Model of forests spatial distribution in the western part of the Karpaty Mts.

Katarzyna Ostapowicz
GIS Laboratory, Institute of Geography and Spatial Management, Jagiellonian University
Cracow, Poland
kostapowicz@gis.geo.uj.edu.pl

SUMMARY

The aim of the paper is to present the statistical methods and the spatial analysis, which are used to quantitative and qualitative description of different land cover type changes and also to analyze the associated influence of natural and anthropogenic factors. The chosen type of land cover is forest in the western part of Karpaty Mts.. Among the statistical methods relation analysis by the use of the multiregresion, multilogistic and ANOVA test will be undertaken. Among the spatial analysis the trend analysis and the neighborhood analysis will be used. The connection of quantitative and qualitative analysis allows to create the complex model of forest area changes with the use of statistical and mathematical methods.

KEYWORDS: *usability and quality: issues and applications, statistical methods, spatial analysis, modeling*

INTRODUCTION

The changes of land use and cover together with the influence of natural and anthropogenic factors have been researched wide range (Zheng et al. 1997, Verburg et al. 1999, Tekle, Hedlund 2000, Briassoulis et al. 2001, Burgi 2002, Kozak & Troll 2002, Stehman et al. 2003, Turner et al. 2003). The present analysis is based on the information, which was derived mostly from the satellite images or the air photos. Previous papers present models which describe this issue in connection with natural factors or with socio-economical factors by the use of different statistical or mathematical methods (Berry et al. 1996, De Koning 1999, Irwin, Geoghegan 2000, Cumming, Vernier 2002). It has been few papers analyzing quantitative and qualitative changes being influenced by both groups of factors: natural and socio-economical. The aim of this paper is to present a method leading to creation of a complex model discussing quantitative and qualitative changes in land use and cover. The changes are indicated by the use of statistical and spatial analysis with avail of GIS tools on the example of forest cover and pattern in the western part of the Polish Karpaty Mts. Valorization of particular spatial structure provides the instruction for optimum terrain management. The analyzed changes are associated with the qualitative changes like forest and non-forest area conversion and modification of forest features like fragmentation. The natural elements, which were chosen cover: altitude, slope and aspect while anthropogenic elements cover: size of population and density of road network. For the study area the analysis of forest changes was correlated only with natural factors and for data captured five years earlier than data for the remaining part of the Karpaty Mts. (Troll 1999, Troll 2001). As a result of the research the relationship between distribution of forest and altitude a.s.l. was described using multiregression and logistic function. Altitude a.s.l. and slope explained the contemporary forest distribution only partially but the increase of values of this variable reflected the increase of proportion of forest.

STUDY AREA

The research is carried out on the area of about 3229 km^2 in the western part of the Polish Karpaty Mts (Figure 1). The environment is characterized by parallel pattern of the main geological-tectonics-morphological structures and meridian running of axis of the main river abasement points out a spatial, horizontal regularity, on which vertical structure is overlapped expressed by climatic, vegetation and soil layers. In primeval vegetation cover forest was of main importance. The forests of western part of the Karpaty Mts. are the richest in Poland. The present state of species structure and health condition is a result of anthropisation present for more than 500 years. It started in the thirteenth century with colonization, then in nineteenth century culmination of deforestation has taken place and many forest management mistakes were done, which were connected with clear cutting management, “sprucerage” and artificial foresting of glades and alps. Next in twentieth century the repeated succession and experiments with a monoculture of spruce forest rebuilding have taken place. At present the slow succession of forest is observed, which is connected with policy transformation and following socio-economical changes.

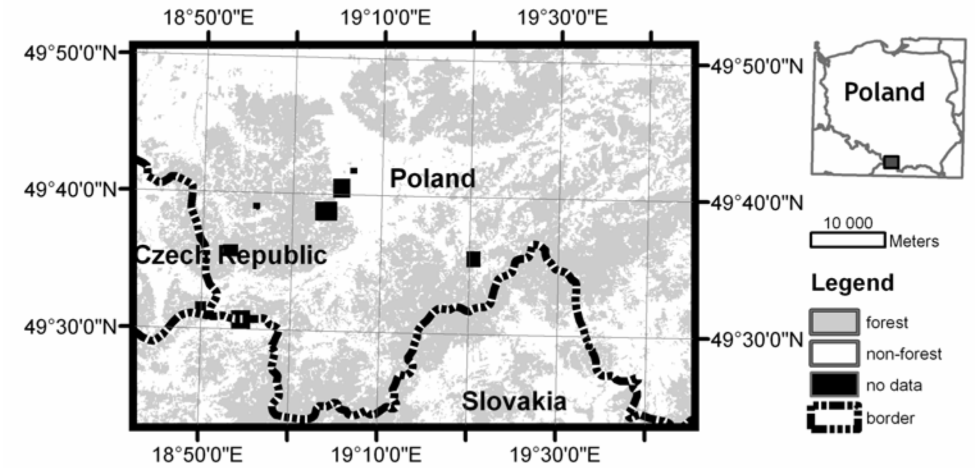

Figure 1: Study area – the western part of the Polish Karpaty Mts.

MATERIALS

The Landsat ETM 188/25 scene taken in May 2001 (GIS Laboratory) and the Landsat ETM 188/26 scene taken in May 2001 from the NASA Global Orthorectified Data Set were used as a source of information about forest distribution. The Landsat image was a part of the standard scene (path 188 row 25). Ortophotomaps and forest maps were used for the validation. The information about the natural factors (altitude a.s.l., slope, aspect) was taken from the Shuttle Radar Topography Mission digital elevation model (SRTM DEM). The data was provided by the U.S. Geological Survey, EROS Data Center. The information about anthropogenic factors (point map of population and line map of road network) was the digital vector data (Kropiowski 2003) which was taken from topographic maps in scale 1: 50000 and statistical data from the Polish Main Statistical Office (GUS).

METHODS

From the Landsat image the satellite map of forest was obtained. Two classes of land cover were delimited: forests and non-forested area. Forest class included all forest areas: coniferous, deciduous and mixed forest. Non-forest class covered arable land, meadows, pastures, urban and water area. areas cover by clouds were excluded from the analysis. The approach used in the study combines the use of image segmentation and standard supervised classification algorithms (Kozak et all 2005). The data sets have spatial resolution of 28.5 m. The segmentation was carried out using the eCognition software (Baatz et all. 2001). All bands except for the thermal one were used in the segmentation process. Scale factor influencing the size of spatial objects was set to 10. Classification was performed using nearest neighbor classification (Baatz et all. 2001).

The forest changes were measured by characterizing changes of the three forest variables: the type of land cover (qualitative, binary data), percentage of the forest area and fragmentation (quantitative continuous data) witch were calculated in moving window. The moving window was size 11 on 11.

Fragmentation was calculated by the use of the forest fragmentation index (Butler et all 2004). The components of forest fragmentation index (FFI) were as follows:

- percentage non-forest cover (pnf),
- percentage edge (pe),
- interspersion (in).

Percentage of non-forest, percentage of edge, and average interspersion metrics were summarized for each of the moving window. In the final model, the metrics were given equal importance as shown in Eg.1.

$$FFI = \frac{(pnf + pe + in)}{3} \quad (1)$$

From SRTM three maps were obtained: altitude a.s.l., slope gradient (quantitative, continuous data) and aspect (qualitative data). The digital materials about the anthropogenic factors were resampled to the UTM (34 N) coordinate system and converted from vector data to raster data. From road maps the distance was calculated and the map of distance from the road was created (quantitative, continuous data). The map of spatial changes of the population (quantitative, continuous data) was derived from the point map of the population amount using the kriging.

The proportion of forests in the 200-m classes of elevation, 5-degrees classes of slope, aspect classes, 500-m classes of distance from road and 1000 classes of population were assessed. The elevation, slope and aspect range was sufficient to depict vertical changes in the distribution of forest. The horizontal changes were reflected by the road distance and population density range.

The autocorrelation of analysis data was also researched. For land cover type, altitude a.s.l., slope, aspect, distance from road and population data the I Moran index was calculated. This analysis was involved to choose the number of sampling points - 382. So small group of the sampling points was connected with high autocorrelation of data around 0.9 for altitude a.s.l.. For each of the sampling points, using map algebra, information about type of land cover (forest or non- forest), percentage and fragmentation of forest area, altitude a.s.l., slope, aspect, distance from road and population was added.

The relation between the factors was analyzed using three types of methods. The choose of the method depended on the type of data. For the relation between the type of land cover and four qualitative, continuous natural and anthropogenic factors were used the multilogistic regression. The relation between continuous, quantitative natural and anthropogenic variables was calculated using multiregression analysis. The relation between the type of land cover and aspect was measured using the ANOVA test.

The general regularity of spatial changes in the type of land cover, percentage and fragmentation was obtained from trend analysis (first and second level) for values in the sampling points.

RESULTS

The forest area in 2001 covered 37 % of the study area. Forest distribution varied in reference to vertical and horizontal variables. As far as the vertical distribution is conserved, the proportion of forest area increased with elevation from 10 % for the lowest class (200-400 m a.s.l.) to 95 % in the highest class (1400-1600 m a.s.l.) but above 1600 m a.s.l. the proportion of forest decreased suddenly. Similarly the proportion of forest area is the largest in the class with the highest gradient of slope (above 21^{o}). This value of forest area in the slope classes increased from 15 % to 97 %. Forest distribution was almost similar for each of the aspect classes. Generally, the value was about 45 - 55 % for each of the classes of aspect, the largest value was observed for the western slope. The vertical changes of the forest area were reflected in the increase of the forest distribution with the decrease of population from 2% for the class with the highest number of people (above 20000) to 45% for the class with the lowest number of people (below 1000). The proportion of forest area in the population classes can be distinguished into two belts, a lower one (above 1200 people) with percentage of forest around 2-4 % and a higher one (below 1200 people) with forest area covering 40-45 % of each class. The proportion of forest area increased with the increase of the distance from road from 23 % for the class with the lowest distance from road (below 500 m) to 70 % for the highest distance from road (above 3500 m) (Figure 2).

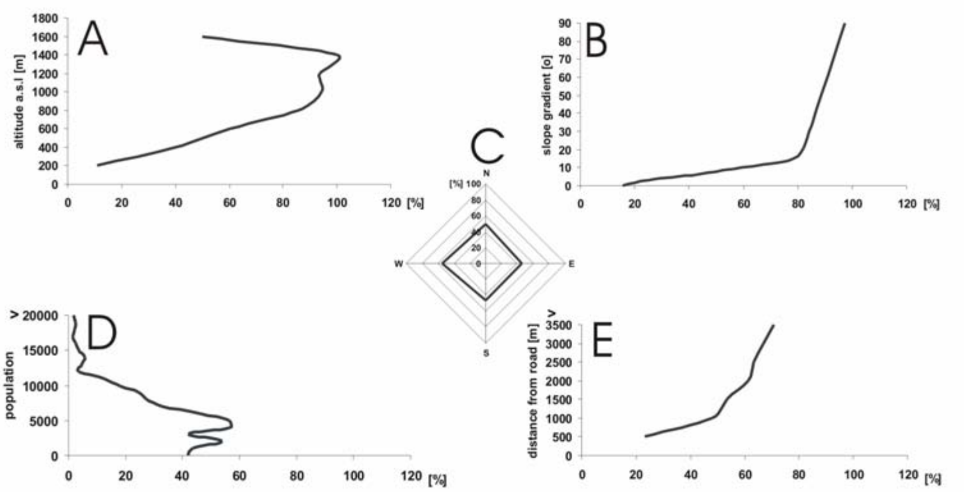

Figure 2: Percentage of forest in the classes of: A - elevation, B - slope, C – aspect, D – population, E – distance from road.

The relation between the type of land cover (forest – non-forest) and elevation, slope gradient, distance from the road and the size of population correlated relatively well – 0.3.

The proportion of the forest area was correlated strongly with these continuous variables (elevation, slope, distance from road and population) – 0.7. The strongest correlation was observed for the relation to elevation and slope – 0.6, for the distance from road the correlation was much more lower – 0.18, for population was the lowest convert correlation was observed -0.12 (Table 1). The relations of the fragmentation to continuous variables were similar but opposite to the relation of the proportion of forest area (Table 1). The relation of forest fragmentation to percentage of forest area was very strongly correlated – 0.9. All results were statistically correct for the level $\alpha = 0.05$.

Variable	**Correlation analysis**		**Multiregression analysis**		
	r	**N (p)**	**R**	**R^2**	**F (df)**
PROPORTION OF FOREST AREA					
Altitude	0.61	382 (<0.05)	0.73	0.53	F(4,378) = 107.31
Slope gradient	0.64	382 (<0.05)			
Distance from road	0.18	382 (<0.05)			
population	-0.12	382 (<0.05)			
FRAGMENTATION					
Altitude	-0.61	382 (<0.05)	0.71	0.51	F(4, 378) = 97.12
Slope gradient	-0.64	382 (<0.05)			
Distance from road	-0.18	382 (<0.05)			
population	0.12	382 (<0.05)			

Table.1: Relation between proportion of forest area, fragmentation, altitude, slope, population and distance from road, multiregression analysis.

The relation between aspect and two dependence variables, percentage of forest area and fragmentation was very low – 0.16 (Table 2).

	R	R^2	F	p
PRECENTAGE	0.16	0.024	2.34	0.05
FRAGMENTATION	0.16	0.024	2.38	0.05

Table 2: Relation between proportion of forest area, fragmentation and aspect, ANOVA test.

Spatial distribution of the percentage of the forest area and the fragmentation showed longitudinal variability, with the first order trend surface explaining more than 50 % of variation (Table 3). The changes of variable from southern-west to northern-east were observed.

	PRECENTAGE		FRAGMENTATION	
	R^2 (%)	F (df)	R^2 (%)	F (df)
linear	60.37	288.66 (2/379)	50.75	148.41 (2/379)
quadratic	63.64	131.07 (5/376)	54.38	67.95 (5/376)
cubic	64.80	76.40 (9/372)	55.62	39.13 (9/372)

Table 3: Share of forests in the research area, trend statistics.

DISCUSSION AND CONCLUSIONS

The statistical model of the forests spatial distribution in the western part of the Polish Karpaty Mts shows the strong relation of horizontal and vertical change of the forest area and the change of the natural and the anthropogenic variables. Natural factors as elevation and slope gradient had the greatest influence on the forest spatial expansion. The increase of altitude and slope gradient was the cause of the increase in the proportion of forest. The anthropogenic factors as distance from the road and population were not so significant. The forest area increased together with the increase of distance from road and the decrease of population. The low value of relation index between population and forest was the result of population distribution. The population, as it was presented, changed regularly but it was not the linear regularity. The slightest influence on the distribution of forest area was exerted by the aspect of slope. Generally, a very strong correlation between dependent variables was observed. The increase of forest area goes together with the decrease of forest fragmentation.

Situation, which has been observed on the study area, is similar to the situation of change in the land pattern, especially in the forest areas in other mountains, especially in the European and Northern American mountains (Kozak & Troll 2002, Kozak 2004, Turner et all 2003). For the part of analysis, which included the natural variables, similar relation was obtained as for analysis, which was made for the earlier point of time (Troll 1999, 2000), but the current model is more complex because anthropogenic variables were added and not only the distribution of percentage of forest but also the fragmentation of forest were analyzed.

The spatial distribution of forests in the study area reflects particularly the spatial changes of terrain which are determined by variation of natural network of the abiotic environment. This distribution is connected also with accessibility of terrain for human activity, mostly for agriculture and urbanization and with historical management changes (Troll 2000). With increase of elevation and slope the condition of terrain for agriculture is worse but for expand of forest area quite good. So, the distribution of forest is related to accessibility of area for antropization.

This analysis allows for statement that the statistical model could be created with good results for the explanation of changes of land mosaic using statistics not only for quantitative variables but also for qualitative variables (continues and discrete).

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