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ROLE OF ECOLOGICAL FACTORS ON LEAF SIZE SPECTRA IN AN EVERGREEN FOREST, WESTERN GHATS, INDIA - AN ECOLOGICAL HOTSPOT

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ABSTRACT
Leaf morphological characteristics of woody species were examined in tropical rain forest at Kudremukh National Park in the central Western Ghats, India in relationship with ecological and environmental factors. For leaf size analysis, Raunkiaer leaf size classification was adopted. The data was collected from 114 sample plots of the size 31.6 x 31.6 m distributed randomly in the study area. In each plot the proportion of leaf size classes and other leaf morphological characters were calculated and correlated with the ecological and environmental data. A significant correlation of leaf morphological character with percentage evergreeness and in few instances with elevation and rainfall was obtained. Average leaf width decreased with increase in elevation. Mesophyll leaf class dominated the stand, whereas, leptophyll and nanophyll leaf classes are sparingly represented. Proportions of serrate and whorled leaves increased with increase in elevation. A significant effect of percentage evergreeness of the stand was found on leaf size and leaf morphological characters.

KEY WORDS: Kudremukh National Park, Raunkiaer, Leaf size classification, Evergreeness

INTRODUCTION
Plants in the tropical forests show several characteristic features in the form and arrangement of their photosynthetic organs. Many such traits such as leaf size, shape, arrangement and form show strong correlation with the prevailing environment (Richards, 1952) and also they are determined by climatic conditions of the area (Hamann, 1979).
The leaf size spectrum of an area gives an idea of the adaptation of the plants with the surrounding environment. It can also be used as a physiognomic character in assessing the field relationships of vegetation in different geographical regions. The size and shape of fossil leaves are potential paleo-precipitation indicators and helps in the reconstruction of paleoclimate conditions (Peter *et al.*, 1998). The relationship between environmental factors and leaf size (growth form attribute) helps in studying vegetation at regional scale (Floret *et al.*, 1990).
Leaf size classification, the brainchild of Raunkiaer (1934), selected an obvious morphological character, namely, dimension of transpiring surface as an index of adaptation to prevailing climatic conditions. Based on the dimension of leaves, he classified the leaf size into six classes – leptophyll (up to 0.25 cm²), nanophyll (0.25 – 2.25 cm²), Microphyll (2.25 – 20.25 cm²), Mesophyll (20.25 – 182.25 cm²), macrophyll (182.25 – 1640.25 cm²) and Megaphyll (> 1640.25 cm²).
It is a generally observed that leaves are large in moist tropical vegetation (equatorial rain forests), medium in temperate and small in drier areas. In the tropical rain forests, at least 80% of the species exhibit mesophyll leaf size and interestingly, the emergent trees have higher percentage of mesophylls (Richards, 1952). Generally, leaf size tends to decline towards drier areas with prolonged dry season (Zanzen, 1975).
Leaf size spectra of flora and communities are not widely available as the way life form spectra are. Few scattered studies are available with respect to leaf size spectra. Brown (1919) studied the relation of leaf types to altitudinal variation in mountains of the Philippines. Richards (1952) studied the leaf size in the tropical rain forest of Shasha Reserve, Nigeria and observed the predominance of mesophyll leaf size class. The study conducted by Beard (1946) on the leaf size classes in seasonal evergreen forests of Trinidad, showed a higher percentage of mesophyll class in emergent trees as compared to the lower storey. The leaf size and shape are highly sensitive to moisture conditions. It has been shown that the average leaf width increased with the logarithm of annual rainfall, in well-drained sites of lowland tropics, (Givinish, 1984). Generally, the average width of leaves or their lobes or leaflets tends to decrease toward dry, sunny or nutrient-poor habitats (Volkens, 1887; Schimper, 1898; Raunkaier, 1934; Shields, 1950; Webb, 1968; Walter, 1973; Hall and Swaine, 1981). Bonnie (2002) used the leaf spectra for the estimation of paleoclimates in the miocene prevailing in Tugen hills, Kenya and he found that the leaf size primarily correlated with yearly or seasonal rainfall and also observed the predominance of non-entire leaf margins in deciduous plants. Kathryn (2000) found increase in leaf size with the increase in precipitation in Bolivian forests. In India no studies found dealing with leaf size spectra. Majority of studies dealt with leaf phonological aspects and life form spectra rather than leaf

size classification. However, Kushwaha and Sing (2005) in their studies on leaf phenology of deciduous forests used leaf size while comparing canopy and sub-canopy species.

The present study deals with the leaf size spectra of woody species in Kudremuk National Park, an ecological hotspot of the central Western Ghats, India. Emphasis has been made to study the implications of environmental and ecological factors on the leaf size spectra of the region.

MATERIALS AND METHODS

Study area

The study area, Kudremukh National Park, recently declared National Park in Karnataka is probably one of the largest reserves of high altitude grasslands in the Western Ghats spreading over an area of 600.32 km^2 with geographical limits of 13^{o} 01^{1} to 13^{o} 29^{1} N latitude and 75^{o} 00^{1} to 75^{o} 25^{1} E longitude. The topography of the area is undulating with the altitude ranging from 300m in the lowlands of western part of the park to the highest of 1892 m in the southern part of the park. The climate is typically monsoonic and the major rainfall is from southwest monsoon ranging from 3500 mm to a maximum of 8500 mm and the bulk of the rainfall is received between mid-June to August (Fig.1).

The vegetation of the area falls under the category West Coast tropical evergreen forest (Champion and Seth, 1968). Pascal (1988) broadly classified these forests as *Dipterocarpus indicus* Bedd. - *Kingiodendron pinnatum* (DC.) Harms. - *Humboldtia brunonis* Wall. and *Poeciloneuron indicum* Bedd - *Palaquium ellipticum* (Dalz.) Baill. - *Hopea ponga* (Dennst.) Mabberly type. The forests in the area are diverse, having patches of both moist deciduous and evergreen biotopes as well as large expanse of grasslands (Sringeswara, 2006). The ‘shola’ forests, compact patches of forest having a stream running in between, are found in high altitudinal ranges in the southern part of the park. These ‘shola’ forests are interconnected by vast stretches of grasslands forming a unique shola-grassland complex.

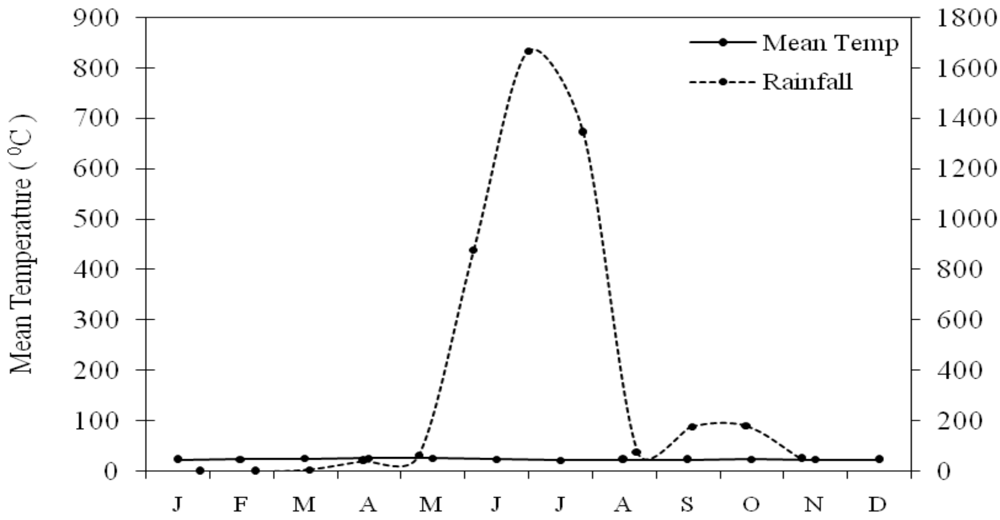

Fig. 1: Ombrothermic graph of Kudremukh National Park of the central Western Ghats averaged over past ten years

Data collection

One hundred-fourteen sample plots, of the size 31.6 x 31.6 m, were laid out covering all the vegetation types found in the area and considering the ecological gradients. Each species was assigned to a leaf size class based on Raunkiaer leaf classification (Raunkiaer, 1934). Leaf area of each species was calculated as two thirds of the product of length and width of the leaf as stated by Cain and Castro (1959). Average leaf width for each sample plots was determined as outlined by Givinish (1978a) using the characteristic leaf width of each leaf size classes. In addition to the leaf size classes, the arrangement of leaves, leaf margin and nature of leaf types (simple or compound) were recorded and subjected to analysis. The environmental and ecological data pertaining to each sample plot was collected. The environmental data composed of rainfall (obtained from the World climate data of 1 km resolution; source: http://biogeo.berkeley.edu/worldclim/bioclim.htm), altitude, aspect (the aspect classes were valued from one to eight depending upon the onset and withdrawal of the rainfall (Pascal, 1988) and the values are as follows N-3, NE-1, E-2, SE-4, S-6, SW-7, W-8 and NW-5), and dry months (duration of the dry period obtained from the bioclimatic map of Western Ghats by Pascal (1982)). Ecological data consisted of percentage of evergreeness (Chandran, 1993), and disturbance levels. Canonical Correspondence Analysis (CCA) (Terbraak, 1987) and Pearson correlation coefficient (Pearson, 1896) were used to explore the relationship with the ecological and environmental factors and different leaf criteria. Software ‘Pcord4’ (McCune and Mefford, 1999) was used for analysis of the canonical correspondence and Pearson correlation coefficient.

In the CCA ordination biplot, the environmental and ecological variables assigned as vectors radiating from the center and leaf classes were represented by points. The relative length and the angle between vectors indicated the degree of correlation between variables and axis and among variables (Terbraak, 1987).

RESULTS AND DISCUSSION

A total of 280 woody species were recorded from the 114 sample plots in the study area. Out of 280 woody species 75% of the tree species belonged to the mesophyll leaf size class. The occurrence of mesophyllous species in primary evergreen vegetation is 83.21% followed by 'shola' forest (82.89%) and it was least in moist deciduous forest (71.60%). Majority of the species exhibited alternate type leaf arrangement which is to the tune of 77.14% compared to opposite and whorled type. In moist deciduous and 'shola' types the representation of alternate leaf arrangement is comparatively lesser than other three vegetation types (67.90 and 72.37%, respectively). Species with simple leaves are dominant with 74.29% incidence as compared to those with compound leaves (25.71%). The percentage of species with simple leaves is comparatively high in secondary evergreen forest (84.62%) and that with compound leaves in semi-evergreen forests (25.78%). In all vegetation types, the species with entire leaves dominated with 85.36% than species with serrate leaves (14.64%). Primary evergreen forests showed high percentage of entire leaves (86.86) (Table 1). As far as the leaf width concerned, the average leaf width decreased with increase in altitude (Fig. 2).

Table 1: Leaf-size classes (%), arrangement of leaves (%), nature of leaves (%) and leaf margin (%) in different vegetation types of Kudremukh National Park of the central Western Ghats

Category	Vegetation type					Total
	Primary evergreen	Secondary evergreen	Semi-evergreen	Moist deciduous	'Shola'	
Leaf-size class						
Leptophyll	-	-	0.89	1.23	-	0.71
Nanophyll	-	-	1.33	2.47	-	1.07
Microphyll	11.68	13.46	18.67	18.52	14.47	18.57
Mesophyll	83.21	81.73	74.67	71.60	82.89	75.00
Macrophyll	5.11	4.81	4.44	6.17	2.63	4.64
Arrangement of leaves						
Alternate	78.83	77.88	77.33	67.90	72.37	77.14
Opposite	20.44	21.15	21.33	29.63	25.00	21.43
Whorled	0.73	0.96	1.33	2.47	2.63	1.43
Nature of leaves						
Simple	82.48	84.62	74.22	81.48	84.21	74.29
Compound	17.52	15.38	25.78	17.28	15.79	25.71
Leaf margin						
Entire	86.86	85.58	85.78	82.72	77.63	85.36
Serrate	13.14	14.42	14.22	17.28	22.37	14.64

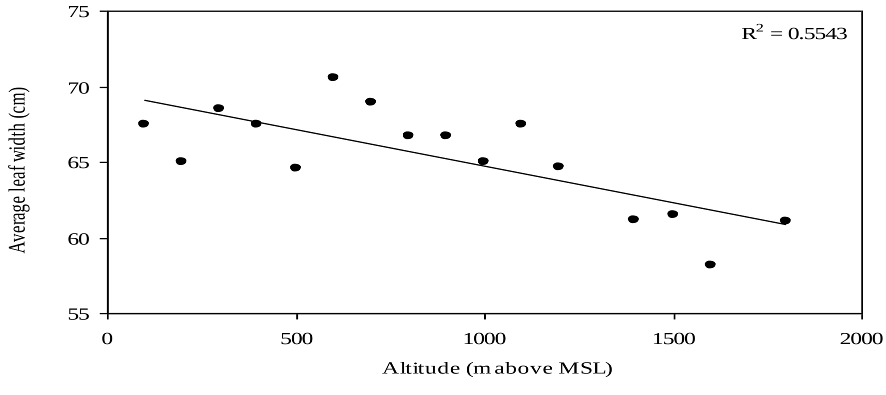

Fig. 2: Trends in average leaf width with respect to the altitude in the Kudremukh National Park of the central Western Ghats

Results of the present study also pointed out that, the percentage of evergreenesss is one of the important gradients in distributing the leaf size classes among different vegetation types (Fig. 3). The Eigen values of three CCA Axes were 0.009, 0.008 and 0.004 and total variance ("inertia") was 0.24. The Monte Carlo test showed significant (P = 0.01) positive correlation of environmental and ecological variables with the Axis 2.

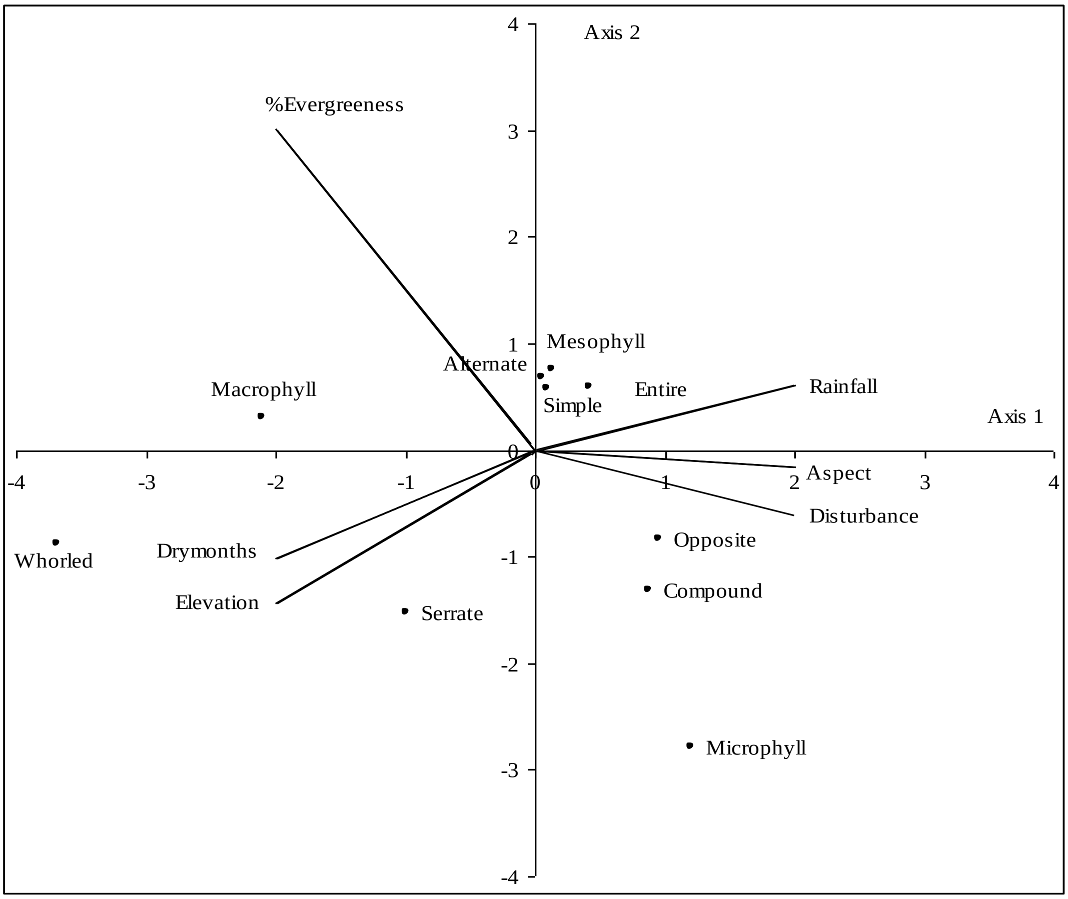

Fig. 3: Canonical Correspondence Analysis ordination biplot of leaf morphology and environmental and ecological traits in Kudremukh National Park of the central Western Ghats

Significant positive correlation, according to Pearson correlation matrix, was observed with percentage of evergreeness and mesophyll leaves (P = 0.01), alternate leaves (P = 0.001) and simple leaves (P = 0.05) and negative correlation with microphyll leaves (P = 0.01), opposite leaves (P = 0.001) and compound leaves (P = 0.05). Elevation is positively correlated with serrate leaf form and negatively correlated with the entire leaves (P = 0.001). Rainfall is negatively correlated with leptophyll leaf class (P = 0.05) (Table 2).

Table 2: Pearson correlation of environmental and ecological variables with leaf classes and leaf morphological characters in the Kudremukh National Park of the central Western Ghats

	Elevation	Duration of Drymonths	Rainfall	%Evergreeness	Aspect	Disturbance
Leptophyll	0.073	0.01	-0.232*	-0.261**	0.195*	-0.029
Nanophyll	-0.182	-0.132	0.044	-0.333***	-0.029	0.201*
Microphyll	0.069	0.154	0.091	-0.269**	0.199*	0.051
Mesophyll	-0.022	-0.2*	-0.069	0.305**	-0.163	-0.039
Macrophyll	-0.03	0.166	0.012	0.061	-0.07	-0.08
Alternate Leaves	0.149	0.114	0.078	0.428***	0.119	-0.042
Opposite Leaves	-0.182	-0.134	-0.069	-0.449***	-0.078	0.053
Whorled Leaves	0.115	0.065	-0.048	0.027	-0.185	-0.036
Entire Leaves	-0.347***	0.002	0.041	0.044	0.076	-0.02
Serrate Leaves	0.347***	-0.002	-0.041	-0.044	-0.076	0.02
Simple Leaves	0.009	-0.082	0.045	0.252*	-0.082	0.044
Compound Leaves	-0.009	0.082	-0.045	-0.252*	0.082	-0.044

***, ** and * - significant at P = 0.001, 0.01 and 0.05, respectively

The tropical rain forests are characterized by the dominance of mesophyll leaf size class. The macrophyll and microphyll leaf classes are sparingly present and leptophyll and nanophyll leaf classes are quite often absent (Richards, 1952). Results of the present study revealed that 75% woody species belonged to mesophyll leaf class. Leptophyll and nanophyll leaf classes were absent. The proportional distribution of different leaf size classes in different vegetation types might suggest their resource sharing and their extent of adaptability to the surrounding environment. The predominance of mesophyll leaves in evergreen vegetation type could be correlated to their habitat preferences, which is a combination of wetness and heat characteristic of the rain forest climate (Richards, 1952). Although rainfall is the major determinant for the leaf size (Richards, 1952; Sringeswara *et al*, 2003), the present result does not show significant correlation with leaf classes except leptophyll leaf class, which is negatively correlated (P=0.05). This could be attributed to the prevalence of less variation in the rainfall pattern as well as the vegetation types in the study area. Interestingly, the percentage of evergreeness significantly correlated with the leaf classes (Table 2).

The percentage of alternate leaf arrangement is high in all vegetation types, as alternate leaf arrangement helps in trapping more solar radiation with the occupation of minimum space. And, also the possession of alternate or opposite leaves is often a familial character (Cronquist, 1981). The percentage of species with compound leaves are more in semi-evergreen and disturbed evergreen types, which consisted of more number of pioneer and colonizer species. The presence of compound leaves could be attributed to the reduction in transpiration and respiration by shedding the leaf rachis only after leaf fall, as rachis has high proportion of living cells (Givinish, 1976; 1978a and b; 1979). In addition, plants with compound leaves favor the premium put on height, which helps to compete for light in forest gaps (Givinish 1978b). Leptophyll laves are the common adaptations to water stress regions (Judith, 1998) and Moist deciduous vegetation has higher percentage of leptophyllous species. The present study indicated that leptophyllous species are deciduous in nature (*Phyllanthus emblica* L. *and Acacia pennata* (L.) Willd.) and are found in drier and disturbed habitats. Presence of leptophyll leaves in drier habitats could be attributed to the less total surface area of the leaves, which helps to withstand water stress. Brunig (1970) also found the dominance of leptophylls in stands with extreme fluctuation of water regime.

The present study revealed that the percentage of species with serrate leaves increases with increase in elevation. Julio *et al*. (2003) also observed the increase in serrate leaves with increase in elevation. The present study also revealed that, the average leaf width decreased with increase in elevation. The decrease in leaf width with increase in altitude could be attributed to the harshness of the prevailing climatic conditions, decrease in soil fertility and also the influence of high intensity short-wave radiation, which reduced the leaf growth. Dolnicki and Kraj (2001) in their study observed that in the higher elevation region, the influence of high intensity short-wave radiation slowed the leaf growth. Givinish (1984) also observed the decrease of the average leaf width with increase in elevation. On the contrary, Brown (1919) observed the increase of leaf size with increase in altitude and Bout and Okitsu (1999) noted distinct leaf size zonation along an altitudinal gradient in Mt. Pulog, in the Philippins instead of a continuous change. Dolph and Dilcher (1980a, 1980b) claimed that the elevational trend in leaf size is discontinuous, and recognized four foliar belts in which there is little or no systematic variation in leaf size. However, Givinish (1984) disproved the Dolph and Dilcher's claim and reported a continuous change in the elevation trend with Dolph and Dilcher's data and reasoned the deviation trend for the application of methodology. In support of Givinish's study we also did find the discontinuity in the average leaf width with respect to elevation and distinct foliar belts in the study area. This leaf size classification and comparison of this environmental factors shed light on the adaptive mechanisms of plants to the surrounding environment, which should be kept in mind while implementing management practices aiming conservation.

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