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A composite indicator for assessing habitat quality of riparian forests derived from Earth observation data

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ABSTRACT

Riparian forests are precious, complex habitats fostering high biodiversity where effective monitoring of habitat quality is particularly important. We present a composite indicator, referred to as Riparian Forest composite Indicator: focus on Structure (RFI_S), for the assessment of habitat quality and identification of 'hot-spot' areas where conservation actions need to be taken. The RFI_S is composed of seven indicators derived from very high resolution (VHR) satellite imagery and LiDAR data, calculated on patch level. These indicators assess four important attributes of riparian forest quality: (1) tree species composition, (2) vertical forest structure, (3) horizontal forest structure and (4) water regime. For the aggregation of the RFI_S, two different weighting schemes, expert-based and statistical weighting, are applied. Forest patches with high cumulative RFI_S values represent patches of good habitat quality. These patches are primarily found along water bodies, reflecting the importance of water bodies for the structural complexity, an optimum water regime and tree species composition. For forest patches of low habitat quality the RFI_S helps to design suitable measures to improve habitat quality status through its decomposability into the underlying indicators. A sensitivity analysis to test the robustness of the RFI_S shows that the indicator variance in terrain roughness has the strongest influence on the composite indicator. Finally, a comparison with an existing expert-based map on conservation status reveals the potential of a complementary quantitative assessment of habitat quality in the study site. We hence conclude that the RFI_S has a high capability to support sustainable forest management complementing regularly gathered in situ data.

Introduction

Riparian forests are complex ecosystems that foster high biodiversity (Tockner and Stanford, 2002; Ward et al., 2002) and provide important ecosystem services to society (Wantzen and Junk, 2008) but are highly threatened at the same time (Tockner and Stanford, 2002). An effective assessment and monitoring of habitat quality for such ecosystems is particularly important. We here refer to habitats as "terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural" (Habitats Directive (HabDir, Council Directive 92/43/EEC), Art 1) where "plant and animal communities as the characterising elements of the biotic environment operate together with abiotic factors at a particular scale" (Davies et al., 2004, p. 286).

Habitat quality should account for the specific structure and functions of a habitat that are necessary for its long-term maintenance and the long-term survival of its typical species (sensu HabDir, Art 1) and can be assessed using suitable indicators. Indicators thereby can represent and integrate information, which is not measurable directly (Müller et al., 2000). To measure multi-dimensional concepts like environmental quality, composite indicators, compiled of relevant indicators based on an underlying model (Nardo et al., 2008) are a powerful tool (OECD, 2004), as they reduce the number of separate parameters while retaining the underlying information (Saisana and Tarantola, 2002).

For the monitoring and sustainable management of forest habitats, various descriptive indicators have been developed (Noss, 1999; Marchetti, 2004; Geburek et al., 2010) and adapted for the use of Earth observation (EO) data (Bock et al., 2005; Duro et al., 2007; Nagendra et al., 2013). The use of EO-derived indicators enables an area-wide coverage, regular updates, cost-efficiency, transferability and the harmonization of data sources as well as results (Duro et al., 2007; Vanden Borre et al., 2011). When combining EO data of different sources such as VHR satellite imagery and LiDAR data,

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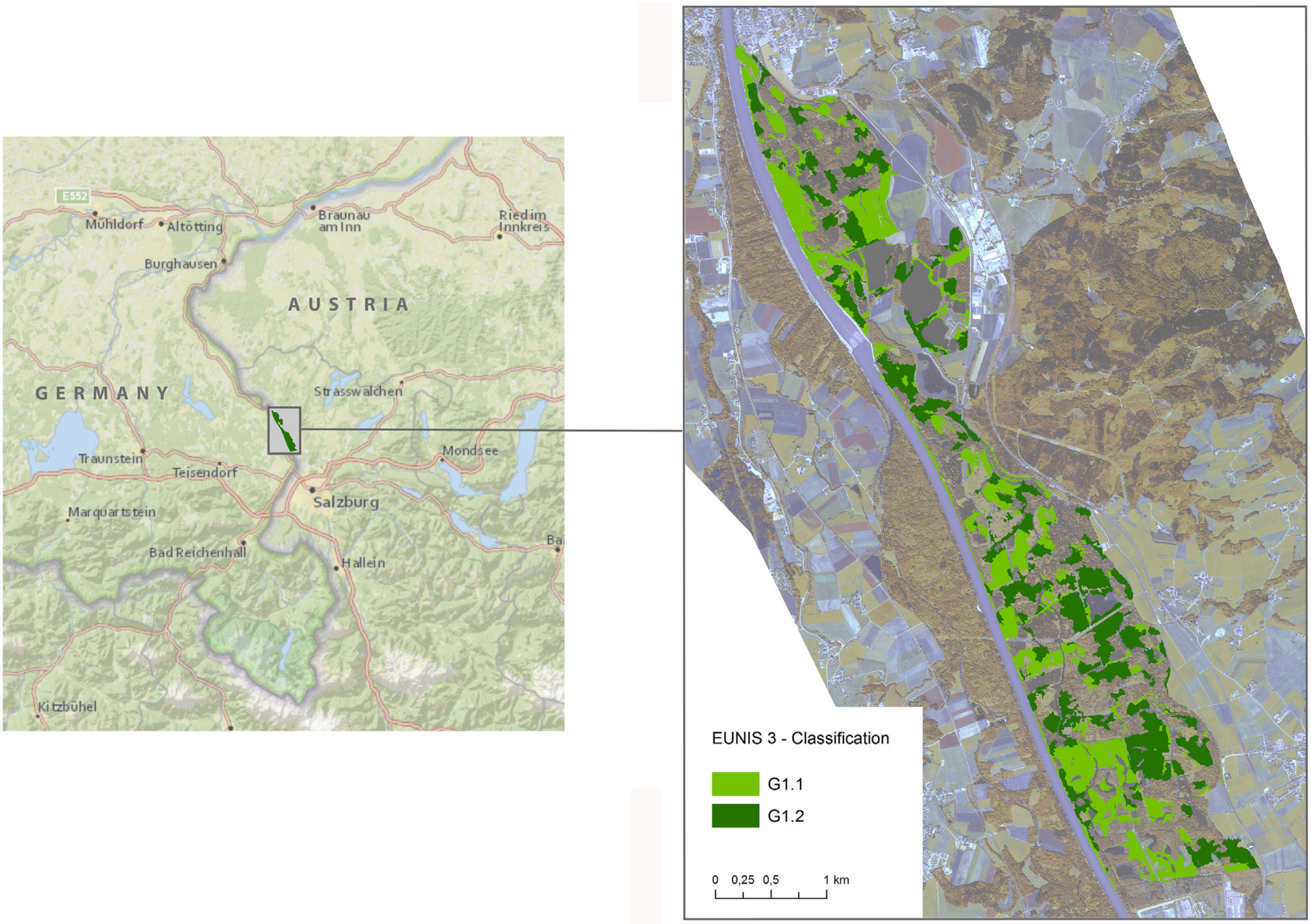

Fig. 1. Natura 2000 riparian forest Salzachauen.

it is possible to link information on tree species composition and vertical forest structure (Duro et al., 2007; Nagendra et al., 2013).

Habitat quality of riparian forest is characterized by its specific structure, which in turn is essential for the provision of its key functions. These are the regulation of water quality as well as the provision of critical habitat and moving corridors (Azim, 2006). For assessing riparian forest quality we here focus on the particular structure described by attributes which are also used in expert-based field assessment, such as biotic attributes of forest composition, vertical and horizontal structure, the abiotic attribute of water regime as well as forest disturbance (Ellmauer, 2005; BfN, 2010). Table 1 presents these attributes and related indicators which were selected based on the ability to be derived from EO data and calculated on individual patch level. Indicators with a positive direction are thereby assumed to increase habitat quality whereas a negative direction of indicators might decrease habitat quality. Using patch level allows a spatially explicit assessment of habitat quality (Langanke et al., 2007) considering patches as discrete areas of mainly homogeneous environmental conditions (Wiens, 1976).

In the present study, seven EO-based indicators were selected based on their relevance for a study site in a continental riparian zone and aggregated into a composite indicator referred to as RFI_S (Riparian Forest composite Indicator: focus on Structure) to assess riparian forest habitat quality. Two different weighting schemes were applied and the robustness of the RFI_S in relation to the influence of single indicators was analysed. Results were compared to an expert-based conservation status map.

Materials and methods

Study site and EO data

The semi-natural Natura 2000 site Salzachauen (Austria, 9.12 km^2) is located along the regulated river Salzach in the alpine foreland (Fig. 1). The vegetation is mainly composed of riparian and gallery woodland (EUNIS: G1.1) and mixed riparian floodplain and gallery woodland (EUNIS: G1.2; Davies et al., 2004). Main human-induced pressures are plantations of allochthonous tree species and river regulation.

For deriving selected indicators, we used a WorldView-2 image (acquired in June 2012, 8 multispectral bands, 2 m ground sampling distance (GSD), pan-sharpened to 0.5 m GSD) and airborne LiDAR data acquired in April 2006 with a mean point density of 1 point/m^2. LiDAR data were used for the creation of a digital terrain model (DTM), a digital surface model (DSM) and a normalized surface model (nDSM) with a spatial resolution of 1 m. The time gap between the EO data used is justifiable, as only minor micro-relief changes occurred in this period due to flood events. As baseline patch geometry we used the EUNIS categories G1.1 and G1.2 (Davies et al., 2004) of a semi-automated habitat delineation with a nominal scale of 1:4000 (Strasser et al., 2014) (Fig. 1). The outlines of the delineated units were generalized by applying the PAEK (Polynomial Approximation with Exponential Kernel) algorithm. All polygons with an area less than 100 m^2 were merged with the neighbouring polygon sharing the longest boarder. After merging, forest patches with a total area less than 400 m^2 were