

Spatial Patterns of Abundance and Diversity of Socioeconomic Important Plant Species in a Human Inhabited Protected Area at Korup, Cameroon

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Abstract:

We present data on sample richness, relative abundance, and community structure of economic plant species assemblage from a globally important hotspot of biodiversity- the inhabited central region of Korup National Park, southwestern Cameroon. Patterns of species diversity and spatial variability across major locations are described. We recorded 23 species, the mean richness location 13.3 (minimum: 7, maximum: 20, median: 13, standard error of the mean 3.436) which is significantly low compared to the ever increasing population. We found that population pressure and cultivation of native habitat reduces economic plants species diversity, a conclusion that has important implications in light of the rapid conversion of parts of the protected area for agriculture and fuel-wood in human inhabited protected areas of sub-Sahara Africa. The Mantel test statistic showed a significance level ($P=0.001$), but there is a large scatter of observations and correlation is low ($r=0.2225$) among values of the gradient and ecological distance matrices. The ordination analysis revealed six axes accounting for only 30.14% of the total variance (Pseudo- $F=1.78207$; $P<0.001$, $n=1000$ permutations), suggesting that soil variables may not be important in the spatial distribution of plant species. These conclusions emphasize the importance of stratified long-term sampling in biodiversity studies and demonstrate that superficial levels of sampling effort can lead to erroneous conclusions regarding patterns of floristic species. Continuous existence of such protected areas, ecological integrity and sustainable human livelihoods in the areas would require that both education of the population and eco-agriculture based on the cultivation of these economic plant species be given priority. [Journal of American Science 2009:5(2) 54-68] (ISSN: 1545-1003)

Key words: Economic plant species; Ecological integrity; Sustainable human livelihoods; Korup National Park

1. Introduction

The diversity and distribution of food and medicinal plants in hotspots of biodiversity that are inhabited by poor dependent forest communities who cannot integrate traditional markets, but need alternatives for income generation need special

attention in ecology. As human population density in such areas continues to increase with time, so too is increase pressure on the ecological milieu through uncontrolled degradation and conversion to other land uses, in order to meet up with the challenges of life. The resulting impacts are in the form of loss of biological resources, damage to habitats and

ecological services [Costanza et al., 1997; De Groot et al., 2002]. To the extent that humankind neglects to maintain such global life-supporting ecosystems, current and future generations will be confronted with increasing severe instances of environmental induced changes.

In the central zone of the Korup national park (KNP), Cameroon, the belief that ecological security became secured following the creation of the park in 1986 pervades calculations of local and national policy makers, but this belief is not based on direct observation of the situation today. The living consequences in the enclave central zone of the park include, decline in wildlife population of plants and animals, and above all, the emission of green house gases through environmentally harmful agricultural practices.

The preservation of biodiversity and ecosystem services of such areas requires accurate information from a wide variety of sources. Since inhabitants of such areas depend on food and medicinal plants as their main source of livelihood, information about their biodiversity and spatial distribution with respect to environmental variables is essential. Such information is needed to better predict the effects of future manipulations on biodiversity, stand development, and long-term ecosystem structure and function. This can take the form of designing alternative form of cultivations such as eco-agriculture [McNeely and Scherr, 2002], agro-forestry or analog forest [Earles 2005; Scherr and Shames 2006] that can reduce pressure on biodiversity, at the same time sustaining livelihoods and/or food security. This system shares a vision of “farming with nature,” an agro-ecology that promotes biodiversity, recycles plant nutrients, protects soil from erosion, conserves and protect water [Scherr and Shames 2006].

Researchers have explored a variety of methodologies for describing the spatial distribution of diversity on large and small scales. To describe community structure and compare samples, diversity indices such as the Shannon [Shannon, 1948], the Simpson's [Simpson, 1949], etc., have been used. However, such indices have been found not to provide sufficient information to order communities in diversity [Kindt, 2006], and in some cases, when ranking differs; it is not possible to be categorical that a particular site is more diverse than another, even if the sampling regime adopted has been appropriately standardized [Whittaker et al. 2001].

Differences in vegetation cover over large areas have been linked to regional climatic gradients or to local differences in parent materials [AbdEl-Ghani 2000; Bennie et al., 2006]. Sebastiá (2004) found that soil fertility was the main environmental gradient structuring subalpine, calcareous grassland communities at the landscape scale. On the contrary, Van der Moezel and Bell (1989) found highest species richness to occur on soils with the lowest nutrient content in the mallee region of Western Australia. Hahs et al. (1999) also reported a strong negative correlation between soil nutrient concentration and species richness in sclerophyll heath vegetation in Victoria. These contradictory findings show that environmental factors act differently across scales and/or regions. One cannot therefore adopt results from other regions however similar they maybe in biophysical characteristics.

In this study, we describe the floristic diversity of food plants and medicinal plants in a human inhabited protected area; the Korup National Park (KNP) of south western Cameroon, using diversity profiles and ordination techniques.

Previous work has been taxonomic, focused on forest structure and dynamics. This study, which is the first of its kind in the region, aims to evaluate the

importance of soil factors in determining spatial patterns in the distribution of food and medicinal plants species. This involves (a) sampling the vegetation and soil variables, (b) biodiversity ordering, (c) the identification of soil variables that display patterns in distribution and (d) an assessment of the significance of the relationships between these variables and the flora that may inform the selection of conservation prescriptions.

2. Materials and methods

2.1 Study area

The study area (1,260 km²) is located in Ndian Division, southwestern Cameroon, between latitudes 4° 54' and 5° 28' north; and longitudes 8° 42' and 9° 16' east of the equator, at the Cameroon-Nigerian border and is contiguous with the Oban National Park-Nigeria. It is believed that Korup lies at the centre of the Guinea-Congolian forest refugium, one of only two Pleistocene refugia proposed for Africa. Our study focuses on central zone of the Park. The region is of interest partly because it is inhabited by man, and because it is important for conservation since it has many rare, endemic and economic plant species.

2.2 Biophysical conditions

Based on personal investigations, region reaches elevations of up to 1130 m (peak of Mt. Yuhuan), the soil is sandy (70%-80%), and acidic (pH 3.7-4.7). The climate is characterized by a single distinct dry season from December to February and a single-peak wet season from June to October. Mean annual rainfall is in excess of 5000 mm per year [Zimmermann, 2000]. A mean annual maximum temperature of 34 °C, and a mean minimum temperature of 23.8 °C have been calculated. Data for the coastal region indicates that the mean annual relative humidity is 83%, the mean daily maximum is 98% and the minimum is 66%. The flora and fauna of

the Korup region is known to be part of the Hygrophilous Coastal Evergreen Rainforest that occurs along the Gulf of Biafra, and is part of the Cross-Sanaga-Bioko Coastal Forest ecoregion [Olsen et al., 2001]. This ecoregion is considered an important center of plant diversity because of its probable isolation during the Pleistocene [Davis et al., 1994] and holds an assemblage of endemic primates known as the Cameroon faunal group [Waltert et al., 2002].

2.3 Sampling design

Field work took place from February 23rd to June 15th of 2008. Thirty modified Whittaker plots (Fig. 1) [Stohlgren et al., 1995], five each per location-the buffer zone, primary forest, secondary forest, the Mt. Yuhuan, Erat, and Ekon1 were set up and surveyed.

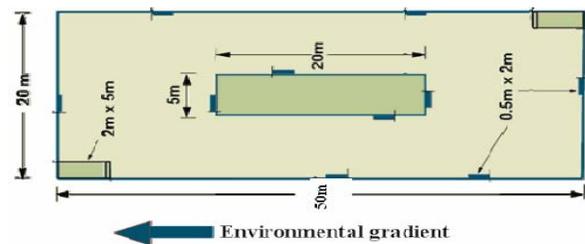


Fig. 1 Modified-Whittaker nested plot setup (adapted from Stohlgren et al., 1995)

The locations of the plots were chosen randomly so as not to create a subjective bias. Plots are placed parallel to the major environmental gradient of the vegetation type being sampled to encompass the most heterogeneity. To eliminate effects of topography, only flat areas (slope <5°) were sampled.

2.4 Variables measured

2.4.1 Soil variables

A total of 100 soil samples (5 per plot) were collected from each plot. The collections were done at the corners (4) and the center (1) with a 2.5 cm diameter soil increment core to depths of 15-20 cm

and pooled into one composite sample. For each sample, surface litter was first removed. The collected soil samples were sent to the University of Dschang, Cameroon for analysis. Some of the variables include, but not all, pH, organic matter (OM), sand, clay, silt, saturated bases (BS), percentage phosphorus, potassium, sodium, and magnesium.

2.4.2 Topographic variables

On each plot, UTM coordinates and elevation (m) were derived from a global positioning system (GPS).

2.4.3 Vegetation variables

In the smallest subplots (1m²) all herbs, grasses and saplings are identified and counted (include all plants less than 50 cm in height). In the two subplots of 10 m², all trees and shrubs \geq 1cm dbh are measured. In the central 20 m \times 5 m sub-plot, all trees \geq 5 cm dbh are identified and measured, while trees of (dbh) \geq 10 cm not already covered by the subplots are identified and measured in the entire 1000 m² plot area. Cumulative plant species (i.e., additional species found in either the subplots or plot) are recorded successively in the entire sub-plots. Voucher specimens of plants were collected and sent to the National Herbarium in Yaoundé for identification. Not all specimens could be identified to species level as some genera are currently undergoing revision. Food and medicinal plants were sorted after concerting with local authorities, traditional doctors, and some experts. Food and medicinal plants include all edible and medicinal tree growth-forms encompassing trees, shrubs and ground cover.

2.5 Data analysis

BiodiversityR software developed by Roeland Kindt [Kindt and Coe, 2005], built on the free R 2.6.1 statistical program and its contributing packages such as the vegan community ecology package [Oksanen et al., 2005] was also employed.

2.5.1 Richness, abundance and density of tree species

Total species richness was determined as the total number of plant species present in each 1000 m² quadrat (sampling site) or each 5000 m² location. Total and average tree species richness and tree abundance were calculated for the survey and for separate locations. We define abundance per site or location as the observed number of tree species that were counted on that site or location. Species accumulation curves were calculated using the exact method for calculating the average number of accumulated species when sites are accumulated in a random pattern [Kindt and Coe, 2005]. They were calculated for the subset option, location so that differences in species richness could be analyzed.

2.5.2 Diversity ordering

The performance of different richness estimators varies depending on differences in richness, sampling effort, and community evenness [Colwell and Coddington, 1994], and the relative biases and inaccuracies remain poorly understood, meaning that the most robust estimates are often only for the lower and upper boundaries [O'Hara, 2005]. Hence, diversity research need not be based on single indices of diversity or evenness. As such, techniques for diversity and evenness ordering were used that produce diversity and evenness profiles. In addition, the first order Jack-knife non-parametric estimator was used. Rényi's (1970) showed that;

$$H_{\alpha} = \frac{1}{1-\alpha} \ln \left(\sum_{i=1}^N P_i^{\alpha} \right);$$

for $\alpha \in \{0, 0.25, 0.5, 1, 2, 4, 8, \infty\}$

(1)

Where (H_{α}) denotes Renyi diversity profile values, and P_i is the relative abundance of species i . For any

given community, H_α is a parametric measure of uncertainty in predicting the relative abundance of species. A parameter restriction ($\alpha \geq 0$) has to be imposed if H_α should possess certain desirable properties discussed in the remainder that renders it adequate in ecological research [Legendre and Legendre, 1998]. From the diversity profile, an evenness profiles, $InE_{\alpha,0}$ can be obtained, where,

$$InE_{\alpha,0} = H_\alpha - H_0 \Leftrightarrow E_{\alpha,0} = e^{H_\alpha - H_0} \quad ;$$

$$E_{\alpha,0} \cong N(0, \sigma^2) \quad (2)$$

Shannon's index is a limiting function of the Renyi's profile function as $\alpha \rightarrow 1$; $\alpha = 2, H_2 = -\ln \sum P_i^2$; (log Simpson index; apparent concentration of dominance). H_0 contains information on species richness, and as $\alpha \rightarrow \infty$, this gives Berger-Parker diversity indices. It can also be dissociated into contributions of species richness, the evenness in proportion of the dominant species and the evenness in the proportions of the other species. Subsequently, the ratio, $\ln(E_1)/\ln(E_\infty)$ can be calculated. This ratio provides an indication of the evenness in distribution of the other species (excluding the dominant species). Furthermore, H_α allows for partial ranking of ecological communities in diversity such that, a community of higher diversity than a second community will have a diversity profile that is everywhere above the profile of the second community. Shannon diversity index gives more weight to rare species; Simpson diversity index gives more weight to most abundant species in a sample [Magurran, 1988].

2.5.3 Spatial variation with respect to environmental variables

The potential influence of explanatory factors on species richness and abundance of sites was analyzed

by canonical correlation analysis [CCA; ter Braak, 1986]. CCA was preceded by a forward selection process. The forward selection procedure was employed to determine the amount of variance explained by each variable at time of inclusion in the model and the significance of each variable. The forward selection procedure resulted in the retention of 6 variables as significant contributors to variation in the ordination: elevation, pH, percentage of sand, clay, organic matter and Carbon: Nitrogen ratio (C: N).

Descriptive statistics of the six environmental variables, grouped by sampling locations, were calculated and differences among sites were tested by single classification ANOVA using the software program SPSS 13.0. The relationships between vegetation and environmental variables were tested using non-parametric Spearman rank correlations between each of the six environmental variables.

2.5.4 Differences in species community structure and species composition

The nonmetric multidimensional scaling (MDS) ordination was chosen because it makes fewer assumptions about the data distribution, and enables the use of a similarity index that excludes joint absences and provides a visually intuitive summary of similarity among sites [Clarke and Warwick, 1994]. Similar matrices were produced using the site-standardized Bray-Curtis similarity index and square root transformed data, as well as presence-absence data. Site standardization (proportioning each species relative to the site total) reduces the contribution that differences in overall abundance make toward differences in community structure. To account for spatial heterogeneity in species richness among sites within any one location (or the importance of geographic distances among sites in determining patterns of community dissimilarity), we used the Mantel's permutation test of the rank correlation

between paired similarity matrices. This was chosen because it can be applied to variables of different logical type (categorical, rank, or interval-scale data), in our case, categorical variables (soil and vegetation variables). Differences in the multivariate community structure between habitat types were examined using an analysis of similarity test ANOSIM) [Clarke and Warwick,1994].

3. Results

3.1 Community floristic, structure and patterns

A total of 23 species of food and medicinal plants were counted in the region. The mean richness on a site was 13.3 (minimum: 7, maximum: 20, median: 13, standard error: 3.436) and the mean abundance was 44.7 (minimum: 32, maximum: 65; median: 38, standard error of the mean 8.08). Some of the structural traits for the six sites surveyed are summarized (table 1).

Table 1 Summary of the community floristic structure and patterns in the central KNP

Parameter	ALL	B	EK	ER	M	P	S
Total plot (20x50m) number	30.0	5.0	5.0	5.0	5.0	5.0	5.0
Total area sampled(ha)	3.0	0.5	0.5	0.5	0.5	0.5	0.5
Abundance(Total tallied stems):	1349.0	190.0	217.0	233.0	260.0	225.0	224.0
1. Woody stem(>=5cm)	734.0	100.0	94.0	136.0	147.0	121.0	136.0
2. Shrubs/herbs/grasses(<1cm)	615.0	90.0	123.0	97.0	113.0	104.0	88.0
Mean stems/ha	449.7	380.0	434.0	466.0	520.0	450.0	448.0
Mean species richness/site	45.0	38.0	43.4	46.6	52.0	45.0	44.8
Mean diameter/stem(cm)**	25.6	27.7	26.4	25.0	23.3	25.3	25.7
Mean basal area (m ² /ha)**	0.00126	0.00121	0.00103	0.00134	0.00125	0.00122	0.00141
Total richness	23.0	23.0	20.0	23.0	23.0	23.0	22.0
Jack.1	23.0	30.2	21.6	27.8	23.8	24.6	25.2
J	0.866	0.822	0.880	0.912	0.802	0.848	0.785

** This applies only to woody stems of dbh ≥ 5 cm. Richness (S) = number of species; Jack.1 is the first order Jackknife diversity index. B: Buffer zone forest site; EK: Ekon1; ER: Erat; M: Mountain forest site; P: Primary forest site; S: Secondary forest site. (Names are given just to distinguish sampling locations, for most of the forest is primary. Secondary forest here refers to the old village site of Ekundu-kundo-a former village in the park, now resettled at the peripheral zone). Erat and Ekon1 villages still remain in the park.

Stem density range from 380 ha⁻¹ in the buffer

zone to 520 ha⁻¹ in the mountain. The first order Jack-knife estimate for the total richness for all sites combined was 23.0.

Furthermore, there is no significant difference in structural traits between the six plots (ANOVA $P < 0.002$).

The species richness-site curve (Fig. 2) approached an asymptote.

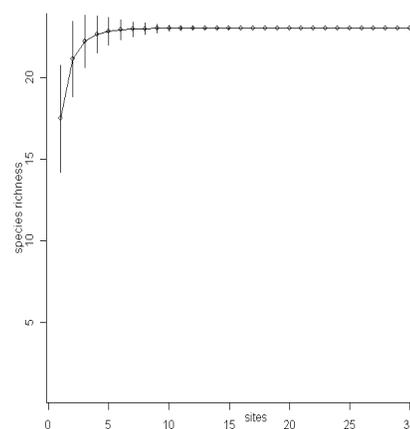


Fig. 2 Species accumulation curve based on rarefaction

At species richness=23, the curve became asymptotic with the site's axis, making comparisons among locations easier.

3.2 Diversity ordering: species richness and abundance and comparisons between locations

In terms of abundance distribution, *Anchomanes deformes* (AND,n=350), a medicinal plant, belonging to the Araceae is the most abundant (Fig. 3). This is followed by *Masularia acuminate* (n=98) and *Cola lepidopta* (n=82).

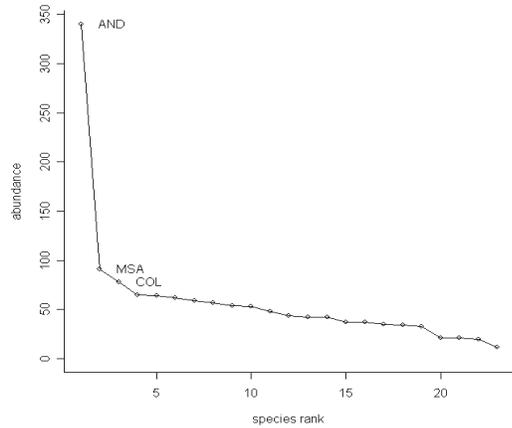


Fig. 3 Rank abundance curve for food and medicinal plants in central KNP

In terms of species richness distribution, Renyi's profile (Fig. 4) for Erat (ER) was above those of other locations.

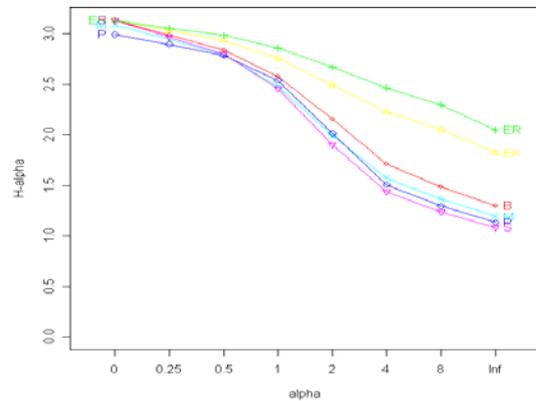


Fig. 4 Renyi's richness profiles for central Korup

Erat is therefore, relatively richest in food and medicinal plants than the other sites, closely followed by Ekon1 (EK). The intersecting profiles for the mountain (M) and secondary forest (S) makes it difficult to rank them.

In terms of evenness, the evenness profile of Erat was again above the profiles of the other locations (Fig. 5), indicating a more even distribution of species in this location than in the other locations.

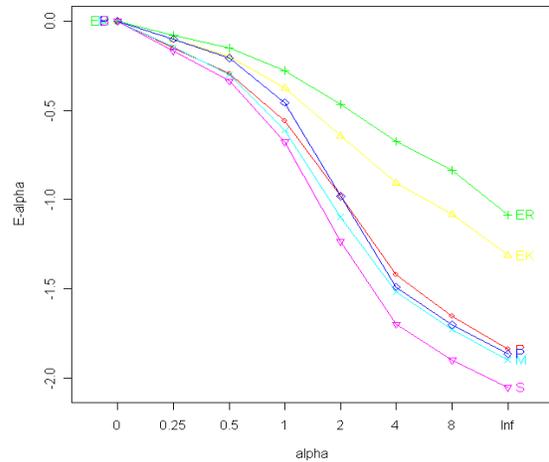


Fig. 5 Renyi's evenness profiles for central Korup

The evenness profiles for the buffer zone (B), the mountain (M) and primary forests (P) were intersecting. It is difficult in this case to rank the locations in terms of evenness distribution in these locations.

Table 2 shows the results for species richness (H_0), evenness in the distribution of the dominant species (E_{∞}), and evenness in the distribution of other species ($\ln E_1 / \ln E_{\infty}$) for comparisons between locations of overall species diversity.

Table 2 Species diversity distribution of the dominant species, and evenness in the distribution of other species ($\ln E_1 / \ln E_{\infty}$) for comparisons between locations of overall species diversity

Site	0	0.25	0.5	1	2	4	8	H_{∞}	$E_{\infty,0}$	$E_{1,0}$	$\ln E_1 / \ln E_{\infty}$
B	3.1355	2.9864	2.8429	2.5787	2.1536	1.7142	1.4808	1.2958	0.1589	0.5730	0.3027
EK	3.1355	3.0344	2.9372	2.7597	2.4930	2.2297	2.0517	1.8230	0.2692	0.6868	0.2863
ER	3.1355	3.0577	2.9855	2.8589	2.6703	2.4636	2.2993	2.0488	0.3373	0.7584	0.2545
M	3.0910	2.9445	2.7903	2.4801	1.9925	1.5736	1.3623	1.1921	0.1497	0.5429	0.3217
P	2.9957	2.8964	2.7884	2.5404	2.0139	1.5063	1.2930	1.1314	0.1550	0.6342	0.2442
S	3.1355	2.9699	2.8001	2.4598	1.8999	1.4369	1.2361	1.0816	0.1282	0.5088	0.3290

NB: $E_{\infty} \equiv E_{\infty,0}$ and $E_{1,0} \equiv E_1$

When comparing the values of H_{∞} , which indicate the proportion of the dominant species, table 2 shows that Erat had the largest values for the sampled species, while the secondary forest was the

least. In direct comparisons between the locations, on the number of species sampled, Erat (ER; $\text{Ln}(E_\infty)=-1.08669$) had the least value. The ratio, $\text{Ln}(E_1)/\text{Ln}(E_\infty)$ is least for the primary forest (P). This suggests a more even distribution of other species in the primary forest. H_0 is largest in B, EK, ER and S. This suggests these locations to be richest, while the primary forest (P; $H_0=2.9957$) to be least rich.

Food plants were significantly more abundant in Erat and Ekon1 locations but with lower levels of relative abundance elsewhere ($H = 8.88$, $df = 3$, $P = 0.03$, all pairwise comparisons significant; Mann–Whitney $U > 16$, $P < 0.05$).

3.3 Differences in community structure and species composition between locations

NMDS scores of an ordination based on presence–absence data indicate that Erat, Ekon1 and secondary forest sites are segregated, but the other sites are not distinct from any of the others (Fig. 5).

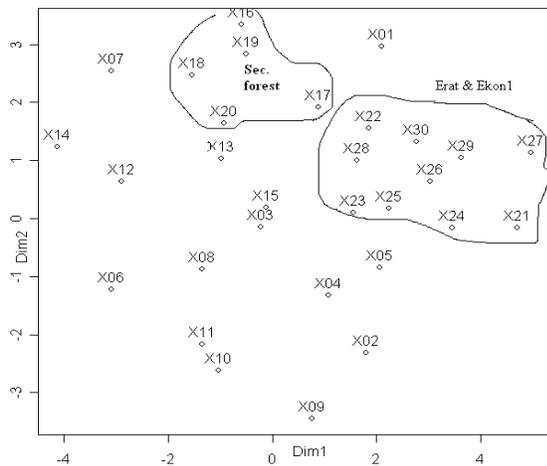


Fig. 6 Nonmetric multidimensional scaling ordination (NMS random (distmatrix, perm=1, k=2)) showing differences in the community structure among four habitats based on presence-absence data and the Bray-Curtis similarity index. A stress value of 22.14173 indicates a fair goodness of fit of the 2D configuration

This suggests that these sites host a subset of species that are also found elsewhere

3.4 Analysis of differences in species composition

The observations in the previous section are supported by the pairwise ANOSIM tests, with all comparisons of multivariate community structure among locations (ANOSIM: Global $R = 0.3725$, significant < 0.001 ; $n=1000$ permutations; Bray-Curtis distance). Empirical upper confidence limits of R : 90%=0.0926; 95%=0.1140; 97.5%=0.1430; 99%=0.1954. Figure 7 shows that there is evidence for a relationship between the ecological distance and location, however the relationship is not very strong.

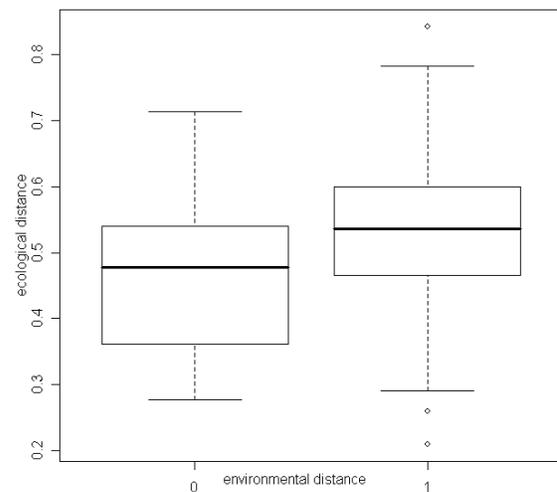


Fig. 7 Bray-Curtis distances in relationship with differences in locations for the central Korup dataset

The importance of geographic distances among locations in determining patterns of community dissimilarity (Mantel test) provided the following results: (Mantel test: permutations = 1000; statistic r : 0.2225; significance: < 0.001). Empirical upper confidence limits of r : 90%=0.0548; 95%=0.0721; 97.5%=0.0849; 99%=0.1068.

The results show that although the significance level of the correlation is quite small ($P = 0.001$), there is a large scatter of observations and correlation is low (among values of the gradient and

ecological distance matrices). Constrained ordination technique was used to properly investigate the influence of environmental variables on species composition since these techniques provide a more comprehensive result.

3.5 Spatial variation with respect to environmental variables

Species showed some degree of spatial distribution that reflects patterns in environmental heterogeneity. Pearson-product moment correlation coefficient revealed some statistically significant correlations among the soil variables (Table 3).

Table 3 Pearson –product moment correlation coefficients (2-tail test) between environmental variables

	Clay	Sand	Elevation	C:N	pH
Sand	1.00**(0.00)				
Elevation	-0.776**(0.00)	-0.776**(0.00)			
C:N	0.399*(0.029)	0.399*(0.029)	-0.1(0.598)		
pH	-0.077(0.686)	-0.077(0.686)	0.114(0.548)	-0.051(0.788)	
OM	0.235(0.211)	0.235(0.211)	-0.174(0.357)	0.318(0.087)	0.298(0.109)

P values are in parentheses. C: N=Carbon/Nitrogen ratio; OM=soil organic matter; pH=soil pH.

**Correlation is significant at 0.01 level; *Correlation is significant at 0.05 level.

Clay and sand show a very strong positive correlation and vary in a similar manner with the other variables. Both have a strong negative correlation with elevation. The pH has very low correlation with respect to other soil variables.

The ordination (CCA) analysis revealed that the six axes (table 4) accounted for only 30.14% of the total variance (Pseudo-F: 3.539042; significance: 0.003, n= 1000 permutations).

Table 4: Eigenvalues extracted from canonical correspondence analysis and percentage of variation explained by each axis

	Inertia		Proportion			
Total	1.2999	1.0000				
Constrained	0.3918	0.3014				
Unconstrained	0.9081	0.6986				
Axis	CCA1	CCA2	CCA3	CCA4	CCA5	CCA6
Eig.values	0.1461	0.1004	0.05395	0.04362	0.02611	0.02165
Accounted (%)	11.24	18.96	23.112	26.467	28.476	30.142
Intraset correlation coefficients						
Clay	-0.56987	-0.3172	-0.54625	-0.00952	0.1522	0.5028
Sand	0.102533	0.5757	0.56499	-0.28089	0.1619	-0.4819
Elevation	-0.908243	-0.3090	0.17015	0.12513	0.1105	-0.1516
C:N	0.021487	0.3286	-0.56300	0.32387	0.2914	-0.6208
pH	-0.004273	-0.4306	-0.02631	0.28147	0.8398	-0.1717
OM	0.217706	0.3239	0.57086	0.53923	0.2092	0.4332

The ordination diagram (Fig. 8) and intra-set correlation coefficients (Table 4 above) showed that the canonical axes were related to different environmental gradients: axis 1 and 3 were related to decreasing clay ($r = -0.56987$ and -0.54625 respectively), and increasing clay in axis 6 ($r=0.5028$). Elevation decreased significantly in axis 1 ($r = -0.908243$); while axis 5 was related to an increasing soil pH ($r = 0.8398$)

The most important gradient is the elevation-clay continuum (Fig. 8), increasing along a gradient south east or from the right to left.

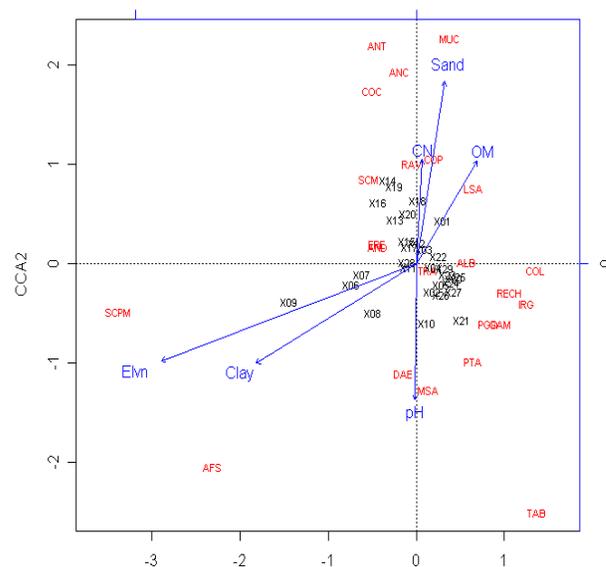


Fig 8 Canonical correlation analysis for central KNP

AFS: *Afromomum sp.*; SCPM: *Scyphocephallum manni*; DAE:

Dacryodes edulis; SCM: *Schumanniphyton magnificum*; MUC: *Musanga cecropioides*; ANT: *Angylocalyx talbotii*; PTA: *Pycnanthus angolensis*; COC: *Cola chlamydantha*; ANC: *Annickia chlorantha*; COP: *Cola pachycarpa*; COL: *Cola lepidopta*; IRG: *Irvingia gabonensis*; RECH: *Recinodendron heudelotii*; ALB: *Alstonia boonei*; POGA: *Poga oleosa*; RAV: *Rauvolfia vomitoria*; TAB: *Tabernaemontana brachyantha*; LSA: *Lasianthera Africana*, MUC: *Musanga cecropioides*, COP: *Cola pachycarpa*.

The arrows representing the environmental variables indicate the direction of maximum change of that variable across the diagram. Similarly, sand, C:N and OM increase north east, while pH increases southward.

The length of the arrow is proportional to the rate of change, so a long pH arrow indicates a large change and indicates that change in pH is strongly correlated with the ordination axes and thus with the community variation shown by the diagram. In this case the strong correlation between sites X08 to X12 (Mountain), elevation and % clay content is unsurprising.

The most important gradient is the elevation-clay-sand continuum, with sand increasing on lowlands gentle-slopes. Clayey soils have higher concentrations of nitrogen and most cations, including aluminum ions. Clays have more binding sites for cations, largely because clay content is positively correlated with organic matter, which is an important determinant of cation exchange capacity in soils with clays of low activity.

Soil pH did not show any strong association with any of the axis. Some plant species show strong association with soil variables while some did not. For example, *Lasianthera africana*, *Cola pachycarpa*; *Musanga cecropioides*, and *Rauvolfia vomitoria* are related with C:N ratio, OM, and sand. However, a majority of the species seems not to have a significant correlation with soil variables.

A posteriori tests however did not produce consistent groupings of locations. Only elevation and

sand showed significant differences between forest locations. Sites were significantly different among with respect to soil variables in one-way MANOVA (df=20, 329, Wilks' $\lambda = 0.182$; $F = 11.055$; $P = 0.001$). Generally, the soils were quite sandy, clayey, acidic and similar across the entire region.

4. Discussion

4.1 Brief description of vegetation in central Korup

Though there are many economic plant species, our attention was focused on food and medicinal plants since this form a major source of household income and food. No evidence of industrial timber logging could be found in the area.

The central zone of Korup National Park contains a very rich flora, with many plant species that are poorly known or have very limited distribution. Due to lack of information on distributions and taxonomy, it is impossible to describe species as “endangered” or, “threatened”; instead, the term “rare” is used to indicate species of concern to forest management. Rare food plants in the buffer zone, secondary forest, mountain and primary forest areas include (but not all), *Coula edulis*, *Elaeis guineensis*, *Monodora* spp., *Poga oleosa*, *Scorodophloeus zenkeri*, *Baiillonella toxisperma*, *Recinodendron heudelotii*, *Afrostryax lepidophyllus*, *Garcinia kola*, *Poga oleosa*, *Recinodendron heudelotti*, *Tetracarpidium conophorum*, *Tetrapleura tetraptera*, and *Treculia africana*. However, most of these food plants are found in substantial quantities in Erat and Ekon1 area and yield substantial income to the households.

Other forest fruit trees of importance include, but not all, *Cola lepidopta*, *Cola pachycarpa*, *Dacryodes edulis*, *Irvingia gabonensis*, *Trichoscypha acuminata*. These plants are unevenly distributed in the area. *Gnetum africana* for

example can hardly be seen in the buffer zone, secondary, mountain and primary forest.

The conversion of forest in some of the locations (Erat and Ekon1) for farmland is one of the primary threats facing the conservation of this important biome. Consideration of the relative biodiversity value of the entire region is severely limited by a paucity of data from other areas. It is unfortunate that the deployment of an intensive sampling campaign is both time demanding and financially costly, and accordingly many recent studies of amphibian diversity in the area have not been based on a statistically defined methodology.

4.2 Spatial patterns of food and medicinal plants relative to abundance and diversity

We found that patterns of overall food and medicinal plants relative abundance in our samples were strongly influenced by the distribution of the two dominant species (*Anchomanes deformes*-a medical plant), which were present all over the central zone of KNP. In contrast, a number of other species in this study also displayed peaks of relative abundance both within specific locations (*e.g.*, most food plants are found in the forest around Erat and Ekon1 while most medicinal plants were concentrated elsewhere). The botanist, who currently works with the *Smithsonian* project observed that the central zone has a little more different kinds of species than further south. This observation has important implications for the design of both biodiversity assessment and population monitoring studies.

In line with little or low similarity in species richness in the different locations, we observed significant differences in the composition (presence – absence data) of the both food and medicinal plants assemblages. In particular, Erat-Ekon1 and the secondary forest habitats exhibited distinct differences in community structure, and species

composition. This suggests that they are comprised of a nested subset of the larger species pool found within the wider landscape.

4.3 Diversity and evenness profiles

As diversity profiles and evenness profiles generally show a sample size-dependent accumulation pattern (influenced by the underlying species abundance distribution), comparisons of diversity between various studies are only meaningful if based on the same sample size to neutralize the influence of sample size on diversity [Rennolls and Laumonier; 1999].

We observed increasing ranges of diversity and evenness profile values associated with increasing scale. Similar observations on the variation of the Shannon (scale 1) and Simpson (scale 2) diversity indices resulted in recommendations to use the Shannon diversity index for comparisons among sites, as this index would be more sample-size efficient in yielding significant differences [Gimaret-Carpentier; 1988]. However, where the evenness in the species abundance distribution differs among sites (a factor eliminated by choice of a species abundance distribution model [Magnussen; 1995]), comparisons based on the Simpson index may be more efficient. Especially where species abundance distributions are not known *a priori*, we recommend analyses based on accumulated Rényi diversity profiles, also because calculation of several profile values does not pose major computational difficulties. Calculation of Rényi diversity and evenness profiles allows separating the influence of species richness and the evenness on diversity. Our methodology of calculating average profiles, therefore, allows for separation of the effects of three factors that influence diversity: richness, evenness and sample size.

4.4 Comparison of overall diversity in the different locations

Results for $\ln(E_\infty)$ did not yield a consistent pattern. In some cases, the dominant species was less evenly distributed, while in other cases the reverse pattern could be observed.

The intersections of diversity profiles indicate situations of partial ordering in our data set and difficulties to order most groups in diversity. Similarly, the intersecting evenness profiles is an indication that many groups cannot be ranked in evenness. However, the slow decrease in the joined curve of sites such as in Erat and Ekon1 locations as α increases are associated with greater evenness in the community. Elsewhere, diversity profiles decrease rapidly between $\alpha=0$ and $\alpha=2$, indicating the presence of rare species or low equitability/evenness. Samples from the Erat had the highest diversity and evenness respectively, both because of the unlimited total number of species present (both at low value at $\alpha=0$ and at $\alpha=3$). On the contrary, the secondary forest location had all time least species richness and evenness.

Analysis of differences in diversity among areas allows the prioritization of activities. However, an understanding of the underlying factors for differences among diversity may be crucial to select priority areas. For instance, we observed a relationship between proximity to forests on the evenness of the dominant species. However, as proximity to forest is obviously correlated with other factors such as altitude, rainfall, and population density, we could not separate the influence of proximity to forests from these co-varying factors.

4.5 Spatial variation with respect to environmental variables

Three species were shown here to have clear distribution patterns within the patch, and similar distribution patterns were found for other species. Patterns in species distribution were similar to those for environmental variables, and CCA suggested

relationships between species occurrence and some of these environmental variables. In general the known habitat preferences of these species support the interpretation that for some species, at this scale, distributions are strongly influenced by environmental variables. Resource limitations prevented a larger area from being sampled, and the range of species and environmental variables that could be included was restricted. It is not known if results would be influenced strongly by inclusion of a greater number of species, and it is not known if findings for the central region are typical of other patches in regions.

Soil nutrients such as Phosphorus, Potassium, and Calcium etc, present in reasonable quantities, were unfortunately found in this case to be uncorrelated with species richness in our forward process modeling. We are also astonished that pH and organic matter had very little influence on species richness. These suggest that species richness is not correlated with soil fertility and pH of the area. Our conclusion joins those of Van der Moezel and Bell (1989) who found highest species richness to occur on soils with the lowest nutrient content in the Mallee region of western Australia, and Hahs et al. (1999) who reported a strong negative correlation between soil nutrient concentration and species richness in sclerophyll heath vegetation in Victoria. Adam et al. (1989) also found a strong negative relationship between soil phosphorus concentration and species richness in the coastal plant communities of New South Wales.

At a broader scale, Margules et al. (1987) found that the diversity of *Eucalyptus* species in southeastern Australia was related to mean annual rainfall, mean annual temperature and solar radiation. These salient factors, including slope, angle, rocks, stoniness and other landscape characteristics, were unfortunately left out in this

study because of resource limitations. Also, resource limitations prevented a larger area from being sampled, and the range of species and environmental variables that could be included was restricted. It is not known if results would be influenced strongly by inclusion of a greater number of species, and it is not known if findings for this patch are typical of other patches in the Korup national park.

4.6 Implications of results for conservation planning and food security

In our household survey, we noticed that important food /economic and medicinal plants such as *Gnetum africanum*, *Garcinia kola*, *Poga oleosa*, *Irvingia gabunensis*, *Cola chlamydantha* and *Baillonella toxisperma* are either fast declining, scarce or absent. This partly explains the reason for continuous hunting and environmental unfriendly agricultural practices-clearing the grass with fire, encroaching into the forest as farmland is becoming limited due to the growing population. If government cannot meet up with the cost of resettlement, then environmental education and agricultural diversification (eco-agriculture/analog forestry), using the economic crops could be important for conservation purposes and food security.

By identifying foods and medicinal plants of lower relative diversity (the rare species), priority can be given to these use-groups for diversification. The lack of evenness in the distribution of these species showed that diversity could be increased substantially in many use-groups by targeting evenness, rather than targeting richness. Like Kindt et al. (2006) suggested, evenness increment could be achieved by encouraging farmers to establish trees in more even numbers (influencing the demand for tree germplasm) or by more species-even germplasm distribution (influencing the supply of tree germplasm).

5. Conclusion

The data presented here indicate that patterns of diversity in food and medicinal plants can vary significantly across ecological scales. Importantly, we found that cultivation of these plants reduce their numbers, increase pressure on the nature reserve, and may lead to food and environmental insecurity in future, everything being equal, a conclusion that has important implications in light of the rapid conversion of tropical forests for agriculture and fuel wood across much of sub-Saharan Africa [Mittermeier et al., 2003]. In addition to the consequences of cultivation for food and medicinal plants communities in the region, the fact that species composition differ among major habitat types means that conservation planners need to give adequate consideration to landscape scale variability in order to ensure maintenance of regional diversity. We have shown that superficial levels of sampling effort, such as a narrow focus on a particular area, can lead to erroneous conclusions regarding patterns of diversity in the region. Simple ecological data such as those presented here are of importance to conservation in the face of growing threats to biodiversity. The fact that few research projects have the time or resources to deploy sufficient levels of sampling effort remains a major problem for conservation.

Amongst the variables considered in this study, the variables that contributed significantly to explain the differences between vegetation units were elevation, clay and sand content. We were able to document differences in diversity among the different locations. Our results could be interpreted in terms of the global biodiversity conservation value of one location over the other. In this context, we want to stress the importance of studying differences in composition among locations, investigating genetic diversity and reproductive ecology of component species, and sampling species diversity in natural

ecosystems adjacent to the agroecosystems that we sampled, to evaluate their conservation value.

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