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Monitoring height and greenness of non-woody floodplain vegetation with UAV time series

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ABSTRACT

Vegetation in river floodplains has important functions for biodiversity, but can also have a negative influence on flood safety. Floodplain vegetation is becoming increasingly heterogeneous in space and time as a result of river restoration projects. To document the spatio-temporal patterns of the floodplain vegetation, the need arises for efficient monitoring techniques. Monitoring is commonly performed by mapping floodplains based on single-epoch remote sensing data, thereby not considering seasonal dynamics of vegetation. The rising availability of unmanned airborne vehicles (UAV) increases monitoring frequency potential. Therefore, we aimed to evaluate the performance of multi-temporal high-spatial-resolution imagery, collected with a UAV, to record the dynamics in floodplain vegetation height and greenness over a growing season. Since the classification accuracy of current airborne surveys remains insufficient for low vegetation types, we focussed on seasonal variation of herbaceous and grassy vegetation with a height up to 3 m. Field reference data on vegetation height were collected six times during one year in 28 field plots within a single floodplain along the Waal River, the main distributary of the Rhine River in the Netherlands. Simultaneously with each field survey, we recorded UAV true-colour and false-colour imagery from which normalized digital surface models (nDSMs) and a consumer-grade camera vegetation index (CGCVI) were calculated. We observed that: (1) the accuracy of a UAV-derived digital terrain model (DTM) varies over the growing season and is most accurate during winter when the vegetation is dormant, (2) vegetation height can be determined from the nDSMs in leaf-on conditions via linear regression (RSME = 0.17–0.33 m), (3) the multitemporal nDSMs yielded meaningful temporal profiles of greenness and vegetation height and (4) herbaceous vegetation shows hysteresis for greenness and vegetation height, but no clear hysteresis was observed for grassland vegetation. These results show the high potential of using UAV-borne sensors for increasing the classification accuracy of low floodplain vegetation within the framework of floodplain monitoring.

1. Introduction

River floodplains have multiple functions that often conflict spatially, such as water conveyance and water storage during peak discharge, hot-spots for biodiversity, agricultural use and space for recreation (Schindler et al., 2014). Restoration projects of floodplain ecology have resulted in a more natural and heterogeneous floodplain vegetation and have enhanced ecological value and biodiversity of the floodplains (Göthe et al., 2016; Straatsma et al., 2017). The drawback is that developing more natural floodplain vegetation results in increasing hydraulic roughness (Lee et al., 2004), which decreases the conveyance capacity of the floodplain and increases flood risk (Makaske et al., 2011). Hence, up-to-date maps of floodplain vegetation are of high importance for the spatial planning and management of floodplains, to balance the benefits of more natural vegetation with its risks for flooding.

Due to vegetation development, both ecological and hydraulic characteristics of the floodplain vegetation are expected to change over time (Baptist et al., 2004). To document and evaluate these changes, monitoring of floodplain vegetation is essential. Floodplain vegetation is commonly mapped using remote sensing imagery, such as for the Mississippi River (Dieck et al., 2015), Rhine Delta (Houkes, 2008) and Murray-Darling Basin (Eco Logical Australia, 2015). However, reported land-cover classifications show low accuracies for grassland and herbaceous vegetation, due to the spectral and structural similarity of these vegetation types (Geerling et al., 2007; Straatsma et al., 2008; Knotters and

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Brus, 2013). In the field, grassland and herbaceous vegetation can be discriminated by their height. Most grassland species have a maximum height up to 0.5 m. Herbaceous vegetation can reach from 0.5 m up to 2.50 m. Vegetation height is not only relevant to distinguish different vegetation types, but it is also a relevant characteristic determining the vegetation's hydraulic roughness during floodplain inundation (Kouwen and Li, 1980).

The above-ground biomass of most floodplain grassland and herbaceous species dies down in winter. Therefore, their variability in height over time is larger than for woody plants, such as shrubs and trees. The recent increase in availability of unmanned airborne vehicles (UAV) offers the potential to increase monitoring frequency compared to conventional airborne imagery with airplanes, because UAVs are relatively inexpensive and easy to deploy (Dandois and Ellis, 2013). Moreover, the spatial resolution of UAV imagery is in the order of centimetres instead of decimetres (conventional airborne) or meters (satellite), which allows for observation of fine-scale spatial patterns. This is desirable, because grassland and herbaceous vegetation can vary at a scale of decimetres to metres, especially when a floodplain is used for grazing.

In theory, the height of an object may be observed from the UAV imagery with photogrammetry by subtracting the digital terrain model (DTM) from the digital surface model (DSM) of the vegetation, resulting in a normalized DSM (nDSM) (Weidner and Förstner, 1995). The extraction of a DTM from a UAV-derived DSM remains challenging, because of the inability to see the terrain surface through a canopy (Baltsavias, 1999). It also remains unclear how well a UAV-derived DSM can estimate the elevation of a vegetated surface, because vegetation has an irregular surface, especially low vegetation like grassland and herbaceous vegetation.

In addition to vegetation height, photosynthetic activity or greenness can also give information on vegetation type (Cihlar et al., 1996), especially when time series of greenness are used (Müller et al., 2015). The simplest sensors to use on a UAV are consumer-grade digital cameras, which can be adjusted to record near-infrared radiation (Nijland et al., 2014). However, it remains unknown whether such a camera yields meaningful time series for natural grassland and herbaceous vegetation. Time series of combined vegetation height and vegetation greenness are already used for monitoring and classification in forestry (Dandois and Ellis, 2013) and agriculture (Bendig et al., 2015), but it has remained unexplored for low vegetation types like grassland and herbaceous vegetation.

The combination of multitemporal height and spectral data may reveal new possibilities to identify vegetation-type specific seasonal changes, as valuable information for vegetation monitoring at floodplain scale. Therefore, the aims of this study were to (1) evaluate the accuracy of a UAV-derived DTM, (2) evaluate the accuracy of vegetation height derived from UAV imagery nDSMs of low floodplain vegetation over a year, (3) evaluate the performance of multitemporal, high-spatial-resolution UAV imagery for extracting temporal vegetation height and greenness profiles of low vegetation in floodplains and (4) assess how changes in height and greenness during one growing season differ among different vegetation types. To achieve our objectives, a field study was performed in a 1 km^2 floodplain along the lower Rhine in the Netherlands.

2. Study area

We studied the Breemwaard floodplain (Fig. 1A), sized 116 ha, which is located on the southern bank of the river Waal in the Netherlands (Fig. 1C). The floodplain used to have a morphologically dynamic character, which disappeared at the end of the 19th century, due to sand and clay excavation and the construction of groins along the channel bank (Peters et al., 2011). Further clay and sand mining in the 20th century resulted in large pits, which developed into lakes with marshes and small riparian woods still present today. Clay mining for dike reinforcement was combined with nature development after the 1995 flood, and resulted in a large elongated water body. Its swampy northern bank was overgrown by young willow trees, which were cut in 2012 to reduce vegetation roughness.

Today, approximately 30% of the area is used for hay production and is frequently mowed. Several parts of the floodplain are managed by private owners and are used as grazing fields for ponies, as willow fields, or as reed fields. The remaining part is a nature area that is managed by the state forestry, and is pastured by cows and ponies as part of labour-extensive natural management. Some sections within the nature area are fenced off for cattle, and have developed into riparian woodland. This variability in management resulted in a spatially heterogeneous distribution of vegetation types and structure.

Typical floodplain vegetation along the river Waal includes hayfields, agricultural fields, grassland, herbaceous vegetation, thicket and riparian woodland. This study focused on low vegetation, which was categorised into the classes pioneer, natural grassland, production grassland, high herbaceous, low herbaceous and reed vegetation (Fig. 1B). Pioneer vegetation had a cover of less than 25%. The existing pioneer vegetation was often organized in patches of a few individual plants and did not exceed a maximum height of 0.5 m. The remaining surface was bare substrate. Production grassland had a dense surface cover, comprised a low number of species and was all-year lower than 0.5 m. Height of natural grassland also did not exceed 0.5 m, but it was much higher richer in species than production grassland. Herbaceous vegetation contained most different species and was subdivided in a low class, with height up to 0.7 m and a high class, with height up to 2.5 m. Reed vegetation could grow up to 3 m and comprised a relatively low number of species.

3. Methods

The work flow consisted of three consecutive phases (Fig. 2). First, multitemporal field data collection was carried out, consisting of two simultaneous operations, which are measurements of reference data in the field and acquisition of imagery with a UAV. Second, the UAV imagery was processed into point clouds with colour attributes for each time step. Third, terrain height, vegetation height and vegetation greenness were calculated per plot for the analyses. In the analyses we evaluated (1) the use of DSMs as DTM and the selection of the best performing DSM, (2) an nDSM-derived predictor for vegetation height, (3) temporal profiles of vegetation height and greenness, and (4) the patterns in vegetation height versus greenness over time.

3.1. Multitemporal data collection

3.1.1. Field data acquisition

Twenty-eight field plots (around 15 × 15 m; Fig. 1C) with a different average vegetation height of low vegetation were selected during the first survey in February 2015. Initially 26 plots were selected in February 2015, of which 25 plots had a complete time series of 6 time steps. These were supplemented with a pioneer (nr. 5) and high herbaceous (nr. 28) plot in April 2015 to achieve a broader range of variation in these vegetation types. Plot 27 was excluded after June, because it was excavated during recreation of a natural river bank. Plot 15 was excluded in January, because it was flooded then. Species composition was not a factor determining plot selection, because of the dormant state of the vegetation at that time. Outlines of the plots were measured with