ANALYZING STRUCTURE OF FORESTS NEAR WARSAW ON THE BASIS OF SATELLITE IMAGERY AND AERIAL PHOTOGRAPHS

Magdalena Wrzesien[1], Karol Zaremski[2]

Remote Sensing of Environment Laboratory
Faculty of Geography and Regional Studies, University of Warsaw
ul. Krakowskie Przedmiescie 30, 00-927 Poland
T: +48 22 5521507, e-mail: [1]septy@wp.pl, [2]karolz@uw.edu.pl

Abstract
Forests are rich ecosystems, which fulfill significant functions as scientific, educational and finally recreational. Forest landscapes play a key role, particularly near urban areas like Warsaw, where they are affected by the town and its inhabitants. Collecting data about forests and analyzing it are desirable tasks for the purposes of environmental monitoring, protection, planning and management in different scales (spatial/time). Remotely sensed data proved to be very useful sources of information about forest characteristics as a specific ecosystem and as a part of the boarder landscape.
The aim of this study is to present methods and techniques used for analyzing and effectively using satellite images and aerial photographs for certain purposes in forestry and environment protection.
Analyses were made on the example of Landsat ETM+ satellite images acquired in 2000 and set of aerial photographs obtained in 1997 (PHARE, true color, 1:26000, 1:5000) and 1992 (color infrared, 1:10000). The areas under study are three forest complexes located near Warsaw: Kampinoski National Park, Chojnowski Landscape Park and Las Kabacki Reserve, which differ in size, diversity, and level of protection.
Automated solutions in forest studies deliver objective and high quality thematic data, which are competitive to the conventional survey mapping methods.

Introduction

Forest is a complex ecosystem, which performs a scientific, educational and recreational role and is a basic part of the natural environment and landscape structure. Remote sensing is one of accessible tools, which may in significant way extend knowledge about forests and complete existing methods. Mapping of structural attributes, especially species composition and age classes, is an important task in forest research and management. Airborne and satellite data proved to provide much information for forestry applications. Using remotely sensed images supports, complements and replaces time taking terrain data acquisition.
Forest species and age recognition can be reliably achieved through satellite images and aerial photo processing. In the 1970s data from broad band sensors were used to distinguish between coniferous, deciduous and mixed stands (1). When ground and spectral resolution were improved also mapping tree species and age classes became possible (2). Additionally applications of satellite images to: describing forest condition (3), monitoring and inventory of degraded forest (4, 5, 6), and fire protection (7, 8) were under investigations.

Study area and data

Three complexes were chosen to analyze forest structure: part of Kampinoski National Park (KPN) – Sierakow Reserve), part of Chojnowski Landscape Park (ChPK) – Uroczysko Chojnów and Las Kabacki Reserve. The areas of study are located in the central part of Poland near Warsaw. They differ in size, diversity, way of protection and accessibility for people.
Sierakow Reserve is the biggest reserve in KPN. Its area comprises 1205 ha. It is located in north-east part of KPN. The dominant forest species are alder and birch on marshy terrain, pine with oak's addition

on dunes. Areas neighboring with marshes are covered with mixed forest composed of oak, hornbeam and pine. Deciduous stands (oak and hornbeam with pine) appear in a few places.
Stands in Sierakow Reserve are average 89 years old (the oldest are pines – 110 years old, oaks – 100 and the youngest birches – 58 years old).
ChPK is located to the south of Warsaw. ChPK is a mosaic of agriculture and forest areas. Uroczysko Chojnow is the main forest complex, which occupies 2166 ha in the central part of the ChPK. Pine, oak, birch and alder of different ages are dominant tree species in this area.
Las Kabcki Reserve is located in southern part of Warsaw. It covers 918 ha. Las Kabcki is a diverse forest composed of pine, oak, birch and aspen. Large stands achieved age of 120-160 years old.
Satellite image was acquired on 5th May 2000 by Landsat ETM+ (Enhanced Thematic Mapper). Three fragments of satellite scene, presenting areas of investigation, were used. Six optical bands with 30 m ground resolution were used.
There were also used aerial photographs: true color (one - 1:26000 and four - 1:5000) obtained in 1997 in PHARE programme (PL 9206) and five color infrared (1:10000) acquired in 1992. Photographs were georeferenced and mosaics were created.
In preliminary processing topographical maps in "1942" coordinate system as well as forest maps were used.

Methods

The main method of analysis used in this study is supervised classification, which is based on parametric decision rules. The classification was carried out for each region separately. The procedure used for the classification of forest cover was as follows:
1. Masking the area surrounded forests of interest was generated on the basis of maps
2. Choosing channels (TM2, TM3, TM4, TM5) appropriate for the tree species and age classes delineation was done on the basis of results of unsupervised classification (Isodata Algorithm). Two combinations of channels and one single channel were used: TM4 TM3 TM2, TM4 TM5 TM3 and single TM4.
3. Defining classes for supervised classification was performed on the basis of results of unsupervised classification and interpretation of the reflectance of each tree species and age class (Figure 1, 2, 3). After analysing data, classes for final classification of satellite images were chosen: five classes (in all areas of investigation): oak, pine, alder, birch and non-forested area and sixth – beech. Age classes possible to distinguish were: in Las Kabacki Reserve and Uroczysko Chojnów II-V (20-100 years old) for all species and VI (over 100 years old) for oak, in Sierakow Reserve both options for all species. For each class (species/age) was collected a set of training pixels that give description of spectral response of the defined class. The same steps were taken to classify aerial photographs, but it turned out that that kind of data are too detailed (one tree crown is mapped with over one hundred heterogenic pixels).

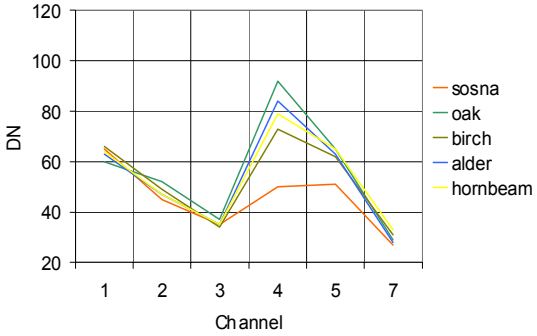

Figure 1. Spectra of tree species in Sierakow Reserve

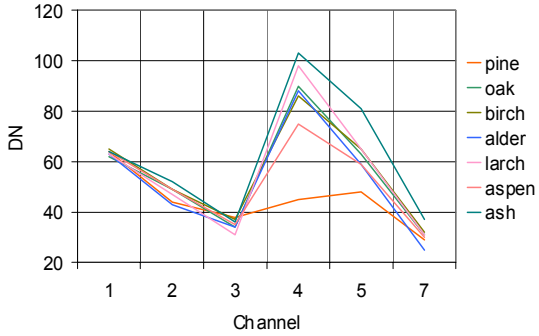

Figure 2. Spectra of tree species in Uroczysko Chojnow

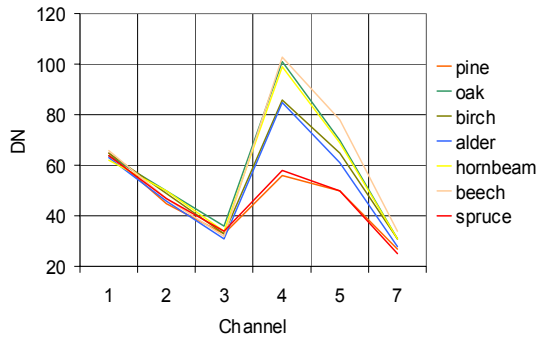

Figure 3. Spectra of tree species in Las Kabacki Reserve

4. Performing supervised classification process (Maximum Likelihood Algorithm), satellite image was processed first to get general information about the object.
5. The results of classification are thematic maps that show spatial distribution of tree species and age classes
6. To assess the classification accuracy the validation pixels and additionally maps were used. The confusion matrix was generated from the test pixels for each map. The accuracy was assessed using two measures: overall classification accuracy and kappa coefficient (9) (Figure 4, 5).

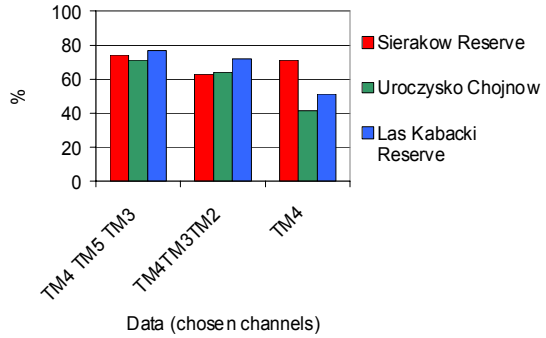

Figure 4. Overall tree species classification accuracy

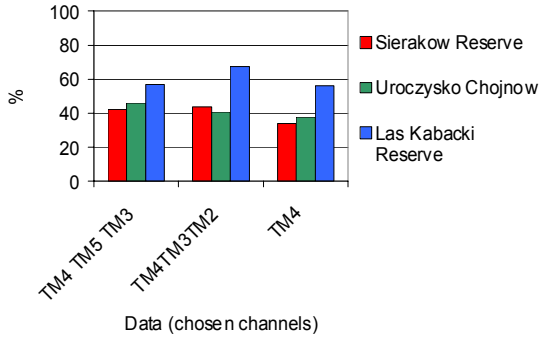

Figure 5. Overall age classes classification accuracy

7. Best classified maps, which show species structure on the basis of TM4 TM5 TM3, were chosen for further analysis with ecological indicators, accessible in Fragstats, which is the programme developed at the Oregon State University (http://ftp.fsl.orst.edu):

- area metrics [class area *(CA)* is the measure of landscape composition; specifically, how much of the landscape is comprised of a particular patch type; total landscape area *(TA)* defines the extent of the landscape; largest patch index *(LPI)* at the class and landscape levels that quantifies the percentage of total landscape area comprised by the largest patch]
- patch density, size, and variability [number of patches *(NP)*; patch density *(PD)* expresses number of patches divided by unit area, which facilitates comparisons among landscapes of various sizes]
- shape [landscape shape index *(LSI)* measures the perimeter-to-area ratio for the landscape as a whole; fractal dimension *(FRACT)* as a measure of patch shape complexity]
- diversity [Shannon's diversity index *(SHDI)*, which is based on information theory (10), the value of this index represents the amount of "information"; patch richness *(PR)* measures the number of patch types present in the landscape]
- neighbourhood [mean nearest neighbor distance *(MNN)* for patches comprising the class or for all patches in the landscape; interspersion and juxtaposition index *(IJI)* measures the extent to which patch types are interspersed] (11) (Table 1a, 1b, 1c).

Table 1. Landscape structure: a) in Sierakow Reserve, b) in Uroczysko Chojnow, c) in Las Kabacki Reserve

a)

TA [ha]	NP <1; +∞)	PD [nr/ha]	LPI [%]	LSI <1; +∞)	PAFRAC (1; 2)	IJI (0; 100>	PR <1; +∞)	SHDI <0; +∞)
2731,68	557	20,39	12,11	12,19	1,55	97,28	4	1,21

b)

TA [ha]	NP <1; +∞)	PD [nr/ha]	LPI [%]	LSI <1; +∞)	PAFRAC (1; 2)	IJI (0; 100>	PR <1; +∞)	SHDI <0; +∞)
6415,20	2907	45,31	5,94	17,47	1,55	82,77	7	1,64

c)

TA [ha]	NP <1; +∞)	PD [nr/ha]	LPI [%]	LSI <1; +∞)	PAFRAC (1; 2)	IJI (0; 100>	PR <1; +∞)	SHDI <0; +∞)
1996,65	743	37,21	10,06	11,45	1,55	74,72	5	1,18

Results

The results of performing classification are thematic maps that illustrate spatial distribution of tree species and age classes. The overall accuracy obtained for species structure was 41.23% (TM4) – 76.80% (TM4 TM5 TM3) (Figure 7). More particular study, taking age into consideration, gives worse results. The overall classification accuracy was in this case 34% (TM4) – 67.19% (TM4 TM3 TM2) (Figure 8). The best classified area was Las Kabacki Reserve, which is the smallest forest complex and dominant tree species is pine. When percentage of deciduous trees increases, accuracy is getting lower. Deciduous species have similar spectral response, which makes them difficult to distinguish and causes mistakes.

Classification of aerial photographs resulted in thematic maps, which have structure similar to original image because of pixel size. Aerial photographs can't be classified using supervised training only.
Structure of forest as a landscape can be easily described by the set of indices. The most diverse area (on the basis of indices) occurred to be Uroczysko Chojnów (SHDI – 1.63), which is composed of many small (LPI – 5.94) patches (NP - 2907), because of active forestry practices. The most natural complex – Sierakow Reserve has regular shape and consists of small number of relatively big (LPI – 12.11) patches (NP - 557).

Conclusions

Remotely sensed data (Landsat ETM+) digitally processed are valuable source of information for forest research in regional scale and forest stand scale. That kind of data show general characteristics of the certain forest area. It is possible to get the distribution of tree species and age classes. To achieve better results supervised classification should be supported by additional methods or materials that have better spatial and spectral resolution should be used. Results of the analysis also depend on the forest area itself (whether there are more coniferous or deciduous species). Tree species classified with 70% overall classification accuracy is a good issue, so satellite images can be applied in forestry, first of all when the dominant species is pine. If a share of deciduous trees in a forest stand is high, overall classification accuracy is not satisfactory and it is necessary to apply visual interpretation or other techniques. Discrimination of age classes is more difficult and results are worse. Receiving more detailed information of high quality from that kind of data is not possible. Overall classification accuracy was about 40%, which is not good enough. When more particular information is being acquired, additional errors occur, especially when forest area is spatially diverse.
In aerial photographs forests are presented too particularly, so it is impossible to classify that kind of data. Each tree crown is represented by 100-120 pixels that differ in significant way. Important task is the

quality of used materials, which determines amount of information in the photograph and possibilities of interpretation.
Ecological indices easily describe every forest stand and give quantitative information about its structure on the landscape, class and patch level. Indices show how spatial distribution and quality of analysed objects influences forest stand structure.
Landscape ecology offers set of metrics that complete classification results. Information derived from indices depends on input data (important is spatial resolution), so pixel size should be selected carefully. Aim of analyse should determine the spatial resolution of remotely sensed data.

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