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REVIEW

An analysis of the current status and future prospects of Sri Lankan pteridophytes towards a new dimension

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Abstract

Sri Lankan pteridophytes are important on a global and regional scale, because of the isolation of the flora in the Indian Ocean. Sri Lankan pteridophytes have been collected and studied since 1674. However, adequate attention has not been given to all aspects of the study of Sri Lanka's pteridophytes over the last century. The current knowledge is limited to species descriptions and locality checklists based on rapid surveys, and limited information on the ecological and conservation aspects of specific species or groups. Here, we try to critically review all past and current relevant literature to understand the present status and future perspectives of our knowledge. We intend to streamline the future research and conservation priorities of this untapped gene pool in the Indian subcontinent. We realize that the country needs a systematic survey across the island to estimate the number of taxa, with special regard to endemics. We also need to understand the pattern and impact of species distribution. We need to combine the identification of hotspots and more sensitive areas with the assessment of the conservation status of each taxon. This will support the drawing up of conservation guidelines and their implementation. Apart from the analysis of diversity and of ecological assessments, priority must be given to clarify the phylogenetic relationship and biogeographic history of Sri Lankan species. Moreover, pteridophytes need to be included in the country's research agenda for the general advancement of research on pteridophytes on the global level.

Keywords Conservation · Endemism · Extinction · Hotspots · Isolated gene pool

Introduction

Isolation is a key factor in all island biology, and it is usually defined as the distance to the geographically nearest mainland (Itescu et al. 2020). Island biodiversity is changing with some species becoming extinct, others changing in abundance, non-native species, in turn, becoming a part of many ecosystems, and humans shaping many ecological processes (Russell and Kueffer 2019). Human disturbances are greatly threatening to the biodiversity of vascular plants (Dai et al. 2020). Ferns are sisters to flowering plants and are the second-largest vascular plant group on earth besides angiosperms (PPG I (2016); Pryer et al. 2001). They number approximately 11,000 species and are distributed globally outside arctic regions. They have the highest density, though, in tropical mountain areas (PPG I (2016); Smith 1972; Schneider et al. 2004). Hamabata et al. (2019) claimed endangered island endemic plants have vulnerable genomes and are at higher risk of extinction than non-endangered species. Also, island populations usually have reduced genetic diversity and are more susceptible to extinction through genetic and demographic processes (Mills et al. 2004). Hence, the island population requires higher, more urgent conservation priority than the mainland population.

Sri Lanka is a tropical continental island harbouring and preserving unique biodiversity while playing a key role as a part of a global biodiversity hotspot. Despite the collective importance of the Western Ghats–Sri Lanka hotspot, the island Sri Lanka has some exceptional biodiversity that

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differs from the Ghats and southern India (Sarathchandra et al. 2021). Although its land area is not extensive, Sri Lanka is home to nearly 389 + lycophyte and fern taxa including 42 endemics which is a considerable number compared to other Asian countries (Ranil et al. 2022) (Fig. 1). It implies the significance of being an isolated island along with unique geo-climatic characteristics. In Sri Lanka, increasing rates of forest loss have been recorded from 80% in the 1800s to 25% by 2010 while escalating habitat degradation and changes in the microclimate of species. It depicts the necessity of a rapid and strategic plan to assess this unique and isolated gene pool for better planning of conservation, management, and sustainable utilization.

The rich fern diversity of the Indian subcontinent is mostly limited to checklists and species description (Fraser-Jenkins 1984, 1997, 2008, 2010; Fraser-Jenkins et al. 2015, 2016, 2018, 2020). The current knowledge on Sri Lankan lycophytes and ferns is largely based on a substantial collections made during the colonial era, namely Sledge's collections in 1951 and 1954 along with his series of publications from 1956 to 1982, and the two-volume, multi-author "Ferns of Sri Lanka" edited by Monika Shaffer-Fehre in 2006. According to the National Red List-2020, 25 species including one endemic are in the category of Critically Endangered (Possibly Extinct) and 207 species (59%) are treated under the threatened category (Ranil et al. 2020). Due to a

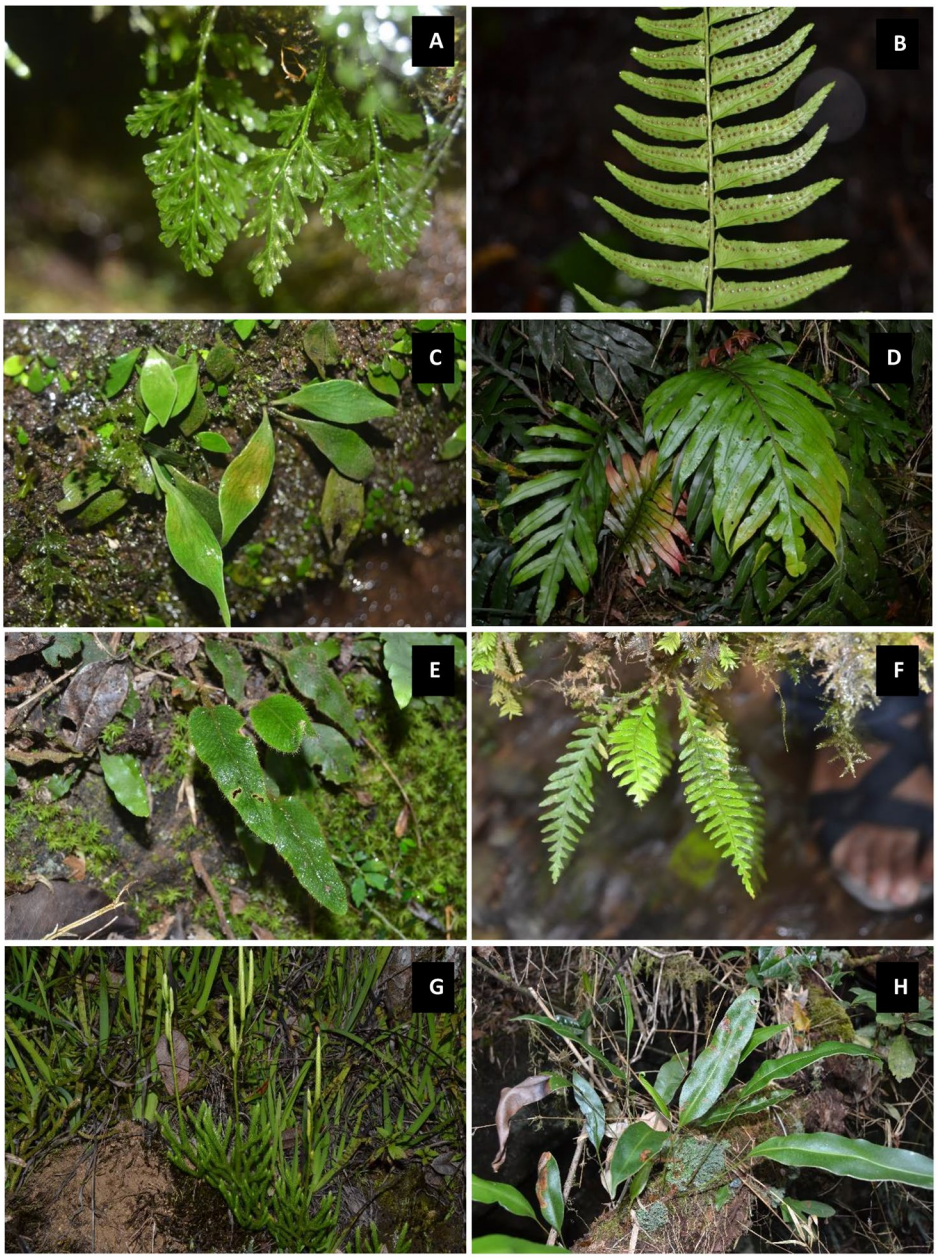

Fig. 1 Species confined to wet zone rainforests of Sri Lanka. A: *Hymenophyllum macroglossum* Bosch (endemic to Sri Lanka), B: *Polystichum harpophyllum* (Zenker ex Kunze) Sledge (endemic to Sri Lanka and South India), C: *Antrophyum plantagineum* (Cav.) Kaulf. (a threatened and rare species), D: *Austroblechum melanocaulon* (Brack.) Gasper & V.A.O.Dittrich subsp. *pallens* (T.C.Chambers & P.A.Farrant) Parris (confined to stream banks of high altitude forests), E: *Elaphoglossum spathulatum* (Bory) T.Moore (distributed in Africa and Sri Lanka), F: *Prosaptia obliquata* (Blume) Mett. (a relatively common ephiphytic species found in both low and high altitude wet zone forests), G: *Lycopodium japonicum* Thunb. (a threatened species in high altitude forests), H: *Elaphoglossum angulatum* (Blume) T.Moore (an endangered and rare species)

lack of updated and recent records, the current distribution pattern and conservation status of species are highly questionable. There is thus an urgent requirement for studies on Sri Lankan pteridophytes in the fields of taxonomy, distributional ecology, conservation biology and genetic variation.

Except some faunal groups (Ellepola et al. 2021), relationships among the Sri Lankan species and those in other geographically related areas are poorly known. The assessment of the phylogenetic relationship of Sri Lankan ferns and their biogeographic history will bring the Sri Lankan pteridophyte studies towards a new dimension of knowledge. Also, conservationists and policymakers claim that the available information is inadequate to set the conservation and management guidelines for all fern taxa in Sri Lanka (Ranil and Pushpakumara 2012; Ranil et al. 2020). Hence, the aim of this contribution is to provide updated information after the critical analysis of the past and present of pteridological studies in Sri Lanka, to serve as a taxonomic and nomenclatural basis for future botanical research, systematic studies, and conservation of this unique plant group.

Figure 1. Species confined to wet zone rainforests of Sri Lanka. A: *Hymenophyllum macroglossum* Bosch (endemic to Sri Lanka), B: *Polystichum harpophyllum* (Zenker ex Kunze) Sledge (endemic to Sri Lanka and South India), C: *Antrophyum plantagineum* (Cav.) Kaulf. (a threatened and rare species), D: *Austroblechum melanocaulon* (Brack.) Gasper & V.A.O.Dittrich subsp. *pallens* (T.C.Chambers & P.A.Farrant) Parris (confined to stream banks of high altitude forests), E: *Elaphoglossum spathulatum* (Bory) T.Moore (distributed in Africa and Sri Lanka), F: *Prosaptia obliquata* (Blume) Mett. (a relatively common ephiphytic species found in both low and high altitude wet zone forests), G: *Lycopodium japonicum* Thunb. (a threatened species in high altitude forests), H: *Elaphoglossum angulatum* (Blume) T.Moore (an endangered and rare species).

Historical expeditions of lycophytes and ferns (1672 – to present)

Sri Lanka has long fascinated botanists due to its unique geographical position in the Indian ocean and its floristic richness known since the 17th century. The systematic botanical study of Sri Lanka was initiated during the period of colonial expansion by the European powers in the 18th and 19th centuries (Dassanayake 2002). Such historical collections were largely deposited in herbaria throughout the world. During the conservation assessment for National Red Lists – 2012 and 2020, we studied approximately 2,500 specimens of Sri Lankan pteridophytes including a few type specimens at the National Herbarium in Peradeniya, Sri Lanka (PDA). In the present analysis, we identified more than 40 worldwide herbaria (A, AAU, AK, B, BEI, BISH, BO, BR, BM, CGE, CUL, CHRB, DD, E, F, G, GH, GZU, H, HAL, HCT, JE, K, L, LD, LIV, M, MICH, MO, NMNH, NMW, NY, OXF, P, RB, S, SING, U, UC, US, W, WELT and Z) that have Sri Lankan fern specimens, mostly distributed during the colonial era. Here we briefly discuss the important collections made by both local and foreign collectors from 1672 to present.

(A) collections made during the colonial era (1672 – 1948)

The first taxonomic knowledge of lycophytes and ferns of the country dates back to the Dutch colonial period. Paul Hermann (1672–1679) had collected a few fern specimens which were first described by Linnaeus (1747) in *Flora Zeylanica* and are currently deposited at the Natural History Museum, London (BM). However, the majority of Sri Lankan specimens were collected in the 19th century during the British Colonial period, by J.T. Walker (1830–1840), William Ferguson (1839–1887), G. Wall (1846–1894), Frederick Hutchinson (1870–1872) and R.H. Beddome (1863–1883, 1892) as botanists and G. Gardner (1843–1849), G.H.K. Thwaites (1849–1888), H. Trimen (1879–1896) and J.C. Willis (1896–1912) who served as Directors of the Royal Botanical Garden, Peradeniya.

Based on these collections, Moon (1824), Thwaites (1864), Wall (1873), Ferguson (1880), Trimen (1885), Yates (1887), and Willis (1911) have prepared catalogs and checklists for Sri Lankan pteidophytes. However, all the above collections were largely made in the central highland of Sri Lanka. With the establishment of the Royal Botanic Gardens, Peradeniya in 1821, many European botanists were involved in the exploration of natural forests in the central highland. Hence, they have not given adequate attention to species in lowland rain forests. After 1900, during two world wars, Sri Lankan fern exploration had been neglected for nearly 50 years until Dr. W.A. Sledge initiated his detailed work on Sri Lankan ferns from 1950 to 1982.

(B) W.A. Sledge's collection (1950 – 1951 and 1954)

The collection made by Professor W.A. Sledge, University of Leeds is considered a landmark of Sri Lankan fern studies. From 1950 until publishing his most comprehensive fern checklist in 1982, his entire taxonomic works are based on his massive collection which is currently deposited in European herbaria, mainly in BM, K and E. His collection dates back to 1950–1951 followed by 1954. As Sledge (1982) mentioned, except for 30 species, at that time he was able to collect allmost all Sri Lankan species during his systematic survey. Like other collectors, though his collection

was also largely based on the central highland of Sri Lanka, he visited some important forest ecosystems in the southern lowland forests for investigations. However, after Sledge's contribution until today no one has conducted a detailed and systematic exploration of the fern flora covering the natural ecosystems of Sri Lanka. Later works were also largely based on Sledge's collection and his detailed taxonomic publications of Sri Lankan pteridophytes rather than on new collections.

(C) other important collections (1955 – to date)

Apart from the above significant collections made during the pre- and post-colonial era, a systematic exploration has not been conducted over the last six decades. However, a number of taxonomists who worked on different families of angiosperms and ferns for the Flora of Ceylon project have collected fern specimens while they worked on families assigned to them. Robert B. Faden has made a substantial collection in 1976 covering different bio-climatic zones of Sri Lanka (Flora of Ceylon 2006). His collection is currently deposited at the Smithsonian Institution (US) and a few other American herbaria. Further, the Auckland War Memorial Museum (AK) and Museum of New Zealand Te Papa Tongarewa (WELT) are home to over 200 Sri Lankan pteridophytes specimens collected by Dr. John Braggins during his visit to Sri Lanka in 1982.

Christopher Fraser-Jenkins, Monica Shaffer-Fehre, Palitha Jayasekara, David Philcox, among many others, collected numerous specimens during approximately 1993–1995 while they were contributing to The Flora of Ceylon Project, which resulted in the two volumes of ferns for the multi-volume "Revision of the Flora of Ceylon" project. Hereafter it is cited as Flora of Ceylon (2006). However, their collections were largely confined to the selected sites of the ecosystems in the central highland of Sri Lanka and few specific sites of lowland rainforests. Only a few local botanists have made fern collections over the last four decades. Among these Prof. B.A. Abeywickrama's Lycopodiaceae collection at the Herbarium, University of Colombo and Dr. Palitha Jayasekara's Hymenophyllaceae collections at the PDA are important from a taxonomic point of view. Although Abywickrama (1964), Hearth and Ratnayake (2003), and Kandepola et al. (2006) conducted rapid surveys of fern flora in selected forests in the Central Province, their specimens have not been deposited in any herbaria. The exploration of ferns in Kanneliya Man and Biosphere Reserve (Ranil et al. 2004) and Piduruthalagala mountain (Ranil et al. 2018) were the only recent and detailed fern collections for the last 50 years. However, none of these collections were able to replace Sledge's systematic and most comprehensive collection until today.

Sri Lanka is still far behind the study of pteridophytes compared to the other countries in the region. To bridge the above gap, it is important to conduct a systematic survey across the island, while particularly focusing on poorly or non-botanized areas in lowland rainforests and isolated hills in all climatic zones. Furthermore, during the red listing process in 2012 and 2020, it was determined that the major impediment in Sri Lankan fern research is a lack of sufficient specimens, specifically within Sri Lanka: currently, there are only 1727 records available via GBIF (www.gbif.org) an average of less than five collections per species and the vast majority of those are from European herbaria. As an example, out of 622 specimens of Sri Lanka grammitid ferns studied, 90% of specimens have been collected before 1970, 60 years ago, and nearly 93% of specimens are currently deposited at 19 herbaria worldwide (Ranil et al. 2019). Hence immediate priority should go to the exploration, collection, and documentation of species distributed in different vegetation types of the country.

Diversity and endemism

Sri Lankan pteridophytes are of special importance due to the species richness and number of endemics to the island and also approximately, 50% of Sri Lankan fern taxa are shared with the fern floras of South Asia, South East Asia, and China (Flora of Ceylon, 2006). The first inventory of Sri Lankan ferns dated back to 1824. Moon (1824) included a list of 83 species of ferns and their local names in his Catalogue of the Indigenous and Exotic Plants growing in Ceylon. The outstanding work carried out by Thwaites (1864) included 222 pteridophyte species. Later, several fern checklists were compiled by British botanists who actively contributed to the field of Sri Lankan botany (Wall 1873; Ferguson 1880; Trimen 1885; Yates 1887; Willis 1911). Starting in 1956, Sledge wrote a series of papers giving revised accounts of genera and groups of genera, and a final paper with a complete and annotated list of all the known pteridophytes of Sri Lanka (Sledge 1982). Prior to this comprehensive checklist, Abeywickrama (1978) also compiled a checklist, which was entirely based on Beddome (1866,1883) and Sledge's series of publications. Though Fernando (2002) also published a checklist for Sri Lankan ferns, none of these species lists was able to replace Sledge's comprehensive and detailed work on Sri Lankan pteridophytes.

Our current knowledge of the pteridophyte flora in Sri Lanka comes largely from above-named two-volume Flora of Ceylon (2006). This is mainly based on morphology, existing herbarium collections and recent fresh collections for the Flora of Ceylon Project, the work increased the 332 taxa listed by Sledge (1982) up to 348. In the last two

decades, there has been substantial progress in pteridology in India, which includes checklists, taxonomic reviews, and other scientific publications (see Fraser-Jenkins 1997, 2008; Fraser-Jenkins et al. 2016, 2018, 2020). The contributions of Jayasekara (1996), Ranil and Pushpakumara (2012) and Ranil et al. (2010a, 2010b, 2014, 2016) also increased the number of taxa known at local levels. Currently, Ranil et al. (2022) is compiling a Sri Lankan pteridophyte list which consists of around 390 taxa including subspecies, varieties and naturalized species. The sequential changes of the number of taxa over the last one and half century are given in Fig. 2.

Despite its relatively small land size, Sri Lanka is home to 42 endemic taxa particularly distributed in the wet zone of Sri Lanka which is a considerable number compared to the endemism in other countries in the region. Sledge (1982) identified 57 endemic taxa during his enumeration of the fern flora of Sri Lanka. Later the Flora of Ceylon (2006) reduced these to 48 which was later reduced by Ranil et al. (2016) to 47 taxa. While reviewing the last decade or two, the number of endemic pteridophytes has changed largely due to recently conducted pteridological studies in South India and also due to reidentification of previously misidentified species. However, the number was further reduced to 42 taxa in a forthcoming Sri Lankan list (Ranil et al. 2021).

Biogeographic significance

Islands are ideal for investigating processes that shape species assemblages because they are isolated and have discrete boundaries. Also due to their isolated nature, islands are characterized by limited colonization and evolutionarily unique biotas (Weigelt et al. 2015). Sri Lanka has long been isolated from mainland India, and the country is blessed with a unique and remarkable diversity of flora and fauna. The genetic diversity of species is primarily a result of geo-evolutionary processes that include spatial, and seasonal variation in the past and present climate, and secondarily due to variation in relief, topography, and soil (Gunawardene et al. 2007; Gunatilleke et al. 2005, 2017; Gunatilleke and Gunatilleke 1990).

Sri Lanka's pteridophytes are of great importance both on a regional and on a global scale. This is due to the island's position as a major, western outlier of the Asia-Pacific pteridophyte flora (Ranil et al. 2019). As Fraser-Jenkins (1984, 2010) stated, the species found in the Sri Lankan/South Indian, or "Hindulankan" region show a strong affinity with the Malesian flora in South East Asia, the Sino-Himalayan flora in north east India and show a lesser degree of affinity to African elements in East Africa, Madagascar, the Mascarenes, and Seychelles. The affinity between Sri Lankan species of other continental areas might recall Gondwanan history or mechanisms of long distance dispersal.

For example, the past and present distributional records evident that Elaphoglossum species in Sri Lanka share with various regions of the world. But such a biogeographic pattern has not been studied yet. Out of four species found in Sri Lanka, *Elaphoglossum angulatum* (Blume) T.Moore is distributed in Africa, South Asia and South-East Asia and shows the Sri Lankan connection with Africa and South-East Asian elements. *Elaphoglossum commutatum* (Mett.ex Kuhn) Alderw. has South-East Asian affinities and occurs in Sri Lanka, South India, Java, Sumatra, Borneo, and New

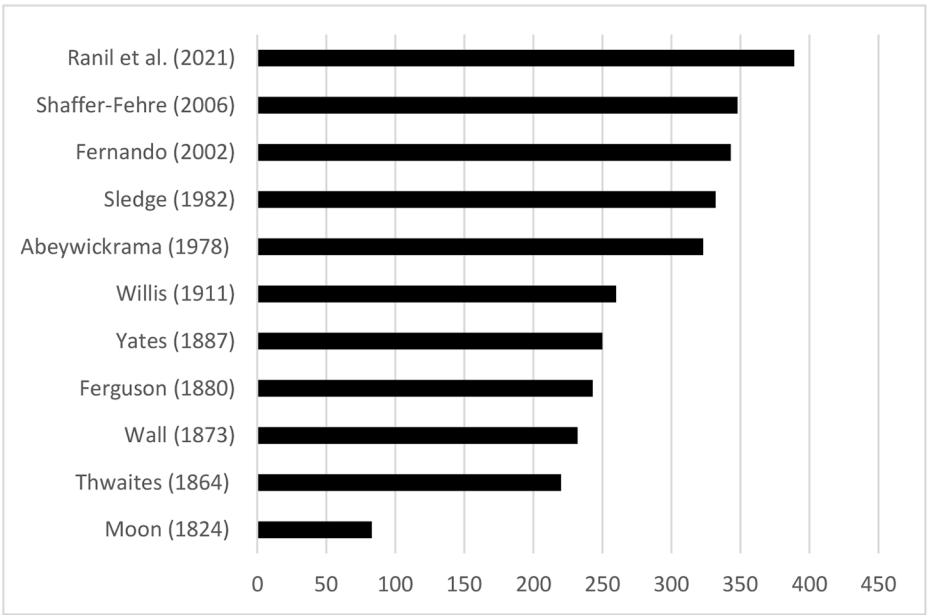

Fig. 2 Change in number of taxa over the last two centuries

Guinea. Interestingly, *Elaphoglossum spathulatum* (Bory) T. Moore is confined to Africa and Sri Lanka, whereas *Elaphoglossum ceylanicum* Krajina ex Sledge is endemic to Sri Lanka. Other classic examples are, *Asplenium gardneri* Baker which is confined to Sri Lanka and Sumatra; Sri Lanka and South India, then, are the Asian center for the African *Pellaea bovinii* Hook. Figure 3 shows several of these interesting distribution patterns of selected Sri Lankan fern species in connection with other geographically related areas. The pattern that has evolved concerning the relationship between distribution and geography still awaits further study.

Holttum (1981) proposed an affinity between Sri Lankan tree ferns and African elements based on morphological similarities. In agreement with Holttum (1981), Ranil et al. (2010b) found evidence of a morphological similarity of *Alsophila srilankensis* (Ranil) Ranil to *Alsophila humilis* J.Sm., in Tanzania and Kenya, and to *Alsophila schliebenii* Reimers in Tanzania. However, Janssen and Rakotonduainibe (2008) claimed that Sri Lankan tree ferns form a monophyletic group not closely related to African tree ferns and that they may have evolved in situ for long periods of time. The phylogenetic position of Sri Lankan tree ferns remains to be further elucidated.

It is clear that Sri Lankan fern species have not been extensively studied for their phylogenetic relationship and biogeographic history. To clarify phylogenetic relationships and the biogeographic history of Sri Lankan species and to compare them to other areas of phytogeographic relationship in the region is a prime need. Therefore, future research needs to be focused on a comprehensive and in-depth analysis of the Sri Lankan ferns to elucidate their phylogenetic relationships as well as their biogeographic history in collaboration with scientists working in the field of biogeography.

Distributional ecology and hotspots

The picture of distributional patterns and ecology of Sri Lankan pteridophytes is vague and the currently available information is inadequate to identify specific habitats and

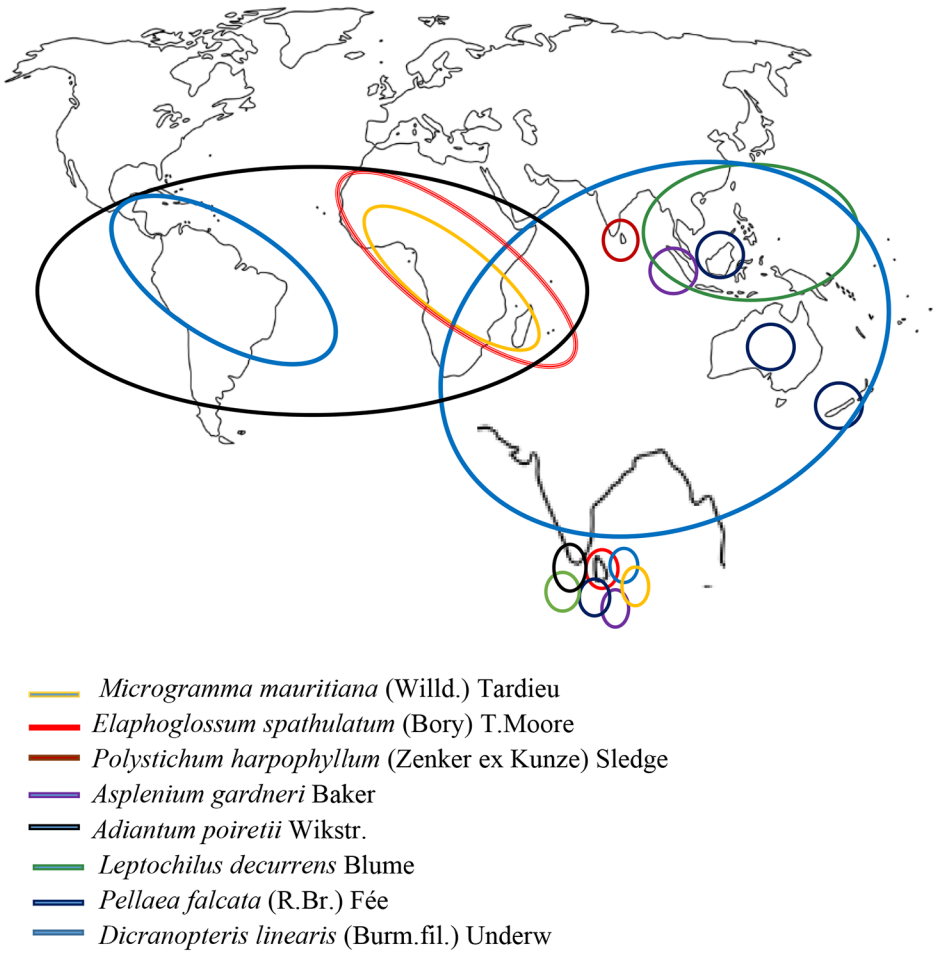

Fig. 3 Distributional range of selected fern species

their distributional range. However, for angiosperms, priority areas, hotspots, and endemic zones have been identified (Gunatilleke and Gunatilleke 1990). We believe that mapping of past herbarium records over the last 200 years will help to identify the priority areas. Then assemblages of future findings will provide a strong base for conservation aspects. Here, we provide some information on such priority areas for pteridophytes after analysis of past distributional records and field experiences over the last two decades.

Most ferns are water-dependent plants that require a continuous supply of moisture for their reproduction and growth. Due to high annual precipitation (2,500–5,000 mm) and high relative humidity associated with elevational gradients, the wet zone creates ideal habitats for pteridophytes (Fig. 4). Approximately 81% of Sri Lankan lycophytes and ferns are confined to the wet zone ecosystems (Jayasekara and Wijesundara, 1993). Moreover, the wet zone; which accounts for only one-third of the country's total land area, contains all currently known endemic pteridophytes (Ranil

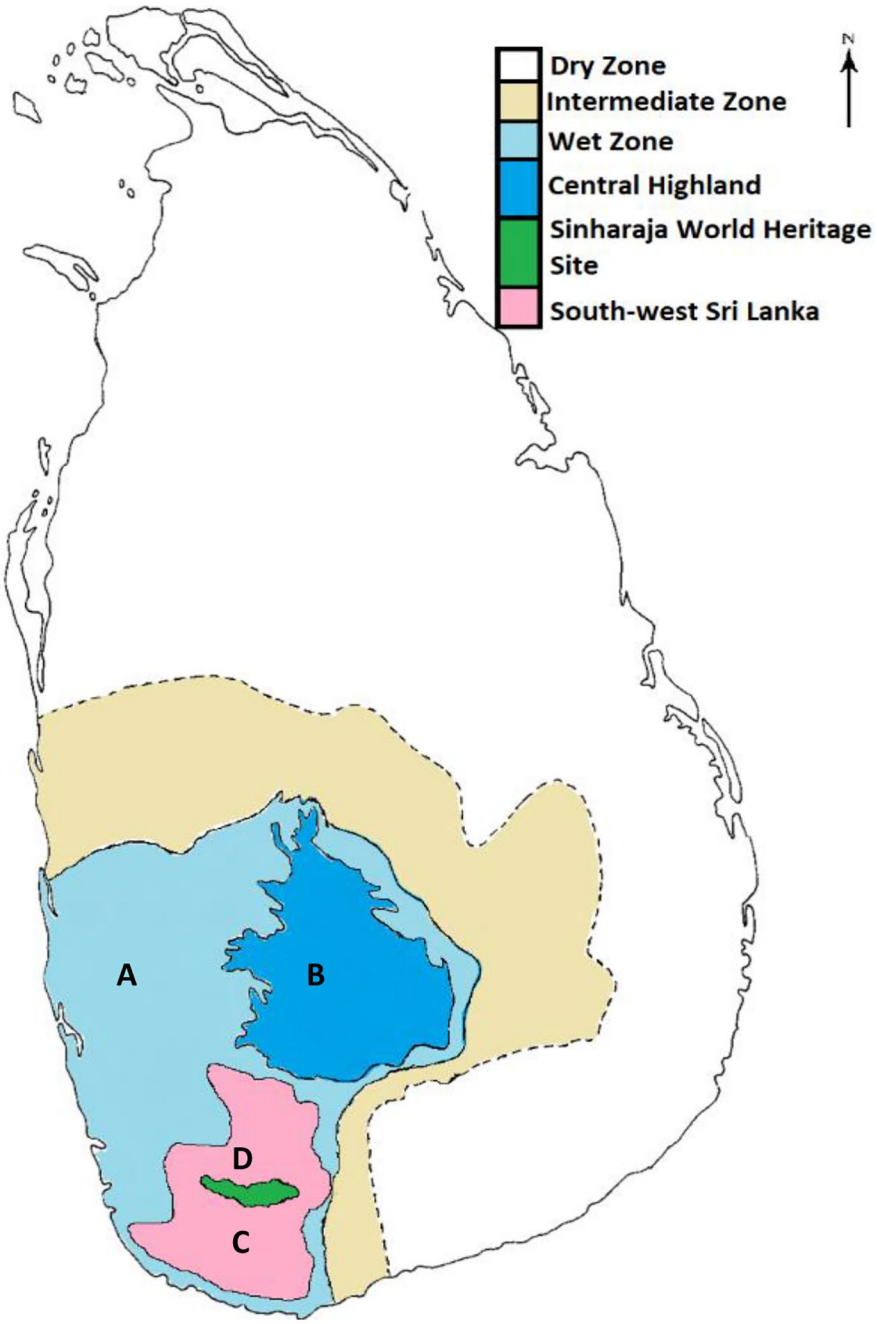

Fig. 4 priority zones for pteridophtes, A: the wet zone of Sri Lanka (covers south-western region and central highlands; mean annual rainfall over 2,500 mm), B: Central highland (the south central part of Sri Lanka and covers thee administrative districts), C: South West of Sri Lanka (covers the lowland and lower montane regions), D: Sinharaja World Heritage Site (covering an area of 8,864 ha and ranging from an altitude of 300–1,170 m); mean annual rainfall 2,500–5,000 mm)

et al. 2008c). Ranil et al. (2017) revealed that all tree fern species are confined to the wet zone of Sri Lanka. This zone is home to all grammitid ferns including eight endemics (Ranil et al. 2019) (Fig. 5). This agrees with the pattern observed for the Island's flowering plants where 88% of the species, and 95% of the endemics, occur in the wet zone (Dassanayake and Fosberg 1980–1991; Dassanayake and Clayton 1995–2000; Dassanayake et al. 1994). We identified three priority areas for pteridophytes, the central highland, South-Western hill forests and Sinharaja World Heritage Site within the wet zone after analysis of past distributional records and field experiences.

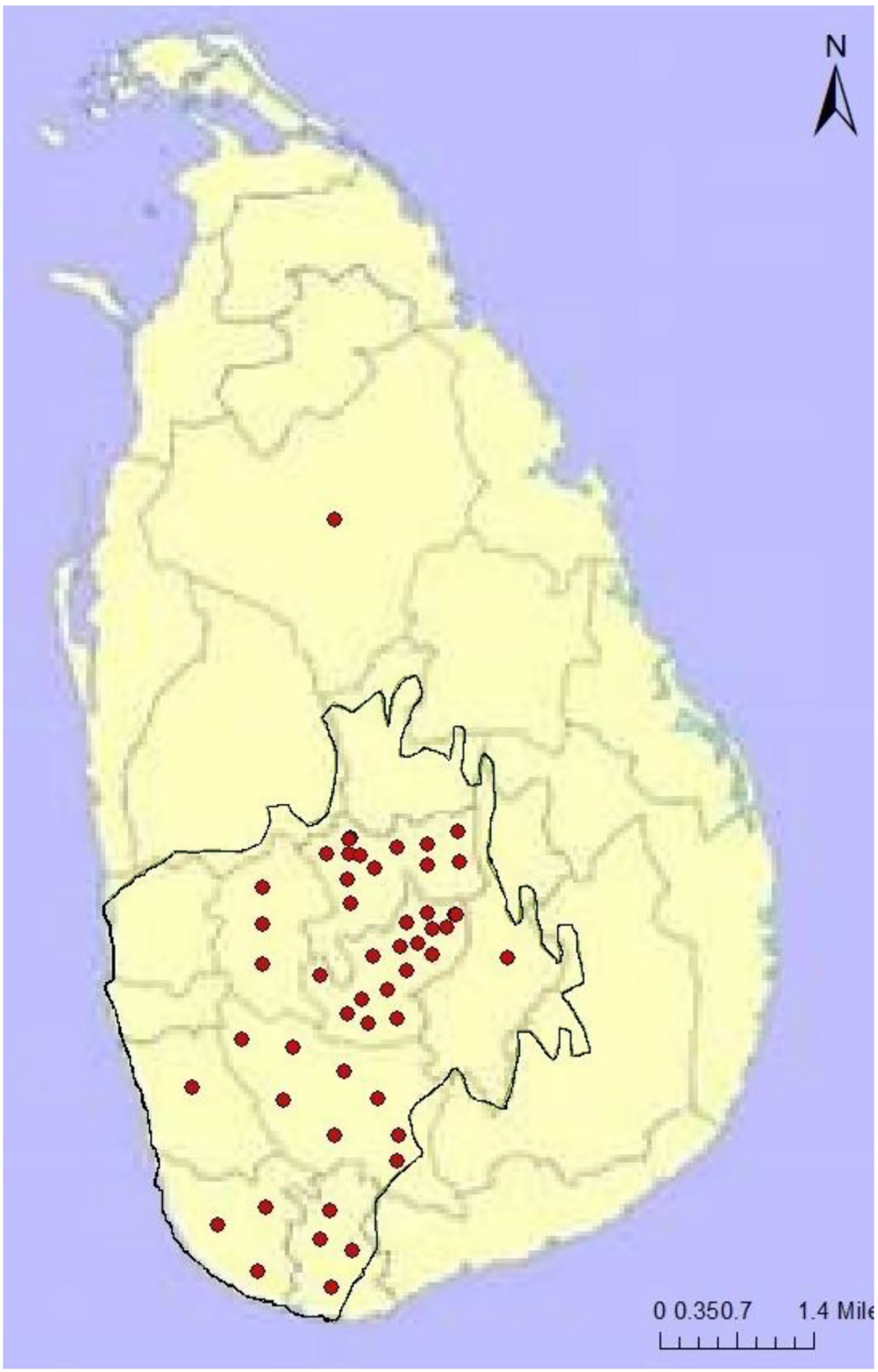

Fig. 5 distribution pattern of grammitid ferns of Sri Lanka; except for one location, all locations are confined to the wet zone forests of Sri Lanka which is demarcated by a black border

(A) Central highland

The central highland is one of the biologically richest and hydrologically most important areas of the wet zone. The central highland (Kandy, Matale, and Nuwara Eliya districts) holds more than two-thirds of the country's lycophytes and fern species Abeywickrama 1964; Herat and Rathnayake 2003; Ranil et al. 2005; Kandepola et al. 2006; Ranil 2006a; Flora of Ceylon 2006; Ranil et al. 2017). Most of the major ecosystems in the central province have been fully botanized for ferns during the colonial era, likely due to their close proximity to the botanic gardens. Therefore, European botanists have carried out most of their surveys associated with montane and sub montane forest in the central province, yielding a substantial amount of specimens and information. Ranil et al. (2008) revealed that the central province alone has 78% of the endemic taxa, of which the Nuwara Eliya district is home to 34 endemic taxa suggesting that area of the central province is a critical habitat for endemic taxa. Such figures will be altered, though, with the decrease of the number of endemics in the future publication. Still, the central highland would be the focal point for Sri Lankan lycophytes and ferns (Fig. 4).

(B) South-Western hill forests

The south-western hill forests of Sri Lanka, harboring a relict of the Decan-Gondwana biota represent an important element of the Sri Lanka - Western Ghats Biodiversity Hotspot (Gunatilleke et al. 2005). The south-western hills of Sri Lanka are defined as the hills and hill ranges in the lowland and lower montane seasonal climatic regions, to the south and south-west of the central massif of the island which has an extensively studied flora and fauna (Gunatilleke and Gunatilleke 1984;1990; Gunatilleke et al. 2005). Lycophytes and ferns of south-western forests have not been adequately investigated since the colonial era. The only detailed assessment that was carried out by Ranil et al. (2004) in the Kanneliya MAB reserve revealed that the area is home to a considerable number of endemic, rare, and threatened ferns. Also, 34 endemic ferns species thrive in South-western forests (Ranil et al. 2008), of which *Alsophila hookeri* (Thwaites) R.M.Tryon, *Alsophila sinuata* (Hook. & Grev.) R.M.Tryon, *Alsophila sledgei* (Ranil, Pushpak. & Fraser-Jenk.) Ranil, *A. srilankensis*, *Trigonospora angustifrons* Sledge and *Leptochilus wallii* (Baker) C.Chr. are confined to South-western hill forests. Among all forests in the region, Sinharaja World Heritage site is considered as the largest relatively undisturbed, primeval lowland, and lower montane rain forest left in the country(Fig. 4).

(C) Sinharaja World Heritage Site (SWHS)

The species richness, distributional pattern, population dynamics, and ecological perspective of the flora in SWHS have been extensively studied over the last four decades. Though the ferns of Sinharaja have not been studied to any great extent, our personal observation and rapid surveys show that the forest is home to approximately 28% of the island's lycophytes and fern species (based on unpublished data). Moreover, the Sinharaja forest itself harbors 86% of the native tree ferns of Sri Lanka (Ranil et al. 2017). Also, SWHS is the type locality of *A. hookeri*, *A. sledgei*, *A. srilankensis*, and *Prosaptia ceylanica* Parris (Ranil et al. 2010a, b; Flora of Ceylon 2006). Surprisingly, the Sinharaja forest is the only known locality for *Lindsaea pectinata* Blume and *Teratophyllum aculeatum* (Blume) Mett. ex Kuhn and both species are confined to restricted populations. *Prosaptia ceylanica* is also confined to its type locality in Sinharaja. The rapid surveys conducted by Ranil et al. (2007) and Sudaya (2006) on Mulawella mountain and the Forest Dynamics Plot in Sinharaja respectively, also emphasized the importance of exploration of this unique group in the SWand isolated gene pool in the SWHS, Sri Lanka.

In this situation we strongly suggest conducting a systematic survey across the island while giving much weight to South-Western forests in the wet zone of Sri Lanka. Also, the botanized and un-botanized mountains and mountain regions of the central highland need to be revisited. For example, Adam's peak world heritage site (21,000 ha) has been largely neglected by fern collectors up to now. Also, the number of isolated hills and hill ranges in the first peniplain across the island need to be explored for ferns due to a significant chance to find new taxa whilst also studying ecological adaptations of species. The Ritigala isolated hill range is the classic example: it is high enough to be cooler and to receive more precipitation than the surrounding dry lowland, it provides an range of environments of different altitudes and it supports a large variety of species that are otherwise distributed over a geographically vast area with diverse climatic conditions (Jayasuriya and Pemadasa 1983). Some fern species were identified as being confined to moist and shady habitats of the tropical rainforest. Interestingly some of these species have been recorded from the summit of Ritigala despite a long dry spell in this locality, namely the lower eastern slope of Ritigala (Abeywickrama and Dassanayake 1955). Furthermore, species reported to be confined to moist and shaded wet zone forests (*Asplenium zenkerianum* Kunze, *Phlegmariurus phlegmaria* (L.) Holub, *Prosaptia alata* (Blume) Christ, *Pyrrosia ceylanica* (Giesenh.) Sledge, *Lastreopsis tenera* (R.Br.) Tindale, *Ophioderma pendula* (L.) C.Presl., *Hymenophyllum tenellum* D.Don, *Pronephrium triphyllum* (Sw.) Holttum,

Microsorum membranifolium (R.Br.) Ching are and *Leptochilus pedunculatus* (Hook. & Grev.) Fraser-Jenk. where discovered on the isolated hill of Ritigala in the very much dryer part of the country. Hence a future systematic survey is required to make an inventory of the fern flora in such unique hills of the drier part of the island and pin-point ecological adaptions and unusual distribution patterns of that flora.

Conservation perspectives

Biological diversity in Sri Lanka is currently under an alarming threat due to increasing population pressure, unplanned agricultural and development activities, habitat degradation, fragmentation, and loss of habitats (Gunatillike et al. 2017; Ranagalage et al. 2020). Between 1900 and 1988 Sri Lanka's forest cover reduced from 70% to about 20% (Preu and Erdelen 1992). These human impacts on the forests in Sri Lanka have caused not only a general degradation of land in the areas directly affected, but have also caused

Fig. 6 a possibly extinct fern species, *Davallia trichomanoides* Blume in Sri Lanka deposited at the Auckland War Memorial Museum (AK)

geo-ecological changes in distant areas (Preu and Erdelen 1992; Ranagalage et al. 2020). As a result, most of the species including lycophytes and ferns have lost their preferred habitats, and remaining habitats are also seriously threatened due to various anthropogenic factors. Here we discuss the initiative taken for the conservation of lycophytes and ferns, and approaches to set the future effective conservation strategies in place.

(A) The National Red list – 2020

According to the National Red List – 2020, out of 350 native taxa, 25 species including four endemics (*Asplenium disjunctum* Sledge, *Dryopteris undulata* (Bedd.) Kuntz, *Leptochilus wallii* (Baker) C.Chr and *Pronephrium gardneri* Holttum) are in the critically endangered (possibly extinct) category (Table 1; Figs. 6 and 7). Moreover, 207 taxa (59%) are in the threatened category (CE: 49, EN:87, VU:71). Another 38 taxa are listed as near threatened (NT). Dryopteridaceae (76%) is the most threatened family followed by Athyriaceae (75%) and Thelypteridaceae (64%). Also out of 42 Sri Lankan endemic taxa, 28 (67%) are listed as threatened in the present Red List. Finally, 16 taxa make up the category "data deficient" (DD) .

Similar to the National Red List – 2012, the National Red List – 2020 was also largely based on historical herbarium specimens and on fresh collections gathered specifically over ca. 50 years for the Flora of Ceylon Project and cited in the Revised Handbook to the Flora of Ceylon: volume 15 (Part A & B) (Shaffer-Fehre 2006; Ranil and Pushpakumara 2012; Ranil et al. 2020). Due to inadequate information and recent records, criteria B (EOO/AOO) was used to assess

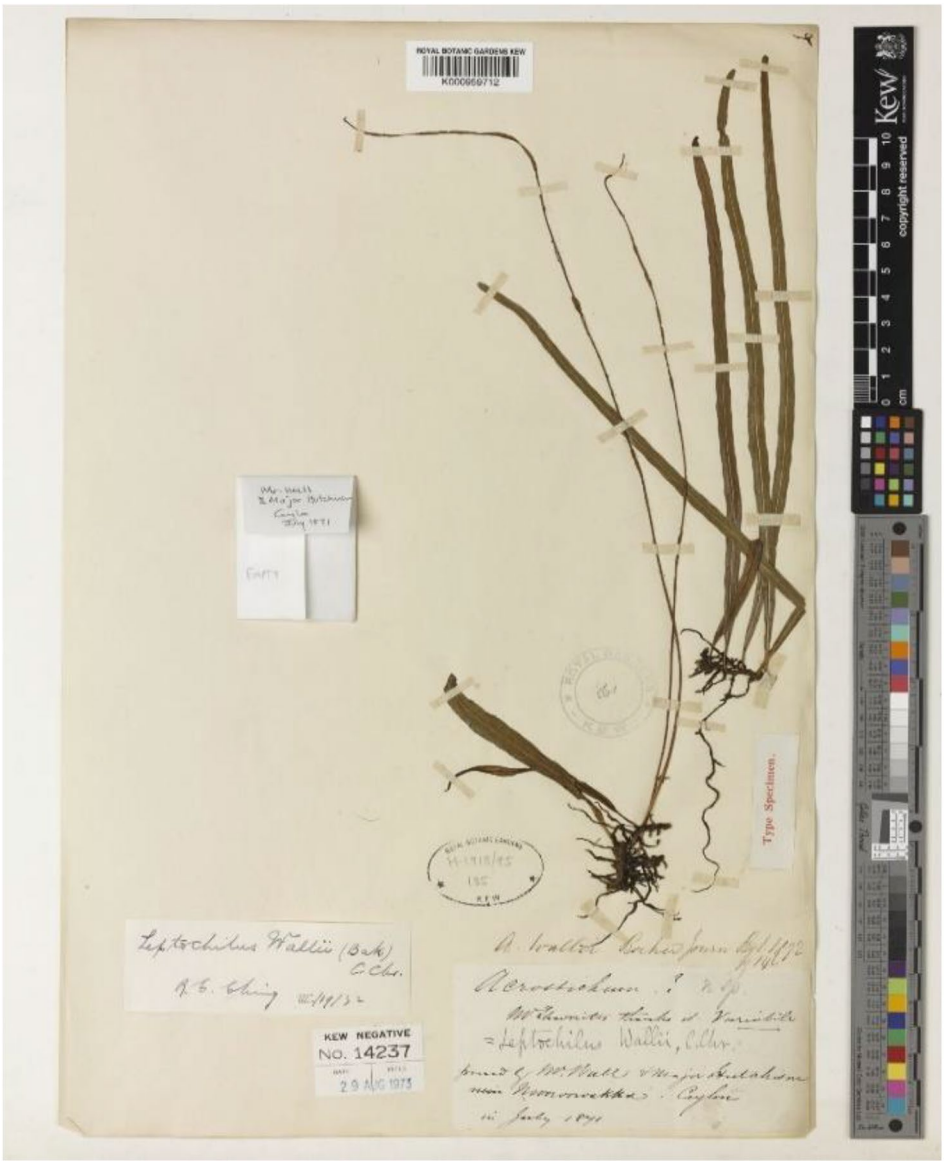

Fig. 7 *Leptochilus wallii* (Baker) C.Chr., an endemic and supposed to be extinct species from Sri Lanka deposited at the Kew herbarium (http://specimens.kew.org/herbarium/K000959712)

the conservation status. The total number of threatened taxa (199) in the 2012 list has increased by eight taxa in the 2020 list which is evidence that there was only modest conducted species exploration from 2012 to 2020. It is a well-known fact that after the W.A. Sledge (1951–1954), no one has conducted a comprehensive survey of the fern flora of Sri Lanka until now. Hence, the conservation status of some of the taxa listed in the National Red List – 2020 must be revised with new sampling in the future.

The best example is the genus *Microlepia* in Sri Lanka. Out of seven *Microlepia* species, three species are considered critically endangered (possibly extinct); two species are critically endangered in Sri Lanka. Also, *Microlepia speluncae* (L.) T.Moore is an endangered species, whereas *Microlepia hallbergii* (d'Almeida) C.Chr. is listed under the data deficient category. Such conservation status was entirely based on a collection made by European botanists during 1819–1888 and a few collections made by Sledge from 1950 to 1954. Therefore, to define a conservation status for species using insufficient and outdated information will not provide a clear picture of their conservation status. Some systematic surveys have resulted in the rediscovery of species supposed to be extinct and further new species and new records from Sri Lankan collectors over the has last two decades. A presumed extinct species, *Didymoglossum motleyi* (Bosch) Ebihara & K.Iwats. been collected by Jayaseekara (1996) during his enumeration of the family Hymenophyllaceae. Also, two new endemics and two new naturalized tree fern species have been recorded during an ecogeographic survey of tree ferns of Sri Lanka (Ranil et al. 2017). The above facts clearly demonstrate that a systematic survey across the island will significantly change the current status of Sri Lankan lycophytes and ferns in the next red listing process.

(B) Ex-situ and In-situ conservation

Currently, most of the natural forests are managed under the protected area network of Sri Lanka and have adequate legal protection. Implementations, though, of such legal measures show a little drawback. Out of a total number of species, 88 have been protected under the Fauna and Flora Protection Ordinance. Species found in the protected area network are legally protected by several acts and ordinances, but in-situ conservation is challenged by some of the illegal activities in natural forests and by the 'climate change' scenario (Ranil and Pushpakumara 2012). The current setup of the ferneries in Botanic Gardens need to be matched with the principles of ex-situ conservation of ferns giving much priority to endemics and endangered species. Hence, the establishment of ferneries is important not only for ex-situ conservation but also to disseminate knowledge to the wide range of concerned audiences, making them aware of the diversity and conservation aspects of ferns and lycophytes.

Table 1 The list of critically endangered (possibly extinct) ferns species in Sri Lanka

Species	Last record
Adiantum poiretii Wikstr.	Dimbula, Nuwara eliya district, ?1880, *Ferguson* (PDA).
Anogramma leptophylla (L.) Link	Near Badulla, Hingumgama, *Freeman* 337A, 338D, 339C, 340D (BM).
Asplenium disjunctum Sledge	Passara, Badulla district, 457 m, Feb 1885, *Pole* (PDA); Mandagala, Monaragala distict, May 1885, *Nevill* (PDA).
Asplenium grevillei Wall. ex Hook. & Grev.	Wehigala, near Matale, Sep 1887, *Frederick* (PDA).
Asplenium pellucidum Lam.	Near Galle, Galle district, (PDA).
Christella zeylanica (Fée) Holttum	Kitulgala, Kegalle district, 1887, *Wall* (P).
Chrysogrammitis glandulosa (J.Sm.) Parris	Nuwara eliya district, Ramboda, ?1849–1888, *Thwaites C.P. 1289* (B, BM, CGE, K, PDA).
Davallia squamata (Decne.) Mazumdar & P.Vijaykanth	*Thwaites C.P. 2834* (P); *3288* (BM, BO, K, P, PDA)
Davallia trichomanoides Blume	?1887 *Wall* (AK).
Dryopteris sledgei Fraser-Jenk.	Locality unkown, "Ceylon" ex Hort. Kew, *J. Smith s.n*., 1857 and 18,858 (BM)
Leptochilus lanceolatus Fée	*Gardner 1157* (K).
Leptochilus wallii (Baker) C.Chr	July 1871, *Wall and Hutchison* (K).
Microgramma mauritiana (Willd.) Tardieu	A photograph of poorly labeled specimens is shown in Fraser-Jenkins (2008)
Microlepia firma Mett. ex Kuhn	Hantana, Kandy district, *Gardner*, 1119 (BM) (1843–1849)
Microlepia majuscula (E.J.Lowe) T.Moore	1900, *Fleischer* (K).
Microlepia platyphylla (D.Don) J.Sm.	*Thwaites C.P. 3277*, (BM).
Oreogrammitis beddomeana (Alderw.) T.C.Hsu	Bogawantalawa, 1520 m, Nuwara eliya district, *Thwaites*, (BM, PDA).
Pellaea boivinii Hook.	*Thwaites* C.P. 3363, (BM, K, PDA).
Pellaea falcata (R.Br.) Fée	Hakgala, Bambarawella fall, Nuwara Eliya district, March, 1890, *Nock*, (PDA).
Pronephrium gardneri Holttum	*Thwaites C.P. 3063*, (K).
Pteridrys cnemidaria (Christ) C. Chr & Ching	*Thwaites C.P. 3274*, (BM,K,W).
Pteris mertensioides Willd.	*Thwaites C.P. 1047*, (BM).
Pteris pellucens J.Agardh	*Thwaites C.P. 3945*, (BM, CGE).

Source: Flora of Ceylon (2006); Ranil et al. (2020)

(C) Future conservation priorities

Conservationists and policymakers claimed that the available information is inadequate to set the conservation and management guidelines for all fern species in Sri Lanka (Ranil and Pushpakumara 2012; Ranil et al. 2020, 2021). Hence, future studies need to be focused on narrowly distributed species, endemic taxa, and species listed under the high-risk categories. Moreover, strengthening of ferneries in the National Botanic Garden Network is important as a supplementary conservation measure of the country's fern flora. Special attention is needed for the study of distributional ecology, particularly threatened and endemic species, in parallel to studies relating to their reproductive biology and habitat preferences. It is strongly recommended that studies on conservation aspects of threatened and endemic species need to be included in the country's research agenda.

Analysis of pteridological researches in Sri Lanka

The rich fern diversity in Sri Lanka has only been studied in some detail by Dutch and British botanists during the colonial era (1640–1948). In addition, a limited number of ecological surveys and botanical expeditions have been carried out during the last century, but such studies failed to replace the significant work done by early botanists during the colonial era. Sri Lankan fern species have not been studied for their phylogenetic relationship and biogeographic history. Hence, future pteridological researches have to be extended to increase our current understanding of studies focusing on all aspects of species in the large extent of un-botanized areas in the island. Here we summarize the pteridological studies conducted by local and foreign botanists over the last two centuries.

(A) Diversity assessments and taxonomic studies

From the beginning until today, the main attention was given to specimen collection, rapid survey and preparing catalogs and checklists (Moon1824; Thwaites 1864; Beddome 1883; Wall 1873; Ferguson 1880; Trimen 1885; Yates 1887; Willis 1911; Abeywickrama 1956, 1978; Sledge 1982; Fernando 2002 and Ranil et al. 2022) rather than in-depth morphological or molecular analysis, and critical assessment of ecological and conservation aspects. But such initial and scattered works have largely supported later studies conducted on Sri Lankan ferns. Among historical botanists, R.H. Beddome has paid adequate attention to Sri Lankan ferns in his enumeration of the flora of British India (Beddome 1883) rather than just listing of species. Although most of Beddome's species are taxonomically out dated, his complete and carefully prepared botanical illustrations are still valid and useful for identification.

William Arthur Sledge (1904–1991) significantly contributed to today's knowledge on the taxonomy of Sri Lankan pteridophytes through field collections and publishing of a series of articles Sledge 1956, 1960, 1962, 1965, 1967, 1968, 1972, 1973a, b, 1973c, 1981a, 1981b, 1982) which provided a strong base for current and future works in Sri Lanka. Apart from that, Manton (1953), and Manton and Sledge (1954) published chromosome numbers and some taxonomic issues of 140 Sri Lankan pteridophytes showing the importance of cytological evidence for fern taxonomy. Panigrahi and Manton (1958) conducted studies in the field of cytology and taxonomic observations on some members of the *Cyclosorus parasiticus* comp1ex. Walker (1956, 1960) identified a new fern genus (*Idiopteris*) from Sri Lanka and conducted a detailed study on the *Pteris quadriaurita* complex in Sri Lanka. Parris (2001a, 2001b) gave a description of Grammitidaceae in Sri Lanka. The initial local involvement of pteridological studies began with Abeywickrama (1956) and later Abeywickrama (1964, 1978), Abeywickrama and Dassanayake (1956); Abeywickrama and De Fonseka (1975) discussed some taxonomic issues in specific species and groups. Additionally Ranil et al. (2006b, 2008) and Rajapaksha (2021) discussed taxonomic issues of selected species.

The five volumes of handbook to the flora of Ceylon is an outstanding work and it was compiled by Henry Trimen from 1893 to 1900 with the support of the Smithsonian Institution and thereafter by the British Overseas Development (BOD) (Dassanayake 2002). Although ferns were not included in Trimen's original five-volume "A Handbook to the Flora of Ceylon", the BOD agreed to finance the preparation of, an additional volume in the new work "A Hand-Book to the Flora of Ceylon" in order to provide an accessible taxonomic basis for studies on fern flora of Sri Lanka. Though the Revised Handbook to the Flora of Ceylon was compiled in 1995, the ferns were published only in 2006 in the last volumes (15 A & B) of the series.

The Hand-Book to the Flora of Ceylon (2006) includes complete and detailed botanical descriptions for 351 taxa with their occurrence data compiled by eminent pteridologists from recognized international institutes. Such descriptions were largely based on previous and newly collected herbarium specimens, particularly deposited at PDA (top collection), BM, E, K. As Flora of Ceylon (2006) stated the previous work of Sledge (1956–1982), too, is a highly erudite treatment that was a welcome guide to many. Even though the Flora of Ceylon – volume 15 is taxonomically out of date and does not contain botanical illustrations, it is

still valid and widely used due to its carefully and accurately prepared species descriptions (Ranil et al. 2020).

Diversity assessment and preparation of species inventory for a particular ecosystem will provide fundamental information to setting a management and conservation guideline. Abyewickrama (1964), Herat and Rathnayake (2003) prepared a species inventory for the Knuckles world heritage site, covering 21,000 ha from the central highland of Sri Lanka. Samarakoon (1999); Kandepola et al. (2007/2008); Ranil and Pushpakumara (2005), Ranil et al. (2006a, 2007, 2014c, 2017) also have conducted a diversity assessment of selected forest ecosystems in the wet zone of Sri Lanka. Recently Daulagala et al. (2020) conducted a survey to assess the contribution of home-gardens to the conservation of ferns. Though most of the assessments are not systematically planned and conducted, findings of such studies are useful to have a general understanding of the level of diversity and species distribution patterns in particular forest ecosystems.

In the last two decades, there has been substantial progress in the field of pteridophyte taxonomy in India which includes checklists, taxonomic reviews and other scientific publications (see Fraser-Jenkins 1997, 2008; Fraser-Jenkins et al. 2016, 2018, 2020). Such studies had an important influence on fern floras in all countries of the Indian Subcontinent. Though contributions of Ranil and Pushpakumara (2012); Ranil et al. (2010a, 2010b, 2014, 2016) and Rajapaksha (2021) also influenced the changes in the number of taxa at local level, Sri Lanka is still far behind the application of modern taxonomic tools in fern studies compared to the level of studies in other countries of the region. Until pteridophytes come to the countries' research agenda, there will not be a substantial progression in fern research in Sri Lanka.

(B) Ethnopteridology

Ranil and Bussmann (2021) provided evidence that although a considerable number of Sri Lankan pteridophytes species have potential as food, medicinal, and ornamental species, they still remain as under-utilized and neglected crop genetic resources. However, Paul Hermann was the first botanist who mentioned the ethnobotanical uses and common names for fern species collected during his tenure in colonial Ceylon (1672–1679). Moon's catalog is one of the best examples of the use of traditional knowledge of plants for botanical nomenclature (Moon 1824). He was the first botanist to list the common names for Sri Lankan ferns. Ranil et al. (2004) compiled a list of species used by village communities during their diversity assessment of lycophytes and ferns in Kanneliya Man and Biosphere Reserve. Moreover, Ranil et al. (2005) conducted a survey on the uses of ferns while interviewing village physicians and indigenous community members. They summarized the food, ornamental and medicinal values with examples. The potential of pteridophytes for the Sri Lankan floriculture industry has been discussed by Ranil et al. (2015), while providing a wealth of information on aesthetic value and market value of native pteridophytes. Ranil and Bussmann (2021) documented 37 species with medicinal, food, ornamental, and other uncommon uses and they further mentioned that such species and their associated knowledge are at risk and highly vulnerable to changing physical environment, increasing population pressure, and rapid development of the socio-economic status of Sri Lanka.

(C) Distributional ecology, reproductive and conservation biology

The distributional ecology of Sri Lankan tree ferns have been studied in detail along with the reproductive biology of selected species (Ranil et al. 2008a, 2010c, 2011, 2014a, b, c, 2017) reported on two naturalized tree ferns from Sri Lanka with the potential of invasion. Though the number of tree ferns is not high in Sri Lanka, the island is globally important due to the presence of a high level of endemism and the occurrence of the only known simple-leaved tree fern (*A. sinuata*) in the world. Apart from that Jayasekara and Wijesundara (1993) have conducted a herbarium survey and revealed that 81% of species are confined to the wet zone of Sri Lanka. Ranil et al. (2005) and Kandepola et al. (2007/2008) studied the species richness along the elevational gradient of two mountains. Ranil et al. (2006) studied the conservation status of lycophytes and ferns in the Udawattakele Forest Reserve while comparing historical records. The presumed extinction of ferns in Sri Lanka has been discussed by Ranil et al. (2010d) in detail. The distributional pattern of ferns along the river bank was studied by Ranil and Pushpakumara (2004). It is important to mention the contribution of Tigerschiöld (1989; 1990) to the study of gametophytes in selected species of the family Thelypteridaceae, and the study on the development of buds of exotic *Polypodium vulgare* by Dassanayake (1964). Apart from the above basic studies, in-depth analysis of distributional ecology, reproductive biology and conservation biology of the Sri Lanka fern flora has not been conducted yet.

Way forward

At present, our knowledge of the Sri Lankan pteridophytes are largely limited to species descriptions and checklists based on rapid surveys. Though adjacent countries have shown significant progress over the last two-three decades,

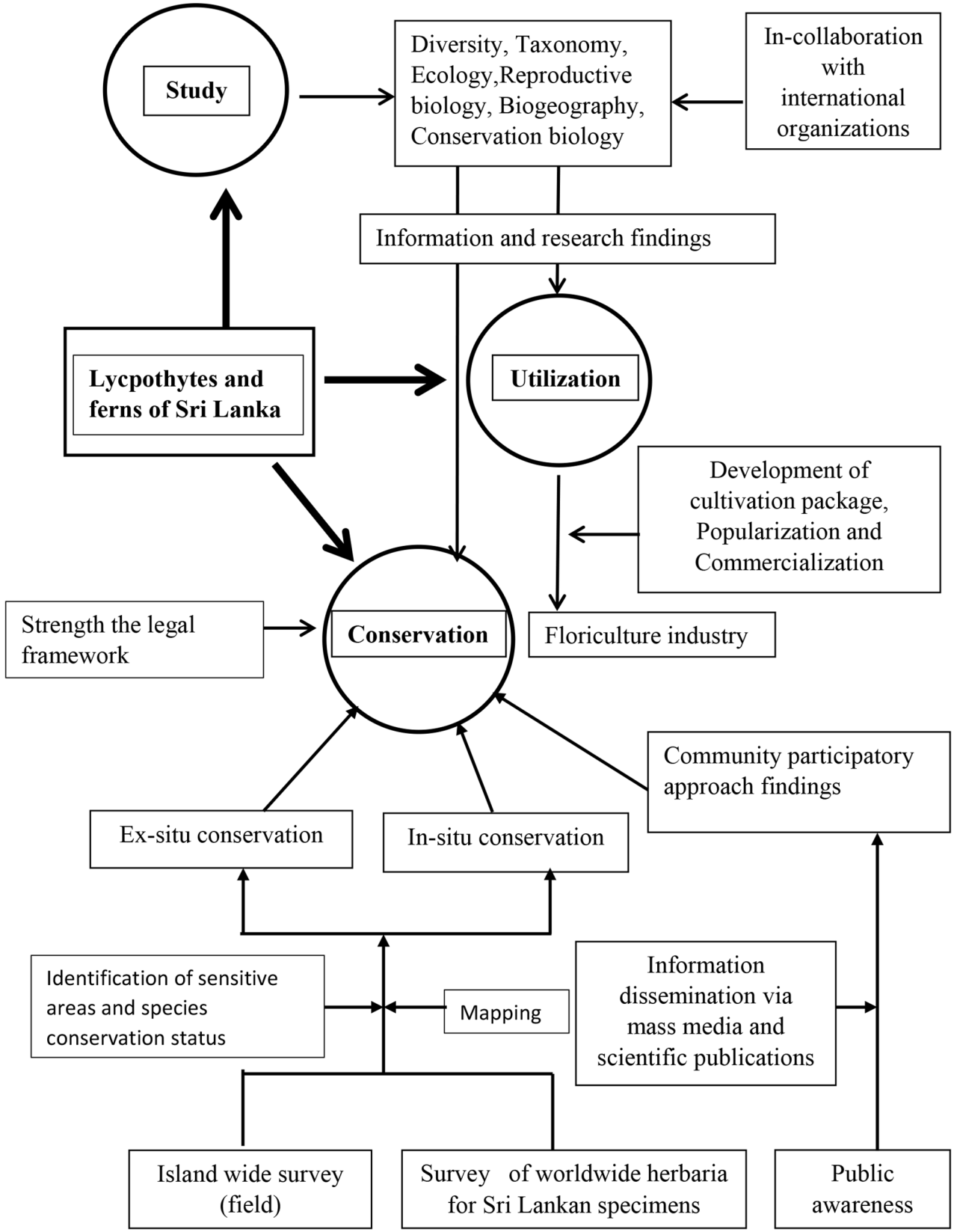

Fig. 8 Conceptual model for study, utilization and conservation of ferns in Sri Lanka

Sri Lanka is still far behind in all aspects of fern researches mainly due to lack of interest, lack of trained and knowledgeable people, and financial inabilities. Though modern botany has moved towards molecular-based approaches, this unique and isolated gene pool in the Indian Ocean has not received adequate attention for biogeographic studies. To bridge this gap and for the advancement of future pteridological studies, we propose the following systematic pathway while summarizing important steps in Fig. 8.

1. **Compilation of available data**: The first priority should go to the compilation of all previous records in collaboration with worldwide herbaria in which Sri Lankan fern specimens are deposited. Also a requirement for in-depth analysis of specimens currently available at the PDA. The end result should be an accessible and complete information-rich database for everyone.
2. **Identification of priority areas**: Mapping of all available data will provide baseline information for the identification of sensitive species and priority areas for ferns. Moreover, it will be helpful to identify hotspots and sensitive areas for immediate conservation action.
3. **Island wide surveys**: A rapid and detailed surveys of ferns and lycophytes are needed that will cover the priority areas across the island. Hence, future botanical researches have to be extended to increase our current understanding of studies focusing on species in the sensitive areas, hotspots, and the large extent of un-botanized areas on the island.
4. **Strengthening of the specimens collection at the National Herbarium and regional herbaria**: Currently the National Herbarium is the only herbarium where fern specimens are housed. The existing collection is limited to about 2500 specimens. Hence, strengthening the national collection is important while developing regional herbaria for ferns in other academic institutes and research stations.
5. **Updating the national checklist**: The checklist is the fundamental document used for the identification of candidate species or groups for researches, setting conservation guidelines, and implementation of policy decisions. For example, the current Flora and Fauna Protection Ordinance of Sri Lanka (fern list) was based on the species list compiled by Sledge (1981) whereas the National Red List – 2012 was based on the Flora of Ceylon (2006). The upcoming checklist is also entirely based on previous records rather than new collections. Hence, a timely updated checklist is needed.
6. **Identification of conservation status**: As previously explained, both National Red Lists (2012 and 2020) were based on old herbarium specimens, mainly in PDA (top set) K, BM, E. Hence, the conservation status of some taxa is highly questionable. Therefore, we strongly suggest the use of updated and recent records when deciding conservation the status of species in the next Red List, otherwise results will not be different from previous lists.
7. **Initiating a new research culture**: The limited studies so far conducted on Sri Lankan ferns are entirely based on personal interests. Currently, there is no research group or any individual who is fully committed to fern studies in Sri Lanka. Hence an initiation of a few research groups affiliated to academic institutes or research institutes is important in starting a new fern culture for the future. Moreover, the collaboration with recognized international institutes is also important, because such collaborations will support the training of people and bring the research to a global stage. For the sake of studies covering phylogenetic relationship and biogeographic history, future researches have to be extended to increase our current understanding of studies focusing on phylogeny and the biogeographical aspect of Sri Lankan ferns.
8. **International collaborations**: The only successful international collaboration so far was the revision of the fern flora under the Flora of Ceylon Project. It resulted in a descriptively and accurately compiled two volumes of lycophytes and ferns of Sri Lanka. Subsequently only few attempts were made to develop collaborations with international institutes and proved unsuccessful. However, we strongly believe that linking with an accredited international institute is the only vital way to advance the fern research and expand the current knowledge on Sri Lankan ferns.
9. **Revision of flora of Ceylon**: The entire process should end up with providing inputs for the revision of two volumes of the fern flora published in 2006. It is the main source that provides the basis for any studies in taxonomy and nomenclature on lycophytes and ferns. Also, it provides all required information to support conservation efforts and the establishment of sustainable management strategies for endemic and endangered fern species.

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Conflict of interest The authors declare that they have no conflict of interest.

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