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Original paper

Forest succession mapping for post-agricultural areas using Sentinel-2, PlanetScope imageries and LiDAR data

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Abstract: The research investigates the possibility of applying Sentinel-2, PlanetScope satellite imageries, and LiDAR data for automation of land cover mapping and 3D vegetation characteristics in post-agricultural areas, mainly in the aspect of detection and monitoring of the secondary forest succession. The study was performed for the tested area in the Biskupice district (South of Poland), as an example of an uncontrolled forest succession process occurring on post-agricultural lands. The areas of interest were parcels where agricultural use has been abandoned and forest succession has progressed. This paper indicates the possibility of automating the process of monitoring wooded and shrubby areas developing in post-agricultural areas with the help of modern geodata and geoinformation methods. It was verified whether the processing of Sentinel-2, PlanetScope imageries allows for reliable land cover classification as an identification forest succession area. The airborne laser scanning (ALS) data were used for deriving detailed information about the forest succession process. Using the ALS point clouds vegetation parameters i.e., height and canopy cover were determined and presented as raster maps, histograms, or profiles. In the presented study Sentinel-2, PlanetScope imageries, and ALS data processing showed a significant differentiation of the spatial structure of vegetation. These differences are visible in the surface size (2D) and the vertical vegetation structure (3D).

Keywords: image processing, secondary forest succession, airborne laser scanning, spatial analysis

1. Introduction

The succession of forest-type plant communities on post-agricultural lands is a very frequent process (Bergen and Dronova, 2007; Bowen et al. 2007; Ruskule et al., 2012). Secondary forest succession takes place on a large scale, and changing economic and demographic conditions intensify this phenomenon (Szwagrzyk, 2004). Land abandonment is influenced by many factors (Gniadek et al., 2017; Smigielski et al., 2017) such as distance from forest complexes, the structure of agricultural plots, demographic changes in rural areas, and migration of rural residents to cities. Monitoring changes in land cover, in particular identifying areas of secondary forest succession, is important in terms of proper land management, granting direct subsidies to agriculture (Szostak et al., 2014; Wezyk et al., 2009) but also extremely significant in terms of increasing the forest cover, determining biomass, issues of renewable energies, and carbon sequestration (Susyan et al., 2011).

The mapping of areas left for natural afforestation is also valid in terms of human safety and environmental protection. It is significant in terms of monitoring the risk of fire, directly in areas where agricultural use is stopped, where forest vegetation is formed, and in the aspect of the fire reaching the complexes of commercial forests or protected or urban areas.

The process of detecting and monitoring changes in land cover, including the succession of vegetation on abandoned farmland, is of wide scientific interest. This study indicates the possibility of automating the process of monitoring wooded and shrubby areas developing in post-agricultural areas by using modern geodata and geoinformation methods based on Sentinel-2 images and laser scanning data.

2. Methods

The study area (Fig. 1) is located in the south of Poland (49° 58′ N, 20° 08′ E) – Biskupice village in Wieliczka district, Malopolska Voivodeship. Analyzed area considers of plots, located between the national road no. 94 and the voivodeship road no. 966. The area was characterized by significant examples of the secondary forest succession process.

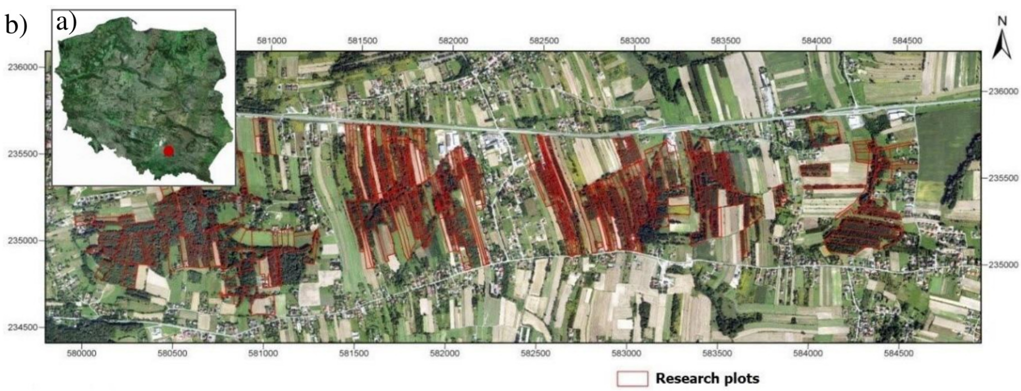

Fig. 1. The study area: a) general map of Poland and b) analyzed plots (abandoned farmlands) – marked red, (background: orthophotomap, 2019; coordinate reference system: PL-PUWG1992)

The study was carried out based on:

– Sentinel-2 satellite imagery (bands: Blue – B, Green – G, Red – R, NIR, pixel size: 10.0 m, date: 25.05.2019, European Space Agency – ESA). The Sentinel-2 satellite imageries (ESA, 2022) consist of two satellites (Sentinel-2A, launched in 2015, and Sentinel-2B, launched in 2017) equipped with multi-spectral high-resolution scanners (13 spectral channels – spatial resolution of 10 m, 20 m, and 60 m) and short revisit time (5 days with two satellites);

- PlanetScope satellite imagery (bands: B, G, R, NIR, pixel size: 3.9 m, date: 05.07.2019). The PlanetScope satellite constellation consists of multiple launches of groups of individual CubeSats (DOVEs; 10 cm × 10 cm × 30 cm) and can image nearly all of Earth's land every day (Planet, 2022);
- LiDAR (Light Detection and Ranging) data – airborne laser scanning (ALS) point clouds (6 points/mm^2, 2019, source: Main Office of Geodesy and Cartography, ISOK project, *pl.* "*Informatyczny System Osłony Kraju przed nadzwyczajnymi zagrożeniami*");
- orthophotomaps (GSD: 0.25 m, 2019, coordinate reference system: PL-PUWG1992);
- cadastral data (portals: GEOPORTAL and WEBEWID).

Sentinel-2 images were downloaded (Copernicus Program, ESA) with the specification of parameters such as acquisition date, and maximum cloud cover. Images preprocessing was done in SNAP software (ESA). The research area was selected (cropped at the image), the channels: R, G, B, and NIR were recorded, exported to the *dim* format, and finally, *tiff* was performed. The supervised classification was carried out in ArcGIS Pro (*Support Vector Machines* method) based on the photointerpretation keys (training plots – GNSS measurements; *Training Samples Manager*) prepared for RGB and CIR (color infrared) compositions. The number of training points was as follows: Forested areas – 202 points, Arable lands – 133, Meadows or Pastures – 168, and Others (buildings, roads, etc.) – 183.

The classification result was generalized (*Majority Filter, Boundary Clean*; ArcGIS Pro). The assessment of the classification results was carried out (based on validation points) by determining: Producer's Accuracy (PA), User's Accuracy (UA), and Overall Accuracy (OA).

The validation points were chosen for each class from the test areas (not including the training areas; *Create Accuracy Assessment Points*, ArcGIS Pro). The number of validation points was as follows: Forested areas – 32 points, Arable lands – 42, Meadows or Pastures – 67, and Others – 11.

Sentinel-2 imageries were compared with the PlanetScope image classification results. The results of image classification were also confronted with photointerpretation of the orthophotomaps and reclassification of ALS point clouds.

The processing of ALS point clouds was started by generating the following models: Digital Terrain Model (DTM) – based on the automatic approximation of the points of the „ground" class; Digital Surface Model (DSM) based on points from the other classes and normalized DSM (nDSM = DSM-DTM). It was done using functions *GridSurfaceCreate* and *CanopyModel* in FUSION software (McGaughey, 2012) with LAStools (rapidlasso GmbH). FUSION is a suite of software developed by station scientists to visualize and analyze airborne lidar data (FUSION, 2022).

The analysis of the spatial range of the secondary forest succession in parcels was carried out using the reclassified nDSM (ALS data). The reclassification of the nDSM (*Reclassify*, ArcGIS Pro) was carried out using a value > 1.0 m for the pixel, representing the height of vegetation above the ground (Wezyk et al., 2009; Szostak 2020). Areas with vegetation of a height below 1 meter are being treated as non-forest.

For deriving information about the structure (2D and 3D) of vegetation the FUSION software was also used – the height of vegetation (*GridMetrics and CloudMetrics*) was calculated as a value of 95^{th} percentile (*P95*) of relative altitude of the ALS point cloud, indicating the height below which there are 95% points (Naesset, 2002). The standard deviation of the height and canopy cover (defined with values of 0%–100%) was also calculated (*Stddev*, and *Cover*; McGaughey et al., 2004). Visualizations of the vertical vegetation structure in the form of histograms were done using *Densitymetrics* – information on the number of laser points reflected from the vegetation, in one-meter vertical intervals for the subsequent cells of the raster (McGaughey, 2012).

3. Results and discussions

In the analyzed area we identified 277 plots (a total area has 139.77 ha), characterized as examples of the forest succession process on abandoned arable lands. For the study plots in the cadastral database (Table 1), we identified classes: Forests, Arable lands, Meadows, Pastures, and Others. In the study were not analyzed parcels with all area class as Forests but parcels with a part as a class Forests and another part as a Meadows, Pastures or Arable lands. Very often these parcels were identified as forest succession areas. The land cover classes as a result of Sentinel-2 classification (Sadkowski, 2021) are shown in Figure 2 and the identified forest succession areas in Figure 3.

Table 1. Land cover classes for the plots in the study area – the results for images classification

Land cover classes	Cadastral data	PlanetScope	Sentinel-2	Ortho	ALS
	Area (ha)				
	Percentage (%)				
Forests and forest succession area	10.76	62.77	65.08	56.32	60.64
	7.70	44.91	46.56	41.73	43.39
Meadows, Pastures	101.38	57.69	56.75	Not analyzed	Not analyzed
	72.53	41.27	40.60		
Arable lands	26.39	18.37	16.52		
	18.88	13.14	11.82		
Others	1.24	0.94	1.42		
	0.89	0.67	1.02		
Total	139.77 ha				
	100%				

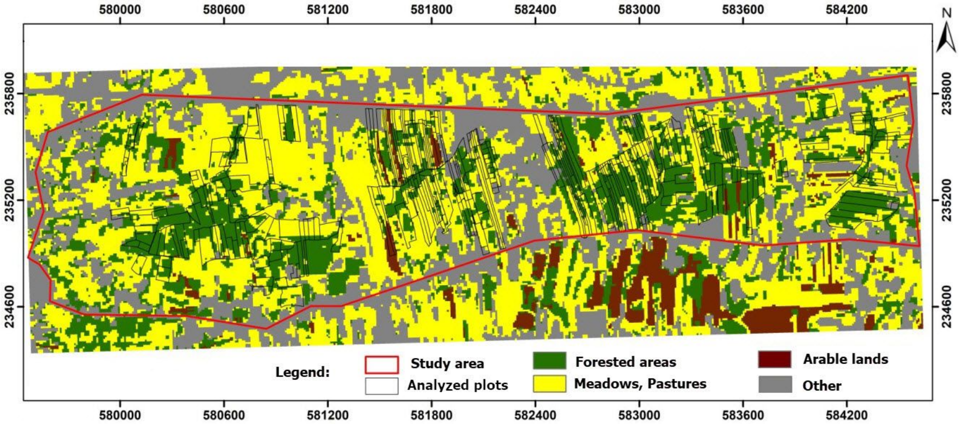

Fig. 2. The study area – results of Sentinel-2 image classification

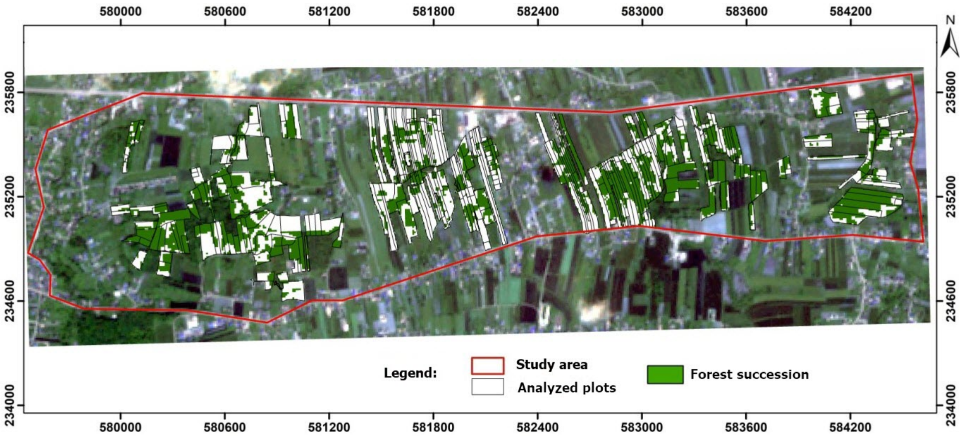

Fig. 3. The forest succession area on analyzed abandoned farmlands

The accuracy assessment parameters for land cover classes were in values: Forested areas – PA: 0.96, UA: 0.91, Arable lands – PA: 0.99, UA: 0.93, Meadows or Pastures – PA: 0.92, UA: 0.98, and Others – PA: 0.90, UA: 0.99. The total parameter – Overall Accuracy was in the value of 0.96.

The result of image classification showed Forests and forest succession areas in total values (Table 1): 65.08 ha as a result of Sentinel-2 image classification (62.77 ha – PlanetScope), which takes 46.56% of the analyzed plots (44.91% – PlanetScope). The intense process of secondary forest succession in terms of the occupied abandoned farmland area has been confirmed. Forested lands take values around six-time (almost 40% difference in percentage area) areas more than figured in the cadastral database (10.76 ha; 7.70%). Mainly it is a result of the abandonment of Meadows and Pastures. Photointerpretation and manual vectorization of the orthophotomaps identified Forested areas (Forests and forest succession) in a value of 56.32 ha (41.73% of the analyzed area), so the difference in total Forested areas according to the PlanetScope image classification results is in value of –4.45 ha (–3.18% of the analyzed area) and for Sentinel-2 as –6.76 ha (–4.84%). Using the reclassification nDSM (ALS point clouds) method as a height > 1.0 m takes the result in value: 60.64 ha as Forested areas (43.39%), so differences are respectively: PlanetScope –2.13 ha (–1.52%) and Sentinel-2 in value –4.44 ha (–3.18%).

The conclusion is that using Sentinel-2 image classification we can get results in identifying forested areas with a difference of around 1.65% in percentage area according to the results of PlanetScope image classification and in value 3–5% difference according to the ALS point clouds processing or photointerpretation and manual vectorization of the orthophotomaps.

We can see how many farmlands abandonment and increased forest succession process is in the study 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 can be shown.

In terms of the growth of trees and shrubs, there were calculated parameters (Bochenek, 2019): the value of vegetation height (95^{th} percentile, Fig. 4), the standard deviation of height, and cover density (Fig. 5). We can observe a more advanced process – the greater height and cover density of forest succession on the left side of the analyzed area.

Figure 6 presents an example of the forest succession area (abandoned arable land plots – R) with a profile generated from the ALS point clouds and histogram (numbers of points) to present optimal information about the vegetation's spatial characteristics.

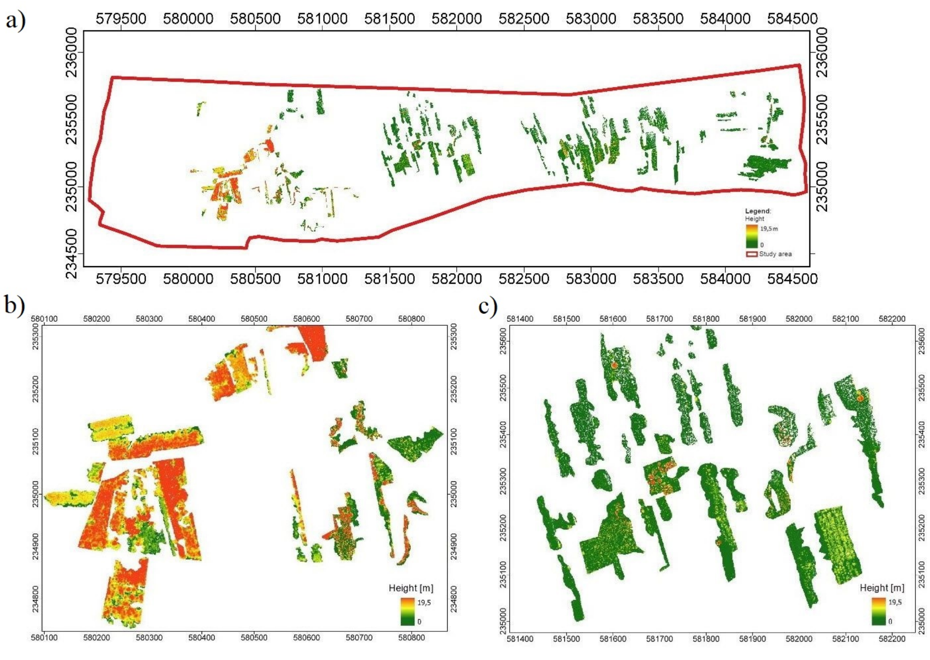

Fig. 4. The results of the ALS point cloud (2019) processing – vegetation height (95th percentile): a) analyzed area, b) left part, c) middle part

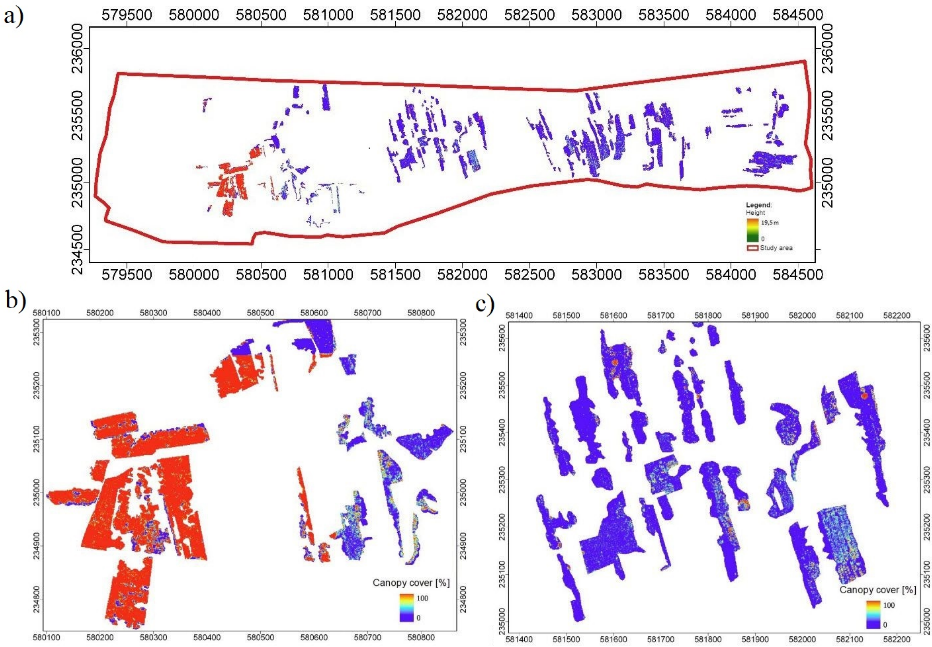

Fig. 5. The results of the ALS point cloud (2019) processing – canopy cover ([0–100%]): a) analyzed area, b) left part, c) middle part

Fig. 6. a) Part of the forest succession area

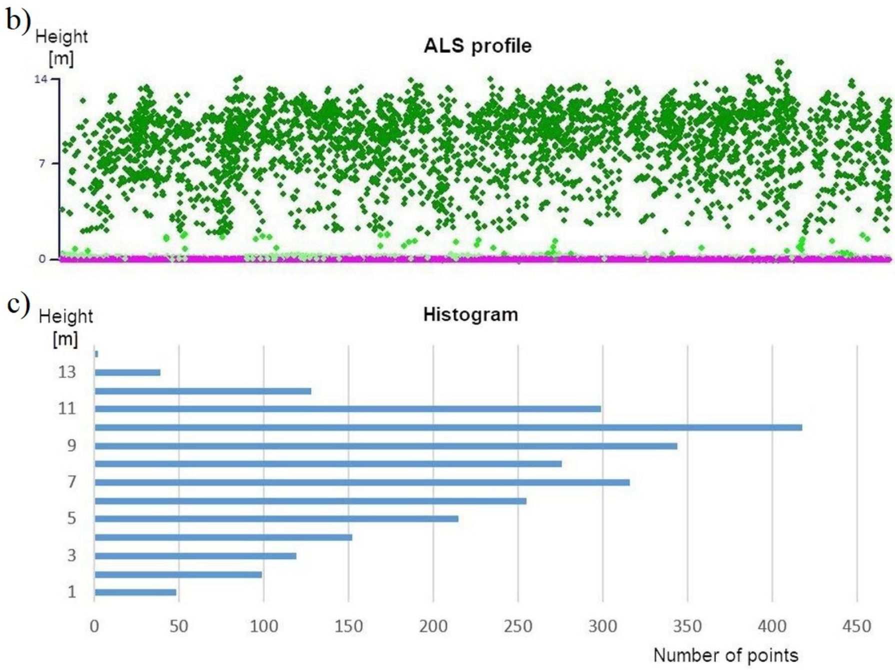

Fig. 6. a) Part of the forest succession area; b) ALS point clouds profile and c) histogram (number of points)

4. Discussion

There are different forest definitions in law over the world as a result of the different characteristics of forest vegetation and the different forms of land use and forest management. There are also political and economic reasons why different countries consider certain areas forests or not (Putz and Redford, 2009; Sasaki and Putz, 2009).

In Poland, forests are defined in the Forest and Cadastral Acts (Journal of Laws, 1991; 2021). The Food and Agriculture Organization of the United Nations (FAO/UN, Forest Resources Assessment, 2004; 2007; 2012) also defined forest lands. The main difference is that post-agricultural areas with forest succession are not considered forests in Poland (due to land use), contrary to the FAO/UN definition (Jablonski, 2015; Jablonski et al., 2017).

The forest cover in Poland, concerning the National Program for Increasing Forest Cover (2003), constitutes 30% of the country's area, and in 2050 it is proposed to value 33%. In this regard, it should be mentioned that the actual forest cover of the country is higher than shown in the data of the Central Statistical Office (Hoscilo et al., 2016; Jablonski et al., 2018). Forecasts of the forest cover growth and plans for afforestation in Poland do not consider the phenomenon of secondary forest succession, and natural forest succession is beyond the reach of official monitoring.

The usage of remote sensing spatial data from different periods offers the possibility of monitoring changes taking place in the environment especially the process of forest succession (Falkowski et al., 2009; Prishchepov et al., 2012; Kolecka, 2016; Lasanta et al., 2017). Aerial and satellite imageries have been successfully used since the early 2000s to estimate the area of forested lands. Satellite image classification and LiDAR technology offer possibilities for collecting 2D/3D information and allows for mapping cover classes and definition of many indices characterizing vegetation so providing possibilities for monitoring land cover, together with the identification of the spatial parameters of the vegetation.

Using Sentinel-2 (ESA) imageries opens up new possibilities in environmental studies (Sekertekin et al., 2017; Forkuor et al., 2018; Marangoz et al. 2018; Szostak et al., 2019a; 2019b; 2020) mainly as a result of the good spatial and spectral resolution. Airborne laser scanner (ALS) point clouds give additional data to perform spatial characteristics of vegetation. ALS is a useful, large-area, and objective method for deriving information about the structure (2D and 3D) of vegetation (Naesset, 2002; Naesset and Okland, 2002; Hyyppä et al., 2004; Maltamo et al., 2004; Andersen et al., 2006; Maier et al., 2008; Singh et al., 2012; Alberti et al., 2013; Kolecka et al., 2015; 2016; 2018; Szostak et al. 2020).

New European Union regulations (European Commission, 2019) allow the willing states to replace or supplement the control system in the agricultural holdings with automated actions. Several member states have already expressed the will to start new technologies – as the European Commission informs. Advantages for the national administration can include a more integrated process of communication with farmers, fewer administrative procedures, because of the smaller number of visits, and a more flexible process of submitting applications.

According to this statement due to the usage of the LiDAR data especially from airborne laser scanning or point clouds generated based on images from UAV (Koska et al., 2017; Ostrowski et al., 2017; Moudrý et al., 2019), objective and 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 mapping plant associations. Geoinformation technologies contain a great potential, to carry out large-area studies of the spatial vegetation structure.

5. Conclusions

Forests are an essential component of the Earth's ecosystem, sequestering carbon and providing a range of ecosystem services. Estimating the area of potential forests is very important due to the need for international reporting. The results presented in the study can support reporting to FAO/UN on the forest area. Estimation of forest area according to international definitions, considering land use and its future development is important in the context of reporting, and estimating carbon stocks and biodiversity to mitigate climate impacts.

In the presented study Sentinel-2 imageries and collected ALS data processing showed a significant differentiation of the spatial structure of vegetation. This diversity is visible in the surface size (2D) and the vertical vegetation structure (3D). Differentiated vertical structures of vegetation indicate a long-lasting natural process of forest succession on abandoned agricultural land. Using ALS point clouds allowed a wider definition of the spatial structure of vegetation than in the case of the work on the satellite imageries alone. The application of the processed Sentinel-2 and ALS data allowed objective and relatively accurate assessment of the range and spatial structure of vegetation.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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