Stereńczak *et al. Forest Ecosystems* (2018) 5:1
DOI 10.1186/s40663-017-0128-5

Forest Ecosystems

RESEARCH

Open Access

Delineation of homogeneous forest patches using combination of field measurements and LiDAR point clouds as a reliable reference for evaluation of low resolution global satellite data

Krzysztof Stereńczak[1*], Marek Lisańczuk[1] and Yousef Erfanifard[1,2]

Abstract

Backgrounds: There are many satellite systems acquiring environmental data on the world. Acquired global remote sensing datasets require ground reference data in order to calibrate them and assess their quality. Regarding calibration and validation of these datasets with broad geographical extents, it is essential to register zones which might be considered as Homogeneous Patches (HPs). Such patches enable an optimal calibration of satellite data/sensors, and what is more important is an analysis of components which significantly influence electro-magnetic signals registered by satellite sensors.

Methods: We proposed two structurally different methods to identify HPs: predefined thresholding-based one (static one), and statistical thresholding-based technique (dynamic one). In the first method, 3 different thresholds were used: 5%, 10%, and 20%. Next, it was aimed to assess how delineated HPs were spatially matched to satellite data with coarse spatial resolution. Selected cell sizes were 25, 50, 100, 250, and 500 m. The number of particular grid cells which almost entirely fell into registered HPs was counted (leaving 2% cell area tolerance level). This procedure was executed separately for each variant and selected structural variables, as well as for their intersection parts.

Results: The results of this investigation revealed that ALS data might have the potential in the identification of HPs of forest stands. We showed that different ALS based variables and thresholds of HPs definition influenced areas which can be treated as similar and homogeneous. We proved that integration of more than one structural variable limits size of the HPs, in contrast, visual interpretation revealed that inside such patches vegetation structure is more constant.

Conclusions: We concluded that ALS data can be used as a potential source of data to "enlarge" small ground sample plots and to be used for evaluation and calibration of remotely sensed datasets provided by global systems with coarse spatial resolutions.

Keywords: Forest structure, Stratification, Global satellite missions

---

* Correspondence: k.sterenczak@ibles.waw.pl
[1]Department of Forest Resources Management, Forest Research Institute, Sękocin Stary, 3 Braci Leśnej St, 05-090 Raszyn, Poland
Full list of author information is available at the end of the article

Background

There are many satellite systems acquiring environmental data on the world (Townshend and Justice 2002), such as Landsat (Cohen and Goward 2004), ALOS PALSAR – Advanced Land Observing Satellite Phased Array type L-band Synthetic Aperture Radar (Borner et al. 2007) or MODIS – Moderate Resolution Imaging Spectroradiometer (Justice et al. 2002). Various organizations and global scale programs, for instance, GMES – Global Monitoring for Environmental and Security, make the above mentioned data available to the society (Donlon et al. 2012). Depending on their spatial extents, such programs might be related to the specific country, continent, or entire Earth. Acquired global remote sensing datasets require ground reference data in order to calibrate them and assess their quality. Regarding calibration and validation of these datasets with broad geographical extents, it is essential to register zones which might be considered as homogeneous patches (HPs). Such patches enable an optimal calibration of satellite data/sensors, and what is more important allow analysis of components which significantly influence electro-magnetic signals registered by satellite sensors.

In remotely sensed datasets with wide geographical extents and coarse spatial resolutions, it seems difficult to conduct decent ground reference measurements, especially in forest sites. It should be considered that spatial resolution of these datasets may vary from few meters even up to several kilometers (Townshend and Justice 2002). Although total surveying enables a precise characterization of given area (e.g., a forest district), most of the time it is difficult to conduct such project over a vast areas due to its time consuming and labor intensive nature, which obviously entail tremendous time and financial contributions (Freese 1962).

Classical spectral data have series of limitations to be used as reference datasets, whereas Airborne Laser Scanners (ALS) have broader possibilities. The superiority of airborne laser scanning data is particularly visible in its possibilities for determination of 3D characteristics of woodlands and forests (Ferraz et al. 2012; McRoberts et al. 2012; Korpela et al. 2012; Amiri et al. 2016; Alexander et al. 2017; Kandare et al. 2017). For many years, ALS data were invaluable and very precise source of information about forest sites. Recently many investigations have been done related with determination of various stand characteristics such as growing stock volume, biomass, or time change analysis of the forest environment, based on ALS data (Holmgren 2004; Andersen et al. 2006; Martinuzzi et al. 2009; McRoberts et al. 2012; Wulder et al. 2012; Chirici et al. 2016; Bottalicoa et al. 2017).

Since large ground sample measurements in forests are almost impossible, it seems reasonable to use another source of data to "extend" small ground sample plots to establish HPs that can be implemented as reference or evaluation data. Many of above mentioned ALS related studies have explored the significant relationship between selected forest characteristics and statistical variables determined based on airborne laser point clouds. Therefore, we can conclude that ALS can be used as a potential source of data to "enlarge" small ground sample plots that can be used for evaluation and calibration of remotely sensed datasets provided by global systems with coarse spatial resolutions.

Delineation of homogeneous patches is possible when one or more characteristics of trees or stands (e.g., tree height, canopy cover, density) are considered in a forest ecosystem. However, stand Structural Variables (SVs) are relatively homogeneous across managed forests which may lead to better identification of HPs in such forests. As shown by recent studies, ALS data can describe three dimensional structure of forest stands to estimate SVs in order to identify HPs (Sverdrup-Thygeson et al. 2016; Alexander et al. 2017). If a starting point is set within the center of a sample plot with a predefined size and specific variables extracted from ALS data are assigned to the point, it is possible to find the adjacent parts of a forest stand that are not different, to some extent, from the starting point at different spatial scales. Thus, the closely connected parts to the starting point in terms of statistical similarities of tree variables may be considered as HPs. Following these steps, one can use ALS data to artificially "extend" ground sample plots to identify clusters of similar areas following the previously presented idea of forest stratification (Parker and Evans 2004; McRoberts et al. 2012). Moreover, Næsset (2005) showed that integration of ALS data and measurements on ground enables a proper calibration of that first set, so the application of a combination of both datasets guarantees higher accuracies.

Nowadays, there are many regions in the world over which surveying measurements have been performed (very often with the use of ground sample plots with a radius varying from few, up to over a dozen meters) along with the simultaneous acquisition of ALS data (Ruiz et al. 2014). Such wide data scattered around the world and similar future data might be an ideal reference material for either: present or future space missions, as well as for evaluation of different products obtained by post processing of satellite data. Apart from existing project related datasets, many countries worldwide have already made their national ALS data acquisitions and National Forest Inventories (NFI) data freely available. Integration of both can result in additional outcomes and benefits.

The main aim of this study is to extend ground sample plots to HPs using selected statistical parameters of classified

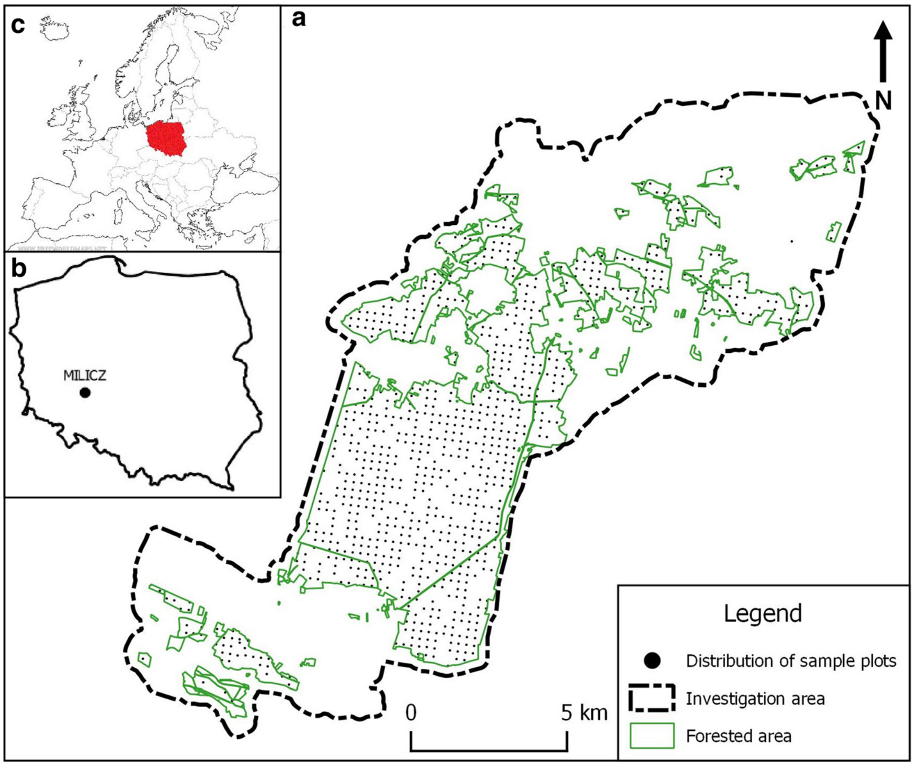


Fig. 1 Milicz Forest District (**a**) in the south west of Poland (**b**) in Europe (**c**)

ALS point clouds, to assess the spatial matching of delineated HPs and low resolution satellite datasets. We hypothesized that aggregation of those forest sections (raster cells), whose SVs describing either trees height and/or canopy density, do not differ significantly (in a statistical meaning) from the SV of given sample plot that might lead to the delineation of HPs. The objectives of this study were twofold: i) to expand the spatial extent of ground sample plots to HPs, and ii) to assess the spatial matching of the identified HPs with remotely sensed datasets of coarse resolution. For this, we proposed two structurally different methods to identify HPs, i.e., predefined thresholding-based one (static one), and statistical thresholding-based technique (dynamic one).

Methods

Study area

This study was conducted in Milicz forest district with an area of 27,000 ha situated in the province of Lower Silesia in south west Poland (Fig. 1). Mean elevation of the region is 125 m above sea level. This intensively managed forest complex administratively belongs to Regional Forest Directorate of State Forest in Wroclaw (pl. RDLP Wrocław). The forest district is home to pure and mixed coniferous and broadleaved stands, both with a fresh variant of the soil moisture. Despite the fact of the relatively high rate of species diversity, Scots pine (*Pinus sylvestris* L.) is the dominant tree species overgrowing the study area. Stands of Scots pine approximately comprise 75% of the forest district, although mixed stands of pine-beech (*Fagus sylvatica* L.) and pine-oak (*Quercus* sp. L.) are observed with the proportion of 6% and 11%, respectively. Distribution of age classes is more or less even. The most frequent age class is 40–60 years (about 30%). Average volume of beech, pine, and oak as the main species of the study area are 300, 300 and 275 $m^3 \cdot ha^{-1}$, respectively.

Ground reference data

There are 900 circular ground sample plots with 12.62 m radius (500 m^2), systematically distributed over the study area in a regular grid pattern (350 m × 350 m). Field measurements have been conducted in summer 2015. Coordinates of the centers of sample plots were calculated using GPS and GLONASS measurements. Raw GNNS observations were acquiring for 25 minutes. After that, a post-processing procedure encoded in the Magnet Tools software was run using data from three nearest reference stations. As a result 0.05 m accuracy of sample plot location has been achieved. Among many characteristics collected during the inventory, the spatial positions of the center of each plot were used in this study.

Table 1 The structural variables (SVs) extracted from ALS point clouds used to identify homogeneous patches

No.	Symbol	SVs	Description	Equation
1	p95	height	95th height percentile of all returns	$x_0 + \frac{h_0}{n_0}\left(\frac{p_{95}-N}{100} - F_{-1}\right)$
2	pFRAMe	density	ratio: number of first returns above median height to the total number of first returns	$\frac{n_{1x\sim}}{N_1}$

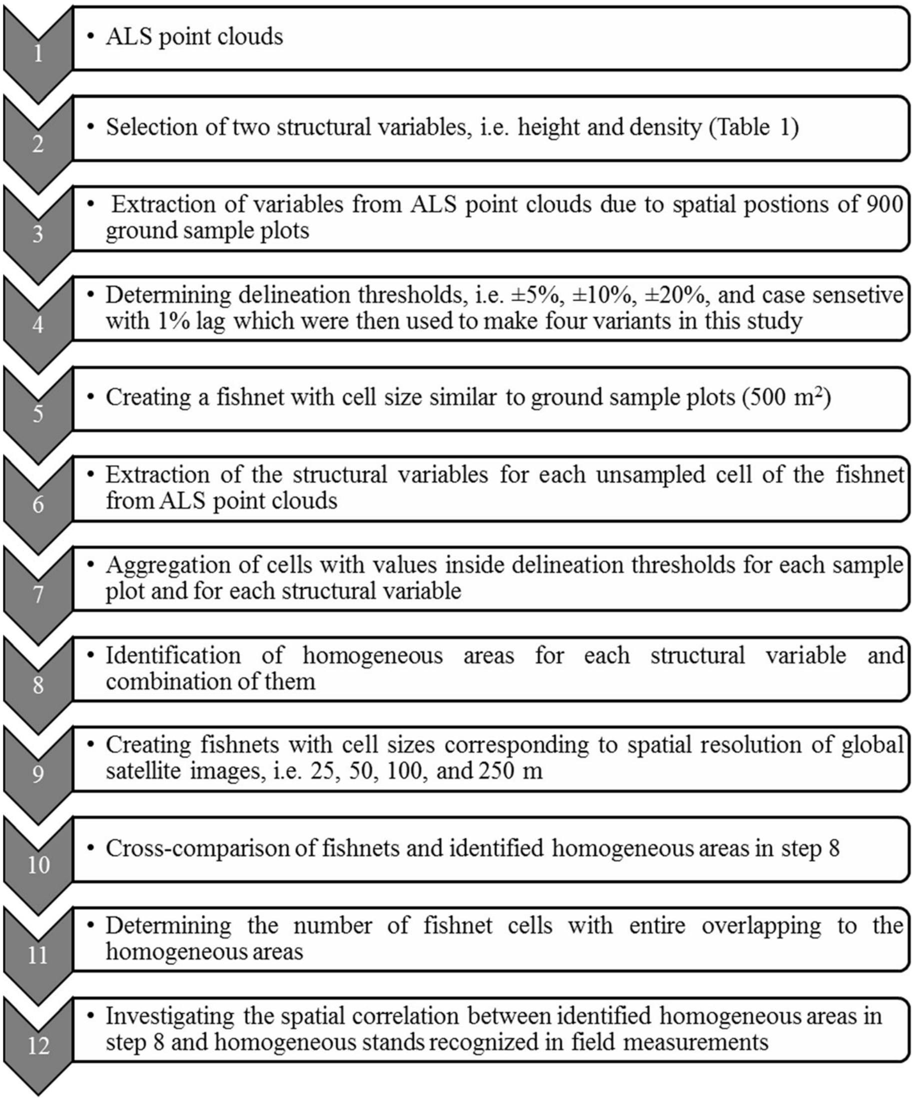
x height of the return; x_0 lower bound of given percentile; h_0 range of the class interval of given percentile; n_0 frequency of the interval of given percentile; *N* total number of all ALS returns; F_{-1} cumulative frequency of the interval preceding given percentile; $n_{1x\sim}$ number of first ALS returns above the values determined by median of all returns; N_1 number of first ALS returns

ALS data

ALS data were collected in August 2015 using Riegl LiteMapper LMSQ680i laser scanning system with 360 kHz pulse rate frequency that resulted in point clouds with a density of 10 pulses·m^{-2}. Mean flight altitude was 550 m from the reference ground point, and the field of view of the scanner system was 60 degrees. Along with the point clouds, a digital terrain model with a spatial resolution of 0.5 m was also delivered by the data provider and used, inter alia to normalize all returns from the raw point clouds.

ALS data processing

ALS point clouds were extracted at spatial positions of ground sample plots in order to calculate different



1. ALS point clouds
2. Selection of two structural variables, i.e. height and density (Table 1)
3. Extraction of variables from ALS point clouds due to spatial postions of 900 ground sample plots
4. Determining delineation thresholds, i.e. ±5%, ±10%, ±20%, and case sensetive with 1% lag which were then used to make four variants in this study
5. Creating a fishnet with cell size similar to ground sample plots (500 m^2)
6. Extraction of the structural variables for each unsampled cell of the fishnet from ALS point clouds
7. Aggregation of cells with values inside delineation thresholds for each sample plot and for each structural variable
8. Identification of homogeneous areas for each structural variable and combination of them
9. Creating fishnets with cell sizes corresponding to spatial resolution of global satellite images, i.e. 25, 50, 100, and 250 m
10. Cross-comparison of fishnets and identified homogeneous areas in step 8
11. Determining the number of fishnet cells with entire overlapping to the homogeneous areas
12. Investigating the spatial correlation between identified homogeneous areas in step 8 and homogeneous stands recognized in field measurements

Fig. 2 Schematic representation of the method applied in this study

ALS metrics characterizing spatial structure of stands within the plots. Among the wide range of metrics derived from ALS data (see Wulder et al. 2012), two SVs were used that describe mean height and density of stands. These two variables may explore stand structure from different points of view. Table 1 contains information about the two SVs applied in this study. Two selected variables represent two main groups of ALS variables describing spatial structure of the stands: height - p95 and density – pFRAMe. However, presented method can use other variables. Utilization of specific variables should be carried out regarding particular goals or requirements of the specified research.

Identification of homogenous patches (HP)

The HPs are defined as continuous patches of similar forest structure and composition. As shown in Fig. 2, in this study, identification of such areas from ALS point clouds was performed by four main variants. In the first variant (variant I - dynamic), the delineation threshold was separately determined for each structural variable in each sample plot. The threshold was defined as a percentage value that was significantly different from the observed value in each sample plot ($\alpha = 0.05$). Specific amounts were added to the observed values of each structural variable of each sample plot in 1% lags and this process was continued to reach the modified values that were significantly different from the observed ones (p-value <0.05). Wilcoxon test was used to check if there was a significant difference between observed and modified SVs, due to non-normal distribution of some SVs. The second group (variants II-IV) had fixed thresholds, i.e., ±5%, ±10% and ±20%. These thresholds define a range for each SV presented in Table 1 in each sample plot. For example, a range was determined for p95 of sample plot No. 1, by adding and subtracting 5% of the original p95 value of that plot.

In the next step, a grid fishnet was created with cell size equal to the area of a single sample plot (500 m^2) and overlaid on the study area. For each cell of the grid, the same SVs (as those for sample plots presented in Table 1) were computed. Finally, starting from the focal sample plots, adjacent grids were spatially merged to each sample plot only if (i) their values were inside earlier computed delineation thresholds for the given variant (dynamic, 5%, 10%, 20%), and (ii) adjacent pixels that met the first assumption could create spatially constant polygons. We allowed that patches could overlap each other. After obtaining all layers representing HPs based on two SVs separately, spatial intersections of polygons representing HPs of both variables per each ground sample plot were also created (p95 × pFRAMe (Intersection)).

In order to investigate artificial "expansion" of small area sample plots, for validation of various low resolution satellite data, earlier outlined HPs were taken under further analysis. It was aimed to assess how delineated HPs were spatially matched to satellite data with coarse spatial resolution. For this purpose, additional grid fishnets with cell sizes corresponding to the spatial resolution were created. Selected cell sizes were 25, 50, 100, 250, and 500 m. The number of particular grid cells which almost entirely fell into registered HPs was counted (leaving 2% cell area tolerance level). This procedure was executed separately for each variant and SV, as well as for their intersection parts.

In this study, each sample plot was a seed point for aggregation of adjacent cells, if their structural variables were similar. Since we had 900 samples we used all of them. If less number of samples is available they can be used as well. Decreasing the number of sample plots may reduce only our possibility to map variability in the study area and limit number or range of homogenous patches. Nevertheless, even one sample plot can be used to identify grid cells similar to that sample plot, so at least one stratum could be delineated through the whole area. Moreover, this study does not raise issues concerning optimization of the proposed method, where we could include some additional variables and analyze them both separately and together. In this study, we introduced another proposition of the look on the forest structure from the ALS perspective, as an identification trial of HPs, which might be used for different purposes (inter alia: for calibration and/or assessment of coarser resolution remote sensing data).

Table 2 Selected statistical characteristics of the homogeneous patches areas for four variants of analysis

Variable	Statistic	Variants area [ha]			
		Dynamic	5%	10%	20%
p95	Maximum	23.15	128.30	560.90	3058.55
	Quantile 25	0.20	0.65	4.66	37.55
	Quantile 75	1.50	7.55	65.79	1328.30
	Median	0.50	2.15	16.73	269.20
pFRAMe	Maximum	18.70	202.45	1449.45	3589.20
	Quantile 25	0.05	0.15	1.05	28.21
	Quantile 75	0.45	4.60	125.23	2722.39
	Median	0.15	0.85	12.95	341.53
Intersection	Maximum	1.60	17.05	222.95	1339.5
	Quantile 25	0.05	0.05	0.30	3.25
	Quantile 75	0.15	0.75	8.36	145.45
	Median	0.05	0.50	1.80	28.00

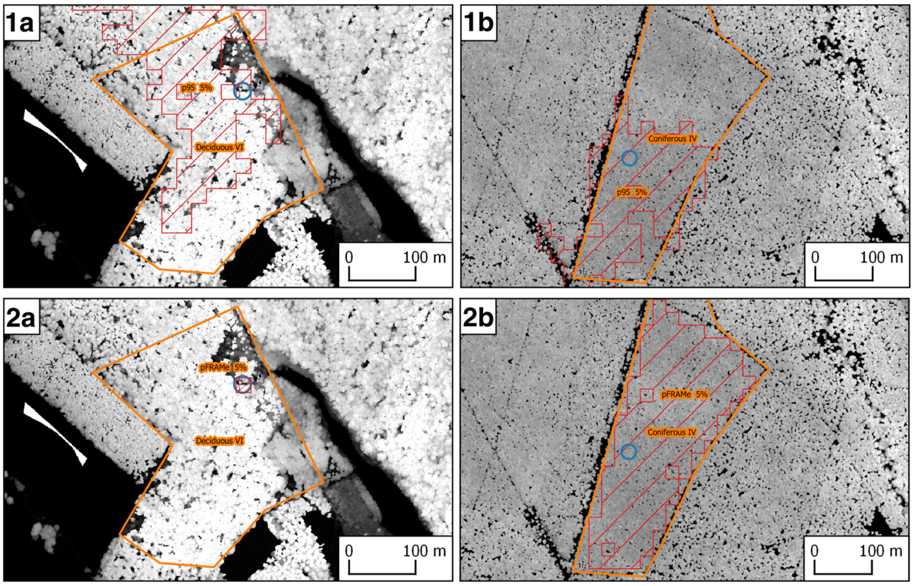


Fig. 3 Examples of homogeneous patches (HPs) as a result of variant II delineation (threshold of 5%), in selected deciduous (**a**) and coniferous (**b**) stands of Milicz forest district for both used variables: p95 (tree height) and pFRAMe (density). As a background, ALS based canopy height model (CHM) is presented, HPs are in red, stand borders are presented by orange line, and ground sample plots are presented by blue circles

Results

A wide range of HPs was obtained for all 900 ground sample plots in all variants either for individual variables as well as for their intersections. Table 2 is a juxtaposition of areas covered by delineated HPs in each variant. The maximum area of HP of each variant was presented to better show the extreme observations such as 3589 ha for variable pFRAMe in variant IV. The minimum area of each variant was not shown as it was 0.05 ha, which was the same as the size of original ground sample plots and each cell of testing fishnet.

Table 3 A number of pixels of grids which fell inside homogeneous patches in particular variants of analysis

Resolution (m)	Variable	Variant I Dynamic	Variant II 5%	Variant III 10%	Variant IV 20%
25	p95	5910	49,716	*	*
	pFRAMe	1439	51,324	*	*
	Intersection	5	289	10,964	*
50	p95	305	5345	108,225	*
	pFRAMe	74	5922	291,254	*
	Intersection	0	9	1075	*
100	p95	0	237	13,304	*
	pFRAMe	0	285	31,422	*
	Intersection	0	0	825	51,810
250	p95	0	0	299	14,250
	pFRAMe	0	0	759	22,124
	Intersection	0	0	42	2863
500	p95	0	0	0	765
	pFRAMe	0	0	0	1449
	Intersection	0	0	0	102

* not calculated variants due to large number of pixels already assigned in HPs in less restricted threshold ranges

As shown in Table 2, the area of HPs increased for wider thresholds. For instance, the smallest HP size related to the intersection of p95 and pFRAMe variables (Intersection). The median of HPs of all variants increased from 0.05 ha for a variant I to 28 ha for variant IV. In addition, the results showed that the trend was non-linear. The size of HPs in each analyzed variant was much larger when we considered only one variable. Moreover, not only average size of HPs increased with increasing the threshold, but also variation in size was higher for wider tolerance intervals, also in all analyzed variants. The medians of all variants were always closer to the first quartile, indicating that obtained distributions of the size of HPs were mainly right-skewed, so there were few really vast HPs and most of them were smaller than the average size.

Parts 1a and 1b in Fig. 3 present HPs respectively in deciduous and coniferous stands based on p95 SV in age class of 100–120 years (parts a on the left) and 60–80 years (parts b on the right). Parts 2a and 2b show the homogeneous patches of the stands according to a pFRAMe variable. Figure 3 also shows that young stands were more homogeneous in terms of SVs (especially coniferous stands) than old deciduous ones.

Table 3 presents numbers of pixels which fell into registered HPs, depending on (i) variant of analysis (I-IV) and (ii) sizes of grid cells of different low resolution

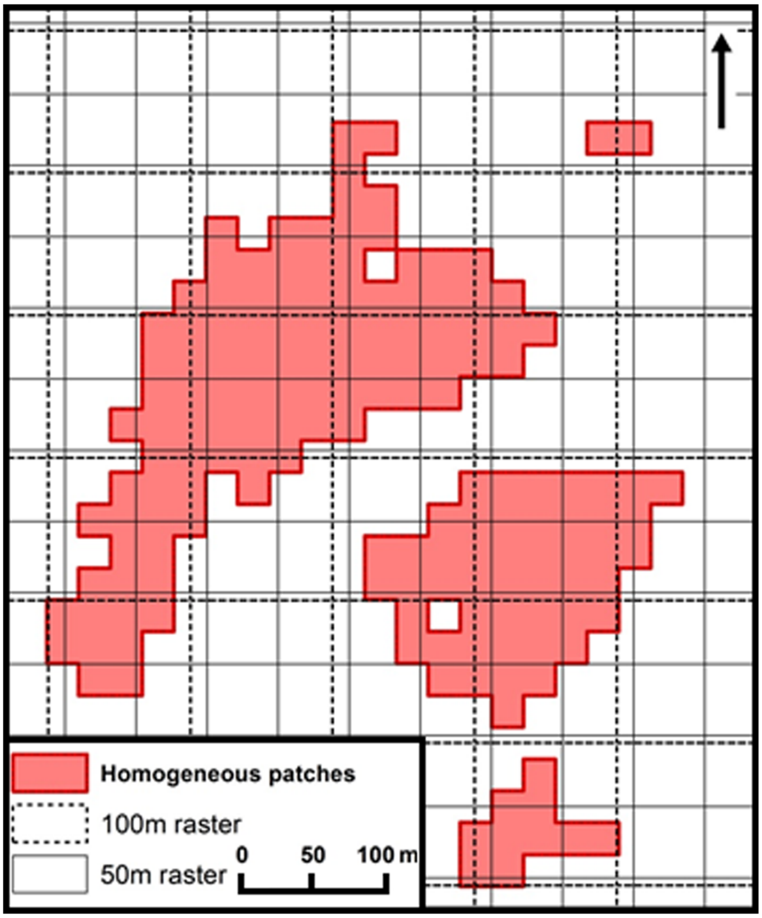


Fig. 4 Example of the relationship between size and shape of homogeneous patches and data resolution interactions

satellite products. For example, in variant II and the 50 m resolution grid, there were more than 5000 cells matched with HPs. The results also showed that the number of entire pixels inside HPs grew in tremendous ratio along with increasing the delineation threshold. The differences between particular variants and spatial resolutions were up to thousands of pixels. Because of that, some results regarding wide tolerance thresholds analyzed on grids with higher resolutions were not shown. The intersection in Table 3 showed that the number of pixels found in HPs for each variant was always significantly lower than for individual variables. This result additionally confirmed the more variables taken into account resulting in smaller area but greater its homogeneity.

Figure 4 is the graphical depiction of analyses which results were reported in Table 3. It shows the adjustment of the spatial resolutions of two satellite products (i.e., 50 and 100 m) and identified exemplary HPs. The results clearly showed that even if the size of HPs was large, the shape of the HPs would have significantly reduced number of pixels entirely found in a given HP, according to spatial resolution of particular data (Fig. 3).

Red polygons in parts 1c and 2c (Fig. 5) show the advantages of applying routines where two (in our case) or more variables were intersected. Visual interpretation of the crown height model (background of all parts shown in Fig. 5), explains that the intersection parts of two analyzed variables outlined one group of deciduous trees with similar age/heights, surrounded by coniferous stands (Fig. 5, part 1c) unlike in case of single variables (Fig. 5, parts 1a or 1b).

Discussion

The overall aim of this study was to identify HPs of tree height and density by classification of ALS point clouds to introduce these areas as reference data for evaluation of remotely sensed datasets with coarse spatial resolution. The results of this investigation revealed that ALS data might have the potential in the identification of homogeneous patches of forest stands in Milicz forest district. We showed that different ALS based variables and thresholds (variants I-IV) of HPs influence the areas

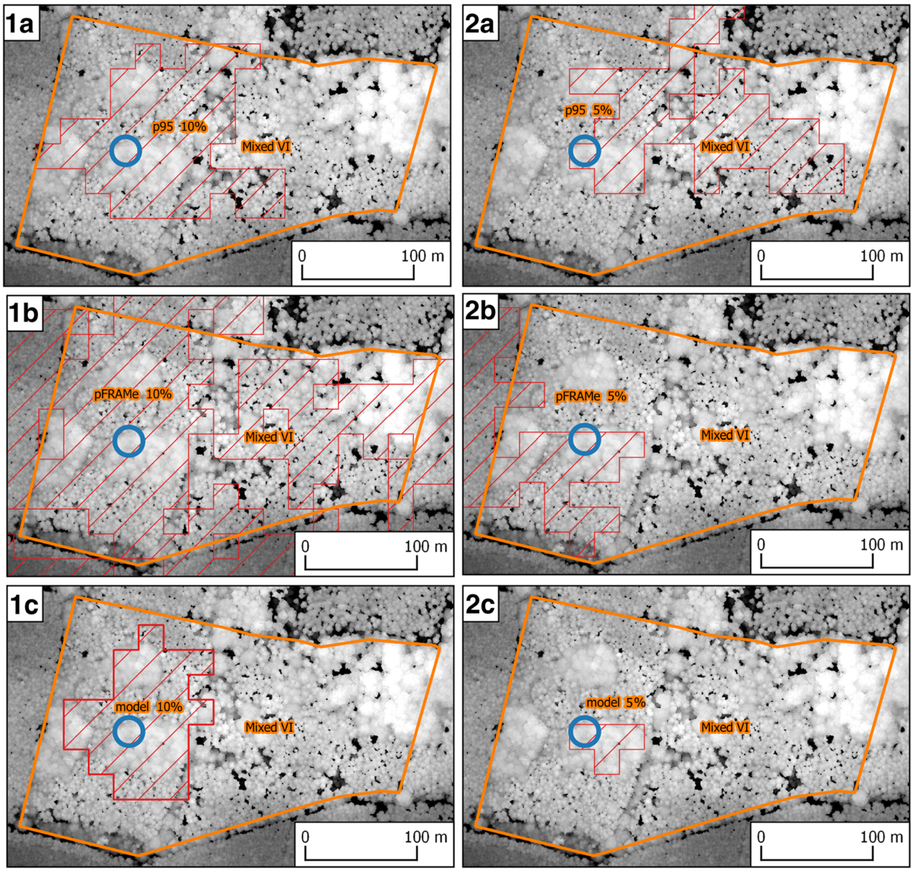


Fig. 5 Example of changes in shapes and sizes of homogeneous patches depending on the selected variant. Parts **a** (upper row) show the results of p95 (tree height) structural variable in variant III (10% delineation threshold, left column) and variant II (5% delineation threshold, right column), parts **b** (middle row) indicate the results of pFRAMe (density) variable, and parts **c** (bottom row) exhibit intersection (overlapping part) of both variables. Excerpt of the Crown Height Model used in analysis serves as a background on each scene, orange lines are boundaries of the stand delineated based on the field surveying, and ground sample plots are shown by blue circles

that can be treated as similar and homogeneous. We proved that integration of more than one variable limits size of the HPs, but in contrast, visual interpretation prove that inside such patches vegetation structure is more constant (Figs. 5 and 6).

In the proposed method, values of ALS SVs extracted for sample plots were considered as benchmark points. Obviously, a similar analysis could be carried out as well without ground sample plots. If so, stratification of the forest district would be the result of such analysis (Parker and Evans 2004; McRoberts et al. 2012). Nevertheless, the final shape of similar analysis should be formed based on assumed study goals, as well as the resolution of analyzed datasets.

It is also important to bear in mind that 5% or 10% thresholds have different ranges for each plot characterized by different values of variables. Obviously, for higher values of variables, such range is greater. This fact has also its reflection on the stand structure. Namely, if we consider the height of the stands (in the study case expressed as 95th of the height of ALS point cloud), young stands usually have lower height variations and height ranges of particular trees within these stands. Accordingly, height related ALS variables extracted at locations of young stands have smaller values as well, thus the tolerance threshold for aggregation of adjacent and similarly young stands is narrower. A similar situation exists in case of older stands, where heights of particular trees differ to the greater extent than it was for young stands. Therefore there should be an adequate response of ALS variables, resulting in wider tolerance interval for those stands. Such dependency seems to be reasonable for outlining stands with similar variations of given parameter or their combinations. Another situation will be when we set a specified threshold e.g. 1 m, not relative one as in our study. Then similar criteria will be set for whole and thus relatively smaller variance for old stands may be observed. This obviously will change the size of HPs for different age classes.

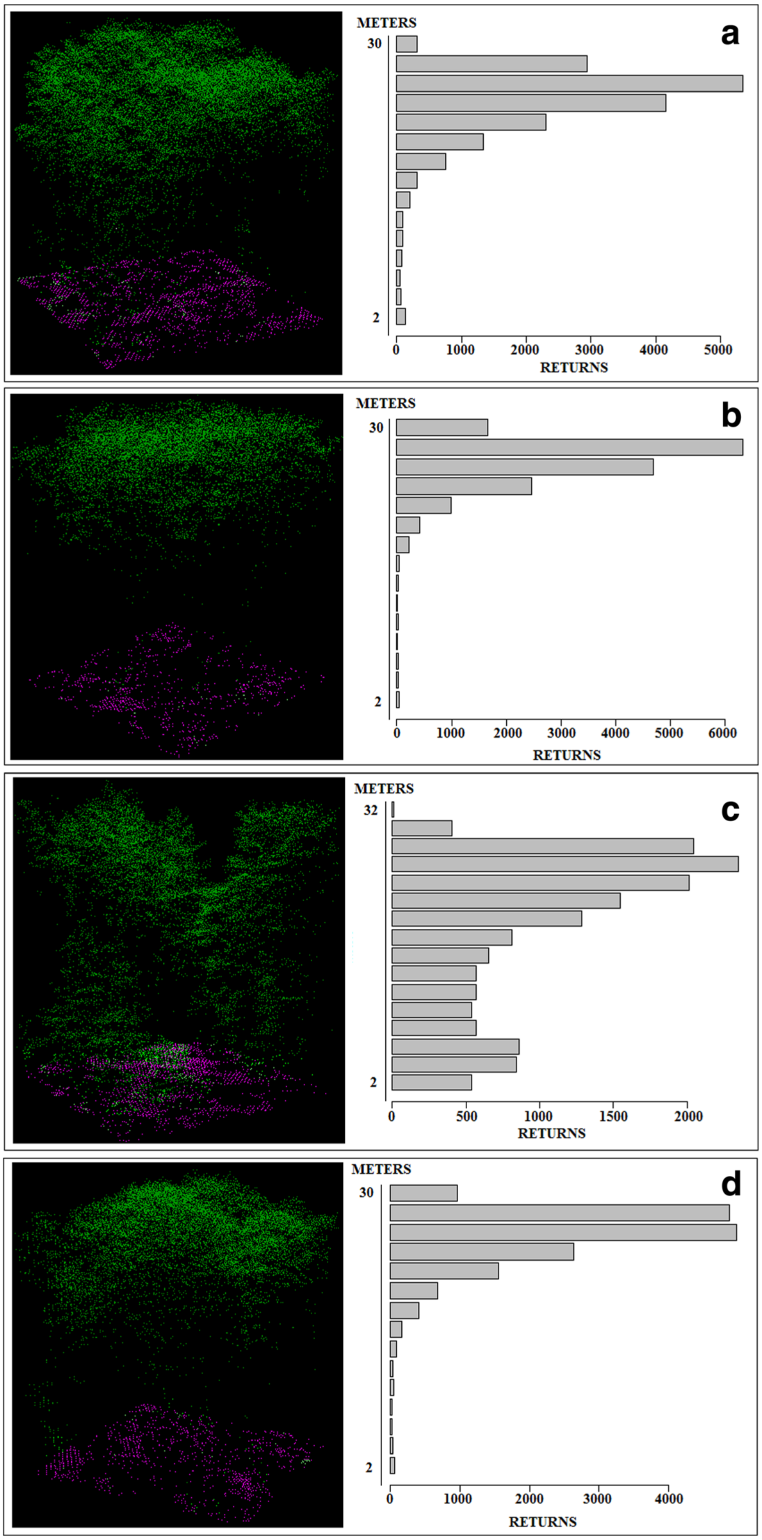


Fig. 6 (See legend on next page.)

(See figure on previous page.)
Fig. 6 Presents 3D spatial structure of ALS point clouds extracted at specific locations within the exemplary stand (60–80 year old mixed stand in Fig. 5). Part **a** (on top) shows mentioned structure, extracted at location of the sample plot (blue circle in Fig. 5). Part **b** represents relevant point cloud structure, extracted at location of one grid found within boundaries of HPs delineated based on p95 SV in variant III. This spot is an example of a good agreement between point cloud structure shown on the sample plot (part **a**) and adequate structure shown in selected spot within such HP. Part **c** is an example of a disagreement according to above. Part **d** shows selected spot (grid) of HPs being an intersection of both SVs analyzed in this study. Next to each 3D image, a relevant histogram is provided to present vertical distribution of the point cloud

In our paper, we analyzed selected ALS point cloud metrics separately, but also we investigated their mutual integration. However, other types of data resulted from modelling of different trees/stands characteristics such as top height, volume or biomass could also be used in the similar analysis to the method proposed in this study. We need to take into account that in our analysis we used characteristics calculated for basic cell grids (fishnets) of similar area to the sample plots. Products, such as standing volume for such areas can give similar values for totally different stands, e.g., the volume of 60 year old one layer pine stand can be similar as for older stand with smaller density and a second layer of oak. From the volume point of view, they will be homogeneous – similar stands, but from the structure or height point of view, they will be significantly different.

According to the obtained results, beyond the identification of HPs, their shapes are very important (Fig. 3). In case of managed forests – the ones where trees overgrow in relatively small areas with evenaged trees with usually 1 dominant tree species, in general, each HP will include only a certain part of such stands. If delineation range for determination of HPs is very narrow, then the HP will have a small size. Along with increasing delineation threshold (range), the area covered by HPs will expand. It is worth to notice that for unmanaged stands, homogeneous areas rarely form vast and continuous patches. In case of forest districts consisting of more natural stands, as a human has relatively less influence on such forest sites, thus there are definitely less artificial borders inside these types of stands. Shape of the HPs limit possibility to fit specified resolution global data inside. So even it HP area is large, shape can limit the possibility of using it for validation/calibration purpose.

Based on the visual interpretation of our results, species composition of stands has a significant influence on final shape and size of HPs. In our case, results presented in Fig. 3 prompts that allocation of the ground sample plots had an effect on shape and size of delineated HPs. In the context of the application of ALS data in forest inventory, Amiri et al. (2016) also highlighted that estimation of SVs of forest stands is negatively influenced by species composition. Typical central European managed coniferous stands consist of only one dominant species with the same age, therefore, one can say that such stands are very homogeneous just how they are. Delineation thresholds selected in this study resulted in good spatial adjustment (overlap) of homogeneous parts and actual borders of managed stands (according to forest management plans), especially for pine stands. In case of mixed and deciduous species, boundaries of HPs were more diverse including many holes and/or islands, i.e. those parts of the stands which had a completely different structure from the stands described on the corresponding sample plot. As a result, spatial adjustment between HPs and global satellite data were much more complicated. Similar to the results of this study, Bottalicoa et al. (2017) also found that estimation of SVs using ALS data is less accurate in mixed stands with high diversity in species composition while it is reliable in conifer plantations with homogeneous structure.

Identified homogeneous forest patches may find the use in analysis of different types of global data. They can serve twofold: for calibration of different global satellite missions, and for their validation. These results were in accordance with the findings of Alexander et al. (2017). They also concluded that ALS data are reliable remote sensing materials for finding homogeneous areas even in natural forests with rich diversity. Moreover, because of the fact that homogeneous definition and parameters might be modified in different ways, the proposed concept could be used in the more detailed analysis, for instance regarding influence of stand structure on registered spectral values.

The proposed concept of integration of ground and ALS data could be used in the development of so called “reference super sites”. An initiative of development of such types of areas in different parts of the globe yet has started. There are already datasets consisting large ground samples (1 ha and more) (Schepaschenko et al. 2017). Unfortunately, costs of acquisition of such reference data are tremendous. Therefore, the cost-efficient concept, if ALS data are available, presented in this article might serve as quasi substitution of ground surveying of vast areas. Thanks to the integration of ALS data stratification, and detailed ground data collected for small areas, it is possible to obtain similar results to those for other planned flight missions.

Conclusions

We demonstrated possible integration of ground sample plots and ALS data to delineate homogeneous patches. Additionally, we investigated the identified areas based on main spatial resolutions of global satellite datasets. Our research is a case study of investigation area being a single forest district (circa 27,000 ha) – the managed one. We did not applied proposed methodology for neither similar nor more diverse forest districts, nor for bigger scales. However it is possible and will be carried out in the future. Based on the obtained results we can conclude that:

i) size of HPs depend on set range of possible differences between analyzed ALS variables and varied regarding the species composition of analyzed stands.

ii) possibilities of spatial adjustment of particular global product grid size (fishnets) and HPs are negatively influenced by size and shape of the HPs.

iii) integration of several ALS variables, especially those related to height and density of forests, allows a decent determination of homogeneous stands.

Finally, based on our findings, we can conclude that ALS data can be used as a potential source of data to "enlarge" small ground sample plots that could be used for evaluation and calibration of remotely sensed datasets provided by global systems with coarse spatial resolutions.

Funding
Data and study have been supported by the project REMBIOFOR (Remote sensing based assessment of woody biomass and carbon storage in forests), supported by The National Centre for Research and Development under BIOSTRATEG program, agreement no. BIOSTRATEG1/267755/4/NCBR/2015. The idea for the study was invented under the DUE GLOBBIOMASS project (contract 4,000,113,100/14/I-NB).

Availability of data and materials
The datasets supporting the conclusions of this article are included in the article.

Authors' contributions
KS: create the ideas, formulation of research question, statement of hypothesis, development of methodology, provide the data, interpretation of data and results, responsibility for supervising research, drafting of manuscript, critical revision, final approval of the version to be published, coordination or management of research activities leading to this publication, gaining the financial support for the project leading to this publication. ML: development of methodology, analysis, and interpretation of data and results, drafting of manuscript, critical revision, final approval of the version to be published. YE: statement of hypothesis, interpretation of the results, drafting of manuscript, critical revision, final approval of the version to be published.

Consent for publication
Not applicable

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Department of Forest Resources Management, Forest Research Institute, Sękocin Stary, 3 Braci Leśnej St, 05-090 Raszyn, Poland. [2]Department of Natural Resources and Environment, College of Agriculture, Shiraz University, P.O. Box 7144165186, Shiraz, Iran.

Received: 14 August 2017 Accepted: 20 December 2017

References

Alexander C, Korstjens AH, Hill RA (2017) Structural attributes of individual trees for identifying homogeneous patches in a tropical rainforest. Int J Appl Earth Obs Geoinf 55:68–72

Amiri N, Yao W, Heurichc M, Krzysteka P, Skidmore AK (2016) Estimation of regeneration coverage in a temperate forest by 3D segmentation using airborne laser scanning data. Int J Appl Earth Obs Geoinf 52:252–262

Andersen HE, Reutebuch SE, McGaughey RJ (2006) A rigorous assessment of tree height measurements obtained using airborne lidar and conventional field methods. Can J Remote Sens 32(5):355–366

Borner T, Papathanassiou KP, Marquart N, Zink M, Meadows PJ, Rye AJ, Wright P, Meininger M, Rosich Tell B, Traver N (2007) ALOS PALSAR products verification. IEEE International Geoscience and Remote Sensing Symposium on Sensing and Understanding Our Planet 2007:5214–5217. https://doi.org/10.1109/IGARSS.2007.4424037

Bottalicoa F, Chirici G, Giannini R, Mele S, Mura M, Puxeddu M, McRoberts RE, Valbuena R, Travaglini D (2017) Modeling Mediterranean forest structure using airborne laser scanning data. Int J Appl Earth Obs Geoinf 57:145–153

Chirici C, McRoberts RE, Fattorini L, Mura M, Marchetti M (2016) Comparing echo-based and canopy height model-based metrics for enhancing estimation of forest aboveground biomass in a model-assisted framework. Remote Sens Environ 174:1–9

Cohen WB, Goward SN (2004) Landsat's role in ecological applications of remote sensing. Bioscience 54(6):535–545

Donlon C, Berruti B, Buongiorno A, Ferreira MH, Féménias P, Frerick J, Goryl P, Klein U, Laur H, Mavrocordatos C, Nieke J, Rebhan H, Seitz B, Stroede J, Sciarra R (2012) The global monitoring for environment and security (GMES) sentinel-3 mission. Remote Sens Environ 120:37–57

Ferraz A, Bretar F, Jacquemoud S, Gonçalves G, Pereira L, Tomé M, Soares M (2012) 3-D mapping of a multi-layered Mediterranean forest using ALS data. Remote Sens Environ 121:210–223

Freese F (1962) Elementary Forest Sampling. Southern Forest Experiment Station, Forest Service, United States Department of Agriculture. Agriculture Handbook No. 232. http://www.fs.fed.us/fmsc/ftp/measure/cruising/other/docs/AgHbk232.pdf. Accessed 04 Aug 2017

Holmgren J (2004) Prediction of tree height, basal area and stem volume in forest stands using airborne laser scanning. Scan J Forest Res 19:543–553

Justice CO, Townshend JRG, Vermote EF, Masuoka E, Wolfe RE, Saleous N, Roy DP, Morisette JT (2002) An overview of MODIS land data processing and product status. Remote Sens Environ 83(1):3–15

Kandare K, Ørka H, Dalponte M, Næsset E, Gobakken T (2017) Individual tree crown approach for predicting site index in boreal forests using airborne laser scanning and hyperspectral data. Int J Appl Earth Obs Geoinf 60:72–82

Korpela I, Hovi A, Morsdorf F (2012) Understory trees in airborne LiDAR data - selective mapping due to transmission losses and echo-triggering mechanisms. Remote Sens Environ 119:92–104

Martinuzzi S, Vierling LA, Gould WA, Falkowski MJ, Evans JS, Hudak AT, Vierling KT (2009) Mapping snags and understory shrubs for a LiDAR-based assessment of wildlife habitat suitability. Remote Sens Environ 113:2533–2546

McRoberts RE, Gobakken T, Næsset E (2012) Post-stratified estimation of forest area and growing stock volume using lidar-based stratifications. Remote Sens Environ 125:157–166

Næsset E (2005) Assessing sensor effects and effects of leaf-off and leaf-on canopy conditions on biophysical stand properties derived from small-footprint airborne laser data. Remote Sens Environ 98(2–3):356–370

Parker RC, Evans DL (2004) An application of LiDAR in a double sample forest inventory. West J Appl For 19(2):95–101

Ruiz LA, Hermosilla T, Mauro F, Godino M (2014) Analysis of the influence of plot size and LiDAR density on Forest structure attribute estimates. Forests 5(5):936–951

Schepaschenko D, Shidenko A, Usoltsev V, Lakyda P, Luo Y, Vasylyshyn R, Lakyda I, See L, McCallum I, Fritz S, Kraxner F, Obersteiner M (2017) A dataset of forest biomass structure for Eurasia. Scientific data 4, article number: 170070. https://doi.org/10.1038/sdata.2017.70

Sverdrup-Thygeson A, Ørka HO, Gobakken T, Næsset E (2016) Can airborne laser scanning assist in mapping and monitoring natural forests? For Ecol Manag 369:116–125

Townshend JRG, Justice CO (2002) Towards operational monitoring of terrestrial systems by moderate-resolution remote sensing. Remote Sens Environ 83(1): 351–359

Wulder MA, White JC, Bater CW, Coops NC, Hopkinson C, Chen G (2012) Lidar plots - a new large-area data collection option: context, concepts, and case study. Can J Remote Sens 38(5):600–618