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Cross-border comparison of land cover and landscape pattern in Eastern Europe using a hybrid classification technique

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Abstract

Eastern Europe has experienced drastic changes in political and economic conditions following the breakdown of the Soviet Union. Furthermore, these changes often differ among neighboring countries. This offers unique possibilities to assess the relative importance of broad-scale political and socioeconomic factors on land cover and landscape pattern. Our question was how much land cover differed in the Polish, the Slovak, and the Ukrainian Carpathian Mountains and to what extent these differences can be related to dissimilarities in societal, economic, and political conditions. We used a hybrid classification technique, combining advantages from supervised and unsupervised methods, to derive a land cover map from three Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) images from 2000. Results showed marked differences in land cover between the three countries. Forest cover and composition was different for the three countries, for example Slovakia and Poland had about 20% more forest cover at higher elevations than Ukraine. Broadleaved forest dominated in Slovakia while high percentages of conifers were found in Poland and Ukraine. Agriculture was most abundant in Slovakia where the lowest level of agricultural fragmentation was found (22% core area compared to less than 5% in Poland and Ukraine). Post-socialist land change was greatest in Ukraine, were we found high agricultural fragmentation and widespread early-successional shrublands indicating extensive land abandonment. Concerning forests, differences can largely be explained by socialist forest management. The abundance and pattern of arable land and grassland can be explained by two factors: land tenure in socialist times and economic transition since 1990. These results suggest that broad-scale socioeconomic and political factors are of major significance for land cover patterns in Eastern Europe, and possibly elsewhere.

Keywords: Central and Eastern Europe; CEEC; Carpathians; Post-socialist transformation; Transition; Land cover; Hybrid classification; Land abandonment; Fragmentation; Landscape pattern; Landsat; TM; ETM+

1. Introduction

Humans are the main force behind global conversions of land cover and remote sensing has been a key technology for monitoring this change (Vitousek et al., 1997). To better understand the human dimension of land change it is crucial to link observed changes to their underlying socioeconomic and political causes (Geist & Lambin, 2002). Land use decisions are made at a range of nested scales. At the finest scales, individuals make decisions about the use of their land. However, individuals are constrained by broad scale determinants such as land management policies, economic conditions, and societal structures. Land change science has focused on fine scale factors and a number of studies have shown their importance (Geist & Lambin, 2002; Linderman et al., 2005). For example, local land use history, individual decision making by landowners, local attitudes, household numbers, and land ownership patterns are all factors affecting land cover change (Dale et al., 1993; Geoghegan et al., 2001; Liu et al., 2003; Pfaff, 1999).

Less is known about the effect of broad-scale political and socioeconomic factors on land cover, despite suggestions that they may increasingly override local factors (Lambin et al., 2001). Investigating the relative importance of broad-scale factors is challenging because they cannot be altered experimentally. An

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alternative approach is to study areas where sudden changes in political and socioeconomic structures occurred, thereby creating "natural experiments" (sensu Diamond, 2001). Eastern Europe has undergone such a natural experiment following the collapse of the Soviet Union in 1990. The shift from a socialistic planning system to a market oriented economy has resulted in fundamental changes to the political and social institutions as well as economic conditions (Bicik et al., 2001; Csaki, 2000). This affected how land use decisions were made, with an increased emphasis on economic rather than political influences (Bicik et al., 2001). In the agricultural sector, the main changes after 1990 have been extensive changes in land ownership and fragmentation of farm fields due to land reforms (Csaki, 2000; Sabates-Wheeler, 2002). In terms of land cover change, land abandonment is occurring at unprecedented rates, and large areas are converting to grassland and forest (Augustyn, 2004; Ioffe et al., 2004; Turnock, 1998). In many Eastern European countries, Estonia (Palang et al., 1998); Czech Republic (Bicik et al., 2001); and Poland (Kozak, 2003), to name a few, forest cover increased slightly throughout the 20th century (Augustyn, 2004). Secondary succession and afforestation on marginal arable land have amplified this trend in the post-socialist period (Augustyn, 2004; Turnock, 1998).

While general land cover change trends in Eastern Europe are recognized, detailed spatial data on these trends are lacking. In Eastern Europe, conventional data such as maps, agricultural censuses, and statistical data differ in scale and accuracy, making comparisons among countries difficult. Remote sensing can provide land cover information in an efficient, unbiased, and representative way for large areas.

Land cover changes in the post-socialist period have been targeted by few remote sensing studies. In Estonia for example, 30% of agricultural lands used in Soviet times had been abandoned by 1993 (Peterson and Aunap, 1998). Changes in village structure were found for an area in southeast Poland and two processes, land abandonment and agricultural intensification, were identified based on a visual assessment of a Landsat image and historic maps (Angelstam et al., 2003). In sub-catchments of the Tisza River in Ukraine, comparison of the Global Land Cover Characterization (GLCC) and the Moderate Resolution Imaging Spectroradiometer (MODIS) land cover product showed a 20% increase in forest cover (Dezso et al., 2005). Landsat TM and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data in conjunction with historic maps revealed that forest cover increased up to 40% in the 20th century for a study area in the Western Polish Carpathians (Kozak, 2003).

For the socialist period, the intensification of agriculture in mountain valleys and loss in forest cover of up to 9% occurred in Slovakia during the period 1976 to 1992. These trends were derived from the analysis of Coordination of Information on the Environment of the European Union (CORINE) land cover data at a scale of 1:100,000 (Feranec et al., 2003). Similarly, a small study area in Ukraine showed patterns of abandonment of arable land and agricultural intensification for the period from 1966 to 1990 (Poudevigne & Alard, 1997).

Thus, although some studies have used remote sensing data to assess land cover change in Eastern Europe, the few existing studies all assess land cover within single countries, often for very small study sites. Comparative meta-analysis of existing studies is impossible due to differences in time periods and methods. No study to date utilizes the natural experiment that occurred in Eastern Europe by comparing land cover or landscape pattern among neighboring countries.

We decided to study the Carpathian Mountains because they are ecologically relatively homogeneous, yet heavily dissected by political borders. Already in socialist times, the Carpathian countries displayed distinct differences in broad-scale socioeconomic factors, for instance in land ownership patterns and land management policies (Turnock, 2002). These differences have been magnified since the fall of the Iron Curtain (Mathijs & Swinnen, 1998) and make the area ideal for cross-border comparisons. The challenge is to select a classification method that is appropriate in this mountainous region for which relatively little ancillary information is available.

The validity of any comparison of land cover among countries depends on the classification accuracy of the land cover map. For Landsat data, phenology information inherent in multitemporal images improves classification accuracy (Dymond et al., 2002; Schriever & Congalton, 1995; Wolter et al., 1995). Using multitemporal imagery however, requires precise georeferencing, because misregistration strongly affects classification accuracy (Townshend et al., 1992). In mountainous terrain, geometric rectification is also necessary to account for relief displacement (Hill & Mehl, 2003; Itten & Meyer, 1993). Publicly available topographic maps from Eastern Europe and the former Soviet Union do not provide the degree of accuracy needed for accurate geometric correction. On the other hand, the manual collection of a well distributed set of ground control points (GCPs) is not feasible for large areas, rugged terrain, or where natural ecosystems dominate and identifiable objects are scarce. An alternative is the use of automated methods based on correlation windows that allow for fast collection of large numbers of GCPs (Hill & Mehl, 2003; Shlien, 1979).

Supervised classification methods are more effective in identifying complex land cover classes compared to unsupervised approaches, if detailed a-priori knowledge of the study area and good training data exist (Cihlar et al., 1998). The latter is particularly important for studies in Eastern Europe, where traditional and reliable data sources for ground truth such as aerial photographs are often lacking. Similarly, obtaining a good training data set for complex study sites (e.g. with a gradient in elevation) in the field is often challenging (Cihlar et al., 1998). In such situations, unsupervised approaches might be preferable (Bauer et al., 1994; Lark, 1995) and they have been rated more robust and repeatable (Cihlar et al., 1998; Wulder et al., 2004).

Ultimately it may be best to combine unsupervised and supervised classification techniques. Three uses of hybrid approaches can be distinguished: first, unsupervised clustering is useful to stratify input images prior to subsequent supervised classifications (Lo & Choi, 2004; Tommervik et al., 2003); second, unsupervised methods can reveal spectrally homogeneous areas for optimized training and ground truth collection (McCaffrey & Franklin, 1993; Rees & Williams, 1997); and third, manually collected training data can be clustered into spectrally homogeneous subclasses for use in a subsequent supervised classification ('guided