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Understanding farmland abandonment in the Polish Carpathians

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ABSTRACT

For more than 100 years, forest cover in Europe has increased substantially due to afforestation and natural forest expansion. The latter, resulting typically from farmland abandonment and subsequent secondary forest succession, has played a major role in marginal mountain areas and possesses various highly important environmental and economic consequences. In the Polish Carpathians, farmland abandonment is a spatially dispersed, locally specific process because of small farm and land parcel sizes, and its extent in the entire region is not well known. This study aims therefore to map current farmland abandonment in the Polish Carpathians and to identify its spatial determinants. To map farmland abandonment we detected secondary forest succession on abandoned fields using Airborne Laser Scanning (ALS) point clouds and topographic data in 230 sample areas (tiles) distributed throughout the Carpathian communes. To reveal the spatial determinants of current farmland abandonment, we investigated variables describing the accessibility and environmental, land cover, and socioeconomic conditions of communes, using best subset regression modelling. The results showed that 13.9% of agricultural land was abandoned and underwent secondary forest succession in recent decades. Topography (mainly slope gradients) and employment outside of agriculture were the two most important spatial determinants of farmland abandonment. Consequently, a substantial forest expansion may be observed in the coming decades throughout the Polish Carpathians if no counteractions are taken.

1. Introduction

Forest expansion plays an important role in transforming contemporary landscapes in several countries (Meyfroidt & Lambin, 2011; Rudel et al., 2005; Sloan & Sayer, 2015). In mountain regions in Europe it starts typically with farmland abandonment followed by secondary forest succession (MacDonald et al., 2000; Price et al., 2016), reflecting a decline in traditional agricultural management, interlinked with environmental, economic and social aspects of agriculture. Therefore, understanding patterns and spatial determinants (Meyfroidt, 2015) of farmland abandonment is an important prerequisite for developing future agricultural policies (Renwick et al., 2013; Verburg & Overmars, 2009). Spatial determinants of farmland abandonment may exhibit significant similarities to spatial determinants of increasing forest cover. For instance, the forest transition theory (Mather, 1992) attributes increases in forest cover to emerging employment opportunities outside agriculture, reflecting economic growth or intensified mobility of the local population (Grainger, 1995; Rudel, 1998). Combined socioeconomic processes typically result in a gradual increase in forest cover on marginal lands where agriculture is less productive (Keenleyside & Tucker, 2010; Pointereau et al., 2008). Topography, in particular slope steepness, and poor soils are often reported as most important determinants of farmland abandonment (Baumann et al., 2011; Gellrich, Baur, Koch, & Zimmermann, 2007; Müller, Leitão, & Sikor, 2013). Remote and dispersed fields with limited accessibility often require additional effort to cultivate which may stimulate a decline or termination of agricultural activities (Müller et al., 2013; Prishchepov, Müller, Dubinin, Baumann,

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& Radeloff, 2013). Population change, ageing farmers, and several economic alternatives to agriculture also contribute to farmland abandonment (Baumann et al., 2011; Lieskovský et al., 2015; Pazúr, Lieskovský, Feranec, & Oťaheľ, 2014).

In mountain regions, biophysical factors not only influence where farmland abandonment is likely to occur, but also affect rates of secondary forest succession. Secondary forest succession at higher elevations may be impeded by unfavourable climatic conditions (Pointereau et al., 2008; Tasser, Walde, Tappeiner, Teutsch, & Noggler, 2007), persistence of existing plant communities (Beaufoy, Baldock, & Clark, 1994; Kucharzyk, 2004; Kuemmerle et al., 2008) or overgrazing by animals (Holtmeier, 2009). In contrast, agricultural areas well below the timberline react relatively quickly to land abandonment. Here, evolution of dense grass communities (an initial stage of succession) generally lasts up to 2 years and is half of that for lowlands (Kostuch, 2003). Additionally, nearly 30% of trees germinate in less than 5 years (Delang, 2013; Tasser et al., 2007). For instance, meadows between 800 and 1200 m a.s.l. in the Alps and fallow lands in the Carpathians were completely forested within 15 years from the abandonment (Kostuch, 2003; Tasser et al., 2007).

Forest expansion on abandoned farmland has a variety of environmental consequences. Some positive effects can be observed, such as expansion of native vegetation species, increase in biomass and the carbon sequestration potential (Hostert et al., 2011) and reduced soil erosion (Renwick et al., 2013). Even the early stages of secondary forest succession imply a loss of traditional rural landscapes, landscape attractiveness and cultural heritage (Fischer, Hartel, & Kuemmerle, 2012; MacDonald et al., 2000; Tasser et al., 2007; Verburg, Eickhout, & van Meijl, 2007). Depending on the composition and configuration of spatial patterns of land cover, the succession can either decrease or increase landscape fragmentation and biodiversity (Bennett & Saunders, 2010; Senft, 2009; Tews et al., 2004).

Since at least World War II, forest expansion on abandoned farmland has been observed in the post-socialist countries in Central and Eastern Europe (CEE), in particular Slovakia (Bezák & Mitchley, 2014; Lieskovský et al., 2015; Pazúr et al., 2014), Romania (Grădinaru et al., 2015; Müller et al., 2013), the Ukraine (Baumann et al., 2011; Stefanski, Chaskovskyy, & Waske, 2014), and Poland (Szwagrzyk, 2004). The Polish Carpathians have also experienced a gradual decline in agriculture since the interwar period which then accelerated after the collapse of socialism in 1989 in the CEE countries and the consequent political and socioeconomic transformations (Hostert et al., 2011; Kozak, 2010; Kuemmerle et al., 2008; Wężyk & de Kok, 2005). Post-1989 changes in agriculture have induced a widespread forest succession on fallow or abandoned farmland, significantly contributing to increasing forest cover in the region (Kozak, 2010; Szwagrzyk, 2004). The scale of this process, however, is not known. In many cases, landowners are not aware of how much of their land has been overgrown with shrubs and trees (Szwagrzyk, 2004), therefore, contemporary digital topographic data sets do not provide updated information, and more detailed census data are freely available only in aggregated forms. For instance, the recent Polish agricultural census (PSR, 2011a, 2011b) reported a notable decrease in farmland area between 2002 and 2010 in the Carpathian provinces of Małopolska and Podkarpacie (by 16.5% and 14.9%, respectively). This is roughly in line with Kuemmerle et al. (2008) who reported that 13.9% of farmland used in the Polish Carpathians during socialist times was abandoned after 1989. Local estimates of farmland abandonment are often higher: between 14.9% and 46.6% of the agricultural land in the Beskid Średni Mountains (Ostafin, 2009) or 31.0% in the Carpathian commune of Szczawnica (Kolecka et al., 2015).

The Airborne Laser Scanning (ALS), an active remote sensing technology, offers the potential for enhanced ability of forest succession mapping by taking into account structural vegetation information (Falkowski, Evans, Martinuzzi, Gessler, & Hudak, 2009; Kolecka et al., 2015; Martinuzzi, Gould, Vierling, & Nelson, 2012; Wężyk & Gęca, 2013; van Ewijk, Treitz, & Scott, 2011). In particular, a variety of ALS-derived metrics were used by Falkowski et al. (2009) to map six stages of succession in a mountainous coniferous forest and by van Ewijk et al. (2011) to characterize four stages of forest succession in a mixed forest. Martinuzzi et al. (2012) found that ALS-derived metrics improved the performance of forest type classification and forest succession delineation. Wężyk and Gęca (2013) utilised ALS point clouds to automatically map forest succession and update local census data. Kolecka et al. (2015) developed a method to map various stages of secondary forest succession and indicated that it can effectively cover large areas with broad-scale ALS projects, such as the national Informatyczny System Osłony Kraju (ISOK) project (ISOK, 2014).

Up-to-date local-scale case studies based on various methodological approaches have shaped an initial understanding of the importance of farmland abandonment in the Polish Carpathians, indicating its occurrence at high elevations, on steep slopes, far from built-up areas and near forest edges (Kolecka et al., 2015; Kozak, 2003; Ostafin, 2009). However, these local-scale case studies have not revealed the large-scale patterns and spatial determinants of farmland abandonment, as its comprehensive mapping at a very high spatial resolution has not been performed yet. Thus, the goals of our study were as follows: (1) to map abandoned farmland in the Polish Carpathians using recently completed national ALS data from Poland allowing to detect various stages of secondary forest succession at a very high spatial resolution, and (2) to identify spatial determinants of farmland abandonment. In this manner, we attempted to increase the understanding of the spatial determinants of future forest cover change in the Carpathian area, which may contribute to improved estimates of the future carbon budget and inform decision makers who are interested in protecting endangered cultural landscapes.

2. Study area

We studied the entire Polish Carpathians (20,000 km^2, Fig. 1), which were divided into the 200 communes listed in the Carpathian Convention (CC, 2015). As several communes were administratively subdivided into rural and urban parts, the total number of areal units was 236. The Polish Carpathians cover the northernmost section of the Carpathian arc, ranging from relatively low foothill zones of 300 m a.s.l (Pogórze Karpackie) to 2500 m a.s.l in the Polish part of the Tatra Mts. (Balon et al., 1995). Several large urban centres are located in or close to the mountains (e.g., Kraków, Rzeszów, Bielsko-Biała). The typical landscape consists of a mosaic of agricultural lands and forests, with most settlements located in the valleys. Following a period of forest cover increase that started in this part of Europe around the mid-19th century (Kozak, 2010; Munteanu et al., 2014), Based on data from national spatial databases (Dobosz, Kozak, & Kolecka, 2015), forests cover 47% of the study area and farmland 42%, with approximately equal shares of arable land and grasslands.

3. Data and methods

To achieve the first goal of our study, we relied largely on the methodology proposed and tested by Kolecka et al. (2015) and used structural vegetation information derived from ALS data and supported by national topographic vector data. The potential determinants of farmland abandonment were then evaluated using general regression models based on socioeconomic and