Use of LiDAR to map and monitor habitats

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Abstract

Key is the challenge to develop a biodiversity observation system that is transmissible and cost effective. Measuring and reliable reporting of trends and changes in biodiversity requires that data and indicators are collected and analysed in a standard and comparable way. LiDAR is an alternative remote sensing technology that allows to increase the accuracy of biophysical measurements and extend spatial analysis into the third dimension. At the same time, the EBONE project shows that the way forward is to measure habitat diversity as a proxy for biodiversity on the basis of plant life forms including environmental information using a stratified random sampling system. The objective of our study was to assess to what extent LiDAR can be used to map and monitor plant life forms and General Habitat Categories according to EBONE (Bunce et al., 2008) methodology. The study area was located near Chaam, in the Southern part of the Netherlands for which we obtained LiDAR data from FUGRO. Conclusions are that LiDAR provides accurate height measurements on shrubs and trees, even in early spring when no leaves are present. Unfortunately, not the whole range of plant life forms could be measured with LiDAR. Combination of LiDAR with false-colour aerial photographs provides a powerful tool with e.g. Fusion software and decision tree classifiers for the identification of plant life forms. Regression analysis between field measurements and LiDAR measurements on the height of various plant life forms showed an adjusted R square of 0.95. Since the latest generation of LiDAR will have an accuracy of approximately 2 to 3 centimeters, it is assumed that cryptogams and dwarf chamaephytes (below 5 cm) are difficult to measure with LiDAR. In general, it has been demonstrated in this study that good characterization of 3d-vegetation objects is possible with LiDAR. Comparison with a full field survey of the general habitat categories showed uncertainties in the proposed methodology as well as in the used field methods.

1. Introduction

This study has been implemented within the framework of the EU- FP7 project EBONE "European Biodiversity Observation Network: a project to design and test a biodiversity observing system, integrated in time and space". The key challenge is to develop a biodiversity observation system that is transmissible, cost effective and provides added value to the currently independent data sources of in situ data and EO. The key activities involve the integration between EO with field measurements in a consistent and repeatable manner. Measuring and reliable reporting of trends and changes in biodiversity requires that data and indicators are collected and analysed in a standard and comparable way. This is valid for a national park, but also for larger areas such as the European Union. However, at present, all responsible authorities (over 100 national and regional agencies) have different approaches. Worldwide the problem is even greater because in different continents species and ecosystems differ between the continents. Therefore there is a need to develop a coherent system for data collection that can be used for assessments at the European and global scales. EBONE will deliver a European contribution to the development of a global biodiversity observation system that is spatially and topically prioritized. Fortunately, new EO technologies are improving the collection and analysis of biodiversity information. These increasingly sophisticated monitoring systems, which consist of satellite, air, land and ocean-based instruments, are being interlinked through the Group on Earth Observations (GEO) to form a Global Earth Observation System of Systems (GEOSS).

Background in methodological aspects of the EBONE project showed that the way forward was to measure habitat diversity as a proxy for biodiversity on the basis of plant life forms but also including information on environmental variation in humidity and trophic levels using a stratified random sampling system. Based on these life forms a total of 130 General Habitat Categories (GHCs) were defined, which is still being extended in the current project. The same categories can be applied to areal, linear and point features to assist recording and subsequent interpretation at the landscape level (see also Figure 1).

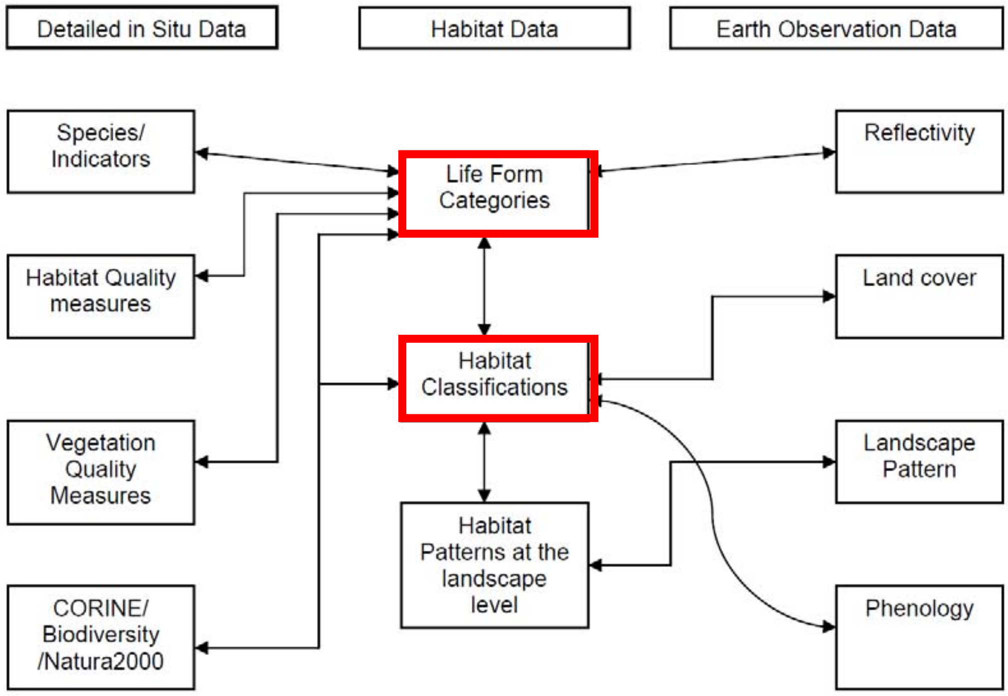


Figure 1 Relations between different land and biodiversity observation levels.

2 Objectives and study area

The objective of this study is to determine to what extent can we use LiDAR data to map and monitor plant life forms and General Habitat Categories according to EBONE (Bunce et al. 2008) methodology ?

The study site is located near Chaam, in the Southern part of the Netherlands in the Province Noord-Brabant, for which we obtained test data from FUGRO (largely responsible for AHN-2). For the Netherlands there is a good reason to focus on the use of LiDAR data since the country was covered for the first time in 2003 from wall to wall, with 1 height measurement per square meter, namely for the construction of a detailed and accurate national elevation model. In the meantime a second version is becoming available in the next years (2011/2012) with a even higher precision. The intention is to cover the Netherlands completely every 5 years and this operation is largely financed by subscription of waterboards that need this information for their water management. Errors in height measurements can have dramatic consequences for the assessment of flooding risks.

3. Materials

3.1. LiDAR

LiDAR (Light Detection And Ranging) is a remote sensing system used to collect topographic data. A LiDAR uses a laser (emitter) to send a pulse of light to an object and a telescope (receiver) to measure the intensity scattered back (backscattered) to the LiDAR. Aircraft permits the collection of topographic information over a strip ~ 300 meters in width from 600 meter altitude. Also helicopters are being used for the collection of LiDAR data. Most laser systems can record several returns for each pulse. Multiple returns occur when the laser beam is only partially blocked. Part of the laser energy is reflected back to the sensor, the remaining laser energy continues downward. In principle you can have up to 5 returns per pulse, but more typically is 2-3 returns. By acquiring first- and last-pulse data simultaneously, it is possible to measure both tree heights and the topography of the ground. Normally, you have 1 -10 measurements per m^2 or 10,000 – 100,000 measurements per ha. Most systems record the amount of energy reflected by target objects, such as intensity. Data delivered as XYZ points in a “data cloud”. Because airborne LiDAR captures high-resolution vertical and horizontal spatial data, it shows great potential for integration with ecological research (Lefsky et al. 2002). In contrast with other optical remote sensing techniques offering only a continuous coverage, it directly measures the physical attributes of vegetation canopy structure, highly correlated with the basic ecological functions of interest to sicentists. Moreover, LiDAR is less affected by shadows and occlusions, as well as less dependent on weather conditions (St-Onge 2005; Korpela et al. 2009).

The precision or accuracy of LiDAR data has improved increasingly. Fugro Aerial Mapping BV is one of the companies that collects LiDAR data in the framework of the AHN-2 project. Alterra obtained a test data set from Fugro Aerial Mapping B.V. for the study area Chaam in 2009. For this data set FUGRO used the FLI-MAP 400 system. This system is carried on board of a helicopter, integrated with high-resolution photo and video camera and a precise GPS system. The data was acquired during three days in 2009, March 13, 15 and 16, with a minimum point density of 10 points per m^2 at three different scan angles: forward 30°, nadir, backward 30°. Additional important characteristics are the options for a 150.000 Hz of 250.000 Hz scan using Multiple Pulse in Air (MPiA) technology, and direct in line-scan attachment of RGB colours the laser measurements. The absolute accuracy for a single point can be guaranteed below 3 cm. An additional advantage is that data are delivered classified into ground points & non-ground points.

3.2. Fieldwork

Field work was done in December 2009 and February 2010. Field work was hampered in by severe winter conditions and caused some delays. All photographs were taken on the 22nd of February 2010 when weather conditions were already slightly better (see Figure 2). For objects with a height lower than 2.5 meter a measuring staff was used. For taller objects a laser distance meter was used. First the horizontal distance was measured, then the angle to the crown of e.g. tree was measured. The following height formula was applied: distance * TAN(RADIANS(angle) + height tripod.

3.3. Fusion software

FUSION/LDV is a free software developed by USDAA (United States Department of Agriculture) Forest Service Pacific Northwest Research Station in collaboration with the University of Washington and distributed by the USDA Forest Service Remote Sensing Applications Center (RSAC). The software is built to help researchers understand, explore, and analyze LiDAR data (McGaughey, 2010). LiDAR data sets are generally large and require extensive preprocessing before to be used in GIS or image processing software. Considering this, Fusion handles simple tasks such as extracting a sample of LiDAR returns for an area of interest and allows to view the data interactively. The software offers a complete and comprehensive system including LiDAR data analysis and processing. Thus, this program is primarily a viewing tool for LiDAR data, providing as well basic analysis functions very useful to explore and extract information from LiDAR data.

4. Methodology and results

4.1. LiDAR measurements on objects

The VG4D viewer from the VG4D product suite was used to carry out the measurements on the objects in the LiDAR data. For this, a profile view of the object of interest was created and the object width and height was measured on screen using the interactive distance measure tool in the profile view window. One observation that can be made from both views is that the exact width and height is not easy to indicate unambiguously. A best approximation was made by measuring several points and using an average value as the outcome.

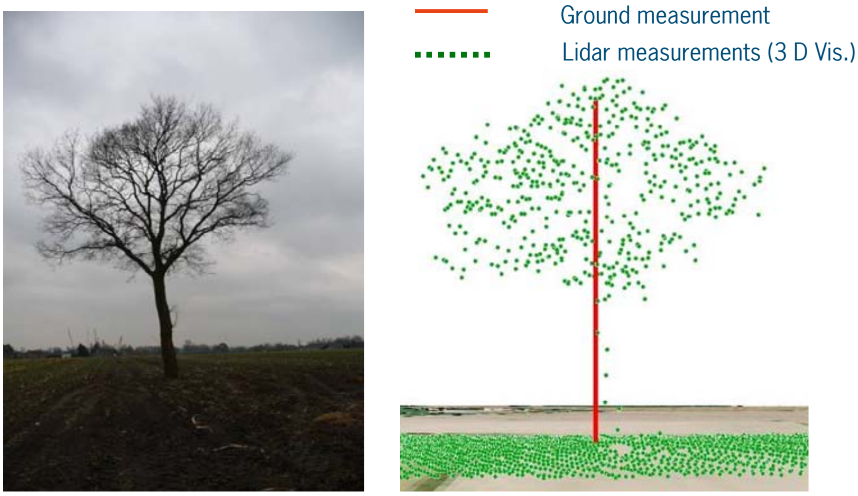


Figure 2 Visual comparison of a single tree (object 1) as seen in the field (left) and 3D view by LiDAR measurements. Red pole indicates the height measurement of the object in the field. Green dots are the LiDAR measurements.

Compound objects like a hedgerow or a line of trees vary a lot in both width and height due to the differences in width an height of the single objects that are part of the compound object (Figure 2). The estimation of the height and width of the compound object is indicated by using both minimum and maximum values. Table 3 shows the measurements for all selected objects.

Table 1 Field and LiDAR measurements on selected vegetation objects for the study area of Chaam.

	Lidar		**Field work**	
object	**Height**	**Width**	**Height**	**Width**
Single tree	11.9	9.8	11.71	8
Hedge row with bush	4.4	2.5 - 5.3	5.20	2.5
Single tree	11.3		11.54	6
Hedge row	7 - 7.8	6.8 - 7.8	8.56	5
Fringe of reed	2.9	3.6 - 5	2.20	4
Solitary tree	11.1	7.8	12.53	8
Row of willows	6.7 - 7	2.0 - 3	9.34	2
Blackberry and reed	1.3 - 5	4.0 - 7	5.20	4
Blackberry, low vegetation	0.25	-	0.75	4
Single tree	17.2	9.0 - 12	19.53	10
Forest with pines and birch	16.4 - 20		17.45	-
Dould line of Oak trees	8.5 - 8.9	4.7 - 6.4	9.57	5
Line of trees and bushes	15.9	7.0 - 8	15.89	10
Oak trees in line	14.0 - 16	8	16.00	8
Rough wood at water fringe	0.6	0.6 - 2.5	0.75	2
Pitrus in ditch	ruis		0.75	7
Hedge with hornbeam	1.2	0.3 - 0.5	1.10	35
Con. Forest with edge of dec.	10.5		11.10	36
Solitary tree	10.25	8.5 - 10.8	11.28	5
Blackberry, low vegetation	1.2	3.5 - 4	1.70	4
Hedgerow	3.6 - 4.2	4.1 - 5	4.45	4
Rough field	0	-	1.00	-
Hedge with conifers	1.6	0.6	1.50	0
Row with birch trees	10.6	4.2	11.75	3
Oak trees in line	11.4	5 - 8	12.82	6

If we take the maximum height from the LiDAR data we can calculate the regression statistics with the field measurements. The regression analysis shows a good correlation between the field measurements and the LiDAR measurements, with an adjusted R square of 0.95 (n = 24). For the width of objects, there is more variance and it is also more difficult to measure in the field, especially if objects are larger. For the regression analysis we took the average width measured by LiDAR against the field measurements. The result is an adjusted R square of 0.89 (n = 19), which still can be considered as good. This small study shows that measurements made by LiDAR are quite accurate, even if data are acquired in early spring when no leaves are present. The only vegetation that did no give any return from the LiDAR data was a field with *Juncus effesus*. It is not clear yet why the Pitrus does not give any return, while a reed fringe consisting of *Phragmites communis* gives consistent measurements.

4.2. Decision tree classifier

A decision tree can provide a good classifier to identify the individual plant life forms at the pixel level based on the integrated use of the information in the aerial photographs and LiDAR imagery. The use of aerial photographs as an additional source of information is highly required, especially to discriminate vegetation from non-vegetated areas (Figure 3).

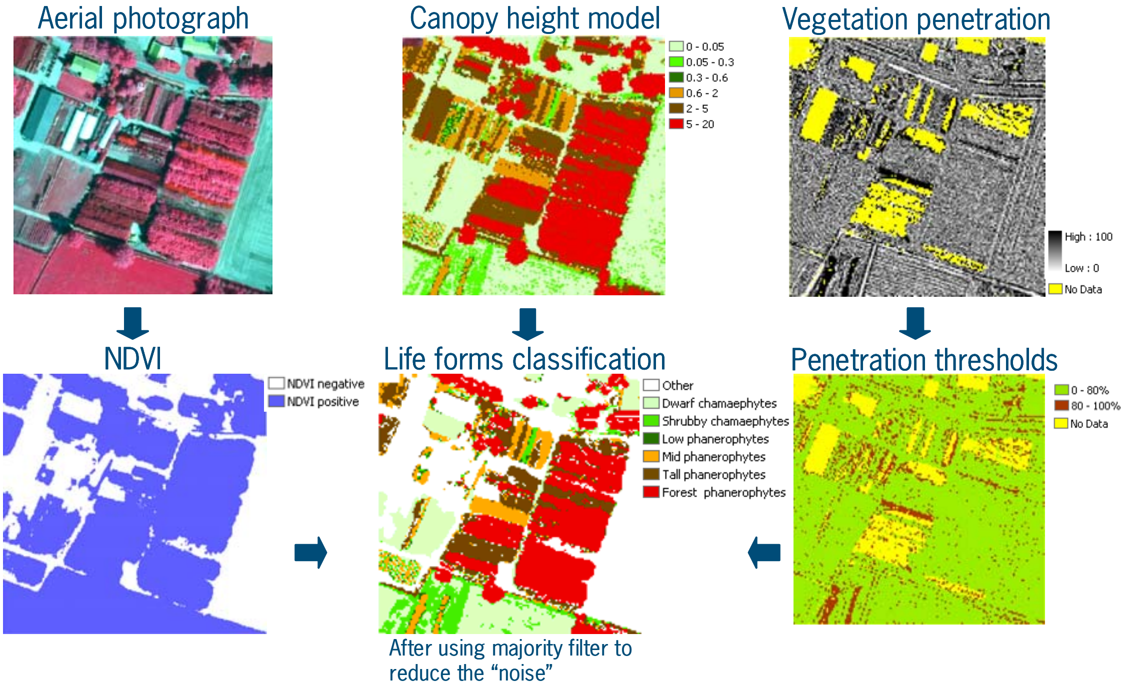


Figure 3 An example of proposed methodology in which different layers calculated by Fusion software for the LiDAR data and layers derived from the false-colour aerial photographs are integrated by a decision tree classifier to identify the individual plant life forms at a pixel level.

Preliminary results using the decision tree classifier were quite satisfactory by integration of LiDAR data with false-colour aerial photographs and enables to identify most life forms in the tree nursery.

4.3. Habitat mapping and classification

Following the promising results obtained using a decision tree classifier to indentify plant life form at pixel level, the pixel-based classification method presented above was applied on a larger study area (1x1km) and used as starting point for the habitat mapping unit identification. As explained in the previous example, a NDVI index computed from the aerial photographs is used to discriminate vegetated and artificial areas. This selection is completed integrating the Dutch topographic map (Top10 vector) to remove urban or crop elements. Concerning the latter, not all the crops are filtered out. Some types of crops, like vineyards, are considered as relevant habitat categories (Figure 4).

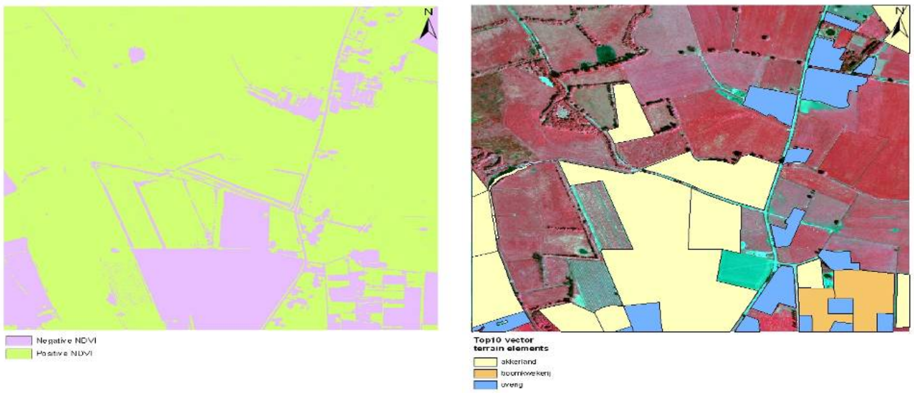


Figure 4 NDVI index mask (left) and Top10 vector mask (right)

From the LiDAR data, a canopy height model is computed at 2m grid cell size. The NDVI mask, Top10 vector mask and the canopy height model are then mosaiced. The classification rules are applied on the mosaic in order to produce 9 categories on a pixel basis :

- No vegetation (from the NDVI information)
- Crop field (from the top10 data)
- Other (from the top10 data)
- Tree nursery (from the top10 data)
- Canopy height between 0 and 10cm (from the canopy height model)
- Canopy height between 10 and 60cm (from the canopy height model)
- Canopy height between 60cm and 2m (from the canopy height model)
- Canopy height between 2 and 5 m (from the canopy height model)
- Canopy height higher than 5m (from the canopy height model)

The classification output (Figure 5) is smoothed using a majority filter with a kernel window of 3 by 3 pixels before a segmentation was performed.

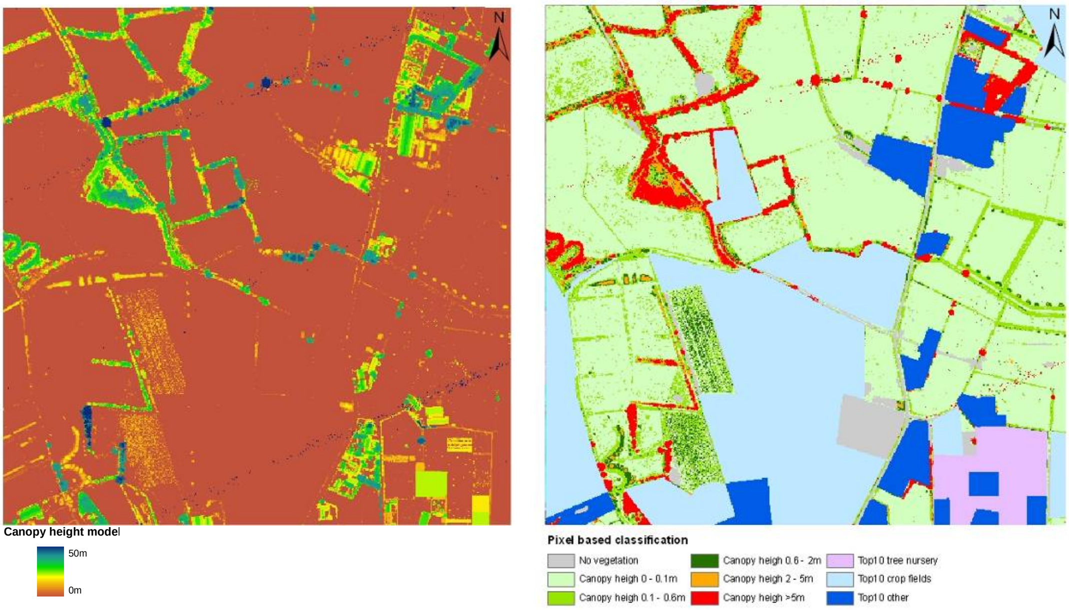


Figure 5 Canopy height mode (left) and pixel based classification output (right)

From the pixel-based classification, the delineation of habitat mapping units can be performed. To do so, a multi-resolution segmentation and a spectral difference segmentation methods are carried out using eCognition. First the multi-resolution segmentation is run using a scale factor of 15. The shape criteria is set really low (0.05) whereas the compactness criteria is relatively high (0.7). The spectral difference segmentation is carried out in two steps. First, the segmentation is applied to all the objects created during the multi-resolution segmentation using a maximum spectral difference set as 0.17. Then a second spectral difference based segmentation is performed only for the objects presenting a average value superior to 2.5 (see the value attributed to the pixel according to the classification described above) using a maximum spectral difference value of 0.5. The composition of individual plant life forms is determined normally for every habitat mapping unit with a minimum area of 400 m^2. In order to fit to this requirement, a “cleaning” is done to dissolve all objects presenting an area smaller than this limit. A filtering is also performed based on the ratio width/length of the object to remove the small and long objects that can be generated by border effect. The width/length ratio used is set as superior or equal to 7.

The produced objects are exported as shapefile and some zonal statistics are computed in order to give the percentage of each general habitat category present in each polygon.

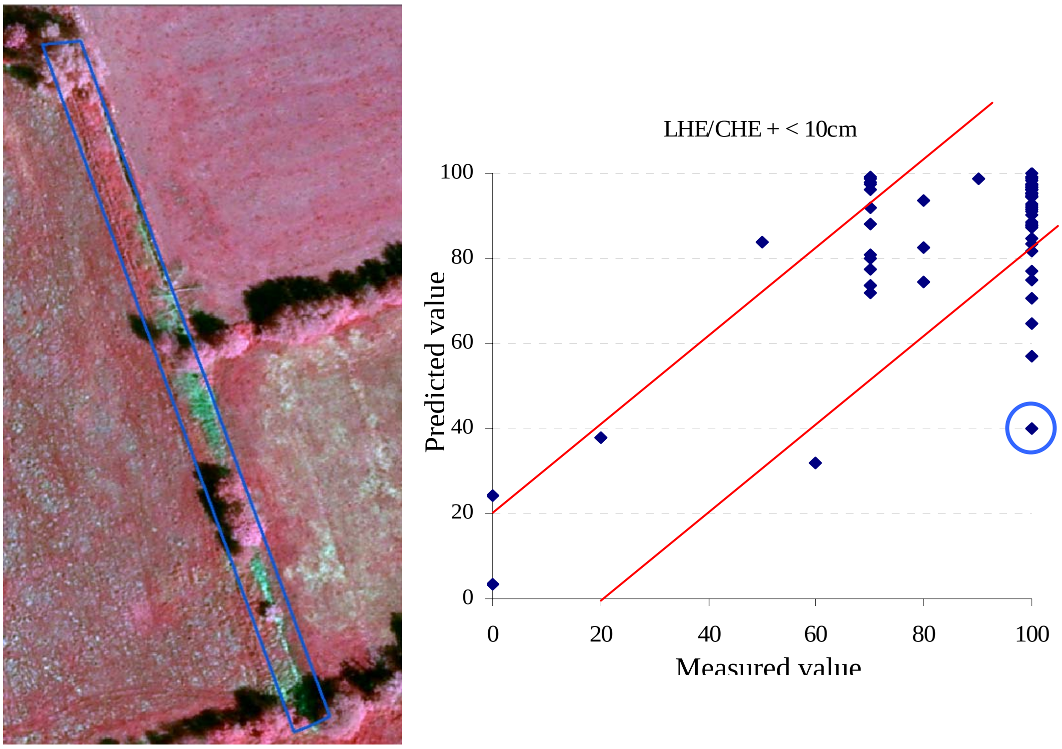
4.6. Validation

In order to validate the result of the semi-automated procedure for the detection of the proper mapping units used for the General Habitat Categories, the produced outputs have been compared with fieldwork data (Figure 6).

Figure 6 Visual comparison of semi-automated (yellow) and field based manual (blue) delineation of the habitat mapping units.

Considering the identification of habitat mapping units, the result obtained from the semi-automated procedure appear quite satisfying when compared to the field based manual delineation. The next step of the validation was to compare the plant life form identification inside each habitat mapping unit. To do so, the zonal statistics on general habitat categories were computed using the field based delineated habitat mapping unit. Those statistics can then be compared to the field observations.

Figure 7 shows that most of the percentages of Leafy hemicryptophytes (LHE) and Caespitose hemicryptophytes (CHE) obtained using the semi-automated procedure are less than 20% different from the field observations. The point circled in blue in the graph presents a large difference between the field measured value (100%) and the semi-automated predicted value (40%). When looking at the habitat mapping unit corresponding to that point, it appears that some trees are present in the unit that was classified on the field as 100% Leafy hemicryptophytes (LHE) and Caespitose hemicryptophytes (CHE). This explains the lower percentage given by the semi-automated classification provides a for this general habitat category. The table in figure 7 presents the predicted (white) and observed (green) percentage of the different life forms for this particular unit.



ID	LHE/CHE_f	LHE/CHE + < 10cm	MPH_f	MPH	TPH_f	TPH	FPH_f	FPH
85	100	40	0	11	0	26	0	23

Figure 7 Validation graphs for Leafy hemicryptophytes (LHE) and Caespitose hemicryptophytes (CHE) and details concerning an outstanding value.

5. Conclusions

LiDAR provides accurate height measurements on shrubs and trees, even in early spring when the objects of interest still did not have any leaves. Early spring is the standard time for LiDAR measurements over the entire area of the Netherlands (primary interest is the update of the Dutch elevation model). Regression analysis between field measurements and LiDAR measurements of the height of various plant life forms showed an adjusted R square of 0.95. Unfortunately, not the whole range of plant life forms could be measured with LiDAR. Since the latest generation of LiDAR measurements have an accuracy of approximately 2 to 3 centimeters, it is assumed that cryptogams and dwarf chamaephytes (below 5 cm) are difficult to measure with this technique. In general, it has been demonstrated in this study that good characterization of 3d-vegetation objects is possible with LiDAR. But surprisingly, there were also problems with the identification of some specific vegetation types, such as fields with Juncus effusus (caespitosa hemicriptophytes). This vegetation type does not reflect any LiDAR measurements and is therefore invisible for LiDAR. Occasional data gaps occur through “shadow effects”, but the use of different scan angles solves this problem. Combination of LiDAR with false-colour aerial photographs, both available for the whole of the Netherlands, provides a power tool with e.g. Fusion software and decision tree classifiers for the identification of plant life forms. Additional combination with topographic maps is needed to mask urban environments for which the EBONE does not distinguish life forms. Comparison with a full field survey of the general habitat categories showed uncertainties in the proposed classification and segmentation methodology as well as in the used field methods. Combination of LiDAR height measurements in combination with species specific hyperspectral measurements might be a step further forward.

Aknowledgement

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