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Assessment of Diversity and Distribution Pattern of Pteridophytic Flora in Dunumadalawa Forest Reserve in Kandy District, Sri Lanka

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Pteridophytes are a group of non-flowering, vascular, and spore-bearing plants. They are not much economically important to humankind as angiosperms; however, they have potential as commercial and environmental resources. Many of them are horticulturally desirable and used for decorations and ornamental purposes. Further, some are used as medicines, food, and fodder, pollution indicators, and for controlling insect pests. During recent decades, much research indicates a decline in the worldwide fern population due to some reasons such as climate change, the use of land for agriculture and other commerce-related uses, predators, invasive species and overexploitation. Under these circumstances, in the present study, the species diversity and richness, distribution, and conservation perspectives of pteridophytic flora in Dunumadalawa forest reserve in Kandy district, Sri Lanka, were investigated using the random sampling method. Every possible area that supports the growth of fern flora in the forest was visited frequently, and representative samples were collected and preserved as herbarium specimens. The species were

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identified using the “Revised Handbook to the Flora of Ceylon” (Vol. XV and XVI) and verified with the specimens deposited at the National Herbarium, Royal Botanic Gardens, Peradeniya, Sri Lanka. The study found a total of 11 families of pteridophytes from different habitats, consisting of 16 genera and 31 species.

Keywords: Pteridophytes; ferns; diversity; Dunumadalawa forest; Sri Lanka.

1. INTRODUCTION

Sri Lanka is an island located on the southern coast of the Indian subcontinent in South Asia (50.55' – 90.55'N, 79.42' – 81.52'E) and is a biodiversity hotspot. The climate of Sri Lanka is warm and tropical with two distinct dry and wet seasons. The distinct geographical features of Sri Lanka have given rise to three climatic zones; wet, dry and intermediate. Though Sri Lanka is a very small island, it has many forest types and a great biological diversity due to the variations in altitude, temperature and the annual rainfall. In the 1880s, more than 80 % of the land in Sri Lanka was covered with natural forests, but this was reduced to about 44% by 1956 due to the introduction of plantation crops such as tea, coffee and cocoa [1]. In a study completed in 2010, estimated and mapped forest cover of Sri Lanka is apporoximately 1.95 million ha including dense forests, open forests and savannah forests [2].

Forests are the most diverse ecosystems on land because they hold the vast majority of the world's terrestrial species. The most biologically diverse and complex forests on earth are tropical rainforests, but these forests are being destroyed and degraded at alarming rates. Deforestation comes in many forms, including fires, clear-cutting for agriculture, ranching and development, unsustainable logging for timber, and degradation due to climate change, which alter the biological diversity of a forest. Sri Lanka has high floristic richness and species diversity, with the endemic elements heavily concentrated in the wet southwestern quarter of the island. Despite the fact that the flora of Sri Lanka has been extensively studied since the eighteenth century by various botanical experts, some of the secondary forests, such as Dunumadalawa, remain poorly studied, thus begging further investigations [2].

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Dunumadalawa Rorest Reserve, also popularly known as Wakarawatte after its original estate name, Walker’s estate, comprises mainly a secondary growth forest since the site was used earlier for tea and cocoa plantations. Situated on the edge of the Hantana mountain range, the topography of the area varies considerably, from flat lowland plains marked by scattered hillocks and slopes. The forest consists of different types of habitats, such as woody areas, grasslands, pine plantations, and several permanent and temporary lentic and lotic water bodies. It is also characterized by a canopy and sub-canopy of mixed plant species, which includes some native as well as alien invasive plant species. The transformation of original forests into secondary forests and isolated forest patches duly has raised an adverse impact on the floristic richness of the island to a greater degree. The streams that flow through the forest form the catchment of two permanent reservoirs, Dunumadalawa Lake, and Roseneath Lake provide drinking water for some areas of Kandy city [3].

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Sri Lanka contains a considerable number of secondary forests, but unfortunately, the research done on these forests is limited, and hence, not much information is available on their floral and faunal composition [4].

Similarly, the information on the floristic richness of the Dunumadalawa forest reserve is very scanty. The forest is not explored floristically, and the species composition of the flora and their diversity, as well as different plant communities and the population structure of the reserve, have not been studied yet. Further, the natural flora of Dunumadalawa is adversely affected by invasive plants, more dominantly *Myroxylon balsamum* (L.) Harms (Katta Kumanchal), where some areas of the forests are fully invaded, sweeping out the native flora. Some other invasive species like *Clusia rosea* Jacq. (Gal Demata), *Lantana camera* L. (Hinguru) and *Clidemia hirta* (L.) D. Don (Kata Kalu Bowitiya), are also progressively invading, causing a major threat to the native flora as well as the fauna that rely on them. Thus, it would be very important to reveal the hidden flora when implementing possible conservation strategies.

Studies on pteridophytic flora in Sri Lanka commenced in the late 18th and early 19th

centuries and have basically been focused on cataloging genera and species based on taxonomic studies and the preparation of species inventories for selected ecosystems. Research work on pteridophytes continued from the mid-1950s to 1982, including cytological studies and monograph preparations [5, 6,7]. With the aim of utilization and *in-situ* and *ex-situ* conservation of ferns in Sri Lanka, many Sri Lankan scientists extended their research work to encompass the aspects of ecology, genetics, and reproductive biology of some pteridophytes, as well as their ethnobotanical uses, domestication, and conservation measures [8,9].

Pteridophytes (i.e. ferns and lycophytes) are non-flowering seedless vascular plants growing compactly in moist, shady habitats in temperate and tropical forests. They are the second-largest component of the world's flora and one of the oldest and most primitive vascular plant groups on earth. The majority of them are terrestrial, but some are epiphytic, while others are lithophytic or hydrophytic. Pteridophytes are an important component of the flora, biodiversity, natural habitats, and ecosystems but are of minor economic significance to mankind as compared to other plants, especially angiosperms. However, some pteridophytes are useful for decorations and ornamental purposes and can be grown as indoor as well as outdoor plants under varied levels of shade. In addition, some members, such as *Pteris vittata* L. ("the brake"), accumulates arsenic in their fronds, and this is the first fern identified as a natural arsenic hyperaccumulator [10] and helps in environmentally friendly phytoremediation processes. Further, several species are used as medicine and food [11].

An assessment of the diversity and an analysis of the pteridophytic flora of the Dunumadalawa forest reserve have been identified as facts of great importance and need investigation. Hence, a preliminary floristic study of the pteridophytes was carried out as the first step in generating baseline taxonomic information for helping the sustainable conservation and management activities of the pteridophytic flora in Dunumadalawa. This present study will provide information that will be helpful to conservationists, ecologists, forest managers, and future researchers who are interested in carrying out further ecological studies and who are concerned about the conservation of existing pteridophytic species in this fascinating forest in the hill country of Sri Lanka.

2. MATERIALS AND METHODS

2.1 Study Area

Dunumadalawa Forest Reserve (7º17'00" N; 80º38'49" E; 548-972 m above sea level) situated in the Kandy district of the Central Province of Sri Lanka is approximately 480 hectares in extent of land and aquatic habitats, including two major lakes named Dunumadalawa Lake and Roseneath Lake. The topography of the forest varies from flat plains with some scattered low hills to gently sloping valleys. The immediate borders of the forest are the *Pinus* plantation to the southeast at Matinapatana, which then runs into villages and a small, private tea estate; the Tea Research Institute (TRI) and Hantana tea estate to the west, which is the beginning of extensive tea cultivation leading to Heeresagala, Bowalawatte, and the Hantana hills in the southwest; Kandy town to the north; and Ampitiya town and other villages on the east. Kandy has a wetter and cooler climate and a dry season from December through April, followed by a season of monsoonal rain from May to July and December to January. The mean annual rainfall recorded from the south-west monsoon (April to August) is 1800-2500 mm. During the intermonsoonal period (March to mid-May), the city and the suburbs experience light rain and strong humidity, with an average of 70-79%.

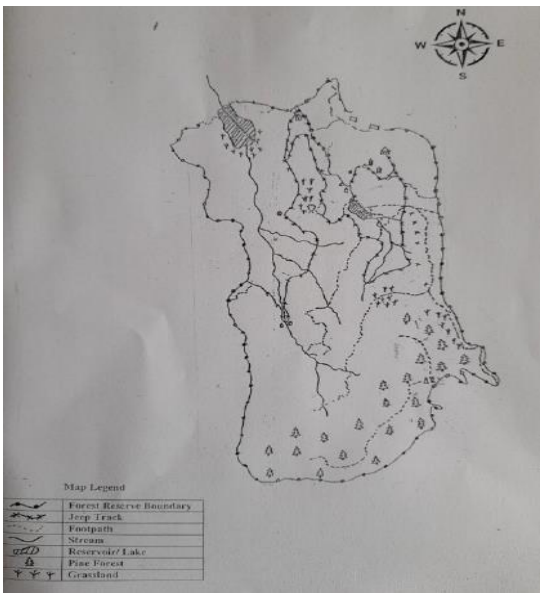

Fig. 1. Area map of the forest

2.2 Collection of Fern Species

This study was basically based on primary data collection through repetitive field surveys. Preliminary observations and the collection of samples were done using random sampling method, over a one year period in several locations of the forest, including the sides of the trails, footpaths, and rough roads in the forest, areas associated with reservoirs and every possible other areas which support the growth of ferns. Other than these species some epiphytic ferns were also sampled. The areas dominated by the invasive *M. balsamum* were not surveyed as the ground cover was completely dominated by saplings/seedlings of *M. balsamum.* The Pine plantation to the southeast at Matinapatana was also not considered for sampling due to the lack of pteridophytes in the poorly grown understory layer. During this survey, the diagnostic features of all the specimens were studied and relevant field notes were made on fresh plant material. The ornamental values of the collected species and possible threats were also identified and recorded. The collected specimens were tagged, dried and herbarium specimens were prepared to be deposited in the proposed herbarium in the Dunumadalawa forest.

2.3 Taxonomic Identification

The species were recorded, photographed and collected as vouchers for identification. The species were identified using the "Revised Handbook to the Flora of Ceylon" (Vol. XV and XVI) and verified with the specimens deposited at the National Herbarium, Royal Botanic Gardens, Peradeniya, Sri Lanka.

3. RESULTS AND DISCUSSION

3.1 Abundance of the Species

This study was conducted to provide a preliminary report, particularly on the diversity of pteridophytic flora in Dunumadalawa forest reserve. A total of 11 families of pteridophytes from different habitats were recorded, consisting of 16 genera and 31 species. Family Pteridaceae is the dominant family represented by 15 species followed by the family Polypodiaceae consisting of 04 species (Fig. 2, Table1). Family Tectariaceae and Thelypteridaceae represented by 3 and 2 species respectively. Families such as Anemiaceae, Blechnaceae, Marrattiaceae, Selaginellaceae,Gleichniaceae,Nephrolepidaceae and Dryopteridaceae are represented by only one species each. *Adiantum* is the most abundant genera represented by 8 species.

The climatic and edaphic conditions and the shady moist environment of the forest reserve favors the growth of many pteridophytes and they comprise a significant component of the forest ecosystem. Wide array of habitats ranging from stream banks, shady slopes and partially shaded patches of wet forest floor provide preferable micro habitats for different types of ferns to grow. Nearly all fern species collected in this study are terrestrials except *P. lanceolata* and *D. quercifolia* which are epiphytic. There was no confined pattern of distribution for many of the terrestrial species and they randomly found in different habitats including forest floor, road sides and river banks.

Among the terrestrial ferns, *B. occidentale* (Fig. 3A) is the most abundant and widely distributed species which grows luxuriantly forming thickets in many places. Typically *B. occidentale* grows as a low growing fern covering large area of forest floors and that growth pattern was observed in this forest making it as the fern species with the highest density. Mainly this fern is confined to the protective shady slopes of the roads/trails in the forest. *A. pulverulentum* (Fig. 3B) is the second abundant species, grows luxuriously in the roadsides and shady and hilly areas throughout the forest and does not show any confined pattern of distribution. The forest favors the growth of some *Adiantum* species such as *A. capillus-veneris* ("Maiden hair fern") (Fig. 3C) and *A. trapeziforme* ("Giant Maiden hair fern") (Fig. 3D) and *A. caudatum* ("Walking Fern") (Fig. 3E) as well, however they show more restricted distribution as patches in the shady areas.

The fern flora of the forest consists of some primitive ferns such as *A. crassipes* (Fig. 4A), *T. zeilanica* (Fig. 4B) and *A. phyllitidis* (Fig. 4C) and *D. linearis* (Fig. 4D). *D. linearis* which is identified as a pioneer species also commonly found in the forest floor, mostly in open areas. They are considered as the first invaders of bare lands and more evident in large gaps created by fallen trees. Magtoto et al. [12] stated that extensive rhizome formation and high litter content of *D. liniaris* makes the land suitable for other native plants to grow after their colonization and finally leads to ecological succession. Among the species listed, some such as *N. brownie* and *T. crenata* are infrequent and showed a limited distribution with few scattered individuals, restricted to more specific shady areas.

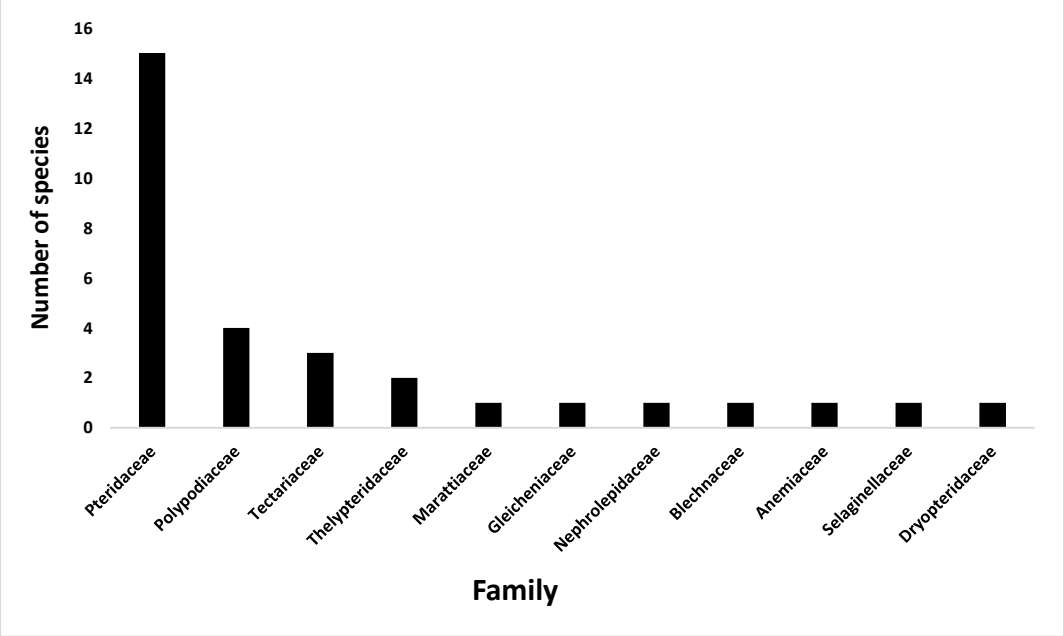

Fig. 2. The number of species in each family of pteridophyte recorded in the forest reserve

Table 1. Checklist of pteridophytic flora recorded in the forest reserve - their families, common habitats and valued features as ornamental plants

Botanical name	Family	Habitat	Ornamental Features
Pteris multiaurita J. Agardh	Pteridaceae	TE	BP, DF, PP
Pteris quadriaurita Retz Retz	Pteridaceae	TE	BP, DF, PP
Pteris vittata L. subsp. vittata	Pteridaceae	TE	BP, DF, PP
Pteris otaria Bedd.	Pteridaceae	TE	BP, DF, PP
(*Pteris quadriaurita* Retz x *Pteris multiaurita*)			
Pteris ensiformis Burm.f.	Pteridaceae	TE	BP, DF, PP
Pteris sp.	Pteridaceae	TE	BP, DF, PP
Pityrogramma dealbata (C. Presl) Tryon	Pteridaceae	TE	BP, DF, PP
Adiantum capillus-veneris L.	Pteridaceae	TE	BP, DF, PP
Adiantum hispidulum Sw.	Pteridaceae	TE	BP, DF, PP
Adiantum trapeziforme L.	Pteridaceae	TE	BP, DF, PP
Adiantum diaphanum Blume	Pteridaceae	TE	BP, DF, PP
Adiantum latifolium Lam.	Pteridaceae	TE	BP, DF, PP
Adiantum pulverulentum	Pteridaceae	TE	BP, DF, PP
Adiantum caudatum L.	Pteridaceae	TE	BP, DF, PP
Adiantun sp.	Pteridaceae	TE	BP, DF, PP
Anemia phyllitidis (L.) Sw.	Anemiaceae	TE	BP, DF, PP
Blechnum occidentale L.	Blechnaceae	TE	BP, DF, PP
Selliguea montana (Sledge) Hovenkamp.	Polypodiaceae	TE	BP, DF
Pyrrosia lanceolata (L.) Farw.	Polypodiaceae	EP/EL	DF
Drynaria quercifolia (L.) J. Smith	Polypodiaceae	EP/EL	DF, HP
Microsorum scolopendria (Burm.f.)Copel.	Polypodiaceae	EP/TE	DF, PP
Angiopteris crassipes Wall.ex C.Persi.	Marattiaceae	TE	BP, DF, PP
Selaginella crassipes Spring	Selaginellaceae	TE	DF, CR
Dicranopteris linearis (Burm.f.) Underw.	Gleicheniaceae	TE	BP, DF, PP
Tectaria crenata Cav.	Tectariaceae	TE	BP, DF, PP
Tectaria zeilanica (Houtt.) Sledge.	Tectariaceae	TE	BP, DF, PP
Tectaria ploymorpha (Wall.ex.Hook.) Copel	Tectariaceae	TE	BP, DF, PP
Christella dentata (Forssk.) Brownsey & Jermy	Thelypteridaceae	TE	BP, DF, PP
Christella hispidula (Decne,) Holttum.	Thelypteridaceae	TE	BP, DF, PP
Nephrolepis brownii (G. Forst.) C.Presl	Nephrolepidaceae	TE	BP, DF, PP
Arachniodes sledgi Fraser-Jenk.	Dryopteridaceae	TE	BP, DF, PP

(Habitats denoted as EP- Epiphytic, EL- Epilithic, TE- Terrestrial and ornamental features denoted as DF – Decorative fronds; PP – Can grow as Pot plants, BP – Can grow as Bed plants, HP – Hanging plants suitable for hanging baskets and CR – Creeping plants suitable for slopes)

The forest accommodates few epiphyitic pteridophytes found on lower parts of tree trunks. *P. lanceolata* (Fig. 5A), *M. scolopendria* (Fig. 5B) and *D. quercifolia* (Fig. 5C) are seen on rocks or creeping up on trees growing in shady, moist places, quite high above the ground, however show a low abundance.

According to The Red List of Sri Lanka 2020, none of the endemic pteridophytic species were recorded during the survey. Among the 31 species of pteridophytes recorded, 28 species are listed as locally common, 2 are vulnerable and 01 is near threatened [13] *T. polymorpha, C. hispidula* are listed under vulnerable (VU) status, while *S. crassipess* is considered as Near Threatened (NT).

3.2 Potential uses of the Pteridophytes Recorded in the Forest

Despite their value in ecosystems, pterodophytes are potentially important as food, medicine, fiber, ornamental, and decorative plants. Pteridophytes have long been used as medicinal plants for treating human diseases. Different secondary metabolites, such as flavonoids, glycosides, terpenoids, and phenolic compounds, are present in different fern species responsible for antioxidant, anti-inflammatory, anti-cancer, and antidiabetic properties, and thus most of them are being historically utilized in traditional ayurvedic medicine in China and India [14]. Among the species present in the forest, *P. ensiformis*, *D. quercifolia, D. linearis., B. occidentale*, *P. vittata*, *C. dentata,*and *A. capillus-veneris* are medicinally important and have been used for treating various human diseases.

A. capillus veneris is a well-known pteridophyte in Ayurvedic medicine as a source of a high number of phytochemicals and hence widely utilized in treating diseases. Baskaran *et al*. (2018) reported that it has anti-cancer, antidiabetic, and antiviral properties, and leaves and rhizomes are being used for treating diabetes in India and Europe. Additionally, *A. capillus veneris* has an antifungal property and is used to remove dandruff as well as treat cough and throat infections [14,11].

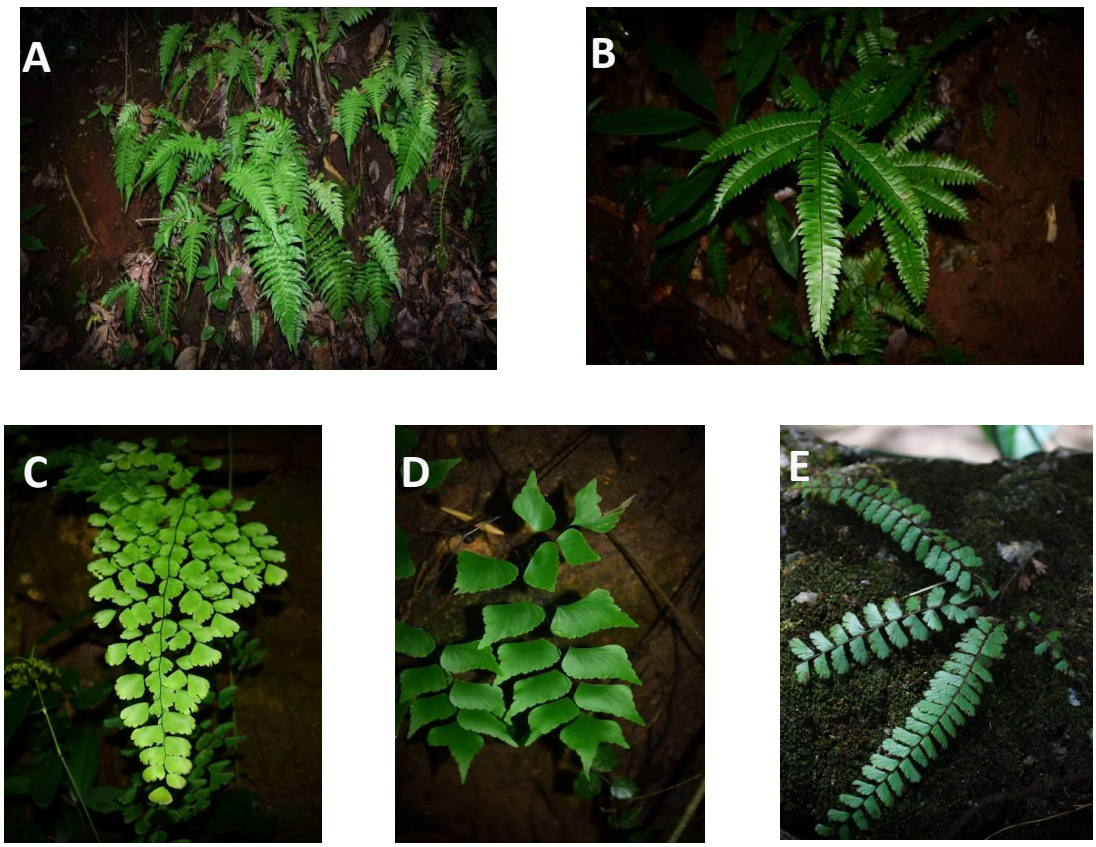

Fig. 3. Habit of A. *B. occidentale*, B. *A. pulverulentum*, C. *A. capillus-veneris*, D. *A. trapeziforme*, E. *A. caudatum*

Many researchers have reported on the high antioxidant activity of *P. ensiformis*, *D. linearis, D. quercifolia, B. occidentale,* and *P. vittata,* which have been utilized traditionally to cure many human ailments [15,16,17,18,19]. In vitro assays clearly demonstrated the presence of anti-tumor compounds in some fern species, more specifically in *A. capillas venaris* and *C. dentata.* The whole plant of *A. capillus venaris* is used by the tribes of the Valparai Hills, Western Ghats, for treating various human illnesses [14,20].

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Several studies have revealed the presence of various phytochemicals that can act as protective agents against pathogenic bacteria and fungi. *D. quercifolia, P. vittata, A. capillus veneris,* and *A. caudatum* are some of the well-studied pteridophytes with antimicrobial activity [14].

The leaves of *A. caudatum* are used to cure cough, fever, skin diseases, jaundice, scabies, abdominal pain and constipation, while *D. quercifolia* is used for treating typhoid, hectic fever, dyspepsia, and cough [14,11].

Apparently, ferns are not being widely used as food and have less importance as a major food source. [11] However, *A. crassipes* stem is used as a source of starch in India and the Philippines. Young fronds of *P. enisiformis* with coiled hook-shaped tips are steamed and eaten [11].

Pteridophytes in particular add beauty to nature and contribute a great deal to man's pleasure. Even though the flowers are lacking, pteridophytes have great value as ornamental plants, mainly due to the presence of beautiful fronds. Further, the ability to grow in moist and shady places both indoors and outdoors, easy propagation methods, the presence of evergreen fronds, indoor survival ability, and the survival habitats ranging from the ground, pots, tree trunks, and hanging baskets make the ferns as suitable candidates to grow as an ornamental plant [21].

Most of the *Adiantum* species are important as ornamental plants due to their attractive fronds, delicate beauty, and grace, and they are exported as ornamental foliage plants. Among them, *A. caudatum* and *A. capillus veneris* are more popular due to their delicate, super-finely textured fronds [21]. Among the Pteridaceae, *P.vittata* and *P. quadriaurita* are treasured due to their attractive fronds [11,21].

Further, the ornamental epiphytic species *D. quercifolia,* commonly called "Oak Leaf" fern, is grown as an epiphyte mostly on tree trunks, decaying trunks, or hanging baskets [22].

Apart from the major uses mentioned above, pteridophytes have some agricultural applications as well. *D. linearis* is used as a shade plant in tea plantations, and thick layers of this species are used to block the water flow in small-scale irrigation systems [23]. Further, *A. hispidulum* and *C. dentata* are considered problematic weeds in tea plantations, especially in the upcountry of Sri Lanka [23].

3.3 Possible Threats to Native Pteridophytic Flora in the Forest

Natural and human activities pose a major threat to native flora, including pteridophytes. Due to the conservative status of the Dunumadalawa reserve, human activities such as deforestation for timber and road constructions, collections done for medicines, and overexploitation for ornamental purposes are rare or highly unlikely to occur inside the forest.

Fig. 4. Habit of A. *A. crassipes*, B. *T. zeilanica*, C. *A. phyllitidis*, D. *D. linearis*

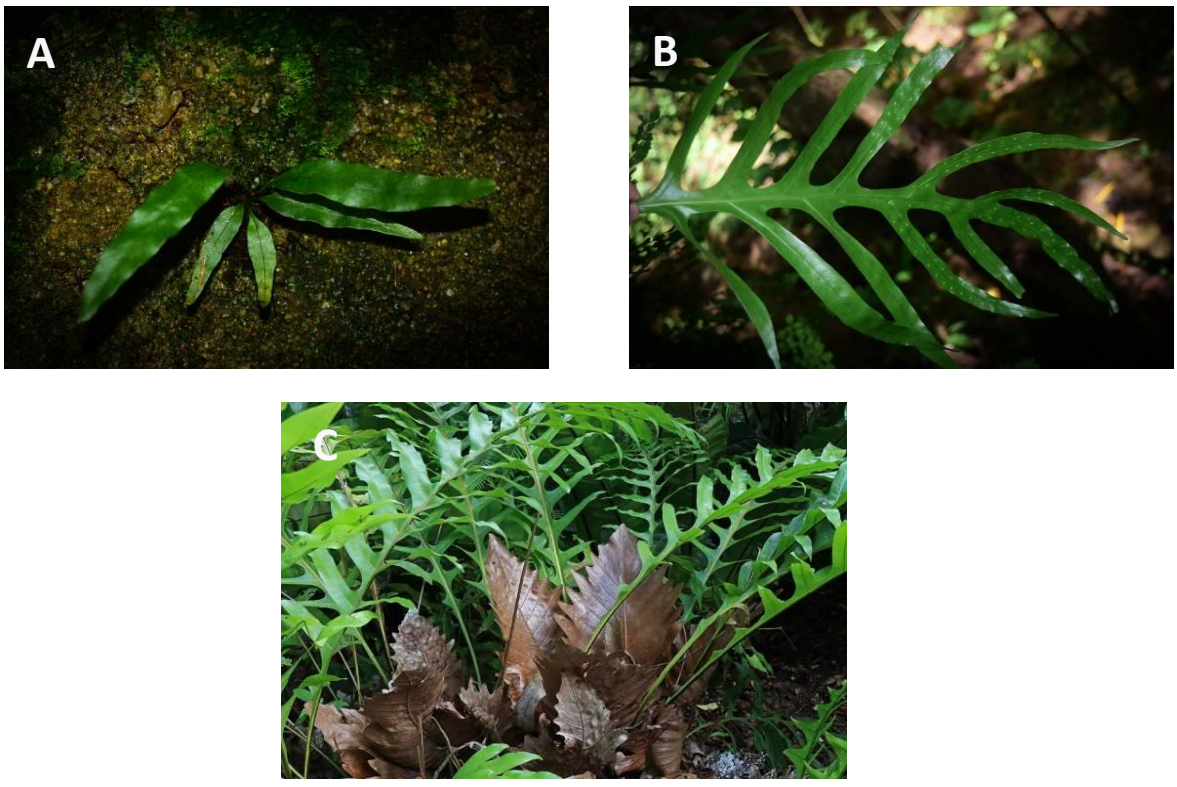

Fig. 5. Habit of A. *P. lanceolata*, B. *M. scolopendria*, C. *D. quercifolia*

Among the natural threats, invasion by alien invasive species is considered one of the most immediate threats to Sri Lankan pterydophytic flora, and it is more prevalent in mountainous areas such as Knuckles and Udawattakale. In Dunumadalawa as well, the major threat arises from the natural factors, basically the invasion by alien invasive species, more specifically *M. balsumum*. Some areas of the forest are completely invaded by the invasive species, sweeping out the native flora and also posing significant threat to the regeneration of

pteridophytes. A similar situation is also observable in the Udawattakale, where much of the native flora is swept away by *M. balsamum* (personal communication). The reasons for the invasive nature of *M. balsamum* are: mass flowering from July to September; the self-pollination nature of the flowers; production of a large number of fruits; and the tolerability of seeds to a wide range of light conditions ranging from complete sunlight to darkness. Further, the absence of specific pests or pathogens attacking seeds allows for a high seed bank in the soil, thus enhancing the threat to local flora [24]. Along with *M. balsamum*, other invasive species such as *C. rosea*, *C. hirta,* and *L. camera* are invading the forest at an alarming rate, imposing a major threat to the native flora and biodiversity, which adversely affects the biological equilibrium in the forest ecosystem.

4. CONCLUSIONS

Dunumadalawa Forest Reserve harbors a high number of pteridophytic flora with a wide array of life forms ranging from terrestrial, epiphytic, and epilithic species. The study found a total of 11 families of pteridophytes from different habitats, consisting of 16 genera and 31 species. The family Pteridaceae is the dominant family, represented by 15 species, followed by the family Polypodiaceae, consisting of 4 species. Among the terrestrial ferns, *B. occidentale* is the most abundant and widely distributed species, which grows luxuriantly, forming thickets in many places.

Disturbances due to human activities are scanty, however, invasive species pose a major threat to native pteridophytic flora. Thus, immediate actions to control and eliminate the invasive species and the implementation of conservation strategies are urgent needs.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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