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Original research paper

Monitoring of secondary forest succession on abandoned farmland using LiDAR point clouds

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Abstract: The purpose of the study was an assessment of LiDAR point clouds for automating the mapping of land use and land cover changes, mainly land abandonment and the process of secondary forest succession. Detailed information about land cover was determined based on airborne laser scanning data. The presented study focuses on the analysis of the spatial range and structure of vegetation. The study area was located in Milicz district in the voivodeship of Lower Silesia – the central west part of Poland. The areas of interest were parcels where agricultural land had been abandoned and forest succession processes had progressed. Analysis of the spatial range of the secondary forest succession was carried out using a reclassified nDSM. Reclassification of the nDSM was done using > 1 m, > 2 m and > 3 m for the pixel values, representing the height of vegetation above the ground. Parameters such as height of vegetation, standard deviation of height and cover density were calculated, to show the process of the increase in forest succession on abandoned agricultural land. The results confirmed a discrepancy between the cadastral data and the actual use of the plots. In the study area, more than three times as much forested and wooded area was detected than had been recorded in official databases. Analyses based on airborne laser scanning point clouds indicated significant diversity in the vertical and horizontal structure of vegetation. The results demonstrated gradual succession of greenery in the research area.

Keywords: ALS, nDSM, LULC changes

1. Introduction

Land abandonment and the exclusion of land from agricultural production is a frequent and popular theme of studies (Bowen et al., 2007; Lasanta et al., 2017; Lieskovský et al., 2015; Navaro and Pereira, 2012; Śmigielski et al., 2017). Currently functioning remote sensing technologies and a large resource of geoinformation tools allow remote research, including research into dynamic land use/land cover (LULC) changes and processes of forest succession. Regarding this aspect, there are many studies which use images (Bergen and Dronova, 2007; Prishchepov et al., 2012), LiDAR data (Ewijk et al., 2011; Falkowski et al., 2009) or a combination of the two (Singh et al., 2012). Some studies also present the possibility of using remote sensing technologies to detect secondary forest succession on abandoned land in Poland (Kolecka et al., 2015; Kolecka et al., 2016; Szostak et al., 2014; Wężyk and de Kok, 2005; Wężyk et al., 2009) and in this aspect present analyses based on LiDAR point clouds to indicate the structure of vegetation (Kolecka, 2018; Szostak et al., 2018).

Monitoring of LULC changes is essential in terms of European Union programmes on assessment of biomass, renewable energy and problems around CO_2 sequestration (Susyan et al., 2011). Within the framework of simplifying and modernizing the common agricultural policy, the European Commission (2018) accepted new rules, which for the first time clearly allow the application of modern technologies during the control of subsidies for farms and agricultural holdings. According to these regulations, physical control visits to farms can be replaced with automated systems based on the analysis of the data from earth observations. This will allow for using satellite images and other data from the earth observations during the process of checking that farmers are complying with the requirements of the European Union in terms of area payments – either direct payments to farmers or payments within the framework of the support of the development of rural areas. This will lead to a reduction in the number of check-up visits to agricultural holdings. As the European Commission states, visits in the field will only be necessary if digital evidence is not sufficient to verify compliance with the application. The proposed new approach to monitoring uses satellite or observation technologies. These data are then automatically processed with the help of computer algorithms which can define, e.g., an example of the use of land in agricultural areas. This information is then compared and combined with existing information in the system regarding the identification of agricultural plots, referring to each individual application for help in assessing whether payment can be made.

The aim of this study was to investigate the possibilities of using LiDAR (Light Detection and Ranging) data – Airborne Laser Scanning (ALS) point clouds for monitoring LULC changes, mainly with regard to forest succession on agricultural land and for indicating diversity in the vertical and horizontal structure of vegetation. LiDAR technologies allow the definition of many indices characterizing various aspects of vegetation (Alberti et al., 2013; Andersen et al., 2006; Hyyppä et al., 2004; Maier et al., 2008; Maltamo et al., 2004; McGaughey et al., 2004; Naesset and Okland, 2002; Tompalski, 2012; Wężyk et al., 2008). In this study, parameters such as the height of vegetation, standard deviation of height and cover density, will be calculated to obtain information about the process of forest succession.

2. Methods

The study area (Figure 1) is in the central west part of Poland – the locality of Pracze, Milicz district, voivodeship of Lower Silesia (51°28′30″ N, 17°12′30″ E). In previous studies (Szostak et al., 2014; Szostak et al., 2018; Wężyk et al., 2009), monitoring of

LULC changes and the process of secondary forest succession has been started for this area. Analysed parcels are situated close to the State Forests (administered by the State Forest National Forest Holding). In these areas – directly adjacent to forests, we can very often observe examples of agricultural production abandonment and the beginning of uncontrolled forest succession.

a)

b)

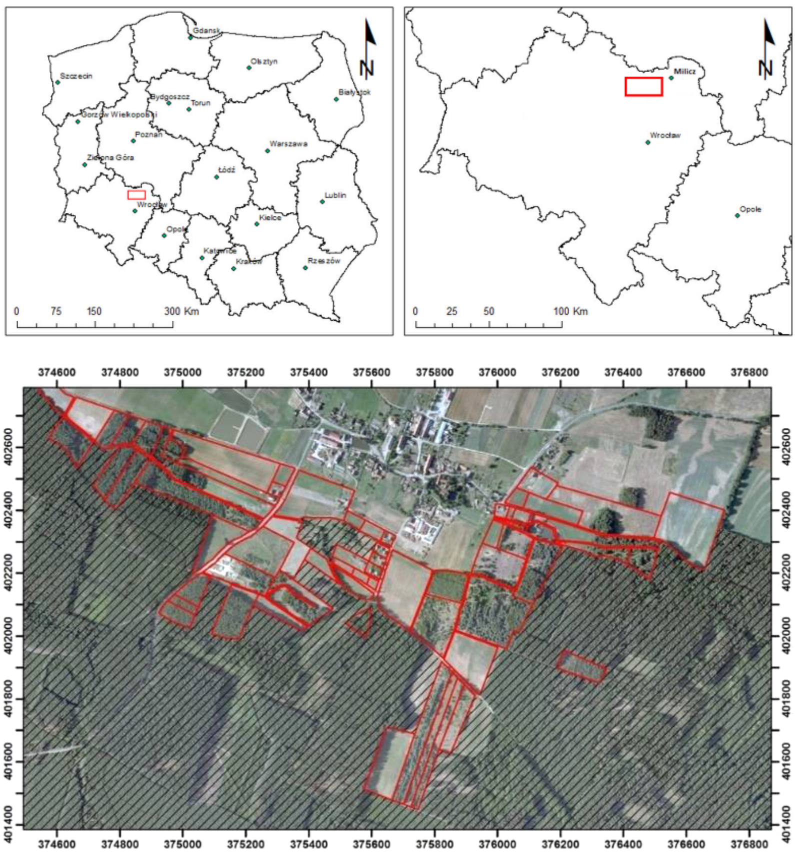


Fig. 1. The study area: a) general map of Poland, b) analysed plots – plots of the state forest marked in red – hatched area. Background: orthophotomap (source: Main Office of Geodesy and Cartography; coordinate system: PL-PUWG 1992)

The study was carried out based on ALS point clouds (2015) from the REMBIOFOR project (4 points/m^2, ALTM 3100 Optech laser scanner; Jagodziński et al., 2018; Socha et al., 2017; Stereńczak et al., 2018). The results were compared with those of previous studies (Szostak et al., 2014, Szostak et al., 2018; Wężyk et al., 2009) based on point clouds from the year 2007 taken from the Directorate General of State Forests in the Warsaw research project (14 points/m^2, TopoSys Falcon II scanner; Wężyk et al., 2008) and from the year 2012 taken from the ISOK project (6 points/m^2, source: Main Office of Geodesy and Cartography (Główny Urząd Geodezji i Kartografii; GUGiK; *projekt “Informatyczny System Osłony Kraju przed nadzwyczajnymi zagrożeniami”*).

The processing of ALS point clouds (2015) was started by preparing a Digital Terrain Model (DTM) based on the automatic approximation of the points of the "ground" class, a Digital Surface Model (DSM) based on points from the other classes and a normalized DSM (nDSM) where the relative altitude is determined as the difference between the absolute altitude of a given point and the place found exactly under this point on the DTM surface. DTM and DSM preparation was performed using the *GridSurfaceCreate* and *CanopyModel* functions in FUSION Version 3.50 (R.J. McGaughey, Pacific Northwest Research Station; McGaughey, 2012) together with LAStools (rapidlasso GmbH). nDSM (DSM-DTM) was generated in ArcGIS (Esri).

Analysis of the spatial range of the secondary forest succession was carried out using reclassified nDSM (Figure 2). Reclassification of the nDSM (*Reclassify*, ArcGIS, Esri) was carried out using > 1 m, > 2 m and > 3 m for the pixel value, representing the height of vegetation above the ground (Szostak et. al., 2014; Szostak et al., 2018; Wężyk et al., 2009). To prepare the area nDSM > 1 m, > 2 m and > 3 m inventories for the whole study area, the *Zonal Statistics as Table* function (ArcGIS, Ersi) was applied.

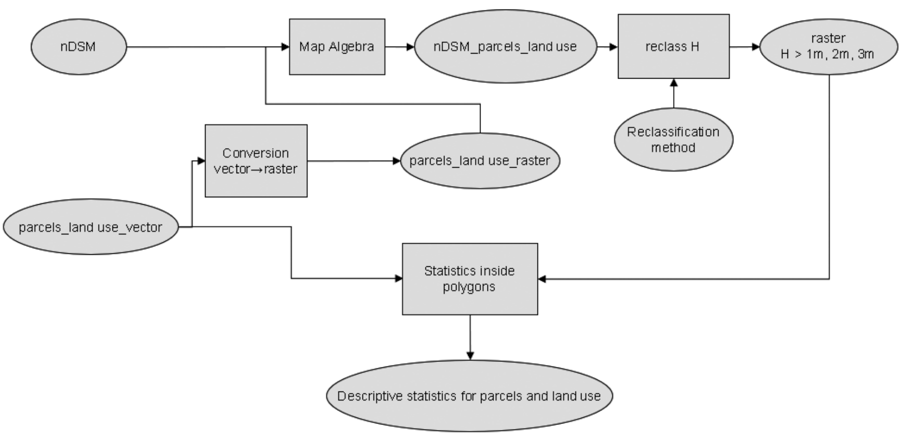


Fig. 2. The scheme of analysis

ALS data were also used also for obtaining precise information about the structure (2D and 3D) of vegetation. Using FUSION software (with LAStools), the height of vegetation was calculated (*GridMetrics* and *CloudMetrics*) as the value of the 95th percentile of relative altitude of the ALS point cloud, indicating the height below which there are 95% points (Naesset, 2002) and the cover density was also calculated (*Cover*; McGaughey, 2012).

3. Results

Official (cadastral) data are presented in Figure 3. In the study area in the cadastral database there were *Forest* (F), *Arable land* (A), *Meadow* (M), *Pasture* (P) and *Other* (O) classes. The results of the reclassification nDSM at height > 1 m are presented in Figure 4.

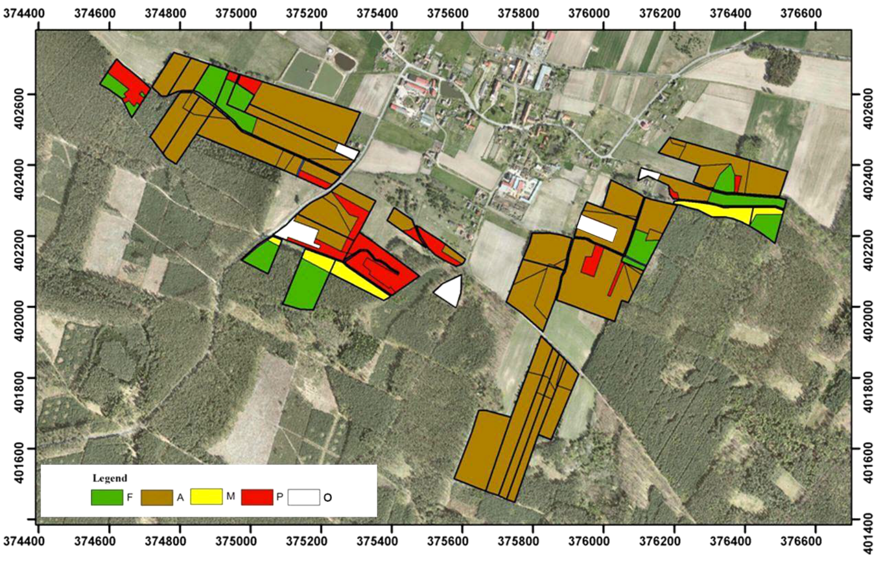


Fig. 3. The study area – cadastral data

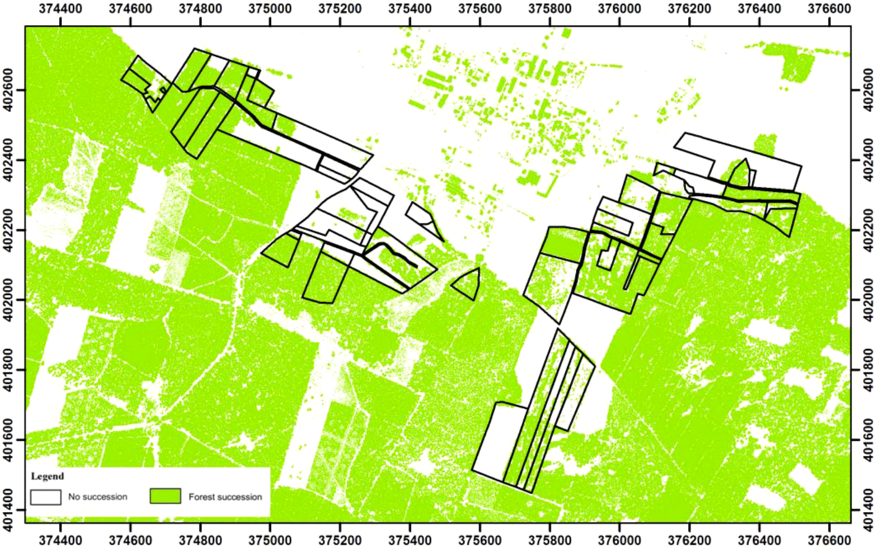


Fig. 4. The study area – reclassified nDSM (height > 1 m)

The study area is an example of forest succession on abandoned agricultural parcels. The total areas of LULC classes as a result of nDSM (ALS data, 2015) reclassification are presented in Table 1. Changes in total areas of LULC classes between 2007, 2012 and 2015 (Table 1) were calculated using nDSM > 1 m for the year 2015 and the results from previous studies for the year 2012 (Szostak et al., 2018) and the year 2007 (Szostak et al., 2014; Wężyk et al., 2009).

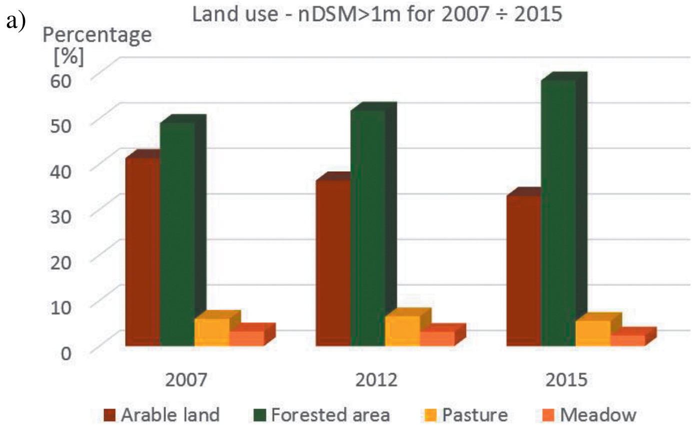
Table 1. Land use in the study area – result for ALS data processing (nDSM)

LULC classes	Area [ha] / Percentage [%]					
	Cadastral data	ALS 2015			Difference	
		nDSM > 1 m	nDSM > 2 m	nDSM > 3 m	2015÷2012	2015÷2007
Forested area (F)	5.73	23.87	23.19	22.59	2.73	4.03
	14.00	58.35	56.69	55.22	6.66	9.85
Arable land (A)	27.53	13.51	13.99	14.50	−1.40	−3.40
	67.28	33.02	34.21	35.44	−3.42	−8.31
Pasture (P)	4.14	2.23	2.38	2.45	−0.41	−0.22
	10.12	5.46	5.84	6.01	−1.00	−0.53
Meadow (M)	2.05	0.96	0.97	0.98	−0.32	−0.34
	5.01	2.34	2.8	2.40	−0.78	−0.83
Other (O)	1.45	0.35	0.39	0.40	−0.58	−0.07
	3.54	1.0	0.9	1.0	−1.42	−0.17
Total area	40.92 ha					

The results of the reclassified nDSM (2015) at heights > 1 m, > 2 m and > 3 m show similar trends in the forest succession process as the previous studies (Szostak et al., 2014; Szostak et al., 2018). In the study area, more than three times as much forested and wooded area was detected than had been recorded in official databases. We observed that the increase in the process of secondary forest succession – the area for nDSM > 1 m – for *Forested area* (F) was 1.66% higher than for nDSM > 2 m and 3.13% higher than for nDSM > 3 m. The same trend was seen in the previous studies (Szostak et al., 2014; Szostak et al., 2018) based on analyses of ALS data from 2007 and 2012.

The progress of secondary forest succession in terms of the occupied area was confirmed. The greatest changes in the total areas of the various LULC classes between 2007 and 2015 (Table 1, Figure 5) occurred for *Forested area* (F) and *Arable land* (A). Comparing nDSM > 1 m results for 2007, 2012 and 2015, we notice a decrease in *Arable land* and an increase in *Forested area*. The total decrease in *Arable land* area between 2007 and 2015 was −3.40 ha (−8.31% in the analysed study area) and the increase in *Forested area* was 4.03 ha (9.85%).

The results of point cloud processing (nDSM, 2015 and 2007) are shown in Figure 6. We can see how many changes (increases in forest succession processes) occurred in the analysed area.



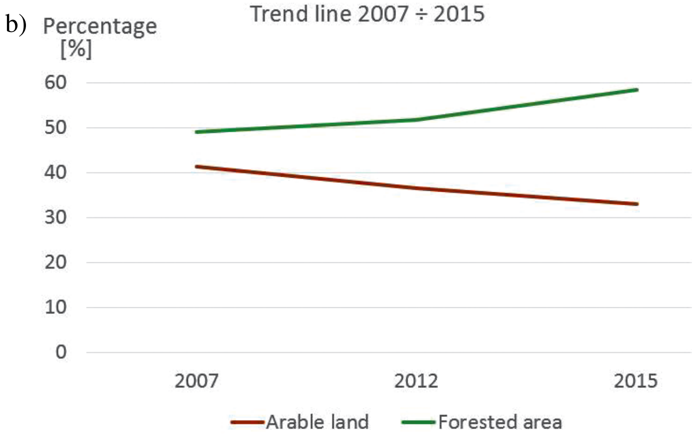
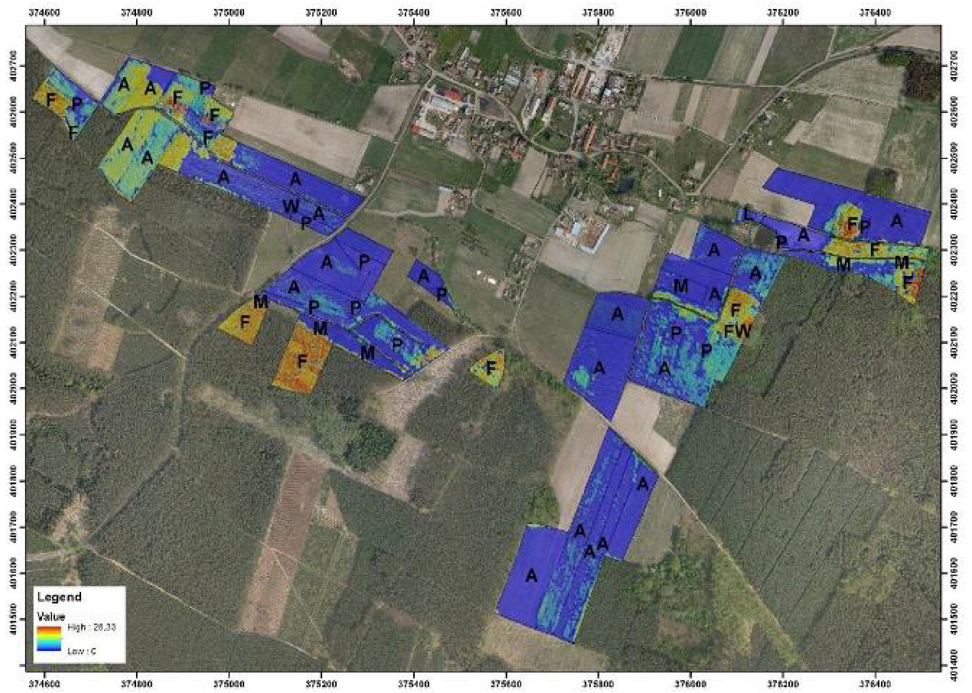


Fig. 5. Land use in the study area between 2007 and 2015: a) nDSM > 1 m;
b) trend line for classes *Arable land* and *Forested area*

Using ALS data, the progress of secondary forest succession, not only in terms of the occupied area but also in terms of the growth of trees and shrubs, was confirmed. In terms of the growth of trees and shrubs, precise parameters were calculated: the value of vegetation height (95th percentile) and the standard deviation of height. Processing of point clouds from 2007, 2012 and 2015 shows that the mean height of the vegetation in the forest succession area was: in 2007 – 11.91 m, in 2012 – 12.20 m and in 2015 – 14.97 m, i.e., an increase in height of 0.29 m during the period 2007÷2012, 2.77 m during the period 2012÷2015 and a total increase of 3.06 m for the whole period 2007÷2015. The cover density was also calculated, giving the results: 2007 – 39.5%, 2012 – 40.6% and 2015 – 55.3%. The cover density value also increased in the study area between 2007 and 2015.

The graphical results of point cloud (2015) processing: vegetation height (95th percentile) and standard deviation of height are presented in Figure 7.

a)



b)

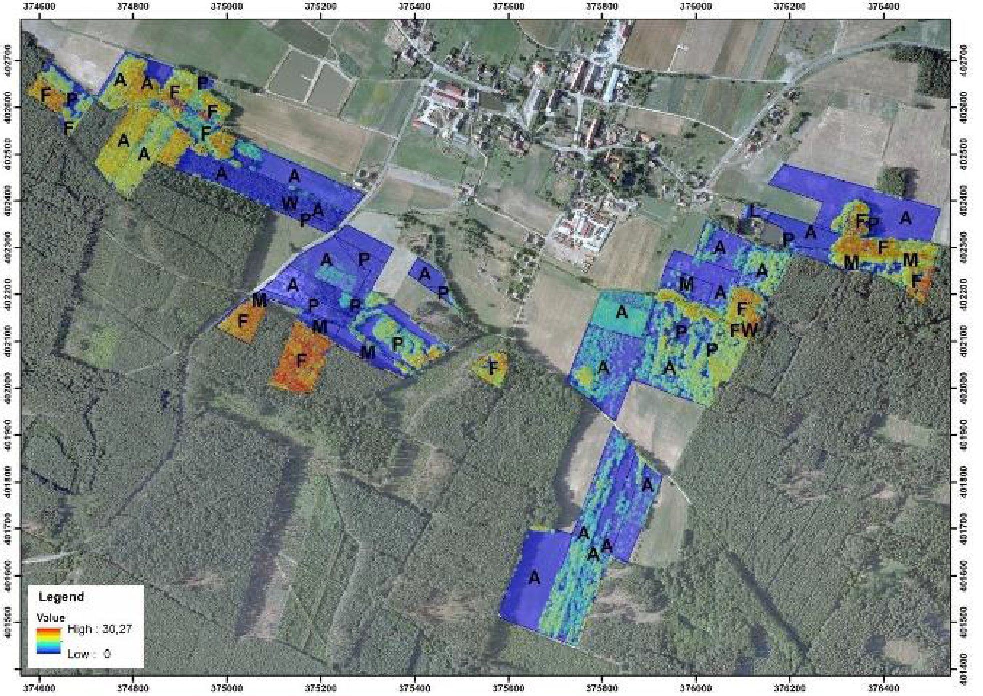


Fig. 6. Forest succession area: nDSM 2007 (a) and 2015 (b); background: orthophotomap

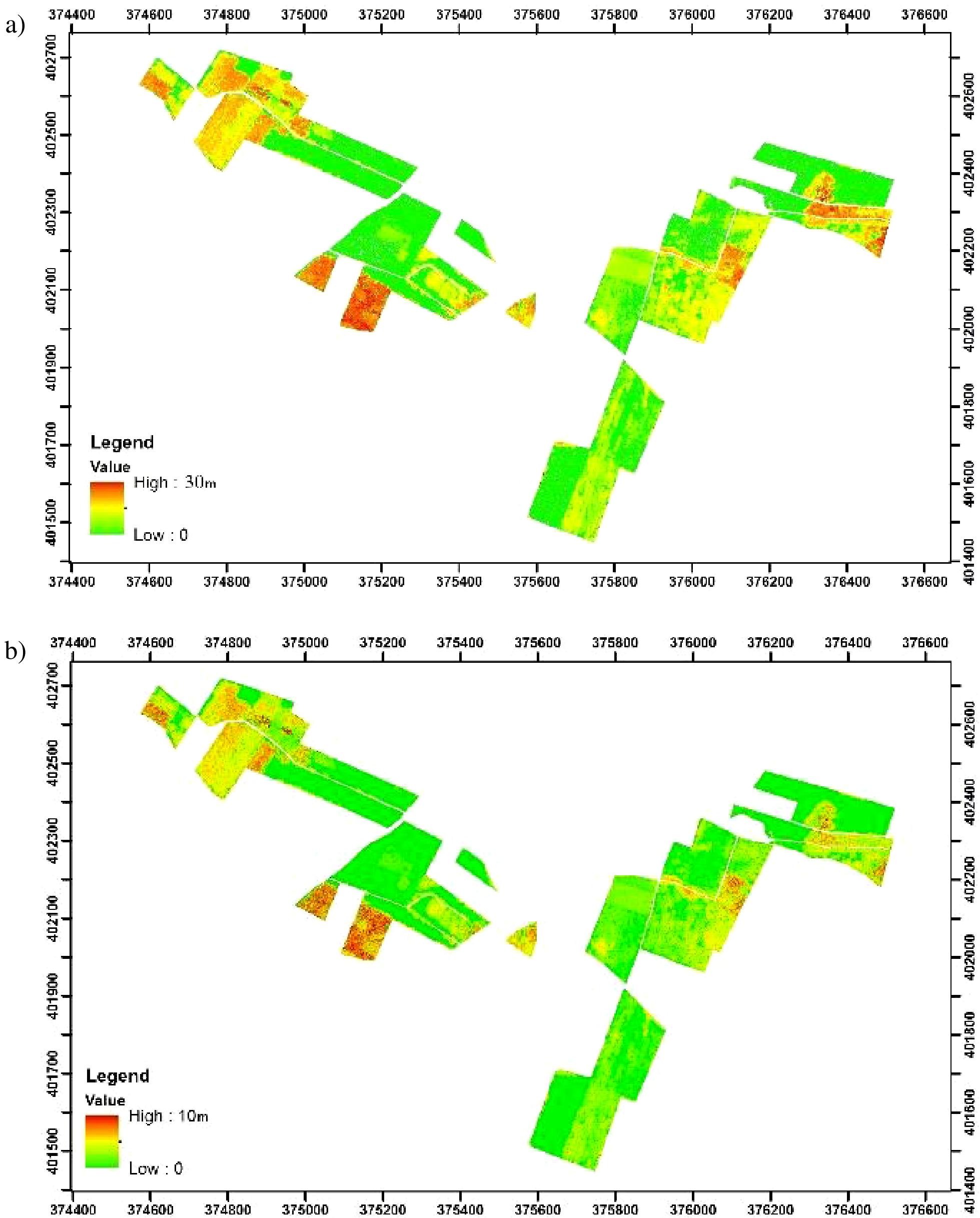


Fig. 7. The results of point cloud (2015) processing: a) vegetation height (95th percentile); b) standard deviation of height

As the final step in analysing forest succession, a map of height changes in vegetation was prepared for the period 2007÷2015 (Figure 8).

At the end of the study, an assessment of LiDAR point clouds was made for automation of the mapping process of forest succession for general areas near State Forest

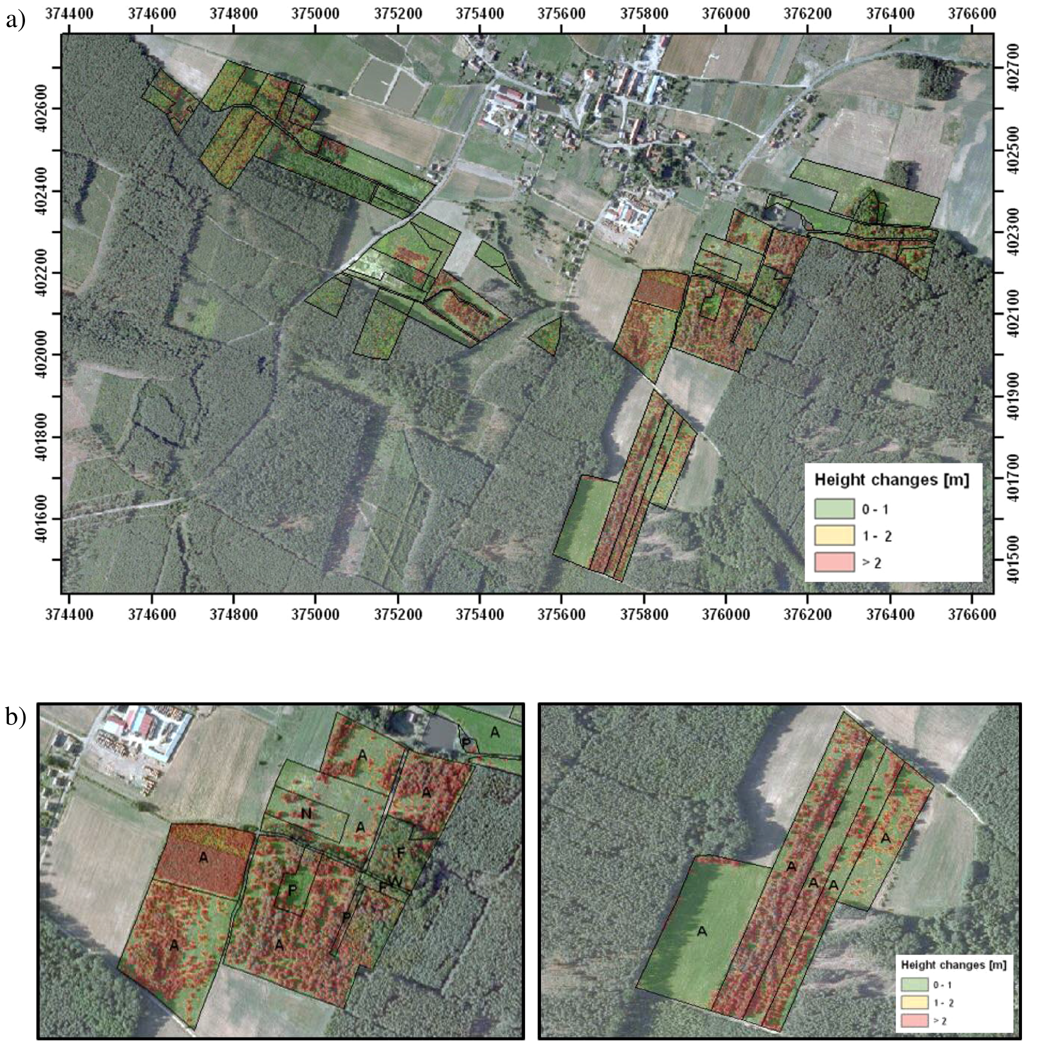


Fig. 8. Forest succession area: a) increase in height of vegetation (2007÷2015); b) selected parts of the map, as examples of the largest height changes

parcels in Milicz (Figure 9; Błajda, 2015), based on ALS data (2012) from the ISOK project.

Based on reclassified nDSM, abandoned land was selected as an example of forest succession areas. These parcels had a total area of 282.50 ha. Detailed information about the results of the reclassification nDSM for > 1 m, > 2 m and > 3 m cadastral data and the results of manual vectorization of the orthophotomap (GSD: 0.25 m; coordinate system: PL-PUWG 1992; ISOK project, 2012) for this area, are presented in Table 2. The results showed similar results for the general parts of Milicz to the results for the study area. We can see an increase in total the forest succession total area – three times as much *Forested area* (F) than had been recorded in the cadastral database. We notice at the other site a decrease in the following classes: *Arable land* (A), *Meadow* (M) and *Pasture* (P).

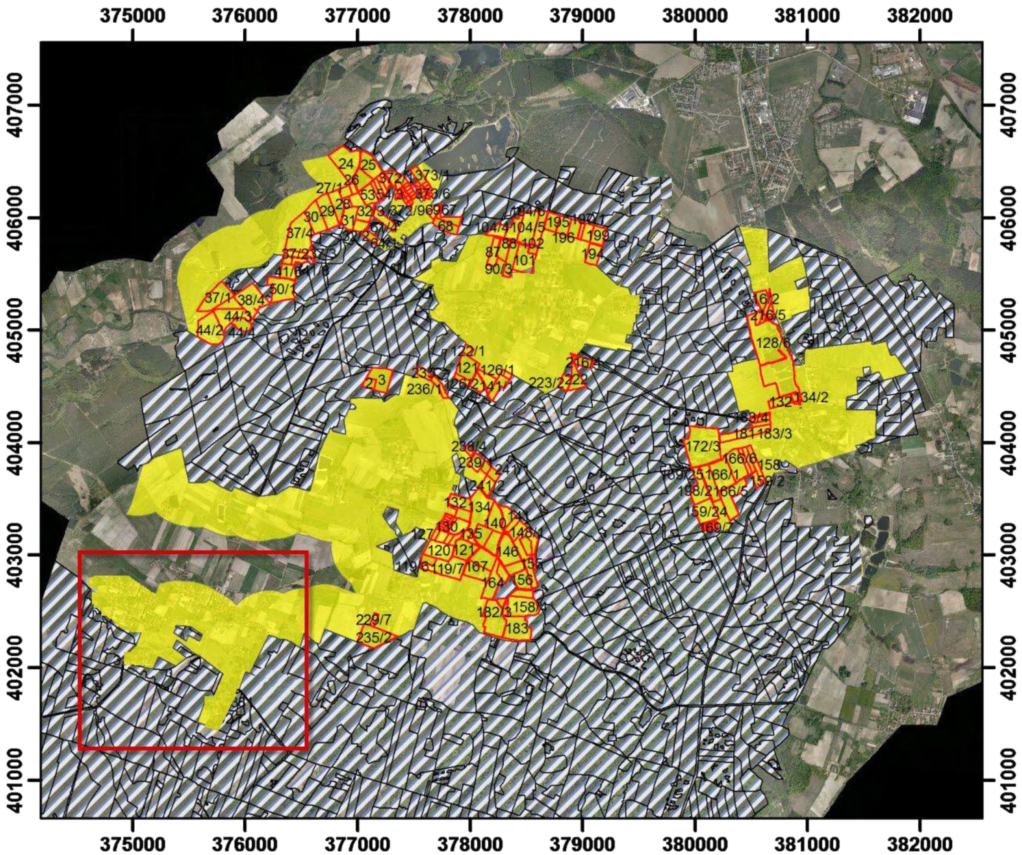


Fig. 9. Mapping forest succession area in Milicz: State Forest plots – hatched area, the study area – red rectangle, analysed area close to the State Forest parcels – yellow, land abandonment (forest succession) – red parcels with numbers (background: orthophotomap)

The results (Table 2) confirmed the possibility of using ALS point clouds for automation in mapping land use and land cover changes, mainly land abandonment and the process of secondary forest succession. The results of the reclassification nDSM > 1 m for general parts of Milicz are similar to the results of traditional methods, i.e., manual vectorization of the orthophotomap. For the main classes it was: 1.61 ha (0.57%) difference in *Forested area* (F) and 1.36 ha (0.48%) in *Arable land* (A). Comparing these results with those of previous studies (Szostak et al., 2014; Szostak et al., 2018) confirmed that good results can be obtained using ALS point clouds. The results are better than using classification of Sentinel-2 images (Szostak et al., 2018).

Table 2. Land use for general parts of Milicz – results for ALS data processing

LULC classes	Area [ha]				
	Percentage [%]				
	Cadastral data	ALS 2012			Orthophoto
		nDSM > 1 m	nDSM > 2 m	nDSM > 3 m	
Forested area (F)	33.84	94.06	86.09	79.73	92.45
	11.98	33.30	30.48	28.22	32.73
Arable land (A)	113.06	81.2	85.71	89.64	82.56
	40.02	28.74	30.34	31.73	29.22
Pasture (P)	37.68	29.76	30.46	31.02	28.87
	13.34	10.53	10.78	10.98	10.22
Meadow (M)	79.53	66.38	68.19	69.3	65.74
	28.15	23.50	24.14	24.53	23.27
Other (O)	18.39	11.1	12.05	12.82	12.88
	6.51	3.93	4.26	4.54	4.56
Total area	282.50 ha				

4. Conclusions

The use of remote sensing spatial data from different periods of time, offers the possibility of monitoring changes taking place in the environment. New European Union regulations allow willing states to replace or supplement their control system for agricultural holdings with an automated and less resource-consuming system. The European Commission states that several member states have already expressed an interest in using new technologies. Advantages for the national administration could include a more integrated process of communication with farmers, simpler administrative procedures because of the smaller number of visits and more flexible processes for submitting applications.

According to this statement, due to the use of LiDAR data, an exact assessment of many biometric features of vegetation connected with the spatial distribution of the point cloud is possible. These indicators are often defined for the needs of planning and the inventory, and for mapping plant associations. Geoinformation technologies show great potential for carrying out large-area studies of the spatial vegetation structure. Point clouds generated based on images from UAV can also be used for this purpose. In 2018 new satellite laser scanning mission began (GEDI and ICESat-2), so in future we can also test the possibilities of using these satellite data for detecting and monitoring forest succession areas.

In the presented study, collected airborne laser scanning point clouds showed significant differences in the spatial structure of vegetation. This diversity is visible in the surface size (2D), the vertical vegetation structure (3D) and the time dimension (4D).

Differentiated vertical structures of vegetation indicate a long-lasting natural process of forest succession on abandoned agricultural land. Using ALS point clouds allowed wider and more precise definitions of the spatial structure of vegetation than in the case of work using orthophotomaps alone. The application of the processed ALS data allowed objective and relatively accurate assessment of the spatial structure of vegetation.

Acknowledgements

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