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PLANT BIOGEOGRAPHY AND CONSERVATION OF THE SOUTH-WESTERN HILL FORESTS OF SRI LANKA

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ABSTRACT. **–** The south-western hill forests of Sri Lanka, harbouring a relict of the Deccan-Gondwana biota, represent an important element of the Sri Lanka-Western Ghats Biodiversity Hotspot. The tree vegetation of five of these forests along an altitudinal gradient from 300–1250 m a.s.l was quantitatively analysed. While tree density over 30 cm gbh increased with increasing altitude, tree size decreased. The canopy, sub-canopy and understorey tree strata in each forest type were largely dominated by species representing distinct forest communities along this altitudinal gradient except for a few widespread species. Classification and ordination analysis of three hill forests along this gradient broadly separated each forest into a distinct floristic/bioclimatological forest community. These analyses further revealed the presence of ecologically distinct species assemblages on the ridges, slopes and valleys within each forest type. These results highlight the presence of both landscape and habitat level floristic heterogeneity in the south-western hill forests of Sri Lanka, which need to be considered in their conservation management. A high proportion of the tree species (41%) enumerated in Hinidumkanda, Sinhagala and Tibbottagala are globally threatened. The Rakwana-Deniyaya hill range in the south-eastern lower montane zone is among the least protected owing to the inadequate knowledge of their rich biological wealth, which is highlighted in this study. A landscape level integrated conservation plan for the remaining natural ecosystems along the Gin Ganga (River) from its headwaters in the Rakwana-Deniyaya hills through the southern Sinharaja forest cluster and the Kanneliya-Hinidumkanda cluster extending to the Hikkaduwa marine sanctuary seascape at the confluence of the Gin Ganga with the Indian Ocean is recommended as a model river basin landscape-seascape conservation area for this biodiversity hotspot.

KEY WORDS. **–** Sri Lanka, biogeography, conservation, lowland hill forests, biodiversity hotspot.

INTRODUCTION

The south-west of Sri Lanka, encompassing approximately 20,000 km^2, is the only aseasonal ever-wet region in the whole of South Asia (Ashton & Gunatilleke, 1987). This area is of considerable biogeographic significance to the South and South-east Asian region for harbouring an exceptional diversity of a relict biota distinct from that of the Western Ghats of India (Ashton & Gunatilleke, 1987; Ayyappan & Parthasarathy, 2001; Gunatilleke & Ashton, 1987; Morley, 2000; van Welzen et al., 2003). The moist rain forests of the Western Ghats of peninsular India and the aseasonal rain forests of south-west Sri Lanka are together considered a refugium of the relict biota of the former Indian plate (Myers et al., 2000). This plate rafted in isolation from other continents for a period of over 25 million years in the mid-Paleocene to late Eocene Epochs (60–35 million years) during which the evolution of taxa within families and genera continued. Many of them have subsequently receded in distribution as a consequence of later competition from Eurasian taxa and climatic changes accompanying the changing landscape. These taxa now persist as isolated relicts, vicariants, or endemics in climatically favourable enclaves like south-western Sri Lanka and the Western Ghats of peninsular India (Ashton & Gunatilleke, 1987; Morley, 2000; Swamy et al., 2000).

In both regions, the natural forests are fast disappearing due to expanding human populations. In southwest Sri Lanka, much of the lowland and lower montane rain forests were cleared in the latter part of the 19th century primarily for expansion of plantation agriculture and its attendant anthropogenic influences. Recognising the regional as well as global significance of these two regions of biogeographic alliance, southwest Sri Lanka and the Western Ghats of peninsular India have been declared one of the 25 global 'Hot Spots' of biodiversity as they harbour exclusively in them 0.7 % of the plants and 1.3 % vertebrates listed in the global literature with their habitats under threat (Myers et al., 2000). Taking in to consideration the numbers of endemics and endemic species/area ratios for both plants and vertebrates, and their habitat loss, the Sri Lanka/Western Ghats region is also ranked among the eight 'hottest hotspots' underlining the global significance of their conservation.

The south-western hills of Sri Lanka are defined as the hills and hill ranges in the lowland and lower montane aseasonal climatic regions, to the south and south-west of the central massif of the island. The rain forests of the south-western hills are threatened as a result of unabated habitat destruction. Consequently, the natural vegetation that remains is often restricted to isolated peaks such as Kalubowitiana (Fig. 1) and to the hill ranges such as Kanneliya, Nakiyadeniya, Dediyagala, Polgahakanda and Hinidumkanda in the coastal lowlands, the Sinharaja cluster of forests at middle altitudes (Fig. 2) and the lower montane forests and table-lands of the Rakwana-Deniyaya hills at the eastern boundary, which abut the seasonally dry forests to their east (Figs. 3A–C). The south-western hills are well separated from and located southwest of the central massif of the island. Abbey Rock (1300 m) and Gongala (1358 m) represent the highest peaks of the Rakwana–Deniyaya hills. The south-western coastal hill ranges commencing immediately east of Kalutara and forming an arc up to about 30 km wide and parallel to the coast-line towards the south-east, terminating just inland of Hulandawa in Matara District, is considered as the floristically richest area of Sri Lanka and indeed of all South Asia (area 7 of Fig. 6; Ashton & Gunatilleke, 1987: 275).

Fig. 1. Kalubowitiana kanda: an isolated lowland hill (735 m) to the south of the Sinharaja World Heritage Site, surrounded at the base by paddy fields and home gardens.

Geology. **–** The main lithotectonic unit of almost the entire southwest of Sri Lanka is known as the Highland Complex. It comprises metamorphosed Precambrian sediments and gneisses of igneous origin (Cooray, 1997). In the extreme south-western part of this Highland Complex, the crystalline metamorphic rocks are considered as a separate group, as they are predominant in granitic gneisses, relatively rare in the rest of the Highland Complex that extends to the central massif and north-eastern lower peneplain (Cooray, 1984). The main metasedimentary rock types in the south-western region are hypersthene bearing charnockite gneiss of granitic origin, inter-banded with garnet-sillimanite-graphite gneisses (schists), cordierite-bearing gneisses and garnet-quartz-feldspar granulites and gneisses (Cooray, 1988).

A conspicuous geological feature within this region is the presence of a metabasic (amphibolite and pyroxine granulites) band of intrusive rocks, extending over 30 km in the SE-NW direction, known as the 'Sinharaja basic zone'. This zone is characterised by a marked aeromagnetic anomaly due to the high percentage of magnetite present in these basic rocks (Cooray, 1984).

Fig. 2. The mid-elevational hill forests (300–900 m) in Sinharaja World Heritage site dominated by *Mesua-Shorea* (*Doona*) forest formations.

Land form. **–** The land form of the Sabaragamuwa hills, of which the Rakwana-Deniyaya hills form a part, represents a series of sub-parallel strike ridges running in a SSE-NNW direction. These ridges have been etched out of a much larger metamorphic bedrock structure by differential weathering and erosion of lithologically less resistant beds (Erb, 1984). Heavy rainfall (>500 cm yr^{-1}) from both the south-west and north-east monsoons has resulted in deep weathering and active

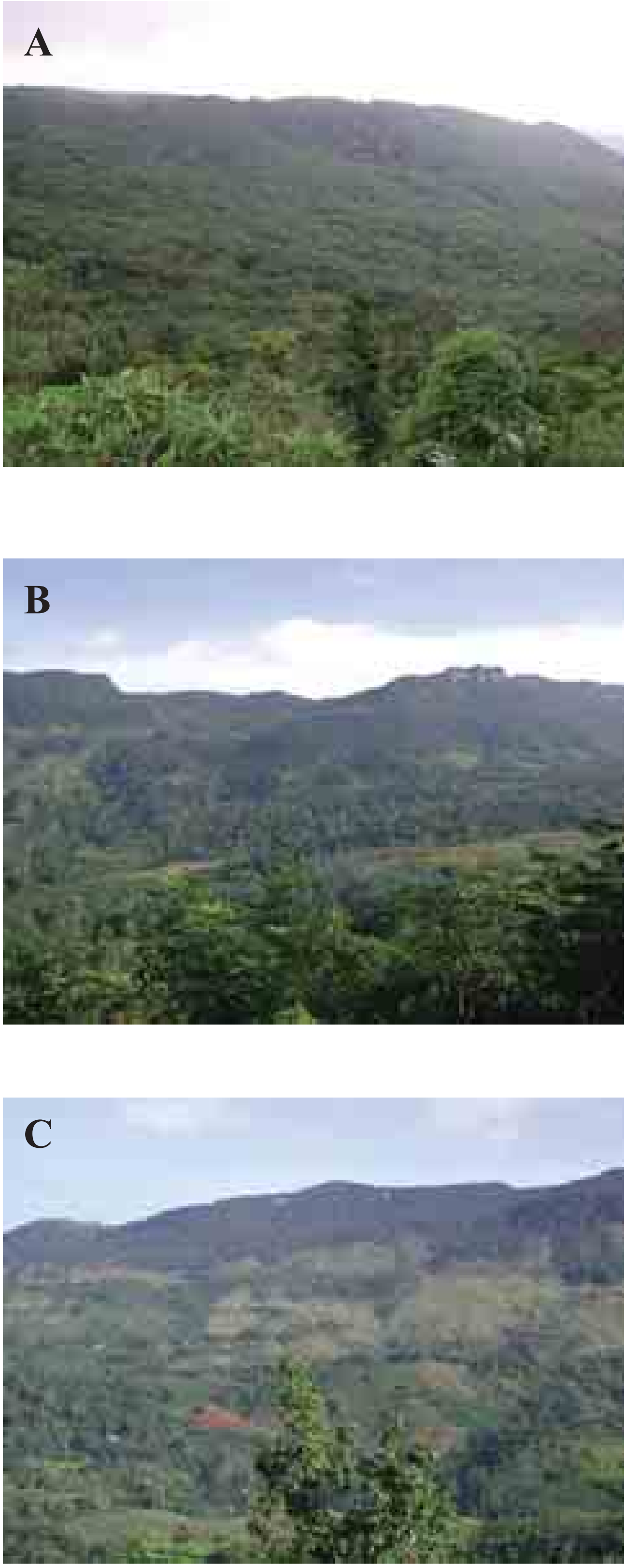

Fig. 3. A, lower montane forests (1000 –1300 m) in the Eastern Sinharaja region. The canopy is dominated by hill dipterocarp species (*Shorea trapezifolia* and *S. gardneri*). B, lower montane forest above Ensalwatta tea plantation. The rocky outcrop to the far right is Gongala (1358 m), the highest peak in the Rakwana-Deniyaya hill range. C, land-use pattern in lower montane areas in Deniyaya. The Lower valleys are predominantly home gardens, lower and middle slopes are planted with tea, and only the upper crests remain clothed with natural forests.

Fig. 4. The stepping-stone arrangement of rocks at the top of the Handapan Ella, a waterfall dried out in the dry season.

erosion almost to base level in the south and south-west flowing Nilwala, Gin and Kalu rivers. In contrast, the lower rainfall to the east has resulted in less weathering and erosion, giving rise to waterfalls and rapids in tributaries of east-flowing rivers such as the Walawe.

The Rakwana-Deniyaya hills are characterised by a number of remnants of ancient structurally controlled erosion surfaces, including the Handapan Ella plateau at 1250 m above sea level (a.s.l.) and the Thangamale plateau at 1128 m a.s.l. The Handapan Ella plains have a central undulating valley, several km^2 in extent, covered by grasslands and forests. It is surrounded by a rim of mountain ranges clad in windswept lower-montane forests (Fig. 4). Across these ranges, the peaks of Ilumbekanda (1192 m), Beralagala (1385 m), Suriyakanda (1310 m), Kabaragala I (1234 m) and Kabaragala II (1291 m) stand out. The Sabaragamuwa hills drain mainly along a series of more or less parallel strike-, fault- and joint-controlled valleys running in the SSE-NNW direction (Erb, 1984). Weathering of these hills has been intense. Consequently, extensive deposits of talus and colluvial material resulting from active mass-wasting have formed deep residual soils, characteristic of this region.

Soils. **–** The modal soils of the entire south-western region of Sri Lanka, except certain parts of the coastal plains, are the Red-Yellow Podzolic soils with low base saturation. They belong to the modern Soil Taxonomic Order Ultisols and Suborders Udults and Humults (Panabokke, 1996). The coastal plains, especially the lower floodplains and river deltas, have recently-formed alluvial soils of the Order Entisols belonging to the Sub Orders Aquents, Fluents and Psamments. Within the coastal plains, there are isolated residual hilly areas of Red-Yellow Podzolic soils with soft and hard laterites (Great Soil Group Plinthudults).

***Objectives.* –** The objectives of this study were to: examine the variation in structure and floristic composition of the tree flora in the vegetation of the south-western hill forests of Sri Lanka with increasing altitude; analyse the community structure of three hill forests along the altitudinal gradient in order to provide scientific underpinning for the conservation of plant communities recognized in the south-western hill forests; and estimate the number of globally threatened plant species in the IUCN Red List for Sri Lanka that are harboured in each study site in order to strengthen the cause for the conservation of their habitats.

MATERIALS AND METHODS

The information gathered on phytosociological surveys of four hill forests (Gunatilleke & Gunatilleke, 1984, 1985) and one plateau have been re-examined in this paper so as to meet the above objectives. At some of these sites (Hinidumkanda, Sinhagala, Tibbottagala), quantitative data were collected from 20 randomly placed 0.25 ha paired plots. In the remaining sites, floristic information were collected from fewer and smaller number of plots during short visits to these sites. The geographical locations of these study sites and their altitudinal ranges are given in Table 1 and Fig. 5.

***Study sites.* –** A brief description of the study sites follows: Hinidumkanda or Haycock (300–668 m a.s.l.) is a prominent lowland hill forest located in the hinterland of the south-western coastal plains. It is a member of the broader Kanneliya-Nakiyadeniya-Dediyagala cluster of forests, but separated from it by the valley of the Gin Ganga [= river]. In the more interior Sinharaja range of forests, is Sinhagala (550–730 m a.s.l.), also a lowland hill forest, and east of it is Tibbottagala (670–900 m a.s.l), which represents the upper limits of the lowland rain forests. Still further east and up the altitudinal gradient on the broader south-western landscape, the Sinharaja range extends to the Rakwana-Deniyaya hills, Suriyakanda to the north and Gongala and Abbey Rock to the south. This area encompasses Illumbekanda, Handapan Ella, Suriyakanda, Thangamale Plains and Gongala, and the natural vegetation represents lower montane evergreen forests (Fig.5).

***Vegetation Sampling.* –** In Hinidumkanda, Sinhagala and Tibbottagala, 5–5.5 ha of primary forest per site were quantitatively sampled (Table 1). In each site 10–12 locations along the elevation gradient were selected randomly. At a given location, two plots, each 0.25 ha in extent, adjacent to each other, were demarcated, when space was available. Mostly rectangular plots (25×100 m) were used to keep within-plot heterogeneity at a minimum. Where space was limiting, especially near the summits and ridge tops, square plots (50×50 m) were selected. In each plot, all trees > 30 cm gbh were sampled by measuring their girth at 1.3 m above the ground. In the lower montane forests at Suriyakanda only 0.25 ha was sampled and trees > 30 cm gbh were enumerated; at Handapan Ella, as the trees were all much smaller, only 0.1875 ha was studied and the lower limit of trees enumerated was 15 cm gbh, compared to those in the rest of the study sites. Herbarium material from trees enumerated was collected for identification to their respective species, based on Dassanayake et al. (1980–2000).

***Multivariate Vegetation Analyses.* –** A vegetation classification based on Two Way Indicator Species Analysis (TWINSPAN) and an ordination based on Detrended Correspondence Analysis (DCA, DECORANA) using PCORD version 4 software (McCune & Mefford, 1999) were performed, with species abundance data of Hinidumkanda, Sinhagala and Tibbottagala as three representative hill forests along the altitude gradient of south-west Sri Lanka from 300–900 m a.s.l. The data were analysed for all three sites together as well as separately.

***Assessment of threatened species.* –** To assess the threatened status of the species identified in the study sites, they were compared with the threatened Sri Lankan plant species documented in the IUCN Red List (IUCN, 2003).

RESULTS

***Structure and floristic composition of tree vegetation.* –** A stratigraphic profile of an idealized broad sector of the island's floristically rich south-western landscape, from the coastal region to the eastern boundary of the Rakwana-Deniyaya hills, depicts its major geomorphology, soil and natural vegetation features at a glance (Fig. 5). Salient landscape level differences of these features from the coastal south-western lowlands to south-central hills in the Rakwana-Deniyaya range are also summarized in Fig. 5. The structural features, floristic composition and the dominant species in the canopy, subcanopy and understorey tree strata of the forests studied are given in Tables 1 and 2. A comparison of structural features, such as density (ha^{-1}) of the forests shows a steady increase from the south-western lowland hills to the lower montane plateau (Table 2), with a concomitant decrease in tree height and girth. At the lower montane altitude, there is a preponderance of individuals with girth lower than 30 cm. In the Handapan Ella plains, the density of individuals between 15 and 29.9 cm gbh was 3,386 trees ha^{-1}. In other areas, individuals of this size-class were not enumerated and comparison was therefore not possible.

The dominant tree species in the canopy, subcanopy and understorey tree strata varied among sites, with the exception of a few widespread species (*Palaquium petiolare, Anisophyllea cinnamomoides, Myristica dactyloides, Calophyllum trapezifolium and Garcinia hermonii*) (Table 2). In general, the dipterocarp-dominated lower montane forests shared more species with their lowland counterparts than with those in the Handapan Ella plateau.

Table 1. Some site details and structural and floristic composition of the tree flora (> 30 cm gbh) of lowland hill forests and lower montane forests in the southwest of Sri Lanka. Numbers within brackets represent unidentified species.

Site details and features of vegetation	Hinidum-kanda	Sinha-gala	Tibbotta-gala	Suriya-kanda	Handapan-Ella
Geographical location (° N, ° E)	6.13, 80.18	6.23, 80.28	6.24, 80.32	6.26, 80.38	6.26, 80.36
Elevation range (m)	300–668	550–730	670–910	950–1310	1250–1300
Area sampled (ha)	5	5.5	5	1.25	0.1875
Density ha^{-1}	764	769	712	848	2341
Number of species	140 (21)	125 (15)	140 (17)	75 (21)	40 (23)
Endemic species (%)	75	75	60	>50	>50

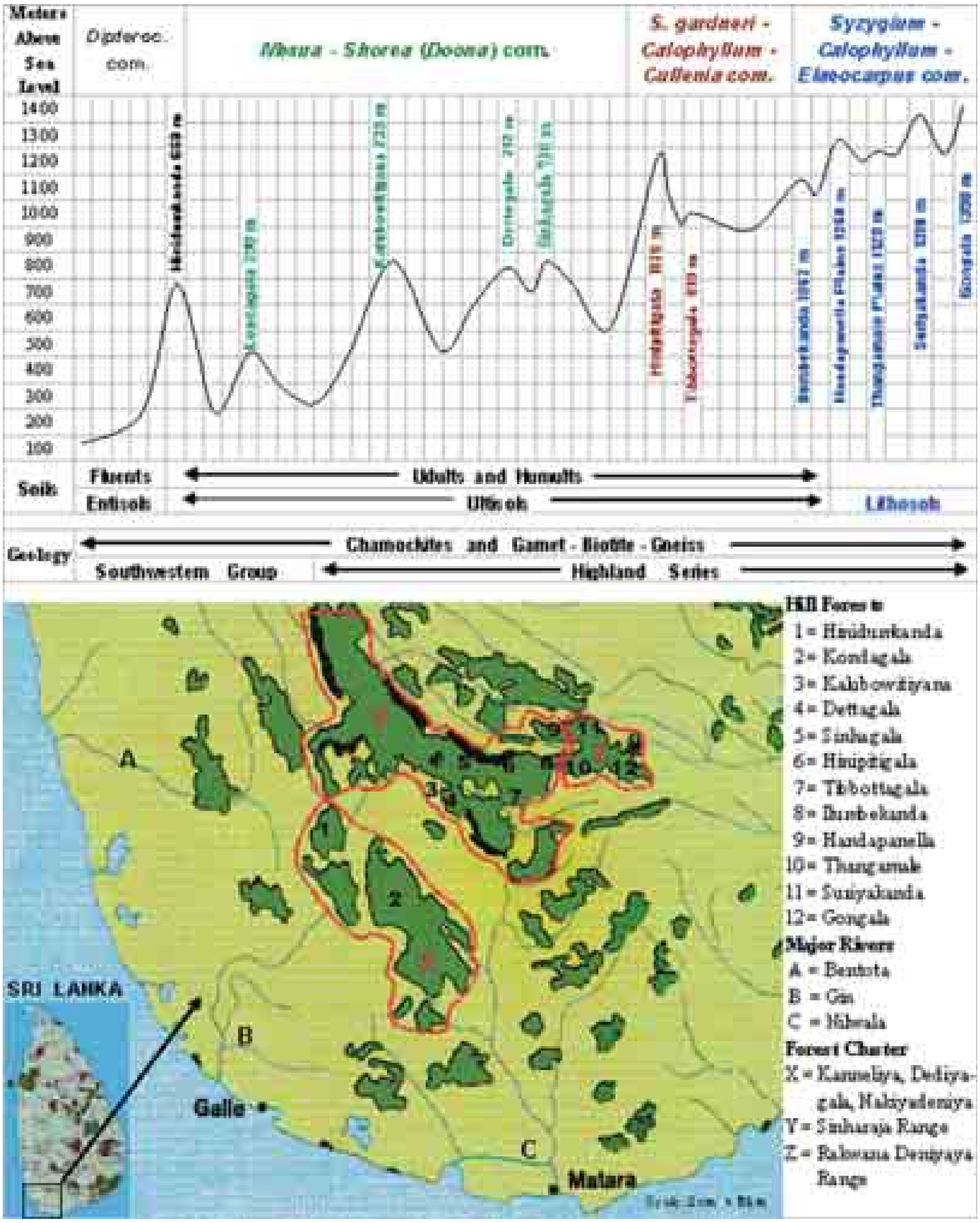

Fig. 5. Above: a diagramatic sketch of the relief profile of hills of southwest Sri Lanka, indicating their geology, soil and forest types. The elevation at the peak of each hill is given along side its name. Below: geographical distribution of natural forests in southwest Sri Lanka showing their fragmented nature and the approximate locations (numbers in map) of some of the hill forests.

Table 2. The dominant species in different canopy, sub canopy and understorey tree strata in hill forests in the southwest of Sri Lanka. (*Calo.* = *Calophyllum, S. gard.* = *Shorea gardneri, Syzyg.*= *Syzygium, Elaeoc.* = *Elaeocarpus*). * = species endemic to Sri Lanka. ** = subspecies endemic to Sri Lanka. L/LH = lowland/lower montane; RF = rain forest.

Hill forest studied	Hinidumkanda 300 – 668 m	Sinhagala 550 – 730 m	Tibottagala (*Ecotone) 670 – 900 m	Suriyakanda 950 – 1050 m	Handapan Ella 1250 – 1300 m
Forest type	lowland (hill) RF	lowland (hill) RF	lowland/lower-montane RF	lower montane RF	lower montane RF
Vegetation community	*Diptero-carpus*	*Mesua-Shorea (Doona)*	*Calo.-Shorea*	*S. gard.-Calo.-Cullenia*	*Syzyg.-Calo.-Elaeo.-*
Canopy and Sub-canopy dominants:					
Dipterocarpus zeylanicus (Dipterocarpaceae)*	+				
Chaetocarpus castanocarpus (Euphorbiaceae)	+				
Cyathocalyx zeylanica (Annonaceae)	+				
Palaquium petiolare (Sapotaceae)*	+		+		
Anisophyllea cinnamomoides (Rhizophoraceae)*	+	+	+		
Myristica dactyloides (Myristicaceae)	+	+	+		
Mesua nagassarium (Clusiaceae)**		+			
Mesua ferrea (Clusiaceae)*		+			
Shorea worthingtonii (Dipterocarpaceae)*		+			
Shorea affinis (Dipterocarpaceae)*		+			
Cullenia rosayroana (Bombacaceae)*		+			
Cullenia ceylanica (Bombacaceae)*			+		
Calophyllum trapezifolium (Clusiaceae)*			+	+	+
Shorea trapezifolia (Dipterocarpaceae)*			+	+	
Shorea zeylanica (Dipterocarpaceae)*				+	
Shorea gardneri (Dipterocarpaceae)*				+	
Hydnocarpus octandra (Flacourtiaceae)*				+	
Elaeocarpus glandulifer (Elaeocarpaceae)*				+	
Axinandra zeylanica (Crypteroniaceae)*				+	
Palaquium laevifolium (Sapotaceae)*					+
Syzygium revolutum (Myrtaceae)					+
Syzygium micranthum (Myrtaceae)*					+
Syzygium cordifolium (Myrtaceae)*					+
Garcinia echinocarpa (Clusiaceae)					+
Agrostistachys coriacea (Euphorbiaceae)*					+
Understorey Tree Dominants:					
Gyrinops walla (Thymelaeaceae)	+			+	
Garcinia hermonii (Clusiaceae)*	+	+	+		
Xylopia championii (Annonaceae)*		+	+		
Dillenia triquetra (Dilleniaceae)		+			
Humboldtia laurifolia (Fabaceae)		+			
Diospyros insignis (Ebenaceae)				+	
Fahrenheitia zeylanica (Euphorbiaceae)				+	
Strobilanthes spp. (Acanthaceae)					+
Bamboo sp. (Poaceae)					+

Among the lowland hill forests sampled, the number of tree species enumerated was comparable in Hinidumkanda and Tibbottagala, but lower in Sinhagala. Their numbers declined progressively in the lower montane forests, again partly due to the lower girth limit of 30 cm selected for comparison among sites. Interestingly, the number of endemic woody species was highest in the lowland forests and decreased with altitude.

The canopy/sub canopy layer. – The most abundant species at Hinidumkanda were *Dipterocarpus zeylanicus* (Dipterocarpaceae), *Palaquium petiolare* (Sapotaceae), *Cyathocalyx zeylanica* (Annonaceae), *Chaetocarpus castanocarpus* (Euphorbiaceae), *Anisophyllea cinnamomoides* (Rhizophoraceae) and *Myristica dactyloides* (Myristicaceae) (Table 2). However, both the structure and the abundant species around the peak of Hinidumkanda differed from those of the middle and lower elevations (Gunatilleke & Gunatilleke, 1984). *Cullenia rosayroana* (Bombacaceae), *Myristica dactyloides*, *Stemonoporus canaliculatus* (Dipterocarpaceae) dominated the canopy, subcanopy and the understorey tree layer of the summit vegetation, respectively. Endangered species like *Diospyros oppositifolia* (Ebenaceae) and *Schumacheria angustifolia* (Dilleniaceae) are restricted to the summit of Hinidumkanda. This hill forest represents the *Dipterocarpus* and *Vitex-Dillenia* (*Wormia*)-*Chaetocarpus-Anisophyllea* communities in de Rosayro's forest classification (de Rosayro, 1950).

Sinhagala, unlike Hinidumkanda, is dominated by the *Mesua-Shorea* (*Doona*) association, which is the climax forest community in the mid-elevational lowland wet evergreen (rain) forests of Sri Lanka (de Rosayro, 1950; Gaussen et al., 1966; Greller & Balasubramanium, 1993). The species characteristic of the ridge plots in Sinhagala were *Mesua nagassarium* and *M. ferrea* (Clusiaceae), *Humboldtia laurifolia* (Fabaceae), *Shorea worthingtonii*, *S. affinis*, *S. cordifolia, S. disticha* (Dipterocarpaceae) and *Palaquium laevifolium* (Sapotaceae). At middle and lower elevations of this hill forest, the most abundant canopy species were *Anisophyllea cinnamomoides* (Anisophylleaceae), *Dillenia triquetra* (Dilleniaceae), *Shorea congestiflora* (Dipterocarpaceae) and *Campnosperma zeylanica* (Anacardiaceae). The highest diversity of genus *Shorea* among the sites sampled, represented by five species, was recorded in this hill forest.

In the lower montane ever-wet forests of Tibbottagala (670 – 900 m a.s.l), the most abundant canopy and subcanopy species were *Calophyllum trapezifolium* (Clusiaceae), *Shorea trapezifolia* (Dipterocarpaceae), *Palaquium petiolare* (Sapotaceae), *Anisophyllea cinnamomoides* (Anisophyll-eaceae) and *Myristica dactyloides* (Myristicaceae) (Table 2; Gunatilleke & Gunatilleke, 1985). The latter two species are also abundant in the two lower-elevation forests (Table 2).

In Suriyakanda (950–1050 m a.s.l.), the lower montane rain forests were dominated by *Shorea gardneri* (Dipterocarp-aceae), *Calophyllum trapezifolium* (Clusiaceae) and *Cullenia* spp. (Bombacaceae). Similar forest types have been observed in sites abutting the tea estates in Rakwana-Deniyaya hills. These forests represent the *Shorea* (Doona)-*Cullenia-Calophyllum* community of the lower montane notophyllous evergreen dipterocarp rain forest type of Greller & Balasubramanium (1993).

In Handapan Ella plateau (1250–1300 m a.s.l.), a forest resembling the lower montane notophyllous evergreen mixed rain forest of Jayasuriya et al. (1993) and Greller & Balaubramanium (1993) dominated by the *Syzygium-Calophyllum-Eleocarpus* association was observed. This climatically and edaphically influenced vegetation on the plateau was short-statured, sometimes exposed to mist and during the dry months of the year to strong desiccating winds. It is heterogeneous in its floristic composition, harbouring elements from lowland and lower-montane rain forests and to a lesser degree those from the upper-montane forests. Among the common canopy tree species recorded in plots as well as in general field collecting were those of *Syzygium* (Myrtaceae), *Semecarpus* (Anacardiaceae), *Memecylon* (Melastomataceae), *Symplocos* (Symplocaceae), *Palaquium* (Sapotaceae), *Calophyllum* and *Garcinia echinocarpa* (Clusiaceae). However, the dominant forest species of Handapan Ella plateau on shallow soils with impeded drainage were not shared by those of any other forest type examined in this study (Table 2). This forest type may be an edaphically influenced variant in shallow soils. Interspersed with the lower montane rain forests of Handapan Ella and Thangamale plains and beyond them at Ensalwatta and Beverly estates (although to a lesser extent) are grasslands, quaking bogs and marshes, each with their own characteristic biodiversity, which remain poorly studied to-date.

Understorey Vegetation. – Among the most abundant understorey tree species were *Garcinia hermonii* and *Gyrinops walla* (Thymelaeaceae) in the lowland hill forests of Hinidumkanda. In the entire Sinharaja range *Garcinia hermonii* and *Xylopia championii* (Annonanceae) dominated the undersorey stratum based on the Important Value Indices (Gunatilleke & Gunatilleke, 1985). *Diospyros insignis* (Ebenaceae) and *Fahrenheitia zeylanica* (Euphorbiaceae) dominated the understorey of the lower montane forests in Suriyakanda (Table 2).

On the Handapan Ella plains, the members of Rubiaceae and Acanthaceae (*Strobilathes* spp.) were frequent in the understorey. Bamboo species along with those of *Eriocaulon* and *Osbeckia*, common also in the open grasslands near rocky outcrops, extend into the forest interior in some areas. On the plains as well as its outer and inner forested rim an exceptionally rich orchid flora, some rare and endangered elsewhere in the island, is present. The rare and cryptic root parasite *Christisonia* (Orobanchaceae), only visible when in flower, is locally abundant on the forest floor in a few areas. No less than 55 species of orchids, some rare and threatened, as well as probable new species of Loranthaceae, Hymenophyllaceae, Lycopodiaceae, Gesneriaceae and Eriocaulaceae have also been reported from Handapan Ella and Ensalwatta forests (Suranjan Fernando, pers. comm.). Three main streams that flow through the plains converge on a rocky substratum at the north-eastern edge giving rise to a waterfall, overlooking the Deepdene estate and Rakwana-Kalwana road down below. On this escarpment, either side of the water fall, is an extensive stand of *Loxococcus rupicola* (an endemic and monotypic genus), a palm species characteristic of rocky steep habitats (Fig. 6).

***Multivariate analyses.* –** In the TWINSPAN classification using all 62 plots from the three hill forest sites (Fig. 7), the first division based on the indicator species *Cullenia ceylanica* and *Bhesa zeylanica* clumped the 22 Sinhagala plots and the 20 Tibbottagala plots as group 1 (mid-elevational and lower montane forests) and all 20 Hiniduma Kanda plots as group 2 (coastal lowland hill forest) based on the indicator species *Cyathocalyx zeylanica*, *Vitex altissima* and *Calophyllum moonii*. In further divisions of group 1, 10 of the Tibbottagala plots, representing those in the high plateau and the valley, grouped together and the remaining 10 with the 22 Sinhagala plots. Subsequent divisions of the latter group separated the Tibbottagala slope plots, from the Sinhagala valley plots in one branch and the Sinhagala ridge and upper slope plots in the opposite branch. The successive divisions of the Hinidumkanda plots in group 2 separated the valley plots, ridge plots and the upper and lower slope plots into four clusters. The dendrogram (Fig. 7) gives the details of the clusters, the indicator species and the Eigen values at each level of division. By comparing the results of the TWINSPAN analyses and ordination, the divisions in the classification were ecologically meaningful at level 4 where plot clusters in valleys, slopes, ridges summits and plateaux in respective hill forest separated out (Figs. 7, 8).

The groups of plots in each of the three hill forests separated out in the two-dimensional ordination (Fig. 8). Those groups in each study site that emerged in the classification fall in close proximity to each other, and away from plots in the other two study sites, with one exception, where the Sinhagala plots on the ridge and upper slopes clustered adjacent to the Tibbottagala plots on steep slopes. In a given site the greatest separation among plots along these two axes is shown by the Tibbottagala plots, suggesting that this site has more community diversity than either the Hinidumkanda or Sinhagala forests. Within each site, finer scale clustering into ridge, slope and valley plots were evident from both the ordination and classification (Figs. 7, 8). The multivariate analyses done for each site separately showed results similar to that obtained in the analyses of all three sites considered together, and is therefore not detailed here.

***Globally Threatened species.* –** In the three study sites, Hinidumkanda, Sinhagala and Tibbottagala, that were quantitatively sampled with greater intensity than the other two sites, 224 woody species were recorded (Table 3). By comparing these species with those reported in the IUCN Red List, their threatened status was examined. There are 290 globally threatened Sri Lankan species in the 2003 IUCN Red List (IUCN, 2003). Among them, 78 are Critically Endangered, 73 are Endangered, 129 are Vulnerable and the remaining 10 belong to the Lower Risk, Extinct and Data Deficient categories. In the three hill sites studied, 118 (41%) of these species were recorded in the following categories: 31 Critically Endangered, 16 Endangered, 66 Vulnerable, and 4 Lower Risk. The data for individual sites (Table 3; Gunatilleke & Gunatilleke, 1991) show that the number of threatened species at Hinidumkanda is 91, which ranks highest, followed by Sinhagala with 83 and Tibbottagala with 68; the number of threatened species restricted to each of these sites is 26, 8 and 4, respectively.

Fig. 6. A stand of *Loxococcus rupicola* (Araceae) on steep rocky slopes near Handapan Ella.

DISCUSSION

***Forest types represented.* –** In the past many attempts have been made to classify the forests of Sri Lanka using floristic (de Rosayro, 1950; Gaussen et al., 1966), bioclimatic and physiognomic (Greller & Balasubramaniam, 1993; Koelmeyer, 1957) characteristics (Table 4). The floristic analysis of the present study reveals that the Hinidumkanda vegetation represents both the *Dipterocarpus* and *Vitex-Dillenia* (*Wormia*)-*Chaetocarpus-Anisophyllea* communities of the wet evergreen forest climax formation of de Rosayro's classification and the lowland mesophyllous evergreen dipterocarp rain forests of Greller & Balasubramaniam. The Sinhagala vegetation, on the other hand, represents the *Mesua-Doona* (*Shorea*) community of de Rosayro; but in Greller & Balasubramaniam's classification, the distinction between these coastal and inland lowland forest communities of de Rosayro has not been made. The presence of several abundant species in Tibbottagala (670 – 900), which are also found in both Hinidumkanda (300–668 m) and Suriyakanda (950–1050 m), suggests that the Tibbottagala vegetation represents an ecotone between lowland and lower-montane forests of this region. In Tibbottagala, *Mesua nagassarium* is replaced by *Calophyllum trapezifolium* as one of the most abundant canopy species.

Floristically, the Suriyakanda vegetation conforms to the submontane evergreen forests of Koelmeyer (1957), *Doona-Calophyllum-Syzygium* series of Gaussen et al. (1966), and the lower montane notophyllous evergreen dipterocarp rain forests of Greller & Balasubramaniam (1993). de Rosayro has not recognised this as a distinct forest type in his classification. The Handapan Ella vegetation, characterized by the absence of *Shorea gardneri*, corresponds to the lower montane notophyllous evergreen mixed rain forests of Greller & Balasubramaniam (1993). This distinct forest type has been overlooked in other forest classifications. The floristic data in our study support the forest classifications based on distinct floristic assemblages although no single classification

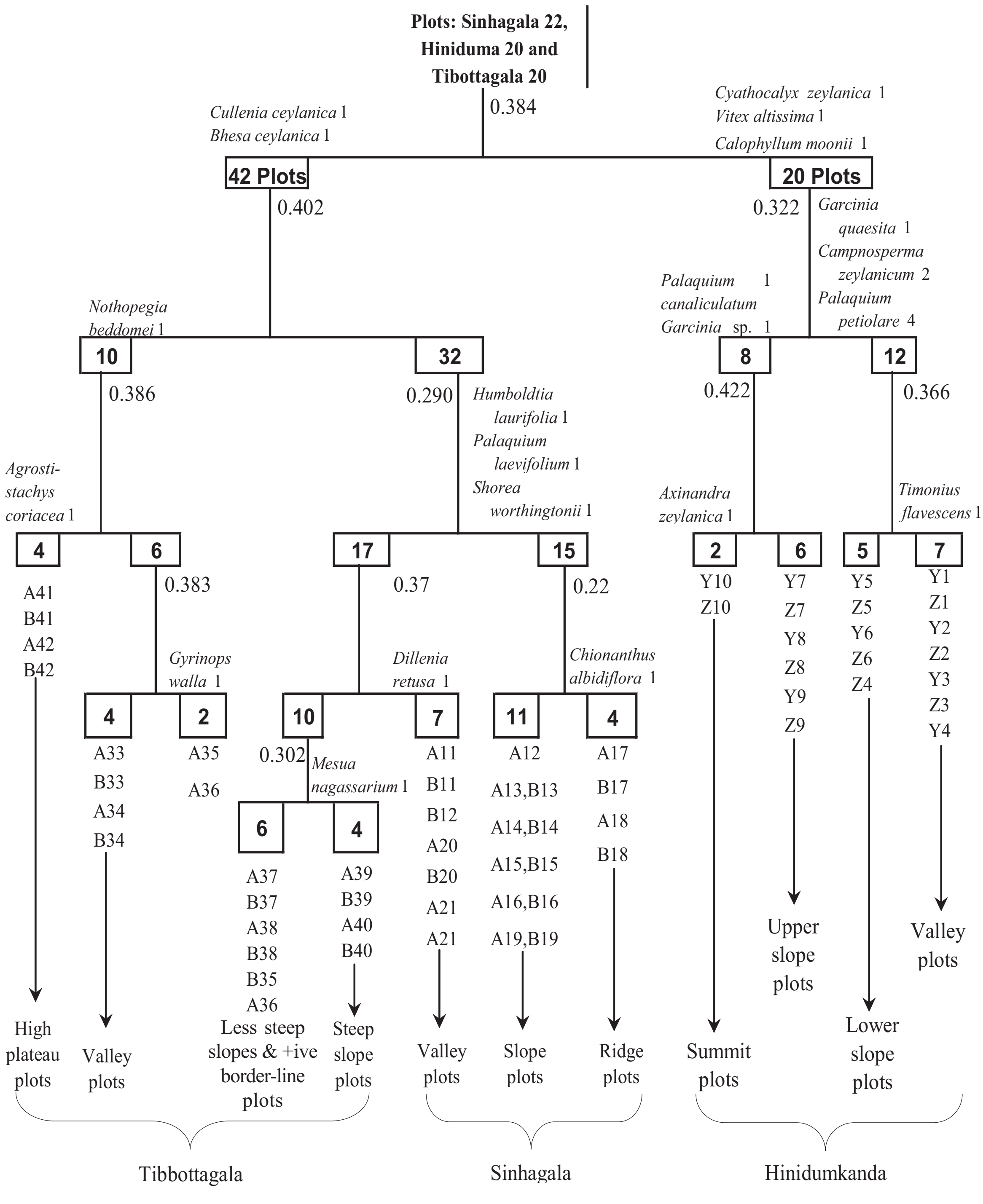

Fig. 7. Classification (Two-Way Indicator Species Analyses) of 62 plots sampled in the hill forests of Hinidumkanda (plots Y1– Y10, Z1– Z10), Sinhagala (A11 – A21, B11 – B21) and Tibbottagala (A33 – A42, B33 – B42) in southwest Sri Lanka, using abundance data of each species. The indicator species and the eigen values at each division are also given.

Table 3. Numbers of species in the south-western hill forests of Hinidumkanda (Hinidum.), Sinhagala and/or Tibbottagala (Tibbott.) in different categories of the 2003 IUCN Red List. CR = critically endangered, EN= endangered, VU = vulnerable, LR/cd = lower risk: conservation dependent; RIRL, NIRL = number of species recorded and not recorded in the Red List, respectively.

Study Sites Sampled	CR	EN	VU	LR/cd	Sub Total: RIRL	Sub Total: NIRL	Total
Hinidumkanda only	6	4	16	–	26	42	68
Sinhagala only	3	2	3	–	8	6	14
Tibbottagala only	1	1	2	–	4	11	15
Hinidumkanda & Sinhagala	3	2	10	–	15	4	19
Hinidumkanda & Tibbottagala	1	2	1	–	4	13	17
Sinhagala & Tibbottagala	8	–	6	–	14	12	26
Hinidum., Sinhagala & Tibbot.	9	5	28	4	46	19	65
Total in all three sites	31	16	66	4	117	107	224
Individual Study Sites							
Total in Hinidumkanda	19	13	55	4	91	78	169
Total in Sinhagala	23	9	47	4	83	41	124
Total in Tibbottagala	19	8	37	4	68	55	123

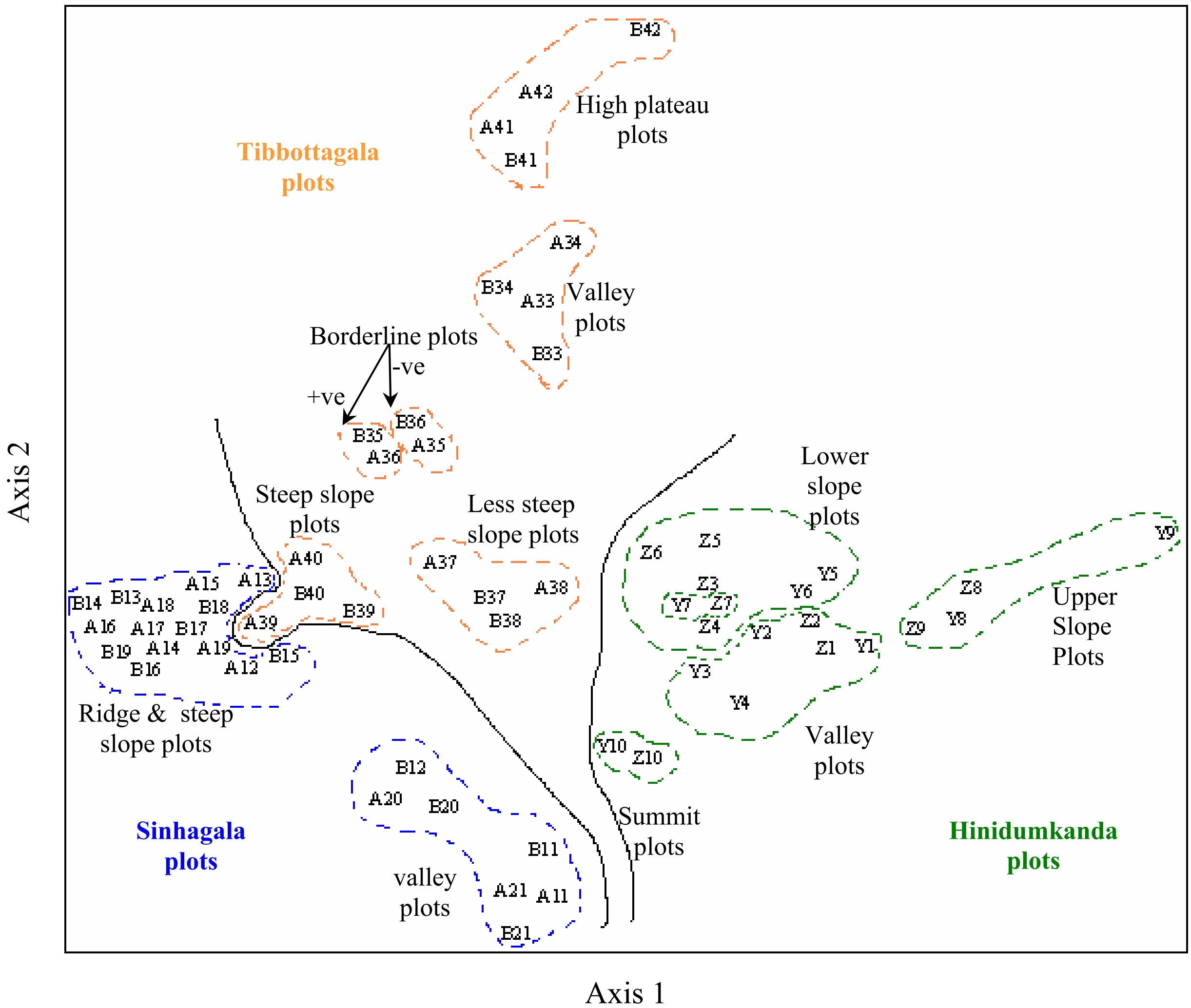

Fig. 8. Ordination (Detrended Correspondence Analysis) on the 62 plots sampled in the hill forests of Hinidumkanda (plots Y1–Y10, Z1–Z10), Sinhagala (A11–A21, B11–B21) and Tibbottagala (A33– A42, B33–B42) in southwest Sri Lanka, using abundance data of each species. The plot distributions in the ordination diagram are indicated by the plot number used in field sampling.

Table 4. The south-western hill forests of the present study according to different forest classifications in the literature.

Hill forests sampled in present study	Forest classification of			
	de Rosayro (1950)	Koelmeyer (1957)	Gaussen et al. (1966)	Greller & Balasubramaniam (1993)
Hinidumakanda	*Dipterocarpus* community *Vitex-Dillenia-Chaetocarpus-Anisopyllea* community	Tropical wet evergreen forests	*Doona-Dipterocarpus Mesua* series	Lowland mesophyllous evergreen dipterocarp rain forests
Sinhagala	*Mesua-Doona* community	Tropical wet evergreen forests	*Doona-Dipterocarpus Mesua* series	Lowland mesophyllous evergreen dipterocarp rain forests
Tibbottagala	*Mesua-Doona* community	Tropical wet evergreen forests	*Doona-Dipterocarpus Mesua* series	Lowland mesophyllous evergreen dipterocarp rain forests
Suriyakanda	Not recognized	Submontane evergreen forests	*Doona-Dipterocarpus Syzygium* series	Lower montane mesophyllous evergreen dipterocarp rain forests
Handapan Ella	Not recognized	Not recognized	Not recognized	Lower montane mesophyllous evergreen mixed rain forests

recognised all the different forest communities encountered in our survey. Interestingly, the six forests quantitatively sampled by us, along this altitudinal gradient some 80 km direct east from the south-west coast represent five different forest types.

This study emphasizes the need for a quantitative analysis of a much larger database including those from other forests in the south-western region of Sri Lanka in order to identify distinct floristic communities facilitating a review the existing forest classifications in a more objective manner recognising at the same time micro-scale habitat variations to capture the habitats of localised endemics.

Floristic variation. – Both TWINSPAN and DCA of pooled plots of the three hill forests revealed the presence of distinct floristic communities akin to those described in literature along the altitudinal gradient at landscape level. Separation of plots in each of the three hill forests along axes 1 and 2 in the DCA provides quantitative evidence for the presence of distinct forest communities in the coastal lowland (Hinidumkanda), interior mid-elevational (Sinhagala) and lower montane/ ecotone (Tibbottagala) hill forests confirming previous qualitative classifications of the vegetation. The only exception was the overlap of four steep slope plots (A39, B39, A40 and B40) in Tibbottagala with the ridge and steep slope plot cluster in Sinhagala (Fig. 8), owing to the higher proportion of species shared between them.

Both analyses indicated a finer scale separation of floristically recognizable local communities in valleys, lower and upper slopes and high plateau or summit plots in each hill forest. However, the plots on the ridges, summits or plateaux, slopes and valleys in each hill forest separated from their counterparts in both analyses suggesting their distinctiveness. This provides evidence for spatial heterogeneity and ecological differentiation of tree species along the finer-level climatic and topographic gradients and consequently, provides the scientific underpinning for conservation management planning of these forests.

The presence of distinct species assemblages on the ridges, slopes and valleys, along the altitudinal gradient of the *Mesua-Shorea* (*Doona*) community in hilly topography has been further supported by census data of the 25 ha Forest Dynamics Plot (FDP) in Sinharaja, where all free standing woody plants > 1 cm dbh have been enumerated and plotted on a contour map (Gunatilleke et al., 2004). This FDP plot spans an elevation range of only 150 m; yet it depicts eight different habitats based on topography, convexity and slope. Further, at least for some canopy dominant taxa, the ecophysiological adaptations of their seedlings to micro-climatic gradients of light, moisture and soil nutrients along the topographic gradient during early establishment and recruitment phases have been shown (Ashton et al., 1995; Gunatilleke et al., 1996,1997,1998). All these studies, including the present study, show habitat specialization of plants along small scale gradients in the hill forests of Sri Lanka, which has important conservation implications considering the fact that many of these species are relict endemics.

Localized distribution of threatened species. – Comparison of the species in the IUCN Red List (Table 3) in the three quantitatively sampled forests, shows that 43% of the 224 species identified were found only in one of the three sites, depicting very localized distribution of these species, particularly in Hinidumkanda with as many as 68 species. With 169 tree species it is also the richest among the study sites sampled. Among the endangered species in the IUCN Red list that are highly restricted in their distribution and enumerated in Hinidumkanda are *Shorea dyeri, S. lissophylla and Diospyros oppositifolia.* The results of this study also show that tree species richness decreases with altitude, Hinidumkanda ranking highest and Handapan Ella the lowest, the latter probably being also due to the smaller extent of forest studied. On the other hand most, if not all, studies in Sri Lanka, including our own, have so far failed to investigate the diversity of the herbaceous and lower plant floras, components of the vegetation known to increase in diversity with altitude.

The remaining forests in southwest Sri Lanka represent only a small fraction of less than 9% of their original extent. Today even these are also highly fragmented, most small in extent, with receding boundaries due to a multitude of human impacts. Hinidumkanda is one of the few protected areas that represent the *Dipterocarpus* community. High point-endemism and high habitat specialization in Sri Lanka's rain forest species demands that the remaining forests in its south-western quarter, however disturbed or fragmented they are, need to be conserved with a sense of urgency. Among these are the representatives of the *Dipterocarpus* community in the coastal belt and hill forests and high plateaux of the Rakwana-Deniyaya hill range representing the lower montane notophyllous evergreen mixed/Dipterocarp rain forests. Compared to these forests types, the *Mesua-Doona* community is better protected in the Sinharaja and the Kanneliya-Dediyagala-Nakiyadeniya groups of forests.

Conservation issues. – In response to criticism mounted against the first Forestry Master Plan for Sri Lanka (Anon., 1986) and subsequent assessment of the environmental implications of the Forestry Sector Development Project, an Environmental Management component was included in this project (Anon., 1997). This component was mandated to evaluate all remaining natural forests in the country with respect to their importance for biodiversity, in terms of ecosystem and species diversity, and their value for soil and water conservation. This study, commonly referred to as the National Conservation Review (NCR), inventoried and analysed the data of selected groups of plant and animal species in 204 forests in the island. Among the recommendations of the NCR, those related to the present study are, (a) all montane forests should be strictly protected by upgrading the status of proposed reserves to conservation forests, or even national heritage wilderness areas; and (b) the largest remaining forests in the wet zone should be designated in their entirety as conservation forests, inter alia, Sinharaja complex (a group of 13 forests including Handapan Ella Plains, Diyadawa and Dellawa) and broader Kanneliya, Nakiyadeniya and Dediyagala (KDN) complex so that the long-term conservation of biodiversity could be ensured.

The biological value of the forests in close proximity to the northern, western and southern borders of the Sinharaja World Heritage Site (WHS) has been recognised and identified as conservation forests, based on recommendations of the NCR. However, forests along the eastern perimeter of the Sinharaja WHS, where part of this study has focused (Suriyakanda and Handapan Ella), have yet to receive the attention they merit. These areas were not adequately surveyed for their biological wealth even during the NCR. With respect to plants, they harbour an exceptionally diverse herbaceous and epiphytic flora including orchids, balsams, ferns, bryophytes, lichens, fungi & algae, a component of the vegetation in all ecosystems, which was not studied by the NCR and for that matter, has almost entirely been neglected in Sri Lankan biodiversity surveys.

Therefore, relying entirely on the NCR as the source of quantitative scientific information for purposes of conservation planning could lead to serious omissions of areas rich in herbaceous and epiphytic plants which are at greater threat of extinction considering their sensitivity to habitat alteration and habitat size decrease. Consequently, due to the dearth of adequate scientific information, particularly with respect to the rich flora of herbaceous and lower-plant taxa, some areas of the Rakwana-Deniyaya hills are not included in the current protected area system. Hence, they are in imminent danger of being degraded further through poaching, timber and firewood harvesting, cardamom cultivation, illicit gem prospecting and other activities inimical to biodiversity.

Forest degradation and destruction. – The threats to the many fragile ecosystems of the Handapan Ella plains appear to be extensive, particularly in the grasslands and stream banks, where thousands of gem pits (most ~1 m deep) have been dug over the years. These illegal encroachers have caused extensive damage to the forest by cutting wood and poaching animals in this fragile ecosystem.

In early 2004 there was an even more sinister threat to the relict forest fragments adjoining the eastern boundary of the Sinharaja WHS, despite repeated requests and recommendations made to annex them to the Sinharaja WHS to increase its conservation value. Instead, these state-owned forest lands were blocked out and sold for tea and cardamom cultivation. This irresponsible act, amidst public protests, including those of scientists familiar with the biological wealth of the region and its conservation value, has irreparably damaged this fragile ecosystem, critically endangering some of the threatened animal and plant taxa exclusive to the Rakwana-Deniyaya hills.

The forests near the south-eastern boundary of the Sinharaja WHS abutting the Sinharaja Division of the

Fig. 9. *Shorea gardneri* and *S. trapezifolia* dominated lower montane forest stand at1000m altitude near Sinharaja division of the Ensalwatta tea plantation.

Fig. 10. Wind-swept and gnarled crowns of the canopy dominant monospecific dipterocarp (*S. gardneri*) stands in eastern Sinharaja.

Ensalwatta Plantation and also Beverley and Manikkawatta Estates are on long-term lease to plantation companies. These appear to be relatively free of any encroachments for gem prospecting and wood-cutting. The forests surrounding the Sinharaja Division of the Ensalwatta Plantation represent *Shorea gardneri* (Sinhala: Rath Dun) and *Shorea trapezifolia* (S: Yakahalu Dun) tree formations at their very best (Figs. 9, 10). These magnificent forest stands, traversed by streams and spectacular waterfalls, harbour abundant wildlife, including a small herd of elephants, and are an important watershed for the downstream communities.

Similarly, forests in the highest peaks of the Rakwana-Deniyaya hills, viz., Abbey Rock (1300 m) and Gongala (1358 m), those near Panilkanda and Aninkanda estates, Naigala, Kabaragala, Beralagala, Suriyakanda and Kurulugala deserve to be conserved. Apart from a few explorations for taxonomic and preliminary ecological study purposes, their conservation value is yet to be evaluated and documented (Jayasuriya et al., 1993). Several animal species endemic to the Rakwana-Deniyaya hills and new to science have been collected from this region (Bahir & Ng, 2005; Manamendra-Arachchi & Pethiyagoda, 2005; Pethiyagoda & Manamendra-Arachchi, 1998).

Extension of the current eastern boundary of the Sinharaja WHS to include these forests within an appropriate protected-area category is proposed once again (Gunatilleke & Ashton, 1987), as an urgent measure to conserve their rich biodiversity.

The presence of a small herd of elephants in the Rakwana-Deniyaya hills is an important criterion for establishing a wildlife reserve in this region. Their migratory routes need to be studied in order to demarcate and establish habitat corridors connecting the surrounding forests, particularly to the north of the Rakwana-Deniyaya hills. As a dwindling population of elephants similar to that inhabiting the Peak Wilderness area, a conservation management plan for wet zone elephants should also be considered. The role of the elephant in the functioning of these complex rain forests is virtually unknown. Such a study would especially benefit nature-based tourism in this region.

The issues highlighted in this paper should be addressed coherently with a sense of urgency, before the next wave of 'development' overwhelms Sri Lanka. Conservation planning for Sri Lanka's south-western region should not be done piece-meal or on a short-term basis, but at landscape level that takes long-term impacts into consideration. Appropriate corridors and buffer zones including multi-species home gardens, where appropriate, could be used to link the different ecosystems and forest types in this region.

The present study provides sound evidence that the south-western hills and, the Rakwana-Deniyaya range of lower montane forests in particular, indeed possess high conservation value. However, they have hitherto remained relatively unprotected owing to their biological and ecological value not having been adequately assessed in previous biological surveys. We hope that this study will serve as a stimulus for demarcating such high-priority conservation landscapes (both protected and yet unprotected) along the Gin Ganga basin from its headwaters in the Gongala area through southern Sinharaja, KDN complex and Hinidumkanda and remaining mangroves, together with the Hikkaduwa Marine sanctuary seascape beyond its confluence with the Indian Ocean at Gintota as an integrated model river basin landscape-seascape conservation area. Where feasible, linking of neighbouring forest areas through restoration corridors with already available research experience for this region Gunatilleke (1999) is also strongly recommended. The stratigraphic profile accompanying the map of the south-west Sri Lanka in Fig. 5 provides some directions for the initial identification of the relevant areas for this exercise.

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