Conservation status of newly discovered subpopulations of two globally threatened tree species in the East Usambara Mountains, Tanzania

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Abstract Two globally threatened tree species, the Critically Endangered *Cola porphyrantha* (Malvaceae) and the Endangered *Gigasiphon macrosiphon* (Fabaceae) are narrowly distributed in Kenya and Tanzania. In Tanzania, both species were first located in an isolated, unprotected forest fragment in the East Usambara Mountains in the early 2000s. As no assessment of these subpopulations had been made since then, we surveyed the forest fragment as well as nearby unprotected forest fragments. In contrast to the early 2000s when only five and two mature trees of *C. porphyrantha* and *G. macrosiphon*, respectively, were located, we found 18 and five mature trees of these species. We did not find either species in intensive surveys of seven neighbouring unprotected forest fragments but we located a single *G. macrosiphon* beside a river close to one of the unprotected fragments. *Gigasiphon macrosiphon* was also previously known from two sites in Amani Nature Reserve in the East Usambara Mountains, but recent surveys, including our own, failed to relocate these subpopulations. Because of heavy anthropogenic disturbance in the one site where the two species still occur and their general absence from adjacent forest, we are working with the local community to protect the isolated fragment. Additionally, in situ planting of locally grown seedlings of both species is being supported by Amani Nature Reserve.

Keywords *Cola porphyrantha*, Critically Endangered, Eastern Arc Mountains, endemic, forest fragmentation, *Gigasiphon macrosiphon*, rarity, Tanzania

Introduction

Plant diversity and endemism are exceptionally high in the Eastern Arc Mountains of Tanzania and Kenya (Lovett, 1998; Burgess et al., 2007), which are part of the Eastern Afromontane Biodiversity Hotspot (Mittermeier et al., 2004). However, the forests in the Eastern Arc ranges are under severe threat from deforestation, habitat fragmentation and resource extraction, such that, together with other forests in this hotspot, they are considered one of the most threatened sites globally (Brooks et al., 2002). Conserving these forests is therefore a priority. This is especially true of tropical African plant species, of which over a third are threatened by extinction (Stévart et al., 2019).

Of the 13 mountain blocks that make up the Eastern Arc Mountains, the East Usambara Mountains in north-east Tanzania are amongst the best studied in terms of trees and other plants (Hamilton & Bensted-Smith, 1989; Iversen, 1991; Burgess et al., 2007). The East Usambara Mountains harbour 16 endemic tree species (R. E. Gereau, unpubl. data, 2024) and > 20 near-endemic tree species (Iversen, 1991; Burgess et al., 2007). Despite the extensive botanical coverage (reviewed in Hamilton & Bensted-Smith, 1989), new tree species (Cheek, 2002; Dawson & Gereau, 2010; Gosline et al., 2019) and new subpopulations of restricted-range species (Dawson & Gereau, 2010) continue to be discovered in the East Usambara Mountains. Here we document the distribution, relative abundance and conservation status of two globally threatened tree species that we have studied since their initial discovery in an unprotected forest remnant of these mountains.

Cola porphyrantha Brenan (family Malvaceae) is categorized as Critically Endangered on the IUCN Red List (Luke et al., 2018) and *Gigasiphon macrosiphon* (Harms) Brenan (family Fabaceae) as Endangered (Gereau et al., 2023). *Cola porphyrantha* was first described from a type specimen collected in 1978 from the Shimba Hills, Kenya, with additional records coming from one other coastal forest in Kenya (Cheek, 2007). There was also a collection made in the Shimba Hills in 1968. In Tanzania, the species was found in 2000 at an altitude of 950 m in an unprotected forest fragment in the East Usambara Mountains (Cheek, 2007). Approximately five mature individuals were reported then, and the habitat was described as heavily affected by human activities. *Gigasiphon macrosiphon* is known from three coastal forest sites in Kenya and from four disjunct sites in Tanzania, in two Eastern Arc Mountain ranges (one site in the East Usambara Mountains and two in the Udzungwa Mountains) and one on the Rondo Plateau in Lindi Rural District (Luke & Verdcourt, 2004; Ngumbau et al., 2020; Gereau et al., 2023). The earliest specimens of this species in the East Usambara Mountains were initially reported from Amani in 1906–1912 (Luke & Verdcourt, 2004).

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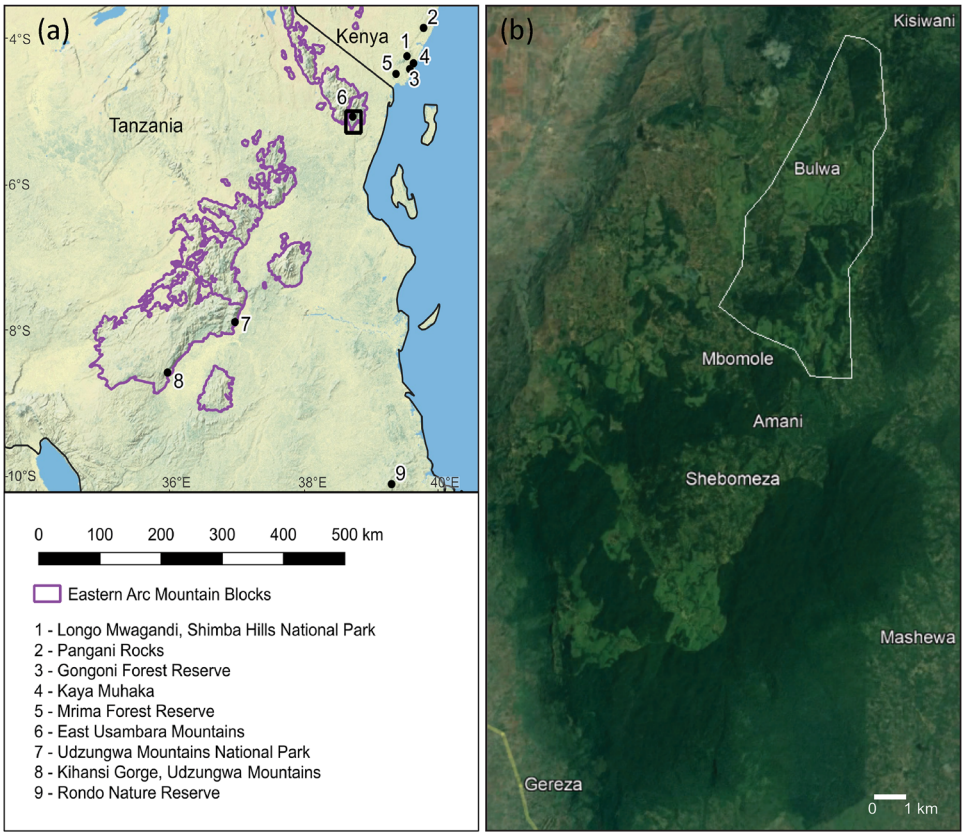

FIG. 1 (a) The East Usambara Mountains, Tanzania, showing the known locations of *Cola porphyrantha* and *Gigasiphon macrosiphon* (Table 2), and (b) the area of forest in the central and southern East Usambara Mountains. Amani Nature Reserve is the largest block of forest, extending from Mbomole south to Gereza and east to Mashewa, not including the enclave of Shebomeza. The polygon is the area surveyed for the two tree species. All forest fragments are unprotected and are managed by local tea estates. We have not provided precise localities of the plots or of the two species because of the potential for their exploitation. The Tanzania map was developed using Platts et al. (2011) for the Eastern Arc Mountain blocks, and the background data were from Stamen Design, under a CC BY 3.0 license, and OpenStreetMap, under an Open Data Commons Open Database License.

Although a cultivated collection was made from Amani in 1937 (Brenan, 1967), there were no further wild records of it from there until we found it near Amani in 2003. Currently, *G. macrosiphon* is known from the same forest fragment in the East Usambara Mountains as *C. porphyrantha*. Two mature trees of *G. macrosiphon* were thought to survive in this fragment in 2003.

As the subpopulations of both of these taxa have not been assessed for almost 2 decades in the East Usambara Mountains and given their globally threatened status, conservation assessments are imperative. To locate mature trees and any seedling and sapling recruitment, we surveyed the forest fragment that was known to harbour both species as well as neighbouring forest fragments of varying sizes. We also assessed threats (e.g. tree cutting, encroachment, direct use of tree species) in all sites that we surveyed, to help us identify conservation strategies that could promote the survival of both of these taxa.

Study area

The East Usambara Mountains rise from the coastal peneplain to 1,501 m (Platts et al., 2011), with forest starting at c. 250 m and being continuous to 1,100–1,200 m in some places (Fig. 1). Mean rainfall is 2,000 mm per year and is seasonal, with long periods of rain during late March–May and short periods of rain during October–November; proximity to the Indian Ocean induces orographic rainfall in most months (Hamilton & Bensted-Smith, 1989). The mean annual temperature is c. 24 °C.

Loss of original forest cover in the East Usambara Mountains is estimated to be > 50% (Newmark, 1998), driven largely by deforestation and habitat fragmentation as a result of the establishment of sisal and tea estates during the colonial period, dating back to the late 1800s (Hamilton & Bensted-Smith, 1989; Newmark, 2002). On the submontane plateau, at 800–1,100 m, extensive tea plantations dissect the forest in the central and southern regions of the East Usambara Mountains. Numerous forest fragments of varying sizes are surrounded by tea and, in some cases, subsistence cultivation (Fig. 1). Most of these fragments have no protected status, lying outside Amani Nature Reserve (8,380 ha) and Nilo Nature Reserve (6,025 ha) in the south and north, respectively. Comparable to trends in earlier decades (Hamilton & Bensted-Smith, 1989; Newmark, 2002), resource extraction, such as timber harvesting, and encroachment for subsistence agriculture continue to threaten both unprotected and protected forests in the East Usambara Mountains (Tanzania Forest Conservation Group, 2017).

Methods

To evaluate the abundance and distribution of *G. macrosiphon* and *C. porphyrantha* in the East Usambara Mountains, we used 15 randomly placed 20 × 20 m vegetation plots to survey the isolated, 17 ha forest fragment that harbours both species (Fig. 1). Additionally, we surveyed 32 randomly placed vegetation plots, of the same size, in seven neighbouring forest fragments (Fig. 1), assuming that similar edaphic factors would increase the likelihood of the presence of the two species. The areas of the seven other adjacent forest fragments we surveyed are 1.3, 4.6, 36.1, 98.3, 114.7, 135.4 and 153.0 ha. To ensure adequate coverage of the forest fragments, we also walked transects through all of the sites, in various directions. Transects were of varying lengths depending on fragment size and shape, and the width of each transect was 5 m either side of the centre line. The vegetation surveys were primarily in May and June 2022 and in January, May and September–October 2023. We made observations of fruiting and flowering of both species and of leaf shedding of the deciduous *G. macrosiphon* on a monthly basis during January 2022–December 2023. We also made fruiting and flowering observations in our ad hoc visits to the site for other research purposes. These observations are from 2000 onwards.

We identified all trees, shrubs and seedlings in all 47 plots, and we measured the diameter at breast height and height of all individuals of the two target species (i.e. seedlings, saplings and mature trees); we recorded root collar diameter for all individuals < 2 m in height. We also recorded any anthropogenic impacts, such as tree cutting or harvesting, in these plots. We recorded the location of all individuals of the two species > 5 cm diameter at breast height, with a GPS, for future monitoring.

Results

We located *C. porphyrantha* and *G. macrosiphon* almost exclusively in Bulwa, the same forest fragment in which they were previously known. We recorded *G. macrosiphon* and *C. porphyrantha* in three and six plots, respectively, of the 15 plots in the forest fragment; both species were found together in a localized area on a steep and rocky slope. We found a total of 47 *G. macrosiphon*, mostly seedlings and small saplings, with several larger saplings and five mature trees (Fig. 2b). We found a total of 153 *C. porphyrantha* in four of the plots, with 18 mature trees and 38 large saplings, and abundant seedlings and small saplings (Fig. 2a). We recorded a further eight saplings in another two plots: four saplings were at a mean of 120 m to the south-east and four at a mean of 130 m to the north-west from the edges of the clump of mature trees. Although we traversed the entire forest fragment, we did not find *G. macrosiphon* and *C. porphyrantha* elsewhere.

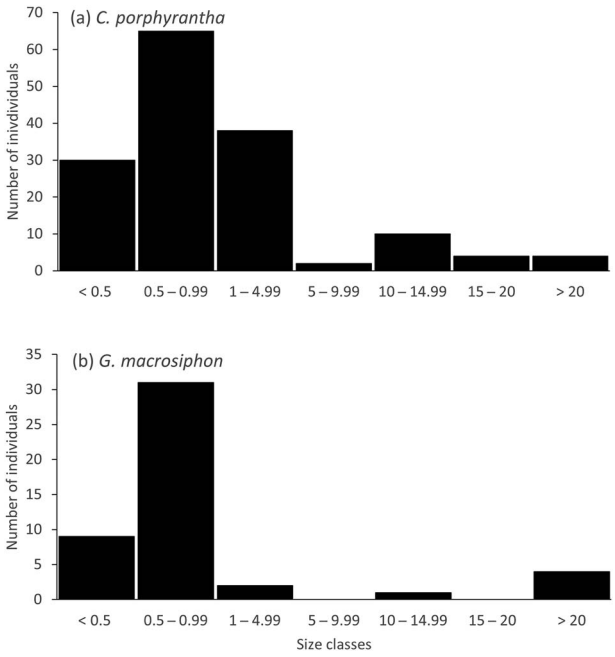

FIG. 2 Size class distribution of individuals of (a) *Cola porphyrantha* and (b) *Gigasiphon macrosiphon* in the East Usambara Mountains, Tanzania (Fig. 1). For *C. porphyrantha*, data were pooled from four 20 × 20 m plots, and for *G. macrosiphon* from three plots. Size classes are based on diameter at breast height for individuals > 1.5 m tall and root collar diameter for individuals below this height. Note the y-axis scales are different.

We surveyed a total 46.6 km of transects through the eight fragments (area in ha/distance in km: 1.3/0.6, 4.6/1.2, 17.0/5.3, 36.1/4.8, 98.3/10.6, 114.7/10.5, 135.4/8.1, 153.0/5.5), and surveyed additional transects on the upper parts of the Dodwe River (2.1 km) and along the Vungwe River at Kwezitu (1.6 km). In all of these surveys we found no *C. porphyrantha* and only a single fruiting tree of *G. macrosiphon*, in rocky terrain near Kwezitu in October 2023.

In the forest fragment that harboured both species, anthropogenic impacts appeared to be low in the five plots in which mature trees of the two species were found, with only two small saplings of *C. porphyrantha* having been cut. However, in the other 10 plots, which were on more gently sloping to flatter terrain, we observed cutting of saplings and poles in all of the plots, and larger trees had been felled in six of the plots, including the two plots where we found saplings of *C. porphyrantha* (all cutting and felling was of species other than *G. macrosiphon* and *C. porphyrantha*).

Flowering and fruiting of both species are variable across the various years of observation (Table 1). Leaf-shedding in *G. macrosiphon* appears to precede the hot, dry season (Table 1). Seed dispersal of *C. porphyrantha* by one of three resident primate species, the blue monkey *Cercopithecus mitis*, was observed opportunistically in 2001, 2021 and 2022. The flowers and fruits of *C. porphyrantha* are shown in Plate 1.

TABLE 1 Flowering and fruiting records of *Cola porphyrantha* and *Gigasiphon macrosiphon* in the East Usambara Mountains, Tanzania (Fig. 1).

Year	Flowering	Fruiting	Leaf shedding
C. porphyrantha			
2000	Oct., Nov.[1]	Not recorded	
2001	Not recorded	Feb., Mar.[1]	
2003	Oct.	Not recorded	
2004	Not recorded	July	
2010	Nov.[1], Dec.[1]	Dec. (immature fruits)	
2011	Feb., Mar.	Apr., May[1]	
2015	Not recorded	Aug.	
2021	Apr., May[1]	June, July[1], Aug.	
2022	Mar., Apr.[1], May, June, July, Dec.[1]	Mar., Apr., May[1], June[1], July	
2023	Jan.–May, Aug.–Oct.	Feb.[1]–June	
G. macrosiphon[2]			
2001	Not recorded	June	Not recorded
2004	Not recorded	May, June	Not recorded
2009	Not recorded	May, June, July	Not recorded
2021	Jan.–Aug.	Feb.–Aug.	Nov., Dec.
2022	Jan.–July	May–July	Nov., Dec.
2023	Jan.[1], Feb.[1]–May	Feb.–May[1], June[1], Sep., Oct.	Nov., Dec.

[1]Peak months of flowering or fruiting.
[2]Also observed fruiting in Kihansi Gorge in October 2005, leaf shedding started in November 2005.

Discussion

Although we surveyed a total of 47 vegetation plots and 46.6 km of transects in the eight forest fragments, most of the *C. porphyrantha* and *G. macrosiphon* that we located were in the one forest fragment in which they were first recorded in the early 2000s. Only five mature individuals of *C. porphyrantha* were previously reported from this location (Cheek, 2007), and two of *G. macrosiphon* (H.J. Ndangalasi & N.J. Cordeiro, unpubl. data, 2000–2003). However, we recorded 161 and 47 individuals, respectively, of *C. porphyrantha* and *G. macrosiphon*, of which 18 and five were of reproductive size (Table 2). In addition, we found a single mature *G. macrosiphon* near Kwezitu, just north of the intensively surveyed forest fragments.

The forest fragment in which we found both tree species has a south-facing aspect on a steep slope, with an abundance of rocks and boulders. We explored similar habitat in all adjacent forest fragments and at comparable elevations, but we found no additional individuals of either species (Fig. 1). The one mature *G. macrosiphon* near Kwezitu is beside a river in an area with rocks and boulders. Given the threatened status of both species and that they are known only from an unprotected, small forest fragment outside Amani Nature Reserve and in unprotected forest near Kwezitu, conservation action is required.

Gigasiphon macrosiphon was first known to be present in the East Usambara Mountains from the three syntypes of its basionym, *Bauhinia macrosiphon* Harms (1915, p. 467). Specimen Braun 1033 was collected in 1906 from the 'right bank of Dodwe River at Amani', and Zimmermann 3088

PLATE 1 A *Cola porphyrantha* (family Malvaceae) tree with almost ripe fruit, and the unisexual flowers, in the East Usambara Mountains, Tanzania. The fruits and flowers are cauliflorous. Photos: Fruiting tree and female flower: N. J. Cordeiro; male flower: H. J. Ndangalasi.

TABLE 2 Locations and status of subpopulations of *C. porphyrantha* and *G. macrosiphon* in Kenya and Tanzania.

	Site (Fig. 1)	Number of mature trees	Source
C. porphyrantha			
Kenya			
Longo Mwagandi, Shimba Hills National Park	1	Formerly 2, now extinct[1]	Luke et al. (2018)
Pangani Rocks	2	Not reported[2]	Luke et al. (2018)
Tanzania			
Bulwa forest fragment, East Usambara Mountains	6	18	This study
G. macrosiphon			
Kenya			
Gongoni Forest Reserve	3	159	Malombe et al. (2015)
Kaya Muhaka	4	21	Malombe et al. (2015)
Mrima Forest Reserve	5	2	Malombe et al. (2015)
Tanzania			
Amani Nature Reserve, East Usambara Mountains	6	0	This study
Bulwa forest fragment, East Usambara Mountains	6	5	This study
Kwezitu forest fragment, East Usambara Mountiains	6	1	This study
Udzungwa Mountains National Park	7	1	Luke & Verdcourt (2004)
Kihansi Gorge, Udzungwa Mountains	8	8	H.J. Ndangalasi, unpubl. data, 2004–2015
Rondo Nature Forest Reserve	9	Not reported[3]	Gwegime et al. (2014)

[1]The last two mature trees in Longo Mwagandi were killed by elephants (Luke et al., 2018).
[2]Luke et al. (2018) did not provide the number of mature trees but stated that the site is affected by limestone extraction.
[3]In six sites in Rondo Nature Reserve, two 1 km transects were surveyed per site and the species was recorded in three sites, but the number of mature trees was not reported.

was collected in 1910 'at Amani'. These two specimens were subsequently destroyed in the Berlin herbarium during World War II (Hiepko, 1987). A third syntype, Grote 3763, was collected in 1912 from near Kihuhwi at 500 m; the specimen at Berlin was destroyed but a duplicate was preserved in the East African Herbarium. Despite these early records, *G. macrosiphon* has not been reported since 1912 from the East Usambara Mountains during the many subsequent wide-scale studies of trees there (Hamilton & Bensted-Smith, 1989; Frontier Tanzania, 1996a,b, 2001a,b, 2002a,b) or in two targeted searches for it in Amani Nature Reserve (Luke & Verdcourt, 2004) and Kihuhwi (A. Mndolwa, pers. comm., 2023). We also failed to relocate it in the Dodwe River area. Of the eight sites in which *G. macrosiphon* has been recorded in Kenya (Kaya Muhaka and Gongoni and Mrima Forest Reserves) and Tanzania (Amani Nature Reserve, Bulwa forest fragment, Udzungwa Mountains National Park, Kihansi Gorge and Rondo Nature Forest Reserve), the largest population is in Gongoni Forest Reserve, with 159 mature trees (Fig. 1, Table 2; Malombe et al., 2015). The size class distribution of *G. macrosiphon* in Gongoni Forest Reserve (Malombe et al., 2015) and the East Usambara Mountains (Fig. 2) is comparable, indicating similar recruitment and the ability to maintain a small subpopulation.

Cola porphyrantha was previously known at two sites in Kenya (Longo Mwagandi in Shimba Hills National Park and Pangani Rocks; Fig. 1, Table 2; Cheek, 2007). When first discovered in 2000 at 950 m altitude in the East Usambara Mountains, this was the only known record in Tanzania, and was 500 m higher than the records in Kenya (Cheek, 2007). Only five mature individuals were reported then, and the small forest fragment was described as heavily affected by human activities (Table 2; Cheek, 2007). The 18 mature trees and high recruitment at different ontogenetic stages (Fig. 2) are suggestive of a subpopulation that is currently stable but small. The eight saplings found at c. 120 m from the main stand of mature trees are probably a result of seed dispersal by blue monkeys, although for the downslope plot, runoff from heavy rains could also have carried seeds from higher up.

Cola porphyrantha and *G. macrosiphon* are narrowly distributed in the East Usambara Mountains and are currently known to co-occur only in an unprotected forest fragment surrounded by tea plantations and subject to heavy anthropogenic disturbance because of proximity to a large village. Although the part of the fragment where these two species occur was little disturbed, probably because of the steep and rocky terrain, widespread cutting of saplings, poles and trees threatens this forest fragment. These species require protection at this site, by either the government or the village authorities, as does the unprotected forest near Kwezitu where we located a single *G. macrosiphon*. An additional concern, at least for *G. macrosiphon*, is that fungal attack, seed predation and seedling herbivory appear to impact early recruitment (Malombe et al., 2015; H.J. Ndangalasi & N.J. Cordeiro, pers. obs., 2022–2024). As we have a basic understanding of the flowering and fruiting periods of these two species (Table 1), and also of seed germination and seedling growth rates

(H.J. Ndangalasi & N.J. Cordeiro, unpubl. data, 2006–2024), we recommend in situ planting of seedlings in Amani Nature Reserve as well as in surrounding forest fragments, to safeguard both species in Tanzania. This process is currently being developed in collaboration with the local management authorities.

Author contributions Both authors contributed equally to study design, fieldwork, data analysis and writing.

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Conflicts of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards.

Data availability The data that support the findings of this study are available on request from the corresponding author (HJN). The data are not publicly available because of the threatened status of the two species, but they have been lodged with the IUCN Species Survival Commission Eastern African Plant Red List Authority.

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