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Journal of Threatened Taxa

Open Access

10.11609/jott.2022.14.1.20311-20538
www.threatenedtaxa.org

26 January 2022 (Online & Print)
14(1): 20311–20538
ISSN 0974-7907 (Online)
ISSN 0974-7893 (Print)

ISSN 0974-7907 (Online); ISSN 0974-7893 (Print)

Publisher
Wildlife Information Liaison Development Society
www.wild.zooreach.org

Host
Zoo Outreach Organization
www.zooreach.org

No. 12, Thiruvannamalai Nagar, Saravanampatti - Kalapatti Road, Saravanampatti,
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continued on the back inside cover

Caption: *Cyrtodactylus myintkyawthurai*, endemic to Myanmar. Medium: Water colours on watercolor sheet. © Aakanksha Komanduri

Journal of Threatened Taxa | www.threatenedtaxa.org | 26 January 2022 | 14(1): 20426–20432

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.6970.14.1.20426-20432

#6970 | Received 10 December 2020 | Final received 04 December 2021 | Finally accepted 12 January 2022

OPEN ACCESS

COMMUNICATION

Abundance and spatial distribution analyses of *Stemonoporus moonii* Thwaites (Dipterocarpaceae) - a critically endangered species endemic to Sri Lanka

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Abstract: Hora Wel *Stemonoporus moonii* Thwaites, a plant species endemic to Sri Lanka, is the central focus of this study. Because of its strictly narrow distribution area of fewer than 100 km^2 and declining habitat, coupled with a high risk of extinction, it is placed under the 'Critically Endangered' category in International Union for the Conservation of Nature Red List category. A field survey was conducted during February–March 2020 in Walawwe-Watta Wathurana freshwater swamp forest to assess the population status of this species. Global positioning system (GPS) coordinates of individuals were documented. The root collar diameter of plants was measured to differentiate adults. Population size analysis was performed using GeoCAT online software, and a distribution map was prepared using Quantum GIS (QGIS 3). A total of 600 plants were recorded, with 50% each adult (root collar diameter more than 2.0 cm) and young individuals (root collar diameter equal to or less than 2.0 cm). The extent of occurrence (EOO) and area of occupancy (AOO) of *S. moonii* were calculated as 0.06 km^2 and 4.000 km^2, respectively. Two subpopulations of *S. moonii* can be seen within the Walawwe-Watta Wathurana Environmental Protection Area. The findings of the present study support the current IUCN Red List status of *S. moonii* as Critically Endangered. Even though the existing populations of this species located within a protected area and not presently exposed to major threats, the location is easily accessible and can potentially be affected by anthropogenic pressures and habitat loss. Therefore, this species and the habitat warrant suitable in situ conservation measures. .

Keywords: AOO (Area of occupancy), Critically Endangered, EOO (Extent of occurrence), GeoCAT, Hora Wel, IUCN Red List, narrow endemic, QGIS, threat of extinction, Wathurana swamp forest.

Editor: Vijayasankar Raman, The University of Mississippi, USA.

Date of publication: 26 January 2022 (online & print)

Citation: Atapattu, K.A.M.R.P., H.D.D.C.K. Perera, H.S. Kathriarachchi & A.R. Gunawardena (2022). Abundance and spatial distribution analyses of *Stemonoporus moonii* Thwaites (Dipterocarpaceae) - a critically endangered species endemic to Sri Lanka. *Journal of Threatened Taxa* 14(1): 20426–20432. https://doi.org/10.11609/jott.6970.14.1.20426-20432

Funding: None.

Competing interests: The authors declare no competing interests.

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Author contributions: K.A.M.R.P. Atapattu, H.D.D.C.K. Perera—manuscript writing, field data gathering. H.S.Kathriarachchi—supervising, proof reading A.R.Gunawardena—map preparation.

Acknowledgements: We acknowledge Mr. Rukman Bandara, and Mr. D.P. Kumara for their support.

INTRODUCTION

Sri Lanka is a tropical island with a total land area of 65,610 km^2 situated in the Indian Ocean. Despite its small size, it has rich ecosystem diversity due to its topography, climatic heterogeneity, and coastal influence (Gunatilleke et al. 2008). It harbors more than 4,100 species of flowering plants, with one-fourth being endemic to the island (Gunatilleke et al. 2008). The southwestern region is the only seasonal ever-wet region in southern Asia, harboring particularly high biodiversity with a high concentration of endemic species. Along with the Western Ghats of India, Sri Lanka is one of the 36 global biodiversity hotspots, and was identified among the eight most significant areas ("hottest hotspots") with a high endemic/area ratio for both vertebrates and plants (Myers et al. 2000).

Walawwe-Watta Wathurana Swamp Forest (WWWSF) is the only freshwater swamp forest in Sri Lanka (CEA 1994; Jayasuriya et al. 2006). Freshwater swamps are described as "nature's kidneys" because they have been found to protect shorelines, prevent floods, clean polluted water and recharge groundwater (CEA 1994). The WWWSF harbors an endemic plant species *Stemonoporus moonii* Thwaites (Kostermans 1992; CEA 1994; Jayasuriya et al. 2006) that was believed to be extinct in the wild until it was rediscovered in 1979 after a lapse of 160 years (Kostermans 1992; CEA 1994). *Stemonoporus moonii* is a small, slender tree with a similar appearance to a climber (Image 1A), hence it is locally known as 'Hora Wel' or 'Berumandoru'. It can be distinguished by the long, slender, persistent stipules on the apical branches, crowded leaves, prominent secondary veins and distinct leaf scars (Image 1B) (Rubasingha et al. 2008). The flowers appear singly or in clusters; the corolla is white, with red longitudinal bands on the abaxial side (Image 1C) (Kostermans 1992).

Stemonoporus Thwaites is the most species-rich (27 species) endemic genus of the family Dipterocarpaceae in Sri Lanka. Almost all species of *Stemonoporus* are categorized as either Endangered or Critically Endangered in the IUCN Red Data Book (Rubasinghe et al. 2008). They are mainly confined to the wet zone and have a well-defined habitat and geographical and ecological range (Dassanayake & Fosberg 1980). The degradation and fragmentation of natural habitats have had adverse effects on the regeneration and distribution of these threatened species (Ediriweera 2004). *Stemonoporus moonii* is confined to WWWSF in Sri Lanka. Many studies suggest that narrow endemic species are susceptible to extinction and that these extinction-prone species grow naturally in a narrow geographical area (Kani 2011). For this reason, narrow endemic species are the first to experience the adverse effects of habitat destruction, fragmentation or alteration.

Stemonoporus moonii was assessed as 'Critically Endangered' in the 1998 IUCN Red List of Threatened Species (Ashton 1998). According to the IUCN (2012), the purpose of categorization of species is to create a relative estimate of the likelihood of extinction of the taxon, where the Red List Criteria should be applied to a taxon based on the available evidence such as several individuals, trends, and distribution (Haciogullari et al. 2019). A taxon is categorized as Critically Endangered when the best available evidence indicates that it meets any of the criteria A to E and therefore it is considered to be facing an extremely high risk of extinction (IUCN 2019). The Red List current assessment lists *S. moonii* as Critically Endangered B1ab(i,ii,iii)+2ab(i,ii,iii). The justification for this categorization is related to its extremely restricted distribution. Both the Extent of occurrence (EOO) and Area of occupancy (AOO) of *S. moonii* estimated to be less than 10 km^2 (MOE 2012).

As per IUCN rules, if an assessment is more than 10 years old, it has to be reassessed. The IUCN category of particular taxa can be changed due to 'genuine' or 'non-genuine' reasons (IUCN 2019). Therefore to assess the status of biodiversity, it is vital to reassess the species periodically. However, no recent published data regarding the current distribution, population size, and threats of *S. moonii* exist. In this study, the current distribution area and population size of *S. moonii* were determined based on comprehensive and up-to-date assessments.

METHODS

Study site

The Walawwe-Watta Wathurana Freshwater Swamp Forest is located in the Kalu Ganga river basin and spread over to 12 ha in the southwestern part of Sri Lanka. It is located on the private land in Bulathsinhala of Damparadugoda, 25 km inland from Kaluthara District in Western Province, and presently managed by the Walawwe-Watta Plantation Company (Image 2). This forest patch is surrounded by Bulathsinhala and Atura in the north-west, Galketiya in the east, and Pahalawelgama in the west. This land is accessible from the Horana-Kalawellawa road through Pahalawelgama and from the Bulathsinhala-Paragoda road. This site is situated along a stream locally known as 'Batapotte ela', which originates

Image 1. Exomorphic features of *Stemonoporus moonii*: A—Mature plants | B—New foliage | C—Flower | D—New branchlet. © H.D.D.C.K. Perera.

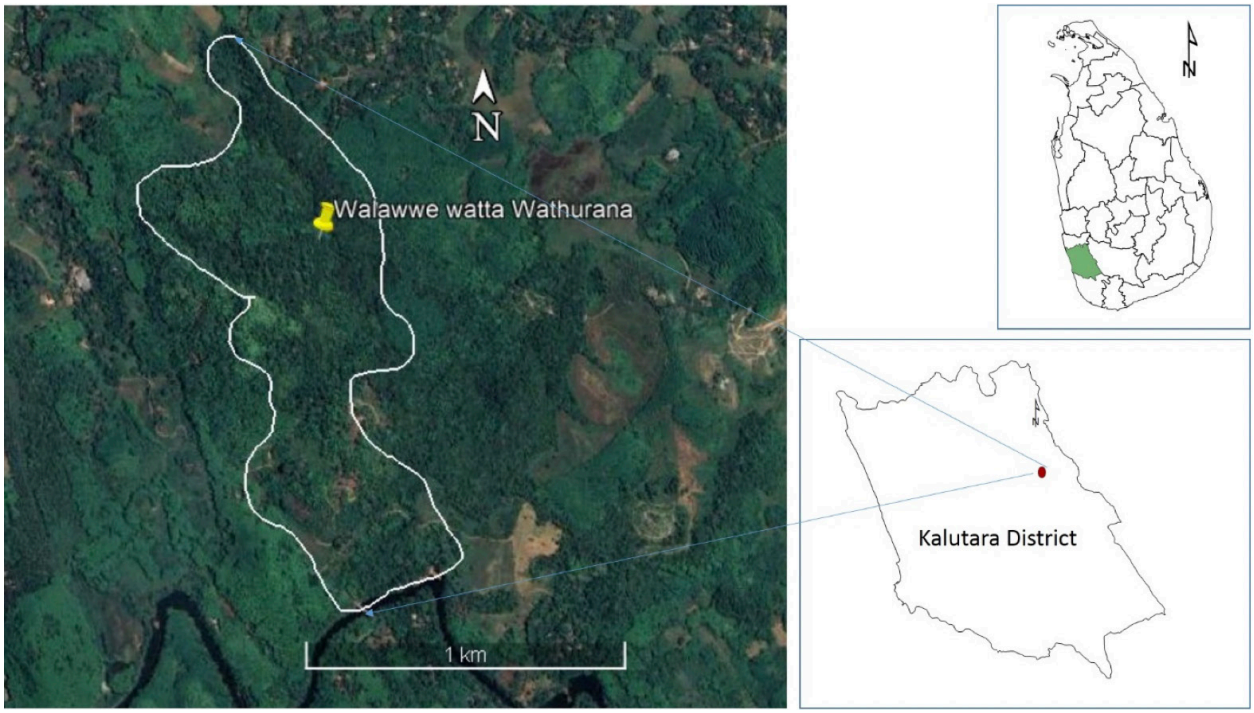

Image 2. The study site in Walawwe-Watta Wathurana Swamp Forest.

at Yatagampitiya and feeds a tributary of the Kalu Ganga. This forest area experiences seasonal flooding twice a year, generally from July to September, and is inundated with up to 3–4 m of water for 1–2 months. The mean annual rainfall of the area lies between 4,000–5,000 mm, and the annual temperature is recorded as 27°C. This area receives rainfall mainly from the south-west monsoon from May to July and the north-east monsoon from October to December (Ashton et al. 2001).

Field surveys

Field surveys were conducted during February–March 2020, and distance sampling methods were used during field surveys. Distance sampling is a widely used technique for estimating the size of a population. For this study the point transect method was used, as it is most appropriate to the rugged and difficult terrain of the site (Haciogullari et al. 2019). In the point transect method, an observer visits randomly-selected points and surveys the species present within a predetermined zone (5 m radius in this study). GPS locations of all individuals in the point

transects were recorded, and root collar diameter was measured. Mature (root collar diameter more than 2.0 cm) and immature (root collar diameter equal to or less than 2.0 cm) individuals were counted to determine the population size. Additionally, special features such as the presence of flowers, buds, or fruits, whether the plant is dead or dead branches are present, and potential threats were recorded.

Abundance and Spatial Distribution Analyses

The distribution of *S. moonii* was analyzed using QGIS 3 (Quantum GIS) software from the obtained locality data. QGIS is an open-source geographic information system. Google satellite image of the study area was overlaid with available locality data of *S. moonii*. GeoCAT online software was used to calculate the AOO and the EOO; this open-source application can perform rapid geospatial analysis for the Red List assessment. EOO was measured using the quickhull method. AOO was calculated by summation of the area of square grids the species occupies (Bachman et al. 2011). For calculating AOO, a 2 km^2 cell size was used, as recommended in the IUCN guidelines (IUCN 2019).

RESULTS

Abundance and Spatial Distribution

Walawwe-Watta Wathurana swamp forest was surveyed for the occurrence and abundance of *S. moonii*. Ten years ago, a few individuals of the species were recorded from the area known as Honaka mountain (H.D.D.C.K. Perera, pers. comm., 22 March 2020). However, in the present study, individuals were recorded only from the WWWSF. Individuals were recorded from the seasonally inundated lands in the forest. In total, 600 individual plants were recorded, including 297 (49.5%) mature and 303 (50.5%) immature individuals (Figure 1). Observations were made at the end of the flowering season (January–March), and only one plant was recorded with flowers and eight plants with flower buds. In the study area, *S. moonii* was commonly associated with the other dominant species, including *Garcinia hermonii* Kosterm., *Dipterocarpus hispidus* Thwaites, *Cullenia rosayroana* Kosterm., *Durio zeylanicus* Auct., *Humboldtia laurifolia* Vahl, *Quassia indica* (Gaertn.) Noot., *Macaranga digyna* (Wight) Müll.Arg., *Ochlandra stridula* Thwaites, and *Calamus* species. No seedlings of *S. moonii* were observed during the study. Of the 600 individuals, six plants were found dead, one dying, and seven others had dried branches. The individuals were mainly found in two major clusters (1 and 2); 169 in cluster-1 and 431 in cluster-2. Some of the individuals in cluster-2 were located at the riverbank of Kudu Ganga (Image 3). The EOO and AOO of *S. moonii* were calculated at 0.057 km^2 and AOO 4.000 km^2, respectively.

Potential threats

Although the population is presently not exposed to threats and is still balanced under natural conditions, it could be threatened by various anthropogenic activities. Possible threats are listed below.

- Wetlands help maintain freshwater flows within river systems and act as a sponge. The changing land-use patterns and illegal tree felling can lead to flooding in the area and could cause significant detrimental effects on the survival of this species.
- Even though Wathurana swamp forest is a protected area, it is easily accessible to nearby villagers who can potentially extract plant parts, collect fuel woods, edible fruits, medicinal plants, poles for agricultural purposes, and timber. The villagers use poles of *S. moonii* to make trellises for beetle vines.
- Due to the modern agricultural practices carried out in the nearby area, the use of chemical fertilizers has increased drastically. Illegal fishing using dynamites is practiced in Batapotte ela stream. Most of these chemicals flow along the water streams of the area, and excess of them tend to deposit in the soil. This may alter the soil composition of the area, which could further impact *S. moonii* population.
- People in the vicinity have already altered parts of Wathurana Wetlands to construct new buildings and establish rubber plantations. Such clearing of Wathurana swamp forest areas for agricultural and developmental purposes may directly affect biodiversity.
- The soil in this forest area contains high proportions of clay, and mining clay deposits in the area may drastically alter the forest's ecological functions.
- The forest clearing and changing land-use patterns in the study area could potentially affect the groundwater table and eventually threaten the existence of the habitat and survival of its flora.

Reassessment of conservation status

As per the National Red List 2012 of Sri Lanka (MOE 2012), *S. moonii* was assessed as Critically Endangered based on the criteria B1ab(i,ii,iii)+2ab(i,ii,iii). Based on the newly-available locality data, an up-to-date conservation status can be assessed to determine whether the current conservation status is still valid or if some degree of modification is required. The AOO and EOO calculated in this study confirm the Critically Endangered status of

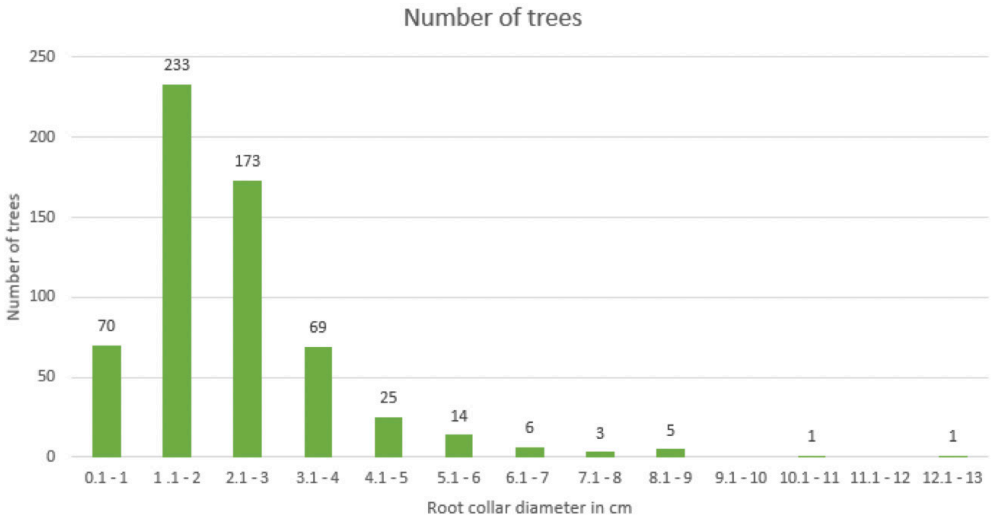

Figure 1. Root Collar Diameter class distribution of individuals of *Stemonoporus moonii* in the Wathurana swamp forest.

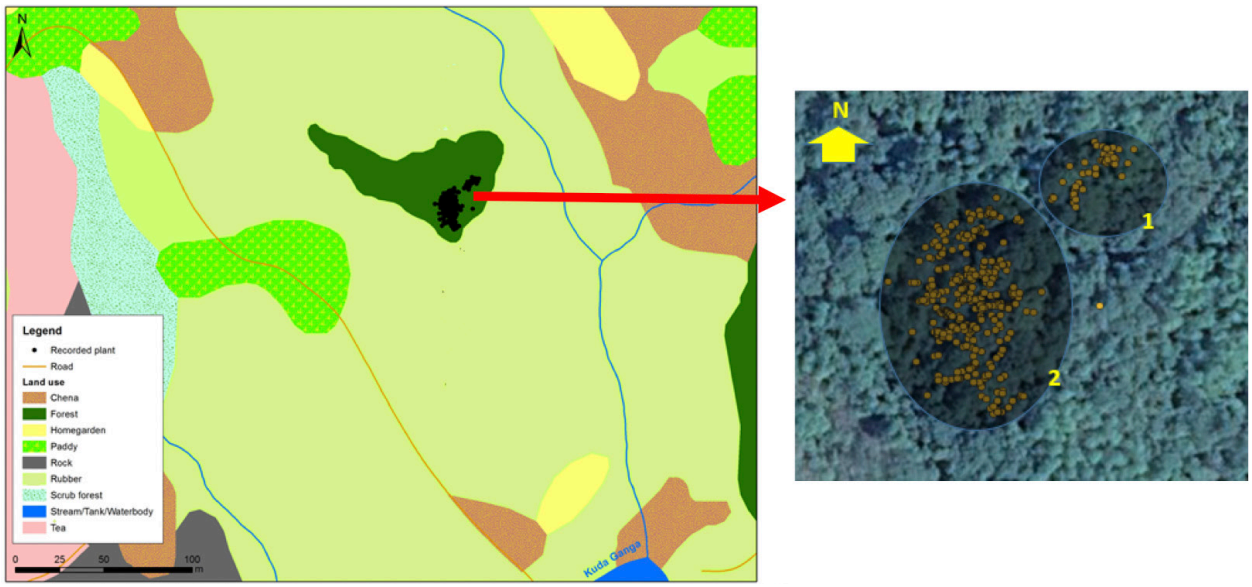

Image 3. Distribution map of *Stemonoporus moonii*

S. moonii due to its restricted distribution and habitat loss. As a narrow endemic species, *S. moonii* is strictly confined to the study area, therefore, has a great chance of being extinct in the wild. Currently, it is assessed as B1, which means its EOO is less than 100 km^2. The calculated EOO value is 0.057 km^2. Therefore, it can be placed in the same category as the current assessment but could also fall under criteria B2 as the AOO is 4 km^2, below the 10 km^2 threshold. Moving to the next step of the assessment, at least two of the three listed sub-criteria, a, b and c, are to be met. According to the current assessment, it is assessed as ab(i, ii, iii), which means (a) severely fragmented or present in only one location and (b) continuous decline observed, estimated, inferred or projected in (i) extent of occurrence (ii) area of occupancy (iii) area, extent and/or quality of habitat. The survey results suggest that criterion (a) could still be relevant, because it is located in only one location.

In this study, two subpopulations of the species were observed within the protected area with a population density of 9,670 plants/km^2 (600 plants/0.062045 km^2). The distance between the two subpopulations was approximately 15 m. The soil types observed in the study area are bog and half bog exhibiting poor drainage compared to the small hillocks. This soil is oxygen and nutrient-poor, and acidic. The seedlings of *S. moonii* have

to thrive in such environmental conditions, and these plants prefer seasonally inundated lands in the forest. Also, a strong case could be argued for the inclusion under the b(i,ii,iii) category, where declines can be seen in EOO, AOO, and habitat quality. However, the category c(i,ii,iii,iv) could not be included due to the absence of historical data. Moreover, based on the obtained results, the ratio between immature and mature individuals remains nearly 1:1. Therefore the decline in the number of mature individuals could not be observed. With this new information, the present reassessment supports retaining the current Critically Endangered status of *S. moonii*.

DISCUSSION

One of the main objectives for this study was to assess the population status of *S. moonii*. Due to its small population size and narrow distribution in Sri Lanka, this has become a threatened species. However, no study has so far been carried out to assess the population size of *S. moonii*, except for the IUCN Red List evaluation (Ashton 1998). The results of the present study reiterate the Critically Endangered status of this species. Due to the absence of historical records, it is impossible to assess if the population experienced any extreme fluctuations. In this study, the root collar diameter of each individual was measured to find out the proportion of mature and immature individuals. Root collar diameter was the only attainable data from the species because even though it is a tree, it grows like a liana in natural conditions. Hence it is not feasible to measure DBH (Diameter at breast height). Population count proves that the species has no issues with reproduction. The presence of young individuals indicates that seed germination is not an issue, and because of that already balanced population size could be maintained. The equal percentage of mature and young individuals shows that species fecundity is not an issue.

During the survey, no extension or alteration in the flowering period was observed. Usually, plants tend to match their developmental transitions with the best time of year for growth and reproduction to maintain high fitness (Blackman 2017). Flowering time is associated with processes that play a key role in eco-evolutionary dynamics (Franks 2015).

In the study area, *S. moonii* is commonly associated with other species, including *Garcinia hermonii* Kosterm., *Dipterocarpus hispidus* Thwaites, *Cullenia rosayroana* Kosterm., *Durio zeylanicus* Auct., *Humboldtia laurifolia* Vahl, *Quassia indica* (Gaertn.) Noot., *Macaranga digyna* (Wight) Müll.Arg., *Ochlandra stridula* Thwaites, and *Calamus* species. In long-lived mixed-species perennial communities, inter-species interactions are more complex. All species share a common environment that interacts with each other, thereby resource competition is high. However, *S. moonii* was distributed well throughout their habitat. Resource allocation strategies prioritize the persistence of a species, allowing them to persist for a long period in their habitat below their maximum size (Dillon et al. 2019).

The present study reveals that *S. moonii* is still strictly confined to WWWSF probably due to the unique environmental conditions of the area. Freshwater swamps particularly grow on fertile alluvial soils, open to river flooding, and generally have intercommunicating streams with well-mineralized water (Penfound 1952; Aselmann & Crutzen 1989; CEA 1994; Mitsch & Gosselink 2000; Gupta et al. 2006). Almost all the individuals of *S. moonii* were recorded from WWWSF and none of them were recorded from any nearby area. Based on these observations it is clear that *S. moonii* has not extended its geographical region and that it prefers a unique habitat.

Although the different natural and anthropogenic circumstances and processes that promote the loss of species in the area do not cause direct pressure on *S. moonii* it has a great chance of being extinct from the wild due to its extremely restricted distribution range. People who are involved in cultivating betel (*Piper betel*), extract these plants as poles to provide the support needed by the betel. Expansion of the agricultural lands and rubber plantations in the nearby area may severely affect their population size. Other than that, a great effect can be caused by the use of chemical fertilizers. Out of the total count, chemical fertilizers are used by 86.67% of farmers in the area and they have been using them for more than ten years (Siriwardana & Sangasuman 2018). These chemicals easily wash out and get into water streams in the area. During the flooding season, these chemicals can be deposited on forest lands. *S. moonii* shows unique features in their distribution only by preferring inundated but most upper margins of the area. Without any doubt, by studying their distribution pattern, it could be said that soil composition and the soil structure cause a great influence on their distribution. If people in the vicinity use these kinds of harmful fertilizers regularly, there is a great chance of altering their distribution, population size, and germination patterns. Many parts of Asia tend to change flow regimes in running waters and consequently impact habitats and species that are sensitive to floods and droughts due to climate change (IPCC 2014). Moreover, the same report on climate change prepared by the Intergovernmental Panel on climate change reveals that

habitats that depend on seasonal inundation, such as flood plain grasslands and freshwater swamp forests, will be particularly vulnerable (IPCC 2014). Many freshwater habitats are similarly isolated and their restricted-range species may be equally vulnerable.

Due to the impending threats, highly restricted distribution and poor awareness among the local public, urgent measures are required to protect this species. Further studies involving ecological assessment of *S. moonii* covering its population trends, demography, reproductive biology, and population genetics are needed to be carried out. Even though this species is distributed inside the protected area, it is necessary to establish focused in situ and ex situ conservation and management programs. Creating awareness among the general public and the relevant authorities is crucial to curtail unintentional damage to the species and its fragile habitat, and to ensure effective and successful conservation of this unique and highly threatened species.

CONCLUSION

Analysis of population data collected during the present study supports the existing 'Critically Endangered' status of *S. moonii*. Maintaining a proper ratio between mature and immature individuals under natural conditions reveals that species fecundity is not an issue. Distribution patterns of *S. moonii* show that they prefer seasonally inundating but most upper margins of the forest. Even though *S. moonii* does not suffer directly from the threats in its natural habitat, it has a great chance of being extinct from the wild because of its narrow distribution. Therefore, suitable conservation measures are urgently needed to protect the populations and habitats of *Stemonoporus moonii*.

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Journal of Threatened Taxa is indexed/abstracted in Bibliography of Systematic Mycology, Biological Abstracts, BIOSIS Previews, CAB Abstracts, EBSCO, Google Scholar, Index Copernicus, Index Fungorum, JournalSeek, National Academy of Agricultural Sciences, NewJour, OCLC WorldCat, SCOPUS, Stanford University Libraries, Virtual Library of Biology, Zoological Records.

NAAS rating (India) 5.64

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Saravanampatti, Coimbatore, Tamil Nadu 641035, India
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Journal of Threatened Taxa

www.threatenedtaxa.org

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

January 2022 | Vol. 14 | No. 1 | Pages: 20311–20538
Date of Publication: 26 January 2022 (Online & Print)
DOI: 10.11609/jott.2022.14.1.20311-20538

Publisher & Host

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