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FOREST COVER CHANGE AND SECONDARY FOREST SUCCESSION SINCE 1977 IN BUDZÓW COMMUNE, THE POLISH CARPATHIANS

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Abstract: One of the most widespread land cover change processes in European countries is the increase in forest cover. Forest expansion on abandoned agricultural land has played a major role in marginal mountain areas since World War II, and especially affected the post-socialist countries in Central and Eastern Europe. This study aimed at mapping forest cover change and forest succession in one of the communes of the Polish Carpathians (Budzów) over two time periods: 1977–1997 and 1997–2009. We identified rates of agricultural land abandonment and forest succession and assessed the dynamics of the process using aerial photographs, orthophotomaps as well as cadastral and census data. The results showed that Budzów commune experienced an expansion of forest cover from 40% in 1977 to almost 45% in 2009, and a significant increase in forest succession from 1% in 1997 to 10% in 2009, at the expense of agricultural land area (54% in 1977 and 40% in 2009). If the trend is widespread over the Polish Carpathians, the real forest cover may be much higher than follows from statistical data.

Keywords: land use change, agricultural land abandonment, forest cover, secondary forest succession, the Carpathians

Introduction

Land cover change is an ongoing global process, affecting biodiversity, ecosystems and climate (Mather 1992; Foley 2005). One of the most widespread processes in European countries is the increase in forest cover due to afforestation and forest expansion on abandoned agricultural land (FAO 2010). Since World War II the latter has played a major role in marginal mountain areas (MacDonald *et al*. 2000), and especially affected the post-socialist countries in Central and Eastern Europe (Kozak 2003; Alcantara *et al.* 2012; Munteanu *et al.* 2014).

Land abandonment is an initial stage leading to secondary forest succession and conversion of agricultural land to forests. Early stages of succession are triggered by seed dispersal, especially in the vicinity of trees and shrubs. In areas of less intensive use, vegetation density increases as saplings and young trees or shrubs are not constantly removed. Therefore, natural reforestation is promoted by the proximity of forest. Depending on site conditions, the first signs of abandonment are visible in less than 5 years without land cultivation when nearly 30% of trees germinate (Tasser *et al.* 2007).

The Polish Carpathians have experienced a gradual decline in agriculture, at least since World War II (Kozak 2010; Munteanu *et al.* 2014). After the collapse of socialism in 1989 and the introduction of an open-market economy, the drop in agricultural land use accelerated significantly (Kuemmerle *et al.* 2008; Munteanu *et al.* 2014; Lieskovský *et al.* 2015). The Polish agricultural census from 2002 (GUS 2003) showed an increase in fallow arable land from 1% in 1990 to 18% in 2002. Kuemmerle *et al.* (2008) reported that 13.9% of farmland used in the Polish Carpathians in socialist times was abandoned due to decreasing profitability of agriculture after 1989. The accession of Poland to the European Union in 2004 and the implementation of the Common Agricultural Policy (CAP) slightly increased the profitability of mountain agriculture. Nevertheless, they have not encouraged restoration of farming activities, and land abandonment and subsequent forest succession has been a widespread and active phenomenon. The recent Polish agricultural census (PSR 2011a, 2011b) reported a notable decrease in agricultural land area between 2002 and 2010 in the Carpathian voivodeships of Małopolska and Podkarpacie (by 16.5% and 14.9%, respectively). Locally, the estimates were even higher, exceeding 45% (Ostafin 2009; Kolecka *et al.* 2015).

Understanding of trends and dynamics of land abandonment and secondary forest succession since political transformation in 1989 is crucial for the prediction of future changes in forest cover. So far, many case studies have investigated past land cover changes over large areas using coarse resolution satellite imagery (Kuemmerle *et al.* 2008; Potapov *et al.* 2011; Griffiths *et al.* 2014). In the Polish Carpathians, however, land abandonment and secondary forest succession are spatially dispersed due to small land parcel sizes. Therefore, the aim of our study was detailed mapping of forest cover change and forest succession in one of the communes of the Polish Carpathians over two time periods: 1977–1997 and 1997–2009. We used aerial photographs and orthophotomaps, as well as cadastral and census data. In this way, we attempt to identify rates of agricultural land abandonment and forest succession, and to assess the directions of the process.

Materials

Study area

We studied the rural commune of Budzów (73.41 km^2) located in the Polish Carpathians in the Małopolska Voivodeship, in southern Poland, 40 km to the south of Kraków (Fig. 1). The commune lies on gentle slopes of the Beskid Średni (Makowski) Mountains, with elevation ranging from 300 m a.s.l. to 820 m a.s.l. and a mean slope gradient of 12° (only 10% of the area is inclined more than 20°). The dominating land cover is a mixture of agricultural land (45%) and forest (40%) (Photo 1; GUS BDL 2015). The entire commune is divided into 60 000 cadastral parcels with a mean area of 0.12 ha (ARiMR 2016). Most forests (73%) are private, whereas the remaining 27% belong to the State Forests National Forest Holding (SF NFH). The state-owned forests are concentrated mainly in the outskirts of the commune (Budzów 2014) and consist of about 300 large parcels. Population of the commune slowly increased from 8001 inhabitants in 1995 to 8770 in 2014. The main activities are agriculture and wickerwork.

Data

The primary data source to assess forest cover changes and secondary forest succession since the 1970s was aerial photographs from 1977 and orthophotomaps available for 1997 and 2009 (Tab. 1; Fig. 2) from the Main Centre of Geodetic and Cartographic Documentation in Poland (CODGiK – Centralny Ośrodek Dokumentacji Geodezyjnej i Kartograficznej). The first period (1977–1997) covers mostly the late socialist times and the early transformation; the following period (1997–2009) covers times of market-oriented economy, and the first 5 years after Poland's accession to the European Union (EU) in 2004.

Several ancillary data (Tab. 1) were used at various stages of this work. The Digital Terrain Model (DTM) and the Polish Topographic Map (PTM) were used for orthorectification of the aerial photographs from 1977.

The national database of topographic objects (Baza Danych Obiektów Topograficznych; BDOT10k) (Dz.U. 2011) and the Land-Parcel Identification System (LPIS) data (ARiMR 2016) provided information about land use and land cover, buildings and infrastructure, and cadastral parcels. They supported aerial imagery analysis.

The digital forest map (LMN – Leśna Mapa Numeryczna) including spatial and attribute information about Polish national forests and statistical data from the Local Data Bank (BDL – Bank Danych Lokalnych) of the Central Statistical Office of Poland (GUS – Główny Urząd Statystyczny) (GUS BDL 2015),

Table 1. Data used in the study

Dataset	Year	Colour	Spatial resolution [m]	Approx. scale of original photographs	Study area coverage	Notes
Primary data						
Aerial photographs	1977	black-and--white panchromatic (B/W)	0.23	1:16 000	98%	unavailable camera calibration report
Orthophotomaps	1997	natural colour (RGB)	0.75	1:26 000	100%	
Orthophotomaps	2009	natural colour (RGB)	0.25	1:14 000	100%	
Ancillary data						
DTM	2009		1.0		100%	digital terrain model
PTM	1975–1983			1:25 000	100%	Polish topographic map
BDOT10k	2013				100%	national database of topographic objects
LPIS	2014				100%	cadastral parcels
LMN	2014					digital forest map
GUS BDL	since 1995					socio-economic statistical data

in particular forest cover and the agricultural censuses from 1997 and 2009, contributed to interpretation and analysis of results.

Methods

The workflow consisted of the following steps: orthorectification of aerial photographs from 1977, vectorisation of forest cover for 1977, 1997 and 2009, vectorisation of forest succession for 1997 and 2009, creation and improvement of land cover masks, and analysis of land cover change across Budzów commune.

Orthorectification of aerial photographs from 1977

The photographs were orthorectified one by one with ERDAS LPS 2013 software, using ground control points (GCPs) measured on orthophotomaps from 2009 or topographic maps from the 1970s and on DTM. In each photograph, 17–31 GCPs allowed us to achieve satisfactory root mean square errors (RMSEs) of image points not exceeding 6 pixels (0.85 mm) and mean residuals of GCPs better than 3.3 m (Hughes *et al.* 2006; Ma, Buchwald 2012). The output orthorectified images had spatial resolution of 0.25 m, which corresponded to the approximate pixel size of the raw photographs.

Vectorisation of forest

Due to various and not compatible definitions of "forest", we established our own definition for this study. We decided to vectorise the tree cover, that is all patches of closed and open forest, and groups of trees, tree lines and single trees if the trees were older than 10 years (Fig. 3). The age of the trees was interpreted visually from their height, length of shadows, span of tree crowns, and presence in an older image.

To obtain forest masks for 1977, 1997 and 2009 we applied a backdating approach (Feranec *et al.* 2007; Kaim *et al.* 2016). First, orthophotographs from 2009 were vectorised. Second, we obtained 1997 forest cover by modification of the referential 2009 forest mask. Third, we vectorised forest cover from 1977 using the 1997 forest mask as a reference. Here, we used the central part of each image to avoid vectorisation of its margins, where the largest residuals appeared. The small fragments of the commune (less than 1%) not covered by the photographs were completed from 1997 data. Small discrepancies between layers up to 2 m were not recorded (IUL 2012). In this way, only the differences in forest area were added to or removed from the newer forest mask, which substantially reduced vectorisation time.

Vectorisation of secondary forest succession

Forest succession was interpreted as young (less than 10 years), low trees and shrubs that appeared on land used formerly by agriculture, in particular arable land and grassland. As previously, the age of the trees was interpreted visually. The approximate threshold to distinguish between low and high trees was 3 m, according to the pace of growth of pioneer tree species, in particular birch and pine (Szymkiewicz 2001).

Secondary forest succession was obtained for 1997 and 2009 through comparison of orthoimages from 1997 and 1977, and from 2009 and 1997, respectively. Presence of young trees and shrubs in the newer image and absence of trees or forest in the older image indicated growth of successional and woody vegetation, and therefore forest succession (Fig. 3).

Correction of manual vectorisation and creation of land cover masks

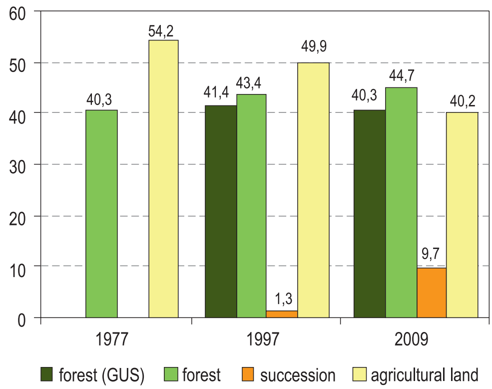
The layers obtained by means of manual vectorisation were checked and corrected by another analyst (Kaim *et al.* 2014). All the vectorised forest and forest succession layers were filtered to eliminate patches smaller than 0.1 ha. Areas not classified as forest or secondary forest succession were categorised as "others", and contained cultivated agricultural land, water, transport or built-up areas. The latter were eliminated using additional information about formal and functional land use and land cover from BDOT10k and LPIS data. They constituted 6.9% of Budzów commune. Because the mask of eliminated areas was constructed using the contemporary data, it was excessive in relation to the former periods. However, this approach ensured a consistent area for analysis.

After elimination of the specific areas, the class "others" corresponded mainly to cultivated agricultural land, in particular arable land and grassland with no signs of secondary forest succession. For each time point we constructed a land cover mask including the appropriate classes: forest (F) and agricultural land (A) for 1977 (referred to as LC1977), and forest, forest succession (S) and agricultural land for 1997 and 2009 (referred to as LC 1997 and 2009), with no data for eliminated areas.

Land cover change analysis

Firstly, we analysed forest cover in 1977, 1997 and 2009, and secondary succession in 1997 and 2009. The results of manual vectorisation were compared to the census data about forest cover in 1997 and 2009 from GUS BDL. Secondly, we overlaid the land cover layers to obtain changes between 1977 and 1997, and between 1997 and 2009 for three land cover categories: forests, secondary forest succession and agricultural land with no visible signs of abandonment. Former agricultural land that was subsequently covered by successional and woody vegetation was an indicator of land abandonment. Land covered by forest at all three times was regarded as stable forest. Thirdly, we investigated the distribution of land cover change against elevation, slope, proximity to stable forest, and distance to five villages and communal administrative centres to assess the influence of the most frequent indicators of agricultural land abandonment, as pointed to by several authors (Keenleyside, Tucker 2010; Bezák, Mitchley 2014; Pazúr *et al.* 2014; Kolecka *et al.* 2015; Lieskovský *et al.* 2015).

Fourthly, we analysed the results against cadastral data to assess how many parcels of agricultural land use have been overgrown since 1977. We did not take into consideration parcels that were at least 90% covered by stable forest, and parcels that overlaid the excluded area by more than 50%. The remaining 42,027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parcels constituted 62% of the commune area. At this stage, the parcels were categorised according to the fraction of various land cover types.

Results

Land cover changes in Budzów commune

Budzów commune experienced expansion of forest from 40.3% in 1977 to 43.4% in 1997, and to 44.7% in 2009. At the same time, agricultural land area decreased from 54.2% in 1977 to 49.9% in 1997, and to 40.2% in 2009. The proportion of forest succession increased significantly from 1.3% in the first period, to 9.7% in the second period (Fig. 4).

In 1997 and 2009 results of manual vectorisation showed more forest in comparison with the census data from GUS BDL. The discrepancy was 2.0% and 4.4% of the commune area, respectively. Moreover, according to GUS BDL data, forest area decreased by 1.0%, whereas manual vectorisation showed an increase in forest cover of 1.3% (Fig. 4).

Since 1977, 15.5% of the commune area experienced forest succession, whereas forest declined in just 0.9% of the commune. 78.7% of the commune had not experienced land cover change, in particular 39.3% covered by forest (referred to as stable forest) and 39.4% of agricultural land (referred to as stable agricultural land) (Tab. 2; Fig. 5).

Between 1977 and 1997, 3.1% of the commune changed from agriculture to forest (19.7% of total land cover change in the commune between 1977 and 2009), and 1.0% experienced forest succession. More than half (60.0%) of the succession in the first period developed into forest by 2009, and the rest remained under secondary forest succession until 2009.

The most significant transitions were observed between 1997 and 2009 when 8.7% of agricultural land experienced forest succession and 1.5% experienced forest regrowth. They constituted, respectively, 55.1% and 9.6% of total land cover change in Budzów. As mentioned previously, part of the secondary forest succession areas in 1997 turned into forest.

Stable forest was located mainly on mountain ridges in the vicinity of the commune and village borders. Stable agricultural land was located at lower elevations and on less steep slopes (475 m a.s.l. and 9.2°, respectively). Most of the successional and woody vegetation regrowth was observed on the boundaries between the two stable classes. From the total secondary forest succession, 68.1% occurred in the neighbourhood of forest, that is 9.8% of the commune area, in particular where the land cover in 1997 was fragmented. The process started from

Table 2. Trajectories of land cover change in Budzów commune between 1977, 1997, and 2009

Land cover change	Period	Land cover type			Area [ha]	Percentage of total area	Percentage of total land cover change
		1977	1997	2009			
Stable forest	1st and 2nd	F	F	F	2,873.28	39.3	
Stable agricultural land	1st and 2nd	A	A	A	2,731.2	39.4	
Successional and woody vegetation increase	1st	A	F	F	241.7	3.1	19.7
		A	S	S	35.7	0.4	2.5
	1st and 2nd	A	S	F	53.7	0.6	4.0
	2nd	A	A	F	119.1	1.5	9.6
		A	A	S	685.1	8.7	55.1
Successional and woody vegetation decrease	1st	F	A	A	10.3	0.2	1.1
		F	S	S	0.9	0.0	0.0
	1st and 2nd	F	S	A	0.2	0.0	0.0
	2nd	F	F	A	18.9	0.3	2.1
		F	F	S	27.4	0.4	2.3
Other changes not consistent in the 1st and 2nd periods		F	A	F	5.3	0.1	0.4
		F	A	S	3.9	0.0	0.3
		F	S	F	2.3	0.0	0.2
		A	F	A	7.7	0.1	0.9
		A	F	S	8.0	0.1	0.6
		A	S	A	12.2	0.2	1.2

Explanations: A – agricultural land; F – forest; S – succession.

the most inconvenient areas (considering elevation and steepness). First period succession affected three types of agricultural land: the highest and the steepest areas where it had not developed into high trees (mean elevation 526 m a.s.l. and mean slope 13.5 for A–S–S trajectory), lower and more gentle slopes where vegetation needed more time to develop into high trees in the second period (506 m a.s.l. and 13.2° for A-S-F), and the lowest and most gentle areas where high trees have grown fast (479 m a.s.l. and 12.9° for A–F–F). Second period succession occupied less steep land (486 m a.s.l. and 12.4° for A–A–F, 485 m a.s.l. and 11.4° for A–A–S).

Land abandonment

Analysis of the results against cadastral data showed that only one third of agricultural parcels have been constantly cultivated since 1977, whereas 24,471 out of 42,027 agricultural parcels underwent forest succession, but at different rates (Tab. 3). The total area of the overgrown parcels constituted 71% of the agricultural land in Budzów commune, and 44% of the entire commune area, with 49% of that belonging to parcels where successional vegetation increased on more than 20% of their area. The parcels with signs of secondary forest succession were rather small, of mean area less than 0.12 ha.

Table 3. Land abandonment in Budzów commune between 1977 and 2009

Percentage of parcel area with successional or woody vegetation change	Number of parcels	Parcel area [ha]	Successional or woody vegetation increase area [ha]	Percentage of successional or woody vegetation increase area in the commune
Increase [%]				
0	17,556	1,337.98	0.00	0.00
≤20	10,850	1,645.69	106.82	1.45
20–40	3,280	465.51	136.13	1.85
40–60	2,305	249.60	124.50	1.69
60–80	2,374	252.48	177.82	2.42
>80	5,662	595.79	555.20	7.56
All parcels with non-zero increase	24,471	3,209.07	1,100.47	
Percentage of commune area		43.69	14.98	
Decrease [%]				
0	36,963	3,598.62	0.00	0.00
≤20	4,564	927.09	30.11	0.41
20–40	252	465.51	3.71	0.05
40–60	127	4.52	2.25	0.03
60–80	72	2.58	1.72	0.02
>80	49	0.76	0.68	0.01
All parcels with non-zero decrease	5,064	1,400.47	38.47	
Percentage of commune area		19.06	0.52	

Discussion

This study was intended to identify rates of agricultural land abandonment and forest succession, and to assess the dynamics of the process in one of the communes of the Polish Carpathians. In the discussion we start with considerations of the accuracy of mapping, then we discuss the dynamics and extent of land abandonment in Budzów commune.

Methodological considerations

In general, manual vectorisation of aerial imagery proved its high value for land cover mapping. The high accuracy of the obtained data, however, might have been affected by several factors (Kaim *et al.* 2014). The formulation of unambiguous definitions of vectorised classes was not straightforward. For example, sparse trees may be classified as open forest or single trees or groups of trees, and vice versa, and roads may divide forest complexes, which can influence total forest cover. To avoid errors, we assumed the approximate tree-to-tree distance and forest road width of 10 m (DGLP 2012). Vectorisation of vegetation was performed according to its age interpreted visually from the height of trees, length of shadows, and span of tree crowns. Moreover, interpretation of 1997 and 2009 imagery was supported by 1977 and 1997 datasets, respectively, to provide reliable results. The issue was particularly awkward for nadir points of the photographs and due to short shadows when photographs were taken at noon or over large forest complexes. To some extent discrimination between coniferous and deciduous trees aided the visual interpretation, but it was influenced by various resolutions and quality of vectorised imagery. For that reason, forest and succession could be misclassified in a few small areas. The vectorisation method, where a newer land cover layer was created by an update of the older layer, allowed us to avoid small discrepancies (up to 2 m) along edges of vectorised patches due to drawing precision and resolution of imagery.

Due to our definition of forest, we did not vectorise successional vegetation from 1977, and therefore vegetation increase in the first period could be slightly overestimated. The data for the second period, however, contained the full information on vegetation change.

General findings

Forest succession on abandoned agricultural land was widespread over the studied commune. As much as 34% of agricultural land in Budzów commune that had been cultivated until 1977 experienced successional or woody vegetation regrowth in the next 32 years and the less-favoured areas were abandoned first. In the first two decades (1977–1997), it was a small-scale phenomenon, comprising small or isolated agricultural areas and forest clearings, and reflected a post-war trend in this area (MacDonald *et al.* 2000; Ostafin 2009). The third decade (1997–2009), however, brought a sudden decrease in cultivated agricultural land that triggered forest succession and a subsequent increase in forest cover. In that period, larger portions of land became overgrown, including not only fields surrounded by forest, but also fields surrounded by cultivated agricultural land. As found by Tasser *et al.* (2007) and Delang (2013), the delay between the end of land cultivation and the moment when the first signs of abandonment become visible is up to 5 years, when nearly 30% of trees germinate. Therefore, we assume that the observed changes were a consequence of land abandonment after the collapse of the socialist system in 1989 and the decline of small-scale agriculture, as suggested by many researchers (e.g. Kuemmerle *et al.* 2008; Linden van der *et al.* 2008; Lieskovský *et al.* 2015). The transition to an open-market economy decreased the profitability of small-scale agriculture as compared to other activities, and led to the abandonment of less-productive areas. Many people gave up labour-demanding agricultural activities as alternative employment opportunities emerged in other sectors (MacDonald *et al.* 2000; Bezák, Mitchley 2014; Lieskovský *et al.* 2015). A similar trend was observed not only in the Polish Carpathians, but also in the Ukraine (Kuemmerle *et al.* 2008), in Romania (Müller *et al.* 2013), Slovakia (Lieskovský *et al.* 2015) and in the European part of Russia (Prishchepov *et al.* 2013).

A marginal proportion of land cover changed from forest in 1977 and 1997 to forest succession in 2009, and 52% of those changes occurred within the large forest patches belonging to the SF NFH. They did not, however, indicate a decrease in forest cover, but resulted from forest management, and according to the DGLP (2012), the temporal woodland clearances were supposed to be restored within less than five years.

Acceleration of land abandonment was also confirmed by a growing discrepancy between legal (GUS BDL 2015) and real forest cover in 1997 and 2009. Even land owners, in many cases, are not aware of how much of their land has been overgrown with shrubs and trees (Szwagrzyk 2004). On the other hand, the discrepancies may result from long (2–5 years) delays in official reclassification from agricultural land use to woodland or forest (Jabłoński 2015). If the trend is widespread over the Polish Carpathians, and studies from other communes confirm these findings (e.g. Kolecka *et al.* 2015 showed that in Szczawnica 31% of agricultural land underwent forest succession), the real forest cover may be much higher than follows from statistical data.

Conclusions

Our study showed that in the last decades forest cover in Budzów commune increased due to secondary forest succession on abandoned agricultural land, which follows long term directions of land change in Europe (Munteanu *et al.* 2014). The strength of our analysis was in the high resolution aerial imagery that allowed detailed mapping of the spatially dispersed and locally specific process since 1977, and includes features not detected in coarse resolution satellite imagery (Kuemmerle *et al.* 2008; Potapov *et al.* 2011; Griffiths *et al.* 2014). Furthermore, comparison with cadastral data allowed us to assess the real scale of agricultural land abandonment expressed by the proportion of fallow agricultural parcels. We observed a significant increase in successional and woody vegetation on fallow agricultural land in the last decades. Agricultural land abandonment accelerated soon after the collapse of socialism in 1989 and transition to an open-market economy, when land cultivation became less profitable and new job opportunities outside agriculture appeared (Munteanu *et al.* 2014). The forest increase is likely to continue over the next decades, following the forest transition theory (Mather 1992), unless abrupt changes in the political and economic situation occur (Munteanu *et al.* 2014). Then, more than half of the Polish Carpathians may be covered by forest in 2030–2040.

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