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Ecology of the Swampy Relic Forests of Kathalekan from Central Western Ghats, India

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ABSTRACT

Introduction of agriculture three millennia ago in Peninsular India's Western Ghats altered substantially ancient tropical forests. Early agricultural communities, nevertheless, strived to attain symbiotic harmony with nature as evident from prevalence of numerous sacred groves, patches of primeval forests sheltering biodiversity and hydrology. Groves enhanced heterogeneity of landscapes involving elements of successional forests and savannas favouring rich wildlife. A 2.25 km^2 area of relic forest was studied at Kathalekan in Central Western Ghats. Interspersed with streams studded with *Myristica* swamps and blended sparingly with shifting cultivation fallows, Kathalekan is a prominent northernmost relic of southern Western Ghat vegetation. Trees like *Syzygium travancoricum* (Critically Endangered), *Myristica magnifica* (Endangered) and *Gymnacranthera canarica* (Vulnerable) and recently reported *Semecarpus kathalekanensis*, are exclusive to stream/swamp forest (SSF). SSF and non-stream/swamp forest (NSSF) were studied using 18 transects covering 3.6 ha. Dipterocarpaceae, its members seldom transgressing tropical rain forests, dominate SSF (21% of trees) and NSSF (27%). The ancient Myristicaceae ranks high in tree population (19% in SSF and 8% in NSSF). Shannon-Weiner diversity for trees is higher (>3) in six NSSF transects compared to SSF (<3). Higher tree endemism (45%), total endemic tree population (71%) and significantly higher above ground biomass (349 t/ha) cum carbon sequestration potential (131 t/ha) characterizes SSF. Faunal richness is evident from amphibians (35 species - 26 endemics, 11 in IUCN Red List). This study emphasizes the need for bringing to light more of relic forests for their biodiversity, carbon sequestration and hydrology. The lives of marginal farmers and forest tribes can be uplifted through partnership in carbon credits, by involving them in mitigating global climatic change through conservation and restoration of high biomass watershed forests.

Keywords: biodiversity hot spots, carbon credit, carbon sequestration, conservation, hydrology, *Myristica* swamps, Uttara Kannada
Abbreviations: AGB, above ground biomass; **BA**, basal area; **GBH**, girth at breast height; **IUCN**, International Union for the Conservation of Nature; **IVI**, importance value index; **NSSF**, non-stream/swamp forest; **SD**, standard deviation; **SSF**, stream/swamp forest

INTRODUCTION

The Western Ghats of the Indian peninsula constitute one of the 34 global biodiversity hotspots along with Sri Lanka, on account of exceptional levels of plant endemism and by serious levels of habitat loss (Conservation International 2005). The rugged range of hills stretching for about 1600 km along the west coast from south of Gujarat to the end of the peninsula (lat. 8° and 21° N and long. 73° and 78° E), is interrupted only by a 30 km break in Kerala, the Palghat Gap (Radhakrishna 2001). Covering a geographical area of about 160,000 km^2, the Western Ghats have an average height of 900 m, with several cliffs rising over 1000 m. The Nilgiri Plateau to the north and Anamalais to the south of the Palghat Gap exceed 2000 m in many places. Towards the eastern side the Ghats merge with the Deccan Plateau which gradually slopes towards the Bay of Bengal. The northern half of the Western Ghats is covered with basaltic rocks of volcanic origin whereas the southern half is of Pre-Cambrian rocks of different kinds like the crystalline rocks, the peninsular gneisses and the charnokites. Nearly a hundred rivers originate from these mountains and most run their westward courses towards the Arabian Sea that is close-by. Only three major rivers, joined by many of their tributaries flow eastward, longer distances, towards the Bay of Bengal (Dikshit 2001; Radhakrishna 2001). The Western Ghat rivers are very critical resources for peninsular India's drinking water, irrigation and electricity.

The complex geography, wide variations in annual rainfall from 1000-6000 mm, and altitudinal decrease in temperature, coupled with anthropogenic factors, have produced a variety of vegetation types in the Western Ghats. Tropical evergreen forest is the natural climax vegetation of western slopes, which intercept the south-west monsoon winds. Towards the rain-shadow region eastwards vegetation changes rapidly from semi-evergreen to moist deciduous and dry deciduous kinds, the last one being characteristic of the semi-arid Deccan region as well. All these types of natural vegetation degrade rapidly in places of high human impact in the form of tree felling, fire and pastoralism, producing scrub, savanna and grassland. Lower temperature, especially in altitudes exceeding 1500 m, has produced a unique mosaic of montane 'shola' evergreen forests alternating with rolling grasslands, mainly in the Nilgiris and the Anamalais (Pascal 1988).

Peninsular India is a rich centre of flowering plant endemism, details of which are given by Ahmedullah and Nayar (1987) and Nayar (1996). There are 2015 endemic taxa in this region most of them confined to the Western Ghats, with only 76 taxa associated with the Eastern Ghats. Many of these endemics are threatened due to human impacts and figure in the Red List of the International Union for the Conservation of Nature (IUCN, 2009). Our study, being on the Kathalekan relic forest in Central Western Ghats, focuses mainly on trees and details related to their endemic status highlighting also on the Red Listed tree species in the study area. The high degree of faunal endemism is illustrated through inventorisation of the amphibians.

'Relics' were described by Drude in 1890 as those taxa that occur in disjunct areas, the intermediate link being lost by environmental or geological changes. They have been termed variously as 'palaeoendemics' by Chevalier and

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Guenot in 1925 and as 'relic' or 'ancient endemism' by Herzog in 1926 (Nayar 1996). Most of the endemic plants of Peninsular India are palaeoendemics in ecological niches characterised by habitat temperature/rainfall gradients, and vegetational interphases. The ecological niches of Western Ghats resemble islands so far as the distribution of endemic species is considered (Subramanyam and Nayar 1974). Stebbins (1980) considers 'relict'/palaeoendemics of restricted distribution as museums than active centres of speciation.

The 'relic forests' of Central Western Ghats, the subject of this paper, has to be understood better in a human historical context. Forest alterations began in these mountains with the introduction of agriculture just over three millennia ago (Chandran 1997). Under a community-based landscape management regime that prevailed during the pre-British period, the agricultural communities lived more in the lower altitudes causing alterations in the primeval forests leading to the creation of a mosaic landscape in which patches of unaltered or less altered forests were retained as sacred groves *cum* safety forests. Forests were not seen primarily as sources of timber but viewed more as the provider of fertile lands for agriculture (both of shifting and permanent kind), for pastoralism, as source of non-timber products for subsistence and sale, as hunting resources and also for hydrological security. The British domination of the region from early 19th century marked the end of community-centered forest management. The sacred groves, especially larger ones, along with secondary forests and fallows became part of state reserved forests and in due course lost their special identity. Today many such primeval forest relics remain lost amidst the general category of state reserved forests. Being of evergreen nature with not much scope for harvest of commercial timbers these groves were simply preserved or alienated for alternative uses. A cultural change, emphasizing also temple-centered worship of gods, caused further neglect and decline of the system of isolated sacred groves associated with human settlements. Many 'lost' groves, nevertheless, along with their treasure trove of rare, endemic species can still be traced in parts of south Indian Western Ghats. Most forests, including sacred groves, shifting cultivation grounds and fallow growth on them got merged with state reserved forests. The society's own changing worldview, associating gods with temples than groves, and rising need for biomass the harvest of which was restricted from the state reserved forests also caused degradation of sacred groves closer to habitations (Gadgil and Berkes 1991; Chandran and Gadgil 1993; Chandran 1998).

We refer here as 'relic forests' those ancient forest patches, which have no history of wholesale clearance or major alterations by humans so that the original composition persists to some degree. Many of the sacred groves obviously fit into this definition and are easier to find than any fragments of primeval forests that escaped destruction by humans due to their relative inaccessibility. Most sacred groves known today are from the densely populated west coast or in the vicinity of Western Ghat villages, often standing isolated amidst a humanized landscape. The relic forests of this type are indeed easily visible cultural or biological relics of any countryside in the western peninsular India. There are also lesser known relic forests along the thinly populated core forest belt of the Western Ghats. These could have been sacred groves of the pre-colonial past which lost, or almost so, their special identity as seats of gods due to forest reservation by the state. Such lost groves were often subjected to timber extraction pressures or sometimes even wholesale alterations getting converted into alternative land uses. Thus was forgotten the past of these ancient woods, which the early peasants had preserved through generations in the name of deities, to supplement their livelihoods and to serve vital ecological functions necessary for the stability of life in an otherwise fragile ecological region. Their earlier status lost, these relic forests often got engulfed with secondary forests of slash and burn fallows in the course of time. Their usual presence was more along the high rainfall region with sensitive soils prone to fast erosion and loss of fertility than along the low rainfall Deccan side of the mountains where soil resources are better though fire hazards to the deciduous forests are higher.

The forests which lost their earlier aura of sacredness under community-based management did not get any special consideration from the state and were subjected to routine forestry operations to meet state needs, harming their special biodiversity preserved through ages. Last few decades, however, have seen increased awareness on the need for conservation and sustainable use of the natural resources (Chandran 1998; Pathak 2009). The 1988 ban on timber extraction from natural forests has kindled hopes on biological revival of the Western Ghat forests. A renewed global interest in the institution of sacred groves saw numerous studies carried out in India on these relic forests. These studies mainly harp on linkages between culture and conservation in relation to mostly functional sacred groves. In this paper, on the contrary, we attempt to unravel for the first time, the biological richness of forgotten groves along with the carbon sequestration potential, hydrological and ecological linkages, through a special study of Kathalekan, highlighting also the need and urgency to recognize and salvage many more such relic forests. The main objectives of the study are to:

- characterize relic forests;
- establish norms for the identification of relic forests;
- devise a plan for systematic study of their vegetation;
- record habitat heterogeneity, tree diversity, endemism, basal area and biomass;
- document regeneration status of notable climax, endemic and relic tree species;
- relate hydrological conditions with plant diversity;
- understand faunal significance using amphibians as indicators;
- estimate carbon sequestration potential; and to
- formulate appropriate conservation strategy.

Tropical forests, harbouring rich biodiversity, high endemism and complex ecology, have been steadily impacted by humans, especially since the introduction of farming. Secondary forests throughout the world are increasing dramatically and in many tropical countries they now exceed the areas covered by primary forest (FAO 2005). Slash and burn cultivation which enables releasing nutrients accumulated in biomass in the form of ashes (Nye and Greenland 1960) is regarded as one of the major causes of deforestation in earlier times. Even the world's largest blocks of rainforests, as of central Amazonia, Congo basin and Thailand considered 'undisturbed' had undergone clearances for habitation and cultivation. Such forests elsewhere too may actually be in the process of secondary succession (Froyd and Willis 2008).

'Remnant' primary forests were noticed to exist embedded in tropical agricultural landscapes (Power 1996). In the Pacific New Caledonia, a biodiversity hotspot (Myers *et al.* 2000), exists one of the world's most endangered tropical dry forest, fragments of which from parts of a hectare to several hectares in area, rich in endemics and mostly situated in private lands, have been preserved due to fencing and fire protection (Gillespie and Jaffre 2003). In Ethiopia are many forest relics, considered as islands of diversity, having unique composition reflecting the original climax ecosystems of the Ethiopian highlands (Muys *et al.* 2006). "Enormous, well preserved, relic forests, probably the largest relic forests on the western slope of the Andes" are referred to by Llatas-Quiroz and Lopez-Mesones (2005), who argued for their preservation both for hydrological reasons and their plant wealth. Tropical swamps are often considered relics of the original rainforests. In the highland valleys (1500–2000 m) of New Guinea were many swamps dominated by Myrtaceae (mostly *Syzygium*) and *Pandanus* during the Early Holocene. During the Mid-Late Holocene, swamp forests were cleared using fire for wetland agriculture. However, there are relics still left, although the primeval Myrtaceae suffered a decline (Denham *et al*. 2004; Haberle 2007).

Many parts of the world had the tradition of preserving forest patches as sacred dedicated to deities or deified ancestors. This tradition got strengthened especially with the introduction of agriculture, which necessitated forest clearances in a big way. In shifting cultivation fallows, forests would re-grow, the burning of which after a lapse of several years would add a flush of nutrients to the soil in the form of ashes, facilitating growing the next round of crops. However, the shifting cultivators as well as those who settled with permanent cultivation in valleys kept alive the practice of protection of primeval forest patches as sacred groves. This practice dwindled in most of the world, except in some countries where it prevails among indigenous societies, especially in highlands (Chandran 1998; Hughes and Chandran 1998).

The indigenous people of Yunan, who had high dependence on forest resources for their livelihoods, had also engaged in worship of sacred forests (Pei *et al.* 2009). In the Republic of Togo the local communities protected sacred forests especially on riversides. Several of these forest fragments are considered "modern relics of old and disappearing plant communities". Some of the plant species were stated to be available only within these relics and 56 species were recorded for first time from Togo in these relics (Kokou *et al.* 2006).

The Indian highlands, particularly in the North East India, the Himalayas, the Central India and the Western Ghats-west coast region are rich in sacred groves. The sacred groves are among the last representatives of climax vegetation in the Western Ghats and North East India. In the tribal tract of western Midnapur district even relics of sacred groves, present almost in every village, harbour good number of birds (Deb *et al*. 1997). The groves of north-eastern hill regions of India are considered relics of the original vegetation. In Meghalaya climax species like *Quercus griffithi*, *Lithocarpus dealbatus* and *Schima khasiana* were reported to be regenerating in the shade of undisturbed groves than in the disturbed forests (Tripathy 2005). Sacred groves of Tamil Nadu are considered as the remnants of the forests that once thrived there (Amrithalingam 1998).

Myriads of sacred groves which dot the landscape of the Western Ghats-west coast region are known by various local names like *Devrai* (Maharashtra), *Kan*, *Devarakadu* (Karnataka) and *Kavu* (Kerala). The areas under the groves were much larger once, ranging from few to several hundred hectares. As there is paucity of historical records to make such a claim, an effort was made to reconstruct the traditional land use system in a 25 km^2 area of a peasant dominated undulating terrain in eastern Siddapur of Uttara Kannada. The reconstruction was based on landscape names, folk history, forest settlement records, and vegetation. It was found that nearly 6% of the land was maintained under sacred groves, under community management. By the 1990's the area under groves had shrunk to mere 0.31%, although the number of groves is high (54) even today (Chandran and Gadgil 1998). This appears to be a modest estimate for the Central Western Ghat region, as a forest working plan of 1966 for Sirsi and Siddapur mentions area under Kodkani village (close to Kathalekan) as having a *Kan* of 735 ha and Mulkund one of 1039 ha. Brandis and Grant (1868) reported 171 *Kans* of Sorab taluk (in the neighborhood of Siddapur) as covering over 13,000 ha. So there were two kinds of forests in Central Western Ghats. The *kan* sacred groves and the ordinary forests or *kadu.* The *Kans* were, obviously relic forests protected by local communities as sacred groves cum safety forests. While there was a taboo on timber harvesting from the *Kans* the community collected black pepper, cinnamon bark, fruits and seeds, medicinal plants etc. and tapped palm juice from *Caryota urens* that grew plentifully in them (Chandran and Gadgil 1993; Chandran *et al*. 1998). The *Kans* were hydrologically important being at the source of perennial streams and springs (Anonymous 1923). Some *Kans* of southern Uttara Kannada harbour fragments of *Myristica* swamps, an endangered and ancient habitat of high watershed value (Chandran and Mesta 2001).

Myristica magnifica was known only from southern Kerala (8-10° N) and at Malemane village of which Kathalekan is a hamlet (14.27° N) in the Siddapur taluk. Such swamps with *M. magnifica* were also found in the Mahime village of the adjoining Honavar taluk by Chandran *et al.* (1999). Each of the 51 swamps they recorded in southern Uttara Kannada had *Gymnacranthera canarica*, yet another swamp species of the *Myristica* family and a new record for the district. *Semecarpus kathalekanensis*, a new tree species of Anacardiaceae was described from the swamps of Kathalekan (Dasappa and Swaminath 2000). Recent discovery of two Critically Endangered trees *Madhuca bourdillonii* and *Syzygium travancoricum* from some relic forests of Uttara Kannada, almost 700 km north of their recorded home range in southern Kerala, underscores the need for intensifying efforts for locating more such relics (Chandran *et al.* 2008). Both these species were feared to be extinct according to the *Red Data Book of Indian Plants* (Nayar and Sastry 1987, 1990), but rediscovered later in southern Kerala itself (Sasidharan and Sivarajan 1996; Sasidharan 1997). Nair *et al.* (2007) have provided a comprehensive account of the biodiversity of *Myristica* swamps of Kerala.

Most relic forest studies in India pertain to functional sacred groves in the vicinity of habitations which are in waning state due to anthropogenic pressures, and their ability to sustain rare and threatened species is obviously on the decline. On the other hand there is a whole class of sacred groves, as in the Western Ghats, which lost their special status as abodes of gods under local community management. This happened when the British reserved forests as state property. Consequently these patches of primeval forests got merged with a sea of secondary forests around, often re-growth on shifting cultivation fallows. During periods of intensified exploitation of evergreen forests for meeting industrial demands even these ancient groves were not spared. Kathalekan, the forest studied for the present work, was such a *Kan* sacred grove.

MATERIALS AND METHODS

This study was conducted in the Kathalekan hamlet (14.2639° to 14.2789° N and 74.7389° to 74.754° E) of Siddapur taluk of Uttara Kannada (formerly North Kanara) district in the Central Western Ghats, in the state of Karnataka (**Fig. 1**). Bordered by the Arabian Sea to the west, a major part of the district's 10,291 km^2 area is covered with the low hills of the Western Ghats, their general elevation seldom rising over 600 m. Uttara Kannada has a tropical climate with a well defined rainy season between June and November with an average rainfall of 2500 mm. The western parts of the district, including Kathalekan region, exposed to the South West Monsoon, receive copious seasonal rainfall of 3000 to 5000 mm. The rainfall declines rapidly towards the east and north-eastern parts of Uttara Kannada which merge with the semi-arid Deccan region (Pascal 1988; Bourgeon 1989).

Evergreen to semi-evergreen forests dominate major portion of the district towards the west where rainfall is heavy. With declining rainfall towards the east the forests change from moist deciduous to dry deciduous types. Degraded forests in the form of savanna grasslands, scrub and thickets of biotic origin are present closer to habitations. Most forests towards the west are considered secondary, owing their origin mainly to slash and burn cultivation that was widely prevalent up to mid 19th century and thereafter in an attenuate form until the close of the century. These forests today are in different stages of secondary succession, and in many places appear like the primary forest itself (Chandran 1997, 1998). The region is dominated by complex pre-Cambrian rocks, mainly of the oldest metamorphic type rich in iron and manganese and mingled with quartz and schists. Peninsular gneiss and granites also occur here (Bourgeon 1989).

Fig. 1 Location of Kathalekan.

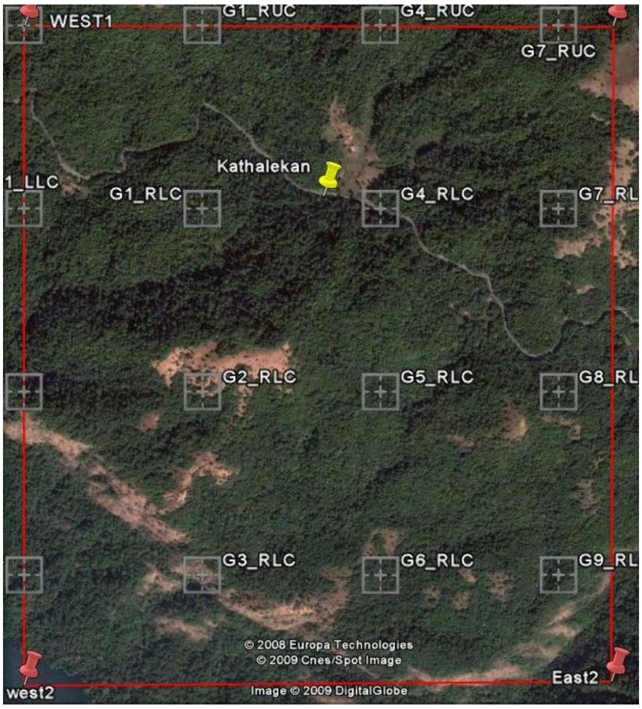

Fig. 2 Imagery of Kathalekan study area showing grids. Image source: Google Earth 2009.

Fig. 3 Sharavathi river.

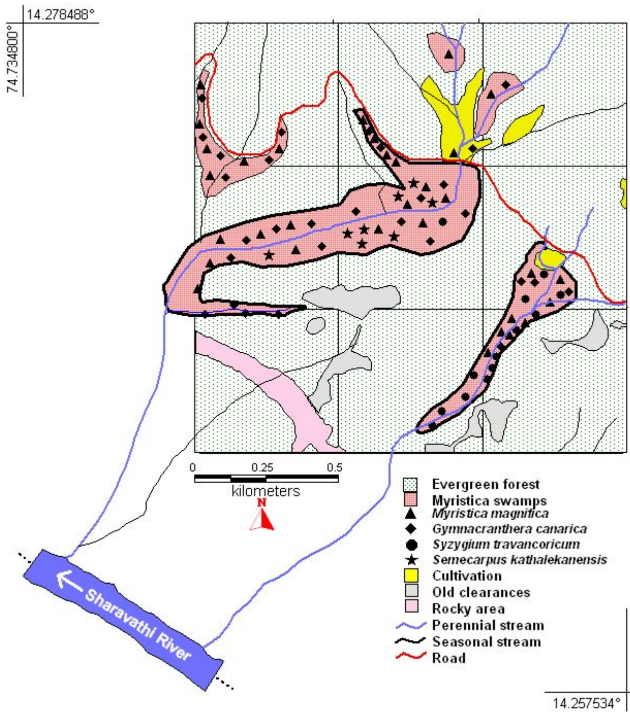

Fig. 4 Land cover of Kathalekan study area. Occurrence of swamp trees shown with symbols.

For a systematic study of vegetation we chose an area of 1500 × 1500 m (total 2.25 km^2). The area was divided into nine grids, each of 500 × 500 m, in three rows of three each (**Fig. 2**). The Honavar-Bangalore road winds its way through the first, fourth and eighth grids. The network of perennial water courses in the study area drain into the river Sharavathi, which runs through a deep gorge (**Fig. 3**) behind our study area. The streams flow sluggishly in some places creating swampy conditions favourable for growth of especially Myristicaceae trees. These *Myristica* swamps occur in almost all grids, very small in grids 3 and 7, and larger in 4, 5, 8 and 9 (**Fig. 4**). The gorge of the river is flanked by rocky precipices, a part rising in grid 3. The general elevation of Kathalekan ranges between 500 to 600 m. A hill to the north-east, just outside our study area, rises to 800 m. Towards north are more hills of 700 to 800 m; their slopes covered with forests whereas their tops are grassy with clumps of dwarf trees and shrubs. The folklore says these hills were under *kumri* (slash and burn) cultivation during earlier days. Some such old clearances, said to be used formerly for shifting cultivation, occur in grids 2, 3, 5 and 9 (**Figs 2, 4**). These clearances were larger than present in earlier days and today the forest could be seen advancing towards the open tops in a slow process of vegetational succession. Some farms are found in grids 4, 7 and 8, parts of which are infringements into the *Myristica* swamps.

Forest vegetation was sampled grid-wise using transect-based quadrat method. This method was found useful especially in surveying human impacted heterogeneous forest patches of Central Western Ghats (Chandran and Mesta 2001; Ramachandra *et al.* 2006; Ali *et al.* 2007). The length of the transect was fixed at 180 m. Five quadrats for study of trees (woody plants having minimum girth of 30 cm at GBH or 130 cm height from the ground), each of 20 m × 20 m area were laid along the transect alternately on right and left leaving an interval of 20 m between two quadrats. Within each tree quadrat, at two diagonal corners, two sub-quadrats of 5 m × 5 m were laid for studying shrubs and tree saplings (<30 cm girth). Within each of these two herb layer quadrats were also laid

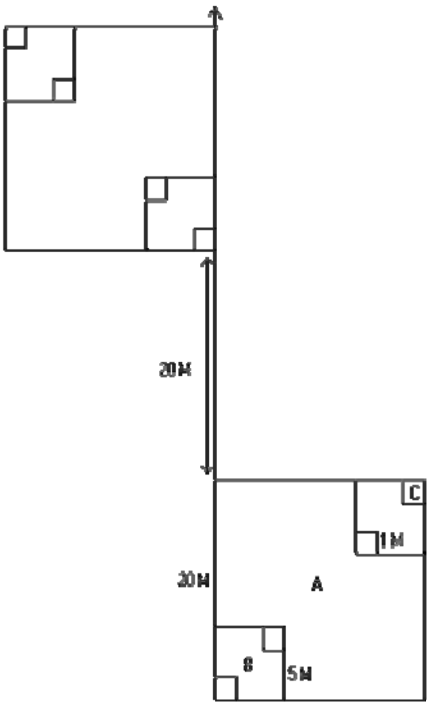

Fig. 5 Typical transect with quadrats. A: 20 m × 20 m for trees; B: 5 m × 5 m for shrub layer; C: 1 m × 1 m for herb layer.

for enumeration of herbs and seedlings of trees (**Fig. 5**). Notes were made of the climbers and other associated species.

Each grid was studied using two transects, one for water courses (stream/swamp forest, SSF) and another for other forests (non-stream/swamp forest, NSSF). Water courses on the uneven terrain being heterogeneous, we placed the five quadrats of the transect selectively in different segments so as to represent variations in vegetation, and the data was recorded in the same way as for NSSF. The data was analyzed (**Table 1**) to calculate species diversity (using Shannon-Weiner diversity index), basal area of trees, importance value index (IVI), regeneration status of trees (based on the presence of small girth classes and saplings) and carbon sequestration potential (Ravindranath *et al.* 1997; Murali *et al.* 2005; Ramachandra *et al*. 2006). The trees were grouped under evergreen and deciduous and transect-wise percentage of evergreenness calculated (% of evergreen trees among the total number of trees in the transect). Percentage of trees endemic to the Western Ghats is expressed as percentage of tree endemism.

Standing biomass is computed based on empirical equation Y = -2.81 + 6.78*(BA), where y is biomass (t/ha) and BA is basal area (m^2/ha) and carbon stock is computed assuming that the carbon content of dry matter is 50% of live biomass (Ravindranath *et al*. 1997). Carbon sequestration potential is estimated transect-wise and extrapolated to one hectare for both SSF and NSSF.

RESULTS AND DISCUSSION

Characterization of relic forest

Observations on forest structure and composition and nature of soil surface, in combination with forest history are helpful in distinguishing late successional secondary forests from relics of primary forests. In the western Uttara Kannada district, annual rainfall though high (>3000 mm), is seasonal and confined to about six months, which makes the evergreen forests here more susceptible to disturbances than southern forests with shorter dry period (Pascal, 1988). The entire region was widely affected by slash and burn

Table 1 Details of calculations/indices used in the study at Kathlekan, central Western Ghats, India.

Purpose	Calculation/index	Notes
% Evergreenness (trees)	$\frac{\#\text{Evergreen trees}}{\text{Total \# trees}}\times 100$	To estimate evergreen tree composition (%) in the forest.
% Endemics (trees)	$\frac{\#\text{Endemic trees}}{\text{Total \# trees}}\times 100$	
Basal area (m²)	$\frac{(\text{GBH})^2}{4\pi}$	
Density	$\frac{\#\text{Species A}}{\text{Area sampled}}$	Provides information on the compactness with which a species exists in an area.
Relative Density	$\frac{\text{Density of species A}}{\text{Total density of all species}}\times 100$	
Frequency	$\frac{\#\text{Quadrats with species A}}{\text{Total \# of quadrats sampled}}$	Provides information on the repeated occurrence of a species
Relative Frequency	$\frac{\text{Frequency of species A}}{\text{Total frequency of all species}}\times 100$	
Relative basal area	$\frac{\text{Basal area of species A}}{\text{Total basal area of all species}}\times 100$	
Important Value Index	R. density + R. frequency + R. basal area	
Shannon Weiner's diversity index	$H' = -\sum_{i=1}^{S} p_i \ln p_i$	The value of Shannon's diversity index is usually found to fall between 1.5 and 3.5 and only rarely surpasses 4.5.

Source: Ramachandra *et al.* 2007
where GBH: Girth at breast height (or at 130 cm) R. density: Relative density, R. frequency: Relative frequency, R. basal area: Relative basal area
H': the Shannon diversity index, p_i: fraction of the entire population made up of species i
S: numbers of species encountered, ∑ sum from species 1 to species S
The power to which the base e (e = 2.718281828.......) must be raised to obtain a number is called the natural logarithm (ln) of the number.

Fig. 6 ***Myristica*** **swamp.** Tree in foreground: *Myristica fatua* var. *magnifica*.

Fig. 7 ***Myristica magnifica*** **fruits.**

Fig. 8 ***Gymnacranthera canarica*.**

Fig. 9 ***Syzygium travancoricum*.**

Fig. 10 ***Semecarpus kathalekanensis*** **saplings.**

cultivation cycles (Chandran 1998). More changes happened later from commercial forestry and developmental pressures. Long fallows after shifting cultivation, however, favoured return of the forest with most of the original tree species, except some relics. Among the primeval forest patches spared to some extent from alterations are many sacred groves and *Myristica* swamps (**Fig. 6**), which might also be part of sacred groves (Nair *et al*. 2007). These swamps, their substratum covered in entanglement of roots shaped like loops, knobs, serpents, flying buttresses, etc. support their primal nature. Dominant among the swamp trees are some species of the archaic family Myristicaceae. Their relatively large, recalcitrant seeds are suitable for swampy conditions and support their lineage from more equatorial aseasonal forests. Favourable hydrology of the swamps permitted the survival of relic species in higher latitudes with pronounced climatic seasonality (Chandran and Mesta 2001). The swamp exclusive *Myristica magnifica* (**Fig. 7**) and *Gymnacranthera canarica* (**Fig. 8**), *Syzygium*

Table 2 Details of plant species that provide relic forest status to Kathalekan.

Species	**Distribution: Kathalekan**	**Reported northern range/ Western Ghats**	**Remarks and reference**
Dipterocarpus indicus (E)	All grids	Restricted to few kans only	
Gymnacranthera canarica (E)	In swamps of 6 grids	From *Myristica* swamps only	Chandran and Mesta 2001
Holigarna beddomei (E)	4 grids	One locality, south of UK- from herbarium	Ramesh and Pascal 1997
Holigarna nigra (E)	Grid 8 and outside sample area	One locality in central UK – from herbarium	Ramesh and Pascal 1997
Madhuca bourdillonii (E)	Outside sample area	Reported from southern Western Ghats; range extended to UK swamps	Very rare; Chandran *et al*. 2008
Mesua ferrea	2 grids	Some sacred groves of UK	
Myristica magnifica	In swamps of six grids	From *Myristica* swamps only	Chandran and Mesta 2001
Semecarpus kathalekanensis (E)	2 grids	First report from Kathalekan	A relic in swamp; Dasappa and Swaminath 2000
Pinanga dicksonii	All swamp grids	Gregarious undergrowth palm in southern UK only	
Syzygium travancoricum (E)	In swamps of 4 grids	Reported from southern Western Ghats; range extended to UK swamps	Chandran *et al*. 2008
Vateria indica (E)	Outside sample area	Natural population in *kans* only	Chandran and Gadgil 1998

Note: E–Endemic to Western Ghats, UK–Uttara Kannada district

Fig. 11 ***Dipterocarpus indicus*** **in a relic forest.**

travancoricum (**Fig. 9**), *Madhuca bourdillonii* and the newly discovered *Semecarpus kathalekanensis* (**Fig. 10**), and others like *Palaquium ellipticum*, *Mesua ferrea* and *Vateria indica* may be considered among the relic trees of Uttara Kannada (**Table 2**).

The Western Ghats exhibit a progressive decline in tree endemics from the south to the north, increasing dry period northwards being the principal decisive factor. Of the 318 tree species considered endemic, 85% occur in lat. 8-10° N which receive maximum of 8-10 months of rainfall. Lat 10-12° has 71% endemics, 43% in 12-14°, 22% in 14-16°, 17% in 16-18° and only 9% tree endemics north of 18°, with only 3-4 rainy months. In higher latitudes, more sensitive, hygrophilous species persist only in favourable pockets. Such relatively intact fragments of ancient vegetation, standing in isolation or amidst secondary forests, with one or more relic tree species, which are otherwise in their home range in wetter southern forests, may be considered as relic (Pascal 1988; Ramesh and Pascal 1997).

Dipterocarpus bourdilloni, for instance, has its northern limit at 11.41°, with a lone locality at Pushpagiri in Kodagu at 12.41° (Ramesh and Pascal 1997), where it may be considered a relic species. *D. indicus* (**Fig. 11**) on the other hand has its notable northern pockets at Kathalekan (14.27°), Karikan (14.33°N), another patch at 14.38°N and recently found also in Asollikan (14.66°N), a sacred forest, its extended northern range (Chandran *et al*. 2008). Pollen samples from the Arabian Sea off Karwar coast at 14.82°, show that the species had a more northern range and its decline started during fourth millennium BP, may be due the beginnings of slash and burn cultivation and the onset of drier climatic conditions (Caratini *et al*. 1991; Chandran 1997). *Palaquium ellipticum*, *Mesua ferrea* and *Vateria indica* may be considered as some other relic trees of Uttara Kannada.

The occurrence of *Syzygium travancoricum* and *Madhuca bourdillonii* at Kathalekan and some other smaller groves of Siddapur and further north at Asollikan highlights the importance of looking at Western Ghat forests more from the angle of ecological history, which will help us in recognizing and conserving relic forests. Given in **Table 3** are latitudinal distributions of some relic forest trees along with percentage of endemism from 20 forests (including Kathalekan) that we studied in central Western Ghats. The southern forests at Nilavase, Karini, Yadnala and Hindlamane (13-14°N) in general are relics of climax forests, having one or more of the relic species such as, *Poeciloneuron indicum* (its distribution stops just south of Uttara Kannada), *Dipterocarpus indicus*, *Palaquium ellipticum* and *Vateria indica.* This latitude marks the end of a rainfall zone getting about seven rainy months. North of 14°, because of increasing summer dryness, the relic species occur more in the *kans* which were or still are sacred locally. The presence of *Myristica* swamps in Kathalekan, Halsolli and Asolli enhance their relic status.

Species diversity, endemism and relic status

The Western Ghats constitute one of the unique biological regions of the world with high level of endemism in flora and fauna. Kathalekan landscape is one of well wooded hills and valleys. A small area of 2.25 km^2 studied using 18 transects (covering 3.6 ha) had 132 tree species of 92 genera and 37 families. In the 10 sub-quadrats/transect (each 5 × 5 m) for enumerating shrubs and tree saplings, covering altogether 0.45 ha, 33 families, 59 genera and 66 species were recorded. Although survey of herbs requires repeated visits we could, nevertheless, in a short period observe 169 species belonging to 110 genera and 40 families. We also recorded 31 species of lianas and climbers belonging to 30 genera and 22 families.

Through nine transects in the NSSF, we recorded 1335 trees belonging to 97 species of 37 families; from nine transects in the SSF was recorded 1026 trees belonging to 81 species of 27 families. **Fig. 12** depicts species-area relationship. The average tree number per transect was higher (148) in NSSF than SSF (114). Dipterocarpaceae is the leading

Table 3 Latitudinal distribution of some primary forest relic trees and % of tree endemism from the central Western Ghats, India forest samples.

Forest	°N	Relic tree species									% end	Remarks
		Di	Po	Pa	My	Gy	Se	Sy	Va	Ma		
Nilvase	13.44								+		46.61	Relic forest
Karini	13.55	+	+	+							38.28	Relic forest
Yedanala	13.75		+								33.93	Relic forest
Hindlamane	13.87	+		+							24.14	Part secondary
Hudil	14.04										74.19	Sec. forest
Hadgeri	14.12	+									54.76	Relic forest
Kanur	14.17										24.00	Sec. forest
Hessige	14.19										50.00	Sec. forest
Chik basti	14.22										10.34	Sec. forest
Ambepal	14.26	+									55.43	Relic forest
Kathalekan	14.27	+		+	+	+	+	+	++	++	81.75	*Kan*+ swamp*s*
Halsolli	14.30				+	+					81.40	Swamp
Mattigar	14.29							+	+		**	*Kan* (Relic)
Arlihonda	14.28							+			**	*Kan* (Relic)
Gundbala	14.32										44.71	Sec. forest
Tulsani	14.34										82.76	Sec. forest
Karikan	14.35	+									58.52	*Kan* (Relic)
Kalve	14.46										57.47	Sec. forest
Surjaddi	14.46										61.29	Sec. forest
Asolli	14.64	+				+				+	62.60	*Kan* + swamp

++ – Found outside the sampled area, % end – % of endemic tree individuals in the total number of trees, **- not estimated
Di–*Dipterocarpus indicus*, Po–*Poeciloneuron indicum*, Pa–*Palaquium ellipticum*, My–*Myristica magnifica* Gy–*Gymnacranthera canarica*, Se–*Semecarpus kathalekanensis*, Sy–*Syzygium travancoricum*, Va–*Vateria indica*, Ma–*Madhuca bourdillonii,* Sec. Forest: Secondary Forest

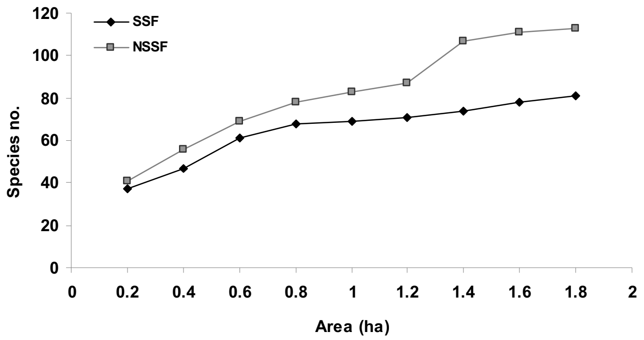

Fig. 12 Species-area relationship.

Table 4 Distribution of some relic tree species in the nine grids of Kathalekan, central Western Ghats, India.

Grid #	Di	Pa	My	Gy	Mf	Hb	Se	Sy
1	+	+	+	+	+	+		
2	+	+	+	+	+			
3	+	+		+	+			
4	+	+	+	+				+
5	+		+	+			+	+
6	+	+	+			+	+	+
7	+	+	+	+	+	+		+
8	+		+	+		+		+
9	+	+	+					+

Di–*Dipterocarpus indicus*, Pa–*Palaquium ellipticum*, My–*Myristicamagnifica*, Gy–*Gymnacranthera canarica*, Se–*Semecarpus kathalekanensis*, Sy–*Syzygium travancoricum*, Mf–*Mesua ferrea*, Hb–*Holigarna beddomei*

Table 5 Grid-wise details regarding tree diversity and evergreenness in SSF of Kathalekan, Central Western Ghats, India.

Grid #	No. of species	No. of individuals	% of evergreen trees	Shannon-Weiner index
1	37	119	99.16	2.92
2	27	106	99.05	2.67
3	32	117	97.43	2.74
4	29	116	99.13	2.52
5	21	91	98.9	2.55
6	30	125	99.2	2.76
7	37	105	99.04	3.08
8	29	126	100	2.69
9	33	121	99.17	3.04
Total	81	1026		
Average	31	114	99.00	

SSF–Stream/swamp forest

Table 6 Grid-wise details regarding tree diversity and evergreenness in NSSF of Kathalekan, Central Western Ghats, India.

Grid #	No. of species	No. of individuals	% of evergreen trees	Shannon-Weiner index
1	41	157	99.58	3.39
2	39	173	99.42	3.18
3	37	104	91.35	3.42
4	38	129	98.45	3.12
5	39	158	97.47	3.16
6	23	165	98.79	2.39
7	44	141	95.74	3.36
8	34	113	97.35	2.91
9	18	186	98.92	1.77
Total	97	1335		
Average	35	148	97.45	

NSSF–Non-stream/swamp forest

NSSF family with 328 trees of only two species *viz. Hopea ponga* and *Dipterocarpus indicus*, followed by non-swamp species of Myristicaceae (108 trees), mainly *Knema attenuata* and small numbers of *Myristica malabarica*, and *M. dactyloides*. Myrtaceae follows with 108 trees, of various species of *Syzygium. S. gardneri*, a well established climax species of the region is the most dominant. The edges of swamps and streams in the SSF are also dominated by Dipterocarpaceae (206 trees), followed by swamp exclusives *M. magnifica*, *Gymnacranthera canarica*, of Myristicaceae (196 trees) exclusive to the swamp proper. Cornaceae (97 trees) is represented by *Mastixia arborea.* Exclusive to the SSF are also *Semecarpus kathalekanensis* and *Syzygium travancoricum*. Distribution of some notable relic species in the nine grids is given in **Table 4**. Only small number of trees species, having special adaptations in their root systems and physiology to cope with the anaerobic conditions of the swamp (Hook and Scholtens 1978; Kozlowski 1982). **Tables 5** and **6** provide details on tree diversity in SSF and NSSF respectively and family-wise tree numbers are given in **Fig. 13**. Shannon-Weiner diversity index is higher for NSSF than for SSF. Chandran and Mesta (2001) had also reported low diversity of *Myristica* swamp forests.

Grid-wise details regarding tree endemism are given in **Table 7**. Number of endemics and percentage of endemism

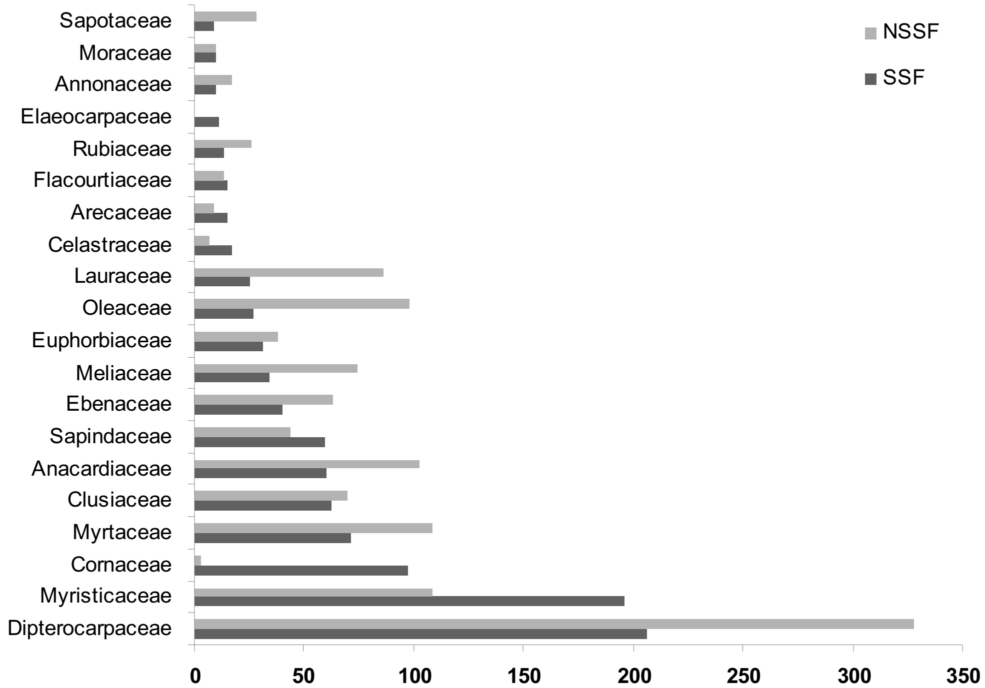

Fig. 13 Family-wise number of trees in SSF and NSSF. For the first 20 families.

Table 7 Grid-wise details of tree endemism in the SSF and NSSF of Kathalekan, Central Western Ghats, India.

Forest types	No. of transects	No. of families	No. of sp.	Endemic sp	% endemic sp	Total trees	% tree endemism
SSF	9	27	81	36	44.5%	1026	71.3%
NSSF	9	34	97	33	35%	1335	51.08%

SSF–Stream/swamp forest, NSSF–Non-stream/swamp forest

are higher in SSF, highlighting its importance. Endemics that require wetter conditions tend to congregate in the streams and swamp habitats of the relic forest. Of the tree species *Semecarpus kathalekanensis* that merits inclusion in the IUCN Red List as Critically Endangered, as it is newly discovered and with less than 50 breeding individuals (Vasudeva *et al*. 2001) and others already Red Listed, such as *Syzygium travancoricum* (Critically Endangered), *Hopea ponga* and *Myristica magnifica* (Endangered) and *Gymnacranthera canarica* (Vulnerable) are swamp specific. Chandran and Mesta (2001) had also observed higher tree endemism in the *Myristica* swamps than in adjoining forests. Details of dominant tree species of NSSF and SSF, according to IVI, are given in **Tables 8-9**. Kathalekan is a high evergreen forest reflecting favourable moisture conditions. There is a negligible mix of deciduous trees in the grid 3 of NSSF. Those trees, which lack regeneration under the dense canopy of evergreens, indicate past disturbances.

Neither high number of endemic tree species in a forest nor high percentage of tree endemism necessarily confers relic status to a forest. For instance Tulsani has about 83% tree endemism (**Table 3**), mainly due to domination of *Knema attenuata*, of Myristicaceae, that grows well in the fire protected secondary forests of Western Ghats. Moreover the hills of Tulsani were under shifting cultivation until a century ago (Pearson and Aitchison 1908).

Some grassy/savannized hill tops, having a shifting cultivation past, occur in grids 2, 3, 5, 6 and 9. One such between grids 2 and 5 is known as "seven-year *kumri*" (*kumri* refers to slash and burn cultivation). This hill has isolated clumps of stunted, fire tolerant trees and shrubs, such as *Careya arborea*, *Glochidion johnstonei*, *Catunaregam spinosa*, *Tamilnadia uliginosa*, *Bombax malabaricum*, *Scutia myrtina*, *Terminalia paniculata*, etc. Such savannized hill tops indicate that in the past people had lived amidst a mosaic of primeval forests, including swamps, shifting cultivation areas and fallow forests. The prohibition of shifting cultivation in the late 19th century has caused slow advance of forests closing in on these clearances.

Regeneration status

Kathalekan is a well established climax forest. Such conclusion has been arrived at from observations on regeneration status, based on the presence of smaller girth classes of notable climax forest trees, which are also relics of the past for the northern latitude of 14°. We have presented in **Figs. 14-16** the girth classes of *Dipterocarpus indicus*, *Palaquium ellipticum*, *Gymnacranthera canarica*, *Syzygium travancoricum*, *Myristica magnifica* and *Semecarpus kathalekanensis*, the species which confer relic status to the Kathalekan forest. The number of individuals in smaller girth classes constitutes the future growing stock for the respective species. All the listed species have satisfactory regeneration, except *S. kathalekanensis.* The population of this swamp specific species suffered from an attempt made by a local farmer to start a betelnut garden in its habitat. Cause for concern continues for all the swamp exclusive trees, as the swamps themselves are highly threatened habitats, mostly having been converted into agricultural areas in the past (Krishnamoorthy 1960; Chandran and Mesta 2001) Streams and swamps have started drying up in summer because of water diversion for irrigation by few resident farmers. These happenings have reduced the survival chances of the juveniles of swamp exclusives. The juveniles of the flagship relic species, *D. indicus*, are in good number throughout the forest, including in late successional growth. Absence of forest fires ever since the prohibition of shifting cultivation during the British period, and many mature trees in the relic forest may be considered reasons for its good regeneration. Continued protection of Kathalekan and preventing a couple of resident farmers from putting up bunds across the streams can guarantee regeneration of the scarcer swamp specific trees too.

Basal area and Importance Value Index (IVI)

In **Table 8**, a list of 10 tree species showing highest IVI for each of the nine SSF grid transects is highlighted. *Gymna-*

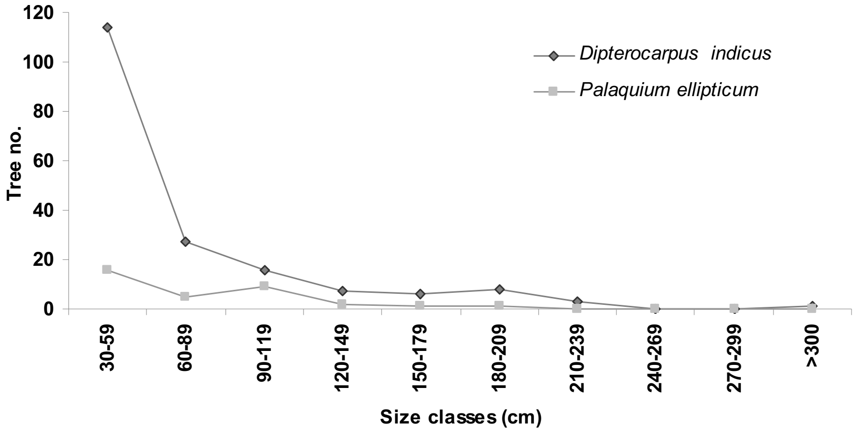

Fig. 14 Girth classes of *Dipterocarpus indicus* and *Palaquium ellipticum*.

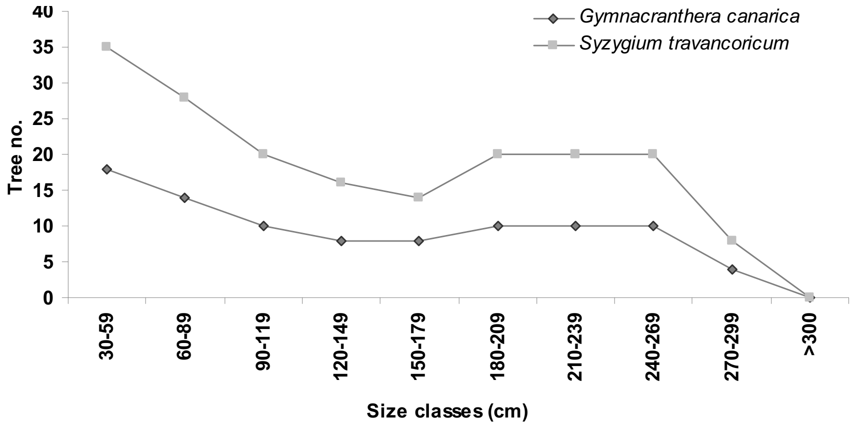

Fig. 15 Girth classes of *Gymnacranthera canarica* and *Syzygium trvancoricum*.

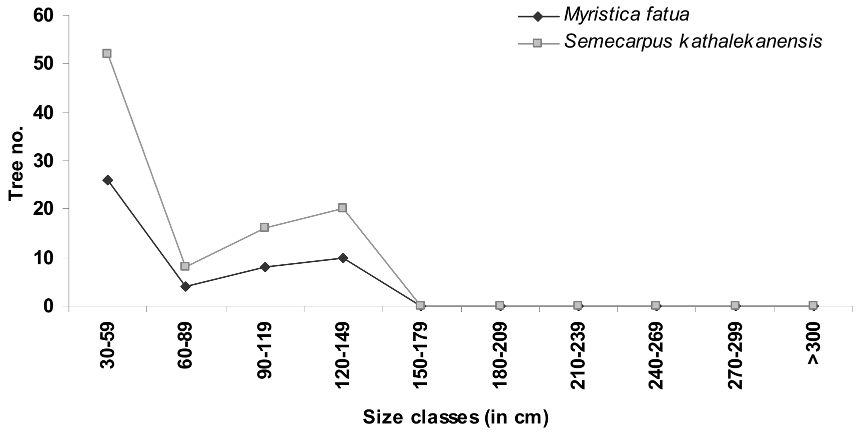

Fig. 16 Girth classes of *Myristicamagnifica* and *Semecarpus kathalekanensis*.

cranthera canarica and *Myristica magnifica* occur in six grids each and *Syzygium travancoricum* in four. The satisfactory regeneration of the last one is a promising northward range extension for a Critically Endangered species. *Semecarpus kathalekanensis*, found only in two grids, and Siddapur taluk being the only place in the world where it occurs, its population and regeneration are cause of concern (Vasudeva *et al*. 2001). Notable of the high IVI species of NSSF (**Table 9**) are *Holigarna grahamii* (high IVI in 8 grids), *Aglaia elaeagnoidea*, *Dipterocarpus indicus*, *Dimocarpus longan*, *Hopea ponga* (in 7 grids), *Knema attenuata*, *Syzygium gardneri*, *Olea dioica* (in 5 grids) and so on. Average basal area of trees estimated (**Tables 10, 11**) is significantly higher (51.97 m^2/ha) in SSF than in NSSF (39.25 m^2/ha). Basal areas, for 45 SSF quadrats and 45 NSSF quadrats are shown in **Fig. 17**. Basal area is higher in many SSF quadrats than NSSF. The swamps are notable for their large sized trees.

Hydrological status

Relic forests of the Western Ghats are remains of the primeval forests that existed before anthropogenic alterations began, especially with the introduction of agriculture. Relic forests, multi-storeyed as they are and never completely clear-felled or burned down by the fires of shifting cultivators, and the organic debris on the floor never destroyed, are ideal set ups in humid tropical mountainous terrain. Despite the fact that the Central Western Ghats have five to six months of dry season, the water stored and released by the relic forests, which were sacred during pre-colonial times, cause streams to flow perennially. This was true of the *Kan* forests of Uttara Kannada district, Kathalekan (meaning the 'dark sacred grove') being no exception. The close links between *Kans* and water bodies have been brought out in earlier observations by the British foresters (Anonymous, 1923); it was an inevitable part of traditional

Table 8 Leading 10 (in bold) Importance Value Index tree species (grid-wise) in the SSF of Kathalekan, central Western Ghats, India.

Trees	**Grid-wise Importance Value Index (IVI)**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Gymnacranthera canarica	**45.26**	**17.15**	**64.39**	**99.29**	**47.62**	--	--	**26.55**	--
Mastixia arborea	**35.74**	**52.04**	**16.73**	**26.38**	**26.65**	6.65	**8.91**	**37.19**	**9.89**
Myristica magnifica	**35.33**	**28.11**	--	**29.29**	**15.26**	--	--	**40.84**	**11.82**
Syzygium cumini	**15.26**	--	2.74	--	--	--	--	--	--
Dimocarpus longan	**13.63**	**11.46**	**9.64**	**13.60**	**11.36**	**15.17**	**31.38**	5.37	**16.77**
Pterospermum diversifolium	**13.31**	--	--	--	--	--	--	--	--
Syzygium hemisphericum	**8.42**	**20.63**	**11.46**	4.22	--	5.27	--	6.65	5.01
Dipterocarpus indicus	**8.11**	**19.57**	**11.19**	**11.16**	**17.09**	--	**41.83**	3.07	**21.82**
Mesua ferrea	**8.08**	--	--	--	--	--	4.36	--	--
Hopea ponga	**7.90**	**27.82**	**41.83**	**11.06**	**29.31**	**62.74**	--	**22.89**	**35.75**
Syzygium gardneri	6.01	**18.94**	2.74	**10.96**	5.28	4.44	**28.90**	--	**13.15**
Olea diocia	6.80	**10.07**	5.68	3.59	3.91	**13.12**	2.70	**15.64**	**22.64**
Lophopetalum wightianum	--	**9.32**	**9.92**	**13.56**	**14.29**	--	--	**7.48**	2.45
Calophyllum apetalum	--	--	**39.27**	--	--	7.92	--	--	--
Garcinia gummi-gutta	--	--	**10.96**	--	7.29	**19.22**	6.81	--	5.16
Calophyllum tomentosum	--	--	**7.16**	--	**26.70**	6.31	--	3.01	**14.37**
Syzygium travancoricum	--	--	--	**10.65**	--	**25.84**	--	**54.83**	**25.86**
Hydnocarpus laurifolia	--	--	--	**7.17**	--	**12.02**	5.73	**8.63**	--
Semecarpus kathalekanensis	--	--	--	4.13	**42.45**	--	--	--	--
Caryota urens	--	7.09	4.21	--	**17.79**	2.99	4.51	**9.11**	2.86
Elaeocarpus tuberculatus	--	3.16	--	--	10.02	**13.62**	--	**6.84**	--
Mangifera indica	3.17	3.19	6.66	3.09	3.88	**15.15**	--	5.31	--
Diospyros candolleana	5.73	3.22	2.74	--	--	**13.68**	2.94	6.67	8.22
Aglaia elaeagnoidea	5.87	3.26	2.76	--	--	**12.62**	**15.05**	2.79	**10.99**
Ficus nervosa	2.85	--	--	--	--	--	**14.93**	--	8.85
Holigarna beddomei	5.01	--	--	--	--	9.10	**12.28**	4.54	--
Meiogyne pannosa	--	--	--	--	--	--	**12.14**	--	2.46
Litsea spp.	6.0	7.95	--	3.15	--	--	**11.70**	--	--
Diospyros crumenata	--	--	6.10	--	--	5.45	**9.95**	--	--
Palaquium ellipticum	3.94	--	--	--	--	--	8.47	--	3.96

SSF–Stream/swamp forest

Table 9 Leading 10 (in bold) Importance Value Index tree species (grid-wise) in the NSSF of Kathalekan, central Western Ghats, India.

Trees	**Grid-wise Importance Value Index (IVI)**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Litsea floribunda	**23.20**	--	6.84	--	7.28	--	--	--	--
Dimocarpus longan	**20.23**	**15.28**	**12.81**	**21.98**	**13.37**	--	2.01	**9.91**	**9.69**
Syzygium hemisphericum	**17.85**	**--**	**--**	--	4.51	--	--	**8.27**	--
Knema attenuata	**17.55**	**23.73**	**15.36**	8.16	**30.55**	5.30	8.26	7.63	**12.47**
Holigarna grahamii	**16.20**	**17.76**	**17.32**	**11.62**	6.57	**8.73**	**19.91**	**12.68**	**32.63**
Syzygium gardneri	**14.31**	**32.07**	**33.07**	**11.96**	**26.04**	--	**14.53**	--	--
Dipterocarpus indicus	**13.93**	**12.46**	**26.04**	**40.82**	**28.70**	**42.51**	**31.10**	6.84	4.72
Aglaia elaeagnoidea	**12.48**	9.81	**12.33**	**13.73**	**15.58**	6.39	**11.21**	**13.28**	**12.54**
Garcinia talbotii	**11.44**	**14.42**	**11.07**	**14.48**	2.43	--	7.82	--	--
Sysygium spp.	**11.07**	**--**	--	8.15	**10.18**	**8.83**	3.29	6.28	**9.02**
Hopea ponga	5.73	**23.91**	5.54	**22.34**	**14.14**	**35.64**	**9.84**	**45.14**	**115.43**
Palaquium ellipticum	--	**14.15**	**11.20**	**12.84**	**12.13**	--	6.01	--	--
Persea macrantha	5.51	**11.26**	2.99	2.77	4.73	4.78	--	--	4.29
Mesua ferrea	--	**10.54**	4.57	--	--	--	4.79	--	--
Artocarpus hirsutus	--	--	**16.84**	--	--	--	--	--	--
Drypetes elata	--	--	**9.06**	2.63	--	--	--	--	--
Diospyros candolleana	6.34	2.65	--	**14.23**	5.50	6.83	2.00	2.82	7.68
Canarium strictum	--	--	--	**12.40**	--	--	--	--	--
Olea dioica	10.71	--	5.06	3.01	**20.54**	**57.63**	**11.19**	**36.15**	**39.59**
Calophyllum tomentosum	--	6.31	3.80	5.56	**9.40**	**36.85**	--	--	--
Syzygium cumini	--	--	--	--	--	**20.69**	--	5.33	--
Ixora brachiata	--	--	7.02	--	--	**15.14**	--	--	**17.82**
Symplocos racemosa	--	--	7.32	5.54	--	**12.53**	--	6.52	--
Holigarna ferruginea	5.49	--	--	--	6.64	**10.03**	--	--	--
Aglaia anamallayana	2.05	5.78	9.02	--	--	--	**18.81**	--	--
Litsea spp.	5.22	5.35	--	4.41	2.01	--	**16.23**	**8.28**	--
Garcinia gummi-gutta	2.61	2.63	6.75	2.41	--	--	**11.63**	--	--
Polyalthia fragrans	--	--	--	2.92	--	--	**9.85**	--	--
*Syzygium travancoricum**	--	--	--	--	--	--	--	**33.51**	--
*Myristica magnifica**	--	--	--	--	--	--	--	**15.18**	--
Hydnocarpus laurifolia	--	--	--	--	--	--	--	**10.14**	**8.44**
Lagerstroemia microcarpa	--	--	--	--	--	--	--	--	**8.41**

NSSF–Non-stream/swamp forest

* Swamp specific tree species occur only where the transect happens to pass through a swamp

Table 10 Estimated above-ground biomass (Agb/ha) and carbon storage/ha for SSF of Kathalekan, Central Western Ghats, India.

Grid no	Basal area (m^2/ha)	Agb (t/ha)	Carbon storage (t/ha)
G1	43.16	289.85	145
G2	40.02	268.53	134
G3	88.10	594.51	297
G4	61.10	411.45	206
G5	43.47	291.92	146
G6	40.15	269.43	135
G7	31.80	212.78	106
G8	55.05	370.41	185
G9	64.84	436.80	218
Mean	51.97	349.52	174.76
Std. deviation	16.34	110.79	55.39

SSF- Stream/swamp forest

Table 11 Estimated above-ground biomass (Agb/ha) and carbon storage/ha for NSSF of Kathalekan, Central Western Ghats, India.

Grid no	Basal area (m^2/ha)	Agb (t/ha)	Carbon storage (t/ha)
G1	32.72	219.03	110
G2	39.14	262.58	131
G3	45.41	305.09	153
G4	35.87	240.42	120
G5	39.84	267.28	134
G6	50.86	342.04	171
G7	28.54	190.72	95
G8	41.24	276.80	138
G9	39.63	265.88	133
Mean	39.25	263.32	131.66
Std. deviation	6.20	42.04	21.02

NSSF- Non-stream/swamp forest

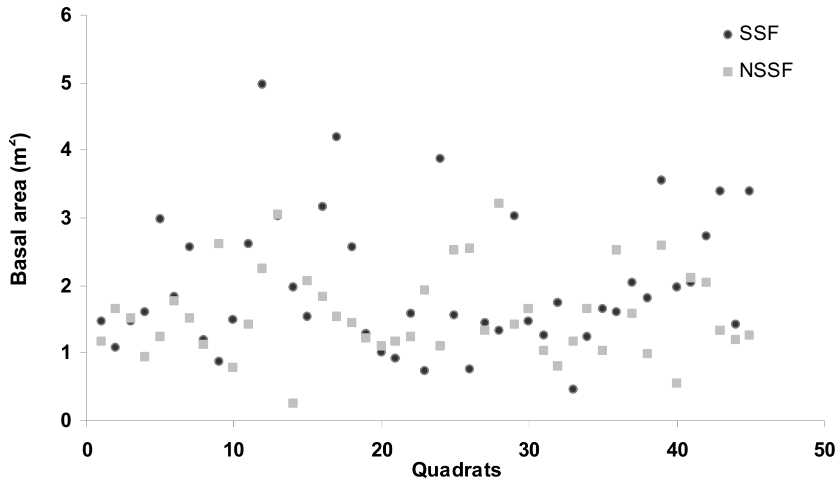

Fig. 17 Basal area of trees in 45 SSF and 45 NSSF quadrats.

ecological knowledge of the region (Chandran and Gadgil 1993). The water courses of Kathalekan, studded with *Myristica* swamps, though in a waned state today, are enough evidence of the excellent hydrology the region enjoyed. Members of Dipterocarpaceae and Myristicaceae, families with recalcitrant seeds and well known for their hygrophilous nature, seldom transgress in their distribution the limits of the tropical rain forest (Ashton 1964; Fedorov 1966; Chandran and Mesta 2001). Most other dominant tree families of Kathalekan, such as Anacardiaceae, Clusiaceae, Lauraceae, Myrtaceae etc. are also dominant in especially South-East Asian rain forests.

Faunal richness

The Western Ghats are also rich in faunal diversity and endemism (Daniels 2003; Sreekantha *et al.* 2007) accounting for 330 butterflies (11% endemics), 289 fishes (41% endemics), 157 amphibians (85% endemics), 156 reptiles (62% endemics), 508 birds (4% endemics) and 120 mammals (12% endemics). The Sharavathi Valley forests, which include also Kathalekan, constitute the northern limit for distribution of endemic and endangered primate lion tailed macaque, *Macaca silenus* (Krishnamurthy and Kiester 1998). Of the 64 species of fresh water fishes recorded from Sharavathi River 18 are Western Ghat endemic and 24 confined to Peninsular India. These include three new species of fishes, *Batasio sharavatiensis* (Bhat and Jayaram 2004), *Schistura nagodiensis* and *S. sharavathiensis* (Sreekantha *et al.* 2006). The very distribution of endemic fresh water fishes is highly correlated to terrestrial landscape elements, of which quantity and quality of evergreen forests are more decisive (Sreekantha *et al.* 2007). We also made a study of the amphibians to illustrate faunal endemism as indicators of better hydrological conditions of the relic forests. We recorded 35 species from Kathalekan of which 26 (74%) are endemics to the Western Ghats (endemic species are given in **Table 12**). There were six aquatic, 19 semi-aquatic, eight arboreal and two terrestrial species. The endemic species occur in greater number and diversity in and around the *Myristica* swamps. Among the aquatic species, *Nyctibatrachus aliciae*, *N. major* and *Micrixalus saxicola* are endemic to the Western Ghats and are exclusive to the evergreen forests having torrential streams. Their northernmost distribution range within the Western Ghats is limited to the 15°N in Uttara Kannada). Interestingly, these species of *Nyctibatrachus* and genus *Micrixalus* are among the most ancient genera (~60-70 mya) after *Nasikabatrachus* (~100mya) to have evolved (Roelants *et al.* 2007) in the Western Ghats. Arboreal species *Philautus ponmudi*, a Critically Endangered species, has its northernmost distribution range ending at Kathalekan. It is worth noting that, the arboreal and aquatic amphibians share highest number of endangered species at Kathalekan (three and one respectively; **Table 13**).

Table 12 Details of the amphibians of Kathalekan, Central Western Ghats, India.

Amphibian groups	No. of species	Habitat	Endemic status	IUCN status
Caecilians	2	Semi-aquatic: 2	Endemic: 2	DD: 2
Toads	2	Terrestrial: 1	Non-endemic: 1	EN: 1
		Arboreal: 1	Endemic: 1	LC: 1
Frogs	31	Semi-aquatic: 17	Non-endemic: 8	CE: 1
		Aquatic: 6	Endemic: 23	EN: 4
		Arboreal: 8		VU: 5
				NT: 2
				LC: 12
				DD: 7

CE–Critically endangered, EN–Endangered, VU–Vulnerable, NT–Non-threatened, LC–Least concern, DD–Data deficient

Table 13 Endemic amphibians of Western Ghats observed in Kathalekan, Central Western Ghats, India.

Name	Habitat	IUCN status*
Fejervarya brevipalmata	Semi-aquatic	DD
Fejervarya caperata	Semi-aquatic	DD
Fejervarya granosa	Semi-aquatic	DD
Fejervarya kudremukhensis	Semi-aquatic	DD
Fejervarya mudduraja	Semi-aquatic	DD
Fejervarya rufescens	Semi-aquatic	LC
Hylarana aurantiaca	Semi-aquatic	VU
Ichthyophis bombayensis	Semi-aquatic	DD
Ichthyophis malabarensis	Semi-aquatic	DD
Indirana beddomii	Semi-aquatic	LC
Indirana semipalmata	Semi-aquatic	LC
Micrixalus saxicola	Aqauatic	VU
Minervarya sahyadris	Semi-aquatic	EN
Nyctibatrachus aliciae	Aqauatic	EN
Nyctibatrachus humayuni	Aqauatic	Vu
Nyctibatrachus major	Aqauatic	Vu
Nyctibatrachus petraeus	Aqauatic	LC
Pedostibes tuberculosus	Arboreal	EN
Philautus bombayensis	Arboreal	VU
Philautus ponmudi	Arboreal	CR
Philautus tuberohumerus	Arboreal	DD
Philautus wynaadensis	Arboreal	EN
Philautus neelanethrus	Arboreal	EN
Polypedates pseudocruciger	Arboreal	LC
Rhacophorus malabaricus	Arboreal	LC
Sphaerotheca leucorhyncus	Semi-aquatic	DD

*http://www.iucnredlist.org/amphibians

Biomass and carbon sequestration

Carbon is the key element of life in the biosphere. Vegetation and soil accumulate the carbon, while natural sources (volcanoes, etc.) or anthropogenic activities (thermal power generation, biomass burning, etc.) emit carbon. Emission and sequestration of carbon need to be in balance in the Earth system to maintain favorable environmental conditions for life. In this context, with the changes in the regional and global environmental conditions evident from consequences of climate changes, quantification of sources and sinks of carbon merits high importance. An attempt is made here to quantify the amount of carbon sequestered by SSF as compared to NSSF studied in the nine grids of Kathalekan.

The carbon sequestration by trees of SSF and NSSF (grid-wise) is given in **Tables 10**, and **11**. Above ground biomass (AGB) of SSF is significantly higher than NSSF (NSSF: AGB Mean ± SD; 263.32 ± 42.04 t/ha; carbon stored 131.66 ± 21.02 t/ha and for SSF: AGB 349.52 ± 110.79 t/ha; carbon stored 174.76 ± 55.39 t/ha; t_{AGB}=2.14, p=0.035, t_{CS}=2.14, p=0.035) and therefore higher ability to sequester carbon per unit area than the other forests within the grids. This is higher compared to earlier estimates of 65.4 t/ha (Ravindranath *et al*. 1997; Chhabra *et al*. 2002) and 67.4 t/ha (Haripriya 2000) for Indian tropical forests. Our finding that the tree covered SSF can accumulate significantly more biomass than the NSSF, and therefore sequester more carbon is a promising signal in the dismal scenario of global climatic change. The rich network of water courses of the Western Ghats has suffered severely due to deforestation and unregulated water use by humans. In our study area overuse of water by a couple of farmers poses threat to the future of swamps. It will be a good idea to reach the benefits of carbon credits to the millions of grassroot level farmers of the Western Ghats, whose services may be more fruitfully used in designing micro-level sustainable models of water use for agriculture and in restoring and safeguarding the pristine nature of water course forests.

Conservation strategy

The bulk of primeval forest fragments in whose conservation the pre-colonial farmers appear to have played key role, have perished during the period of modern forestry, whose foundations were laid by the British (Chandran and Gadgil 1993; Chandran 1997). Menon and Bawa (1997) estimated that between 1920 and 1990, 40% of the original natural vegetation of the Western Ghats was lost or converted to other land uses. Myers *et al*. (2000) estimate that only 6.8% of the 182,500 km^2 of primary forest vegetation of Western Ghats-Sri Lanka biodiversity hotspot remain today. Most literature on sacred groves of the Western Ghats, which are relics of ancient forests, deal with mostly small isolated forest patches in the midst or close to human habitations. The current study highlights the possible existence of numerous vegetational relics of high biodiversity and watershed values. Kathalekan is a live example of a relic forest with congregation of rare elements of Western Ghats biodiversity, practically unknown until recent studies indicated its biological importance (Dasappa and Swaminath 2000; Chandran and Mesta 2001). It was in another such relic forest in Central Western Ghats *Madhuca bourdillonii* and *Syzygium travancoricum*, threatened species of Southern Western Ghats were reported for the first time (Chandran *et al*. 2008). The innumerable water courses of Western Ghats, under proper management, can better the hydrology of Peninsular Indian rivers. SSF forests with higher biomass highlight their greater potential in carbon sequestration. In this highly human impacted global biodiversity hotspot, small farmers and tribal population can be more fruitfully used as guardians of watershed forests and partners in more restrained use of water resources for agriculture. We suggest evolving a watershed-based forest management system for Western Ghats and similar humid tropical mountains in which the relic forests and water course forests have huge scope for carbon sequestration. Such services while serving the cause of biodiversity conservation can mitigate global climatic change and uplift the livelihoods of local population due to carbon credits. As the bulk of forests come under governmental jurisdiction, the prime task before Western Ghat States is to initiate steps for identification of relic forests, which lie unknown otherwise amidst human impacted secondary forests, and preserve such precious heritage for posterity.

CONCLUSION

Forests of the Western Ghats, one of the global biodiversity hotspots, have been steadily affected by human activities, especially since the introduction of agriculture. In traditional, community centered, pre-colonial land use, however, a sustainable balance was maintained between farmers and forests. This was facilitated through maintenance of a decentralized system of forest reserves, the sacred groves, in a mosaic of landscape elements which had shifting cultivation areas, secondary forests on fallows in different stages of vegetational succession, rice fields and spice gardens in valleys, and savannized lands as pastures. Network of natural water courses and swamps, covered with characteristic tree species of rarer kind would have been key feature of Central Western Ghats. As historical records of Uttara Kannada testify, the pre and early colonial period up to mid-19th century was also one of richest wildlife as well. The many patches of sacred forests, often hundreds of hectares in extent, functioned as favorable pockets for persistence of several sensitive climax species of the Western Ghats, which could not easily re-colonize the fire burnt fallows and savannas. Their remains today are the relic forests, the subject of this paper.

State monopoly over forests, beginning with the British, early in the 19th century, spelt an end to the community-based landscape management. Most sacred groves, secondary forests and other unclaimed lands came under state monopoly as reserve forests. State driven and revenue oriented forest management policies focused mainly on timber extraction and on raising of tree plantations. Even the sacred groves of primeval nature were treated like any other forests. Whereas such relic forests, remaining isolated amidst human habitations suffered from extraction pressures from local people themselves, who were denied their traditional rights in the reserved forests, the larger groves of thinly populated areas got merged with secondary forests and lost their sacred value. Their remains today with rare relic species went almost unrecognized in conservation circles, until studies have been initiated from the angle of ecological history.

Our study at Kathalekan in Central Western Ghats, reveal that the forest is a mosaic of primary forest rich in relic trees like *Dipterocarpus* and *Palaquium* and a network of perennial streams and swamps sheltering *Semecarpus kathalekanensis*, *Syzygium travancoricum*, *Myristica magnifica*, *Gymnacranthera canarica* (the last three in threat categories of IUCN Red List). Persistence of these Western Ghat endemics, and relic species in this forest calls for serious attention from conservationists and forest managers to initiate programs immediately for recognizing and salvaging more fragments of such ancient forests that lie hidden amidst a sea of secondary forests. The fact that water course forests have not only rare species but also high biomass and greater carbon sequestration potential also calls for revision of forest management policies, as the innumerable stream courses of Western Ghats offer tremendous potential for carbon stocking per unit area while also bettering the hydrology of these mountains, which form the main watershed for the entire Indian Peninsula. Millions of subsistence farmers and other forest dwellers of Western Ghats can not only be partners in micro-level planning for prudent water use but also stand to gain in a big way from carbon credits for their new role as promoters and guardians of watershed vegetation. Rendering such service for mitigating global climatic change can also, same time, serve well the cause of relic forests and relic species in an otherwise much impacted biodiversity hotspot.

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