, N. gracilis,* and *N. tobaica* were found in Samosir Regency (Nainggolan et al., 2020; Sitorus et al., 2021).

The habitat distribution of *N. rigidifolia* was modeled using various predictors of bioclimate, topography, and soil. The model output revealed that elevation is the most important predictor of the probability of the species' presence (Fig. 4B), contributing 89.96 % (Table 1). A previous study on *N. rigidifolia* reported its occurrence in lower mountain forests at elevations of 1000 to 1500 m asl (Akhriadi et al., 2004). Meanwhile, this study revealed that *N. rigidifolia* inhabits highland forests at a higher elevation of 1700 to 1800 m asl. The predicted highly suitable areas range from 1241 to 2447 m asl, indicating an expansion of the potential elevation range for *N. rigidifolia* distribution.

4.5. Prioritizing area for N. rigidifolia conservation

Some *Nepenthes* online communities and enthusiasts provide information regarding *N. rigidifolia* although it requires scientific confirmation. Online carnivorous plant forums mentioned this species completed with its photographs notwithstanding that further identification is necessary. In addition, *Nepenthes* enthusiasts also informed that *N. rigidifolia* was probably located in several regions of North Sumatra, including Mount Sibuatan and Sipiso Piso Hill (Karo Regency), Delleng Simpon (Pakpak Bharat Regency), Dolok Sanggul (Humbang Hasundutan Regency), and Simalungun Regency. Unfortunately, this information has a lack of spatial data. Consequently, there are no additional occurrence records of *N. rigidifolia* employed for spatial analysis of its habitat distribution prediction. Furthermore, a study of *Nepenthes* diversity in seven regencies of North Sumatra carried out in 2019 was unable to locate this species (Mansur et al., 2022). Therefore, further field investigations are required to validate its occurrence in those areas.

The overlapping area between EOO and the highly suitable area is 0.94 km^2, specifically in Lae Pondom Protected Forest on the border of Karo and Dairi Regencies. Both occurrence records of *N. rigidifolia* from this study were found in this region. Therefore, we suggest that Lae Pondom Protected Forest be considered the priority conservation area for *N. rigidifolia*. In addition, the Lae Pondom Protected Forest is home to other *Nepenthes* species, namely *N. spectabilis* and *N. tobaica* (Mansur et al., 2022; Tarigan & Ritonga, 2020). Furthermore, there are approximately 363.24 km^2 comprising regions with high habitat suitability outside the EOO, which we recommend as secondary conservation areas for *N. rigidifolia*.

However, the Natural Resources Conservation Agency of North Sumatra Province, which is responsible for protecting rare animal and plant species, does not operate in those areas. Hence, monitoring activities for the *N. rigidifolia* population must be coordinated between the Natural Resources Conservation Agency and the authorities of those areas. In addition, those areas are easily accessible to local communities, making them vulnerable to *Nepenthes* harvesting. Illegal harvesting activity for commercial purposes is one of the main factors contributing to the decline of the *Nepenthes* population in North Sumatra (Mansur, 2013). It is important to educate local communities to increase their awareness of the need to preserve the *Nepenthes* population.

5. Conclusions

Additional occurrence records from this study contribute to determining the probable geographical range of *N. rigidifolia*. It is recommended that Lae Pondom Protected Forest in Karo Regency, North Sumatra, Indonesia, be prioritized as a conservation area for this species. The habitat suitability model predicts the maximum likelihood of occurrence for *N. rigidifolia* in mountain forests with an elevation of over 1200 m asl in seven regencies around Lake Toba, namely Asahan, Dairi, Humbang Hasundutan, Karo, Samosir, Simalungun, and Toba Samosir. The government must, on priority basis, establish conservation areas to arrest the decline of the *N. rigidifolia* population and promote its conservation.

Funding

This study was supported by the Mohamed bin Zayed Species Conservation Fund (MBZ Fund), UAE [grant number 222529482].

CRediT authorship contribution statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

We would like to thank H.H. General Sheikh Mohamed bin Zayed Al Nahyan (Chairman of the MBZ Fund), H.E. Razan Khalifa Al Mubarak (Managing Director of the MBZ Fund), and Nicolas Heard (Head of Fund Management of the MBZ Fund) for funding this study. We would like express our gratitude to the Director General of Conservation of Natural Resources and Ecosystems, Ministry of Environment and Forestry, Republic of Indonesia for granting us permission to access genetic resources and wildlife. We also extend our thanks to Harto (Directorate of Scientific Collections Management), Dendy Shine Simbolon, Reinhard D.M.T.S. Simarmata, Vivin Numiria, Tomson Berutu, Jungma Seven P. Sinaga, Demak P. Simangunsong (Environment and Forestry Service of North Sumatra Province), as well as local communities in Karo, Dairi, Pakpak Bharat, and Simalungun Regencies for their assistance and support during the fieldwork. Additionally, we extend our sincere gratitude to Pitra Akhriadi for his assistance in species validation as a *Nepenthes* expert and the author of *Nepenthes rigidifolia*. We would like to express our gratitude to the staff of Herbarium Bogoriense for granting us permission to access the isotype of *N. rigidifolia* and for their assistance in depositing our specimen.

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