Journal of Tropical Forest Science 9(3): 299 - 314 (1997)

ECOLOGICAL OBSERVATIONS IN THE FRESH WATER SWAMP FORESTS OF SOUTHERN KERALA, INDIA

Viju Varghese & B. Mohan Kumar*

College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur - 680 654, India

Received July 1994

VARGHESE, V. & KUMAR, B.M. 1997. Ecological observations in the fresh water swamp forests of southern Kerala, India. Composition, structure, diversity and edaphic attributes of three fresh water swamp forests in southern Kerala were analysed. Methodology involved establishing 0.5-ha sample plots at Kulathupuzha, Anchal and Shendurney in the Western Ghats and enumerating all trees ≥10 cm girth at breast height. Soil profile development, physico-chemical and electro-chemical properties of the swamp soils were also examined. The swamp vegetation exhibited lower floristic diversity than other tropical evergreen forest formations in the Western Ghats. Variations in floristic spectrum of the swamp sites studied were small. Family Myristicaceae dominated the fresh water swamps with *Gymnacranthera canarica* and *Myristica magnifica* accounting for most of the stand basal area, relative density and importance value index. Diameter and height distributions followed a negative exponential relationship. Soils were silty or sandy loams of moderate to neutral pH and modest organic C levels. N, P and K contents of the swamp soils were lower than in other forest ecosystems of the region. *In situ* redox potentials showed moderate levels of oxidation suggesting oxygenation of the swamp rhizosphere by knee roots.

Key words: Fresh water swamp forests - edaphic attributes - floristic diversity - redox potential - vegetation structure

VARGHESE, V. & KUMAR, B.M. 1997. Pemerhatian ekologi hutan paya air tawar di selatan Kerala, India. Komposisi, struktur, kepelbagaian dan edafik semula jadi tiga hutan paya air tawar di selatan Kerala telah dikaji. Metodologi melibatkan penubuhan sampel plot 0.5-ha di Kulathupuzha, Anchal dan Shendurney di Ghats Barat dan pengiraan semua pokok ≥ 10 cm lilit pada aras dada. Perkembangan profil tanah, ciri fiziko-kimia dan ciri elektro-kimia tanah paya juga diuji. Tumbuh-tumbuhan paya mempamerkan kepelbagaian flora yang lebih rendah berbanding lain-lain hutan tropika malar hijau di Ghats Barat. Di tapak paya yang dikaji, perubahan dalam spektrum flora didapati kecil. Famili Myristicaceae menguasai paya air tawar dan *Gymnacranthera canarica* dan *Myristica magnifica* menyumbang kepada kebanyakan luas pangkal dirian, kepadatan relatif dan indeks nilai kepentingan. Taburan diameter dan taburan ketinggian mengikuti perhubungan eksponen negatif. Tanahnya berkelodak atau lom berpasir daripada pH sederhana kepada neutral dan paras C organik sederhana. Kandungan N, P dan K tanah berpaya lebih rendah daripada ekosistem hutan yang lain di kawasan tersebut. Potensi redoks *in situ* mempamerkan tahap pengoksidaan yang sederhana dan ini mencadangkan pengoksigenan rizosfera oleh akar lipat.

**Corresponding author.*

Introduction

Swamps and marshes are physiographic features of low-lying areas resulting from hydrologic and geomorphologic peculiarities (Taylor *et al.* 1990). They support characteristic vegetation types, subjected to seasonal flooding. In the tropics, such vegetation occurs frequently amid natural forests and along the flood plains of major rivers. They form integral parts of the wet land ecosystems, serving as habitats, nursery grounds and sources of food for many organisms (Brown *et al.* 1979). They also serve as nutrient traps (Brinson 1977).

In India fresh water swamp forests (4C/FS1 of Champion & Seth 1968) occur mainly in the valleys of Western Ghats (Krishnamoorthy 1960) and in the foot hills of Himalayas (Dakshini 1960, Ghildial & Srivastava 1989). They are isolated, small woods, often few hectares in extent. Many swamp forests, however, face extinction due to anthropogenic factors, particularly conversion to wetland paddy fields (Krishnamoorthy 1960).

The swamps remain completely inundated during a greater part of the year. According to Krishnamoorthy (1960), the *Myristica* swamps of Travancore remain waterlogged between June and January. Restricted gas exchange between rhizosphere and the aerial environment is a major problem in this context. It decreases the oxygen concentration in the root zone, elevates carbon dioxide levels and increases root resistance to water uptake (Smit & Stachowiak 1988). Flooding also decreases the redox potential of the soil, alters soil reaction (increases pH of acidic soils and decreases pH of alkaline soils), changes specific conductance and ionic strength, and causes a wide spectrum of other physical and chemical changes (Ponnamperuma 1984). Consequently, swamp vegetation possesses several adaptive traits that enable it to survive under hostile environments. Floristic composition of the fresh water swamps also would depend on the extent of soil reduction and other soil physico-chemical properties, which are, in turn, dependent on the periodicity, duration and depth of flood waters. However, little information is available from the tropics concerning the physical, chemical and electro-chemical properties of swamp soils.

Our objectives were to characterise the floristic diversity of fresh water swamps of southern Kerala and to examine the physico-chemical properties and electrochemical properties of the soil that support this unique vegetation type. We hypothesised that because the swamps form isolated niches that favour only a particular set of specialised tree species, floristic diversity of the swamps would be lower than those of other evergreen forest formations in the Western Ghats. Further, like the wet land rice, the swamp vegetation may oxygenate the rhizosphere. Therefore, we postulated a lower redox potential drop in the swamp rhizosphere. In this context, Ponnamperuma (1984) observed that a flooded rice soil has both aerobic and anaerobic zones, including the oxidised rhizosphere. However, divergent views exist regarding the mechanism of aeration of flooded rice soils (John *et al.* 1974, Raskin & Kende 1983).

Materials and methods

Study areas

Study sites were located in the fresh water swamp forests of Kulathupuzha (Ku), Anchal (An) and Shendurney (Sh) valleys in the Western Ghats (8° 55' - 9°14' N , 76° 55' - 77° 5' E), as they represent the most important fresh water swamp formations in southern Kerala (Figure 1). The terrain is very rugged and form part of the Western Ghats, the mountain range running along the western margin of Deccan plateau in peninsular India (see Pascal 1988 for details). Soils are Inceptisols. All three study areas experience a warm humid climate. Weather data recorded at the nearby (<10 km) Indo-Swiss Project Regional Station, Kulathupuzha during 1992 show that the mean maximum temperature ranged from 30.4 °C (January) to 36.4 °C (March) and mean minimum temperature, from 20.1 °C (January) to 24.0 °C (April) with a bimodal (June-July and October-November) total rainfall of 2909.9 mm. Altitude is <300 m and the forests generally form a closed canopy. Ground is covered by the looped knee roots and the dominant species according to Krishnamoorthy (1960) are *Myristica magnifica* (very frequent), *Gymnacranthera canarica* (frequent), *Myristica malabarica, Lagerstroemia flos-reginae, Lophopetalum wightianum, Anthocephalus cadamba, Eugenia montana* and *Carallia integerrima.*

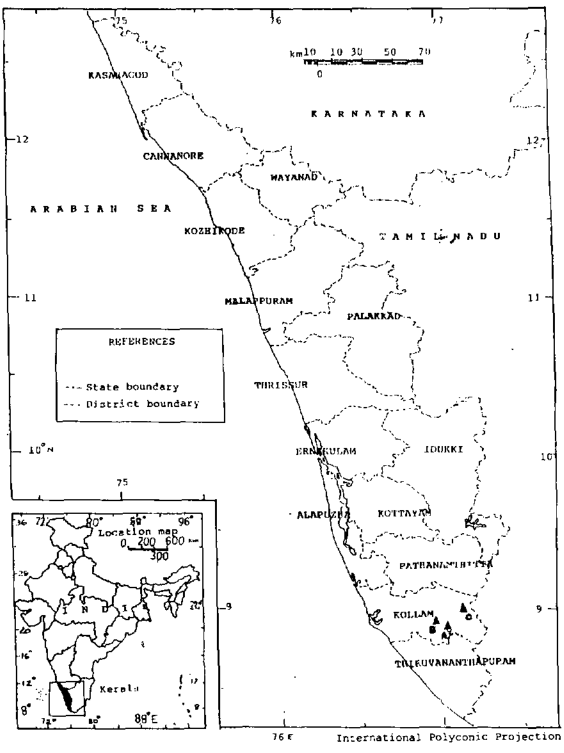

Figure 1. Map of the study area showing the three sampling sites used in the analysis of fresh water swamp forests of southern Kerala (▲ : A-Ku, B-An and C-Sh). Inset shows the location of the study area in the peninsular India

Methods

Site selection and vegetation sampling

After a detailed reconnaissance of the entire area and based on visual observations on physiographic features and floristic composition, three representative sample plots, each 0.5 ha in extent (50 quadrats of size 10 × 10m), were established at Ku, An and Sh sites during March to May 1992 (dry period). The quadrats were established using bamboo stakes and outlined by coloured nylon ropes. Height and girth at breast height (GBH) of all trees and shrubs ≥ 10 cm GBH were measured using a Suunto clinometer and tape respectively (GBH values were subsequently converted to diameter at breast height, DBH). Additionally individuals <10 cm GBH were counted and recorded by species.

Floristic structure and diversity

Using the vegetation data, species-area relations and structural attributes such as diameter and height distribution of trees were computed. Phytosociological parameters (% frequency, density, relative density, basal area and relative basal area), importance value index [(number of individuals of a species/number of individuals of all species × 100) + (number of quadrats of occurrence/total number of quadrats studied × 100) + (basal area for the species/basal area for all species × 100); Curtis & McIntosh 1950], Simpson's floristic diversity index (Simpson 1949) and Shannon-Wiener indices (Shannon & Wiener 1963) were also calculated. However, for the <10 cm GBH category, only frequency, density and relative frequency were computed. A detailed profile was drawn of a representative strip of 80 × 10 m demarcated in each area by charting the position of the tree bases, their crown projections and the extent of ground vegetation. For all charted trees, heights to the crown's top and bottom were recorded and a size-to-scale representation made with consideration to canopy architecture.

Soil studies

With the objective of characterising the soil profile development under fresh water swamp forests, profile pits (one each at the three locations) were dug up to 1 m depth. Soil samples from different horizons were collected and after morphological examination (AISLUSO 1970, SSF 1992), the samples were air dried, ground to pass through a 2-mm sieve and used for chemical analyses in the laboratory.

Three replicate samples from each of the soil horizons were analysed as follows (Jackson 1958): soil pH in a 1:2.5 mixture of soil and distilled water; organic C by Walkley-Black method; total N by micro-Kjeldahl's method; extractable P by Bray and Kurtz method; available K by flame photometry (from water samples, aqueous extracts of soils and normal neutral CH_3COONH_4 extracts). Also, mechanical analysis (hydrometer method: Jackson 1958) was performed on unreplicated horizon-wise samples from each site.

In situ redox potential (Eh) of the soil-water system was measured using a combination of Pt-saturated Ag-AgCl electrode (TOA electronics, Ltd. Japan) during October 1992 (between the wet seasons, when the plots were revisited). Measurements included the following two situations: (a) at 5-10 cm below the soil water interface (11, 5 and 10 random spot measurements at Ku, An and Sh sites respectively; copious knee roots were present at all spots), and (b) from a nearby submerged rice field (fallow) at the Sh site (5-10 cm depth; nine random spot measurements; lacking vegetation and knee roots). In addition, redox potentials of air dried soil samples collected from the profile pits (1:1 soil-water suspension; three replicates) were also measured. Redox values reported are corrected potentials with respect to the standard hydrogen electrode in millivolts (mV).

Statistical analyses

The data on the soil physico-chemical properties were analysed following the hierarchical analysis of variance technique using the statistical package, MSTAT.

Results and discussion

Floristic composition and diversity

Gymnacranthera canarica, Myristica magnifica, Lophopetalum wightianum and *Myristica malabarica* were the predominant tree species at all sites (having more than 100 individuals per ha and/or importance value indices (IVI) > 20; Table 1). *Knema attenuata,* despite being abundant at other sites, was absent at Ku site. The number of stems (≥10 cm GBH) per ha ranged from 1364 at An site to 2024 at Sh site. Average stand basal areas were 95.54, 71.08 and 130.14 m^2 ha^{-1} at Ku, An and Sh sites respectively. Most of these (56-75%) were accounted for by just two species (*G. canarica* and *M. magnifica*). The high basal area observed especially at the Sh site (over others) is intriguing. It may be due to higher density (Table 1) and/or presence of few large trees (>90 cm DBH) at this site (Figure 2). Dominant floristic elements were similar for all three sites, in the <10 cm category also (Table 2).

A total of 16 families were represented at Ku, 15 at An and 9 at Sh sites in the ≥ 10 cm GBH category. Of these, seven plant families at Ku and six each at An and Sh sites registered an IVI>10. Myristicaceae formed the most dominant family at all three sites (with an IVI of 179, 159 and 191 respectively at Ku, An and Sh sites). It also accounted for 75, 67 and 87% of the total stems present and 80, 70 and 73% of the stand basal area at these sites. Other important families included: Celastraceae (IVI: 24, 27 and 30 respectively at Ku, An and Sh sites), Flacouritaceae (13, 18 and 18), Dipterocarpaceae (11, 6 and 16), Myrtaceae (13, 16 and 13) and Anacardiaceae (14, 13 and 12).

Table 1. Phytosociological attributes of fresh water swamp forests (≥10 cm girth at breast height) of southern Kerala

Species	% Frequency	Density (no. ha^{-1})	Relative density (%)	Basal area (BA) m^2 ha^{-1}	Rela. BA (%)	Importance value index
1. Kulathupuzha						
Gymnacranthera canarica	100	650	36.48	42.24	44.20	99.47
Myristica magnifica	100	658	36.92	29.02	30.36	86.09
Lophopetalum wightianum	52	122	6.85	3.72	3.89	20.51
Holigarna beddomei	30	34	1.91	4.38	4.58	12.13
Myristica malabarica	22	30	1.68	4.98	5.21	11.03
Syzygium montanum	32	52	2.92	1.84	1.93	10.86
Hydnocarpus pentandra	38	50	2.81	0.78	0.82	10.76
Anthocephalus chinensis	22	24	1.35	3.80	3.98	9.46
Vateria indica	24	32	1.80	2.24	2.34	8.65
Persea macrantha	20	24	1.35	0.70	0.73	5.84
Lagerstromia flos-reginae	18	22	1.23	0.48	0.50	5.12
Elaeocarpus tuberculatus	18	18	1.01	0.40	0.42	4.81
Tetrameles nudiflora	8	14	0.79	0.34	0.36	2.65
Leea indica	10	10	0.56	0.06	0.06	2.50
Macaranga peltata	8	10	0.56	0.06	0.06	2.13
Glochidion zeylanicum	8	10	0.56	0.04	0.04	2.11
Diospyros buxifolia	6	6	0.34	0.16	0.17	1.63
Hopea parviflora	6	6	0.34	0.14	0.15	1.61
Artocarpus hirsuta	4	4	0.22	0.12	0.13	1.10
Xanthophyllum arnottianum	4	4	0.22	0.04	0.04	1.02
Cinnamomum malabatrum	2	2	0.11	0.00	0.00	0.49
Total	532	1782	100.01	95.54		
2. Anchal						
Gymnacranthera canarica	94	350	25.66	28.78	40.47	79.80
Myristica magnifica	98	320	23.46	11.60	16.31	54.02
Knema attenuata	78	138	10.12	4.70	6.61	28.06
Myristica malabarica	56	104	7.62	4.88	6.86	22.63
Lophopetalum wightianum	70	96	7.04	3.30	4.64	21.85
Hydnocarpus pentandra	52	66	4.84	1.12	1.58	13.97
Syzygium montanum	36	44	3.23	3.34	4.70	13.16
Macaranga peltata	46	70	5.13	0.64	0.90	12.72
Holigarna beddomei	18	18	1.32	5.68	7.99	11.92
Leea indica	30	38	2.79	0.20	0.28	7.43
Elaeocarpus glandulosus	22	22	1.61	0.36	0.51	5.32
Carallia brachiata	12	14	1.03	0.98	1.38	4.15
Persea macrantha	8	10	0.73	1.54	2.17	4.06
Hopea parviflora	8	10	0.73	1.36	1.91	3.81
Vitex altissima	14	14	1.03	0.38	0.53	3.60
Xanthophyllum arnottianum	14	14	1.03	0.14	0.20	3.26
Artocarpus hirsuta	6	8	0.59	0.92	1.29	2.75
Lagerstromia flos-reginae	8	10	0.73	0.18	0.25	2.15
Cinnamomum malabatrum	8	8	0.59	0.28	0.39	2.14
Vateria indica	4	4	0.29	0.62	0.87	1.75
Glochidion zeylanicum	6	6	0.44	0.08	0.11	1.42
Total	688	1364	100.01	71.08		

continued

Table 1 (continued)

3. Shendurney						
Gymnacranthera canarica	100	728	35.97	57.98	41.50	94.59
Myristica magnifica	100	656	32.41	24.62	18.93	68.46
Knema attenuata	90	224	11.07	5.88	4.52	31.00
Myristica malabarica	74	152	7.51	10.20	7.84	28.02
Lophopetalum wightianum	56	70	3.46	11.16	8.58	21.63
Hydnocarpus pentandra	44	54	2.67	1.00	0.77	10.97
Hopea parviflora	20	22	1.09	5.28	4.06	8.57
Syzygium montanum	30	34	1.68	2.08	1.60	8.42
Holigarna beddomei	18	18	0.89	7.66	5.86	9.86
Artocarpus hirsuta	16	22	1.09	2.74	2.11	5.93
Persea macrantha	10	14	0.69	3.26	2.51	4.91
Vateria indica	12	14	0.69	1.64	1.26	4.01
Lagerstromia flos-reginae	8	8	0.40	0.10	0.08	1.84
Cinnamomum malabatrum	6	8	0.40	0.54	0.42	1.84
Total	584	2024	100.02	130.14		

Comparison with other forest types in the Western Ghats suggests that floristic diversity of the swamps is low [21 species (≥10 cm GBH) each at the Ku and An sites and having only 14 tree species at the Sh site; Table 3]. The total numbers of species (disregarding girth limits) were 35, 31 and 29 respectively at Ku, An and Sh sites. In the high elevation (2000 m a.s.l.) evergreen shola forests of Eravikulam, Jose *et al.* (1994), however, reported 942 stems (≥10 cm GBH) belonging to 53 species in a 0.5-ha plot. In the mid elevation (900 m a.s.l.) wet evergreen *Cullenia-Mesua-Palaquium* forest type of Attapadi, Pascal (1988) observed 303 individuals (≥10 cm GBH) belonging to 32 species, in 0.2-ha area. Similarly in the low elevation (425 m a.s.l.) *Dipterocarpus-Kingiodendron-Humboldtia* forest type of Kadamakal, he recorded 460 stems (≥ 10 cm GBH) of 70 species in 0.16 ha. The numbers of individuals tallied in the 0.5-ha plot area in the present study (891, 682 and 1012 respectively for the Ku, An and Sh sites in the ≥ 10 cm GBH category, and 1107, 891 and 1245 in the <10 cm GBH category) are, however, comparable to previously reported values for the Western Ghats.

For the ≥10 cm GBH category, the species-area curve reached an asymptote at 3000 m^2 both for the Ku and An sites. Similar values were reported for other forest ecosystems of the Western Ghats (Jose *et al.* 1994; 2500 m^2). The species-area curve of Sh site, however, levelled out at a much lower value of 300 m^2. Fewer number of species at the Sh site (Table 3) and their even spatial distribution may have resulted in this earlier levelling off in the species-area curve. Apart from indicating the adequacy of the sampled area, this also gave a good indication of how heterogenous each sample 0.5-ha plot is.

Table 2. Density, percentage frequencies and relative frequencies of important (having >25 per cent frequency) fresh water swamp species in the <10 cm GBH category

Species	Percentage frequency	Density ($no.ha^{-1}$)	Relative frequency (%)
1. Kulathupuzha			
Gymnacranthera canarica	100	596	13.37
Myristica magnifica	100	614	13.37
Lophopetalum wightianum	64	166	8.56
Holigarna beddomei	60	66	8.02
Myristica malabarica	30	92	4.01
Syzygium montanum	50	94	6.68
Hydnocarpus pentandra	48	78	6.42
Anthocephalus chinensis	38	68	5.08
Vateria indica	42	62	5.61
Persea macrantha	40	78	5.35
Leea indica	26	52	3.48
Others	150	248	20.05
Total	748	2214	100.00
2. Anchal			
Myristica magnifica	100	382	12.69
Gymnacranthera canarica	96	290	12.18
Knema attenuata	88	196	11.17
Myristica malabarica	84	118	10.66
Lophopetalum wightianum	70	132	8.88
Hydnocarpus pentandra	54	108	6.85
Syzygium montanum	40	56	5.08
Macaranga peltata	48	68	6.09
Leea indica	32	44	4.06
Holigarna beddomei	26	44	3.30
Elaeocarpus glandulosus	26	54	3.30
Others	124	290	15.74
Total	788	1782	100.00
3. Shendurney			
Gymnacranthera canarica	100	690	14.66
Myristica magnifica	100	560	14.66
Knema attenuata	100	402	14.66
Myristica malabarica	80	206	11.73
Lophopetalum wightianum	60	116	8.80
Hydnocarpus pentandra	46	66	6.74
Syzygium montanum	38	94	5.57
Holigarna beddomei	34	52	4.99
Artocarpus hirsuta	26	38	3.81
Others	98	266	14.37
Total	682	2490	99.99

Floristic diversity of An site was the highest of the three study areas (Simpson's diversity index, D=0.85; Table 3). Implicit in here is the lowest concentration of dominance (highest probability of two different species occurring in any given pair of trees in 100 randomly selected pairs of individuals). An site also registered the widest distribution of individuals among species (Shannon-Wiener's H') and a more equitable or even distribution (high E). The relatively high floristic diversity noted at the An site is perhaps an artifact of the fewer number of individuals present there. Moreover, diversity, as a measure of floristic richness was low in the fresh water swamps as a whole (D: 0.73-0.85; H' 2.46-3.69: Table 3), compared to other forest ecosystems of the Western Ghats (Pascal 1988, Jose *et al.* 1994). These authors have reported D>0.90 and H' ranging from 3.6 to 4.86. Lower floristic diversity observed in the swamps could be attributed to factors such as adverse environmental conditions (flooding and the associated soil changes) and the consequent habitat specialisation, which permits only few species to colonise the area. Swamps also represent isolated and/or disjointed pockets of woody vegetation, often separated by other forest formations. Isolation can prevent or drastically reduce immigration, thus favouring lower floristic diversity (Leigh *et al.* 1993).

Table 3. Floristic diversity indices (GBH ≥10 cm) of the fresh water swamp forests of southern Kerala (area: 5000 m^2)

Site	Number of species	Number of individuals	Simpson's index (D)	Shannon-Wiener indices		
				H'	Hmax	E*
Kulathupuzha (Ku)	21	891	0.73	2.53	4.39	0.58
Anchal (An)	21	682	0.85	3.69	4.39	0.84
Shendurney (Sh)	14	1012	0.75	2.46	3.81	0.65

*E=E'/Hmax.

Vegetation structure

The diameter distribution showed a negative exponential relationship with many small individuals and few large ones at all sites (Figure 2). Implicit in this inverse 'J' shaped distribution pattern is the adequacy of natural regeneration in these forests, as a truncated lower size classes would have indicated a threatened ecosystem. The diameter structure of the predominant tree species (Figure 2) and their height distribution (except <5 m class) also tended to follow the negative exponential relationship (data not shown).

Profile diagrams (Figure 3a-c) covering representative strips suggest a pronounced canopy continuity. Physiognomically the fresh water swamps represent a multi-tiered structure. Crowns are very dense, forming five distinct strata. Emergents like *Lophopetalum wightianum, Hopea parviflora, Holigarna beddomei* and *Artocarpus hirsuta* formed the first strata. *Myristica* dominated the second strata while all intermediate trees formed the third strata and the suppressed individuals formed the fourth strata with the ground flora (mainly aroids) constituting the bottom-most layer. Crowns tapered from the base to the top except in *Anthocephalus chinensis* and *H. beddomei*, both of which had circular crowns.

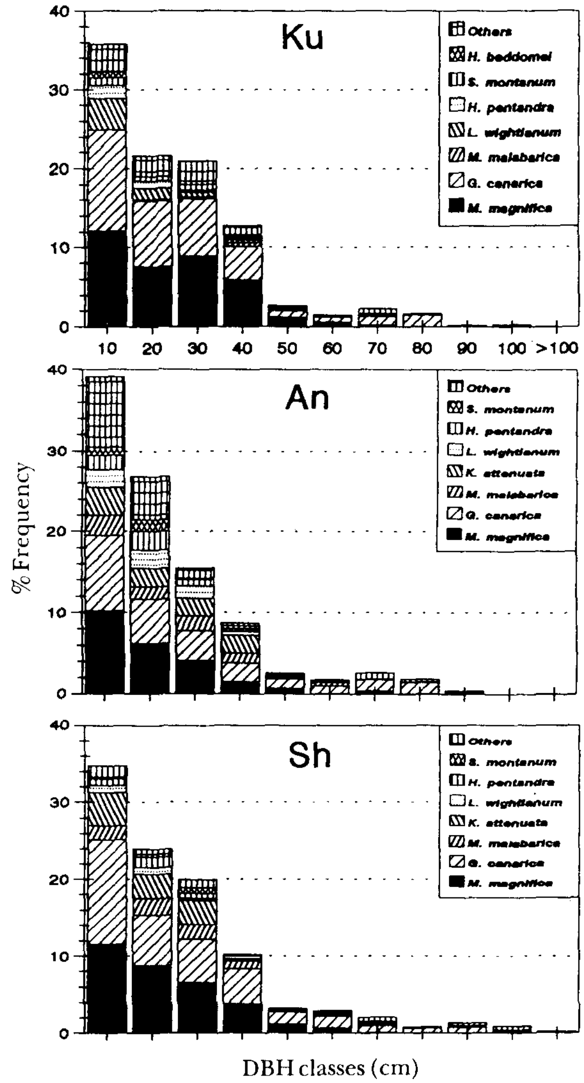

Figure 2. Diameter (DBH) distribution of fresh water swamp forests of southern Kerala (≥ 10 cm GBH)

Edaphic attributes

The soil profiles at all three sites could be broadly divided into O_a, A_1, B_{21} and B_{22} horizons. This, however, is based on a limited sampling of one profile from each location. Nevertheless, as the locations are sufficiently close by and vegetational, hydrological and climatological features are broadly similar to each other, we feel

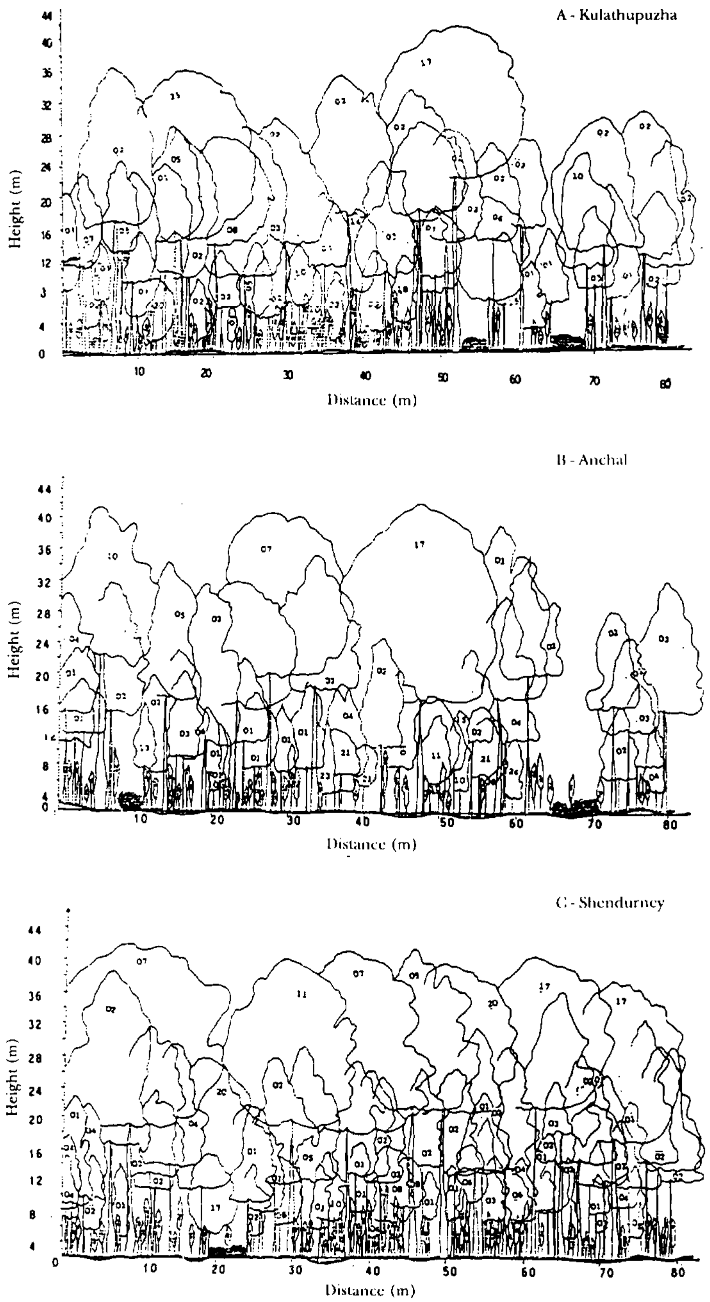

Figure 3. Profile diagram of the fresh water swamp forests. A - Kulathupuzha, B - Anchal and C - Shendurney (01- *Myristica magnifica*, 02- *Gymnacranthera canarica*, 03 - *Myristica malabarica*, 04 - *Knema attenuata*, 05- *Lophopetalum wightianum*, 06 - *Hydnocarpus pentandra*, 07- *Hopea parviflora*, 08 - *Lagerstromia flos-reginae*, 09 - *Vateria indica*, 10 - *Syzygium montanum*, 11- *Artocarpus hirsuta*, 12 - *Diospyros buxifolia*, 13 - *Vitex altissima*, 14 - *Tetrameles nudiflora*, 15 - *Xanthophyllum arnottianum*, 16 - *Carallia brachiata*, 17- *Holigarna beddomei*, 18 - *Cinnamomum malabatrum*, 19 - *Elaeocarpus tuberculatus*, 20 - *Persea macrantha*, 21- *Macaranga peltata*, 22 - *Glochidion zeylanicum*, 23 - *Leea indica*, 24 - *Elaeocarpus glandulosus*, 25 - *Anthocephalus chinensis*).

that the present sampling procedure may suffice to portray the generalities in this respect. The surface soil had a dark reddish-brown coloration in comparison to the lower horizons showing organic matter accumulation at the top (Tables 4 and 5). Granular structure in the surface horizon was followed by a subangular blocky structure in the sub-surface layers especially at Ku and An sites. Granular structure is characteristic of a vigorous forest cover that favours maintenance of good soil structure. Predominance of coarse fragments (Table 4) may be due to pedogenic processes, especially colluviation, which may be responsible for swamp soil formation.

Clay content of the swamp soils, although low, increased with depth (Table 5). A fluctuating water table might be responsible for migration of clay to the lower layers of the profile. Site variations in clay and sand contents were not statistically significant, despite pronounced ($p<0.05$) variations in silt percentage. The An site registered high silt content especially in the lower horizons.

The swamp soils were moderately acidic to neutral (pH 5-7). Moderating effects of water logging on soil pH are reported by Ponnamperuma (1972). The most dramatic effect of flooding, however, is a depletion in its oxygen level and a concomitant reduction in its redox potential (Eh), a measure of its tendency to accept or give of electrons (Ponnamperuma 1972, Adams 1990). There are only few reports characterising the redox potential of fresh water swamp forest ecosystems. We, therefore, measured the redox potentials (Eh) of the swamp soils from different situations at the three selected locations.

In situ redox potentials (Eh) of the fresh water swamp soils (5-10 cm below the soil-water interface) were in the positive range. Mean Eh values were: 317 mV (n=11; range 269 to 369) at Ku, 353 mV (n=5; range 299 to 399) at An and 324 mV (n=10; range 219 to 409) at Sh. Site variations were small in this respect. Strongly oxidised soils usually have Eh values >500 mV. Although strongly negative Eh values are rarely found in near-surface layers of natural wetlands, the present values are reckoned as moderately high (oxidised) for flooded soils, presumably due to oxygenation of the swamp rhizosphere by roots.

Significantly, a nearby submerged field (at Sh site) without any vegetation registered a much lower Eh value of 194 mV (n=9; range 99-269). This remarkable variability in the redox potentials of vegetated and non-vegetated soils strongly suggest oxygenation of the rhizosphere by plant roots. We, therefore, hypothesise that knee roots, endowed with numerous lenticels, when present, translocate oxygen downwards and release it into the rhizosphere. This is to keep the immediate root environment oxygenated, possibly to avert the toxic effects of extreme soil reduction. As the forest floor is completely covered with numerous knee roots, this may have a pronounced effect on the redox state of the entire swamp rhizosphere.

Inter-site variations in redox potentials of air dried soil samples were significant, with the Sh site registering higher values (Table 5). Differences between horizons were, however, small. The relatively high Eh values at the Sh site may be associated with its low organic matter status (Table 5). Ponnamperuma (1984) suggested that presence of organic matter and high temperature (35 °C) may favour rapid Eh

Table 4. Morphological description of the soil profiles of the three study areas

Horizon	Depth (cm)	Description
1. Kulathupuzha		
O_a	20 - 0	Dark reddish-brown 5 YR 3/4 (M), silty clay loam, medium weak granular structure, moist very friable, slightly sticky and non-plastic, fine roots plenty, rapid permeability,clear smooth boundary.
A_1	0 - 30	Dark reddish-brown 5 YR 3/4 (M), sandy clay loam, medium weak granular structure, moist friable, slightly sticky and slightly plastic, fine roots plenty, moderate permeability, diffuse wavy boundary.
B_{21}	30 - 60	Dark yellowish-brown 10 YR (M),gravelly sandy clay loam, fine quartz gravel plenty, coarse subangular blocky, slightly sticky and slightly plastic, fine roots few, moderately slow permeability, diffuse wavy boundary.
B_{22}	60 - 80	Dark reddish-brown 5 YR 3/4 (M), gravelly sandy clay loam, fine quartz gravel plenty, coarse subangular blocky structure, slightly sticky and slightly plastic, medium roots plenty, moderate permeability.
2. Anchal		
O_a	20 - 0	Very dark greyish- brown 10 YR 3/2 (M), sandy loam, medium weak granular structure, moist very friable, slightly sticky and non-plastic. Medium roots plenty, moderate permeability, clear smooth boundary, fine roots plenty.
A_1	0 - 30	Dark reddish- brown 5 YR 3/4 (M), sandy clay loam, medium weak subangular blocky, moist friable, wet slightly sticky and slightly plastic, medium roots plenty, moderate permeability, fine roots plenty, diffuse wavy boundary.
B_{21}	30 - 50	Dark brown 7.5 YR 3/2 (M) with dark reddish-brown 5 YR 3/4 mottles few, clay loam, medium weak, subangular blocky, moist firm, wet sticky and slightly plastic. Fine roots few, moderate permeability, gradual wavy boundary.
B_{22}	50 - 80	Dark yellowish-brown 10 YR 4/4 (M), sandy clay loam, fine quartz gravel plenty, medium moderate subangular blocky, moist firm, wet sticky and slightly plastic, fine to medium roots few, moderate permeability.
3. Shendurney		
O_a	20 - 0	Dark brown 10 YR 4/3 (M), sandy loam, medium weak granular structure, moist very friable, wet slightly sticky and non-plastic, fine roots plenty, rapid permeability, diffuse wavy boundary.
A_1	0 - 10	Greyish-brown 10 YR 5/2 (M), gravelly sandy loam, weak granular structure, moist very friable, wet slightly sticky and non-plastic, fine roots plenty, rapid permeability, diffuse wavy boundary.
B_{21}	30 - 60	Dark brown 10 YR 4/3 (M), gravelly sandy clay loam, medium moderate, massive structure, moist friable, wet slightly sticky and slightly plastic, few fine roots, moderate permeability, diffuse wavy boundary.
B_{22}	60 - 80	Dark reddish-brown 10 YR 5/3 (M), gravelly sandy clay loam, medium moderate massive structure, moist firm wet slightly sticky, slightly plastic, medium roots few, moderate permeability.

Table 5. Physical, chemical and mechanical properties of fresh water swamp forest soils of Kerala

Site	Soil depth (cm)	pH	Eh (mV)	Organic C (%)	Total N (%)	Available P (ppm)	Available K (ppm)		Sand (%)	Silt (%)	Clay (%)
							CH_3COONH_4	Aqueous			
Ku	20-0	5.60^{a}	419	2.10^{a}	0.36^{a}	3.43^{a}	43.33^{a}	15.67^{a}	89	6	5
	0-30	5.87^{b}	459	0.80^{b}	0.19^{b}	2.38^{b}	37.33^{b}	10.33^{b}	86	6	8
	30-60	5.88^{b}	489	0.57^{c}	0.13^{c}	1.40^{c}	33.00^{c}	7.00^{c}	87	6	7
	60-80	5.96^{b}	489	0.24^{d}	0.06^{d}	0.35^{d}	29.33^{d}	6.00^{c}	84	6	10
An	20-0	6.27^{c}	499	1.76^{e}	0.27^{e}	2.60^{b}	25.00^{e}	14.17^{a}	91	5	4
	0-30	6.26^{c}	499	1.08^{f}	0.15^{c}	0.35^{d}	19.67^{f}	11.67^{b}	89	6	5
	30-50	6.33^{c}	519	0.75^{b}	0.11^{c}	0.56^{d}	25.00^{e}	12.00^{b}	86	8	6
	50-80	6.46^{d}	509	0.20^{d}	0.05^{d}	0.91^{f}	18.00^{f}	11.33^{b}	87	8	5
Sh	20-0	6.48^{d}	519	1.22^{g}	0.24^{e}	2.03^{b}	14.00^{g}	10.50^{b}	91	5	4
	0-10	6.21^{c}	499	0.60^{c}	0.18^{b}	1.68^{cg}	12.33^{g}	9.83^{c}	91	4	5
	10-60	6.11^{e}	529	0.43^{h}	0.11^{c}	1.12^{c}	17.00^{fg}	11.33^{b}	88	4	8
	60-80	6.01^{f}	529	0.35^{h}	0.11^{c}	1.80^{g}	24.67^{e}	10.67^{b}	86	3	11
F test probability											
Between sites		<0.01	<0.05	ns	ns	ns	<0.01	ns	ns	<0.05	ns
Between horizons and within a site		<0.01	ns	<0.01	<0.01	<0.01	<0.01	<0.01	ns	ns	ns

ns : not significant;

Values followed by the same superscript(s) do not differ significantly.

decrease in flooded soils. Site differences in soil organic matter levels were not significant, despite seemingly large variations.

Total N and available P levels at different locations also did not vary greatly, although their profile distribution showed marked differences. Organic C, N, P and K levels declined as profile depth increased (Table 5). Furthermore, C, N, P and K levels of the swamp soils were lower than those of other forest ecosystems in the Western Ghats. Jose *et al.* (1994) reported much higher values for all these parameters in the shola soils of Eravikulam. High rainfall and the fluctuating water table, characteristic of swamps, may be responsible for the observed low nutrient levels, especially N and K (mobile elements, susceptible to leaching). K is of special significance in this regard, as most of it is held in the soil mineral pool (as opposed to N which is predominantly in the organic form). CH_3COONH_4 extractable K values of the swamp soils were particularly low (18-43 ppm; Table 5). In the shola forests of Western Ghats, Jose *et al.* (1994) reported 97-179 ppm of K. We suspected leaching of K as a primary cause for this drastically reduced K content in the swamp soils. Hence, we monitored K levels in flood waters and aqueous extracts of air dried soils. We expected only traces of K in the water column, but found that K contents of the water samples were substantial (2.1, 2.5 and 2.3 ppm respectively for the Ku, An and Sh sites). K levels of aqueous extracts (Table 5) were also considerable. The high proportion of water soluble K can possibly explain the excessive leaching of this element from the profile leading to lower levels of K in the swamp soils.

Conclusion

The swamp forests represent an apparently stable vegetation with reasonably good regeneration potential. They are, however, characterised by a lower floristic diversity than other forest formations in the Western Ghats, owing to habitat specialisation, despite having comparable stem density. Other vegetational features include a pronounced canopy continuity, multi-tiered canopy structure and inverse 'J' shaped diameter structure. Soil hypoxia might have led to the concentration of tolerant species (mostly Myristicaceae) in the swamps, having special adaptive traits. The swamp soils are also characterised by lower amounts of major nutrients than in other forest ecosystems in the region. *In situ* redox potentials of the swamps were greater than those of a nearby flooded fallow soil suggesting oxygenation of the swamp rhizosphere by knee roots.

Acknowledgements

V.K. Venugopal prepared the morphological descriptions of the soil profiles. N. Sasidharan of the Kerala Forest Research Institute, Peechi (KFRI) identified the difficult plant specimens. The facilities provided by C.C. Abraham, former Special Officer, College of Forestry, P.A. Wahid, Radio Tracer Laboratory, and S. Sankar along with his colleagues in the Soils Division of KFRI, the permission to conduct the study in the Thiruvananthapuram and Thenmala Forest Divisions and the Shendurney Wildlife Sanctuary by the Kerala Forest Department and the assistance rendered by Janardhanan and S. Sreekumar, Forest Range Officers and Anirudhan, Assistant Wildlife Warden, are gratefully acknowledged. The present work forms part of the B.Sc. (Forestry) dissertation submitted to the Kerala Agricultural University by the first author.

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