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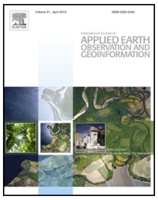

Synergy of airborne LiDAR and Worldview-2 satellite imagery for land cover and habitat mapping: A BIO_SOS-EODHaM case study for the Netherlands

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ABSTRACT

A major challenge is to develop a biodiversity observation system that is cost effective and applicable in any geographic region. Measuring and reliable reporting of trends and changes in biodiversity requires amongst others detailed and accurate land cover and habitat maps in a standard and comparable way. The objective of this paper is to assess the EODHaM (EO Data for Habitat Mapping) classification results for a Dutch case study. The EODHaM system was developed within the BIO_SOS (The BIOdiversity multi-SOurce monitoring System: from Space TO Species) project and contains the decision rules for each land cover and habitat class based on spectral and height information. One of the main findings is that canopy height models, as derived from LiDAR, in combination with very high resolution satellite imagery provides a powerful input for the EODHaM system for the purpose of generic land cover and habitat mapping for any location across the globe. The assessment of the EODHaM classification results based on field data showed an overall accuracy of 74% for the land cover classes as described according to the Food and Agricultural Organization (FAO) Land Cover Classification System (LCCS) taxonomy at level 3, while the overall accuracy was lower (69.0%) for the habitat map based on the General Habitat Category (GHC) system for habitat surveillance and monitoring. A GHC habitat class is determined for each mapping unit on the basis of the composition of the individual life forms and height measurements. The classification showed very good results for forest phanerophytes (FPH) when individual life forms were analyzed in terms of their percentage coverage estimates per mapping unit from the LCCS classification and validated with field surveys. Analysis for shrubby chamaephytes (SCH) showed less accurate results, but might also be due to less accurate field estimates of percentage coverage. Overall, the EODHaM classification results encouraged us to derive the heights of all vegetated objects in the Netherlands from LiDAR data, in preparation for new habitat classifications.

Introduction

A biodiversity observation system that is consistent and cost effective is desirable, but its development and implementation remains a significant challenge. Recent advances in Earth Observation (EO) allow inroads to the design of such a system. Light Detection and Ranging (LiDAR) and Very High Resolution (VHR) multi-spectral sensors are increasingly becoming available. These images provide opportunities for land cover and habitat mapping with a very high spatial resolution of 1 or 2 m (mapping scale ~1:4000) and a high thematic differentiation in such a way that the derived maps meet the demand of end-users such as terrain and nature conservation managers. The launch of the multi-spectral Worldview-2 (WV-2) sensor with eight spectral bands (including the coastal, yellow and red edge as well as a second (overlapping) NIR channel) and a spatial resolution of 2 m provides new opportunities for discrimination of land covers/habitats, hence it is preferred for adoption with the EODHaM system (Lucas et al.,

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2015). A limitation of using optical imagery is that information on vegetation height cannot be retrieved with sufficient reliability unless relationships with, for example, textural measures are provided. As such, LiDAR is complementary to optical EO data, since the technology allows for the measurement of vegetation structure (Mücher et al., 2013). In our case, LiDAR-derived canopy height models (CHM) represent the calculated height of the woody vegetation above the ground surface (in cm) for each individual grid cell. This is critical for the descriptions of woody life forms within the Food and Agricultural Organization (FAO) Land Cover Classification System (LCCS) taxonomy (di Gregorio and Jansen, 2005) and the General Habitat Category (GHC) system for habitat surveillance and monitoring (Bunce et al., 2008). The LCCS system is capable to record any land cover type, independent of specific applications and/or geographical areas. The LCCS is also intended to overcome problems associated with the interpretation of different land cover class definitions. This is because it defines a set of independent diagnostic criteria strictly based on vegetation physiognomy and structure rather than establishing other land cover classes based on terminology (Kosmidou et al., 2014). For habitats we used the definition of Bunce et al. (2008, p. 15): '*An element of the land surface that can be consistently defined spatially in the field in order to define the principal environments in which organisms live*'. The GHC recording procedure has adopted plant life forms, as described by Raunkiaer (1934), as the basis of the habitat mapping and monitoring (Bunce et al., 2008). The GHC method can be considered as an ecological refinement of the land cover categorization used in LCCS (Bunce et al., 2008; Kosmidou et al., 2014).

Since vegetation physiognomy and structure is an important diagnostic criteria in the land cover as well as habitat classification system, this paper puts a major emphasis on the exploitation of LiDAR data for CHM in combination with multi-temporal and multi-spectral VHR satellite imagery. High performance airborne LiDAR systems were generated already in the 1980s supported by Global Positioning Systems (Akay et al., 2008), while their commercial development can be traced back to the mid-1990s only. Therefore, from the perspective of ecological research, LiDAR can be considered as a relatively new technology (Carson et al., 2004). Over the last decade, there has been a notable increase in publications on LIDAR EO which reflects the strong scientific interest. Airborne LiDAR is an active EO technique that measures the properties of emitted scattered light to determine the 3D coordinates (x, y, z) and other properties of a distant target (St-Onge, 2005; Mallet and Bretar, 2009). So LiDAR, in contrast to optical EO techniques, can bridge the gap in providing structural information by capturing the complete 3D structure of individual objects (e.g. vegetation height and density) at the landscape scale (Geerling et al., 2009; Graf et al., 2009). This means a considerable efficacy in costs and efforts for habitat mapping and wildlife management in fine detail across large areas. It may replace many labour-intensive, field-based measurements, and can characterize habitat in novel ways (Vierling et al., 2008; Corbane et al., in this issue), but practical limitations for using LiDAR might be costs and time efforts if the data needs to be acquired for a specific case. Considering monitoring applications, the repeatable and high absolute 3D "*xyz*" LiDAR point cloud accuracy is advantageous since changes can be detected at sub metre scales and the same measurement units can be monitored over time (Korpela et al., 2009). In that sense, LiDAR constitutes an efficient tool for short and long term monitoring of changes in terrain and vegetation structure. Therefore, the authors processed, analyzed and evaluated the use of LiDAR data as a valuable information source to collect information on the vegetation height in addition to the optical information from VHR satellite imagery. The EODHaM classification system (Lucas et al., 2015) was used for the production of regional land cover and habitat maps and is discussed for the Ederheide and Ginkelse heide, as a Dutch case study.

Study area and materials

The BIO_SOS study area is located within the Natura 2000 site the Veluwe in the Province of Gelderland, and falls under the Habitat Directive (Council Directive 92/43/*EEC*) as well as Bird Directive (Council Directive 2009/147/EC). The Veluwe is the largest end moraine in the Netherlands, an undulating sandy landscape that was created during penultimate glacial period, about 150,000 years ago. The present landscape of alternating sand dune areas, heathlands and dry forests were created by a long history of intensive land use. Although the entire Veluwe has a total surface of 912 km^2, the heathland area Ginkelse and Ederheide covers an area of approximately 1000 ha in size and is known for its large area covered by Calluna heather vegetation. The Ginkelse and Ederheide is managed by Ministry of Defense, and is still used as a military exercising area. The Wekeromse Zand, an active inland sand dune area surrounded by forest, 3 km North of the Ginkelse and Ederheide, has a total area of approximately 500 ha and is managed by Geldersch Landschap. The study area includes both protected sites with a bufferzone of 3 km and covers an area of 12.194 ha. Nitrogen deposition is the most important pressure on the habitat quality and is caused by intensive agriculture in the surrounding areas, which is causing moss (*Campylopus introflexus*), grass (*Molinia caerulea*), shrub (*Rubus fruticoses spp.*) and tree encroachment (*Pinus sylvestris* and *Betula pendula*) of the Calluna heather and inland sand dunes.

The LiDAR dataset used in this study originates from the second version of the Dutch national dataset, named AHN-2 (Actueel Hoogtebestand Nederland, see www.ahn.nl), and was acquired in March 2010. AHN-2 has a height precision of a few centimetres and a density of approximately 15 points per square metre. The absolute accuracy for a single point is guaranteed below 3 cm for AHN-2. Worldview-2 was used as VHR satellite imagery. A peak flush image (June 2011), a post-peak flush image (September 2011) and a pre-peak flush image (March 2013) were acquired and analyzed in combination with the LiDAR data of March 2010 (see Fig. 1). The pre-processing was crucial and involved radiometric and correction to top of atmosphere (TOA) reflectance, including topographic correction. The Dutch topographical maps has been used as an additional digital data source to identify the large objects and to stratify the area into agricultural, semi-natural and urban areas.

Method for canopy height model and habitat classification

The CHM is a result of the difference in height between the calculated Digital Surface Model (DSM), indicating the top of the vegetation, and the Digital Terrain Model (DTM), indicating the ground surface. A detailed and accurate DTM had to be processed to capture the micro relief in the terrain. The MCC-LiDAR software was a fundamental tool which was used for the classification of the ground points (Evans and Hudak, 2007). MCC-LiDAR is an iterative multiscale algorithm for classifying LiDAR returns that exceed positive surface curvature thresholds, resulting in all the LiDAR measurements being classified as ground or non-ground (see Fig. 2). The MCC-LiDAR algorithm yields a solution of classified returns that support bare-earth surface interpolation at a resolution commensurate with the sampling frequency of the LiDAR survey. MCC-LiDAR was selected for the classification of ground points because of its curvature capabilities, which are not implemented in other software such as the lasground tool of the las tools suite. All non-ground points were assumed to represent vegetation, which largely applies for protected (semi-) natural areas while some small errors can occur caused by e.g. benches