CROSS-BORDER MONITORING OF LANDSCAPE DYNAMICS IN EASTERN EUROPE

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ABSTRACT

Land use and land cover change (LULCC) depend on environmental, socio-economic and political boundary conditions. The breakdown of the USSR in 1990 can be seen as a unique natural experiment where hypotheses on the relative importance of these pressures may be tested. In this context, border regions are of particular interest: Whereas physical and environmental properties are near-equivalent, the socio-economic and political initial situation as well as the intensity and pace of change differ among countries. Monitoring and analyzing LULCC for different countries may therefore facilitate the linkage between trends and their respective driving pressures.

This study concentrates on the trilateral biosphere reserve *The Eastern Carpathians Biosphere Reserve* and its vicinity, located in the border triangle of Poland, Slovakia and Ukraine. Hosting Europe's last primeval mountain beech forest, the area is a hotspot of biodiversity and encloses a wide range of ecosystems.

We use Landsat data between 1985 and 2000 to study changes in land cover and land use. Two significant points in time, the mid-eighties and the year 2000, were chosen to monitor and quantify landscape dynamics in space and time. To adequately consider phenological differences of land cover classes, multiple scenes for each time period were implemented. To facilitate post-classification change detection, land cover maps were derived using a combination of pixel-based and object-oriented methods. In a first stage, a hybrid pixel-based classification was used to derive broad land cover maps. Using a multi-hierarchical image objects approach these classifications were then enhanced in a second stage. The authors believe that the method proposed in this study is a major step towards a consistent, cross-border data basis, an imperative prerequisite for comparative studies. The classification products will allow for a better understanding of ecological and socio-economic forcing of LULCC and support tests of trend hypotheses of landscape dynamics in Eastern Europe. Thus, the method is of major significance for the clarification of phenomena such as the often mentioned re-wilding processes and, against the background of the enlargement of the European Union, privatization and intensification scenarios.

Keywords: trans-border monitoring, post-socialist land use and land cover change, rewilding, Carpathians, Bieszczady, Landsat, TM, ETM+.

1 INTRODUCTION

Following the demise of the Iron Curtain, the countries of the former Soviet Union and the Warsaw Treaty have undergone a rapid and radical change of their socio-economic structures. This affects a number of factors that in turn directly influence and shape the environment in Eastern Europe such as agriculture and forestry, but also industry and tourism. The transformation that is taking place in Eastern Europe since the Soviet era represents a unique natural experiment that allows for a better understanding of how socio-economic and political forcing affect landscape dynamics and may result in environmental change. Cross-border comparison offers great potential to directly quantify the impact of political and socio-economic pressures. To link landscape changes to their respective pressure requires homogenous environmental initial conditions across borders. The Carpathian Mountains, ranging into seven countries, are such an ecologically homogeneous region. Being one of Europe's most important ecoregions and a hotspot of biodiversity, the area hosts extensive forest ecosystems and is rated pristine when compared to the rest of Europe. However, the region is politically heavily dissected by countries with different political systems and very different land use practices. Starting from disparate socio-economic and political initial situations in 1990, each country also developed in its own way after the breakdown of the Soviet Empire, resulting in different speed and intensity of transformation processes. Thus, the Carpathian Mountains offer the exceptional possibility of investigating the natural experiment of socio-economically and politically induced landscape dynamics in Eastern Europe.

Two significant points in time were identified to monitor landscape dynamics in the Carpathians. As a first time period the mid-eighties were selected, representing the initial situation before the demise of the Soviet Union. As a second point in time the year 2000 was chosen to monitor the landscape response to ten years of post-socialist transformation processes.

As a study site, the trilateral nature conservation park *The East Carpathians Biosphere Reserve* and its vicinity were selected. The area is characterised by a continental climate with an annual temperature range of -40 to +35 C and an average precipitation of 1200–1300 mm. The bedrock dominantly consists of sandstone and shale and elevations from 200 to 1200 meters can be found. Situated in the border triangle Poland-Slovakia-Ukraine the region enables cross-border comparison of landscape dynamics at various perspectives. The concept of biosphere reserves with an attenuating gradient of human pressure is in this regard of major importance [1]. The three countries have different political and socio-economic systems, differences which were already present during the Soviet era. The area hosts a vast range of ecological units, covering near-natural as well as anthropogenically utilized ecosystems at different stages of intensity and ranging from lowland to mountainous ecosystems [2]. In addition, the region allows for the comparison of agriculture and forestry systems.

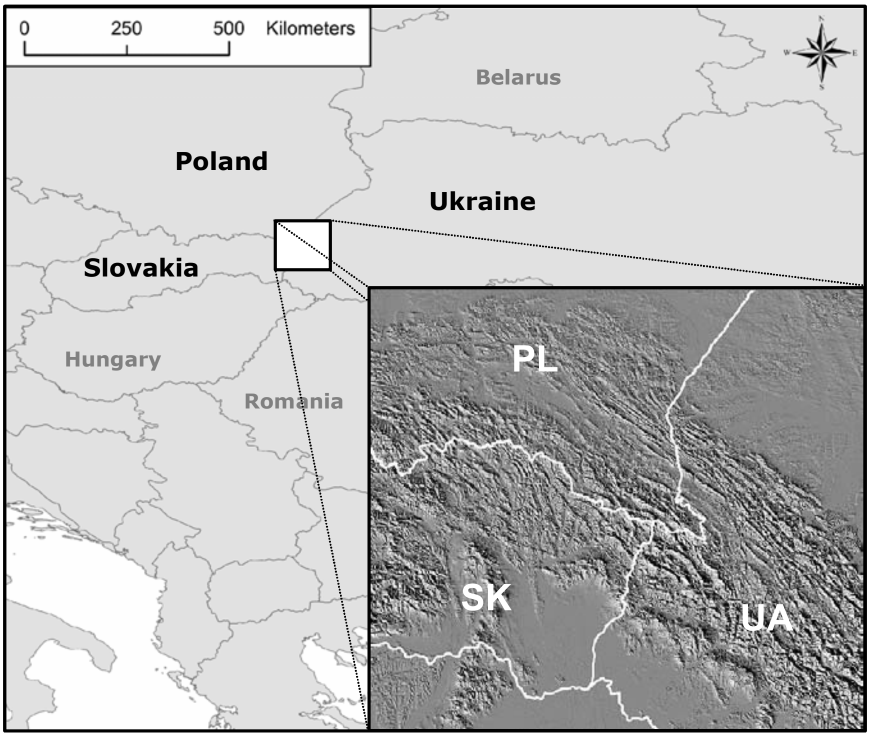

Figure 1. Location of the study site in the border triangle Poland–Slovakia–Ukraine and shaded topography representation of the area.

2 BACKGROUND

Land use and land cover change (LULCC) often is the direct result of anthropogenically induced pressure on ecosystems. The accurate detection of these changes is hence the foundation to analyse and better understand relationships and interactions between humans and their environment [3]. In addition, the understanding of changes at the earth's surface allows for the successful modelling and simulation of the potential impact of change drivers. Remote sensing has become a key instrument to monitor these trends and to reveal the patterns of land cover change [4]. At a global scale, land cover monitoring has advanced to a point where 1-km global land cover data is readily being provided. Nevertheless, there is a need for additional case studies in selected regions at the landscape scale to gain a universal understanding of the drivers of land cover change via comparisons.

Change detection generally relies on the implementation of multi-temporal datasets to quantitatively assess ecosystem changes. A multitude of methods and approaches have been proposed to accurately detect, map and monitor landscape change from remote sensing data [3], [4]. In particular, the comparison of classified images has been a common technique to delineate changes in surface classes. This approach is commonly referred to as post-classification change detection. Although being time and labour intensive, the method combines several advantages. It allows for the inclusion of multiple images (i.e. throughout the vegetation period) for a given point in time. This is important to adequately cover the phenological variability within a land cover class. Inclusion of multiple images also avoids temporal similarity of certain land cover classes (e.g. agriculture and grassland) when only relying on single images. Furthermore, post-classification change detection avoids the necessity to radiometrically calibrate the images to each other. Another advantage is the possibility to derive detailed *from-to* change matrices. However, the accuracy of the change detection directly depends on the quality of the classification outputs [5]. Hence, considerable care has to be taken to ensure optimal data handling when delineating the individual land cover maps and thorough validation of the classification products has to be carried out. A rigorous pre-processing scheme is in this regard very important to

(a) ensure precise geometric correction between multi-temporal imagery

(b) adequately consider atmospheric and topography induced distortions

3 MATERIALS AND METHODS

3.1 DATA

The Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper + (ETM+) sensors provide the spectral and spatial resolution to address change detections on the landscape scale while providing a consistent database of imagery since 1984.

Two Landsat Enhanced Thematic Mapper (ETM+) scenes and four Landsat Thematic Mapper (TM) scenes were selected to produce two individual land cover maps for the study area. While optimal data coverage was available for the 2000 time period, images from different years had to be implemented for the mid-eighties time frame due to the generally high cloud cover in the area. Table 1 shows the acquisition dates and cloud cover of the imagery:

Table 1. Acquisition dates of the Landsat ETM+ and TM scenes used in the classification based change detection.

Path	Row	Sensor	Acquisition Date	Cloud Cover [%]
186	026	Landsat ETM+	2000-09-30	5
186	026	Landsat TM 5	2000-08-21	0
186	026	Landsat ETM+	2000-06-10	0
186	026	Landsat TM 5	1988-07-27	5
186	026	Landsat TM 5	1986-10-02	0
186	026	Landsat TM 5	1985-04-22	0

A Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) was acquired through the German Aerospace Agency (DLR), mosaiked, error corrected using majority filtering operations and resampled to the Landsat TM resolution of 30 meters with a bilinear interpolator.

Ground truth data for accuracy assessment were collected during a field trip in July 2004. Locally homogeneous, and at the same time accessible areas were chosen and located using a GPS device. In addition, extensive photo documentation of inaccessible areas was conducted. The areas covered by those pictures were then located in the imagery to gather reference data. Furthermore, topographic and forest inventory maps were acquired. Aerial imagery was also available for a sub area on the Polish border to Slovakia (acquired in 1996).

3.2 PRE-PROCESSING OF SATELLITE IMAGERY

An operational and validated pre-processing scheme was deployed to geometrically and radiometrically rectify the Landsat imagery. Geometric registration to the UTM/WGS84 system was achieved using an automatic ground control points (GCP) search routine based on correlation windows and the SRTM digital elevation model as a base map. Radiometric rectification was carried out using radiometric transfer code modelling (5S using the Modtran-Mid-Latitude-Summer atmosphere model) under explicit consideration of topography induced effects. Further description of the pre-processing scheme can be found in Hill & Mehl 2003 [6].

3.3 IMAGE CLASSIFICATION

In recent years, the generation of image objects through segmentation algorithms has received increasing attention. Object-based classification encompasses several advantages compared to traditional, pixel-based approaches. Image segmentation can considerably enhance the signal-to-noise ratio and the resulting objects are a better representation of habitat patches found in the landscape. Moreover, the object-oriented approach allows for the implementation of additional information such as neighbourhood, shape and texture parameters. The segmentation can be carried out at multiple levels, thus facilitating the use of sub-object and super-object information. Although the image object approach has an enormous potential to significantly improve the classification, the authors identified two severe drawbacks in the case of spectrally alike land cover classes and high within and between class variability, which is intrinsic for large study sites:

- The generation of image objects leads to a homogenisation of spectral information which might be highly critical.
- The classification tools currently implemented in image segmentation software (i.e. nearest neighbour and hierarchical knowledge trees) perform unsatisfying in separating broad land cover classes (e.g. separating grasslands and deciduous forests).

In addition, object-based classification and image segmentation procedures are very demanding in respect to computational costs. To overcome these limitations, the authors propose a classification scheme that combines the advantages of both pixel-based and image-object-based methods in order to achieve consistent and high-quality classification products for three different countries.

A two-stage classification procedure was performed to derive maps of land cover using Landsat TM and ETM+ data. In stage one, a hybrid pixel-based classification was used to separate broad land cover classes. All scenes from one time period were layer-stacked and a principal component analysis was performed. Then, first six principal components were chosen to reduce the feature space. Next, target areas for critical surface classes (e.g. urban areas vs. agriculture; deciduous forest vs. meadows) were collected and clustered using the ISODATA algorithm. The resulting signature classes were then evaluated and unambiguous signatures were extracted. Those signatures were then used as input training samples for a supervised classification routine using the maximum likelihood classifier.

In stage two, image segmentation was conducted on the first six principal components using the fractal net evolution approach (FNEA) [8]. In a next step, the pixel-based classification (stage one) results as well as auxiliary datasets, such as the SRTM DEM and the normalized difference vegetation indices (NDVI) for all scenes, were imported to the image objects. Using two abstraction levels, multi-hierarchical information and object properties were then implemented in the final classification of the respective land cover maps. Figure 2 summarizes the classification scheme deployed in this study and table 2 displays the classes derived with the analyses. To mitigate the potential source of uncertainty in the change detection analysis arising from erroneous class assignments, Radeloff et al. (2000) suggest limiting the number of land cover classes to a low number of classes [8].

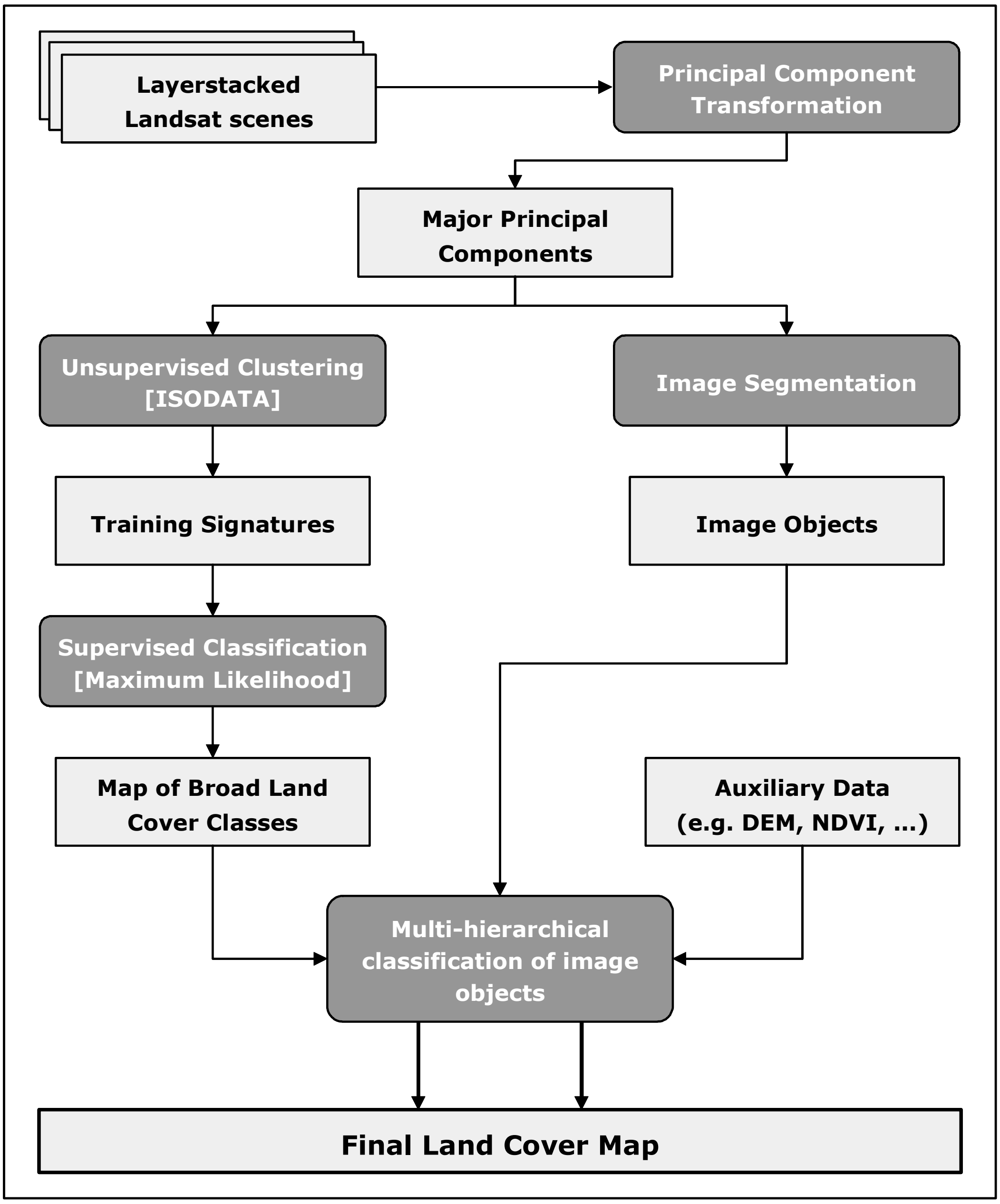

Figure 2. Simplified scheme of the land cover classification.

Table 2. Classes for stage I (hybrid pixel based classification) and stage II (multi-hierarchical classification of image objects)

Classes in Stage I	Classes in Stage II
water	water
settlements	settlements
grassland	grassland
	mountain meadows
forest	coniferous forest
	mixed forest
	deciduous forest
agriculture	agriculture

4 RESULTS

Validation of the classification outputs was conducted based on ground truth points located in the field during summer 2004 using a GPS device. Additionally, topographic maps, forestry maps and aerial photographs (which were available for a sub-area in Poland) were utilised. In total 244 points were gathered using these data sources. Table 3 shows the overall accuracy for the classifications of the two time frames.

Table 3. Overall classification accuracies

Time Period	Overall classification accuracy
2000	85%
1985-88	75%

Whereas the classification for the 2000 time period yields satisfactory results, a moderate level of uncertainty must be stated for the 1985-88 time frame. For both periods, the high level of uncertainty between the land cover classes grassland/meadows and agriculture has been identified as the dominating contributor to erroneous pixel assignments. In addition, a moderate level of ambiguity is connected to the settlements class as some areas of low-density development areas were classified as grasslands. (e.g. Table 4). The forest classes (coniferous, deciduous and mixed forest) were classified with a high accuracy as can be stated for the water class and the mountain meadow class.

Table 4. Absolute error matrix for the 2000 time period (columns: ground truth, rows: classification).

	settle-ments	water	grassland	conifer. forest	decide. forest	mixed forest	agricul-ture	mountain meadows	**Total:**
settlements	31	1	0	0	0	0	0	0	**32**
water	0	13	0	0	0	0	0	0	**13**
grassland	11	3	36	0	2	0	19	1	**72**
coniferous forest	0	0	0	22	0	2	0	0	**24**
deciduous forest	0	1	1	0	34	2	0	0	**38**
mixed forest	0	1	0	1	1	12	0	0	**15**
agriculture	3	2	11	0	0	0	16	0	**32**
Mountain	0	0	0	0	0	0	0	18	**18**
Total:	**45**	**21**	**48**	**23**	**37**	**16**	**35**	**19**	**244**

5 DISCUSSION

The high spectral heterogeneity of the agriculture and grassland classes together with the spectral similarity of some of the subclasses between those two land cover types is assumed to lead to considerable confusion that is manifested in the error matrix. Two possible solutions were identified to solve these problems:

- Minimisation of spectral variability and inter-class confusions through a country-based stratification of the classification procedure for these two classes
- Further clustering of ambiguous classes to derive distinct class signatures

Another considerable problem that has to be solved is the delineation of shrub encroachment. The analyses showed that it is possible to derive areas that are in a moderate or late state of secondary succession as they are spectrally separable or can be retrieved through super- and sub-object information. However, the derivation of shrub encroachment for areas in an early stage of secondary succession proved to be difficult due to the spectral similarity to certain grassland areas. Nevertheless, this land cover class is very important to clarify rewilding scenarios and further understand land abandonment following the fall of the iron curtain. To further explore the capability of mapping shrub encroachment from Landsat TM/ETM+ data in a heterogeneous landscape like the Eastern Carpathians, an upscaling study will be conducted on a sub-area of the study site comparing Landsat imagery to SPOT and IKONOS datasets.

Due to the interim nature of the classification products, it was decided to enforce the improvement of the land cover maps instead of conducting further analyses of landscape dynamics at the present state. The solutions laid out above can probably improve the classification results. We believe that the method proposed in this study is a major step towards a consistent, cross-border data basis, an essential prerequisite for comparative studies of land cover and land use changes as well as dynamics in landscape structure for the Eastern Carpathians Biosphere Reserve and its surroundings. Thus, the approach will lead to a higher level of understanding of ecological and socio-economic forcing of LULCC and support the test of trend hypotheses of landscape dynamics in Eastern Europe.

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