

RESEARCH ARTICLE

Diversity and distributional ecology of tree ferns of Sri Lanka: A step towards conservation of a unique gene pool

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Abstract: Tree ferns are a remarkable group among the lycophytes and ferns. Geographical isolation is suggested as one of the main reasons for local endemism of tree ferns and the island of Sri Lanka has been identified as one of the best demonstration sites to observe this phenomenon. Despite its small size, Sri Lanka has a rich diversity and one of the highest levels of endemism of tree ferns in Asia. Their diversity here is considered as an unique and important gene pool in the world. The present eco-spatial survey is to study the diversity and ecology of tree ferns in Sri Lanka.

The study identified nine tree fern species including one new record of an adventive species. The species are *Cyathea hookeri*, *C. sinuata*, *C. sledgei*, *C. srilankensis*, *C. walkerae*, *C. crinita*, *C. gigantea*, *C. australis* and *Dicksonia antarctica*. Of these, the first five species are endemic to Sri Lanka. *Dicksonia antarctica* and *Cyathea australis* are exotic and naturalised in forest clearings in Pidurutthalagala forest. *Cyathea hookeri*, *C. sinuata*, *C. sledgei* and *C. srilankensis* are confined to limited populations in lowland rainforests (62-550 m). *Cyathea walkerae* is distributed in a wide elevational range throughout the wet zone (30-2,300 m), whereas *C. crinita* shows a restricted distribution pattern at a high altitude range (1,800-2,400 m). In this study *C. gigantea* was recorded additionally from lowland rain forests, though it was previously reported to be confined to submontane and montane ecosystems. The results of this study provide baseline information on the distributional ecology of Sri Lankan *Cyathea* species. It will be useful to assess their current conservation status and to formulate conservation guidelines for these remarkable and spectacular ferns so characteristic to Sri Lanka.

Keywords: Tree ferns, *Cyathea*, diversity, endemism.

INTRODUCTION

Tree ferns are usually placed in two families namely, Cyatheaceae and Dicksoniaceae, which are both ancient families placed relatively early in taxonomic classifications and from among which several major modern lineages of ferns are derived. The family Cyatheaceae has a wide pan-tropical geographical distribution combined with pronounced local endemism (Tryon and Gastony 1975). It contains about 500 species worldwide with diversity centres in tropical rain forests (Holttum, 1963, 1965, 1981; Conant *et al.* 1996; Tryon and Gastony, 1975). Geographical

isolation is suggested as one of the main reasons for local endemism (Tryon and Gastony 1975), and we identified here that Sri Lanka with its relict island flora as one of the best demonstration sites to observe this phenomenon.

Despite its small size, Sri Lanka has a rich diversity and one of the highest levels of endemism of tree ferns in Asia. We prefer to use the genus *Cyathea* in an inclusive sense here, recognising their similar morphology, rather than splitting it into its constituent minor genera, *Alsophila* and *Sphaeropteris*. Sri Lankan tree ferns are now known to consist of eight *Cyathea* species (Cyatheaceae) and one *Dicksonia* species (Dicksoniaceae). Of the seven native species, five (*Cyathea sinuata* Hook. & Grev., *Cyathea hookeri* Thwaites, *Cyathea sledgei* Ranil, Pushpak. and Fraser-Jenk., *Cyathea walkerae* Hook. and *Cyathea srilankensis* Ranil) are endemic to Sri Lanka and two species (*Cyathea crinita* (Hook.) Copel. and *Cyathea gigantea* (Wall. ex Hook.) Holttum) are native to the island but also distributed elsewhere (*C. crinita* is only known otherwise from South India, and *C. gigantea* is a wide spread Malesian element in south and east Asia). *Cyathea australis* (R.Br.) Domin and *Dicksonia antarctica* Labill. are introduced. They are widely cultivated exotic species which have now become naturalised. There is thus considerable diversity in the island and the species present also include a great range of remarkable morphological diversity.

However, information on Sri Lankan tree ferns has so far been almost entirely limited to lists of species and their morphological descriptions (Hooker, 1846; Hooker & Baker, 1865; Thwaites, 1864; Beddome, 1883; Holttum, 1965; Ashton *et al.*, 1997; Philcox, 2006). But since conservation or management of species is based on levels of threat, frequency of occurrence and ecological factors, information on morphological and genetic variation in different areas, taxonomy, cytology, population-ecology, reproductive biology and distribution is essential and we attempt to provide basic information on them in this study. The present eco-spatial survey was conducted as Ranil *et al.* (2011) highlighted the necessity to study the distribution patterns of tree ferns in Sri Lanka for their management and conservation perspectives.

METHODOLOGY

Distribution and mapping

A local eco-distributional survey was conducted covering 42 forests in 10 administrative districts in the country. The forest ecosystems including Proposed Forest Reserves (PR), Forest Reserves (FR), Man and Biosphere Reserves (MAB), World Heritage Sites (WHS) and National Parks (NP) were selected based on the literature and existing herbarium specimens. The forests surveyed are listed in Table 1. The stream network, forest gaps and boundaries and roadside banks of each forest ecosystem were identified as sampling points. Specimens were collected according to standard herbarium techniques. Distribution maps for each species were prepared using GIS technology.

Ecology, habitat requirements and threats

Data on habitat requirements, ecological niches and threats were obtained through direct observation and interviews with peripheral communities as well as with officers of the Forest Department and Department of Wildlife Conservation, where appropriate.

RESULTS AND DISCUSSION

Diversity of tree ferns in Sri Lanka

The study catalogued eight *Cyathea* species (*C. crinita*, *C. walkerae*, *C. gigantea*, *C. sinuata*, *C. hookeri*, *C. sledgei*, *C. srilankensis* and *C. australis*) and one *Dicksonia* species (*D. antarctica*) from natural ecosystems in Sri

Lanka. Other than the historical locality at the fernery in Hakgala Botanic Garden, the only known naturalised wild population of *Dicksonia antarctica* is in Piduruthalagala Mountain and in the adjacent *Eucalyptus* plantation (Ranil *et al.*, 2014). Furthermore, we were also able to record a substantial and well-established naturalized population of *Cyathea australis*, including more than 100 mature individual plants. It is suspected that like a number of other introductions, this species was introduced to Hakgala Botanic Garden during the colonial era and later may have escaped from the garden. The study recorded all previously identified Sri Lankan *Cyathea* taxa except *Cyathea walkerae* var. *tripinnata* Hook. & Baker. Table 2 shows the species diversity of tree ferns in Sri Lanka with their geographical occurrence and conservation status based on the National Red List 2012 (MOE, 2012). Plates 1, 2 and 3 show Sri Lankan tree fern species recorded during the eco-geographic survey. Holttum (1981) suggested an affinity of some Sri Lankan *Cyathea* species with African counterparts, and although Janssen *et al.* (2008) and Korall and Pryer (2014) suggested that the Sri Lankan species they investigated showed no close affinities with African species studied, although there may still be some phytogeographical connection.

Distribution

Table 3 shows the summarised information on the distribution of different tree fern species in Sri Lanka. All the sample points lie in the wet zone of the island and the southern and central provinces show relatively high

Table 1: List of forest reserves in Sri Lanka where the study was carried out.

Administrative district	Names of forest reserves	Forest types and maximum elevation studied
Nuwara Eliya	Hakgala Strict Nature Reserve, Horton Plains National Park, Kikiliyamana Forest, Adam's Peak Wilderness, Kirigalpotta Mountain, Piduruthalagala Forest	Montane and submontane. 2,237 m
Badulla	Udaikeruwa Proposed Forest, Namunukula Forest, Thangamalai Sanctuary	Lowland and montane. 2,719 m
Kalutara	Kalugala Forest Reserve, Runakanda Forest Reserve, Wathurana Swamp Forest, Kukuleganga Forest, Dombagaskanda Forest	Lowland. 203 m
Kurunegala	Hadurukkanda Forest, Dolukanda Forest Reserve	Lowland. 339 m
Gampaha	Horagolla National Park	Lowland. 71 m.
Kandy	Galaha Forest Reserve, Hunnasgiriya Forest, Lookandura Forest, Udawattakele Forest Reserve, Hantana Forest and Gannoruwa Forest	Lowland and submontane. 1,455 m
Matale	Knuckles Conservation Forest	Lowland, submontane and montane. 1,852 m.
Galle	Kanneliya MAB Reserve, Hiniduma Forest Reserve, Kottawa Forest Reserve, Dellawa Forest Reserve, Nakiyadeniya Forest Reserve, Dediya Forest Reserve, Beraliya Proposed Forest and Polgahakanda Forest	Lowland. 560 m
Matara	Sinharaja World Heritage Site, Mulatiyana Forest Reserve, Oliyagankele Forest Reserve, Enasalwatta Forest	Lowland. 285 m
Ratnapura	Sinharaja World Heritage Site, Gilimale Forest, Erathna Forest, Walankanda Forest, Rassagala Forest, Pettigala Forest	Lowland. 772 m

population densities of some species (Figure 1A). *Cyathea sinuata* and *C. hookeri* were recorded previously only from three southern lowland rain forest areas (Kanneliya FR, Sinharaja WHS and Beraliya PR) confined to a few known populations. The present survey records both *C. sinuata* and *C. hookeri* from fragmented forests in the south-west of the country as a few isolated patches in the Hiniduma Forest Reserve and Runakanda PR (Figure 1B). *Cyathea walkerae* has a wide distribution throughout the wet zone (Figure 1C). It occurs commonly in open areas of roadside banks and nearby streams. *Cyathea crinita* has a restricted distribution pattern at high altitude. It is restricted to Nuwara Eliya district (Figure 1D) and is mostly confined to

roadside banks. According to previous records, *C. gigantea* is limited to the montane region, but the present study has revealed that it also occurs in lowland rain forest.

Cyathea srilankensis considered to be a point (very narrow distribution) endemic, confined to two small populations at its type locality at the Sinharaja WHS and a substantial population of *C. srilankensis* in Beraliya PR. *Cyathia sledgei* also has a very narrow distribution, confined to two southern lowland rain forests (Sinharaja MAB Reserve and Kanneliya FR). *Dicksonia antarctica* and *Cyathea australis* occur as naturalised exotic escapes into the natural environment only on Pidurutalagala Mountain in the central highlands of the island. We could find no

Table 2: Recorded distributional range of tree fern species from montane, submontane and lowland rain forests of Sri Lanka.

Species	Geographical status	National Conservation status
1. <i>Cyathea sinuata</i> Hook. & Grev.	Endemic to Sri Lanka	Endangered
2. <i>Cyathea hookeri</i> Thwaites	Endemic to Sri Lanka	Critically endangered
3. <i>Cyathea sledgei</i> Ranil, Pushpak. & Fraser-Jenk.	Endemic to Sri Lanka	Endangered
4. <i>Cyathea walkerae</i> Hook.	Endemic to Sri Lanka	Vulnerable
5. <i>Cyathea srilankensis</i> Ranil	Endemic to Sri Lanka	Endangered
6. <i>Cyathea crinita</i> (Hook.) Copel.	Native to S. India and Sri Lanka	Endangered
7. <i>Cyathea gigantea</i> (Wall. ex Hook.) Holttum	Native to Sri Lanka, China, N., C. and S. India, Nepal, Bhutan, Bangladesh, Myanmar, Thailand, Laos, Cambodia, Vietnam, Malaysia and Indonesia	Endangered
8. <i>Cyathea australis</i> (R.Br.) Domin	Naturalised in Sri Lanka, native to Australia	Not assessed
9. <i>Dicksonia antarctica</i> Labill.	Naturalised in Sri Lanka; native to Australia	Not assessed

Table 3: Distribution patterns of tree ferns in Sri Lanka according to their ecological and habitat requirements.

Species	Elevation (m)	Agro-climatic zone	Forest type	Most common micro-habitats
<i>Cyathea crinita</i>	1,800-2,400	WU	Montane	Roadsides, under storey of <i>Eucalyptus</i> plantation
<i>Cyathea gigantea</i>	80-1,600	WL, WM, WU	Lowland, submontane, Montane	Roadsides
<i>Cyathea hookeri</i>	62-550	WL	Lowland	Stream banks
<i>Cyathea sinuata</i>	62-550	WL	Lowland	Stream banks
<i>Cyathea sledgei</i>	80-550	WL	Lowland	Stream banks
<i>Cyathea srilankensis</i>	62-550	WL	Lowland	Stream banks
<i>Cyathea walkerae</i>	30-2,300	WU	Lowland, Submontane, Montane	Stream banks, roadsides
<i>Cyathea australis</i>	2,000-2,200	WL, WM, WU	Montane	Under storey of <i>Eucalyptus</i> plantation, forest margin
<i>Dicksonia antarctica</i>	2,000-2,200	WU	Montane	Under storey of <i>Eucalyptus</i> plantation, forest margin

Note: WL: wet zone low country; WM: wet zone mid country; WU: wet zone up country; IML: intermediate zone low country; IMM: intermediate zone mid country; IMU: intermediate zone up country; DL: dry zone low country.

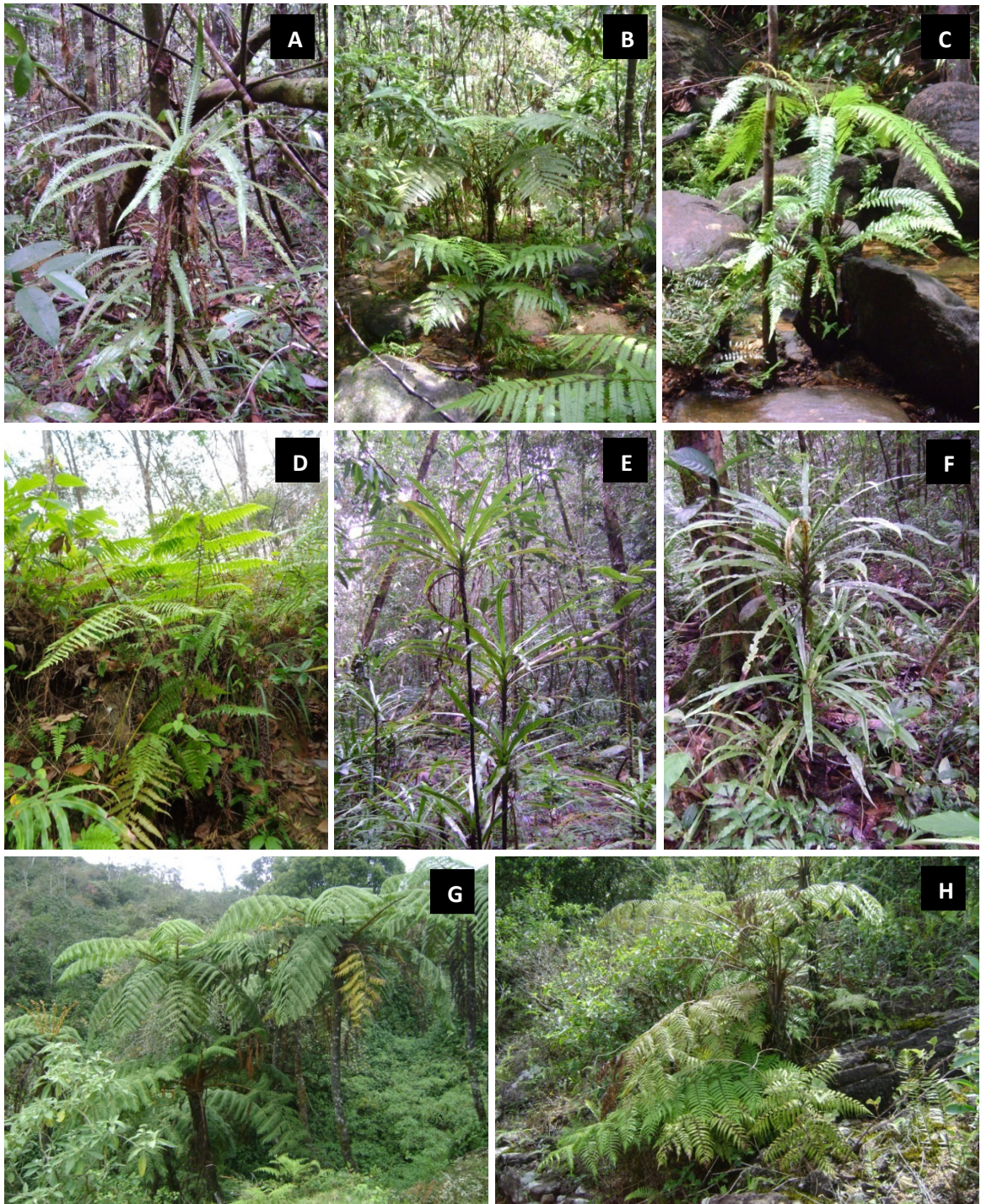


Plate 1A. *Cyathea sledgei* in Kanneliya Forest Reserve (FR). B: *Cyathea srilankensis* in Beraliya Proposed FR. C: *Cyathea hookeri* in Kanneliya FR. D: *Cyathea gigantea* in Udakeeruwa FR. E: *Cyathea sinuata* in Sinharaja WHS. F: Variant of *Cyathea sinuata* in Sinharaja WHS. G: *Cyathea crinita* in Horton Plains NP. H: *Cyathea walkerae* in Knuckles Conservation Forest.

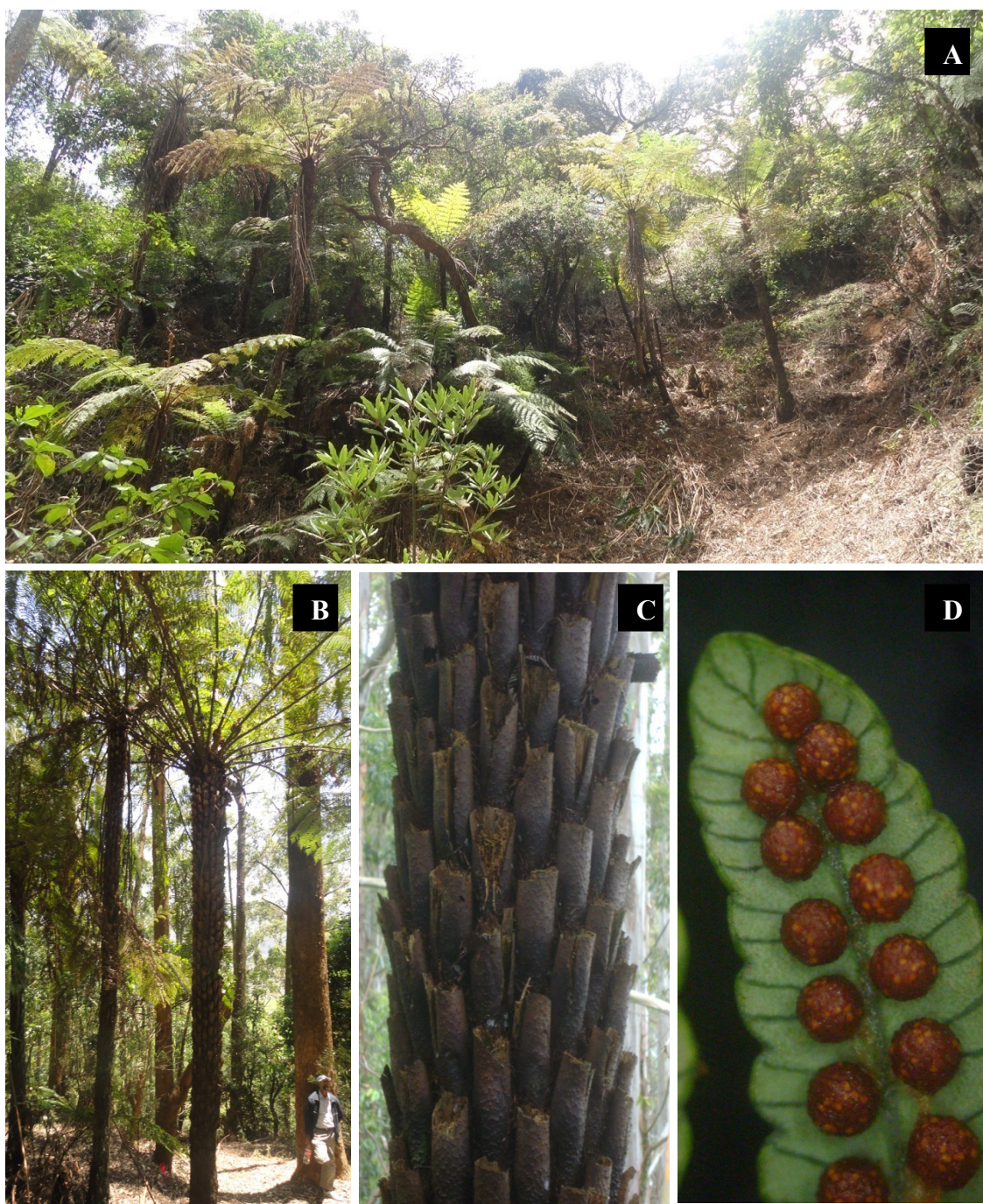


Plate 2A. Well established *Cyathea australis* population at Pidurutalagala Mountain. B: Mature individual about seven meters tall. C: Persistent petiole bases. D: Arrangement of sori.

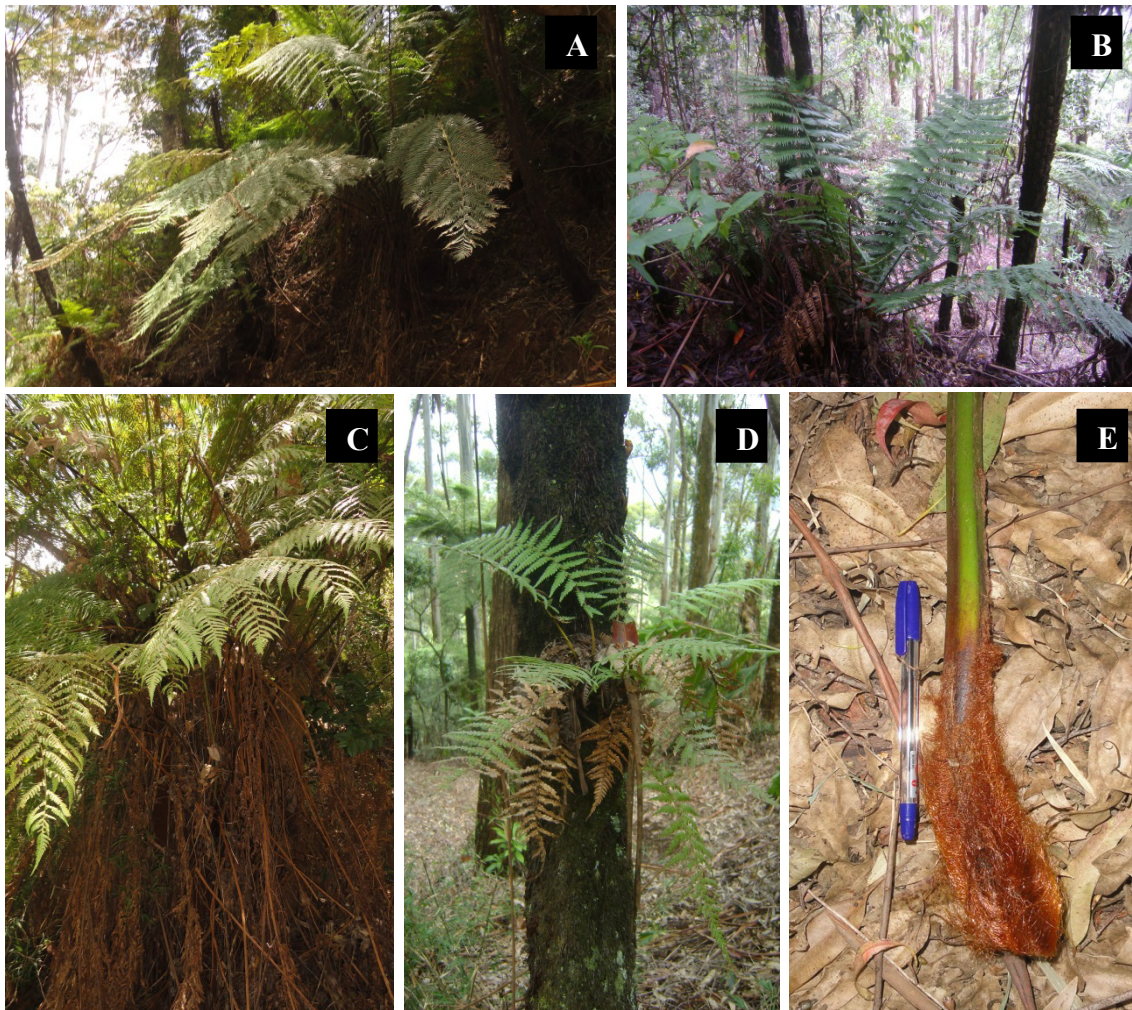


Plate 3A. Mature individual of *Dicksonia antarctica* Pidurutalagala Mountain. B: Juvenile plant growing in a *Eucalyptus* plantation. C: Plant with pendent dead fronds. D: Plant growing as an epiphyte. E: Frond base densely covered with glossy ginger-brown hairs.

information as to whether or when an initial plant might at some stage have been planted there, perhaps in connection with the presence of the Army there, or alternatively and more likely, whether they arrived by wind-dispersal from Hakgala, where they have both been under cultivation for a long time. According to the results obtained from this study, all tree-fern species in Sri Lanka, apart from the more widespread *C. gigantea* and *C. walkerae*, are area-specific and each confined to a few localities.

Ecological and habitat requirements

The ecological and habitat requirements of each species were recorded from direct observation in the field. In Table 3 the summarised information about their ecology and habitats where they were usually found are given.

All these species are confined to the wet zone of Sri Lanka. However, these four species co-occur with each other and are limited to relatively small populations in tropical lowland rainforests. The habitat of these four normally terrestrial species is generally highly localised in the spray zones of fast flowing streams, which indicate that they prefer a highly moist environment. Even though these tree ferns are typically terrestrial, some individuals of *C.*

sinuata were observed on lithophytic habitats on rocky streamside banks. The populations of the above species show scattered distribution patterns. They are confined to low altitudes (ca. 62-550 m) (Figure 1B) and immediately become scarce and then absent with increasing elevation. Of the four species, only *C. sinuata* is relatively common and shows pockets of distribution along water courses, forming dense populations.

The largest populations of *C. sinuata*, *C. hookeri* and *C. sledgei* were recorded from the Sinharaja WHS and the few other known localities had small populations. The mean annual rainfall at Sinharaja WHS is 5,006 mm, whereas the other recorded localities have a much lower mean annual rainfall. Light level, canopy density and flow rate of streams change substantially with time and climatic factors. Stream banks are usually more exposed to direct sunlight than other places in the rainforest. Many fern species are therefore concentrated in such localities. This requirement correlates with the known distribution of tree fern species. These species usually prefer soil with more organic matter, but *C. sinuata* thrives well even on rocky stream side banks. Although the species studied in Sri Lanka are grown fully and had fully fertile fronds, producing spores abundantly,

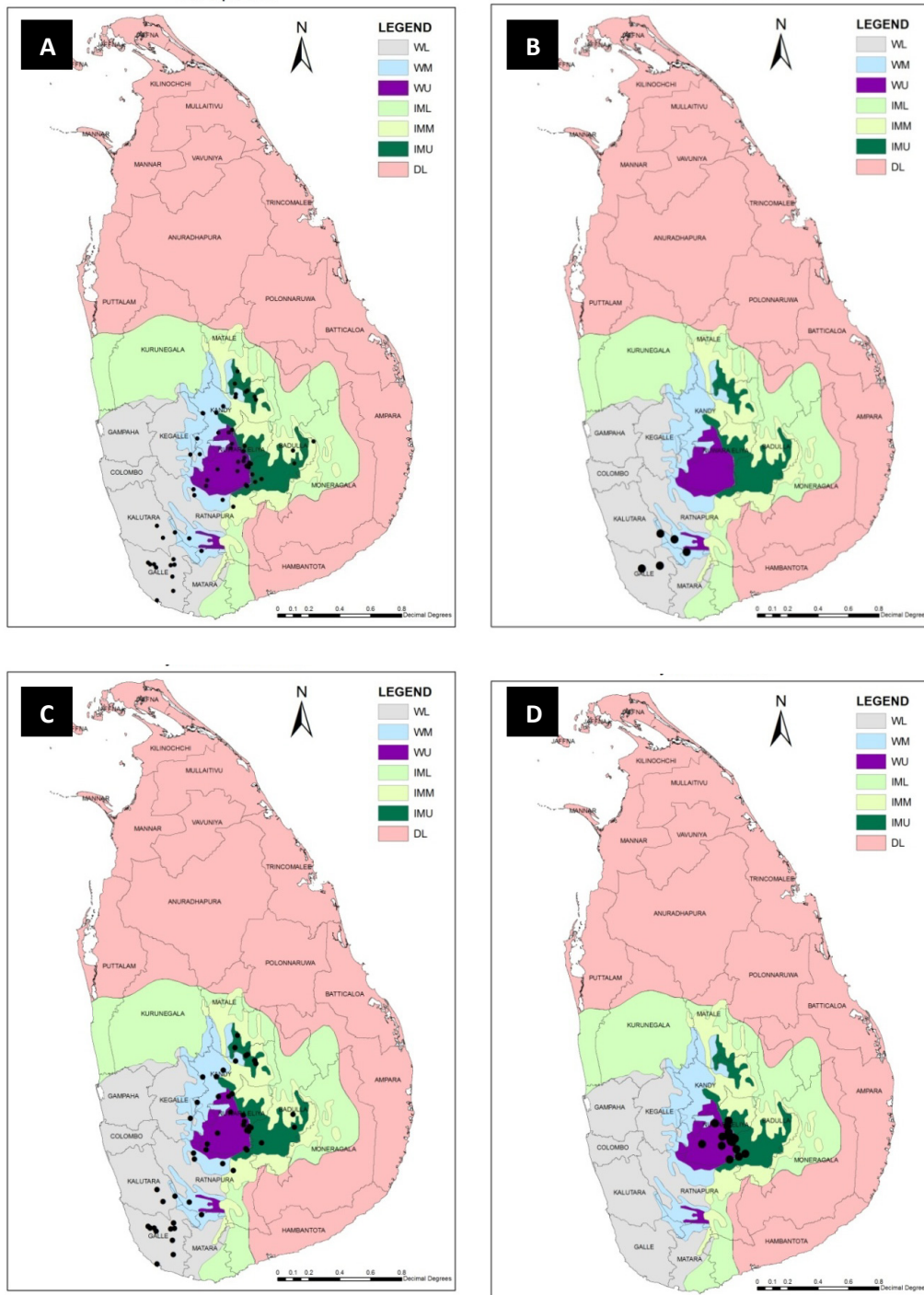


Figure 1. A: Distribution of tree fern species in Sri Lanka. B: Restricted distribution of the endemic and threatened *C. sinuata* and *C. hookeri* in lowland rain forests. C: Wide distribution of *C. walkerae*. D: Localised distribution of *C. crinita*, *Cyathea hookeri*, *C. sinuata*, *C. sledgei* and *C. srilankensis*

the reasons for their localised and patchy distribution are yet to be identified.

Cyathea walkerae

This is the most common and widespread tree fern species in Sri Lanka. Our survey shows that *C. walkerae* is distributed from 30 to 2,300 m altitude, thus inhabiting lowland, submontane and montane forests in Sri Lanka. It can thrive well in a wide range of climatic, topographical and edaphic conditions. Its most common habitats are roadside banks and among streamside vegetation in disturbed forests. It usually prefers 20-40% shade but is

sometimes found surviving in fully open areas.

Cyathea gigantea

According to previous records and herbarium specimens, *C. gigantea* was thought to be limited to high altitude forests in the Central Province (Matale, Kandy and Nuwara Eliya districts). In the present investigation we recorded *C. gigantea* from southern lowland rain forest too, as is well known in other regions within its range. Its distribution ranges from 80 to 1,600 m, usually a single population consists of one or two plants. The most preferred habitat is

roadside banks in secondary vegetation or highly disturbed areas. It usually prefers 50-60% shade level and a substrate with high organic matter content.

Cyathea crinita

This species was observed only in forests at high altitude (1,800-2,400 m) in the Nuwara Eliya district. Within the district, it has a scattered distribution and is mainly confined to Horton Plain National Park and adjacent areas. The species usually prefers cool temperatures and high humidity and thrives well under direct sunlight. But a few small populations were also observed within *Eucalyptus* plantations. Climatic conditions in Nuwara Eliya region presumably represent ideal conditions for its growth and survival (Temperature: 3-15 °C; Annual rainfall: 2,300 mm; RH: 75-90%). Manickam and Irudayaraj (1992) have identified its habitat as shrub-savannas and in open forest streams between 1,500-2,200 m in south India (Palni Hills, Munnar Hills and Anamalai Hills), the only other area of its geographical range.

Cyathea australis and *Dicksonia antarctica*

Well established naturalised populations of *C. australis* and *D. antarctica* were recorded from Pidurutalagala Mountain FR and an adjacent *Eucalyptus* plantation (Ranil *et al.*, 2014). The species inventory of the Hakgala Botanic Gardens shows that these two species were introduced into Hakgala Botanic Garden at least 120 years ago. They have evidently now escaped from the garden and are well established in the adjacent forest. The cool montane micro-climate and high elevation (1,745 m) of Hakgala Botanic Garden evidently match the ecological requirements of *D. antarctica*. This may be the main reason why *D. antarctica* was able to be introduced successfully into the fernery at the garden during the colonial era, as a species of considerable ornamental appeal. A similar micro-climatic environment also occurs in Pidurutalagala Mountain FR and in an adjacent *Eucalyptus* plantation. Both the natural forest area and *Eucalyptus* plantation consist of nearly 40-50 % canopy cover and 20-30% steepness (Ranil *et al.*, 2014). Both species appear to have similar micro-ecological requirements.

Ecological assessment is a continuous process. Detailed close observation and continuous monitoring at consecutive intervals are essential to draw firm conclusions. Many ecological parameters, such as temperature, light level, moisture and shade levels are highly variable over time. Continuous and long term assessment is therefore necessary to identify the detailed ecological requirement of each species.

Conservation perspectives

All tree fern species are confined to primary and secondary forest sites of the wet zone of Sri Lanka. Most of the forests remaining in the wet zone are now fragmented and small in extent. They continue to be degraded due to illegal destructive activities, suffering further fragmentation due to higher human population density in such areas. Further, the areas are highly subject to habitat loss, soil

erosion, environmental pollution and the spread of alien invasive species into disturbed areas. These problems will be worsened by local changes of climate/rainfall and increasing human population pressure.

The survey revealed that four *Cyathea* species (*C. sinuata*, *C. hookeri*, *C. srilankensis* and *C. sledgei*) are confined to a few known lowland rain forests and the population size of each of these species is small. All these forests are within the protected area network; and Sinharaja WHS and Kanneliya MAB reserve are highly protected, with no identified threats to their existing populations except the effect of local climatic change. Beraliya forest is a Proposed Reserve (PR) surrounded by highly urbanised cities and villages. These peripheral communities depend directly on the forest to meet some of their requirements, such as wood, fodder etc. Thus, the *Cyathea* populations in Beraliya PR are under considerable threat. Other small populations of *C. sinuata* and *C. hookeri* were observed in Runakanda PR in Kalutara district. These are under minimal threat from the surrounding community. Upgrading the current conservation status of these two forests is recommended to enhance the conservation of what is left of these magnificent forests, and the rare and threatened species and other animals and plants inhabiting them.

The main habitat of *Cyathea walkerae*, *C. gigantea* and *C. crinita* is roadside embankments, where their existing populations are unprotected and vulnerable to exploitation. The local people are unaware of their conservation value and ecological importance. This is a major impediment for their protection. People collect tree fern trunks directly from the wild from forest reserves as a support for growing orchids. They use the mature or semi-mature tree ferns, as ornamental plants in outdoor landscaping, thus destroying their natural populations, rather than from sustainable and responsible cultivation from spores, *Cyathea crinita*, confined to high altitude forests is also collected by communities. Though it is protected by several local and international laws, people continue to collect them from the wild without hindrance and at an increasing rate despite its dwindling populations.

The ultimate objective of this study is to provide ecological and distributional information on each species for their management and conservation. Members of the family Cyatheaceae are considered to be one of the most endangered plant groups among pteridophytes. Considering their biological importance as spectacular plants of great beauty and the unprecedented rate of threat to their associated natural ecosystems, all members of the family Cyatheaceae have been included in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1975. Furthermore, all tree fern species in Sri Lanka are protected by the Fauna and Flora Protection Ordinance and categorised as threatened species based on Red-listing criteria. Conservation biologists have therefore paid special attention to protect this important group of plants worldwide by providing legal measures to aid their conservation. But it is evident that the measures taken are not applied/enforced successfully in preventing

destruction of tree ferns as the message has not been properly disseminated or enforced locally among adjacent communities, schools, rural villages etc. Local commercial enterprises or people with gardens found contravening/flouting the laws are not being actively inspected and prosecuted. New measures are needed to actively enforce the laws enacted to protect tree ferns, which will also aid conservation of other threatened groups in general.

CONCLUSIONS

This study identified seven native tree fern species (*Cyathea hookeri*, *C. sinuata*, *C. sledgei*, *C. srilankensis*, *C. walkerae*, *C. crinita* and *C. gigantea*), including five endemic species and two adventive species (*C. australis* and *Dicksonia antarctica*). *Cyathea hookeri*, *C. sinuata*, *C. sledgei* and *C. srilankensis*, with limited populations are confined to lowland rainforests, whereas *Cyathea walkerae* is distributed over a wider elevational range throughout the wet zone. *Cyathea crinita* shows a restricted distribution pattern at a high altitude range in the central highlands of the island. In this study *C. gigantea* was recorded additionally from lowland rain forests, though previously it was reported to be confined to submontane and montane ecosystems. The exotic *Dicksonia antarctica* and *Cyathea australis* have naturalised in forest clearings in Piduruthalagala forest. The results of this study provide baseline information on the distributional ecology of Sri Lankan *Cyathea* species to formulate conservation guidelines for this unique gene pool in Sri Lanka.

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