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COMMUNICATION

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Abstract: *Corynandra viscosa* subsp. *nagarjunakondensis* (Cleomaceae), a flowering plant taxon endemic to Nagarjuna of Krishna River Valley, Andhra Pradesh, southern India was assessed for its ecological status. The distribution of this species was mapped, population estimated and the impending threats ascertained. The extent of its area of spread is primarily limited by the water body (Nagarjunasagar) created by the impounding waters when a dam was constructed across the River Krishna at the site of its occurrence. The extent of occurrence (EOO) and the area of occupancy (AOO) of this taxon were estimated to be 0.20 km² and 0.31 km², respectively. The threat assessment places the taxon in the Critically Endangered [B1ab(iii)] category.

Keywords: Ecological impact of dam, endemism, threat assessment.

Telugu Abstract: వామింట కుటుంబానికి (Cleomaceae) చెందిన పుష్పించే మొక్క కొరి నేండ్ల విస్తాసా ఉపజాతి నాగార్జునకొండ డెన్సిసిస్ (*Corynandra viscosa* subsp. *nagarjunakondensis*) ను దక్షిణ భారతదేశ రాష్ట్రమైన ఆంధ్రప్రదేశ్ లోని కృష్ణానది పరివాహక ప్రాంతములో నాగార్జునకొండ వద్ద గుర్తించి వర్ణించడం జరిగినది. ప్రపంచంలో ఈ ప్రాంతానికి పరిమితమైన ఈ ఉపజాతి మొక్క యొక్క విస్తరణ, వ్యాప్తి, లభ్యత, పర్యావరణ సంబంధమైన స్థితిని పరిశోధించడం జరిగినది మరియు ఆసన్నమయ్యే ప్రమాదాలను కుడా గుర్తించడం జరిగినది. కృష్ణానదిపై ఆనకట్ట కట్టడం ద్వారా నిల్వ అయిన నీరు నాగార్జునకొండ ద్వీపం ఏర్పడడానికి కారణమైనందున ఈ ఉపజాతి మొక్కల యొక్క వ్యాప్తి నాగార్జునకొండకు మాత్రమే పరిమితమైనవి. ఈ వర్గం మొక్క యొక్క విస్తృతి (EOO) మరియు విస్తీర్ణ ఉపస్థితి (AOO) ను 0.2 చ.కి.మీ మరియు 0.31 చ.కి.మీ గా గణించడం జరిగినది. ఈ మొక్కల యొక్క లభ్యత, విస్తృతిపై ఆసన్నమయ్యే ప్రమాదాలను అధ్యయనం చేయగా ఈ వర్గం మొక్కలు సమీపకంగా త్వరగా అంతరించిపోయే (Critically Endangered (B1ab(iii))) ప్రమాద స్థితిలో ఉన్నట్లుగా గుర్తించడమైనది. నాగార్జునకొండ ప్రముఖ పర్యాటక స్థలంగా ఆభివృద్ధి చెందుతున్న దృష్ట్యా ఆంధ్రప్రదేశ్ రాష్ట్రం ఈ ఉపజాతి మొక్కలను పరిరక్షించడానికి తగు తక్షణ చర్యలు తీసుకోవలసివుంది.

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Author Contribution: VHR did the field work and IUCN assessment, VVR is overall in-charge of the work and responsible for the pest report, ABR did the herbarium work, and VSR contributed to the taxonomic assessment.

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INTRODUCTION

The concept of endemism is useful in quantifying the biological uniqueness of an area (Peterson & Watson 1998). High endemism usually occurs in areas that have been isolated for a long time, such as islands or isolated forest fragments. Islands are known centers of range-restricted species and show high levels of endemism (Whittaker & Fernández-Palacios 2007). Furthermore, islands are centers of past as well as imminent species extinction (Ricketts et al. 2005). Of late, many species globally have attained endangered category as assessed by the IUCN. If the present trend of intensive human activity continues, it is likely that many more species on our planet will either fall under this category or simply disappear. Preventing these extinctions must be part of a global strategy to reduce biodiversity loss (Ricketts et al. 2005). With so many species at risk of extinction in the near future, efforts to conserve plant biodiversity has to be on a priority basis and through site-specific action. Unfortunately, the efforts are undermined in many a country by lack of comprehensive inventories on one hand and the political will on the other. In India, many species which are endemic or alleged to be endemic from recent discoveries and descriptions, need to be assessed for their threat status.

Sundararaghavan (1988) described *Cleome viscosa* var. *nagarjunakondensis* based on the collection made by K. Thothathri on 13 July 1961 from Nagarjunakonda Hills, Guntur District, Andhra Pradesh, India. Pullaiah et al. (2000: 55) provided an account of this taxon citing Sundararaghavan (1993: 318), which was a reproduction of the 'protologue'. In both these accounts, the taxon was stated to be endemic. Rao et al. (2001) did not report this taxon from Nalgonda District, Telangana. But it is curious to note that Pullaiah & Rao (2002), in their account of Cleomaceae for Eastern Ghats of India, have not included this taxon despite the fact that the type locality falls under Eastern Ghat Hill Ranges while they cited the specimens of Capparaceae (e.g., *Capparis sepiaria* from Nagarjunakonda, another collection of K. Thothathri 9727 [CAL] cf. p.70) from the same habitat. Pullaiah (2015: 70), however, records this taxon for Telangana State even though its extant populations are found on Nagarjunakonda Island, which is no longer the territory under Telangana State with effect from June 2014. There was no further collection or specific study conducted since its description. Therefore, the present study attempts to provide a detailed description of *Cleome viscosa* var. *nagarjunakondensis* based on

the live specimens, map the distribution, estimate the population, and ascertain the threats.

Taxonomic status

Cleome viscosa var. *nagarjunakondensis* Sundararagh. is considered a synonym of *Cleome viscosa* L. by www.plantlist.org, which generally deals with species taxonomy and not below its rank and does not update the accepted names instantly/regularly (last update 2012-03-23); however, the experts on the genus *Cleome* (Cochrane & Iltis 2014) consider it not only as an accepted taxon under *Corynandra* but as a subspecies with which we agree and assess its status accordingly.

The study area

The Nagarjunakonda is a historic Buddhist Village, located at 16.516°N and 79.233°E in a perimeter of 4.31km² in the Krishna River valley in Guntur District of Andhra Pradesh, India. The valley went under water when a tall masonry dam was built across the river Krishna in the 1960s (Image 1 A–C). The reservoir, so-named Nagarjunasagar, has created the island Nagarjunakonda. It is now a tourist spot known for the historic Buddhist town. It is one of India's richest Buddhist sites known in ancient times as Sri Parvata (Barua 2016). The island receives rainfall that ranges from 381–508 mm per annum which is relatively low. The temperature goes up to 49°C during summer (May–June) though the annual temperature ranges from 21–48°C. The soil is of red-gravel with intermingled patches of black soil, particularly restricted to the limestone belt. The vegetation on the flat terrain comprises largely of herbs, shrubs and open canopy trees (Image 1 D). There are exotic trees planted around the archeological buildings in the visitor's zone.

METHODS

Field trips were undertaken regularly during 2012 to 2014 to record the floral component during the pre- and post-monsoon seasons. All elevations, habitats and vegetation types of Nagarjunakonda were mapped. After knowing the terrain, the study area was divided into 100×100 m grids. Four quadrats were selected at random from each grid. The quadrat size used was 1×1m for herbs and grasses. The relevant field data about the habitat, altitude, habit and phenology of the plant species fallen into the quadrats were recorded. The plant species were identified using the Flora of Guntur District (Pullaiah et al. 2000).

For the threat assessment under Criterion B, GeoCAT,

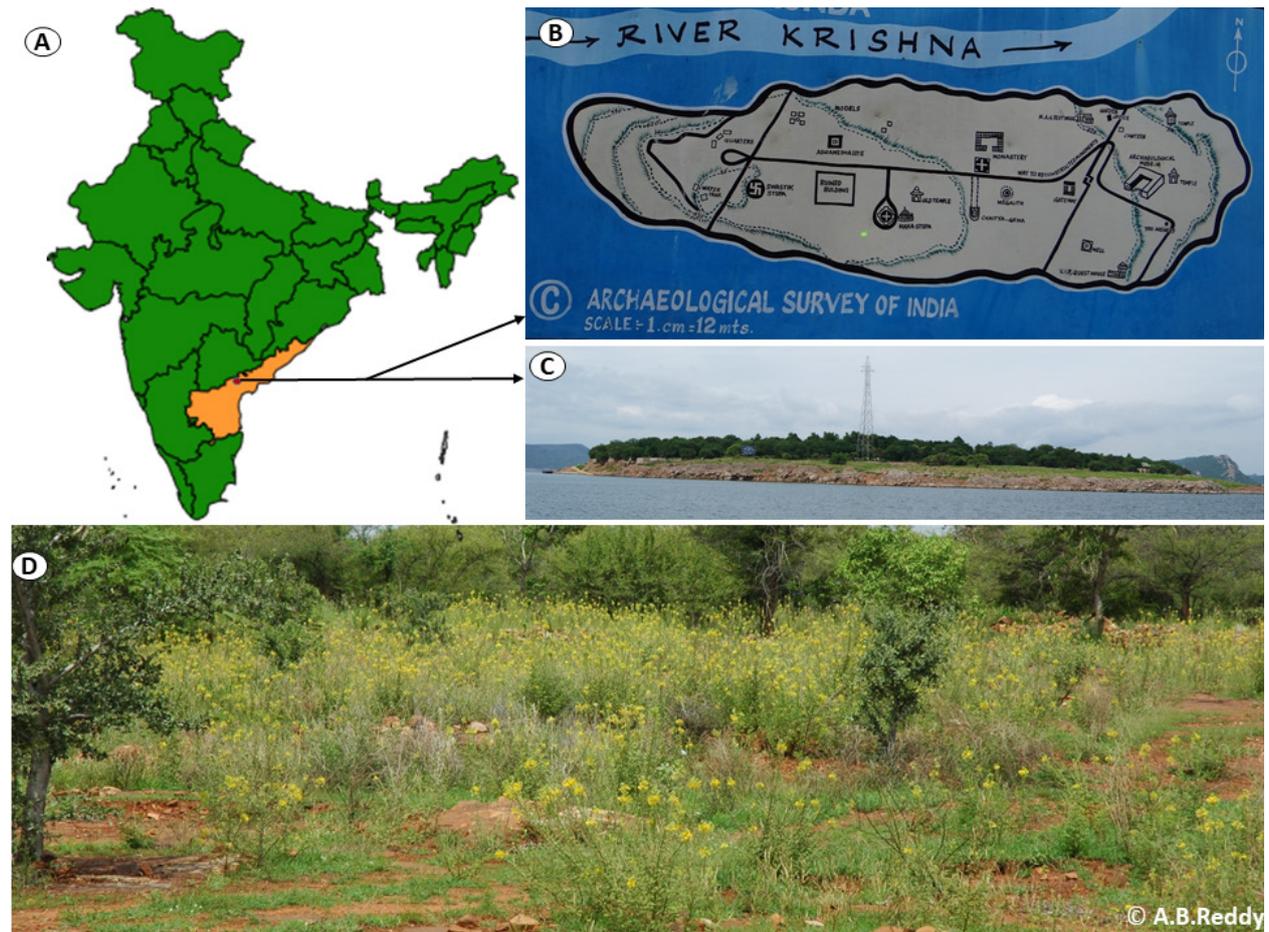


Image 1. Study area. (A) India; (B) Map of Nagarjuna Island; (C) Panoramic view of Nagarjuna Island; (D) Preferred habitat of *Corynandra viscosa* subsp. *nagarjunakondensis*.

an open source browser-based tool was used to perform the rapid geospatial analysis for red-listing the taxa of interest. This tool was developed to utilize spatially referenced primary occurrence data for the analysis of two aspects of the geographic range of a taxon: EOO - Extent of Occurrence and AOO - Area of Occupancy (Maes et al. 2015). The AOO is defined as the area within its 'extent of occurrence' which is occupied by a taxon, excluding the cases of vagrancy. The result is an intuitive environment for web-based GIS and conservation analysis algorithms. Analyses were done and visualized instantly. The tool provides an indication of the threat rating subjected to meeting the full requirements of the assessment criteria in a transparent, repeatable and rapid way through a user-friendly environment (Bachman et al. 2011). The standard IUCN Ver. 3.1 sampling methodology (IUCN 2013) was employed for determining the AOO.

RESULTS AND DISCUSSION

(i) Vegetation of Nagarjunakonda Island

Thothathri (1964) explored the Nagarjunakonda Valley and the surroundings, and reported 251 species representing 156 genera and 45 families of Angiospermae (Tracheophyta: Magnoliopsida). The present study recorded for the group, 193 species of 139 genera pertaining to 58 families from Nagarjunakonda Island. As per the growth forms, there are 39 (20.2%) tree species, 21 (10.8%) shrubs, 103 (53.5%) herbs, and 30 (15.5%) climbers. The vegetation is largely of dry deciduous type.

(ii) Taxonomic Status

Since Linnaeus (1753) described *Cleome viscosa*, it formed the basionym for several new combinations at generic level. It was because the genus *Cleome* L. with about 200 species (Kers 2003) has been conceived and circumscribed differently by later workers, leading to the creation of a number of segregate genera. The

www.theplantlist.org accepts the name *Cleome viscosa* L. whereas the www.tropicos.org considers *Polanisia viscosa* (L.) DC. to be the legitimate name. When this manuscript was written and submitted, the www.catalogueoflife.org viewed the name *Corynandra viscosa* (L.) Cochrane & Iltis as the accepted name and the same website now (since 31 May 2018) replaced that name with *Arivela viscosa* (L.) Raf. Conversely, these websites post these plant names in current use or currently accepted; however, this particular species has features distinct from *Cleome* L., sensu stricto. Now, the recent experts on *Cleome*, who use molecular evidence, assign *Cleome viscosa* either to *Corynandra* (Cochrane & Iltis 2014) or *Arivela* (Barrett et al. 2017), thus considering it distinct from *Cleome* proper. Nonetheless, when there are no major generic differences between these two genera *Corynandra* Schrad. ex Spreng. (1827) and *Arevila* Raf. (1838), the former gets priority being the older name.

The genus *Corynandra* Schrad. ex Spreng. (1827) was resurrected as the earlier name for *Arevila* Raf. (1838) which was recently taken up by Zhang & Tucker (2008). This segregate genus *Corynandra* is characterized by closed-imbricate aestivation of the flowers, higher number of stamens (10-100 plus), adaxial filaments apophysate, capsules sessile and erect with persistent valves that dehisce from the distal end and the seeds with open cleft, and largely of Old World distribution (Cochrane & Iltis 2014). Accordingly, the common weedy species of *Cleome* found in India such as *C. aspera* Koenig ex DC., *C. chelidonii* L.f., *C. felina* L.f., *C. simplicifolia* (Cambess.)Hook.f. & Thomson and *C. viscosa* L., fall under *Corynandra* (Cochrane & Iltis 2014; Barrett et al. 2017). Rafinesque (1838) and Barrett et al. (2017), however, consider *Cleome viscosa* L. as *Arevila viscosa* (L.)Raf. The authors of the present paper do not endorse this particular assessment because the morphological characters used by Barrett et al. (2017) are overlapping to distinguish clearly the Indo-Australian Cleomaceae, the delimitation of the genera *Areocleome*, *Arivela* and *Corynandra*. Even otherwise, *Cleome viscosa* is atypical. It has closed imbricate aestivation, the number of stamens, apophysate filaments and sessile erect capsules of *Areocleome* but differs from it in the apical dehiscence of capsules and seeds with open cleft and without elaiosome. It resembles *Arevila* in yellow flowers, closed imbricate aestivation, number of stamens which are filiform, sessile erect capsules and transversely ridged seed and differing in possessing apophysate filaments, apical dehiscence of capsules and non-eliosomic seeds; however, it resembles *Corynandra* in all the characters

used to circumscribe the genus. Therefore, the taxon under assessment has to be called as follows:

Corynandra viscosa (L.) Cochrane & Iltis in Novon 23(1): 24. 2014. *Cleome viscosa* L., Sp. Pl. 2: 672. 1753. *Sinapiastrum viscosum* (L.) Moench, Suppl. Meth.: 83. 1802. *Polanisia viscosa* (L.)DC., Prodr. 1: 242. 1824. *Arivela viscosa*(L.) Raf., Sylva. Tellur.: 110. 1838.

Corynandra viscosa subsp. ***nagarjunakondensis*** (Sundararagh.) Cochrane in Novon 23(1): 25. 2014. *Cleome viscosa* var. *nagarjunakondensis* Sundararagh. in Bull. Bot. Surv. India 28: 187. 1986 [publ.1988] et Flora India 2: 318.1993; Pullaiah et al., Fl. Guntur Distr. 55. 2000.

(iii) Taxon Description

Erect herbs up to 1.2m tall; woody and sparingly branched from base, viscid, clothed with glandular and eglandular trichomes, foetid. Leaves 3–5(7)-foliolate with petiole up to 4.5cm long at base; leaflets obovate, rhomboid or elliptic-oblong (variable in shape and size), 0.6–3.0 x 0.2–1.5cm, middle leaflet the largest, cuneate, ciliate, apex acute, lateral nerves 5–7 pairs; petiolule 0.5–2.5 mm. Inflorescence lax, few-flowered elongated racemes or terminal corymbs; bracts foliaceous. Flowers solitary and axillary, largely hermaphroditic (Image 2A), a few either with vestigial gynoeceum (Image 2B) or staminate (Image 2C); creamy, 2–2.5 cm across; pedicels up to 2.8cm, elongating up to 4cm in fruit. Sepals 4, glandular pubescent, elliptic-lanceolate, 8–12 x 2.5–4.0 mm, acute. Petals 4, subequal, prominently veined, oblong to obovate, cuneate, apex rounded, outer pair 2.0–2.5 x 0.8–1.0 cm, inner pair 1.8–2.0 x 0.6–0.8 cm (incl. 5–6 mm long claw). Stamens 36-40, dimorphic, adaxial ones apophysate; filaments 1.5–2.0 cm long; anthers 2.0–2.8 mm. Ovary sessile, linear-oblong, 1.0–1.4 cm, glandular hairy; style slender, puberulous, 0.8–1.0 cm long, elongating up to 2cm in capsules; stigma capitate. Capsules linear-oblong, 6.0–8.5 x 0.4–0.5 cm (including persistent style), terete, tapering at both ends, obliquely striate, ribs glandular. Seeds many, 1.5–1.6 mm across, dark brown, glabrous, with fine longitudinal striations, concentric ribs faint, cleft closed or with a narrow opening, non-elaeosomic (the description in the protologue is retained to the extent where there is no variation found).

Illustration: Sundararaghavan (1988: 187): Plate III; Figures 1–8; Present study: Image 2.

Type: India, Nagarjunakonda Hills, 200m altitude, 13.vii.1961, K. Thothathri 9616 (Holotype 9616A; Isotype 9616B-D, CAL).

Note: There are two specimens of *Cleome viscosa*

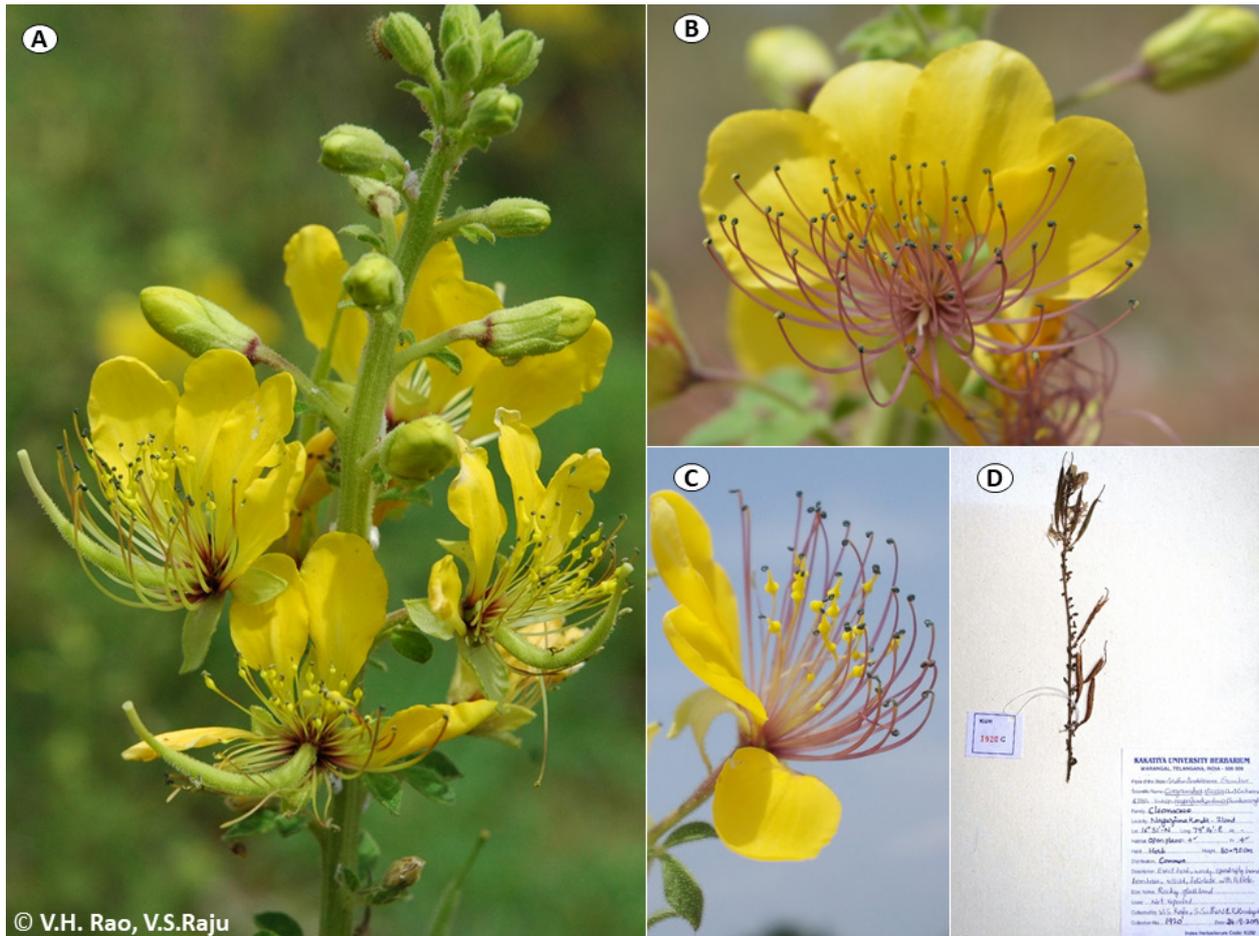


Image 2. *Corynandra viscosa* subsp. *nagarjunakondensis*. (A) Inflorescence with the hermaphroditic flowers (note the insect on the flower bud and the adaxial apophysate [yellow swellings below the anthers] filaments); (B) Flower with vestigial gynoecium; (C) Staminate flower; (D) Voucher specimen (V.S. Raju, S. Suthari & R. Kandagatla 1920 at KUW).

collected by K.C. Jacob on September 7, 1924 proximate to the type locality, i.e., Madinapad Reserve Forest, Guntur District, Andhra Pradesh. These specimens were preserved in MH as *Cleome viscosa* L. with the Madras Herbarium South India Flora acc. no.17458. These were selected by Sundararaghavan (1988) to serve as paratype (A, B). The digital images of specimens were assigned the numbers MH00155624 and MH00155625 by MH. It is not clear from Sundararaghavan (1988), which he assigned A or B. Of these, the latter sheet has two specimens pasted on it. We, therefore, designate the former as A and the latter B; however, it is to be mentioned that these specimens do not exactly compare with those from the type locality bearing relatively shorter, not so conspicuously long stigmas. Moreover, Sundararaghavan has wrongly mentioned the type collection number (at thousand digit) of K. Thothathri as '6616' when his other collections from the habitat of the field trip bear collection numbers in 'nine thousand' series. This was rightly

pointed out by Cochrane & Iltis (2014: 25). Furthermore, the present study reports in this subspecies, for the first time, the presence of staminate flowers and functionally male flowers with vestigial gynoecium.

Ex siccatæ: India, Andhra Pradesh, Guntur District, Nagarjunakonda: 14.ix.2011, A.B. Reddy & P.H. Rao 5056 (BSID); 24.ix.2013, V.S. Raju, S. Suthari & R. Kandagatla 1920 (KUW); 25.vi.2017, V.S. Raju, V.H. Rao & S. Gurappa 4901(KUW).

Flowering & Fruiting: June–September.

Distribution: Asia, India, Andhra Pradesh, Krishna River valley, Guntur District.

(iv) Threat Status

The Assessment: The taxon was not found under closed canopy forests but prefers open scrub of rocky landscape at elevations 196–210 m. After mapping the distribution of *Corynandra viscosa* subsp. *nagarjunakondensis*, the habitat Nagarjunakonda Island

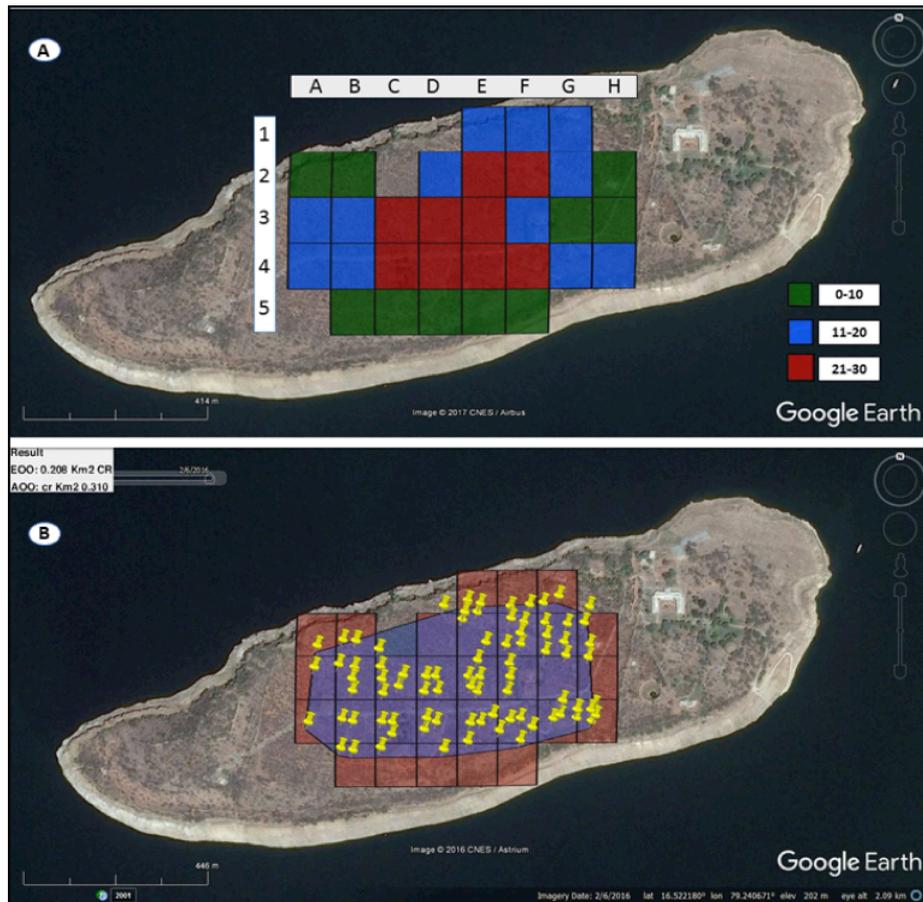


Image 3. Nagarjunakond Island. (A) Grid-wise categorization of population density in the Island; (B) Area surveyed for the occurrence of target species. Minimum Convex Polygon - Polygon Area: 100m², perimeter 0.31km (blue - EOO; red - AOO).

was stratified into 31 grids, each with 100m². The occurrence of this taxon was listed in each grid which had four quadrats of 1m² area. The population in each of these quadrats was determined. The sites of the taxon occurrence was recorded by GPS to estimate the extent of occurrence (EOO) and the area of occupancy (AOO).

A total of 124 quadrats of 1×1 m size were laid in 31 grids of 100×100 m size, and recorded 458 individuals of *Corynandra viscosa* subsp. *nagarjunakondensis*. The average population count among the grids varied between 1.5-7.50 individuals. Based on the population, the grids were divided into three categories (Image 3A) with a class interval of 10, viz.: Category-I (0–10), Category-II (11–20) and Category-III (21–30). Among the class intervals, maximum percent occurrence was noticed in Category-II with 12 grids, followed by Category-I with 10 grids and III with nine grids. The nine grids, namely C-3 and 4, D-3 and 4, E-2, 3 and 4 and F-2 and 4 (Image 3B) showed greater density of the taxon (columns were designated as A–H and rows as 1–5).

IUCN Red List Assessment

The conservation status of the taxon *Corynandra viscosa* subsp. *nagarjunakondensis* which has not been done so far is presently taken-up using the latest IUCN Red List Criteria (Version 3.1; IUCN 2001/2013). Opportunistic data are increasingly used for estimating trends and geographic range sizes. Geographic ranges are determined using: (i) marginal occurrences, (ii) habitat distributions, (iii) range-wide occurrences, (iv) species distribution modeling (including site-occupancy models), and (v) process-based modeling (Maes et al. 2015). The criterion B of the IUCN is used to evaluate a taxon based on its the geographic range in the form of either B1 (EOO) and/or B2 (AOO), leading to assigning the threat category Critically Endangered, Endangered or Vulnerable. EOO and AOO reflect two different processes and represent respectively the spread of extinction risk and vulnerability due to a restricted range and, therefore, useful to estimate both criteria in Red List assessments. In Britain, the combined use of EOO and AOO resulted in the highest Red List category (76%) while in Flanders this was the case for AOO (86%) (Maes et al. 2015). The

re-assessment of *Leucopogon spectabilis* yielded an estimated EOO of 14.8km² and AOO of 32km² and the values for *Tetradlea aphylla* subsp. *aphylla* were 35km² for EOO and 52km² for AOO (Bioscope Environmental 2016). For *Murdannia saddlepeakensis*, Tagore et al. (2016: 9492) showed the larger area for AOO (red) and smaller for EOO (blue) in Figure 1, as can be seen in our study (Image 3); however, they have provided only the value of EOO (1.8 km²), but not the AOO.

Since the estimated values of EOO and AOO are 0.20 km² and 0.31 km² respectively, the taxon under assessment falls under the Critically Endangered category. The conditions such as the population being confined to a single location [of (Ba)] and the (i) extent of occurrence (EOO <100km²); (ii) area of occupancy (AOO <10km²); (iii) area, extent and/or quality of habitat (elaborated below); (iv) number of locations or subpopulations not found further; and (v) the number of mature individuals about 500 [of B(b)] are the conditions which qualify *Corynandra viscosa* subsp. *nagarjunakondensis* to B1ab(iii) of the

above category.

A declining population was observed/inferred (sub-criterion b of B) in terms of the biotic interference on the habitat - where there is a tourism and impact of trekking on the Island, which in fact, comes under category II of protected areas. Forest fire is the other serious threat along with the alien plant invasion. Increased burn frequencies can, therefore, progressively exclude the fire-vulnerable species and increase the pyrophytes. Above all, *Corynandra viscosa* subsp. *nagarjunakondensis* was found severely infested with papaya mealybug (*Paracoccus marginatus* Williams & Granara de Willink: Pseudococcidae, Hemiptera). The papaya mealybug is a small, polyphagous, sucking insect with pest status that attacks several genera of host plants, including the economically important tropical fruits, vegetables and ornamentals. Infestation of the mealybug appeared as clusters of cotton-like masses on the aboveground portion of plants, more so the inflorescence (Image 4 A-C). Both the immature and adult mealybugs suck

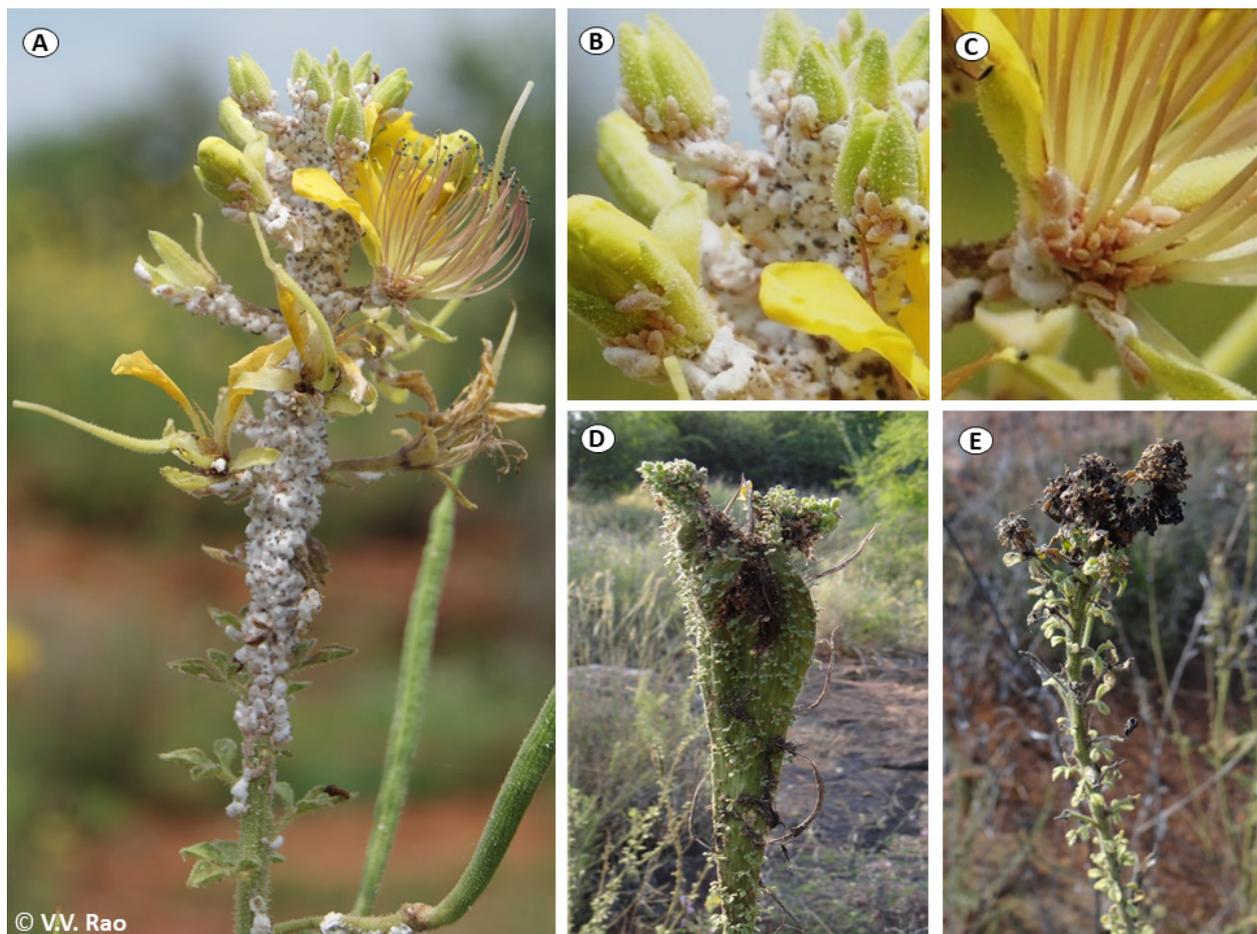


Image 4. *Corynandra viscosa* subsp. *nagarjunakondensis* infested with the Papaya mealybug (*Paracoccus marginatus*): (A) Inflorescence; (B) Flower buds; (C) Colonization on flower; (D) Abnormal growth of shoot due to insect attack; (E) Another kind of deformation of shoot apex.

the sap of the plant and weaken it. Consequently, the leaves become wrinkled, yellowish and wither while the seeds do not develop fully (Image 4 D-E). The honey dew excreted by the bug and the associated black sooty mold formation further impairs the photosynthetic efficiency of the affected plants (Tanwar et al. 2010). This insect, if unchecked, may expedite the decline of the population in the near future.

CONCLUSION

The Nagarjunakonda Island has a unique environment, with vulnerabilities. It harbours small seasonal populations of *Corynandra viscosa* subsp. *nagarjunakondensis* whose luxuriance depends on critical amounts and timing of moisture availability. Tourism promotion by the Andhra Pradesh State Government and the accompanied infrastructure development is a serious threat. Protection of this small precarious habitat and its native biota are essential for the long-term conservation of this taxon. It can come with political will and/or the enforcement of wildlife and biodiversity acts.

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