Applied Geography 55 (2014) 155–164

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

Mapping and monitoring of land use changes in post-Soviet western Ukraine using remote sensing data

Jan Stefanski [a], [*], Oleh Chaskovskyy [b], Björn Waske [a]

[a] *Institute of Geographical Sciences, Freie Universität Berlin, Malteserstrasse 74-100, 12249 Berlin, Germany*
[b] *Institute of Forest Management, Ukrainian National Forestry University, vul. Gen. Chuprynky, 103, 79031 Lviv, Ukraine*

ARTICLE INFO

Article history:
Available online 29 September 2014

Keywords:
Land management
Change detection
Object-based
Multisensor
Landsat
ERS SAR

ABSTRACT

While agriculture is expanded and intensified in many parts of the world, decreases in land use intensity and farmland abandonment take place in other parts. Eastern Europe experienced widespread changes of agricultural land use after the collapse of the Soviet Union in 1991, however, rates and patterns of these changes are still not well understood. Our objective was to map and analyze changes of land management regimes, including large-scale cropland, small-scale cropland, and abandoned farmland. Monitoring land management regimes is a promising avenue to better understand the temporal and spatial patterns of land use intensity changes. For mapping and change detection, we used an object-based approach with Superpixel segmentation for delineating objects and a Random Forest classifier. We applied this approach to Landsat and ERS SAR data for the years 1986, 1993, 1999, 2006, and 2010 to estimate change trajectories for this time period in western Ukraine. The first period during the 1990s was characterized by post-socialist transition processes including farmland abandonment and substantial subsistence agriculture. Later on, recultivation processes and the recurrence of industrial, large-scale farming were triggered by global food prices that have led to a growing interest in this region.

Introduction

Substantial increase in land-based production (e.g., food, fiber, bioenergy) is needed as long as the global demand for agricultural products steadily increases and no changes in consumption occur (Godfray et al., 2010; Lotze-Campen et al., 2010; Tilman, Balzer, Hill, & Befort, 2011). To increase land-based production, either agriculture can be expanded into (other) ecosystems, existing farmland can be intensified, or abandoned farmland can be recultivated. While the transformation of forest to agricultural systems is widely studied and relatively well understood, particularly in the tropics, (Geist & Lambin, 2002; Hansen et al., 2008), patterns of agricultural intensification and abandonment remain unclear for most parts of the world (Fritz et al., 2013; Kuemmerle et al., 2013). However, monitoring status and trends of agricultural landscapes can provide important information to reduce the environmental impact of agricultural production (Zaks & Kucharik, 2011) and to identify potential regions for sustainable intensification or recultivation.

During the last decades remote sensing became a valuable tool for environmental monitoring and land cover mapping. In context of agriculture, existing studies mainly focused on mapping different crop types (McNairn, Champagne, Shang, Holmstrom, & Reichert, 2009; Wardlow, Egbert, & Kastens, 2007; Waske & Braun, 2009) as well as on monitoring changes in cropland extent and the proximate drivers so far (Shalaby & Tateishi, 2007; Wagner, Kumar, & Schneider, 2013; Zhang et al., 2013). However, there are lacks of approaches sensitive to land use intensity because remote sensing can only rarely measure the complex terms of land use intensity (Kuemmerle et al., 2013).

One way for a more nuanced representation of agricultural landscapes is to map land management regimes as proxies of land use intensity (Kuemmerle et al., 2013; Stefanski et al., 2014; Verburg, Neumann, & Nol, 2011). Only a few studies have used such approaches at global (Ellis & Ramankutty, 2008; Václavík, Lautenbach, Kuemmerle, & Seppelt, 2013) or regional scales (Stefanski et al., 2014). Stefanski et al. (2014), for example, used the representation of management regimes that differed in field sizes, i.e., (1) large-scale, mechanized agriculture, (2) small-scale, subsistence agriculture, and (3) fallow or abandoned farmland. While large-scale, mechanized agriculture implied high management intensity, small-scale, subsistence agriculture had basically a low management intensity. To monitor land management regimes, however, requires adequate data sets and methods.

---

[*] Corresponding author.
E-mail address: j.stefanski@fu-berlin.de (J. Stefanski).

http://dx.doi.org/10.1016/j.apgeog.2014.08.003
0143-6228/© 2014 Elsevier Ltd. All rights reserved.

Although optical remote sensing data are generally a powerful tool for mapping land use/cover changes (El-Kawy, Rød, Ismail, & Suliman, 2011; Loveland, Cochrane, & Henebry, 2008), the problem of cloud cover is a potentially limiting factor (Moran, Hymer, Qi, & Kerr, 2002). This seems particularly critical in context of agricultural landscapes. Managed cropland and grassland show typical temporal patterns due to the phenology of planted crops and management activities, while abandoned farmland is not affected by these activities. Nevertheless, a differentiation between grassland and cropland or grassland and abandoned farmland can be challenging due to spectral ambiguity of the multispectral remote sensing data. Accordingly, the use of multitemporal data seems promising. Prishchepov, Radeloff, Dubinin, and Alcantara (2012) recommends the use of three Landsat scenes - from spring, summer, and fall - for a reliable mapping of agricultural abandonment in Eastern Europe.

Moreover, besides the requirement of an adequate data set for one time period, the monitoring of land management changes requires multitemporal data sets from different years for the same study site. However, regarding the repetition rate of typical systems like Landsat and the problem of cloud cover, the generation of adequate multitemporal data sets can be challenging, while data with higher temporal coverage and wide swath (e.g., MODIS and MERIS) are inadequate in capturing land use/cover changes at fine scales.

Synthetic Aperture Radar (SAR) data on the other hand might overcome spectral ambiguities of multispectral data and are (almost) weather independent and thus useful to fill gaps in optical time series. Furthermore, multispectral and SAR systems operate in different wavelengths, ranging from visible to microwave and consequently provide different, but often complementary information (Pohl & Van Genderen, 1998). Thus, a combination of multispectral imagery with SAR data is worthwhile and it has been demonstrated in several studies that multisensor analysis significantly improves the accuracy of land use/cover classifications (Kuplich, Freitas, & Soares, 2000; McNairn, Champagne, et al., 2009; Waske & Benediktsson, 2007).

Besides the availability of adequate image data for all relevant time periods, the use of adequate classifier algorithms and change detection approaches is critical. Standard classifiers are often not adequate for classifying multisensor and multitemporal data sets, because in most cases the class distributions cannot be modeled by adequate multivariate statistical models. However, machine learning algorithms such as support vector machines and classifier ensembles have emerged over the past years in the remote sensing community and are well suited for handling diverse remote sensing data sets (Gislason, Benediktsson, & Sveinsson, 2006; Mountrakis, Im, & Ogole, 2011; Waske, Chi, Benediktsson, van der Linden, & Koetz, 2009). Particularly the classifier ensemble Random Forests (Breiman, 2001) is well suited for handling multitemporal SAR and multisensor data and has proved to be simple and accurate (Rodriguez-Galiano, Ghimire, Rogan, Chica-Olmo, & Rigol-Sanchez, 2012; Waske & Braun, 2009; Waske & van der Linden, 2008).

Remote sensing based change detection includes basically bi-temporal and trajectory-based change detection methods (McRoberts, 2013). While bi-temporal change detection assesses only the type and extent of change between two defined points in time, trajectory analyses use three or more dates to additionally assess trends and temporal patterns of change over time (Carmona & Nahuelhual, 2012; Kennedy, Cohen, & Schroeder, 2007; Mertens & Lambin, 2000). However, using trajectory analyses for detailed characterization of land change dynamics typically requires extensive time series (Kennedy et al., 2007; Sieber et al., 2013). Since the backscatter intensity of SAR data is almost independent from weather conditions, time-series can be produced most reliably using SAR imagery.

In our study, we explored the potential of multispectral Landsat and ERS SAR data to monitor land management regimes in western Ukraine. After the collapse of the Soviet Union, Eastern Europe experienced drastic political and socio-economic changes. This led to farmland abandonment as well as the conversion of (collectivized) large-scale agriculture to small fields, used for subsistence agriculture (Alcantara, Kuemmerle, Prishchepov, & Radeloff, 2012; Kuemmerle, Radeloff, Perzanowski, & Hostert, 2006; Müller & Sikor, 2006). While widespread farmland abandonment often results in land fragmentation and simplification of landscapes (Peringer et al., 2013; Sikor, Müller, & Stahl, 2009), small-scale agriculture or basically subsistence agriculture in rural areas can preserve natural resources (Ioja, Nita, & Stupariu, 2014). Analyzing traditional agricultural land use with its positive aspects for natural and cultural biodiversity in a case study in Eastern Europe seems therefore particularly interesting (Angelstam et al., 2013; Munteanu et al., 2014). More recently, recultivation of abandoned farmland emerges, triggered by the global trend of food prices. Overall, this region is particularly interesting to monitor land management regimes over the past decades.

Farmland abandonment in Eastern Europe was successfully mapped in different studies, using optical remote sensing data at different scales (Alcantara et al., 2012; Griffiths, Müller, Kuemmerle, & Hostert, 2013; Kuemmerle et al., 2006, 2011). In contrast to this, the recultivation of abandoned farmland and extend of subsistence agriculture were rarely discussed. Stefanski et al. (2014) mapped current land management regimes in western Ukraine, including large-scale agriculture and small fields, using optical and SAR data. However, this study is based on a data set from one time period and consequently, temporal changes in land use management were not analyzed. Therefore, we explore the spatio-temporal patterns of land management regimes between 1986 and 2010 in this study.

We used an object-based approach based on Landsat and ERS SAR data to map land use/cover in the years: 1986, 1993, 1999, 2006, and 2010. Then, we used change trajectories to derive changes of cropland (including large-scale and small-scale cropland), grassland, and fallow or abandoned land. Overall, we focused on the following objectives: (1) assessing the potential of SAR data to complement optical data for monitoring land management regimes, (2) analyzing the changes of land management intensities, i.e., the transformation of industrial, large-scale farming to subsistence agriculture., and (3) analyzing the spatio-temporal patterns of farmland abandonment and recultivation.

Material

Study area

Our study area is located in Volynska and Lvivska Oblasts in western Ukraine and covers about 7,500 km^2 (Fig. 1). The study region is dominated by agriculture and forests. Agricultural land use types vary from large-scale, intensively managed farmland to small-scale, subsistence and low intensively managed farmland to fallow or abandoned farmland.

The study area is particularly interesting to monitor land management regimes because this region is characterized by a large variability of socio-economic and environmental conditions, which caused marked spatial heterogeneity in management intensity. During the Soviet time, land management was characterized by collectivized, large-scale farmland (Mathijs & Swinnen, 1998). With the breakdown of the Soviet Union in 1991, drastic shifts in political and socio-economic conditions triggered widespread land changes such as land fragmentation, substantial abandonment of