LANDSCAPE-LEVEL FOREST STRUCTURAL PATTERN OF UDZUNGWA MOUNTAINS, IRINGA REGION, TANZANIA: INFLUENCE OF TOPOGRAPHY

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ABSTRACT

Information on the relationship between topography and landscape-level forest structural pattern is important in formulation of policies for landscape development. This study was conducted to investigate the influence of topographic indices on the landscape-level forest structural pattern in Udzungwa Mountains, Iringa Region, Tanzania. Stepwise multiple regression was used to determine the significance of each of the topographic indices: elevation, slope, aspect, distances from roads, from footpaths, from settlements and from streams in influencing landscape-level forest structural pattern indices expressed as: forest area density, forest patch size, forest connectivity, forest patch edge-interior distance, forest proximity, forest patch shape complexity and forest edge-density. Only elevation, distance from footpaths and distance from streams were found to be statistically significant in influencing landscape level forest structural patterns. The study recommends further research to investigate the influence of elevation, distance from footpaths and distance from streams (factors deemed significant in influencing landscape structure by this study) on landscape functioning.

Key words: Landscape-level forest structural pattern, stepwise multiple regression, topographic pattern, Udzungwa Mountains, Tanzania.

INTRODUCTION

Within the environmental framework, the national forest policy of Tanzania states prevention and control of degradation of land, water, vegetation and air, which constitute life support systems as one of its objectives (URT, 1998). To achieve this objective, information on the existing situation is essential (Haack and English, 1996). Among other parameters, information on the existing spatial landscape pattern is a prerequisite for planning, utilization and formulation of policies and programmes in making any developmental plans (Adinarayana *et al.*, 1994). The landscape level provides the practical basis for information needed in management of ecosystems (Flamm and Turner, 1994).

The expression 'topographic pattern' is here used in a loose sense to include arrangement of both strictly topographic features such as elevation, slope and aspect and other features of a landscape that are not strictly topographic like footpaths, roads, settlements and streams. Topographic pattern may dictate landscape-level forest structural pattern by influencing location of forest patches in relation to other land cover patches in general and particularly specific forest management regimes.

For instance, forest reserves have been reported to be associated with more elevated parts of landscapes than their public forest counterparts (Luoga, 2000) and private land held for agricultural activities (Schelhas and Greenberg, 1996). Luoga (2000) documented significantly steeper slope for reserved forest than for public forest. Although Luoga (2000) and

Schelhas and Greenberg (1996) did not investigate the structural pattern of forest patches, they indirectly highlighted the relation of topographic pattern to forest structural pattern since ownership and management regime may determine forest structural pattern.

Topographic position of a forest patch is an important determinant of its suitability as a habitat for animal species (Neave *et al.*, 1996) and its functioning as a water catchment unit (Liengsakul *et al.*, 1993). Streamside forest patches and corridors function as filters of substances dissolved in run-off water thus maintaining stream water quality (Dramstad *et al.*, 1996; Heraty, 1993) and connect habitats of species in a landscape (Noss, 1991; Schelhas and Greenberg, 1996). Since landholders tend to leave forests along streams either by law or will (WPT, 2001), stream pattern may partly determine landscape-level forest structural pattern. Forest patches along roads and footpaths provide shade to passers-by (Tiwari, 1984). If near settlements, forest patches provide a nearby source of fruits, vegetables, spices, medicinal products and fuelwood (Christanty *et al.*, 1984) thus reducing the walking distance in search of the products and services.

Despite the significance of topography in influencing landscape structure and functioning, the influence of topographic pattern on forest structural pattern in Udzungwa Mountains, Iringa Region, Tanzania has not been documented. The objective of the present study, therefore, was to investigate and document the influence of topography on landscape-level forest structural pattern in Udzungwa Mountains, Iringa Region, Tanzania.

MATERIALS AND METHODS

Study area

The study was conducted in the western part of Udzungwa Mountains ($36^0 00'$-$36^0 02'$E; $8^0 02'$-$8^0 04'$S). The topography is undulating with hills, valleys, high peaks and steep slopes. The elevation of the area lies between 380 and 1934 m above sea level. The main land use activity is agriculture, involving crop cultivation, woodlot establishment and animal husbandry (HIMA, 1999). Five forest reserves, namely: West Kilombero Scarp, Kilanzi-Kitungulu, Kawemba, Kitemele and Makweta were included in the study area (Figure 1).

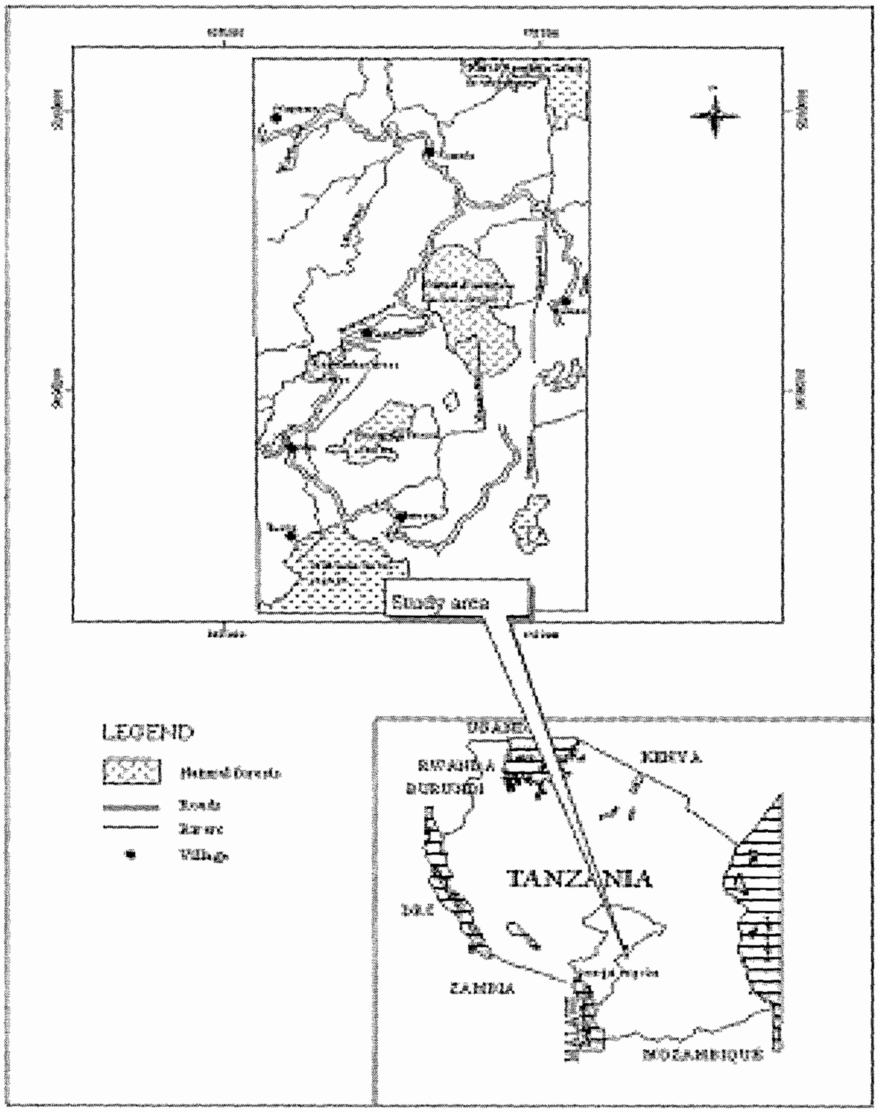

Figure 1. Location of the study area

Data Collection

A Landsat Thematic Mapper (TM) satellite imagery acquired on 23rd of June 1995, a 1:50,000-scale topographic map of 1983 and ground truthing were the main sources of information used in the study. Forest structural pattern indices (namely: forest area density, forest patch size, forest patch shape, forest edge density, forest patch edge-interior distance, forest patch proximity and forest connectivity) were derived from a land cover map (obtained by digital analysis of the satellite imagery) using standard methods (Riitters *et al.*, 2000; Forman and Godron, 1986; O'Neill *et al.*, 1988; Monmonier, 1974; Eastman, 1997; Haines-Young *et al.*, 1996). The significance of these landscape-level structural pattern indices has been documented elsewhere (Riitters *et al.*, 2000; O'Neill *et al.*, 1988; Beaulac and Reckhow, 1980; Soulé *et al.*, 1994; Dramstad *et al.*, 1996; Noss, 1993; McGarigal and Marks, 1995).

Topographic indices maps were derived from the topographic map after digitization of the respective features. The topographic factors used were elevation, slope, aspect, distance from roads, distance from footpaths, distance from streams and distance from settlements. Contours, roads, footpaths, settlements and drainage network of the area were digitised from the 1:50,000-scale topographic map. A digital elevation model (DEM) was constructed. From the DEM, data on elevation, aspect and slope (0-90°) of the study area were extracted and used along with data from distance maps in correlation and regression analysis. To make aspect more interpretable, its values were transformed into the north-easterly orientation (Beers, 1966). The distance maps represented distance pattern of landscape points from roads, settlements, footpaths and streams.

For all the indices, values were extracted using one map created for the purpose of value extraction. The map was created using the on-screen digitizing option and a systematic grid overlaid on land cover map at an interval of 1 km. A total of 152 sampling points were obtained.

Stepwise multiple regression (Laar and Akça, 1997) was conducted to analyze the spatial relationship of the forest structural pattern indices to the topographic indices. Each of the forest structural pattern indices was treated as a dependent variable in turn while aspect, elevation, slope angle and distance (from roads, settlements, footpaths and streams) were used as independent variables. The criterion for entering/removing an independent variable was probability of greater *F* value. A probability of less than 0.05 was used to enter a variable while that of greater than 0.10 was used to remove a variable. The overall significance of the relationship was tested by *F*-statistic while *t*-statistic tested the significance of each individual independent variable in influencing the variation of the dependent variable. A correlation matrix was produced for topographic variables in order to analyze their association and use it in explaining their regression on forest structural pattern indices.

RESULTS AND DISCUSSION

Generally all the models showed a significant regression of the independent variables on the dependent variables as indicated by a negligibly low probability of greater *F* value (Table 1). The model for forest edge density explained the lowest proportion of the variation in the dependent variable in terms of the independent variables while that for forest connectivity had the largest proportion explained (Table 1).

Table 1 Probability of greater *F* value (p*F*), probability of greater *t* value, standard (beta) coefficients (ß) and coefficient of determination (R^2) for stepwise multiple regression of topographic indices on forest structural pattern indices in Udzungwa Mountains, Iringa Region, Tanzania

Structural pattern indices		Topographic indices							p*F*	R^2
		EL	HD	PD	AS	RD	SL	SD		
FA	1#	**0.004**	0.528	**0.000***	0.929	0.236	0.821	0.065	**0.000**	0.406
	2	**0.004**	0.589	**0.000***	0.871	0.155	0.889	0.056	**0.000**	0.439
	ß$	**0.180**	0.045	**0.638**	0.010	0.089	0.009	0.122		
SH	1	**0.000**	0.133	**0.000***	0.602	0.145	0.877	0.227	**0.000**	0.473
	2	**0.000**	0.153	**0.000***	0.838	0.070	0.971	0.198	**0.000**	0.523
	ß	**0.225**	0.108	**0.688**	-0.012	0.104	0.002	0.076		
FC	1	**0.004**	0.393	**0.000***	0.807	0.276	0.829	**0.053**	**0.000**	0.393
	2	**0.004**	0.441	**0.000***	1.000	0.186	0.896	**0.046**	**0.000**	0.652
	3	**0.004**	0.434	**0.000***	0.972	0.404	0.970	**0.046***	**0.000**	0.664
	ß	**0.181**	0.065	**0.590**	0.002	0.054	-0.002	**0.129**		
FS	1	**0.000**	0.357	**0.000***	0.287	0.827	0.952	0.678	**0.000**	0.433
	2	**0.000**	0.423	**0.000***	0.535	0.815	0.880	0.660	**0.000**	0.573

Structural pattern indices		Topographic indices							p*F*	R^2
		EL	HD	PD	AS	RD	SL	SD		
	ß	**0.375**	0.058	**0.658**	-0.034	0.013	-0.008	-0.025		
FE	1	0.226	0.198	**0.030**	0.374	0.787	0.977	**0.001***	**0.001**	0.068
	2	0.219	0.879	**0.030***	0.470	0.962	0.997	**0.010***	**0.000**	0.097
	ß	-0.096	-0.016	**0.178**	0.057	0.004	0.000	**0.211**		
PR	1	0.066	0.812	**0.001***	0.606	**0.027**	0.856	**0.022**	**0.001**	0.066
	2	0.060	0.805	**0.013***	0.573	0.090	0.705	**0.022***	**0.000**	0.098
	ß	0.146	0.026	**0.204**	0.044	0.139	-0.030	**0.187**		
ED	1	**0.000**	0.113	**0.000***	0.345	0.874	0.972	0.287	**0.000**	0.363
	2	**0.000***	0.129	**0.000***	0.540	0.882	0.855	0.247	**0.000**	0.438
	ß	**0.279**	0.124	**0.606**	-0.038	0.009	-0.011	0.074		

[#]Model number (Multiple regression steps). [*]Variable included in the model. [$]Beta coefficients are shown for the final model.

Notes: Bold and bold underlined types connote significance at P < 0.05 and P < 0.001 respectively. EL = Elevation, HD = Distance from settlements, PD = Distance from footpaths, AS = Aspect, RD = Distance from roads, SL = Slope, SD = Distance from streams, FA = Forest area density, FS = Forest patch size, SH = Forest patch shape complexity, FE = Forest edge density, FC = Forest connectivity, PR = Forest patch proximity and ED = forest patch edge-interior distance.

Beta weights (Table 1) showed that all the regressions were positive i.e. increase in the independent variable resulted in increase in the dependent variable, and that for forest area density, forest patch shape, forest connectivity, forest patch size, forest proximity and forest patch edge-interior distance, distance from footpaths had more influence than the other significant variables. For forest edge density, distance from streams had more weight than distance from footpaths. Elevation was more important than distance from streams for explaining the variation of forest connectivity.

For the final models of the stepwise multiple regression output, forest area density, forest patch shape complexity, forest connectivity, forest patch size and forest patch edge-interior distance significantly (P < 0.001) increased with distance from footpaths (PD) whereas the regression of the same dependent variables with distance from settlements (HD), distance from roads (RD), distance from streams (SD), slope (SL) and aspect (AS) was nonsignificant (P > 0.05).

Distance from footpaths was also significant (P < 0.05) for forest edge density and forest patch proximity. Footpaths have been used as a measure of intensity of human access into a landscape (Millward, 1993) a fact that supports the results of this study where distance from footpaths has been a strong influence on all the forest structural pattern variables. The strong positive correlation (Table 2) between distance from footpaths and distance from settlements further supports the connotation that footpaths represent human access.

Elevation (EL) had a strong regression on forest patch shape complexity, forest patch size and forest edge-interior distance (P < 0.001) and on forest area density and forest connectivity (P < 0.05). In the study area, valleys were used for agriculture. This can partly explain the increase of forest area density, which measured the proportion of forest, and forest size with increasing distance from streams, which were found, as usual, on valleys.

Forest connectivity, forest edge density and forest patch proximity significantly (P < 0.05) increased with increase in distance from streams. Patterns of regression of topographic indices on forest structural pattern indices may be explained by the correlation analysis of the topographic indices (Table 2), which showed that distance from streams increased significantly (P < 0.05) with increasing distance from settlements, footpaths and roads, a fact that may explain the increasing forest connectivity, forest edge density and forest patch proximity with increasing distance from streams. Less forest connectivity near streams could have adverse effects on stream quality, which need a buffer zone for protection (Dramstad *et al.,* 1996; Tufford *et al.,* 1998).

Table 2 Correlation coefficients between topographic indices in Udzungwa Mountains, Iringa Region, Tanzania

	EL	HD	PD	RD	SL	SD
EL						
HD	0.027					
PD	-0.001	**0.665**				
RD	-0.069	**0.269**	**0.180**			
SL	0.029	0.023	0.124	0.102		
SD	-0.005	**0.187**	**0.284**	**0.299**	0.005	
AS	-0.087	0.069	0.081	-0.045	-0.012	0.007

Notes: Bold type connotes significance at P < 0.05. EL, HD, PD, RD, SL and SD are as defined in Table 1.

The regression of distance from roads on forest proximity was significant (P < 0.05) for the first model but turned out to be nonsignificant (P > 0.05) for the final model. The significance of the regression in the first model could be due to the fact that part of the road network passes close to natural forests in the study area and partly due to the significant positive correlation between distance from roads and distance from footpaths, which was a significant independent variable for all the dependent variables. The lack of significance in the second model was probably due to weak influence of distance from roads as a determinant variable for forest proximity.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Elevation, distance from footpaths and distance from streams have been the significant topographic variables influencing forest structural pattern in the study area. The pattern was such that the proportion of forest area was bigger the higher the elevation, the larger the distance from footpaths and streams. The same pattern was observed for size of individual forest patches, edge-interior distance and connectivity. Forest patches tended to be closer together the higher the elevation, the larger the distance from footpaths and streams. One of the implications of the current forest structural pattern has been differential animal species extirpation from natural forest reserves as reported by Moyer (1996).

Recommendations

It is not appropriate to give any recommendations for implementation to improve the relationship between landscape-level forest structure and topography basing on the findings of this study alone. It would be appropriate to give the recommendations basing on both the landscape-level structure and functioning of the forests as influenced by topography. This study has narrowed down the topographic factors that would be considered in designing a study to investigate the influence of topography on landscape functioning to only those deemed statistically significant.

Hence, because distance from footpaths, distance from streams and elevation have had a strong association with forest structural pattern of the landscape, further studies should be conducted to investigate the impact of the association on landscape functioning especially erosion, water quality, animal occurrence and movement as the present study was limited only to the structural aspect of the landscape.

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