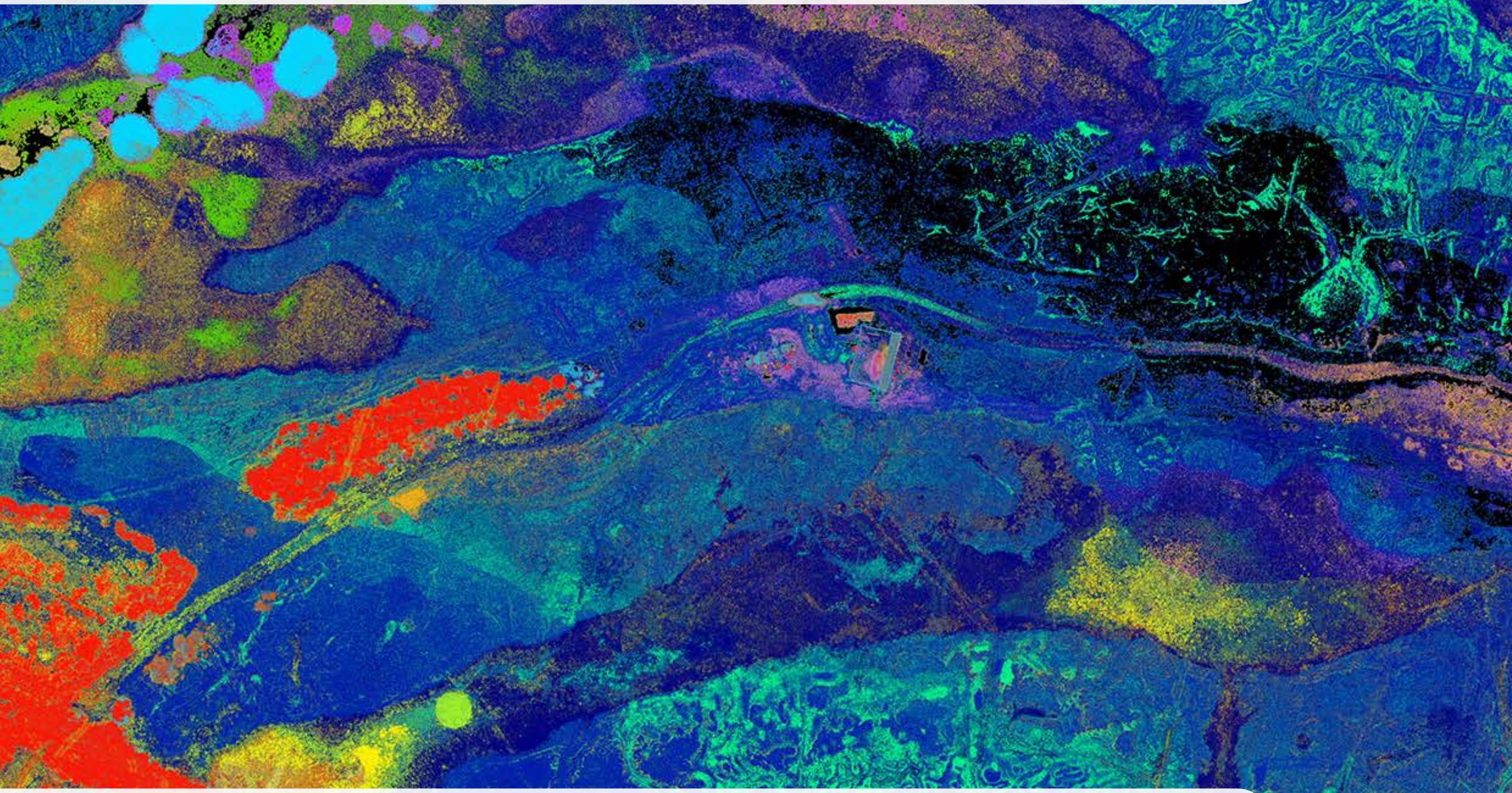
Norbert Pfeifer and András Zlinszky (Editors)

Proceedings

of the International Workshop on Remote Sensing and GIS for Monitoring of Habitat Quality

Vienna, 24–25 September 2014



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OESTERREICHISCHE COMPUTER GESELLSCHAFT ®
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The *International Workshop on Remote Sensing and GIS for Monitoring of Habitat Quality (RSGIS4HQ)* takes place at Vienna University of Technology on 24 and 25 September 2014 and is organized by Vienna University of Technology's Department of Geodesy and Geoinformation and the Austrian Computer Society with support from the Centre for Ecological Research of the Hungarian Academy of Sciences. The conference is held in parallel with GIScience 2014 at the same venue.

The cover image is a cutout from the grassland vegetation map of the Natura 2000 site Hortobágy at Ágota-puszta, Püspökladány, Hungary, created by Vegetation Classification Studio (A. Kania & A. Zlinszky, see page 52).

Edited by Norbert Pfeifer and András Zlinszky.
Type setting of the chapters by the authors.
Compiled by Felix Ortag.

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Think before you print!

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Preface

Biodiversity is one of the most threatened resources globally. Strong commitments to preserving habitats have been made at global, continental and national levels, calling for an evidence-based approach to conservation: monitoring the quality of habitats in space and time.

Remote sensing and GIS have a history in land cover, habitat mapping, and quantification of habitat change. The new challenge is integration and analysis of abiotic factors, vegetation, and habitat maps together with processes influencing the conservation status of each site for quantitative evaluation of habitat quality. This requires high resolution mapping with regional coverage, together with quantitative modeling of how these variables interact to influence habitat quality. The resulting spatially explicit products can build the basis of local ecosystem management and international policy.

The *International Workshop on Remote Sensing and GIS for Monitoring Habitat Quality* brings together remote sensing and conservation scientists, mapping and GIS practitioners, conservation stakeholders and NGOs. We focused beyond land cover and vegetation mapping to the next level of inferring habitat quality and conservation status from processed Earth observation and field data. This international workshop combines the latest developments and future trends in sensor technology, cutting-edge case studies, and operational examples in habitat mapping and quality assessment.

We would like to cordially thank our reviewers who made the peer reviewing of all submissions to our workshop possible. All extended abstracts in these proceedings were accepted based on the peer review by three international experts. With three exceptions in the *late submissions* section which were included because of their modern and relevant topics even though they were not fully reviewed.

Selected full papers based on abstracts from these proceedings will be published in a special issue of the *Remote Sensing* journal (ISSN 2072-4292).

The conference is organized by the Department of Geodesy and Geoinformation at Vienna University of Technology, Austria (http://geo.tuwien.ac.at) and the Austrian Computer Society (http://www.ocg.at) in cooperation with the Centre for Ecological Research of the Hungarian Academy of Sciences (http://www.okologia.mta.hu/en) and simultaneously with GIScience 2014. We are grateful for their support and especially for the contributions of Felix Ortag from the Department of Geodesy and Geoinformation in organizing everything necessary around the conference. We want to thank especially the company Riegl (http://www.riegl.com) for their financial support.

Norbert Pfeifer & András Zlinszky

Vienna, Summer 2014

Beyond Copernicus: New remote sensing approaches to habitat quality mapping and monitoring

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1. Introduction

Traditional methods of remote sensing for habitat quality mapping have most often focused on land cover mapping. While land cover is a very important characteristic of terrestrial habitats in the broadest sense, it rarely captures of the subtleties and complexities of habitats and by default generalises any notion of habitat quality. In remote sensing land cover classes are defined on the basis of human comprehension and conceptualisation of the land surface properties that can be distinguished in the spectral reflectance of the surface at different wavelengths from satellites or airborne sensors. This may make land cover an easily understandable interpretation of remote sensing data, but on the other hand, it is restricting the range of aspects of habitat quality that can be meaningfully characterised if all possible information retrievals from remote sensing were to be considered.

Biophysical parameters, in contrast to land cover classification, can provide important information related to habitat quality that is more directly related to the conditions found in nature. For example, knowledge of the gross primary productivity (GPP) of vegetation can be more significant in determining habitat quality than the type of land cover alone – imagine two types of improved grassland with high and low GPP or species diversity.

The Copernicus initiative, formerly GMES (Global Monitoring for Environment and Security), is Europe's contribution to the Global Earth Observation System of Systems (GEOSS). It funds a series of initial operations of services in support of specific user needs and policies, as well as a series of five Sentinel satellite missions to provide long-term data continuity for operational monitoring.

The GIONET European Centre of Excellence in Earth Observation Research Training (www.gionet.eu) project has provided a supplementary research and development component to the Copernicus programme. It has explored and developed new and innovative monitoring services, some of which are relevant for habitat quality mapping and monitoring and are introduced here.

2. Remote sensing in support of habitat quality mapping and monitoring

2.1 Terrestrial habitats: Forest mapping and monitoring

Forest biomass is one of the world's most important carbon pools and is at risk from tropical deforestation and land use change. The spatial distribution of forest biomass is also important as an indicator of habitat quality in forested or partially forested ecosystems. Forest biomass influences the light exposure and shading of the land surface, the magnitude of diurnal variations of land surface temperature and the soil moisture dynamics.

To date, most applications for forest mapping have used either optical or radar data, but rarely both. Synergies between radar, Light Detection and Ranging (LiDAR) and optical/infrared sensors can be used to improve the retrieval accuracy of aboveground forest biomass (Rodriguez-Veiga et al., in press).

A case study in Mexico by Rodriguez-Veiga et al. (in press) used MODIS 250 m reflectance bands and vegetation indices, the SRTM digital elevation model, and ALOS PALSAR L-band dual-polarization Synthetic Aperture Radar (SAR) imagery to map aboveground forest biomass at the national level at 250 m spatial resolution (*Figure 1*). L-band SAR backscatter generally increases with higher biomass up to around 150 t ha^{-1} when the signal saturates. Above the saturation threshold, this method mostly relies on optical reflectance and the digital elevation model. The topographic elevation of the pixel is an important determinant of forest biomass, because the higher elevation areas are less subject to logging and forest degradation than the lowlands.

A maximum entropy approach was used to identify the relative variable importance and produce the final biomass map. ALOS PALSAR explains approximately 50.9% of variation in biomass, while MODIS showed 32.9% and SRTM 16.2% relative importance.

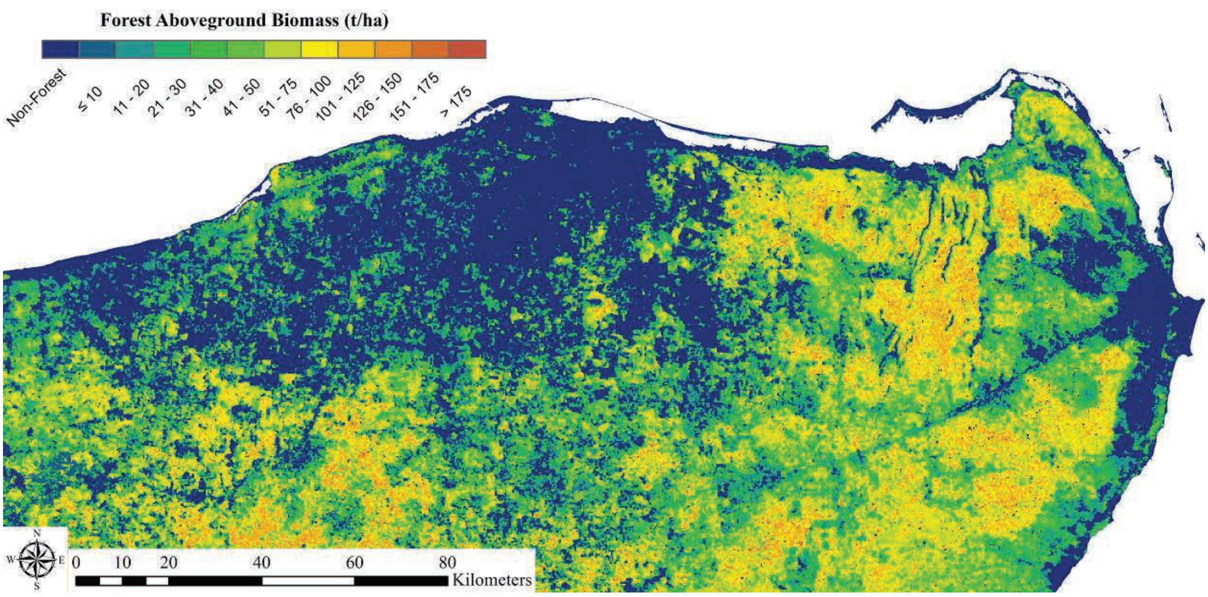


Figure 1: Map of Forest Aboveground Biomass at 250 m spatial resolution for the North coast of the Yucatán peninsula

In addition to forest aboveground biomass, more detailed investigations of biomass components can be made. In a study of high spatial-resolution airborne SAR data at S-band and L-band with co- and cross-polarised channels, Rodriguez-Veiga et al. (2013) found that, more detailed characteristics of the vertical biomass distribution in the canopy can be retrieved. *Figure 2* shows a map of tree crown biomass from Savernake forest, UK. This information was validated with forest inventory data collected in the field. Information on the spatial distribution of tree crown biomass can give important insight into the habitat quality for woodland birds and other tree-dwelling animals.

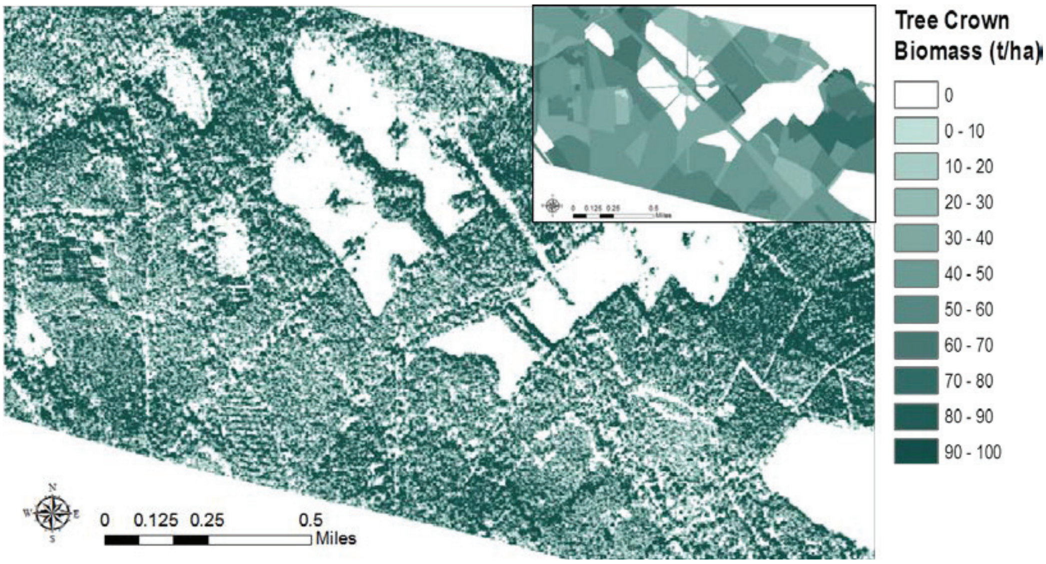


Figure 2: Map of tree crown biomass over Savernake forest, Wiltshire, UK, retrieved from S-band airborne SAR data acquired by Airbus Defence and Space. The inset shows the Forestry Commission stand boundaries.

2.2 Terrestrial/aquatic ecotones: Lakeshore monitoring

Hyperspectral images give sufficient detail to enable an analysis of the complex leaf level responses to environmental pressures. A case study by Stratoulias et al. (2014) for an ecotone on the shores of Lake Balaton in Hungary assessed the capability of hyperspectral imagers to detect the deterioration of reed (*Phragmites australis*), that is reed die-back. Die-back plants showed a marked change in spectral response, with a particularly useful signal being the red-edge position. *Figure 3*a shows a map of the lakeshore near the town of Tihany, classified from hyperspectral data, which highlights in red those reed areas that were detected as having a different leaf physiological response from other reed area (in shades of green).

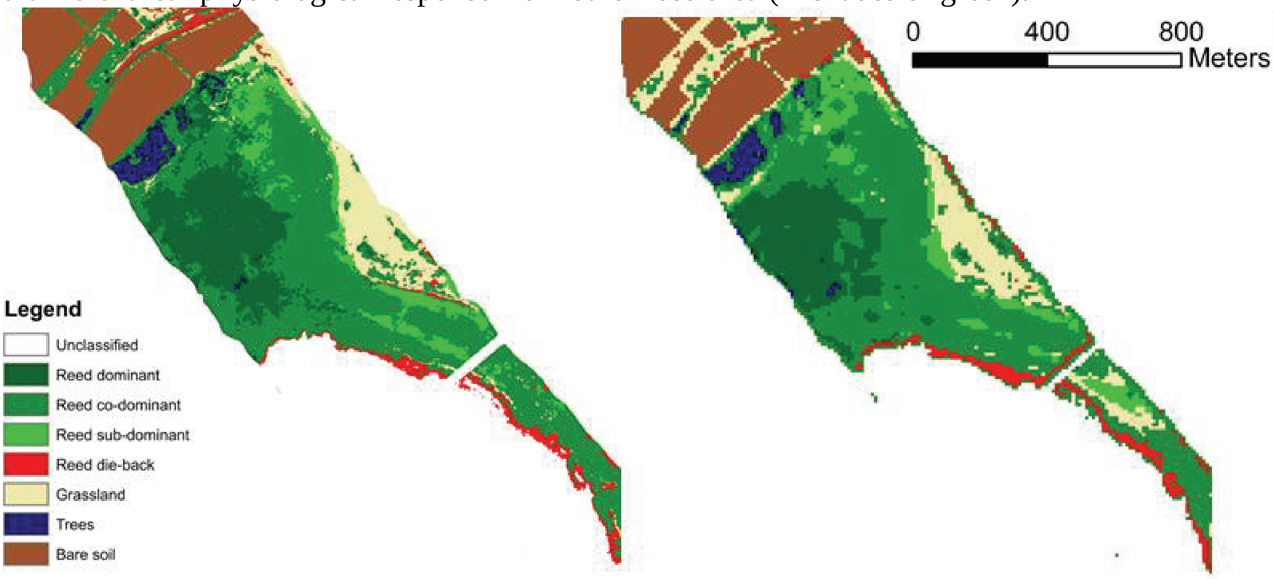


Figure 3: Maps of land cover classes and different reed dominance classes, as well as areas of reed die-back. Left: Map based on airborne hyperspectral data acquired during the EUFAR campaign at Lake Balaton, Hungary, 2010. From Stratoulias et al. (2013). Right: Simulated Sentinel-2 data product at reduced spectral and spatial resolution. From Stratoulias et al. (2014).

Such indicators of vegetation physiology and the condition of photosynthetic systems are powerful tools to assess vegetation health and consequently habitat quality.

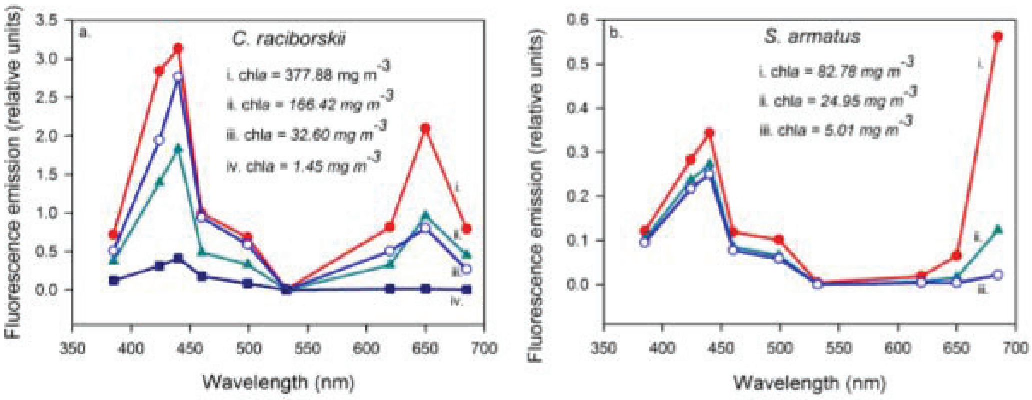
The forthcoming Sentinel-2 satellite mission will not have hyperspectral capability, but it has many spectral bands that differentiate well between the reed classes presented here. *Figure 3*b presents a simulated Sentinel-2 image classification derived from the airborne data, using only the bands also available from this satellite and after resampling to 10 m spatial resolution.

2.3 Freshwater habitats: Water quality monitoring

Palmer et al. (2013) describe the fluorescence signatures of two species of phytoplankton commonly found in the waters of Lake Balaton, in addition to robust retrievals of chlorophyll-*a* concentration, a common proxy for phytoplankton biomass generally, and water quality parameters through their laser induced fluorescence and backscattering signals. Species investigated are commonly found in Lake Balaton, Hungary, and include the potentially toxic cyanobacteria, *Cylindrospermis raciborskii*, which are especially important to monitor. An Ultraviolet Fluorescence LiDAR (UFL-9) was used in a lab experiment to complement *in situ* field measurements of the fluorescence response of the different parameters and species of phytoplankton at different wavelengths when illuminated with a UV laser pulse.

The potential of this new technique lies in the possibility to reliably map water quality parameters, which continue to pose a challenge via passive, satellite remote sensing despite great progress in recent decades. This application would provide information from ship-mounted UFL campaigns along the path of the ship and help understand the spatial and temporal dynamics of water quality, which plays a key role for habitat quality in aquatic and lakeshore ecotone environments. The abundant measurements, on a small to medium spatial scale, also render UFL measurements a potential source of calibration and validation data for satellite retrieval algorithm development.

At a coarser scale, the forthcoming Sentinel-2 mission provides new capabilities to derive spaceborne water quality maps at regular intervals.



(a) (b)

Figure 4: UFL fluorescence emission spectra (excitation laser pulse wavelength = 355 nm) for (a) *Cylindrospermopsis raciborskii* and (b) *Scenedesmus armatus* cultures of varying biomass concentrations. Measurements were obtained in controlled tank experiments. Reproduced from Palmer et al. (2013), *Remote Sensing*.

4. Discussion

The GIONET project has developed a range of innovative remote sensing techniques for mapping and monitoring habitat quality in different types of habitat. The Copernicus programme provides a continuous data stream from European Earth Observation satellites. It is accompanied by a series of operational services that target specific application areas and user needs. This paper argues that there is more potential to develop and implement innovative methods for using remote sensing to quantify biophysical parameters in support of habitat quality mapping and monitoring.

Three examples are provided: forest mapping, lakeshore ecotone mapping of reed beds and lake water quality assessment using UV fluorescence LiDAR. If these data products are continued as operational products or services, ecologists could study the impacts of climate variability, human pressures and environmental changes on the habitat quality. Deriving meaningful biophysical parameters from remote sensing is necessary for analysing ecohydrological processes such as evapotranspiration, soil moisture, photosynthetic activity and carbon storage at a finer spatial scale. The Sentinel satellites with their improved spatial and temporal resolutions will enable a much more relevant analysis of biophysical parameters at the scales that matter for habitat quality.

Ultimately, important ecosystem services such as the provision of food, timber, fuelwood, biodiversity, clean water etc. can be quantified by combining remotely sensed data with ecohydrological process models and economic valuation.

Acknowledgements

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The relevance of habitat quality for biodiversity and ecosystem service policies

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What is habitat quality?

Habitat quality is an inherently abstract concept which tries to summarize the "goodness" of an ecosystem in terms of its deviation from an ideal reference state. This property is generally considered to be related to the long-term functionality and self-organizing capacity of ecosystems, including their capacity to supply ecosystem services. There are several alternative definitions for similar concepts, most of which are based on the structure, composition, and type-specific key processes (Noss 1990) of the local ecosystems. Notable examples include 'vegetation condition' (Gibbons et al. 2006, 2008), naturalness (e.g. Machado 2004), hemeroby (e.g. Sukopp et al. 1990), ecosystem health (e.g. Costanza et al. 1992) and ecological integrity (e.g. Woodley et al. 1993). To measure this property of ecosystems, spatial information is needed. Most generally, habitat quality can be estimated (1) in the field by comparing observations to a standardized list of criteria (e.g. Machado 2004; Molnár et al. 2007), (2) based on field-calibrated modeling and/or remote sensing data (e.g. Li and Kräuchi 2004; Cohen et al. 2005; Gibbons et al. 2008), or (3) constructed as an aggregated index based on several field-observed and/or remotely sensed components (e.g. Bartha 2004; Gibbons and Freudenberger 2006; Standovár et al. 2006).

Habitat quality in global and EU biodiversity policies

Habitat quality is one particular way to provide a key message on the state of the ecosystems, which focusses on the general tendencies with no particular emphasis on any predefined groups of species. Such indicators, describing current state and tendencies of the studied ecosystems, are often called 'biodiversity indicators', as although they might not correspond directly to any of the generally interpreted components of biodiversity, but they can be used as surrogates to reflect general relationships and tendencies (ten Brink 2006). Habitat quality metrics can enter at several points into mainstream policy discussions.

Probably the most important policy initiative at the global level is the recently founded Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES). One of the primary goals of IPBES is to deliver global, regional and thematic assessments on the status and trends of biodiversity and ecosystem services. Species occurrence data exist only for a tiny proportion of the 3 million species known to date, many of which decline partly due to insufficient data and knowledge to counteract negative trends (Pimm et al. 2014). Habitat quality, however, can be an effective proxy for the occurrence and abundance of many species and for the integrity of ecosystems, due to the technical possibility to gain detailed data from large geographic areas, many of which largely unexplored locally. The key role of habitat quality in IPBES is also underlined by the fact that one of the thematic assessments of the platform will be focusing on land degradation and restoration.

Information about habitat quality also plays a key role in several policies in the EU policy arena:

- Measuring the status of ecosystems: The Habitats Directive (Article 17) and the Water Framework Directive require a periodic reporting on the ecological status of major terrestrial ecosystems and water bodies, which is assumed to rely on a detailed evaluation of a vast number of species at a high number of locations. Nevertheless, these data are difficult to be used for compiling habitat quality evaluations, which is caused by deficiencies of the reporting process (e.g. just one data sheet for each Natura 2000 species and habitat type for each country and biogeographical region)
- Ecosystem service indicators: According to Action 5 of EU's Biodiversity Strategy to 2020, each member state is required to map and assess the ecosystems and their services within their territory. As the most accepted conceptual model for ecosystem service delivery, the cascade model (Haines-Young and Potschin 2010, de Groot et al 2010) contains the state of ecosystems as a fundamental element, theoretically all ecosystem service maps and assessments should also embrace habitat quality maps.
- Restoration prioritization support: The 2020 Biodiversity Strategy (Target 2) prescribes that each MS should restore 15% of the degraded ecosystems within its territory. A similar 15% goal is also declared at a global level by the Convention on Biological Diversity (Aichi Target 15). According to an EU-funded study (Lammerant et al 2013) this process should be coordinated by classifying all natural and man-made ecosystems into to a 4-grade ordinal scale based on their level of degradation. Measuring and monitoring habitat quality for many ecosystems can have a great practical importance for this kind of use.
- No net loss of ecosystems and their services: Action 7 of the EU Biodiversity Strategy proposes "an initiative to ensure there is no net loss of ecosystems and their services (e.g. through compensation or offsetting schemes)". Under this target, the Commission seeks innovative new mechanisms, providing systematic tools for compensation for damages to biodiversity in the wider countryside outside Natura 2000 sites. This has to be applied in the context of the mitigation hierarchy (with an order of priority favoring avoidance and reduction of adverse impacts to the use of offsets or compensation), for which measurement of habitat quality is a key indicator from planning to implementation and monitoring of offsetting measures (Rayment 2013).

Considerations for reliable habitat quality metrics

As discussed above, a reliable and informative habitat quality metric should reflect deviation from an ideal state, which should be interpretable in a consistent way for all typical pathways of degradation. This is not easy, not even conceptually. For example, a forest can be too even aged, infected by invasive alien species, can lack a shrub layer, old trees, dead trees, gaps, etc. Furthermore, it is not always easy to identify a single unambiguous reference state, particularly for strongly transformed ecosystems. How can we define an ideal reference state for a cropland or a city? Should it be the last pristine vegetation, which used to be there at the same location prior to the transformations? Or some sort of ideal cropland, or ideal city? Even in the case of well-known semi-natural ecosystems, as European oak forests, an appropriate reference state can be difficult to determine simply because of the constant human presence since the ice age.

Being inherently local and spatially explicit, habitat quality metrics can never allow for structures and processes observable at spatial scales broader than their resolution. Thus habitat quality cannot account for landscape pattern and /or diversity. Furthermore, local habitat quality cannot generally capture outstanding natural values, like the presence of a specific rare species, or unique compositional, structural or historical features.

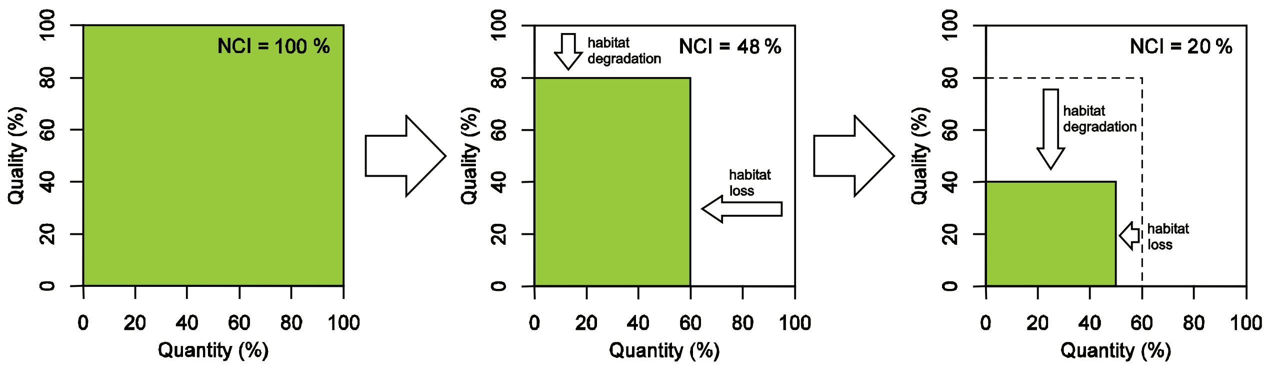

Figure 1: Natural capital is defined as the product of remaining ecosystem size (quantity) and its quality. For example, if the remaining ecosystem size is 50 %, and its quality is 40 %, then 20 % of the natural capital remains (from Czúcz et al. 2012).

Aggregating habitat quality for landscapes – the case of the Hungarian Natural Capital Index

Local habitat quality values can be very useful by themselves, nevertheless, there are several policy contexts, where an overview of larger areas is necessary. To this end habitat quality values can be aggregated in a standardized way so that they could be used effectively in evaluating and comparing ecological state in larger and smaller areas. The simplest and most straightforward aggregation scheme is the Natural Capital Index (NCI) formula (ten Brink 2000, Czúcz et al. 2008, 2012; Figure 1), which is the area weighted mean naturalness of the landscape:

$$NCI = \sum_{i=1}^{n} q_i a_i$$

for a landscape consisting of n homogeneous patches of size a_i and quality q_i. If both size and quality are scaled between 0 and 1 (relative to the entire landscape and the pristine reference state), then an NCI value of 1 will mean a landscape in its original, pristine or undegraded state. The concept of NCI is based on the assumption that biodiversity loss can be modeled as a process driven by two main components: habitat loss due to conversion of natural areas into agricultural fields or urban areas, and degradation of the remaining habitat patches, caused by overexploitation, pollution, fragmentation, invasive species, etc. Thus, NCI summarizes the extent to which a landscape has preserved its original (baseline) natural capital (Figure 1; ten Brink 2007). Combining quality and quantity into one indicator, NCI relies on a hypothetical equivalence between smaller intact, and larger, but degraded patches in terms of ecological value (Figure 1).

It is apparent from the definition and the methods of calculations that NCI is flexible enough to give evaluations of landscapes at various scales. An important and advantageous property of this metric is that it can be used for quick and superficial comparisons, as well as extensive and detailed evaluations. NCI values for larger areas can namely be disaggregated in various ways into the sum of different components:

- Thematic disaggregation: the contribution of specific ecosystem types to the overall NCI value of a larger region can be easily estimated in a straightforward way. To visualize the contributions of specific ecosystem types to an overall NCI value, habitat-profile diagrams can be constructed (Figure 2).
- Spatial disaggregation: the NCI value of a larger region corresponds by definition to the area-weighted average of NCI values of its sub-regions, no matter how the sub-regions are delineated. This rule can help to identify the specific contributions of any area of interest to the NCI of the larger region.

The evaluation of the contributions of different subregions and ecosystem-types can bring new perspectives for policy applications. Flexible disaggregation makes it possible that it is not only the factual numerical values, but also the underlying causes and patterns that can be surveyed in a decision-making process. Consequently, this standardized metric can be used successfully in local and regional policy-relevant decision-making and in environmental communication.

This index is also especially suited for remote sensing: accurate data on spatial extent of each habitat and the naturalness of each study unit (e.g. pixel) can easily be integrated into this model for quantitative evaluation of natural capital at regional or local scale. In addition, the quantification of habitat quality in terms of deviation from a reference state (a “perfect” ecosystem) can also be relatively well followed up with remote sensing and GIS as long as the reference state of the ecosystem also exists and has been covered by the survey. Differences in spectral properties, spatial structure, patch diversity can all be calculated between the reference and the units of the study area.

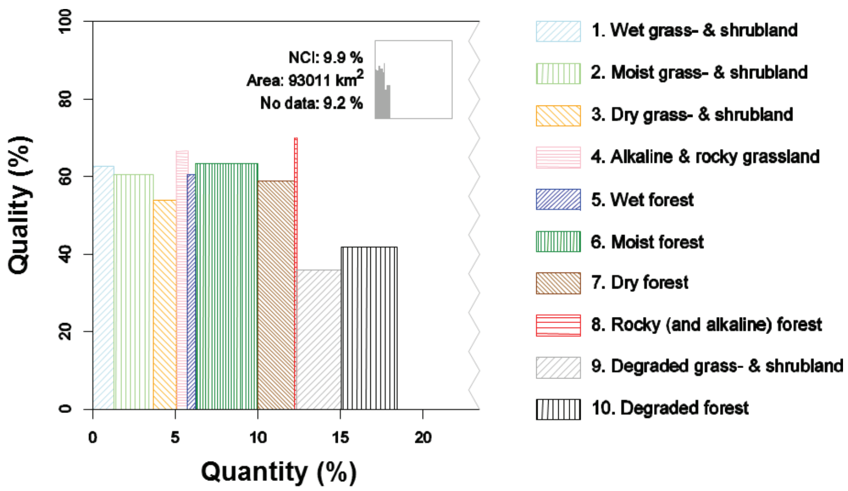

Figure 2: The Natural Capital Index of Hungary, shown in a disaggregated structure identifying contributions of 10 main habitat groups. To add perspicuity to the NCI components, the scaling of the axes is not identical, to provide a visual overview of the magnitudes, a pictogram with identically scaled axes is shown in the upper right corner (from Czúcz et al 2012).

Conclusions

While habitat quality is an abstract concept that can be defined in many different ways, there is a clear demand for reliable and transferable definitions that support quantitative analysis. International biodiversity policy, spearheaded by the IPBES targets, and EU commitments such as the 2020 Biodiversity Strategy all require spatially explicit assessments of habitat quality.

We propose the Natural Capital Index, which is based on deviation from a hypothetical reference state in terms of both area and quality of habitats. While some problems remain, this index is compatible with remote sensing and GIS analysis, and could pave the way towards more reliable habitat assessments in EU and global policy

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UAS based laser scanning for forest inventory and precision farming

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1. Introduction

Airborne Laser Scanning (ALS) has proven a convincing method in vegetation mapping and habitat monitoring over the last decade. As a complimentary approach to photogrammetric techniques laser scanning enables the penetration of several layers of vegetation resulting in high resolution and high precision 3D data.

In this presentation we will focus on the potentials of laser scanning for two major issues of natural resource management, namely precision agriculture and forest inventory.

Up to now remote sensing by commercial civil unmanned aerial systems (UAS) has mainly relied on photogrammetry techniques, making use of small and lightweight consumer-grade digital cameras to account for payload limitations. The new *RIEGL* VUX-1, is the first laser scanner of survey-grade measurement quality specifically developed for use on UAS. The new instrument and the employed *RIEGL* technology are presented. Two applications in vegetation and habitat monitoring are discussed and sample datasets are analysed with respect to precision, quality and content.

2. *RIEGL* VUX-1 Instrument presentation

The small and lightweight laser scanner *RIEGL* VUX-1 has been designed in order to meet with the requirements of UAS. Limitations in size and weight as well as several mounting options for a variety of different types of UAS and their flight characteristics have been considered throughout the development of the instrument.

The *RIEGL* VUX-1 performs a profile scan covering almost 360 degrees, which seems quite uncommon for a LIDAR instrument to be used on an airborne platform at a first glance. This large field of view (FoV) is explained by the typical scanning scenarios for which UAS are meant: areas difficult to access by conventionally piloted aircraft, such as narrow valleys or complexly structured environments. Furthermore, considering the flight path of UAS, the large FoV guarantees a gapless observation of fine structures such as power lines even upon sudden swiveling movements of the aircraft.

The scanning mechanism is based on a fast rotating mirror, which provides fully linear, unidirectional and parallel scan lines, resulting for straight flight paths in an excellent regular point pattern on the surveyed objects.

Figure 1: *RIEGL* VUX-1

eye safety class	Laser Class 1
max. range @ target reflectivity 60 %	920 m
max. range @ target reflectivity 20 %	550 m
minimum range	5 m
accuracy / precision	10 mm
laser pulse repetition rate (PRR) @ 300° FOV	up to 550 kHz
max. effective measurement rate	up to 500.000 meas. / sec
field of view (FOV)	up to 330°
max. operating flight altitude AGL	350 m / 1.150 ft

Figure 2: *RIEGL* VUX-1 instrument specifications

The *RIEGL* VUX-1 features a variety of different interfaces for utmost flexibility and simplicity in system integration. Besides mandatory interfaces for smooth integration with external IMU/GNSS systems for position and attitude determination the instrument provides interfaces for commanding through a UAS on-board control unit, as well as an interface for remote control via a digital radio link of limited bandwidth. With the availability of a radio down-link it is possible to transmit the IMU/GNSS position and attitude measurements as well as the scan data to a ground station PC or laptop. By geo-referencing the scan data in real-time viable information on the coverage and point density, data quality and system status are available for the operator. The raw scan data as well as raw IMU/GNSS data are stored on an internal solid state disk of the laser scanner, available for data processing after the flight.

The *RIEGL* VUX-1 offers all the well-established state-of-the-art features developed for the *RIEGL* V-Line scanners: echo digitization, online waveform processing, multi-target capability, calibrated amplitude, calibrated reflectance, pulse shape information of echo signal on all measurements, variable measurement speed, multiple-time-around capability.

3. Advantages of Laser Scanning in Vegetation Monitoring

By contrast to photogrammetry, which is limited to determining digital surface models (DSM), the technique of laser scanning enables to capture data suitable for the generation of DSM and digital terrain models (DTM). Advanced processing algorithms account for a full exploitation of the information contained in scan data. A typical target situation is measuring areas covered by vegetation. The laser beam may be scattered multiple times, from the tree canopy through layers of branches and low vegetation, until the last echo results from the ground surface. Several target echoes resulting from a single laser pulse emission are obtained by echo digitization and subsequently resolved by online waveform processing, resulting in measurement ranges, echo amplitudes, calibrated target reflectance and pulse shape information.

Laser scan data provide viable information on the condition and status of agricultural and forestry areas. It enables the analysis of factors indicating seasonal growth of vegetation and the detection of significant changes or even deterioration of land. Estimates of bio-mass volume, determination of different habitats, forest inventory and tree growth assessment, detection of deadwood and rolled-lumber are only a few applications where laser scanning is a frequently used technique.

While ALS can be considered an undisputed method in vegetation monitoring nowadays, the new generation of remotely piloted aircraft opens up yet new aspects of surveying. UAS are to be employed for economic reasons as in repeated survey missions, or for reasons of personal safety in otherwise difficult to access areas.

4. Example applications

4.1 Precision farming

Crop growth and health is closely monitored in precision farming in order to minimize the use of fertilizers or insecticides. Airborne laser scanning data enable to observe plant growth while at the same time displaying changes in ground surface, or to detect areas of hail damage. The repetitive task of airborne sensing missions by manned aircraft is a cost-intensive factor. Therefore, UAS could be a cost-effective solution for carrying out these survey missions at much shorter intervals while still at a lower cost in the near future.
We will present a time-series of scans captured over an agricultural field. The data enables the analysis of growth rates and the detection of areas, where the development of agricultural crops differs. It is to be investigated if from such repetitive surveys the relative reflectance attribute may serve to assess the crop's ripeness or the area's humidity

4.2 Forest inventory

Because of their potential in providing digital terrain models, detection of deadwood, biomass and underwood estimation, and canopy change monitoring, airborne laser scanning data have proven significantly relevant for the forest industry. Yet in difficult-to-approach areas or narrow valleys where it would be dangerous or impossible to employ conventional aircraft, UAS come into play. The large FoV of the *RIEGL* VUX-1 provides a comprehensive scan of such environments.

We will present a scan data set captured in a narrow valley with dense vegetation.

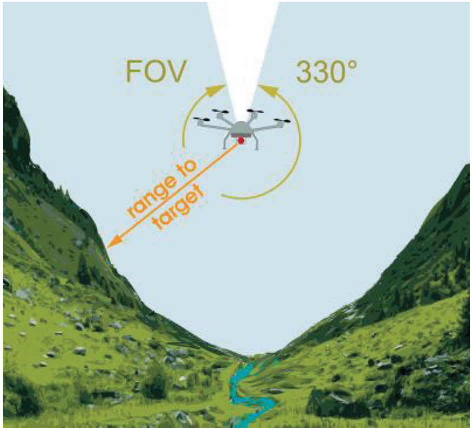

Figure 3: *RIEGL* VUX-1 Field of View

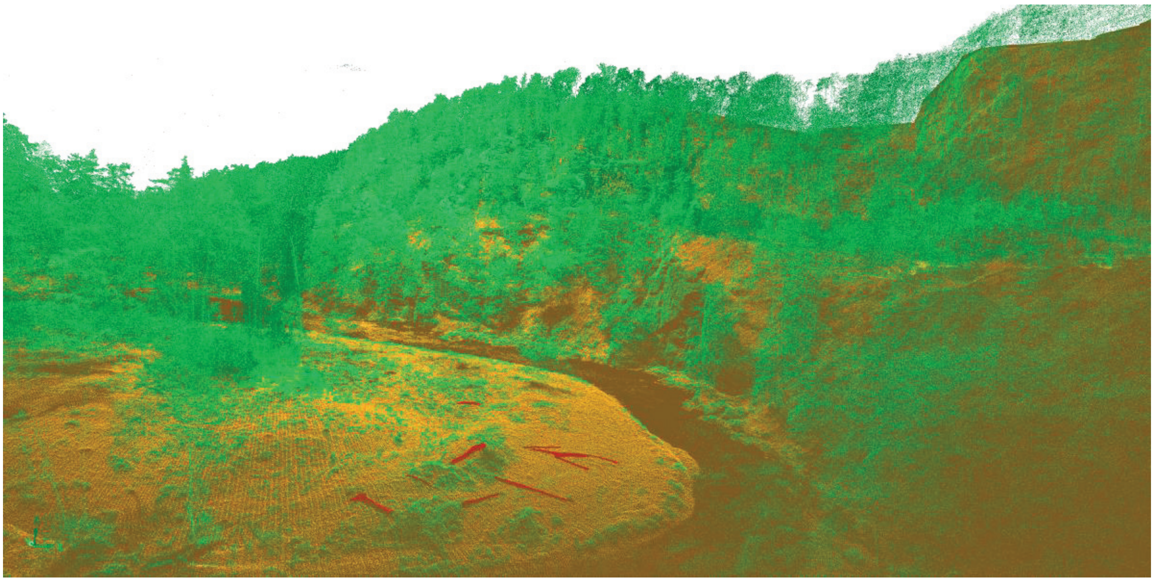

Figure 4: *RIEGL* VUX-1 scan data pointcloud.

Scanning has been performed from a manned helicopter, flying at 60m altitude AGL and at 40 kn speed. Scanning at 550 kHz PRR, the point density is 130 points per square meter. Color encoding corresponds to target classification (ground, vegetation). In the foreground, deadwood is highlighted in red.

For monitoring tree growth, points classified as vegetation are used to estimate the relative canopy height and enable the comparison of different height models collected over a certain period of time. In conjunction with imagery captured simultaneously with the scan data it is possible to identify individual tree species for completing forest inventory maps.

For planning cleanup efforts, fallen trees can be identified as linear structures in the point cloud classified as low vegetation. The analysis of the DTM, which is an inherent product of laser scan data, enables mapping of roads and trenches as well as geomorphologic studies of slope instability and erosion.

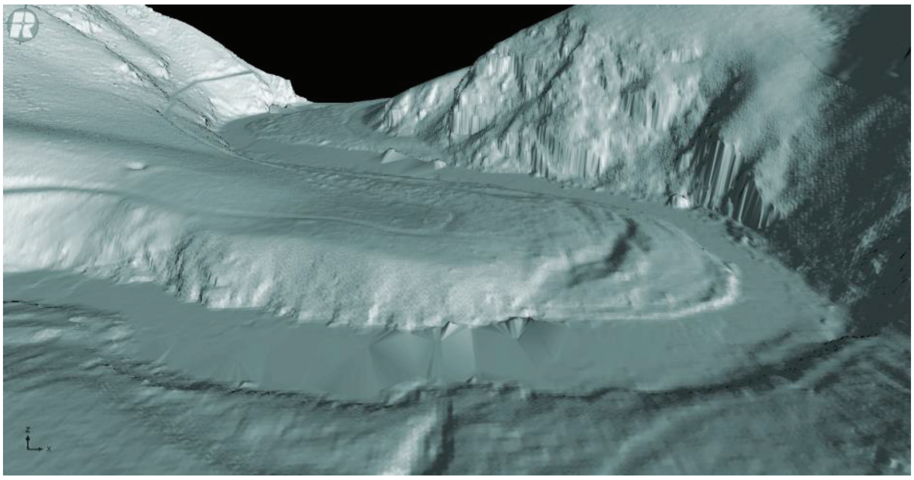

Figure 5: DTM calculated from the *RIEGL* VUX-1 scan data

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Monotoring of instream habitats with focus on morphological dynamics based on Airborne Laser Bathymetry

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1. Introduction

Modelling and monitoring of aquatic habitats crucially relies on the availability of a precise description of the river bed. While traditional, profile-oriented techniques for capturing fluvial topography like tachymetry or echo sounding lack the necessary homogeneity and data density, airborne laser bathymetry (ALB) – also referred to as airborne laser hydrography – is an emerging acquisition method for shallow water areas (Steinbacher and Pfennigbauer, 2010). ALB was long restricted to coastal applications (Irish and White, 1998). The sensors were especially designed for maximum penetration depth (~50 m) and, therefore, use high pulse energy and a large laser footprint of several meters, the latter resulting in a coarse point spacing of 2-5 m (Guenther et al., 2000). New topo-bathymetric sensors, in turn, especially focus on capturing riverine inland waters and the surrounding floodplain area with high sampling density (10-50 points /m^2) and good height/depth accuracy in the range of 10 cm (Pfennigbauer et al., 2010)

In this article we show the annual river bed changes of a near-natural, meandering section of the River Pielach (Neubacher Au, Lower Austria, c.f. Figure 1), their impact on the hydro-morphological units (riffle, pool, backwater…), and the consequences for selected fish species.

2. Study area

The River Pielach is a gravel river situated in the Lower Austrian Alpine foreland. After a 70 km run with a source-to-outlet height difference of 775 m the River Pielach discharges into the River Danube near Melk. The total catchment area adds up to 950 km^2. It is an important retreat area for several fish and bird species like n, barbel, and river kingfisher. (Melcher and Schmutz, 2010). The Neubaucher Au, located at the lower course of the River Pielach between Loosdorf and Melk, is part of the Natrua2000 conservation area *Niederösterreichische Alpenvorlandflüsse* (Area code: AT1219000) featuring many different habitat types. The list of occurring Fauna-Flora-Habitat (FFH) codes contain: 3260 (Water courses of plain to montane levels), 6430 (Hydrophilous tall herb fringe communities), 6510 (Lowland hay meadows), and 91E0/91F0 (Alluvial forests).

3. Data capturing and data processing

The study area was repetitively captured in April, May and October 2013 with the Riegl VQ-820-G topo-bathymetry laser scanner mounted on a Diamond DA42 light aircraft. In June 2013 an annual flood peak (HQ1) occurred which led to a major change of the riverbed topography (reloading of gravel bars) resulting in a change of the hydro-morphological units. Data acquisition was carried out at a flight height of 600 m above ground with a pulse repetition rate of 510 kHz (effective measurement rate 200 kHz). This yielded a dense point cloud with a mean point spacing of 20 cm (i.e. point density: 25 points/m^2, c.f. Figure 2).

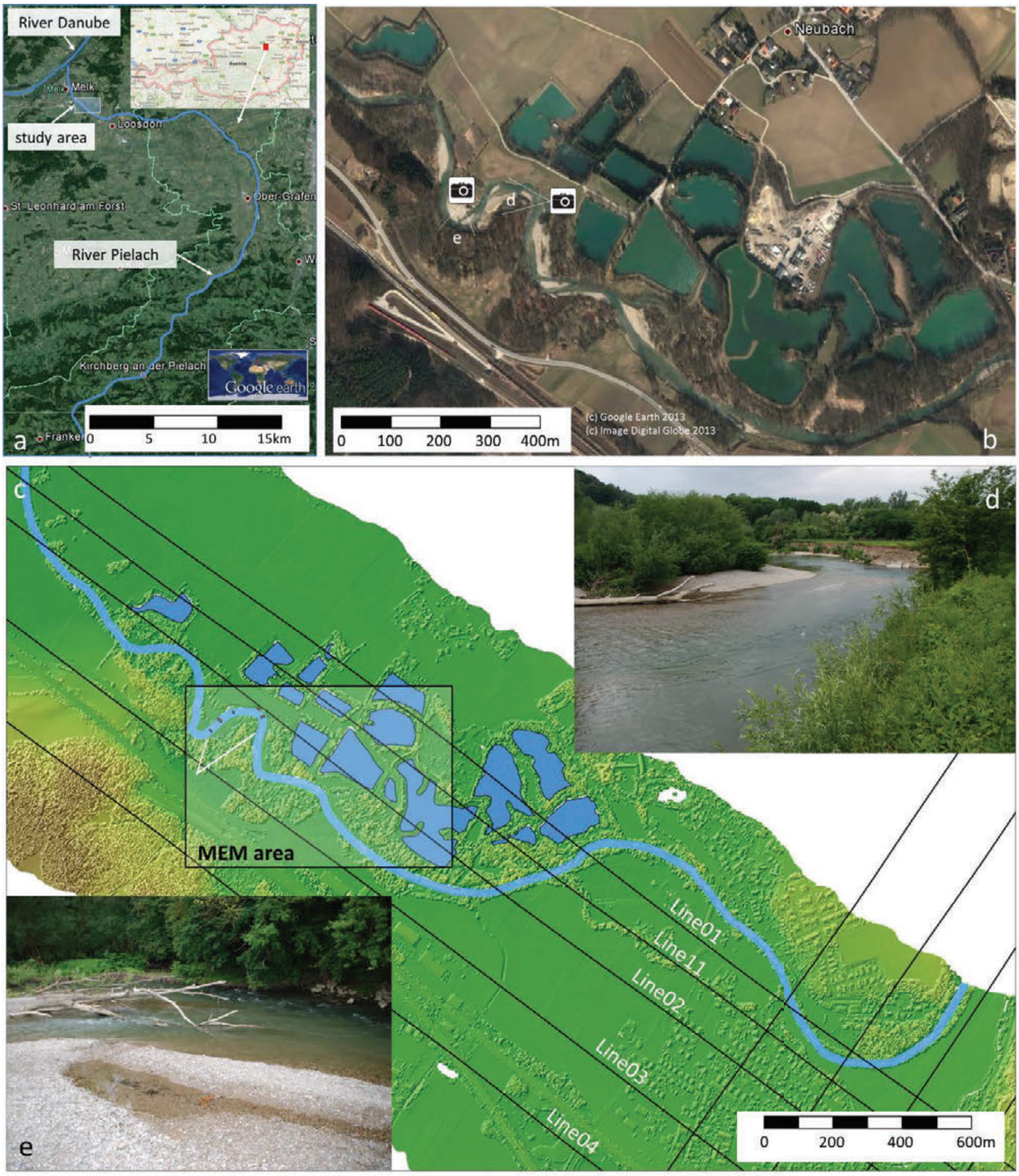

Figure 1: Study area Neubacher Au, River Pielach, Lower Austria; (a) Overview map, River Pielach and location of study area; (b) Digital orthophoto of Neubacher Au; (c) Digital surface model of relevant flight block section, superposition of hill shading and z-coloring overlaid with additional vector data (flight strips, pond and river test area outlines, coarse river outline; (d) and (e) terrestrial photos of meandering river section taken on May 24, 2013

The short laser pulses in combination with online waveform processing allows mapping of extremely shallow areas (water depth < 30 cm). These areas are especially important for juvenile stages of target fish species. Water depths up to 2 m (i.e. 1 Secchi depth) could be measured and, thus, the predominant part of the Pielach channel could be fully captured in all three epochs (c.f. Figure 3). Processing of the laser data (geo-referencing of flight strips, quality control, water surface detection, range and refraction correction, and classification of the laser echoes in: ground, vegetation, water surface, river bed) finally resulted in a Digital Terrain Model of the Watercourse (DTM-W). The regular 0.5 m DTM-W grid, containing the riparian overbank areas and the river bed, was thinned out and a TIN model was derived constituting the geometry basis for the subsequent hydrodynamic-numerical (HN) modelling (Mandlburger et al., 2009).

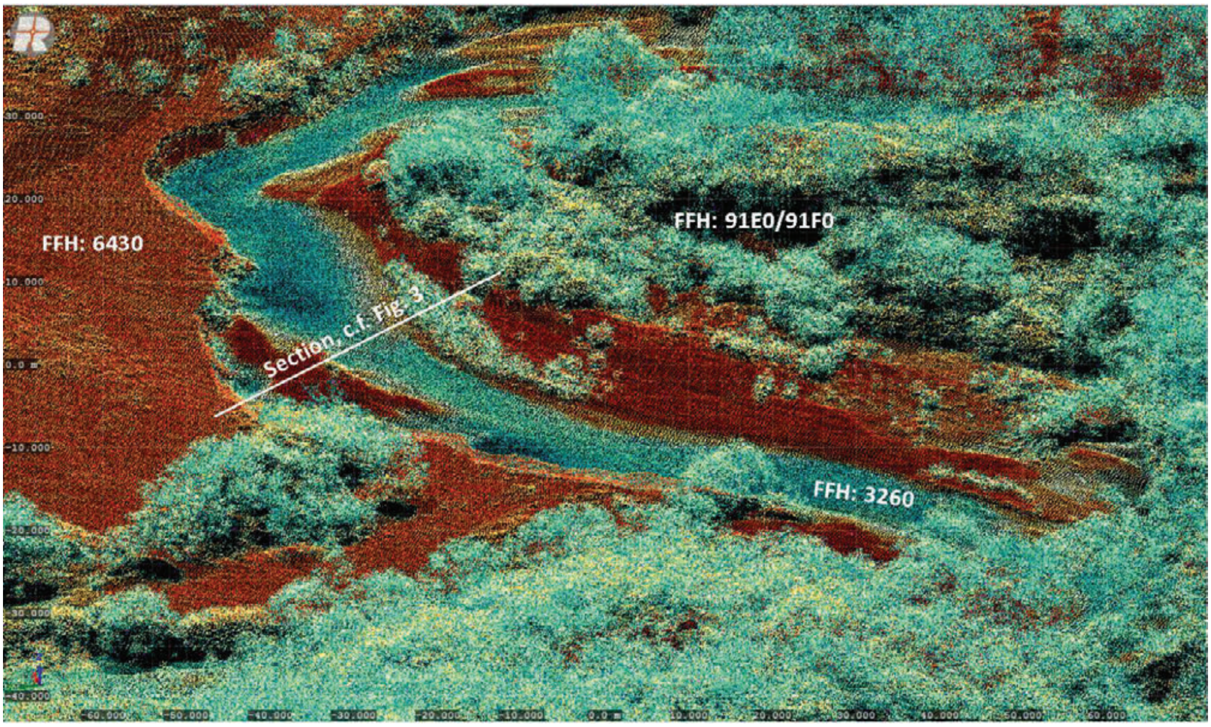

Figure 2: Topo-bathymetric laser point cloud colored by signal reflectance (red=high, blue= low reflectance), and relevant FFH codes

4. Habitat modelling

Based on a two-dimensional depth-averaged numerical model (Nujic, 1999) the abiotic characteristics (flow velocity, water depth and bottom shear stress) of the river Pielach were simulated and analyzed for all three epochs and for three characteristic discharges (low flow, mean flow and the magnitude of an annual flood event) each. Considering the variability in discharge dependent changes of flow variables, a meso-habitat evaluation approach (MEM) was selected to determine the impact of morphological changes on the habitat distribution (Hauer et al., 2009). The MEM approach enables a differentiation of six hydro-morphological units, namely (1) riffle-, (2) fast run-, (3) run-, (4) pool-, (5) backwater-, and (6) shallow water-habitats. Moreover, habitat suitabilities (spawning, juvenile life stage) on the micro-unit scale have been calculated for target species (*Chondrostoma nasus*).

It could be proofed by habitat modeling based on the topo-bathymetric LiDAR point cloud that all six types of hydro-morphological units were present for the studied discharge range in all captured epochs (c.f. Figure 4). This is an indicator for the quality of the investigated site as a natural self-forming river reach. The impact of an annual flood event in June exhibited no significant overall quantitative habitat changes but changes in the spatial distribution could be recorded based on downstream migration of gravel bars (c.f. Figure 5).

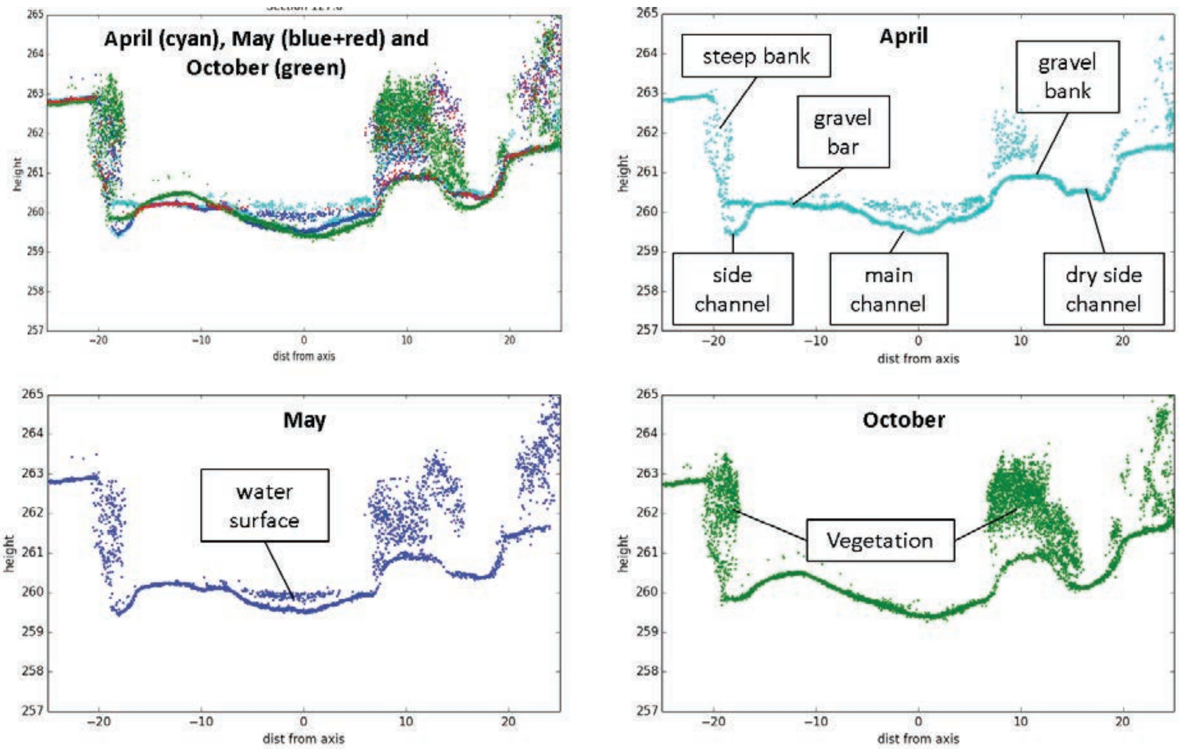

Figure 3: Documentation of annual river bed changes based on the point clouds of a selected cross section captured in April/May/October 2013 (steep bank, side/main channels, gravel bar, gravel bank, dry secondary channel, and vegetation). Note the disappearance of the side channel – an important backwater area for juvenile fish stages – from April to October.

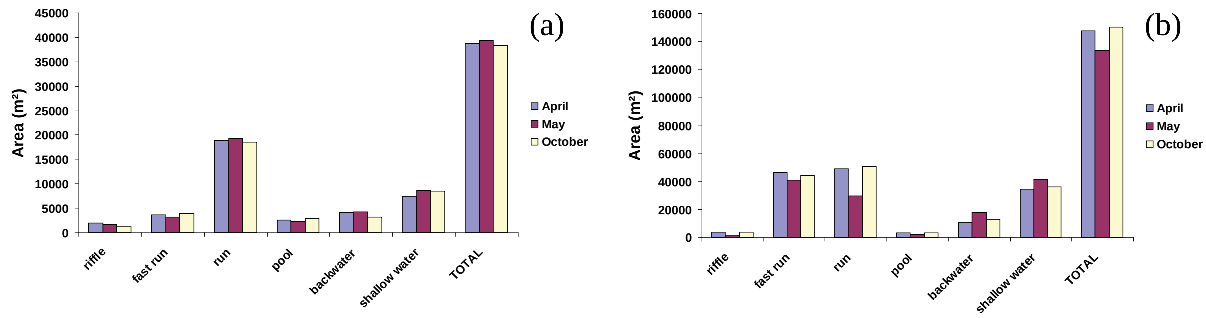

Figure 4: Variability in hydro-morphological units for mean flow (6.52 m^3s^{-1}) (a) and mean annual flood (121 m^3s^{-1}) (b).

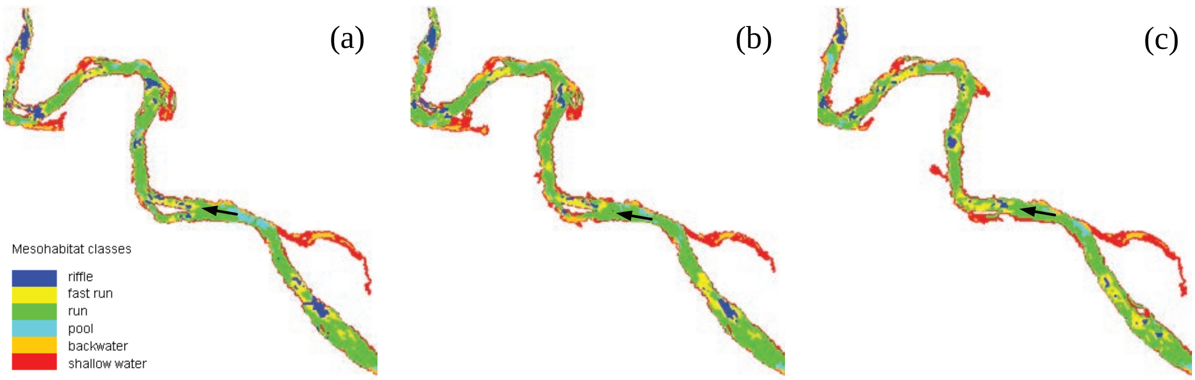

Figure 5: Distribution of hydro-morphological units for mean flow (6.52 m^3s^{-1}) for April (a), May (b), and October (c).

Using the microhabitat analysis of target fish species nase it could be shown that for both investigated life stages, spawning and juvenile, suitable habitats are available for the studied range of low flow and mean flow discharges. In addition, a comparison of the applied meso- and micro-habitat modeling exhibited a strong correlation between spawning suitabilities and riffles as well as habitat for the juvenile stages and shallow water mesohabitat type.

5. Conclusions

It could be demonstrated that Airborne Laser Bathymetry is a suitable tool for quantifying and monitoring the variability and dynamics of aquatic habitats. One of the major advantages of ALB compared to traditional capturing techniques like tachymetry and/or boat based echo sounding is that the study sites are remotely sensed. This is of crucial importance on the one hand for mapping conservation areas, where access is often restricted, but on the other hand for deriving a high quality database for river authorities. The availability of such a detailed description of the fluvial topography enables to address, both, the aims of European Water Framework Directive (EU, 2000) and the European Floods Directive (EU, 2007).

Acknowledgements

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Remote sensing for aquatic habitat quality mapping and EU Water Framework Directive (EU-WFD) reporting

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1. Introduction

The measurement and mapping of a number of parameters important for the water quality, aquatic habitats and biodiversity of lakes have been found to be possible using satellite remote sensing, and particularly the European Space Agency's MEdium Resolution Imaging Spectrometer (MERIS). These include total suspended mater concentration (TSM), the diffuse attenuation coefficient at 490 nm ($K_d(490)$) and phytoplankton biomass via the proxy chlorophyll-*a* concentration (chl-*a*) (Odermatt et al., 2012; Matthews, 2011). These both affect and reflect environmental conditions of lakes and have been recognized as important to monitor through their inclusion in the Water Framework Directive of the European Union (EU-WFD). The mapping of chl-*a*, TSM and Kd(490) is demonstrated here in application to Lake Balaton, Hungary, and the translation of chl-*a* maps to the classification language of the EU-WFD is carried out, highlighting the improvement to the spatial information of the resulting classes possible through the use of remote sensing.

2. Data and methods

2.1 Study site

Lake Balaton in western Hungary (Fig. 1a) is a large (597 km^2 surface area) and shallow (3.3 m average depth) water body. Characterized by hyper-eutrophication which peaked in the 1980s, water quality has since greatly improved. A strong trophic gradient persists, however, related to the nutrient-rich waters of the Zala River inflowing in the southwesternmost Basin 1 and gradual water circulation northeastward to Basin 4 (Fig. 1b). Two annual phytoplankton blooms typically occur; a small spring bloom and a larger late summer bloom. Moderate to high phytoplankton biomass as well as high concentrations of inorganic suspended matter contribute to the highly turbid nature of Balaton. This restricts the proliferation of both submerged and emergent aquatic vegetation which occurs mainly in the very near shore environment.

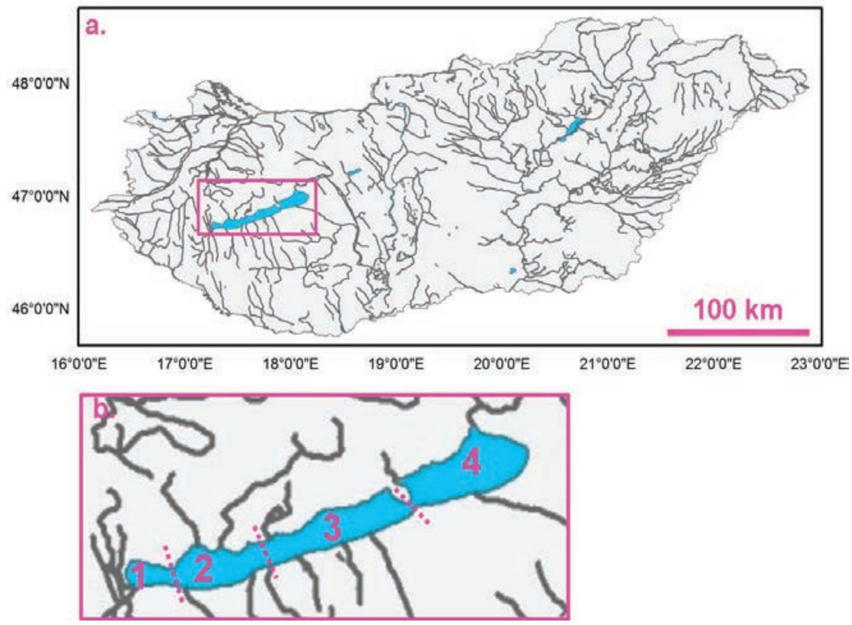

Figure 1. Location of Lake Balaton in western Hungary (a); the division of its four basins (b).

2.2 MERIS satellite water quality mapping

Palmer et al. (2014a) report robust correlation between *in situ* chl-*a* measurements and the Fluorescence Line Height (FLH) algorithm applied to L1b MERIS imagery. The locally calibrated algorithm was then applied to daily MERIS images for chl-*a* mapping, and dekad-binned images were also used by Palmer et al. (2014b) for the extraction, mapping and analysis of phytoplankton phenology metrics. These dekad as well as monthly binned mean chl-*a* maps are translated here for EU-WFD classification. Monthly mean maps of TSM and K_d(490) were produced by and obtained from the ESA funded Diversity-2 project. Both TSM and Kd(490) maps result from the application of neural network-based algorithms (C2R; Doerffer and Schiller, 2007).

2.3 EU-WFD phytoplankton biomass reporting

EU-WFD reporting for Lake Balaton is the responsibility of the Central Transdanucian (Regional) Inspectorate for Environmental Protection and Nature Conservation (Közép-dunántúli Környezetvédelmi, Természetvedelmiés Vízügyi Felügyeloség (hereafter referred to as KdKVI)). Chl-*a* concentrations are measured weekly by the KdKVI between mid-May and mid-September, from samples taken at the centres for the four main basins along the longitudinal axis of the lake (Fig. 1) and are classified in accordance with the commonly referred to trophic status-based water quality classification system of the Organization for Economic Cooperation and Development (OECD; Table 1). The corresponding classification for each sampling date is reported, and made available on the KdKVI website (http://www.kvvm.hu/balaton/lang_en/index.htm), along with the seasonal average. Values reported for August, 2010 are compared here with MERIS image retrieved classes.

Table 1. EU-WFD classification associated with mean annual (mid-May through mid-September) chl-*a* concentrations of Hungarian lakes (personal communication with KdKVI, 2014).

Chl-*a* ($mg\ m^{-3}$)	OECD classification	EU-WFD classification
< 8	Oligotrophic	Excellent
8 – 25	Mesotrophic	Good
25 – 75	Eutrophic	Average
> 75	Hypertrophic	Poor

3. Results

Maps of chl-*a* concentration, TSM concentration and $K_d(490)$, representing the averages of all retrievals for the month of August 2010, are presented in Figure 2 a-c. The typical trophic gradient described in Section 2.1 is clear in the chl-*a* map, with concentrations as high as 35 $mg\ m^{-3}$ in Basin 1 and lower than 5 $mg\ m^{-3}$ in Basin 4. TSM concentrations are found to display a gradient from the north to the south shores of the lake. This is expected to result from the predominant, northerly wind conditions, which favour resuspension along the north shore. TSM concentrations are also lower in Basin 4, which is deeper that the other basins, such that resuspension occurs less readily. $K_d(490)$ reveals a combination of the patterns and features found in chl-*a* and TSM maps, as this parameter is dependent on the light attenuation of these two factors. TSM, however, is clearly the dominant influence.

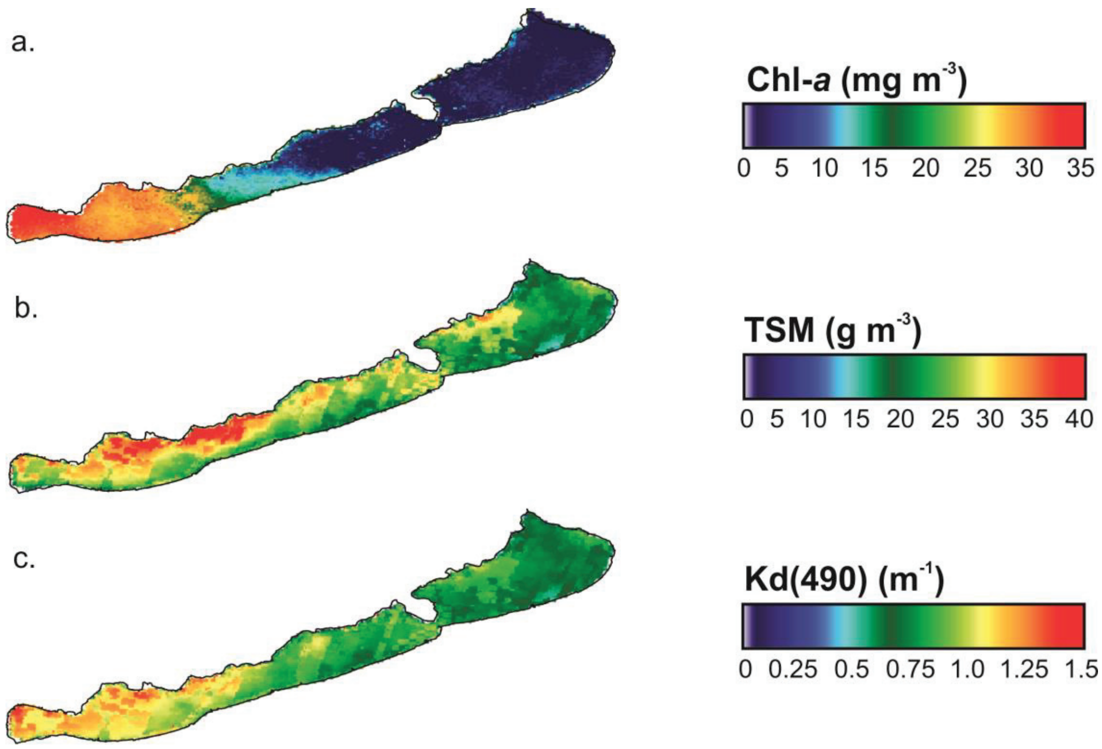

Figure 2. Maps of mean monthly chl-*a* concentration (a), TSM concentration (b), $K_d(490)$, and the probability of cyanobacteria dominance of phytoplankton community composition.

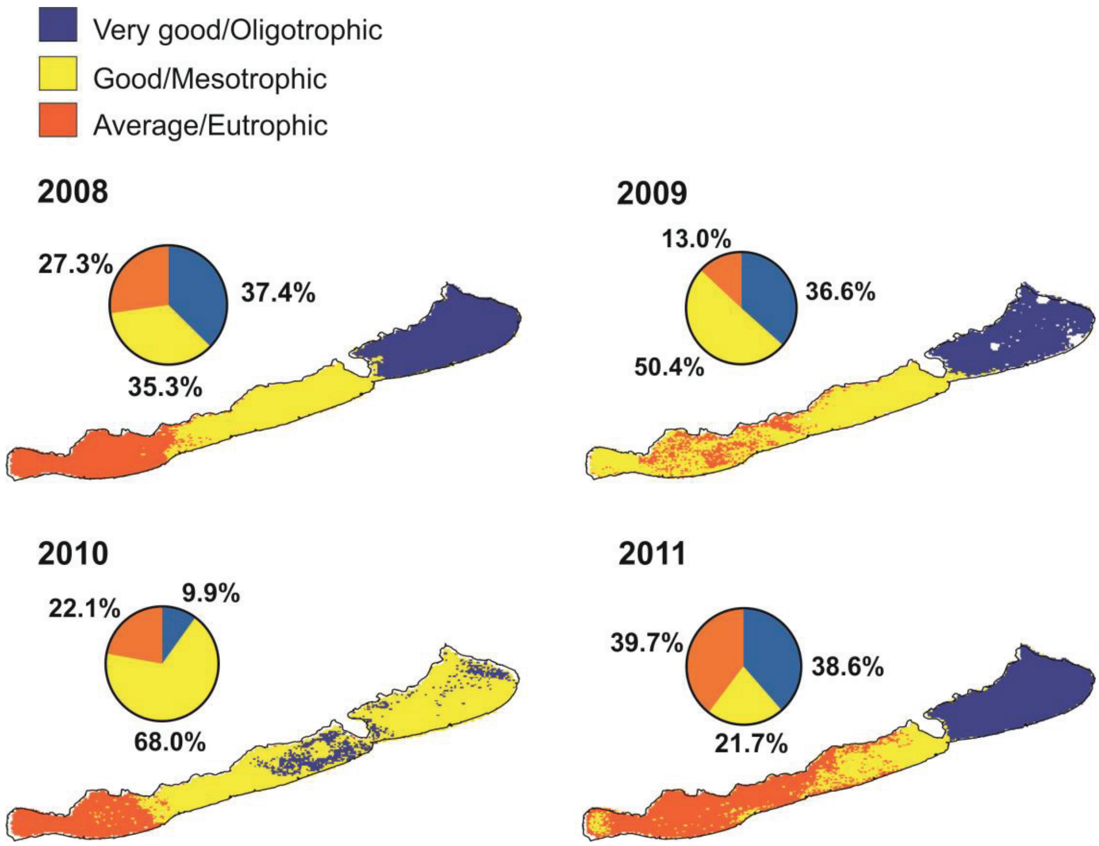

Figure 3. Maps of EU-WFD phytoplankton biomass (chl-*a* concentration) classifications for August 2008, 2009, 2010 and 2011 and % spatial extents of the retrieved classes.

Table 2. Comparison of EU-WFD classifications using *in situ* and using MERIS satellite data from the four main lake basins (Fig. 1) for the same period in August of each year. Of the 16 compared classifications, only 1 (6.25%) is not compatible (highlighted).

Year	Basin	Oligotrophic ("Excellent")		Mesotrophic ("Good")		Eutrophic ("Average")	
		In situ	MERIS	*In situ*	MERIS	*In situ*	MERIS
2008	1					X	X
	2			X			X
	3			X	X		
	4	X	X				
2009	1			X	X		
	2					X	X
	3			X	X		
	4	X	X				
2010	1					X	X
	2					X	X
	3			X	X		
	4			X	X		
2011	1					X	X
	2					X	X
	3			X	X		
	4	X	X				

Chl-*a* maps from August of 2008, 2009, 2010 and 2011, translated into the classes used for EU-WFD reporting are presented in Figure 3. The spatial extent of each retrieved class for each of the four years was also calculated as a percentage of the total. In addition to revealing the general trophic status of each of the four basins, considerable detail on spatial patterns and trends, and the high variability of these over time was revealed. Classification results obtained using MERIS-retrieved chl-*a* concentrations were found to be similar to the results obtained through the conventional monitoring and reporting currently carried out by the KdKVI. Only one of sixteen comparisons was found to deviate, corresponding to only 6.25 % of comparisons (Table 2).

4. Conclusions & outlook

Maps of three parameters of interest from a water quality and aquatic habitat perspective have been produced for Lake Balaton using archive MERIS data. MERIS is no longer acquiring data, but has similar features to the future Sentinel-3 Ocean and Land Colour Imager (OLCI), which is foreseen to provide continuity to mapping and monitoring activities such as those presented here (ESA, 2013). Validation activities using the MERIS archive are continuing and will be followed by similar exercises using OLCI, as well as Sentinel-2 MultiSpectral Imager data. Such maps will serve as complementary data sources for the EU-WFD, as has been demonstrated here for chl-*a* reporting. In addition to providing results comparable with those using *in situ* point measurements, satellite imagery has been demonstrated to provide quantitative, detailed spatial information. The application and comparison of such EU-WFD compatible mapping to other lakes will be interesting, both within Hungary (Lakes Velence, Tisza and Fertő for example) and internationally. When comparing EU-WFD reports from other countries, it is important to keep in mind that each country follows its own methodology and classification, although the standardization of these is underway.

Acknowledgements

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3-D Modeling of Marine Ecosystem Engineers – a Framework for Studying Their Ecological Impact

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1. Introduction

Ecosystem engineers (also termed habitat modifiers or bioconstructors) are organisms that exert important control over resource availability for other biota via modulation of the physical and chemical state of the environment (Jones et al. 1994). Such species create, destroy, and otherwise modify habitats and thereby affect both the resources and the organisms that rely on them, as well as the abiotic stressors they experience. Some ecosystem engineers are new to the systems in which they are present as they invaded from other areas with human aid (intentional or un-intentional). The extent of invasive ecosystem engineers' influence on the environment is a subject of intense scientific study. The marine ecosystems of Israel are strongly influenced by ecosystem engineers, both native and invasive. In the Red Sea, coral reefs and seagrass reshape the local environment, while in the Mediterranean Sea is flooded by invasive, mostly tropical, species (Rilov and Galil 2009), many of which (e.g., bivalves and macroalgae) can be considered ecosystem engineers and thus are expected to reshape the structure and possibly modify the functionality of rocky reefs.

Despite the increase of studies on the ecological impacts of ecosystem engineers, the actual three-dimensional modification of the marine habitat that they create or alter has rarely been addressed. This can be attributed mostly to the difficulty in modelling such modifications, which the marine environment makes even more involved. Thus far, characterization of the ecosystem and its inhabitants was performed via simple image analysis and interpretation, mainly intended to calculate percent cover of the major space occupiers without any information on their actual structural shape. As far as we know, no studies have looked at the influence of invasive ecosystem engineers on fine-scale structural characteristics of the habitat in the marine environment.

In this work, we utilize underwater photogrammetry to quantify the 3-D modifications of natural environments by ecosystem engineers and compare them to native ecosystem engineers. Underwater photogrammetry provides an efficient non-destructive means to document complex environments with limited accessibility. With the growing use of consumer cameras, its application becomes easier, thus benefiting environmental studies which otherwise could not have been materialized. Utilizing cameras for underwater photogrammetry poses however nontrivial modelling problems due to refraction effect and the extension of the imaging system into a unit of both camera and a protecting housing device. In addition, the establishment of reference control networks in such settings is oftentimes difficult. To facilitate the modelling, we developed a model for characterizing the geometric distortions, accounting not only for the multimedia effect, but also for inaccuracies related to the setting of the camera and housing device. We show that only a few additional parameters are needed to model both elements and to preserve the collinearity relation and that no unique setup is needed for estimating the additional parameters. To alleviate the need for deployment of reference control points, we then extended the coplanarity condition, which requires neither knowledge of object space coordinates nor setting a reference control network (Telem and Filin, 2013). However, the coplanarity relation does not hold in such environments because of the refraction effect, and methods that have been proposed thus far for geometrical modeling of its effect require knowledge of object-space quantities. Thus, a geometrically-driven approach which fulfills the coplanarity condition and thereby requires no knowledge of object space data is developed. Results show that no unique setup is needed for estimating the relative orientation parameters using the model and that high levels of accuracy can be achieved. With the establishment of the orientation, a 3-D reconstruction of the habitat and the influence of the ecosystem engineers on its complexity can be derived.

Figure 1: top: a reef made of the invasive oysters. Bottom; a meadow of the invasive green algae *Codium parvulum*.

To test the applicability of this approach to ecological questions in the marine environment we model the 3-D habitat that invasive engineers on Mediterranean reefs create, and compare some of them to similar native species. For example, we focus on the structures that the large invasive Red Sea oysters *Spondylus spinosus* and *Chama pacifica* create (Fig. 1, top), and compare it to reef areas without the oysters. Similarly, we compare the 3-D structure and complexity that the invasive macroalgae *Galaxaura rugosa* and *Codium parvulum* (Fig. 1, bottom) create to that of native macroalgal species such as *Cystoseira spp.* and *Padina pavonica*. We demonstrate the approach in both lab and field settings. Future prospects of the documentation will see us moving from the individual species scale to a complete habitat scale to see how these complexity modifications translate to effects on the structure of ecosystems (i.e., reefs). Further extension of this work will see investigation of the spatio-temporal dynamics of the influence of invaders as the oyster reefs probably grow with time and the invasive macroalgae species are seasonal and, their patches seem to grow from year to year.

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Using Airborne Hydromapping Data for Habitat Investigations in running waters

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1. Introduction

Ecohydraulic studies are an interpretation of the hydraulic situation in running waters with regard to living conditions for their flora and fauna. Bathymetric surveys are the essential basis for these investigations. With increasing computational performance and powerful models for describing the hydraulic situation and stream water habitats, the expectations for basic surveys are rising. Against this backdrop and further reinforced by the stipulations of the European Water Framework Directive, the technology of Airborne Hydromapping, a survey system with a water-penetrating laser system was developed (Steinbacher et al., 2010).

2. Airborne Hydromapping

2.1 Technology

Main part of the Airborne Hydromapping concept is a water penetrating laser system which is able to deliver high resolution information about the riverbed geometry (VQ-820G; Riegl LMS, Research project between University of Innsbruck and Riegl LMS). With this technology it is possible to survey water bodies and riparian strips comprehensively and in high resolution (10–40 points/m^2). Moreover, a penetration of the water body up to a depth of 10 m is achieved under clear water conditions, deeper depths are captured by echo sounding devices (Baran et al., 2013). Detailed and extensive data of riverbeds and riverbanks can be acquired within a couple of flight hours. Additionally, LiDAR points from the water surface are gained by this device and can be used to reconstruct the water table. For turbid water torrents it is also possible to measure the turbidity in the water stream.

This new technology has a great advantage in contrast to traditional survey concepts where multiple cross sections are measured by a survey team. The survey of cross sections is time consuming and may be dangerous or not feasible in places of interest (see Fig. 1).

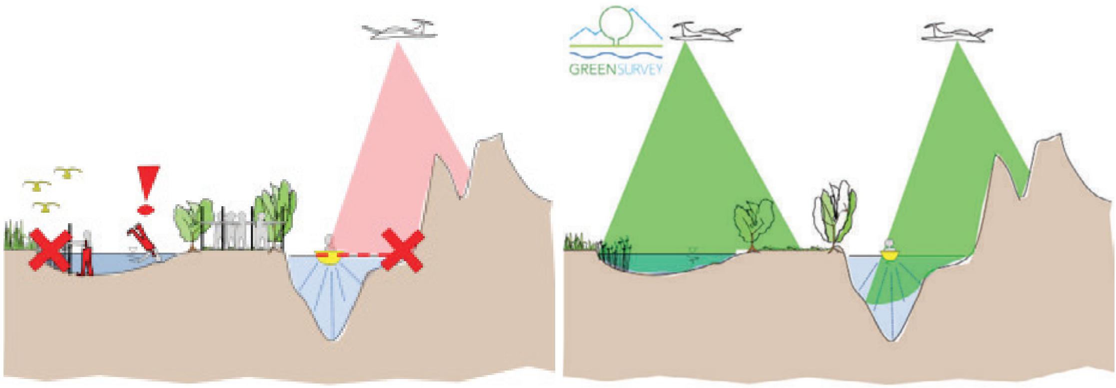

Figure 1: Concept of traditional bathymetric surveys (left) and high resolution bathymetric surveys with Airborne Hydromapping coupled with sonar technics (right).

Airborne Hydromapping survey campaigns result in a comprehensive database, which consists of the original point cloud, the classified point cloud, digital elevation models, numerical meshes and abundant additional information (areal images, thermal data, etc.). The data analysis and visualization is done with the software HydroVish (see Fig. 2), which is a highly efficient software package to handle very huge data sets (larger than a billion points, Benger et al., 2007).

Figure 2: example of a bathymetric terrain model generated on basis of Hydromapping data (visualization with HydroVISH)

2.2 Data quality

In order to calibrate Hydromapping scan data, an additional terrestrial survey of reference points is carried out in a project area. The reference points are defined for example by the outer corners of roofs, or crosswalks on streets and are selected subsequently to the survey flight from the data set. The position of the reference points are then determined using GPS.

Usually, a data set consists of several scan stripes with a large overlap of often more than 50% among the stripes. The stripes need to be aligned to each other due to a slight offset between the stripes. The accuracy of the strip adjustment is usually in the range of 10 cm (standard deviation). Furthermore, the entire point cloud is georeferenced with an accuracy in the order of 8 cm (standard deviation; e.g. Dobler et al. 2013) using the above mentioned reference points.

3. Habitat investigations

Physical habitat models are used successfully as assessment tools of the ecological status of running waters. Structural and hydraulic characteristics are analysed and compared to reference values (e.g. water depths, flow velocities, substrate, Schneider, 2001). In discrete points the habitat suitability of target species is calculated with the help of expert knowledge (e.g. fuzzy rules or preference curves) and the overall habitat availability is calculated as integral value in form of the weighted usable area (WUA):

$$WUA = \sum_{i=1}^{n} HSI_i \cdot A_i \tag{1}$$

with

n = amount of calculation cells (–)

HSI_i = habitat suitability index (–)

A_i = area of the calculation cell (m^2).

The basis of physical habitat modelling is the detailed knowledge of the riverbed geometry and the associated hydraulic conditions in the river. Thereby the precision and resolution of the basic survey plays an important role in the habitat analysis (Hauer et al., 2009). For example, shallow water areas with low flow velocities are important habitats for juvenile fish. However, with interpolated cross section data it is difficult to depict these areas.

Additionally, dead wood structures and overhanging vegetation is important for fish serving as hiding and rest places. These structures can also be captured by Airborne Hydromapping data and analysed for habitat investigations.

The data generated by Airborne Hydromapping are used to create detailed, high-resolution calculation meshes and are therefore capable to accurately describe the hydraulic conditions in large river reaches. It can be used in both, small-scale and large-scale contexts and also opens new avenues for monitoring applications.

Based on a data set acquired in an alpine river in South Tyrol it was shown that 2D hydraulic models are capable to resolve complex and small scale flow patterns like horizontal eddys and backflows. In contrast to cross section based data these patterns can be depicted with high resolution bathymetric data and furthermore analysed in habitat investigations (see Fig. 3). These differences in results of hydraulic models have an effect on the calculation of the weighted usable areas and thereby influence on the results of habitat models.

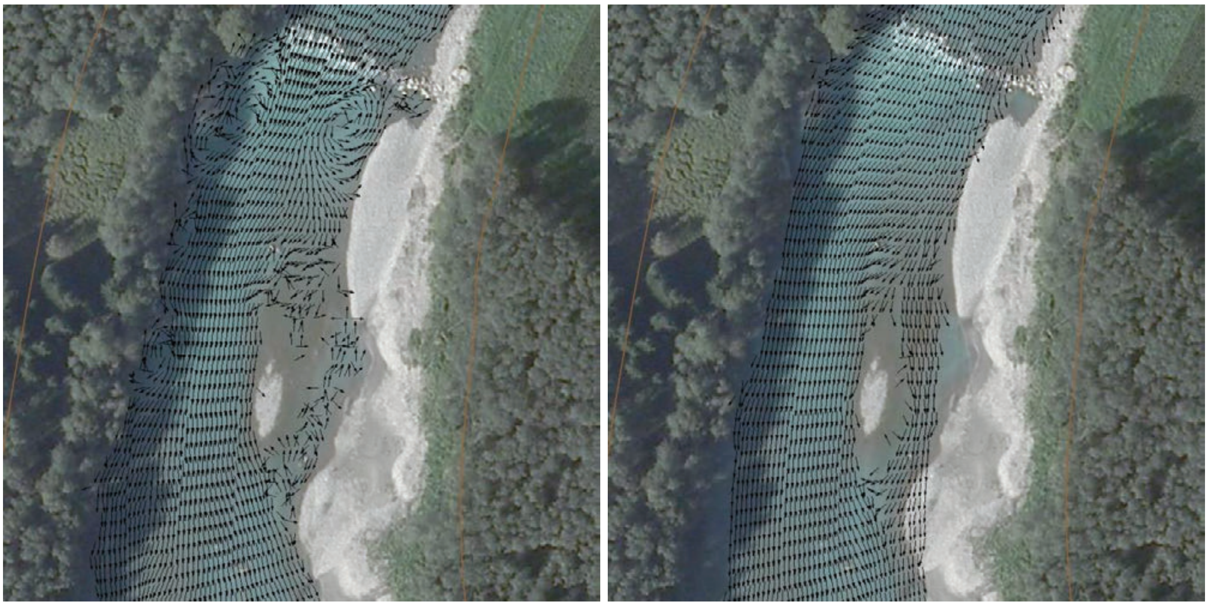

Figure 3: results of 2D hydraulic modelling; left, calculation mesh based on high resolution survey data showing horizontal eddys and backflow patterns; right, calculation mesh based on cross section data not showing eddys and backflow patterns

A further advantage of the airborne strategy is the possibility of large scale data acquisition of investigation areas. In contrast to rather short representative reaches, whole river sections up to several kilometers can be surveyed in high resolution. With a penetration depth of up to 10 m alpine and gravel bed rivers can be surveyed comprehensively that way.

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Intertidal Habitat Characterization of Rocky Shores Using Terrestrial Laser Scans

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1. Introduction

Rocky shore research has been laying the fundamentals for ecological theories and ecosystem modelling for several decades. The rocky intertidal exhibit steep environmental gradients, variable physical conditions over short distances, and inhabits organisms that are mostly sessile or sedentary, reach high densities, and are small in size. These characteristics, combined with the relative ease of accessibility, make it one of the optimal study systems for ecological patterns and processes (Menge & Branch, 2001). Generally, coastal ecological-related research focuses on distribution patterns and dynamics of organisms and community assemblages and on understanding the physical, biotic factors, and processes that affect diversity, distribution and zonation. In recent years, climate change, biological invasions, and accelerated coastal development pose threat to the ecological stability of rocky shore habitats (Rilov & Treves, 2010). This raises additional research interest in this environment both as an indicator of overall ocean health and for conservation purposes.

Rocky shores are generally characterized by three distinctive habitats: subtidal, intertidal and coastal. Among them, the intertidal zones are characterized by diverse communities of marine organisms, many of which are limited to this habitat. These organisms are affected by the unique physical environment where rocky substrata are alternately exposed to air and submerged under water due to daily tidal cycles (Denny, 1999; Menge & Branch, 2001; O'Donnell & Denny, 2008). Other dominant factors that influence the distribution of intertidal organisms are wave exposure, induced hydrodynamic forces, and water coverage dynamics. All these factors strongly relate to the geomorphological features of the rocky substrata including elevation above sea level, the shoreline topographical complexity, and the rock's micro topography, all of which can vary greatly from site to sites. The effect of these components on intertidal marine communities has been studied in the past, mostly on a metre-scale or higher, but in order to accurately represent their ecological patterns and forecast possible ecological changes due, for example to sea level rise, better observations are needed for the small scale topography. Along this line, Fraschetti et al. (2005) indicated that smaller scale spatial resolution would improve the interpretation of the intertidal zone and microhabitats.

Threats such as sea level rise are particularly relevant to regions where the tidal range is small but the intertidal area is large (i.e., large flat rock platforms at sea level). Such is the unique rocky shore habitat of vermetid reefs, a flat rocky formation located at mid sea level that is found in warm-temperate seas where the rocks are softs and easily abraded by waves and winds (Safriel 1974). This is a biogenic habitat, where sedentary gastropods (vermetids) create a crust on the rock flat as well as a rim at the waterline (formed specifically by the species *Dendropoma petraeum*), which stop or compensate the erosion of the rock. Such reefs are very abundant on the eastern parts of the Levant shore, and a recent finding indicates that the populations of the reef-building vermetids are almost extinct, raising the question, what would happen to the integrity of the habitat, especially in light of sea level rise. A detailed 3D characterization of the whole reef area allow to follow geomorphological changes over time, as well as model the effect of sea level rise on the available area for intertidal biota.

While classical surveying is still the commonly-used documentation and mapping technique of rocky shores, it falls short of describing the relevant topographical detail and the dynamic nature of the intertidal zone. Its outcome presents limited characterization of habitat structure and the complexity of reef environments (Marchand & Cazoulat, 2003; Bonnot-Courtois et al., 2005; Vierling et al., 2008). Use of airborne laser scans which has been proposed in recent years (e.g., Vierling et al., 2008; Chust et al., 2008; Brock & Purkis, 2009; Noernberg et al., 2010; Hamylton et al., 2014) provides only decimetre level accuracy and limited resolution. It is also incapable of characterizing the micro-topography and falls short of characterizing in detail coastal cliff edges and other near-vertical features. Moreover, it presents limited flexibility of repeated campaigns due to data acquisition costs.

To address these shortcomings and provide an insight into the effects of reef microhabitat, we apply terrestrial laser scanning technology, which offer centimetre resolution and even higher accuracy, and develop morphological characterizations of the coastal environment. We also sample the biodiversity, which links between rocky shores micro-habitats, biodiversity, and intertidal marine community structure. The proposed application creates a geomorphological and ecological representation of the rocky intertidal coastal system, including its topographical texture and complexity, rim form and completeness, species-habitat relationship, and potential ecological impacts of sea-level rise. Long-term monitoring of the reef would allow us a more accurate estimation of the marine biota changes as a result of the rim and micro-topography modifications.

As the data volume prohibits naïve analyses, we develop methods to characterize the micro-morphology of the reef and its rim. The microstructure is described by its texture and complexity, and allows us to classify microhabitats and possibly explain zonation and patchiness patterns. The rim characterization, which is evaluated in terms of form and continuity, also allows estimation of seawater holding on the reef during low tide. Water held on the platform during low tide create special conditions for the organisms on the reef, thus erosion of the rim would change those conditions, as well as wave dynamics. Long-term rim characterization will provide information on the effect of the disappearance of the rim builder vermetid, *Dendropoma petraeum* on the reef structure. The dense spatial resolution provided by the laser scans allows also testing the effect of various sea level rise scenarios according to IPCC forecasts. The level of detail we achieve improves forecasting of the exact locations and microhabitats that would be flooded and become subtidal. Paired with the biodiversity analysis per habitat, a highly precise prediction of community changes and species loss would be made possible for the first time.

2. Study Sites

The application is demonstrated on two dissimilar sites along the Israeli Mediterranean coast, exhibiting different geomorphological characteristics and distinctive formation of vermetid reefs. The first, Achziv shore, at Northern Israel (Figure 1) is a continuous calcareous eolianite (kurkar) rocky shoreline of ca. 300 meters, extending seaward to create eight separate vermetid reefs (Figure 1b). At the back of the shore, a two metre high rocky cliff borders the shoreline from land.

The second is a tiny islet located at HaBonim shore (Figure 1), which features a well-developed elliptic continuous vermetid reef which surrounds a 4.5 meter high cliff. The platform at this site is approximately 10 cm lower than in Achziv.

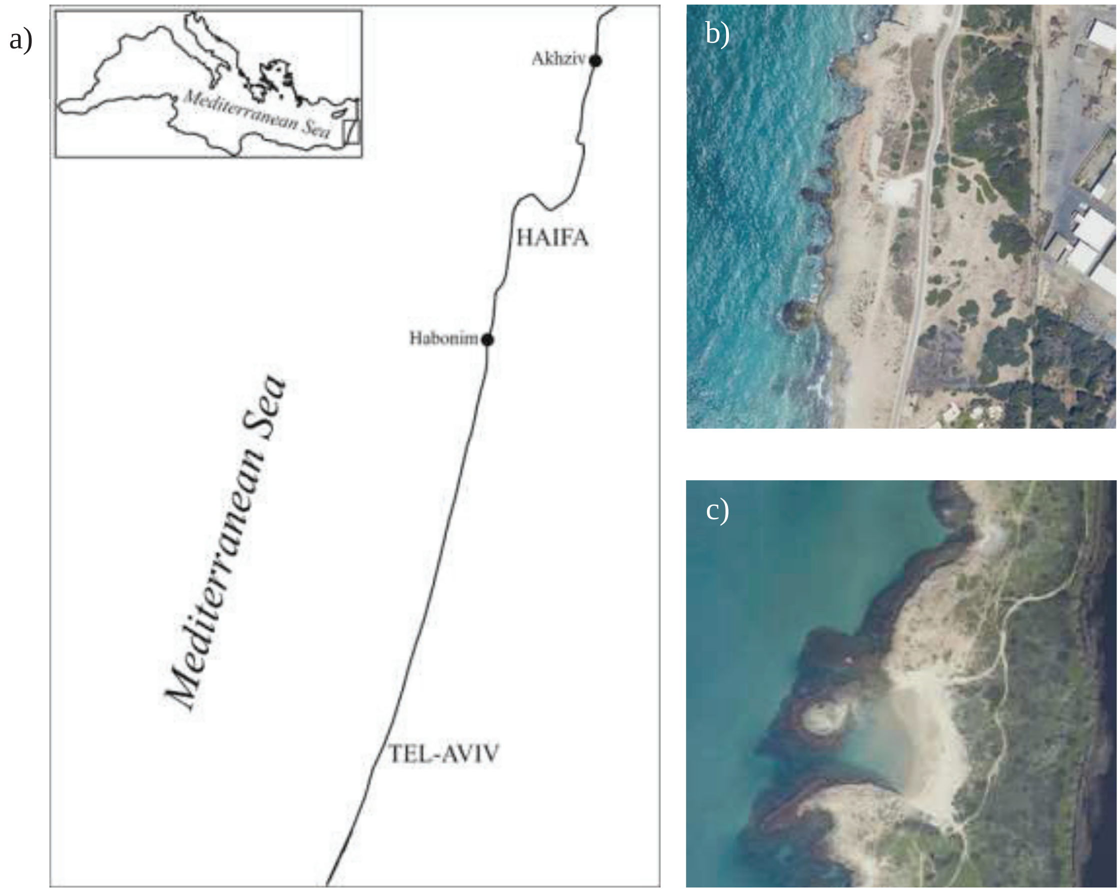

Figure 1: a) Israel coast and sites locations; b) Achziv aerial view; c) HaBonim aerial view

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Gimme my vegetation map in an hour! Towards operational vegetation classification and mapping: an automated software workflow

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1. Introduction

Classifying vegetation based on remotely sensed measurements (ALS) is still largely a topic of rather research interest, but not a widely available commercial service.

Part of the difficulty to bring operational – that is fast, accurate enough for indended use and cost effective – vegetation classification to widespread use in the market, is that in order to produce a quality vegetation map, a number of highly qualifed experts (biologists/ecologists, remote sensing, machine learning, data processing and IT specialists) need to collaborate, often in similar time and/or place, which puts extra demands from organizational and logistical point of view, at the same time preventing any radical drops in costs of such a service (or actually preventing it from becoming a readily available service in the first place).

Another constraint is that the the state-of-the-art algorithms developed for various scientific tasks can only be assimilated very slowly by the producers of major market software packages, keeping them out of reach for everyone except experienced programmers who can code these tools themselves. Most of the large software packages are oriented towards general GIS and image processing tasks, limiting their applicability specifically for vegetation mapping.

This study presents a successful implementation of an integrated suite of software tools called Vegetation Classification Studio, that makes a large part of the process of producing vegetation maps highly efficient by automating what can be made automatic, and by supporting human experts in tasks require their decision and knowledge.

The main principles driving the design of the tool were:

- automating as much as possible of all tedious and repetitious data processing tasks, especially those requiring a lot of precision and care when performed by human operators, and their essence does not require taking creative decisions, or when the quality of their results can be assessed and verified in an objective manner, allowing to substitute human labor with an optimisation algorithms
- implementing enough expert knowledge in the software form so that most decisions required during the processing can be made automatically with a reasonable quality, resorting to human expert knowledge rather only at the very beginning and very end of the process
- try to limit the amount of input data required to bare mininum, taking care of producing of all the necessary intermediate data products automatically, as part of the internal workflow
- support creating and evaluation of many variants and alternatives of vegetation maps, being smart in suggesting reasonable alternative parameters of algorithms at different

processing steps, quantifying their impact on accuracy and quality of the final results, and making the multiple processing results available in a standard form suitable for convenient evaluation by the expert
- processing time matters, so result should be produced fast! — and it's not because of computing resources – but because producing high quality vegetation map requires mutliple cycles of consecutive correction and improvement, and any time that a human waits for a machine to process results impact directly the interactivity of the work and lengthens the final schedule

2. Method

We typically tested the Vegetation Classification Studio on Laser Scanning data, therefore the first step of the process was to calculate point cloud products. This was implemented using OPALS modules: In the first step of the algorithm, subsets of the sensor data are created within the calibration and validation plot outlines. Then, within these patches, a very large number of point cloud attribute derivatives is calculated, representing geometric, radiometric and roughness properties of the surface. Noise reduction and texture filtering is also applied automatically in order to further enhance the information content of the data. The input data can be complemented with any kind of information that can be converted to a raster: standard single- and multi-channel .tif files are used for this intermediate step, allowing direct interoperability with image data sources, vector maps, or other kinds of field information.

A vegetation classification task is essentially a learning problem: from a set of points in n-dimensional space (the data pixels with their respective attribute values), the user-defined groups have to be produced, based on a limited sample of training data. For this general setting, a machine learning algorithm was implemented in Python language, based on the scikit-learn library, accessing the sensor data through GDAL. The learner selected the data products with the highest information content for the respective task, and automatically creates a decision tree for classification. The result is for each pixel a set of probabilities that the pixel belongs to a particular vegetation class.

The accuracies of the classification are tested on the validation dataset, a standardized text report is output, and if this is accepted, a reduced-resolution graphical rendering of the whole study area is produced. For this, only the data derivatives corresponding to the optimum settings are calculated. Visual checking of this output rendering allows detection of any artefacts or classification errors, adjusting the algorithm if necessary, and finally rendering the full-resolution product raster.

3. Results

The Vegetation Classification Studio was tested on a range of sensor data products and habitats: forests, grasslands and wetlands were all tested, mostly with laser scanning data but in some cases also including imaging spectrometry. In practically all cases, the number of detectable classes and their accuracy and reliability were far superior to those achievable with mainstream software. Up to thirty classes could be accurately represented from sensor data, and the reporting and rendering scheme allowed quick feedback to the ecologists of the team, who could focus on extending field data or identifying problems with the output.

One lesson learned was that the system is very sensitive to imperfections of sensor data georeferencing and systematic errors. However, the artefacts these produce are easy to recognize and can often be corrected. The speed of processing allowed several hundred square kilometers to be rendered within hours, allowing for rapid checking of multiple options and final selection of the best products. The output data is ready for immediate viewing in a GIS and colour schemes can easily be adjusted to allow intuitive understanding (including the blending of colours for representing fuzzy class membership), facilitating dialogue between biologists, programmers and remote sensing scientists.

4. Discussion

The Vegetation Classification Studio has proven to be suitable for a wide range of input data and studied vegetation. It has allowed a new way of collaboration between ecologists, remote sensing scientists and programmers, and took remote sensing classification to the very edge of what was believed possible.

The promise from the title – to produce a quality vegetation map in an hour – still cannot be considered realistic for real-world situations, especially when we take into account the time required to prepare field and sensor data. In optimal conditions it did actually happened, that a whole process of making a new version of a vegetation map – after some field data adjustments or with new ALS derivatives or algorithm parameters – resulted in a biologist being able to evaluate a new version of a classified vegetation map of a large area in his GIS viewer in just about 1 hour, which makes that goal seem more and more realistic in a near future.

Future plans are to test the Studio on integrated data from different sensors, apply it further to new habitats and finally to make it commercially available.

Acknowledgements

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Unmanned aerial vehicles in airborne environmental monitoring

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1. Introduction

Airborne remote sensing is a very useful tool in environmental monitoring if information is needed on a large territory within a short period of time. The only limiting factor is the cost, which could be high. For conventional monitoring, a manned aircraft or helicopter is necessary, which needs fuel, well-trained pilot and an airbase, which could be far away from the working area.

The size (and weight) of the high-resolution cameras and other sensors have shown a significant decreasing trend in costs during the last decades, giving an opportunity to use them onboard of small, unmanned aerial vehicles (UAVs or drones) (Sauerbier et al. 2011). The costs are significantly lower (by about a magnitude), and the flexibility of the application is much higher than that of the big aircrafts, due to the lack of airbase need (Sauerbier et al. 2011, Watts et al. 2012).

Several types of airborne monitoring are known, which can be divided into three main types: photogrammetry (Turner et al. 2012, Laliberte et al. 2011, Kelcey et al. 2012, Suárez et al. 2010), sensor mapping (Watts et al. 2012, Rojas et al. 2012) and sampling (Pöllänen et al. 2009, Aylor et al. 2011). In photogrammetry the information is image-type. These images could be high-resolution conventional photos (Sauerbier et al. 2011, Turner et al. 2012) or lower-resolution photos but from a special, well-defined spectral range (multi/hyperspectral imaging, IR/UV imaging) (Laliberte et al. 2011, Kelcey et al. 2012, Suárez et al. 2010). In both cases, two perspectives are possible: perspective from bird's-eye view or from vertical angle. While the first one provides rapid information and it is very easy to use (e.g. in case of emergency operations such as floodings, forest fires, natural disasters), the latter one is often used in GIS systems by converting the photos into orthographic projection and using them as "map layers", e.g. if a pollutant identification and its distribution should be determined. Both of them are usable in different types of environmental monitoring; from disaster emergency actions to the monitoring of pollutants or natural reserve areas.

The protection of natural reserve areas is our primary task to keep the planet for the next generations. Aerial photographs can be used as well for monitoring the wildlife or vegetation (Figure 1), in the latter case multispectral imaging is very informative (Kelcey et al. 2012, Gademer et al. 2010).

In pollution monitoring both conventional and hyperspectral types of imaging are usable. In case of conventional photographs only the visible pollutants (colours) or the impacts of the pollution (foaming, algae growth, etc.) are detectable (Figure 2), while using hyperspectral, especially UV/IR remote sensing other pollutants are transformed into "visible" range (e.g. oil spills) and the concentration of the pollutants can be evaluated (Long, 2012). The previously mentioned sensor remote sensing or sampling methods are also widely utilizable technologies in pollution monitoring (Watts et al. 2012, Rojas et al. 2012, Pöllänen et al. 2009, Aylor et al. 2011).

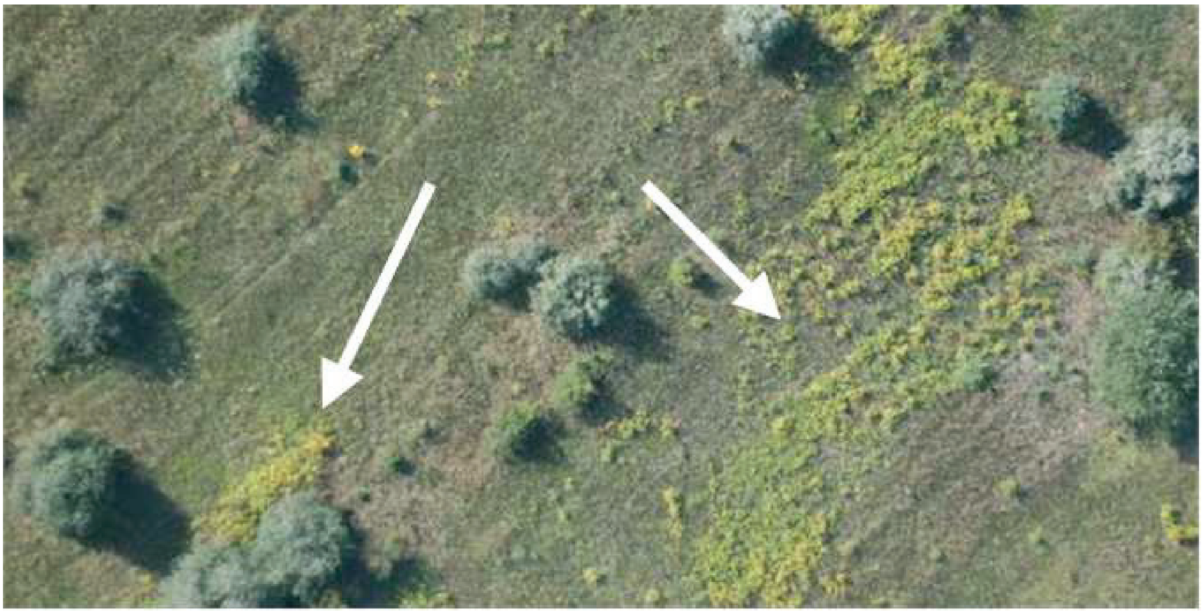

Figure 1: Monitoring of the population of a special plant species via aerial photogrammetry

Figure 2: Monitoring of water pollution from air

2. Experimental

In our survey, two UAVs were used: a MULTIPLEX Easy Star and a STYROMAN Smile (Figure 3). These UAVs were equipped with electric motors (TURNIGY and BLUE RAY types) and were controlled by a 2.4 GHz RC remote control system (FUTABA). A lightweight full-HD (1280×720) camera (FLIP) was used for imaging. The camera was normally positioned in the nose section of the UAV as seen on photos. The angle of down looking was alterable between 2°and 10°. Alternatively, the camera mount could be fixed on the belly of the plane: using this set up vertical angle photographs were taken.

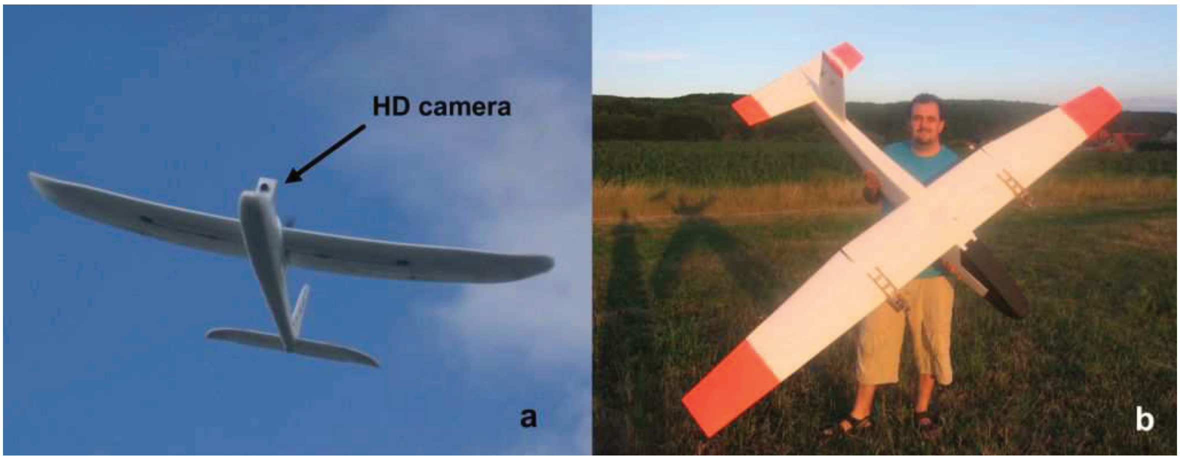

Figure 3: The UAVs used by the authors:
a Multiplex Easy Star (a) and the Styroman Smile (b)

3. Results

The flights were carried out in the area of Bakony Mountains, in Hungary. Several aerial photographs were taken on forests, agricultural fields and on ecological important territories, like wetlands. One of the investigated wetlands (a lake near to Csehbánya) was found rather interesting, since a significant part of the lake exhibited the signs of eutrophication. The growth of algae is hardly detectable from the shore of the lake (ground view), however, it is clearly visible from the air (Figure 4). Since this algae growth has only been detected very recently, further investigations are necessary in different seasons to study the ecology of the lakes and to devise a solution for this problem, if necessary.

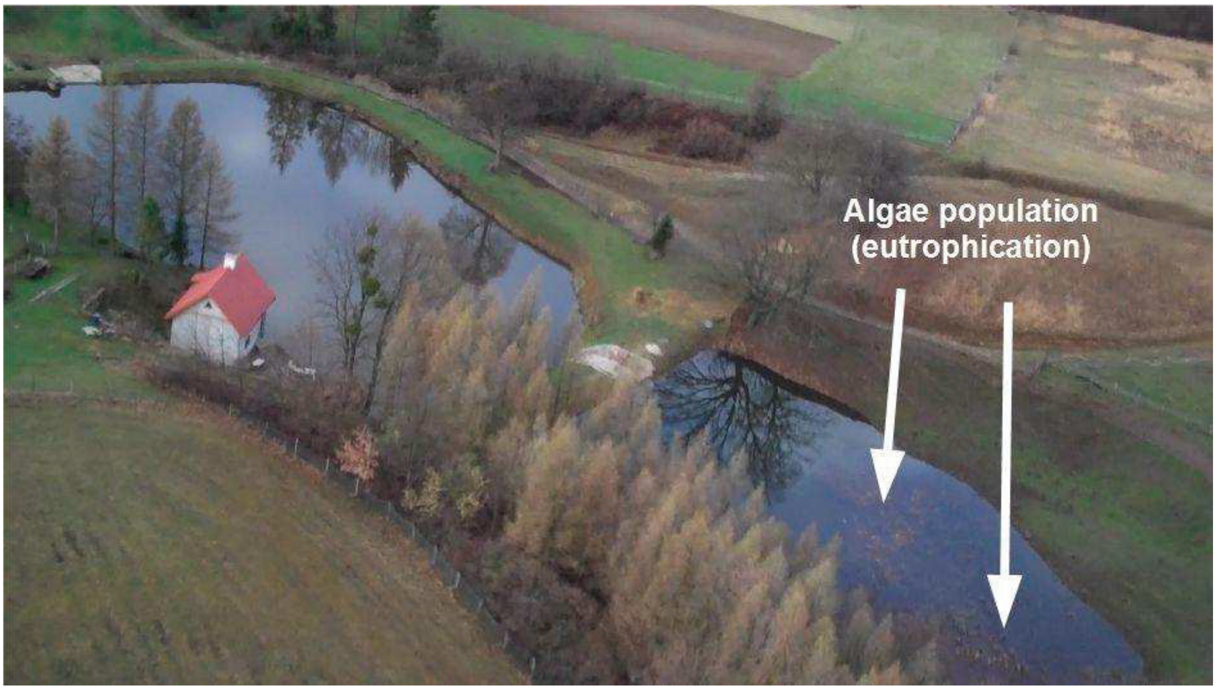

Figure 4: Image made by the authors on a lake
in the neighbourhood of Csehbánya village in Bakony Mountains

Using vertical option the UAV was used successfully in orthographic photos as well. Figure 5 shows an orthophoto made in Bakony Mountains, in the area of Csehbánya Village. This photo is a good example, since buildings, grassy areas and different agricultural fields can be seen in a relative small area.

Figure 5: Orthophoto made in the area of Csehbánya village in Bakony Mountains

As it can be seen, these photos are very informative and utilizable e.g. in agricultural monitoring of land use as well as in this program, in monitoring of natural reserve areas.

By studying the photos our UAVs are found to be very useful for this work; it is one of our future objectives to carry out an air monitoring project for the lakes in Bakony Mountains in collaboration with specialists. It was concluded that both UAVs are suitable for taking orthophotos as well. The noise level of both UAVs was found to be very low due to the electric motors, making those applicable over nature conservation areas as well.

4. Conclusions and future plans

Based on the successful results with this technique using single HD camera the photogrammetric survey will be continued in the area of the investigated lake and it is planned to extend this work to other wetlands and natural reserve areas as well. In addition to the HD photographing the project is planned to be continued with other high performance cameras and sensors to build up a complete “environmental sensing package” for our unmanned aerial vehicles.

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Tree Species Mapping Using Airborne Hyperspectral Remote Sensing

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1. Introduction

Remote sensing technologies offer the capability to rapidly map large areas. The tree species delineation of forests is a very essential step in forest mapping and inventories, however the remote sensing based classification produce forest map with different accuracy level. The hyperspectral data produce valuable information for tree species classification. The main objective of this research is to classify different tree species and their health status by means of airborne hyperspectral remote sensing.

2. Materials and Methods

2.1 Study Area

The study area is located in the Sopron Mountains, situated West – South-West from Sopron, Hungary (~47°40’N, 16°30’E), the altitude is between 200 and 560 m above sea level.

A more detailed investigation was carried out in the Hidegvíz-völgy Forest Reserve. This ER-46 Reserve is one out of 71 forest reserves in Hungary, situated in the North-West corner of Hungary, between Sopron and the border of Austria. This reserve is one of the smallest one in the country. The core area is 19.7 hectare and the buffer area is 37.2 hectare. The investigated forest is a mixed forest, with oak (*Quercus petraea*), hornbeam (*Carpinus betulus*), beech (*Fagus sylvatica*), spruce (*Picea abies*), larches (*Larix decidua*), and others. The health status of the spruce is the worst, because of the bark beetle disease (Horváth 2002).

The last detailed field-survey was carried out in 2013, during a geodetic practical course for forestry students, resulted the tree positions, species, diameter at breast height (DBH), social and health status, and crown sizes for more than 2000 trees.

2.2 Hyperspectral Survey

The hyperspectral survey for the administrative border of Sopron and its surrounding settlements was carried out by an Aztec Piper airplane using AISA Eagle II sensor on the 26th of August, 2011. All the surveyed data were pre-processed, atmospherically and geometrically corrected by Envirosense Ltd., the data collection was supported by our University’s TÁMOP-4.2.1.B project called ‘Urban Ecology’. This project made the ENVI 4.8 image processing software also available.

2.3 Theoretical Background of the Classification

The reflectance of the plants is unique, because of the wavelength-selective absorption of the compounds. For that reason some material is recognizable on the basis of the spectrum-profile (Csorba, 2011).

In case of plants, the structure of the leaves determines the spectral profile. A smaller part of the radiation is reflected by the cuticle wax, and the bigger part gets into the leaf. Between the epidermis and the columnar parenchyma, and in the spongy mesophyll the light is dispersed and as a transformed radiation, it is reflected or let through the leaf. The characteristic of the spectral profile is mainly determined by the chlorophyll molecule, because its main absorption wavelength is about from 420 nm to 435 nm in the blue range, and from 660 nm to 643 nm in the red range. (Király 2007) In the near infrared range predominate the chlorophyll effect, the fluorescence of the chlorophyll. (Bácsatyai 2001) This effect results a steep rising in the spectral profile, the “red edge”. (Figure 1)

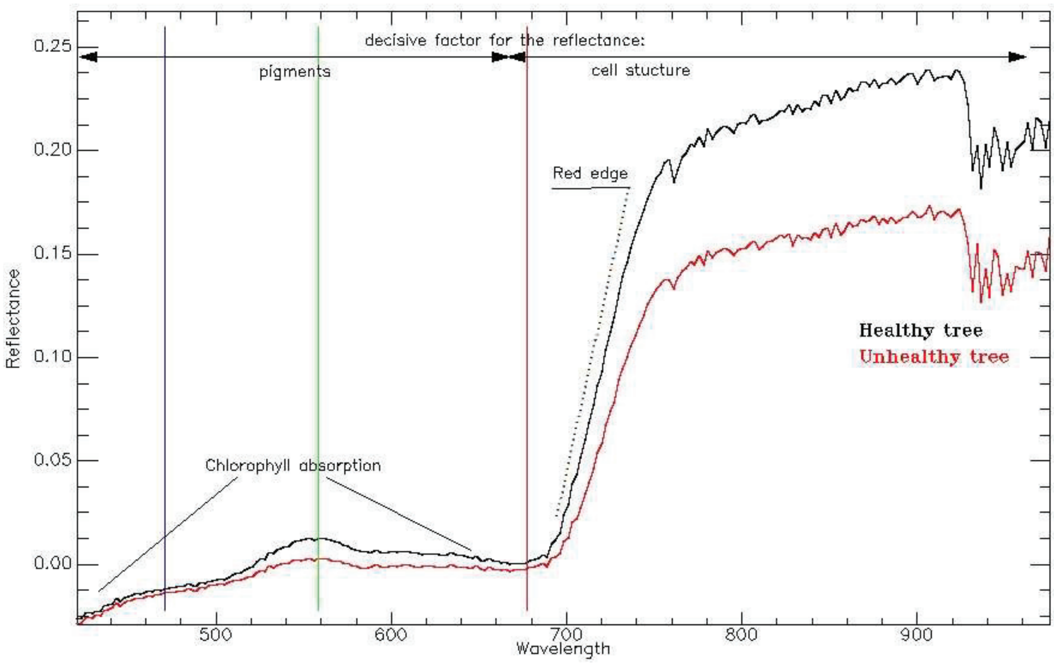

Figure 1: Spectral profile of leaves.

2.4 Classification

Supervised classifications were used to separate four tree species: European beech (*Fagus sylvatica*), sessile oak (*Quercus petraea*), European larch (*Larix decidua*) and Norway spruce (*Picea abies*). The training areas were derived from the reference field-survey in the Forest Reserve. A Minimum Noise Fraction (MNF) transformation was applied first. Several different classification methods were tested, such as Support Vector Machine (SVM), Spectral Angle Mapper (SAM) and Minimum Distance classification.

The chlorophyll effect depends on the health of the plant, so it gives opportunity to estimate the health status of the trees. In this study, we used three different vegetation indices to measure the “red edge” of the tree’s spectral profile. The well-known broadband index: the Normalized Differenced Vegetation Index (NDVI), and two narrowband indices: the Modified Red Edge Normalized Differenced Vegetation Index ($mNDVI_{705}$) and the Modified Red Edge Simple Ratio index, mSR_{705}) were used.

3. Results

The area of the Forest Reserve was analysed with two different classification methods. We tried to use the original hyperspectral images without MNF transformation. The accuracy was 80% with SAM classification, and 55.66% with Minimum Distance classification. We have tried to create Spectral Library based on this area, but it produced low accuracy, because of the noise of the data, and atmospheric effects.

The best accuracy for tree species classification was achieved by Support Vector Machine Classification (SVM) after Minimum Noise Fraction transformation (MNF). The overall accuracy of the result was 93.11%. This result seems very good, but the size of the reference area was too small, so the real accuracy can be lower.

The health status of the trees was analysed in the case of European beech (*Fagus sylvatica*), but the separability based on the applied vegetation indices between healthy and unhealthy beech trees was unsatisfactory. Some other index should be created and tested and better reference data is also necessary for this kind of investigation in the near future.

Acknowledgements

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Estimation of vertical forest layer structure based on small-footprint airborne LiDAR

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1. Introduction

Knowledge about the 3D structure of the vegetation is of critical importance for Natura 2000 (N 2000)-related habitat assessment. Besides the characteristics of the canopy the presence or absence of understory (sub-dominant tree and shrub layers), its cover and species composition are important indicators of habitat quality in many forest types.
Airborne LiDAR is known to accurately depict the canopy surface, an ability that is usually exploited to derive vegetation heights and to compute an nDSM, which may also depict multiple vegetation layers. However, this layer information can only be based on the upper crown heights of the dominant plants. Yet, ALS is capable of entering the canopy through small gaps and thus depicting the arrangement of foliage masses below, a fact that cannot be accounted for in the nDSM.

In this contribution, this penetration capability of ALS is used to derive information on the abundance of sub-dominant vegetation layers.

2. Study area and data

The selected study area is located in Hungary in the Great Forest of Debrecen (Nagyerdö), which is included in the Debrecen-Hajdúböszörményi tölgyesek N 2000 site. The forest consists of several extended old stands (80 – 120 yrs.) with high nature conservation value. The stands are multi-layered, featuring two distinct tree layers (dominant and sub-dominant), as well as a shrub and species rich herb layer. The typical tree species are pedunculate oak (*Quercus robur*), field maple (*Acer campestre*), wild cherry (*Prunus avium*) and linden species (*Tilia* spec.).

For this study airborne LiDAR data acquired under leaf-on and leaf-off conditions with a RIEGL LMS-Q680i full-waveform laser scanner mounted on a fixed-wing aircraft were at hand. The mean echo density was determined with 27.5 echoes / m^2 (leaf-off) and 29.4 echoes / m^2 (leaf-on) under consideration of all available echoes (first, intermediate, last of many).

3. Method

The underlying hypothesis is that the distribution of ALS echoes in the vegetation allows drawing conclusions on its structural complexity. Given adequate penetration of the canopy by the laser beams, a lack of echoes in a certain height interval is therefore founded in the absence of vegetation to act as a reflector, rather than in the occlusion from higher parts of the canopy. The clustering of ALS echoes on the other hand is an indication for the presence of a significant amount of foliage mass, and is consequently considered to represent a vegetation layer.
The presented approach for the estimation of vegetation layer structure is based on this hypothesis. The method derives vertical layering information on pixel and on plot level. In this way, the high spatial resolution provided by LiDAR can be exploited to detect the layer structure of small vegetation objects, while the fine resolution results are used to derive the stratification for an area wide assessment.

On the pixel level, first height densities (i.e. percentage of echoes per height level) are calculated for each grid cell from the LiDAR point cloud. If a pixel holds more than a pre-defined percentage in a certain height interval, this interval is set to 1, if not, it is set to zero (i.e. binarization). Subsequently, the actual layer structure estimation is carried out on a raster basis. The algorithm probes all pixel positions for vertical sequences of intervals set to 0 or 1. A sequence begins or ends if a 0-interval is encountered. One sequence corresponds to one vegetation layer (see *Figure 1*a).
On the plot level, all pixels of one height interval are considered together as one binary map (called a slice). The algorithm proceeds in a similar way as for the pixel, as it searches for slices containing only 0-intervals. Such a slice is consequently considered as a gap, separating two distinct vegetation layers (see *Figure 1*b).

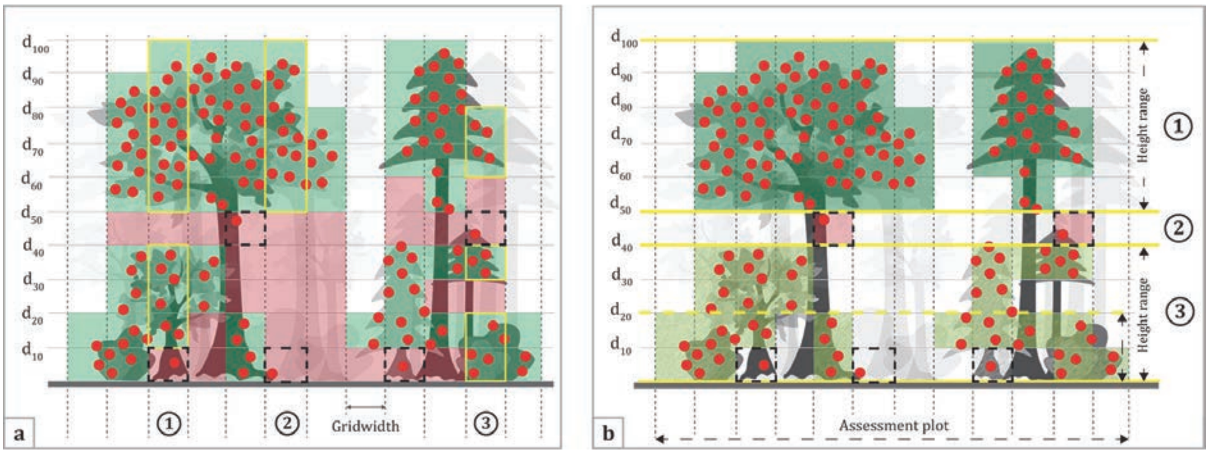

Figure 1: (a) Structure is estimated on the pixel level. Connected vertical sequences of green intervals correspond to one vegetation layer (yellow outlines). Red intervals correspond to vertical gaps (no echoes were found). If an interval does not hold enough echoes, it is neglected (dashed black outlines). In example 1 there are two layers, in example 2 only one layer, and in example 3 there are three layers. (b) Structure is estimated on plot level. All pixels of one height interval are considered together. Example 2 contains only 0-intervals, thus separating the two layers represented by examples 1 and 3.

The dependencies of the method on involved parameters (i.e. grid size, extent of height intervals, threshold used for minimum percentage of echoes) are investigated and the respective results are compared. The ground estimations are used to evaluate the method's success for both data sets (leaf-on and leaf-off) on plot-level. The pixel-based results are evaluated visually using the 3D LiDAR point cloud.

4. Results

The pixel-based result is a map holding the number of vegetation layers found for each pixel. *Figure 2* shows results for two selected assessment plots and different parameter settings. It can be seen that the layer map represents the visual impression from the point cloud very well. Where a distinct shrub and top layer are present, the method detected two layers correctly.

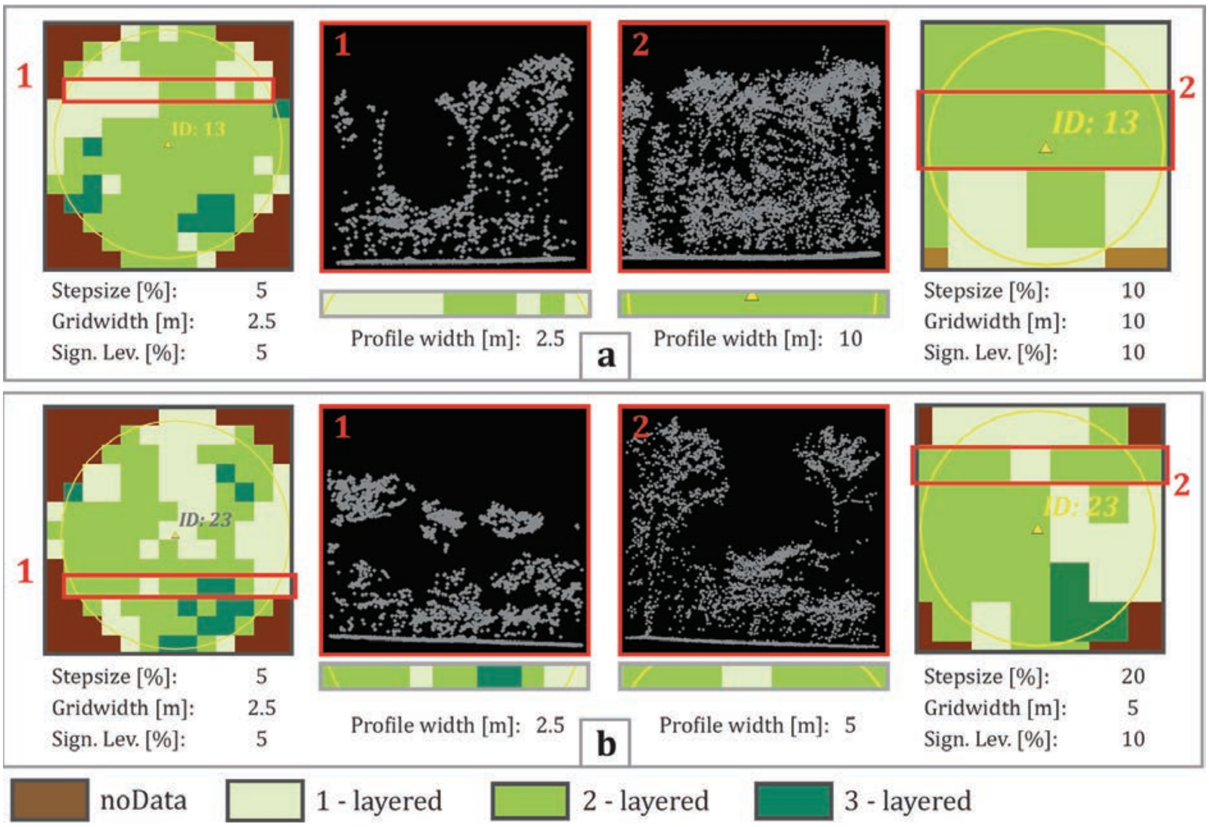

Figure 2: Examples for pixel-based results. The colour-coded maps show the detected total number of layers per pixel. Profiles from the LiDAR point cloud are depicted for comparison. Extracts of the respective locations of the profiles in the layer map are given below the profile views. The profile widths for all examples equal the grid widths used to generate the corresponding layer maps.

For the plot-level, the evaluation was carried out automatically through a comparison of layer presence or absence in the field data and the LiDAR-based results. Computing pairs of completeness and correctness for every used parameter setting determined the quality of the result. The method was successful in the detection of distinct layers, either shrubs or trees, with completeness and correctness > 80%, regardless of data input (e.g. acquisition time, parameter setting). The quality was significantly weaker for sub-dominant tree layers (i.e. in between shrub and top canopy layer).

5. Conclusion

The presented LiDAR-based method for detection of understory vegetation enables the derivation of vegetation layer structure estimates in resolutions and area extent on a highly objective basis, which is not simply doable with manual assessments. The results can be employed to derive the area percentage of a certain site that is one-, two, or multi-layered, and how much is covered by shrub layer. ALS-based layer structure maps are able to deliver a valuable input for the planning of N 2000 ground surveys, in order to optimize involved processes (e.g. identify areas of significant change, or where to go first, etc.), and they can be an essential input in remote-sensing-based habitat quality assessment.

Acknowledgements

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Categorizing grassland vegetation in lowland hay meadows with full-waveform airborne LIDAR: a feasibility study for Natura 2000

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1. Introduction

Grasslands are one of the most diverse and also the most threatened habitat types, especially in Europe. They are also one of the most challenging ecosystems for field habitat mapping since many grassland habitats have a complex fine-scale mosaic structure, and in several cases it is difficult to categorise the non-typical patches.

While forests and wetlands are increasingly studied with remote sensing tools, the application of earth observation methods in grasslands remains very limited. This is partly due to the complexity of grassland habitats, and in addition the low commercial interest and the uncertainty of retrieving the necessary biophysical parameters have also restricted the use of remote sensing for such habitats.

Based on an overview of many habitat mapping studies, the EEA report on terrestrial habitat mapping (NMNH & EEA 2014) concludes that while hyperspectral airborne imaging has potential to determine species composition and multi-seasonal high temporal and spatial resolution satellite images may distinguish between some kinds of grasslands, LIDAR is not useful in this setting.

This is a problem because region-wide coverage of hyperspectral images is not to be expected in the near future, and high temporal resolution mapping can have issues with cloud cover and atmospheric corrections.

Meanwhile, LIDAR is a promising tool since airborne laser scanning campaigns are less sensitive to weather than passive optical imaging, its information content is sufficient for automatic processing in most cases, sub-meter resolutions are typical and region-wide coverage is available for most of Europe.

1.1 Objectives

Our objective was to test the application of a high quality LIDAR dataset for mapping grassland vegetation classes, to evaluate the accuracy of different approaches and collect information on LIDAR-derived parameters useful for grassland mapping.

2. Data and methods

2.1 Study site

Our study site was the Soproni-hegység Natura 2000 site in Western Hungary (N 47°41', E 16°34'), which is a hill region dominated by oak-hornbeam and beech forests. The most widespread grasslands in our study site are lowland hay meadows, which build a diverse mosaic structure with other grassland types such as semi natural dry grasslands with *Bromus* and *Festuca* species, wetter *Molinia* meadows, sedge stands, disturbed and abandoned grasslands, weed patches and shrubs. Most of these meadows are mown twice a year (late spring and late summer /early autumn) regardless of vegetation type.

2.2 Sensor data and field survey

We were constrained to use sensor data collected for the purpose of forest mapping, which means the flight dates were sub-optimal for the grassland vegetation climax: July 2011 and March 2012. A Riegl LMS-Q680 system was used, flown at an altitude of ca. 500 meters above ground. The sensor operated at the wavelength of 1550 nm with full waveform recording and a nominal ground point density of 12.8 pt/m^2.

The acquisition of field data was also carried out in several field visits, timed to allow optimal determination of grassland vegetation type before the spring mowing.

Table 1, Classes used for LIDAR-based grassland mapping

Class name (5 classes)	Class name (10 classes)	Description	Natura 2000 code
Not vegetation	Not vegetation	Asphalt, buildings, water, open soil	
Shrub	Shrub	Shrubs and small trees	
Lowland hay meadow	Lowland hay meadow	Mesophilous, species-rich grassland, mown twice a year, multi-layered canopy	6510 (strictly and exclusively)
Mown meadow (except lowland hay meadow)	Dry meadow	Xeric, calcareous, *Bromus erectus* dominated	6210 (not exclusive)
	Molinia	*Molinia* dominated, tussocks	6410
	Wet high	Wet, grass, *Carex* or *Juncus* dominated	
	Lawn	Artificial lawn regularly mown	
Not mown	Fringe	Tall forbs, local or alien species, hydrophyilous or nitrophylous	includes 6430
	Abandoned	Unmanaged former meadows	
	Meadow like	Degraded grasslands, irregular mowing	

2.3 Data processing and classification

From the LIDAR data, a set of variables were calculated in rasters of 0.5 m resolution. These were based on point attributes (reflectance, echo width, normalized height) and the roughness and variability of the target surface (sigmaZ, variance, openness), both for leaf-off and leaf-on data. Bilateral filtering (Tomasi 1998) was applied in order to conserve major gradients but get rid of random noise. The difference between leaf-off and leaf-on values of each variable was also calculated, and the final set of input rasters was loaded to a multi-band pseudo-image. Pseudo-image “spectra” from the multiband dataset were calculated for each pixel of the training data, and a random forest-based machine learning algorithm was developed in Python for band selection and classification. Since random forests assign a probability to each class for each pixel, fuzzy class membership probability output products were generated together with the classical "hard boundary" vegetation map.

50% of the ground truth polygons were set aside as an independent validation dataset, and confusion matrices were generated for each classification product.

3. Results

Results for 10 classes show overall accuracies of 66%, with a Cohen's Kappa of 0.62 (representing a "good agreement", Altmann 1990) for ten different grassland categories. Not surprisingly, the best performing categories were shrubs, not vegetation, artificial lawns and wet-high vegetation, with both producer's and users accuracies above 80%. Molinia and Dry meadows have accuracies around 70%, while abandoned grasslands have 65% producer's and user's accuracy. Apparently the most difficult categories are lowland hay meadows themselves, meadow-like areas and fringe vegetation with accuracies between 40 and 50%. However, this may be due to the difficulty of identifying these categories in the field, together with the heterogeneity within these classes.

For the alternative set of 5 classes, an overall accuracy of 74% was reached, with a Cohen’s Kappa value of 0.64. All classes have accuracies above 70%, except for lowland hay meadow, which has producer’s and user’s accuracy around 45%. Using only leaf-off or only leaf-on data did not cause substantial drop in accuracy (10 percentage points), and the contribution of noise filtering was also limited (8 ppm), but their combined effect did allow considerable improvement of accuracy. Analysis of the input channels suggested that the most important variables were (calibrated) reflectance, echo width, NDSM height and the seasonality products (differences between leaf-off and leaf-on data).

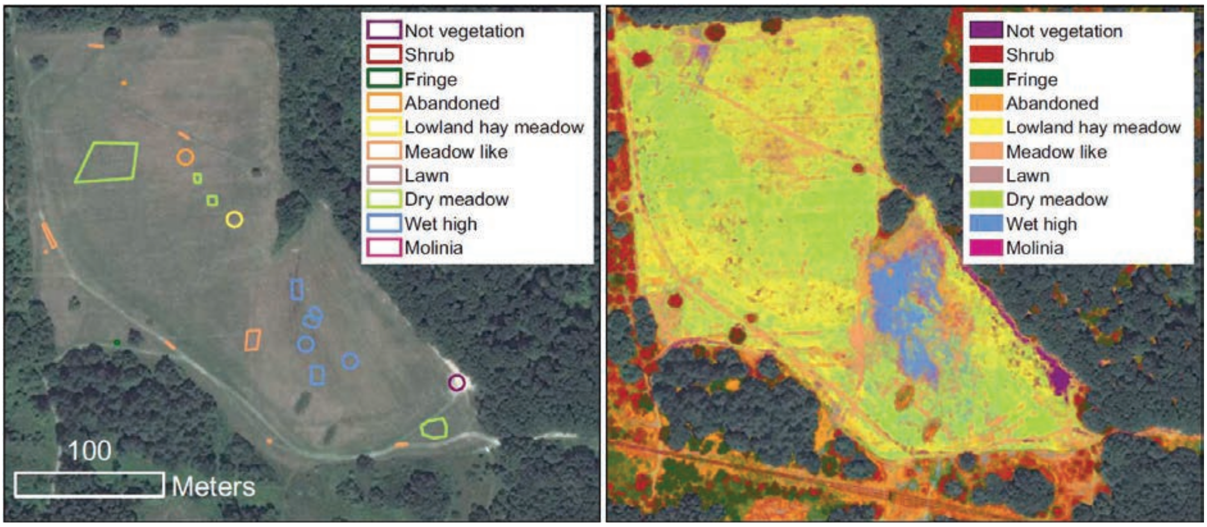

Figure 1: True colour aerial photo of a studied meadow with overlain ground truth polygons; LIDAR-based fuzzy classification of grassland categories.

4. Discussion

LIDAR-based classification of grassland vegetation was tested on a dataset with high resolution and information content, but flown with sub-optimal timing. Ground reference data collection did not include full releveés of vegetation plots, but was based on a pre-developed classification scheme with the purpose of recognizing Natura 2000 habitat types.

On one hand, the accuracy of the classification results reflects the problem of defining and identifying categories in a grassland (a problem also affecting field mapping), on the other hand they are comparable with the repeatability of field surveying itself. The information content of the point cloud was enhanced by using calibrated echo amplitude and full waveform attributes, and the large number of independent output variables was successfully handled by the machine learning algorithm. The resulting vegetation maps have a resolution of 0.5 meters, which together with the wide coverage achieved by the airborne campaign means they provide an unprecedented level of detail and pattern. The fuzzy class-membership renderings even reflect the smooth transitions between classes and the complex fine-scale mosaic structure which is so typical for a grassland, therefore we anticipate that they will be of substantial use for local conservation and monitoring. Based on these results, we believe that LIDAR has a strong potential for mapping grasslands.

Acknowledgements

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Using of MODIS NDVI Time Series for Grassland Habitat Classification and Assessment

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1. Introduction

Satellite images with high spatial resolution are widely used for habitat assessment and surveillance. Their low temporal resolution however, limits their ability for regular monitoring of habitats in adequate time span. Recently, after the launch of the Terra and Aqua satellites with the MODIS (Moderate Resolution Imaging Spectroradiometer) on board, new approaches started to be more frequently used for habitat classification and monitoring. One of the most widespread approaches use time series analysis of vegetation indices (e.g. NDVI – Normalized Difference Vegetation Index) that reflects the temporal profile of vegetation greenness on the land surface.

Semi-natural grasslands in agricultural landscape bear high biodiversity values and there is still lack of precise information on their spatial extent and status at pan European scale. One of the main criteria for good status of the semi-natural grasslands is their extensive usage, e.g. regular cutting and/or grazing. In order to get such information, detection of site management is needed for longer periods (e.g. 10 years) in order to reveal trends for possible abandonment or intensification.

Because of gradual availability of time series products from sensors such as MODIS and under a great expectation of upcoming Sentinel3 mission, we analyzed here suitability of MODIS NDVI time series at 250m spatial resolution for classification and assessment of grassland habitats in Slovak heterogeneous landscape. Particularly, we focused on detection of cutting practices, overgrowing, flooding, overgrazing, which are all considered as important determinants of grassland habitat quality.

1.1 NDVI time series for grassland classification and assessment

Grasslands with similar physiognomy may have different temporal pattern of NDVI affected by a broad range of natural or human driven factors. Multitemporal analysis of NDVI time series iteratively explores the main determinants of seasonality and uses this information for the subsequent classification of grasslands to determine their vegetation type, status and functioning. Grassland classification may include both full coverage classification of grassland areas or exploration and classification of main grassland types based on sampled areas. For example Aragon and Oesterheld (2008) used a combined approach using information of spatial arrangement (from single date HR Landsat TM image) and information on functional properties (NDVI dynamics derived from multitemporal MODIS 250m NDVI series) to map grassland vegetation communities in Argentinean flooded Pampa grasslands. The authors successfully classified 5 grassland vegetation types with an overall accuracy of 76% and documented that grassland vegetation communities significantly differ in their seasonal and interseasonal pattern of NDVI. Hill et al. (1999) classified a pastoral landscape in eastern Australia resulted into 8 broad categories: sown perennial pastures, sown perennial pastures with woodland, sown annual pastures, mixed pasture and cropping, native pastures, native pastures with woodland, degraded or revegetated areas and forest. Paruelo et al. (2001) used NDVI dynamics as a descriptor of ecosystem functioning and widely applied this approach for mapping and classifying ecosystem functional types. They used three measures calculated from the seasonal curve of NDVI: annual integral of NDVI as an estimate of primary production, relative annual range of NDVI and date of maximum NDVI both of which were used to capture the seasonality of primary production

In this context we explored different approaches (including data pre-processing, classification strategies, training and validation data sets) in order to assessed the added value of multitemporal analysis of MODIS 250m NDVI time series for the assessment of grasslands in heterogeneous landscape in Slovakia.

2. Data and processing

Two grassland datasets were used for the analyses (Table 1).

Table 1. Data sets used for this case study.

		Grassland types	NDVI data	Temporal coverage	Source
1	Slovakia	All grasslands on agricultural land (excluding alpine meadows)	16 day; 8 day	2003-2012	National dataset
2	Hungarian lowlands	N2000 grasslands	8 day	2003-2012	EEA

We used homogenous grassland sites derived from Slovak national land parcel information system (LPIS) that were visually inspected on Google Earth in order to omit heterogeneous MODIS pixels. Totally 3758 pure pixels were included in this dataset. Natura 2000 grassland sites across the Hungarian lowlands were extracted from EEA dataset. Only those Natura 2000 sites that contained more than 80 % of grassland habitats were included in data set. Finally, 2800 pixels were randomly selected for the analysis.

We used MOD13Q1 (16 day NDVI with 250 m spatial resolution) and combined MOD13Q1 and MYD13Q1 (8 day NDVI with 250 m spatial resolution) products downloaded from LP DAAC distribution centre for the area covered by Modis tile grid h19v4. Usefulness index and quality assurance layers of the products were utilized in order to minimize negative effects of clouds, cloud shadows, aerosols, sun-sensor geometries and snow. Missing data were interpolated and smoothed using Savitsky – Golay filter within the TimeSat software in order to get complete NDVI time series from 2003 to 2012. As the first step we used PCA of the 2009 annual series (16 days and 8 days time span) in order to explored main season-driven variability in grasslands. The extracted components were later used to produce a broad classification of grasslands based on their seasonality. Finally, we explored several specific multitemporal indexes (e.g. variability in peak season, spring negative anomaly, etc.) to test the potential for detecting specific characteristics of grassland status (e.g. cut management, flooding regime, etc).

3. Results and conclusion

The PCA of 16 day 2009 NDVI time series of Slovak grasslands (data set 1) extracted 5 components with a total explained variance of 91 % (Figure 1). This demonstrates that the seasonal NDVI pattern of grasslands varies substantially. Factor loadings show that it is mainly the different timing of peak season, cutting and different greenness in spring and autumn what determines seasonal variability in Slovak grasslands.

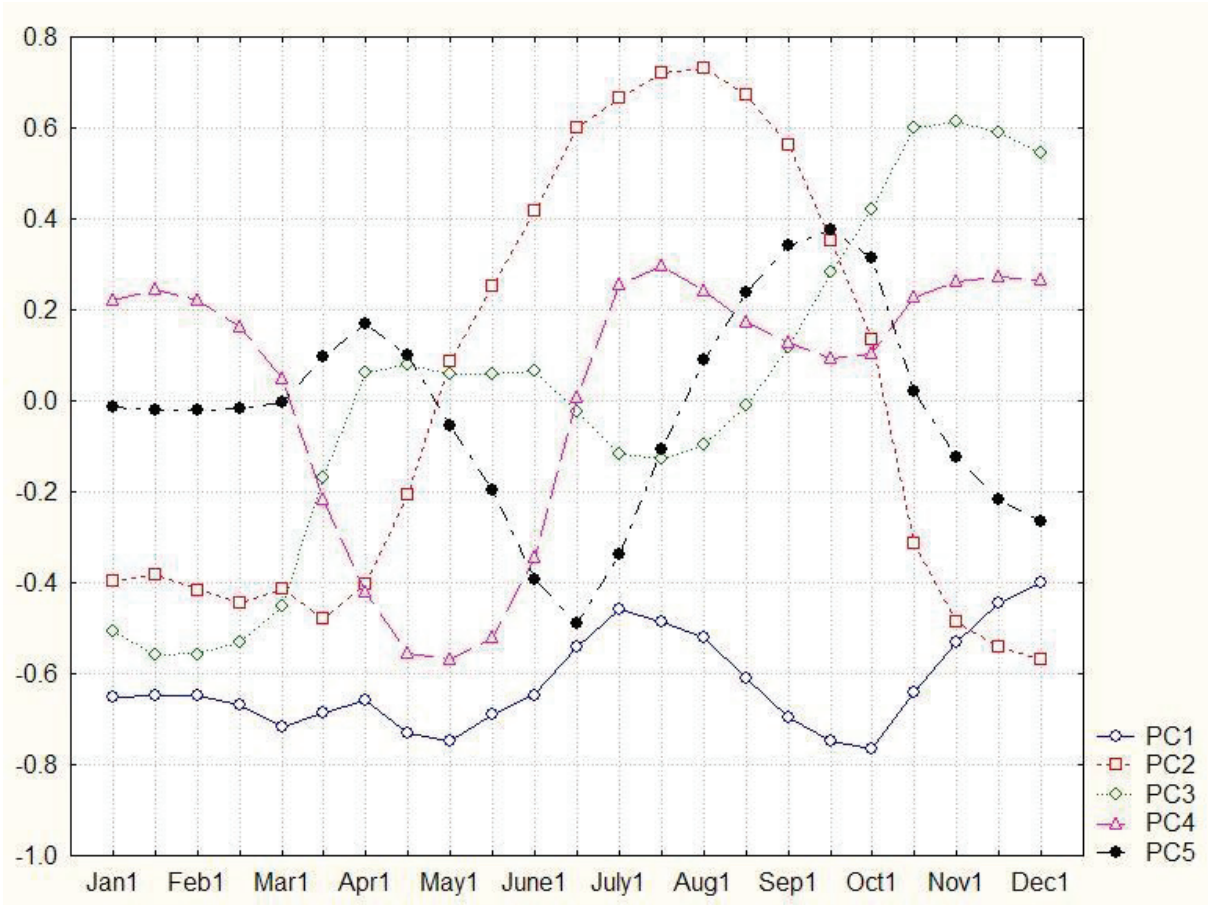

Figure 1: Factor loadings resulted from PCA of 16 day 2009 NDVI composite of Slovak grasslands.

Classification of these 5 components using k-means clustering resulted in 5 main types of grasslands with specific temporal profile of NDVI (Figure 2). It is visible that mainly productivity (blue and purple clusters), different management (red and black clusters) described main differences in managed grasslands. A special case represents green cluster that can be attributed to mountainous grasslands typical with shorter vegetation season and delayed vegetation peak.

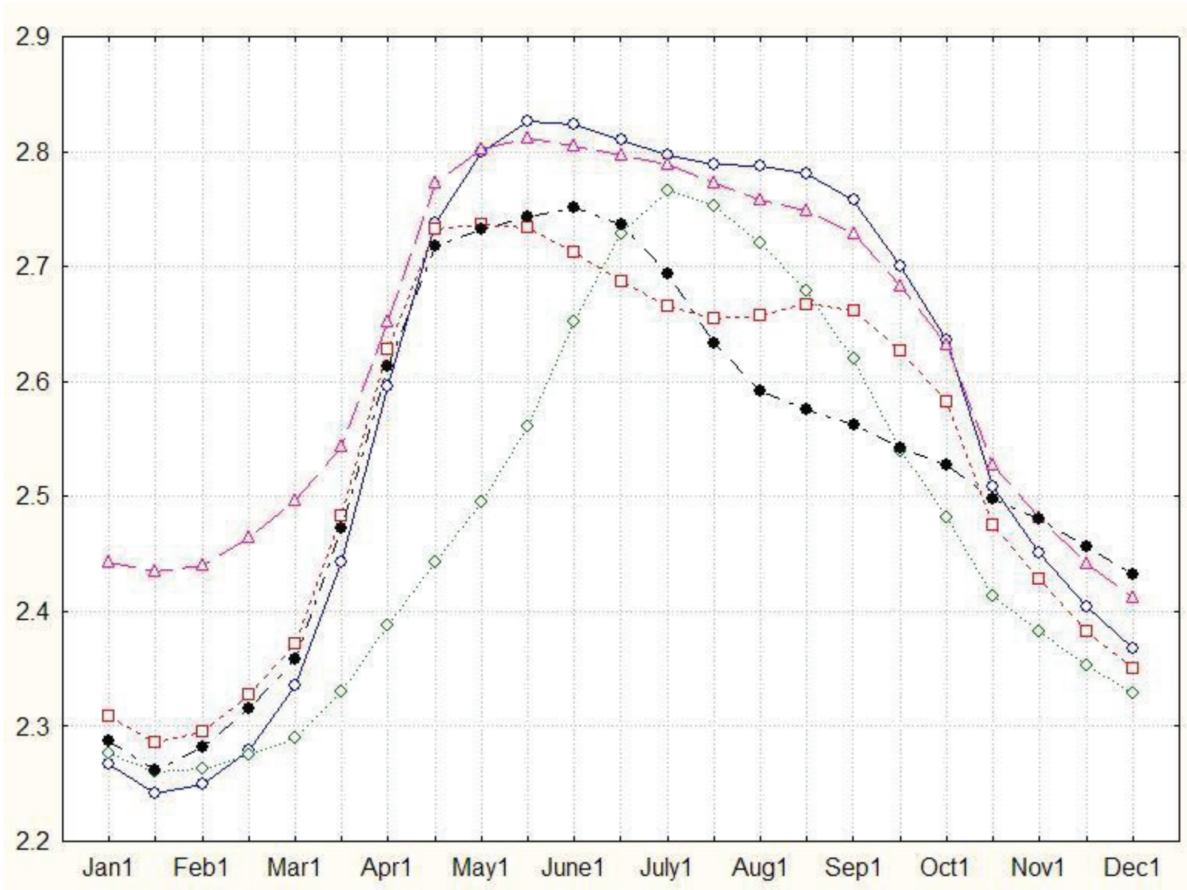

Figure 2: Average temporal profile of NDVI of resulted clusters (16 day NDVI composite of 2009) (original scale of NDVI -1/+1 rescaled to 1/3).

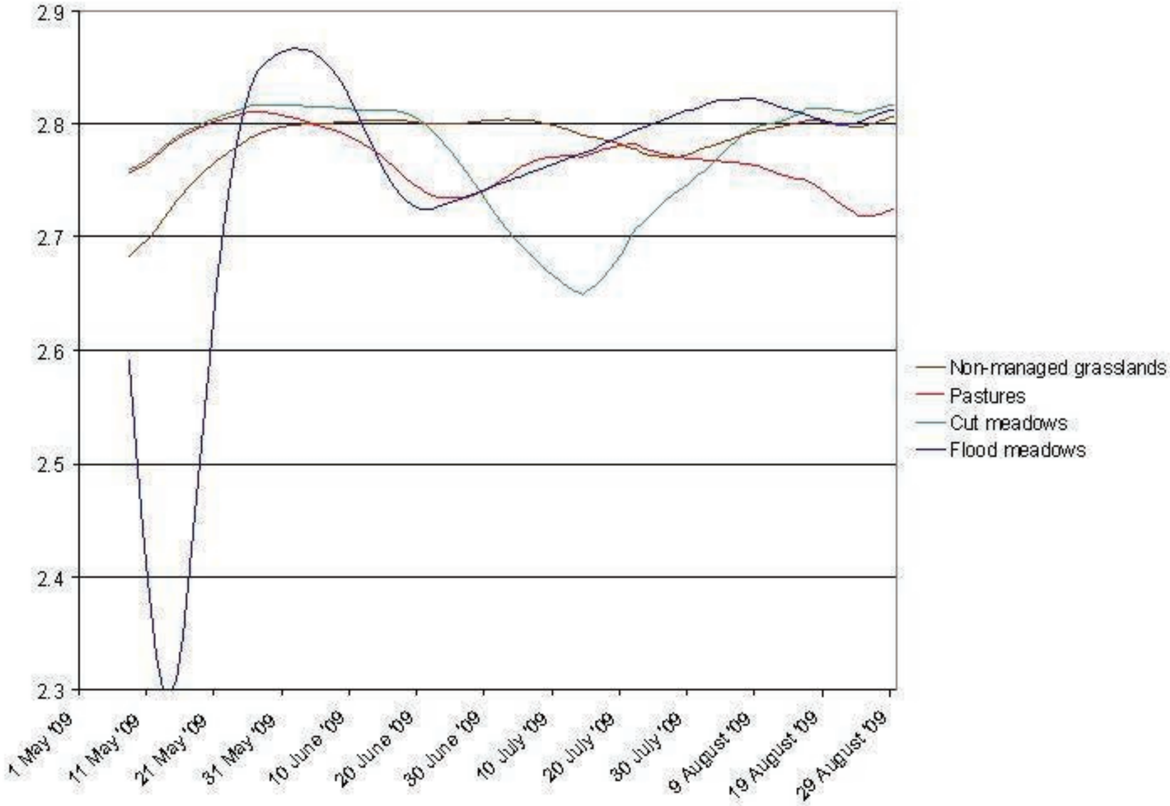

Figure 3: Classification of grasslands using 8 day NDVI composite of vegetation growth period in 2009 (original scale of NDVI -1/+1 rescaled to 1/3)

When we used the same approach with increased temporal resolution (8 day) of NDVI composite data within vegetation growth period (May-September) we obtained slightly different results (Figure 3) with better distinction of flooded grasslands, pastures and cut grasslands. The same approach and data were used for assessment of Hungarian grasslands in N2000 areas (Figure 4). These grassland types exhibit distinct seasonal variability that was later reflected in the following classification: wetland and salt marshes, cut meadows, pastures and non-managed natural grasslands.

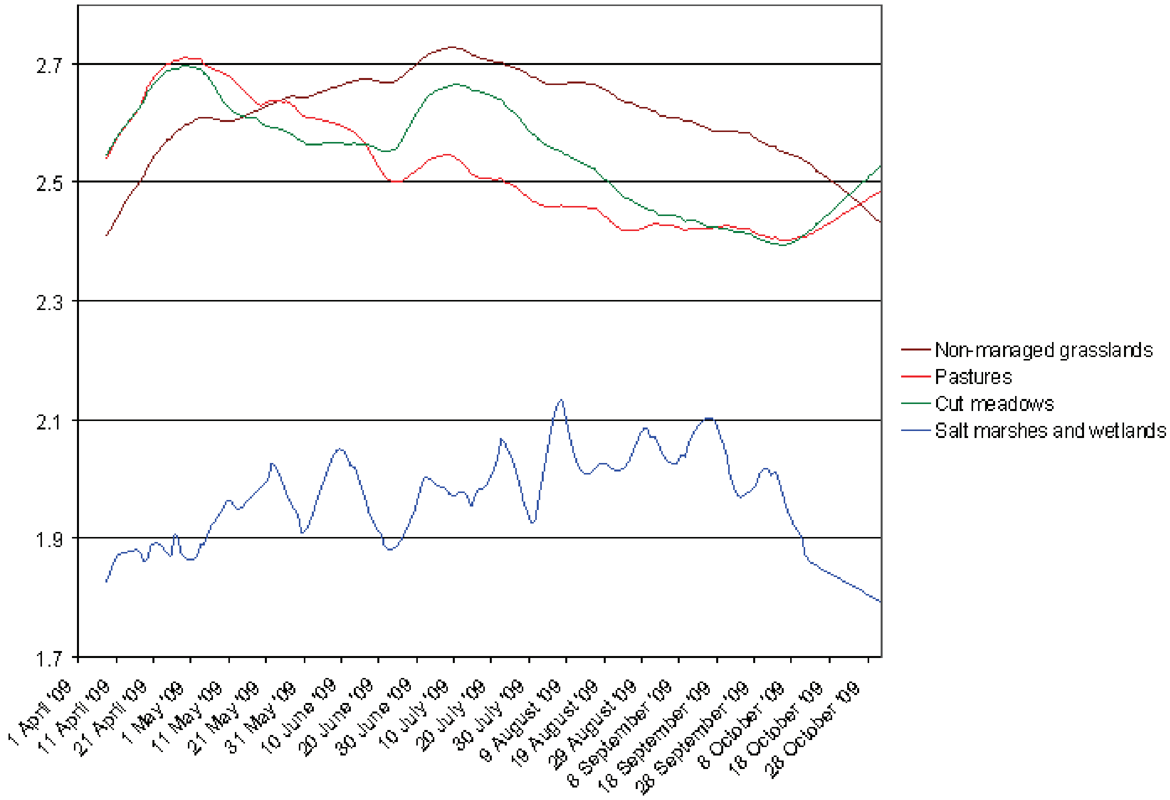

Figure 4: Classification of Hungarian grasslands in Natura 2000 areas using 8 day NDVI composite of vegetation growth period in 2009 (original scale of NDVI -1/+1 rescaled to 1/3).

Grassland seasonal pattern of NDVI varied substantially and reflects not only different vegetation type but also land use, management practices or site hydrology. To conclude, indicators of grassland habitat status can be relatively successfully identified in cases when they represent relatively large compact homogenous areas of similar grassland types or when a regional adaptive approach benefits from a-priori knowledge of the distinct seasonality of the respective grassland habitat type. We demonstrated that when some knowledge on grassland occurrence exists (e.g. from EEA), classification based on temporal NDVI profile brings valuable information on grassland habitat status. In general, productivity (which relate to amplitude of NDVI curve) and seasonality (variance within season) represent main distinctive characteristics of grasslands. Especially, timing of NDVI peak, rate of increase of NDVI in spring, bimodal shape of NDVI, or negative anomaly in spring can be used for distinguishing of extensive meadows, pastures, flooded meadows and abandon overgrown grasslands. However, more regional specific knowledge from grassland experts needs to be used in order to derive consistent algorithms for broader scale habitat assessment and classification.

Acknowledgements

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Monitoring the distribution and dynamics of an alien invasive grass in tropical savanna habitats with airborne LiDAR

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Abstract

Savannas cover 20% of the global terrestrial land surface and account for 30% of global primary production (GPP). Fire is an integral component of savanna ecology and dynamics, particularly in tropical savannas which typically burn every 1-3 years. Fire can markedly alter the structure and biomass of savanna vegetation, so understanding fire dynamics is critical for managing carbon storage and conserving biodiversity in these habitats. Global changes in land-use and climate threaten many of the ecosystem services that savannas provide, and in Northern Australia the spread of an alien invasive grass (Gamba grass - Andropogon gayanus) is presenting an additional ecological challenge. Natural fires in tropical savannas seldom kill tall and established trees, since native grass fuel-loads (and therefore char height and burn intensity) are low. Gamba grass however can reach heights of 4 m tall, and therefore has the capacity to dramatically alter fire effects in the region by increasing fuel-loads by a factor of 10. Gamba grass fires burn much more intensely and transport flames in to the canopy of tall tress, leading to higher rates of mortality and increased greenhouse gas emissions. To fully understand and better manage the spread and consequences of Gamba grass invasion, we need spatially explicit knowledge of where Gamba grass occurs and how fast it is spreading. However the savanna region of Northern Australia is the largest and most intact savanna system in the world, covering 2 million square kilometers, so mapping the extent of habitat invaded by Gamba is challenging.

We used full-waveform airborne LiDAR to map areas of known Gamba grass invasion in the Batchelor region of the Northern Territory, Australia. Our stratified sampling campaign included wooded savanna areas with differing degrees of Gamba invasion and adjacent areas of native grass and woody tree mixtures. The tall and uniform structure of Gamba grass made it readily identifiable in the high-resolution LiDAR points clouds that we collected. We used height and variance based metrics to classify returns from Gamba grass and developed spatial representations (0.5 m resolution) of Gamba grass, native grass, woody cover, and bare ground distribution. Our mapping results provide a robust benchmark for evaluating the rate and pattern of Gamba grass spread from future LiDAR campaigns. In addition, we are using our spatial representations of Gamba distribution to inform satellite image analysis for the evaluation of Gamba grass invasion over the regional scale. Our work to date on this challenge shows huge potential for airborne LiDAR to facilitate the monitoring and management of savanna habitat condition.

The NEWFOR single tree detection benchmark – A test of LIDAR based detection methods using a unique dataset of different forest types within the alpine space.

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1. Introduction

The habitat forest fulfils many ecological and economical functions. Different habitats and species are hosted by the forest which can be related to an ecological function. From an economic point of view forest represents a sustainable key resource which is believed to be climate neutral. To collect information about forested areas to i.e. identify processes within this habitat terrestrial forest inventories (FI) can be performed. In the forestry community FI are a standard to obtain information about forest stands and trees. In most cases these FI are driven by economical aspects and act as an input for forest management tasks. From an ecological point of view FI are mainly carried out to identify natural processes. This is relevant to i.e. identify habitat quality or detect changes. In general the economical interests for these activities are little until now.

Large area tasks as for example harvesting planning or obtaining information for large forest stands are already operational in forest management. The use of remote sensing data and related methods for large area applications has become a standard. This trend can also be seen in the domains of habitat conservation and landscape ecology. In a recent project called Change Habitats 2 (ChangeHabitats2, 2012) the automatically extraction of habitat parameters and landscape metrics from remote sensing data was investigated. Terrestrial FI are still obligatory and probably will never be fully replaceable by automatically methods. Merging information obtained from remote sensing data with FI data could help to reduce the costs of a time consuming inventory. Additionally the spatially limited information of the FI could be linked to larger areas.

The identification of single trees and their parameters is an important task for analysing large forested areas with respect to habitat quality description. Parameters as for example stems per hectare, spatial distribution of trees, tree heights and stem diameters or information about tree crowns as for example a total crown length are of interest. In case of a terrestrial FI these parameters are obtained from measurements based on the single tree level. To obtain such detailed information from remotely sensed airborne data many studies on single tree detection were carried out from the research community resulting in many different algorithms / methods developed in different countries or institutions.

The research project NEWFOR (NEWFOR, 2012) brings together fourteen institutions from six countries within the alpine space working in the field of forestry and remote sensing. The project aims at enhancing the wood supply chain within the alpine space to improve forest timber evaluation and mobilization using new remote sensing technologies. One objective of the project is to test already established as well as new methods that are capable to extract single tree information based on remote sensing data. To test methods established at the project partners and partners outside the consortium a single tree detection benchmark based on airborne laser scanning (ALS) data was initiated. To the authors best knowledge this is the first benchmark ever being performed for different forests within the alpine space. Based on a unique dataset covering different study areas, forest types and structures from different regions in the alpine space the different methods were tested and analysed in a clear and reproducible way.

2. Material and methods

In total 21 study areas in five countries in the alpine space are available in the NEWFOR project (Figure 1). For each study area ALS data and a digital terrain model (DTM) were provided to the benchmark participants. Additionally reference data from FI measurements were available but not handed over to the participants. Only fully calipered FI plots were used.

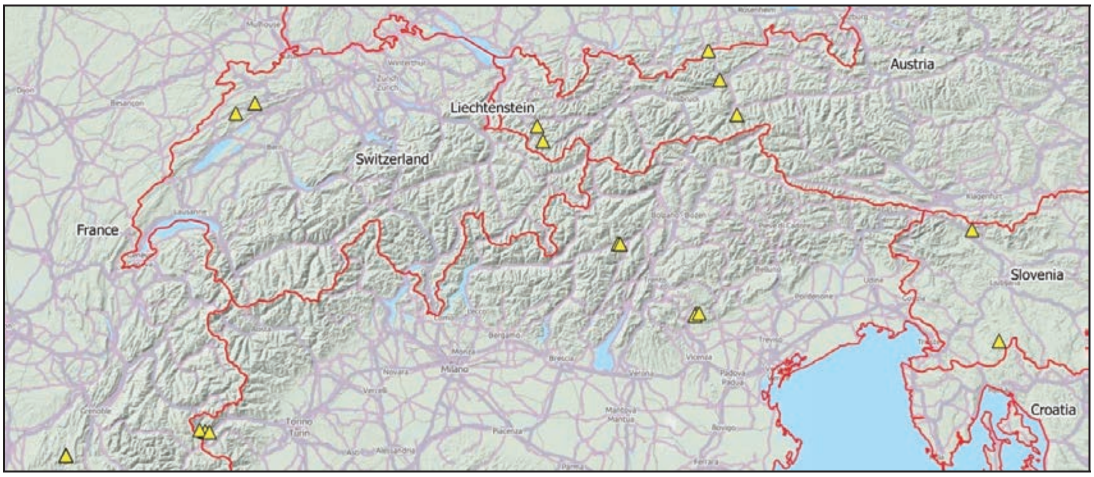

Figure 1: Study areas used for the single tree detection benchmark

Based on these data the participants had to automatically extract single tree information using their algorithm. The minimum requirements for the Benchmark were the detection of tree position and tree height as well as a description of the used algorithm / workflow. The optional requirements for the Benchmark were the extraction of the volume per stem and the extraction of the diameter at breast height.

A fully automated matching procedure between Test trees (partner results) and Reference trees (FI trees) was established for this benchmark (Figure 2).

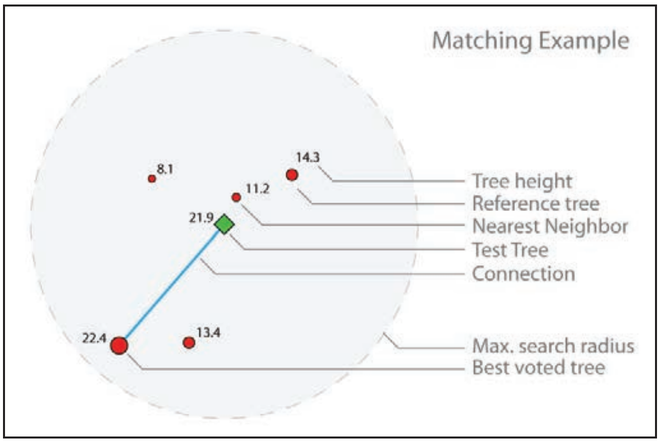

Figure 2: Example for matching trees with the best vote

Only trees inside an Area of Interest were considered for the check to overcome possible detection limitations at the borders of the input ALS data. Starting from the highest Test tree the restricted nearest neighboring Reference trees within a defined neighbourhood were detected. Restricted nearest neighboring means, that there are height criterions and neighborhood criterions which need to be fulfilled to match / assign two trees. Trees with the best neighbourhood and height vote were matched / assigned. This means that not always the nearest neighbouring trees were connected.

3. Results and Discussion

The results of seven institutions were submitted and analyzed within this benchmark. In total 18 study areas of the reference dataset could be used for the matching procedure. Three study areas could not be used because of missing or incorrect data in the forest inventory data. The detection results of each partner were automatically matched against the reference data. The procedure worked for all submitted results.

A visual inspection of the matching results shows a good agreement (Figure 3). The height and neighborhood criterions helped to connect the correct tree pairs in most cases. Especially the height criterion ensured that tall trees are not connected to nearby small trees.

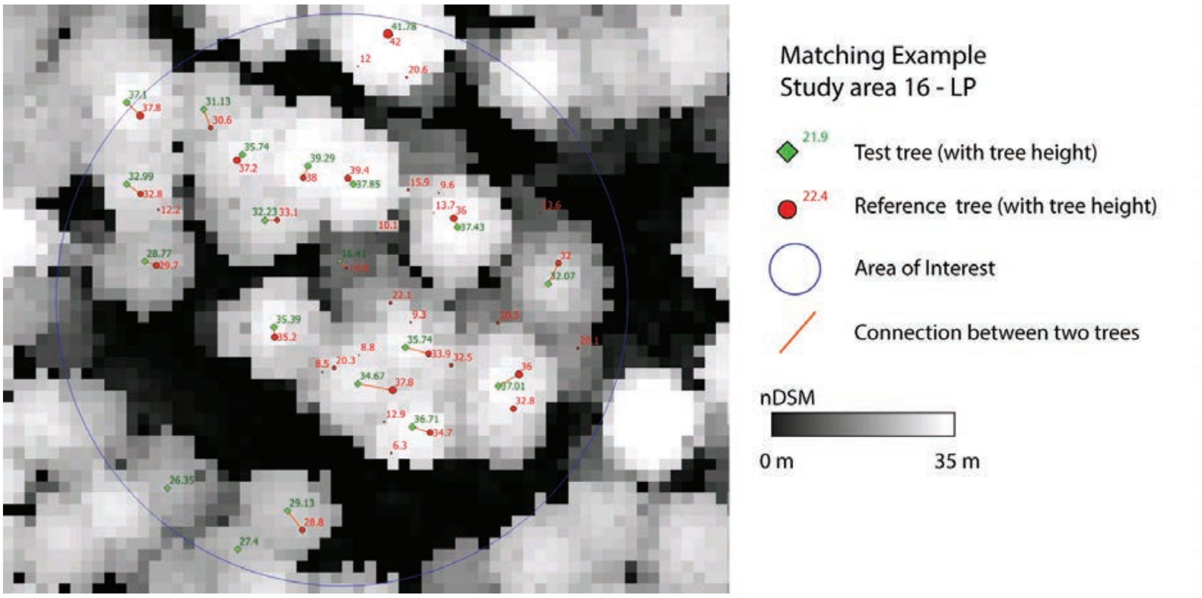

Figure 3: Matching result of participant “LP” for study area 16. The data is displayed as overlay of a normalized surface model (nDSM). The nDSM displays local heights.

A quantitative inspection of the matching results was performed to be able to investigate the results in more detail. For all results the rates of totally extracted trees as well as the rates of correctly assigned trees were derived and visualized. Also the vertical and horizontal accuracies of the matched trees were derived (Figure 4). Additionally a deeper analysis of the results was performed to link the performance of methods, forest structures and type of algorithms.

The goal of this benchmark was to show the potential of existing methods related to tree detection and extraction of different parameters. It could be shown that forest inventory data can be automatically linked to remotely sensed data. The single tree detection results from the benchmark participants are promising in terms of supporting habitat quality description by providing automatically derived forest parameters.

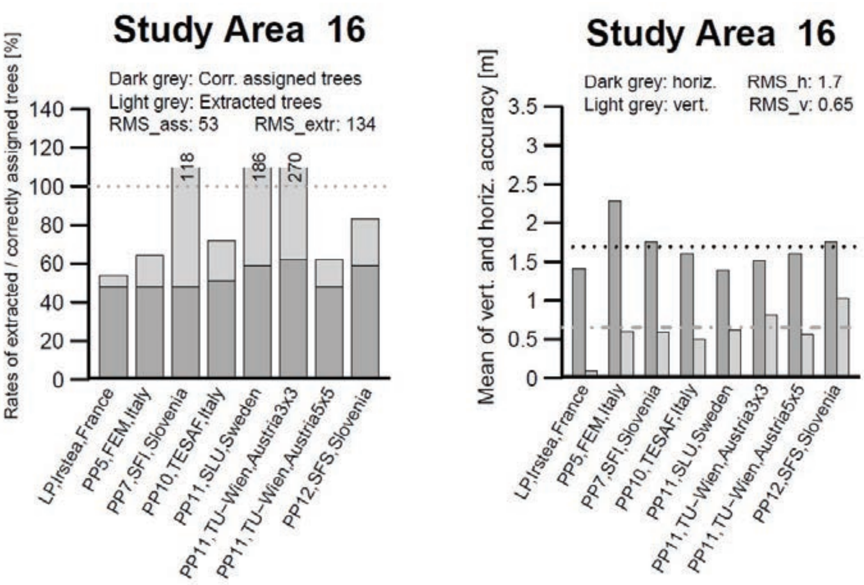

Figure 4: Matching results of all participants for study area 16. The left barplot shows the rates of totally extracted trees in light gray color and the rates of correctly matched trees in dark grey color. The right barplot shows the horizontal and vertical accuracy of the matched trees in dark grey color and light grey color respectively.

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Mapping old natural forest habitat using airborne laser scanning

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1. Introduction

Forest management changes structures and affects biodiversity in forest habitats. While old-growth boreal forests display high within-stand variation in age and size of trees as well as large amounts and diversity of dead wood and old trees, managed boreal forests display a more homogeneous tree composition, age structure and vertical stratification. Several species groups are negatively affected by forest management in Europe and the effect increases with intensity (Paillet et al. 2010).

In Norway, the forest harvest regime changed drastically after World War II, from selection felling to clear felling. Today only a small proportion of natural forests, here defined as forests only affected by extensive selective logging in the past, remains. It is therefore important to establish efficient methods for identifying, delineating and monitoring the remaining areas of old natural forests.

During the last two decades, methods for mapping forests with airborne laser scanning (ALS) have developed. Today, ALS is a standard tool for providing stand level forest inventories over large areas in Scandinavia and also in many other countries around the world. The high spatial detail, the potentially large area coverage and the increasing availability of such data make them an attractive source for mapping and monitoring of forest habitats. Furthermore, the height measurements by ALS provide forest structural information which has been found useful for classifying successional stages of forests (Falkowski et al. 2009). The aim of the current study was to evaluate the potential of ALS data to capture structural differences between old natural forests and old managed forests that can be used to separate these two types of old forests.

2. Materials

The study area is a 17000 ha forested area in south-eastern Norway. We combined current digital forest maps with scanned and georeferenced historical forest maps from 1954. We considered only forest stands currently categorized as old production forest, and separated these into two classes: Stands specified as old forest also in 1954, denoted “old natural forest”, and stands that were clear-cut during the 1950ies, denoted “old managed forest”. In total 667 stands were subjectively selected based on the map data.

ALS data were acquired during August and September of 2007 using a Leica ALS 50-II laser scanner. The laser scanner was mounted on a helicopter flying approximately 600 m above ground level. The scanner was operated with a pulse repetition frequency of 127.5 kHz, a scan angle of ± 36° and was flown with a side overlap of 60%, resulting in a pulse density of approximately 10 m^{-2}.

3. Methods

From the selected digitized stands, we analyzed all ALS echoes inside a circular plot of 0.2 ha in size placed in the interior of the stand. Stands that were not large enough to completely contain this circular plot were excluded from the trial. Thus, 384 plots were used in this study of which 91 were located in old natural forests.

First, we did an explorative analysis of the differences in the distributions of all laser echoes between the two classes. Second, the ability to classify the two classes was investigated. From all ALS echoes above 1.3 m, standard metrics frequently used in operational stand level forest inventories were computed (Næsset 2004). From these metrics a balanced random forest algorithm (Breiman 2001; Chen et al. 2004) was used to classify old natural forest. The random forest algorithm is a popular classification algorithm both for remote sensing data and in ecology (Cutler et al. 2007; Gislason et al. 2006). In addition, a logistic regression model representing a more standard approach was used for the separation of the two classes. For variable selection a standard stepwise technique using the Bayesian information criterion was applied for the logistic model. The classification accuracy of both classifiers was evaluated using leave-one-out cross validation.

4. Results and discussion

The main difference between the two classes is that the old natural forest has a higher density in the lower vertical layers and a lower density higher in the canopy, as can be seen from Figure 1. This indicates that the old managed forests are denser, higher and with less shrub layer vegetation. The strong signal from the lower parts in the old natural forest could also be attributed to a lower crown base height in this type of habitat.

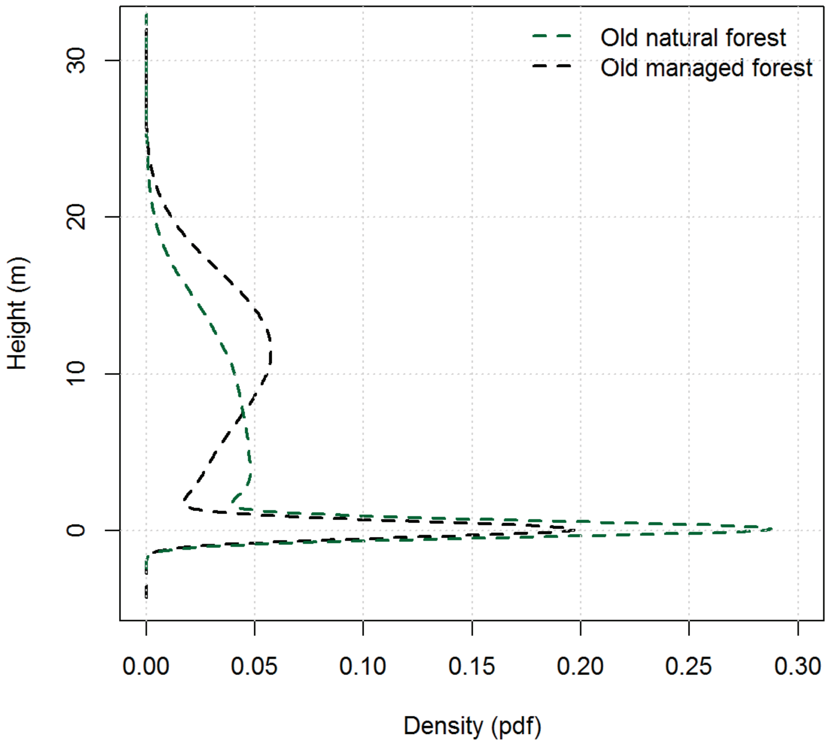

Figure 1: Estimated probability density function of laser echo height for old natural forest and old managed forest for all 384 plots.

The accuracy obtained by the two classifiers appears in Table 1 and Table 2. The overall accuracy was 86-88%, which must be considered as high. The class accuracies were lower for old natural forest than for old managed forest in both cases. The reason why the false positives are higher and the false negatives lower when using random forest were mainly due to the use of a correction for the unbalance in number of observations in the classes in the random forest classification, but not in the logistic classification.

Table 1. Error matrix of the random forest classification of old natural forest and old managed forest.

Classification	Old managed forest	Old natural forest	Sum	User's accuracy
Old managed forest	255	19	270	94.4
Old natural forest	38	76	114	66.7
Sum	293	91	384	
Produser's accuracy	87.0	83.5		
Overall accuracy				86.2
Cohen's kappa				0.65

Table 2. Error matrix of the logistic regression classification of old natural forest and old managed forest.

Classification	Old managed forest	Old natural forest	Sum	User's accuracy
Old managed forest	274	26	300	91.3
Old natural forest	19	65	77.4	77.4
Sum	293	91	384	
Produser's accuracy	93.5	71.4		
Overall accuracy				88.3
Cohen's kappa				0.67

In this study only one size of the observation units was used (0.2 ha). When dealing with classification of forests based on structure, the spatial scale will influence the results and additional scales should be analysed. Also, quantifying spatial heterogeneity horizontally might provide additional and relevant information complementing the information from the vertical stratification. This could improve the classification. Furthermore, for large-scale mapping and monitoring of old natural forest habitat it is important to develop methods to capture reference data also in areas where historical stand records are missing.

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Mapping of Grass Species Using Airborne Hyperspectral Data

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1. Introduction

Vegetation mapping in such complex landscapes requires a huge amount of fieldwork, thus there is an increasing interest to test alternative methods for mapping these areas. Remote sensing techniques, such as application of hyperspectral data can be a promising tool to map the vegetation of these landscapes. In recent years, many studies explored using hyperspectral imagery for vegetation mapping (Boyd and Foody, 2011).

Pannonian alkali grasslands and marshes are high priority habitats for the European nature conservation and are included in the Natura 2000 system as Pannonic salt steppes and marshes. The vegetation types of alkali landscapes are dominated by a few monocot species (grasses, sedges, bulrushes or rushes), differing in traits such as biomass, physiology, canopy cover and phenology. Hyperspectral imaging is a remote sensing technique which is feasible to detect differences in these differences. Our goal was to classify alkali vegetation types based on the differences of their dominant monocot species in Pentezug using hyperspectral data. For the management and conservation of alkali landscapes, it is crucial to have reliable/up-to-date/high resolution vegetation maps of extended areas. This paper investigates whether the combination of airborne hyperspectral imagery and image classification methods using feature extraction can discriminate among species of grass.

2. Methods

2.1 Study area

The study area (~ 23 km^2) is located in the eastern part of Hungary, National Park of Hortobágy, Pentezug. Alkali landscapes are characterized by a mosaic of various vegetation types, including open alkali vegetation, shortgrass steppes, tallgrass meadows, sedge meadows, marshes and alkali reeds. During acquisition, vegetation types that can be found on the study area were located using a DGPS device.

2.2 Data collection

Hyperspectral images were acquired by a push-broom type AISA Eagle sensor over 126 bands with a spectral resolution of 4.6 nm. The sensor was mounted to Piper Aztec aircraft.

2.3 Image processing

Classification of hyperspectral images is a very challenging procedure due to the small number of training areas and large number of spectral bands. Several advanced feature extraction techniques have been developed to reduce the dimensionality of the data (Plaza et al. 2009). In order to explore the information content of the hyperspectral data sets considered Minimum Noise Fraction (MNF) were calculated (Green et al. 1988). Jeffries-Matusita (JM) values were calculated based on training pixels to select the training pairs with good separability. Random Forest (RF), Maximum Likelihood (MLC), and Support Vector Machine (SVM) supervised classification method were applied for vegetation mapping. Feature extraction methods and image analysis were performed with the ENVI+IDL 5.0.

3. Results

The primary outcome of this study was a comparison of image classification methods and training area to evaluate vegetation types of alkali landscapes. The image classification was applied on the original and transformed (MNF) dataset. Random samples were generated for each class to produced five different training samples (10-20-40 and 50 pixels).

A binary tree Support Vector Machine (SVM) classifier was developed in accordance withthe principle of SVM, based on the Jeffries-Matusita (JM) separability measure of selected classes. In particular we analysed the behavior of the accuracy of different image classification methods. The adaptive binary tree SVM on MNF-transformed dataset provided more accurate results than applied RF, MLC and multiclass SVM methods. In this paper, an adaptive binary tree SVM classifier (ABTSVM) is proposed to increase the accuracy of vegetation map.

Acknowledgements

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Individual tree detection as input information for Natura 2000 habitat quality mapping

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1. Introduction

Woodlands and forests make up a substantial part of the ecosystem in Europe and are home to a wide range of species. Indicators suggested for monitoring of habitats include age structure and/or diameter distribution as well as tree species composition (MCPFE, 2007), which all benefit from a description of the forest at a sub-stand level.

Remote sensing is one option to acquire this information for large areas. Data from airborne laser scanning (ALS) are 3D coordinate measurements of light reflections from the ground and other objects. The analysis of the ALS data is often done by aggregating the data into raster cells, extracting features for each raster cell, and relating the features to the information of interest, for example forest variables. This can successfully be done to estimate for example mean tree height (Wulder *et al.*, 2012). However, dense ALS data contain detailed 3D information from which tree crowns may be identified. This has the potential to provide information about individual trees and their properties, for example their tree species (e.g., Holmgren & Persson, 2004).

In this study, individual trees are delineated from ALS data in a forest area in the landscape Uckermark in north-east Germany. Features of the delineated trees may be used for classification of coniferous/deciduous trees as well as habitat trees.

2. Material and methods

2.1 ALS data and processing

As a part of Natura 2000 mapping, ALS data were collected in spring 2011 (May 5th and 6th, leaf-on) and in early spring 2012 (March 22nd, leaf-off). The average point density was 21.8 echoes/m² for the leaf-on and 16.9 echoes/m² for the leaf-off flight. A digital terrain model (DTM) was derived from the data to calculate the height above the ground of each return.

2.2 Tree crown delineation

The delineation of the tree crowns was done by segmentation of a correlation surface model for trees in the topmost canopy layer followed by ellipsoidal tree model clustering of the ALS returns in 3D, both for trees corresponding to the segments from the surface model (i.e., in the topmost canopy layer) and for trees and larger shrubs below.

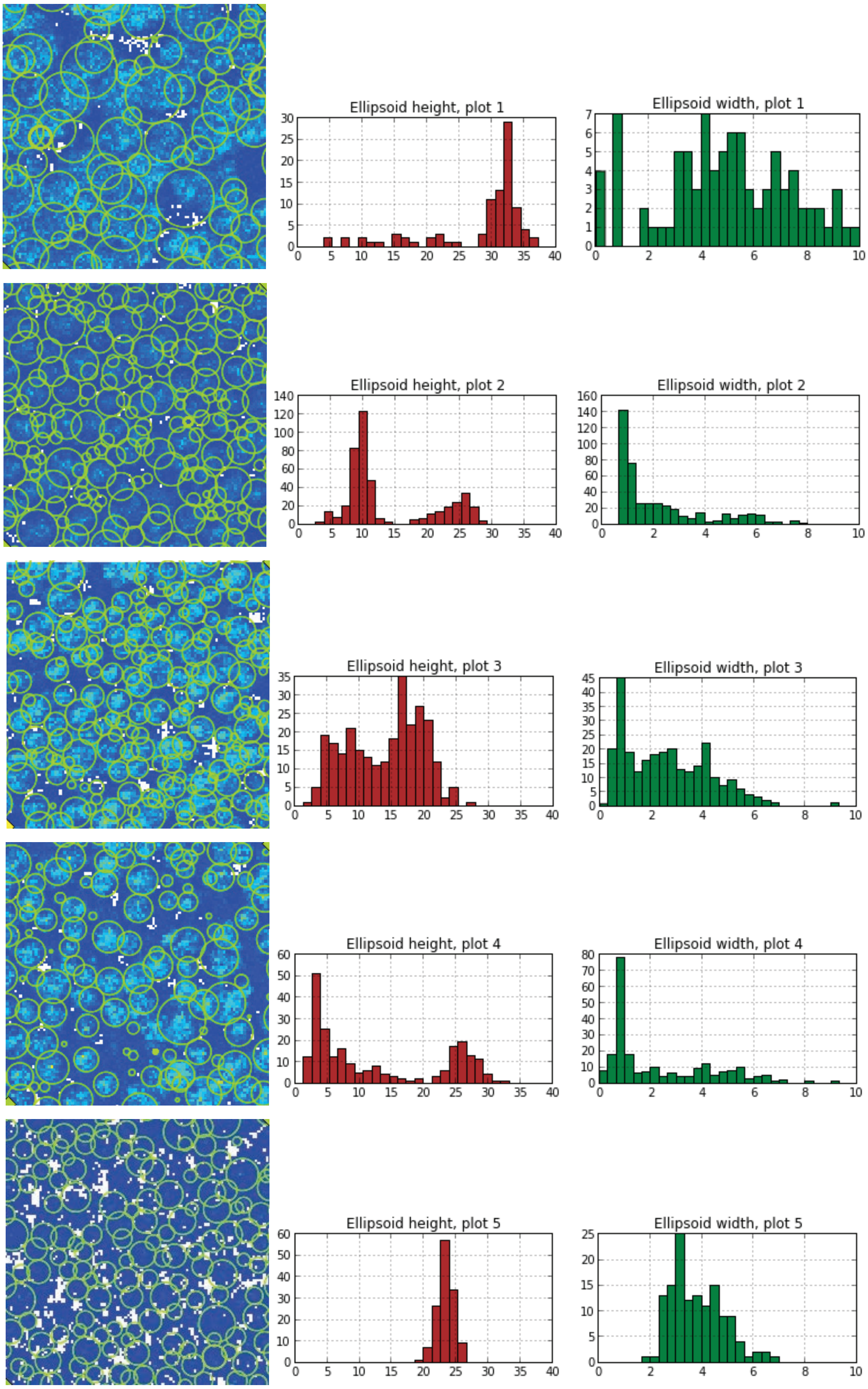

Figure 1: The GIS visualization of delineated tree crowns upon an ALS-derived raster background (point count), together with distributions of fitted ellipsoid heights and widths in [m] on corresponding plots.

The aim of the segmentation was to establish one segment for each tree crown in the topmost canopy layer from the laser returns. A surface model was derived from the laser returns and the surface model was delineated with watershed segmentation. The result was delineated segments containing the tree crowns and horizontal center points corresponding to tree tops.

The aim of the clustering was to establish one cluster for each tree crown in the topmost canopy layer and additionally one cluster for each tree crown and larger shrub below. The algorithm was based on k-means clustering using ellipsoidal tree crown models and utilizing information from the segmentation. Each cluster was described by its 3D center point and comprised the laser returns assigned to it. The idea was that the cluster center should represent the 3D midpoint of the living crown.

For each delineated tree crown, features were derived to describe the height and width of the tree crown, the height distribution (i.e., percentiles of the height above the ground of the returns), and the mean amplitude of the returns.

Figure 1 shows some visualizations of delineated tree crowns, overlaid upon a raster background calculated from the ALS data (point count). The plots were selected manually to represent some different types of forest, homogeneuous within plot. The histograms of ellipsoid heights and widths (corresponding to heights and widths of the identified trees) show interesting distributions of those attributes and a potential for further investigation to understand relevant habitat quality parameters.

3. Discussion and outlook

The features of the delineated tree crowns (i.e., height, width, statistics of the height distribution, and intensity) can be used to characterize tree species or groups of tree species (i.e., coniferous and deciduous trees). The different layers of trees can be mapped and described from the delineated tree crowns, providing information on the height/age/growth distribution. Habitat trees may also be identified assuming that the proportion or size of their tree crowns deviates from other trees. The degree of naturalness of a forest can be assessed by searching for repetitive patterns of trees that are typically associated with artificial plantations. Absence of repetitive patterns indicates a higher degree of naturalness.

Since these properties are difficult to derive without knowledge of the individual trees, the delineation can contribute new information for habitat mapping and monitoring. Habitats can be characterized and new possibilities to detect unknown habitats may be opened.

Acknowledgements

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Vegetation Mapping in Tisza-lake Using Airborne Hyperspectral and LiDAR Data

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1. Introduction

Tisza-lake, the second largest lake in Hungary, is situated between Kisköre and Tiszalök and its total surface is 127 sq kilometres. Therefore it significantly influences the water-regime of the Tiszántúl Region and the Hungarian Great Plain. It is an artificial reservoir that was set up for economic purposes (water supply, flood protection, energy development and tourism), even though a unique and valuable habitat network has formed there.

Tisza-lake belongs to Hortobágy National Park, thus it is also Ramsar site. It is part of the Natural Ecological Network and the Natura 2000 Network (Birds Directive Site and Habitat Directive Site). The two third of the whole reservoir is protected from 2008.

There is a numerous variety of plant communities (forest, aquatic and marshland) developed on the area of the lake, from which wetland plant communities have occupied more and more parts of the reservoir. Since the proportion and the spatial pattern of each plant community continue to change year after year, it is difficult to show them. In many cases it is also difficult to assess plant communities (forest, aquatic and marshland) hence they cannot be evaluated by traditional field work.

Images derived from different remote sensing tools can offer an opportunity for solving this problem, and by targeting processing of them plant communities, vegetation types and individual plant species can be mapped. The remote sensing is often regarded as a useful technique for monitoring and mapping natural areas and habitats. Using airborne and spaceborn images based on (semi) automated spectral pattern recognition algorithms, changes can be detected in near real time (Stone 2010). The remote sensing technologies offer a great potential for monitoring large areas rapidly. Because of large volume of spectral information hyperspectral imagery is capable of separating plant species, which plays important role in mapping invasive plant species (Clark et al. 2005, Underwood et al. 2007).

There are a number of studies focusing on mapping vegetation from remote sensed images at species level (DiPietro et al. 2002, Kokaly et al. 2003, Underwood et al. 2003, Burai et al 2010).

Complementing hyperspectral images (with high spatial and spectral resolution) with elevation data from the Airborne Laser Scanning (ALS) the quantitative attributes can be mapped besides the qualitative ones, furthermore identification and distinction of individual plant species can become more reliable (Narumalani et al. 2009).

2. Study area and data

Our studies were made at a 15.6 sq kilometres study area between the Valki-basin and the Tiszafüred-basin at Tisza-lake (Figure 1). The LIDAR data were acquired using an Airborne Laser Scanner (RIEGL-Q680) with an average point density of 4 per m^2. During data acquisition multiple-returns were detected from the discret returns. The hyperspectral data were collected using an AISA Eagle II push-broom sensor covering the visible (VIS) and near infra-red (NIR) region from 400-1000 nm with a spectral resolution of 4.5 nm and a spatial resolution of 1m. The pre-processing of the hyperspectral data (atmospheric and geometric correction) was performed using CaligeoPro-software.

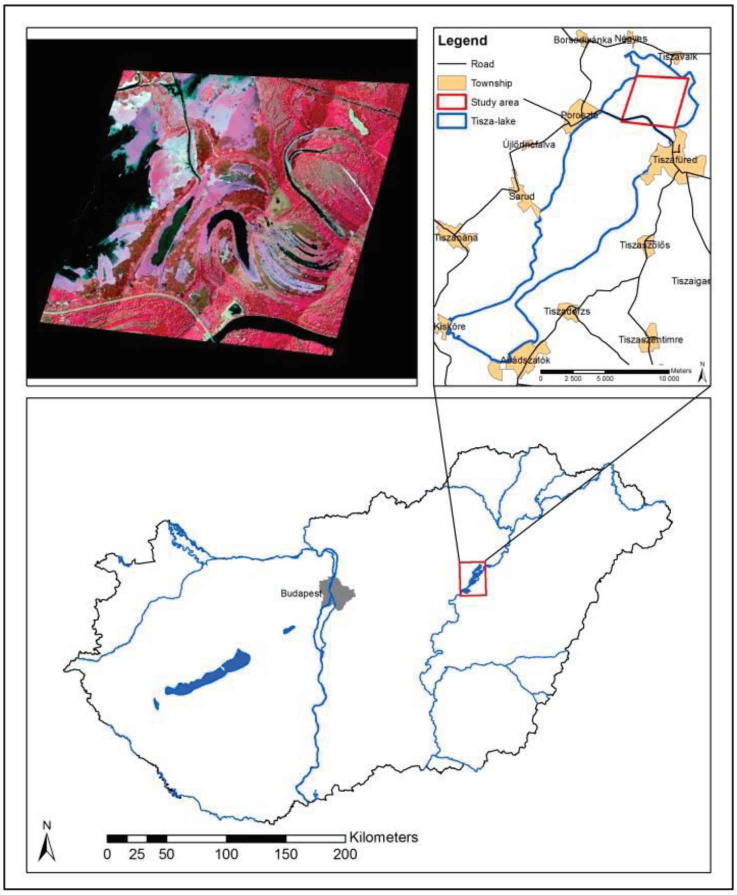

Figure 1: The study area of Tisza-lake

3. The aims of this work

The aim of this research was to elaborate a map showing the marshland and aquatic vegetation of the study area of Tisza-lake by using high-resolution remote sensing images and field datasets. The atmospherical corrected hyperspectral data was also radiometrically calibrated, and the open-water pixels were removed.

This study aimed to compare the pixel and Object Based Image Analysis (OBIA) classification methods, in addition to survey the potential of the joint classification of the hyperspectral data combined with ALS data for aquatic vegetation.

We applied a pixel-based supervised classification on the datasets. The training and the ground truth classes of the typical vegetation types were identified using a DGPS during the field survey. We perform the Spectral Angle Mapper (SAM) classification on the original hyperspectral images, extracted features using Minimum Noise Fraction (MNF). On the MNF bands the following classification methods were performed: Maximum Likelihood Classification (MLC), Support Vector Machine (SVM), and Random Forest (RF).

In our research the Normalized Differential Surface Model - nDSM from LiDAR datasets was taken into hierarchical image processing chain for the object-based (OBIA) classification. The calculated digital elevation model includes the elevation data of the field objects from the surface, which can provide the potential to distinguish and morphologically filter the vegetation types at different high level.

Besides these, an object-based (OBIA) classification was applied on the hyperspectral images, for which we used pre-defined spectral bands and transformated layers (e.g. narrow band NDVI). A hierarchical image processing chain was developed using raster based image classification and object-based (OBIA) classification method.

Finally we examined and compared the accuracy of the classification result derived different classification methods.

The integration of hyperspectral images and ALS data can improve the classification accuracy for individual plant species. Hyperspectral and ALS dataset can improve the effective mapping of specific vegetation types across a range of environments, such as floodplain, aquatic and marshland, in addition they are suitable for investigating and monitoring environmental elements.

Acknowledgements

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Reed Qualification Based on Airborne Laser Scanning

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1. Introduction

Reeds are very precious habitat areas, which can be found extensively in and around the Lake Fertő / Neusiedler. This area is the second largest continuous reed area in Europe. All the extensive reed area should be qualified in every 5 years, according to the Government Decree (No. 22/1998. (II.13.)). This decree also determines the applicable classes, and the necessity of a detailed map. Generally colour infrared orthophotos have been used with visual interpretation and detailed field surveys for this map. Visual interpretation is rather a subjective method, so supporting this qualification with some objective reed parameters are needed. Airborne Laser Scanning can play an important raw here.

2. Materials

2.1 Study Area

The Lake Fertő / Neusiedler is the most western situated saline lake in Europe. Its area is 310 km^2, which is shared amongst Austria and Hungary with the rate of 3:1, but the average water depth is half meter approximately, but never extends to two metres. The lake, and especially its Hungarian part has a very extensive reed area (50% and 85%). The Hungarian part of the lake (75.2 km^2) and its very extensive reed area (62.9 km^2) was in the focus of the current research.

2.2 Airborne Laser Scanning

The Airborne Laser Scanning (ALS) of the area was planned and executed in the frame of a Cross-border Cooperation Programme Austria - Hungary 2007-2013 called GENESEE. The approximately 92.6 km^2 large area over the lake was planned with minimum 4 pulses/m^2, and relative high, 70% overlaps between the stripes (see Figure 1).

The survey finally was executed on the 6th of December, 2011, applying a Riegl 560i full waveform sensor.

2.3 Reference data

The reed was qualified last time (according to the previously mentioned Decree) in 2007, based on a digital metric (UltraCamD) aerial survey with 30 cm GSD (Király and Márkus 2011).

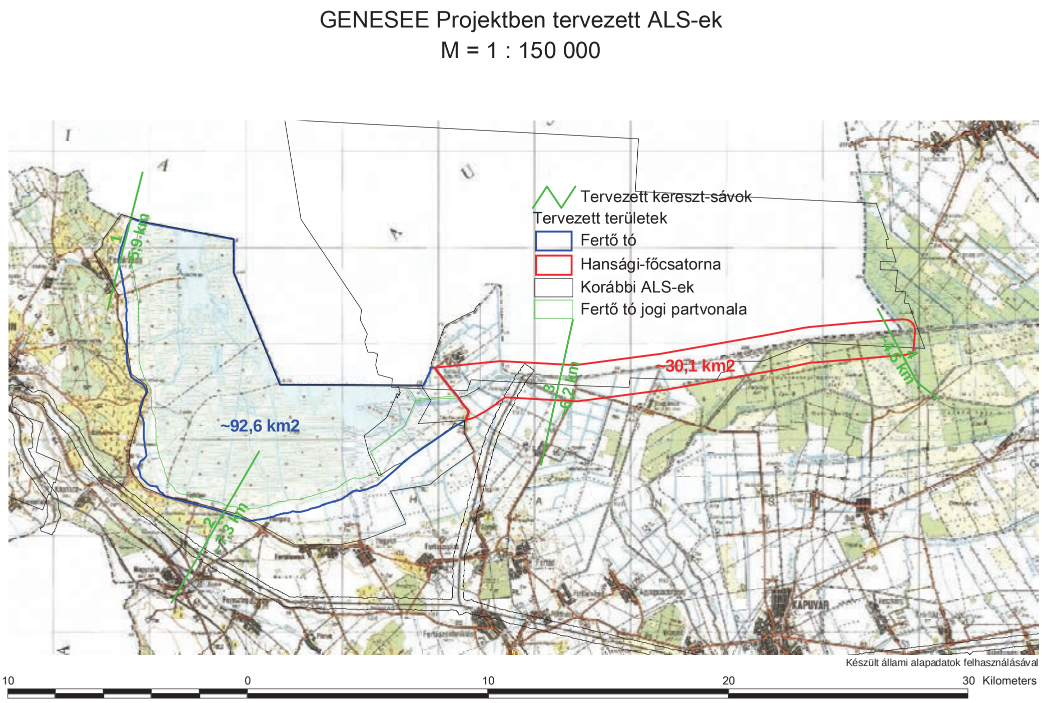

Figure 1: The planned area for the ALS surveys

3. Methods

3.1 Pre-processing

The provided dataset was pre-processed first, calculating the trajectories and point densities, filtering the outliers. The relative and absolute orientations of the strips were also checked using the advance technique in OPALS package (Mandlburger et al 2009).

3.2 Creating the models

The Digital Surface Model (DSM) was created first using a moving plane and also a moving parabola interpolations (Király et. al., 2012).

The creation of the Digital Terrain Model (DTM) was a real challenge in this very flat areas dominated by reed and water. An adaptive filtering technique has been applied finally to have a sufficiently detailed but also reliable subset of points from which the hierarchic robust filtering were applied (Kraus and Pfeifer, 2001).

The normalised Digital Surface Model (nDSM) has been created by subtracting the above two models (DSM-DTM), which is suitable for direct reed-height calculations.

3.3 Deriving reed parameters

The delineation of the reed and water-covered areas was a very crucial point during the data-processing. The vertical distributions of the points as well as the echo-ratio (Höfle et al, 2009) have been calculated for this separation. Additional reed parameters, such as density and stem diameters have been calculated directly from the raw point cloud.

4. Results

The delineation of the reed areas from water-covered areas was most accurate using the echo-ratio layer, with (at least theoretically) exact. The reed density showed a good correlation with the reed-classes, with a R^2=0.73. The stem diameter – which is not directly correlated with a certain reed-class – gave medium correlation with R^2=0.57. However both parameters showed much more spatial variablilities than the reference map.

Acknowledgements

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Quantitative Assessment of the Restoration Progress in the Shirvan National Park using Multi-Temporal Remote Sensing and GIS Analysis

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ABSTRACT

The main objectives of this research were to determine the vegetation peak season for the Shirvan National Park in Azerbaijan, to monitor vegetation cover restoration progress from 2000 till 2010 and to predict the erosion prone areas. The multi-temporal analysis of MODIS Normalized Vegetation Difference Indexes for 2010 year allowed to determine that the vegetation peak season was observed to be during May. The remote sensing analysis of Normalized Difference Vegetation Indexes derived from Landsat-5 (TM) multispectral images for the Shirvan National Park revealed that the areas of bare lands were decreasing during the period of 2000- 2010. 236 sq. km. of bare land in 2000 decreased to 142 sq. km in 2007, in 2009 to 103 sq. km. and in 2010 to 37 sq. km. This was considered as a positive spatiotemporal environmental trend related to a number of strategic improvement measures taken since the establishment of the Shirvan National Park in 2003. However, the largest spatial distribution of bare lands was observed around the Flamingo Lake in 2010 because of the high soil salinity level affecting to restoration progress of vegetation cover.

The predicted soil loss rates by the Universal Soil Loss Equation model without consideration of the vegetative cover factor allowed to determine that critical soil rates more than 10 ton/ha was 38.92 sq. km. whereas with the consideration of vegetative cover factor was 7.8 sq. km. This showed how critical the role of vegetation cover is for the soil protection in the Shirvan National Park.

KEYWORDS: NDVI, USLE, GIS, Remote Sensing, Landsat, MODIS

1. INTRODUCTION

The Shirvan National Park (SNP) was established in 2003 as the first National Park in Azerbaijan. SNP is situated in the coastal zone of the Caspian Sea within the Kura-Araz lowland and has a semi-desert and steppe ecosystems. The SNP was selected because of the national importance of the territory within the protected areas system of Azerbaijan. The particular value of the territory is a habitat for the goitered gazelle and migratory birds. The main goals in the establishment of the SNP were to protect the semi desert landscape, to protect of gazelles, to conduct ecological monitoring, to raise the ecological awareness, and to develop the tourism. SNP is supposed to be an optimal model of national park for other protected areas of Azerbaijan (Burmester 2005). Prior to its establishment and so far, SNP is negatively affected by a number of following anthropogenic impacts: soil salinization from irrigation collectors, overgrazing by domestic livestock, land occupation for agricultural activities etc. Starting from 2003, Azerbaijan Government prohibited the grazing and agricultural activities in SNP, installed water treatment systems, developed wetlands etc. This research provides the basis for the quantitative assessment of the achieved results focused on the improvement of vegetation and soil cover of SNP.

A number of researches were performed for SNP to study its environmental conditions. Schmidt (2005) conducted a research to classify the types of vegetation communities in SNP. Burmester (2005) studied the socio - economic situation and land use conflicts in SNP. BfN (2009) applied the landscape planning principles for the determination of the areas for conservation and development in SNP. FHOOW (2007) developed the report for the future development of the technical infrastructure in SNP. None of these researches had the goals in the determination of the spatiotemporal changes of vegetation cover in SNP for the quantitative monitoring of the environmental changes focused on vegetation cover.

A variety of vegetation cover, land-use and landcover monitoring and change detection principles have been applied and evaluated using GIS and Remote Sensing over the last twenty years (Rogan *et al.* 2002; Woodcock *et al.* 2004; Healey *et al*. 2005). The review of Coppin *et al.* (2004) observed extensive application issues of change detection in management of protected areas. Understanding of the vegetation and soil cover change magnitude and patterns contributes to the establishment of the strategic development plan of the national parks and other protected areas. The main focus of the present research is the monitoring of the vegetation cover changes in the period of 2000-2010 based on the detected vegetation cover growth season and prediction of potential erosion prone areas using GIS and Remote Sensing.

Many investigations have been performed to develop the erosion prediction methodology. Hudson (1995) and Morgan (1995) investigated different approaches. In simple terms, erosion is a function of the interaction between rainfall, soil, slope and land cover but it is obvious that interaction is a highly complex process so that erosion rates vary greatly in spatiotemporal aspects. That's why none of the methods has proved particularly successful when the measured and predicted values were compared. Selection of the appropriate method requires the consideration of the criteria as following: simplicity in the use of the erosion prediction model, data availability and acceptable accuracy. Based on the consideration of these criteria, the Universal Soil Loss Equation (USLE) erosion prediction model developed by Wischmeier & Smith (1978) was considered as an appropriate method combining acceptable accuracy with relative simplicity and the ability to use quite basic data. Although developed initially for agricultural land in the USA east, it has been widely used in many countries of the World (Morgan 2005; Gray & Leiser 1982; Gray & Sotir 1996). It should be stressed that the USLE erosion prediction model predicts only erosion from fieldsized areas on hillslopes by interrill and rill erosion. It does not predict gully erosion, subsurface processes or mass soil failure. USLE erosion prediction method is an empirical model for the estimation of potential soil loss by water based on five factors: the rainfall erosivity, the soil erodibility, the topographic factor (slope length factor and slope steepness index), the vegetative cover and the soil conservation (Wischmeier & Smith 1978). GIS significantly contributed to the optimization of USLE erosion prediction model and has been widely applied so far for the quantitative estimation of soil loss with the spatial visualization of erosion prone areas (Fu *et al.* 2006). Remote Sensing methods in combination with the in-situ measurements significantly contributed to development of the necessary variables for the USLE erosion prediction model and simplification of analysis based on the geographic visualization of soil loss patterns (Ongsomwang *et al.* 2009).

Detailed research objectives are following:
1. Determination of the vegetation cover peak season over SNP using NDVI derived from MODIS 16-day composite NDVI time series data acquired monthly during 2010. The main contribution of this research objective is the selection of the suitable Landsat-5 (TM) images for the monitoring of vegetation cover restoration progress in SNP.
2. Monitoring and assessment of the vegetation cover status in 2000, 2007, 2009 and 2010. The main contribution of this research objective is to determine the vegetation cover restoration progress in SNP based on the NDVIs derived from multi-temporal Landsat-5 (TM) images.
3. Prediction of the erosion prone areas of SNP using the USLE erosion prediction model. The main contribution of this research objective is to predict the areas prone to erosion processes in the quantitative soil loss rates within SNP.

Research questions are following:
1. What is the vegetation cover peak season in SNP for the determination of the optimal archive Landsat-5 (TM) multispectral satellite images?
2. What are the spatiotemporal changes of NDVI as a result of environmental and anthropogenic factors in SNP?
3. Which areas of SNP are erosion prone in the predicted quantitative terms of soil loss?
4. How significant is the role of vegetation cover in the quantitative terms for the protection of soil cover against erosion processes?

2. STUDY AREA

Azerbaijan is located at the crossroads of Western Asia and Eastern Europe. Azerbaijan is bounded by the Caspian Sea to the east, Russia to the north, Georgia to the northwest, Armenia to the west, and Iran to the south. Azerbaijan lies between latitudes 38° and 42° N, and longitudes 44° and 51° E. The area of Azerbaijan is 86.6 thousand square kilometers with around 9.4 million people. Five physical features dominate Azerbaijan: the Caspian Sea with shoreline in the east, the Greater Caucasus mountain range in the north, Lesser Caucasus and Talish mountains in the south and the extensive Kura-Araz Lowland in the country's centre. The study area is located within Azerbaijan's Kura-Aras lowland at the coast of the Caspian Sea. SNP has the total area of 652 sq. km. and stretches from 39°50' N to 39°30' N and 49°03' E to 49°25' E. (Figure 1). From the western part, SNP is under high pressure of agricultural landuse (Figure 2(a)). The Shirvan collector is located in the north of SNP and Baku - Lenkoran motorway is in the west. SNP is located below the Baltic Sea level and elevation rises from the east to west (Figure 2(b)).

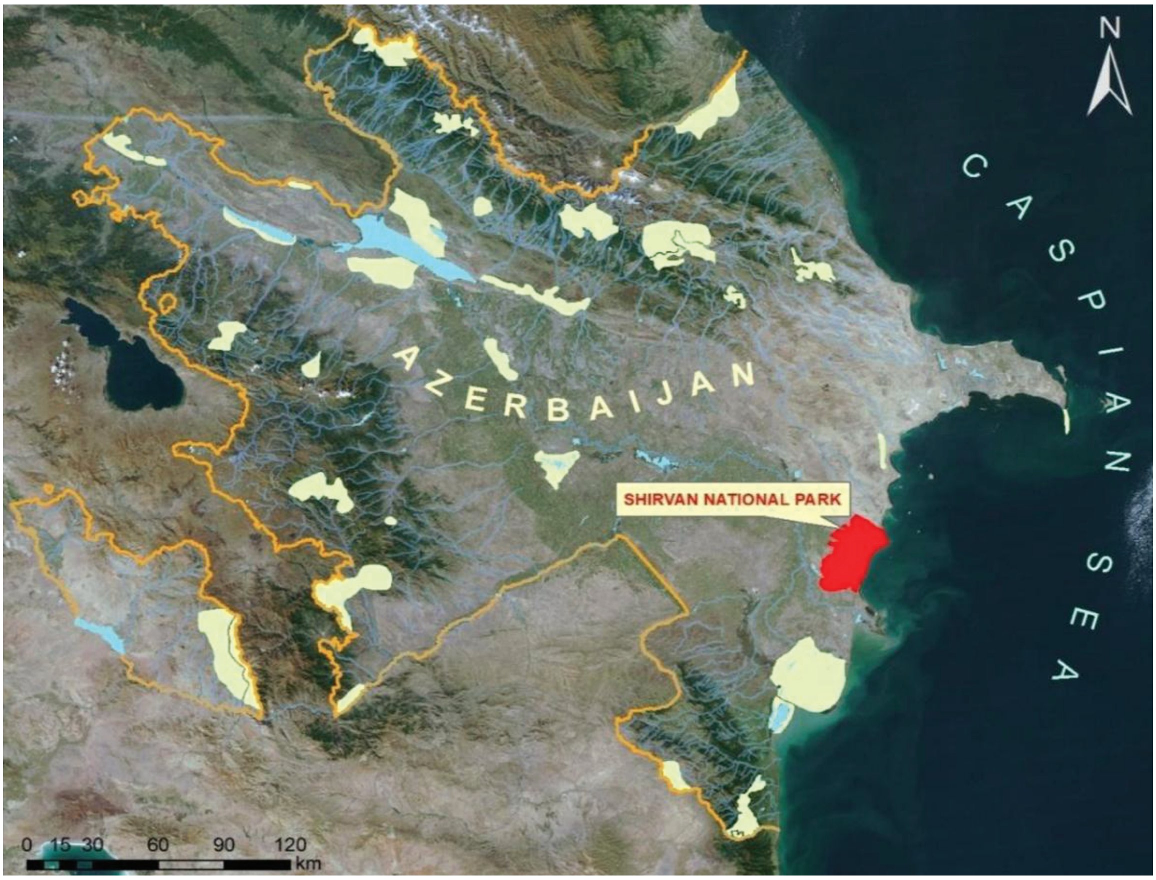

Fig. 1 General Map of Azerbaijan Country and SNP

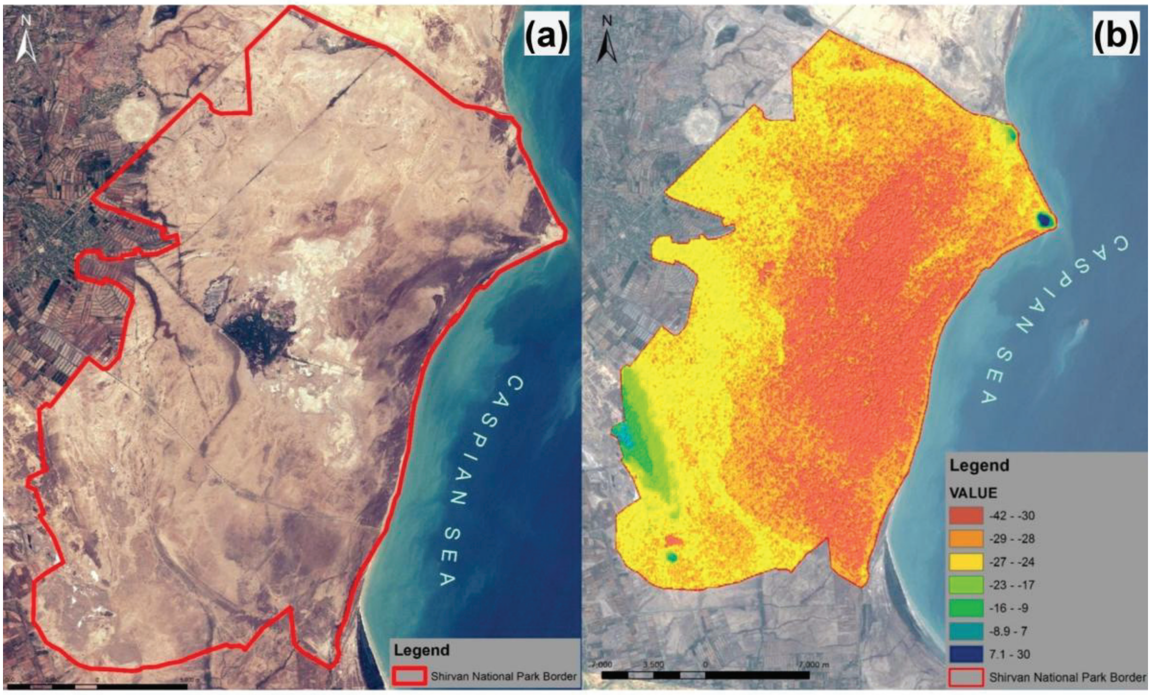

Fig. 2 (a) Detailed satellite image; (b) Relief of SNP

3. DATA PROCESSING

3.1 Determination of Vegetation Peak Season, Conversion of LANDSAT-5 (TM) DN to Top of Atmosphere (TOA) Reflectance and Development of NDVI in SNP

In the present research for the determination of vegetation growth season, MODIS 16-day composite NDVI time series data products with the spatial resolution of 250 m acquired for each month of 2010 were used. MODIS 16-day composite NDVI time series data products are provided by the Earth Resources Observation Systems (EROS) Data Centre (Zhang *et al.* 2009). This product was applied because of the spatiotemporal frequency and easy accessibility for the monitoring of vegetation cover change processes (Townshend *et al.* 1988; Verbesselt *et al.* 2010). Vegetation Index values for the mid of each month during 2010 were extracted for two positions in SNP from MODIS NDVI composite data. The MODIS NDVI was rescaled to 0-200 scale to avoid of negative values and simplify the use in GIS spatial analysis. The entire process allowed to determine the period of vegetation cover peak suitable for the selection of archive LANDSAT-5 (TM) satellite images (Figure 3).

For the environmental monitoring of vegetation cover temporal changes, LANDSAT-5 (TM) satellite images have been used within this present research. The Thematic Mapper sensor is seven-band multi spectral scanning radiometer. The LANDSAT-5 (TM) satellite images acquired in May 21, 2000, June 1, 2007, May 21, 2009 and May 24, 2010 were geometrically, radiometrically and terrain corrected (Level 1G). Geometric correction procedures removed image errors due to factors such as variation in altitude, attitude and velocity of the sensor platform, earth curvature, panoramic distortion, relief displacement and non-linearities in the sweep of a sensor (Lillesand and Kiefer 1994). The normalization procedure from DN data to TOA is crucial when analysis are performed using LANDSAT-5 (TM) multi-temporal satellite images as it largely removes variations between these images due to sensor differences. earth-sun distance and solar zenith angle (Bruce *et al.* 2004; Guyot *et al.* 1994). This is caused by different scene dates, overpass time and latitude differences. This conversion from DN to a TOA reflectance has been applied in many studies because it is the most important step in the computation of accurate NDVI from multitemporal Landsat-5 (TM) satellite images. The conversion of DN to reflectance was performed using the ENVI software. At the first stage, DNs of Landsat Satellite images were converted to radiance and at the second the radiances were converted to top of atmosphere (TOA) reflectance data (Figure 3). The first stage involves the conversion of measured DN to radiance using sensor calibration parameters supplied with the imagery. The conversion is performed using the following Equation 3.1.

$$L = Gain * DN + Bias \quad \text{[Eq. 3.1]}$$

where: L = spectral radiance measured over spectral bandwidth of a channel; DN = digital number value recorded; $Gain$ = (*Lmax* – *Lmin*) ⁄ 255; Bias = intercept of response function; *Lmax* = radiance measured at detector saturation in $mWcm^{-2}sr^{-1}$; *Lmin* = lowest radiance measured by detector in $mWcm^{-2}sr^{-1}$.

The second stage involves calculating top of atmosphere (TOA) reflectance for each band which corrects for illumination variations (sun angle and Earth-sun distance) within and between scenes. The conversion is performed using the following Equation 3.2.

$$\rho_{\lambda} = \frac{\pi d^2 L_{\lambda}}{E_{0\lambda} \cos\theta_s} \quad \text{[Eq. 3.2]}$$

where: p_{λ} = reflectance as a function of bandwidth; d = Earth-sun distance correction; L_{λ} = radiance as a function of bandwidth; $E_{0\lambda}$ = exoatmospheric irradiance; θ_s = solar zenith angle.

The conversion of DN to reflectance was performed using the ENVI software. The Equation 3.3 based on the fact that chlorophyll absorbs RED whereas the mesophyll leaf structure scatters NIR was used for the development of NDVI from LANDSAT-5 (TM) reflectance images (Rouse *et al.* 1974; Pettorelli *et al.* 2005; Fontana *et al.* 2008). The derived NDVI from Landsat-5 (TM) images was also rescaled to 0-200 scale to avoid of negative values and simplify the use in GIS spatial analysis.

$$NDVI = \frac{(nearIR - R)}{(nearIR + R)} \quad \text{[Eq. 3.3]}$$

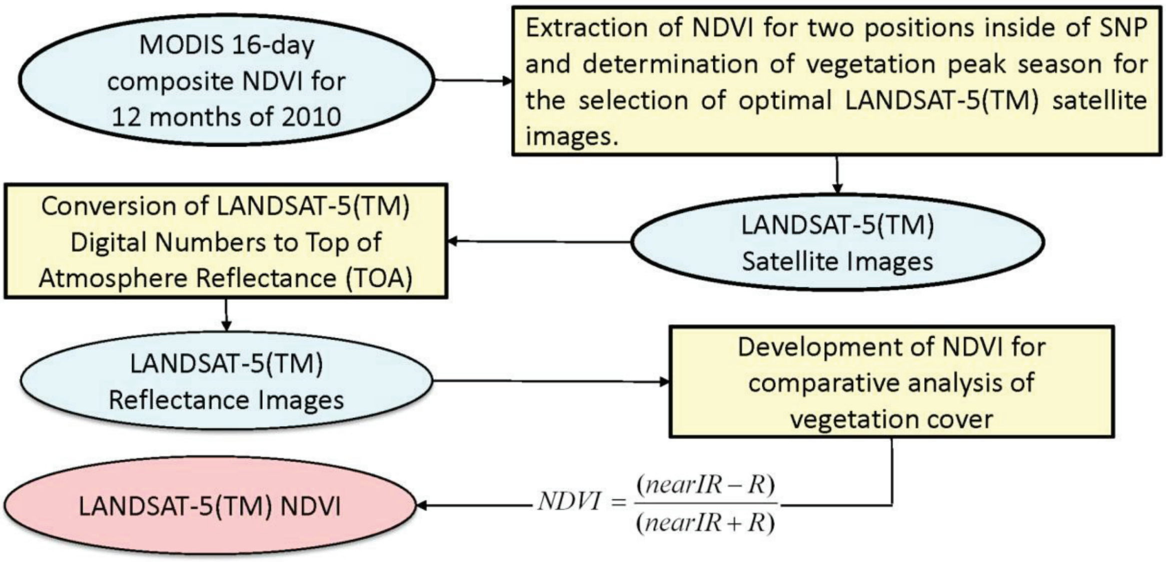

Fig. 3 The workflow for the determination of vegetation peak season, conversion of Landsat-5 (TM) images to reflectance images and development of NDVI

3.2 USLE for the Prediction of Erosion Prone Areas in SNP

Many attempts have been made to develop a methodology for predicting erosion rates. Different approaches are reviewed in Hudson (1995) and Morgan (1995). In simple terms, erosion is a function of the interaction between rainfall, soil, slope and land cover but the interaction is a highly complex process so that erosion rates vary greatly depending on the spatiotemporal conditions (Morgan 2005). None of methods has proved to be successful with the prediction reliability of 100% when the measured values were compared to predicted values (Morgan 1995). Therefore in practice erosion prediction models are mainly used for planning, verification and implementation of erosion-control measures at the potential erosion sites. They are useful tools for planners, politicians and other decision makers on how the environment should be managed based on the quantitative principle. Selection of the suitable erosion prediction method requires the consideration in how easy it is to use the erosion prediction model, to find the input geospatial variables and the accuracy that can be obtained. USLE (Wischmeier & Smith 1978) is considered as an appropriate erosion prediction model combining acceptable accuracy with relative simplicity and the ability to use quite basic data. Although developed initially for agricultural land in the USA east of the Rocky Mountains, it has been widely used in many countries of the World and has been extended for application to environmentally protected areas. It should be stressed that USLE predicts only erosion from field sized areas on hillslopes by interrill and rill erosion. It does not predict gully erosion, subsurface processes or mass soil failure. USLE was used for the present studies because of its simplicity and low requirements for input data and as one of the most widely-used model for effective conservation planning based on predictions of average annual soil erosion rates with the advantage to estimate soil loss over a wide range territories. USLE erosion prediction model quantitatively estimates soil erosion with the following empirical Equation 3.4. (Morgan *et al.* 2003; Wischmeier & Smith 1978; Hann *et al.* 2006):

$$A = R*K*LS*C*P \quad \text{[Eq. 3.4]}$$

where A = mean annual soil loss; R = rainfall erosivity factor; K = soil erodibility factor; LS = topographic factor; C = crop management factor; P = erosion-control practice factor.

Rainfall erosivity is the ability of the precipitation to cause erosion from the impact of raindrops and consequences of the runoff generated by precipitation (Wischmeier & Smith 1978).
The soil erodibility factor (*K)* is a quantitative value that is experimentally determined based on the soil texture and structure parameters (Reusing *et al.* 2000). The soil erodibility factor (K) describes the vulnerability of the soil to detachment and transport caused by raindrops and runoff.
The vegetative cover factor (*C)* is described as the effect of plant or vegetation cover on erosion. It is well known that vegetation cover is a protective layer preventing the direct contact of the erosive agents with the soil.
Among the factors affecting soil erosion, soil loss is also very sensitive to topographical factor (LS) (Renard *et al.* 1997). Flow direction, flow accumulation and slope are computed using Digital Elevation Model (DEM) of 5m spatial resolution. DEM was developed using 1:25000 topographic maps through the extraction of spot heights and contour lines. The workflow of the USLE erosion prediction model is presented in Figure 4. The methods including the equations and input data for the computations of foregoing USLE factors are presented in Table 1.

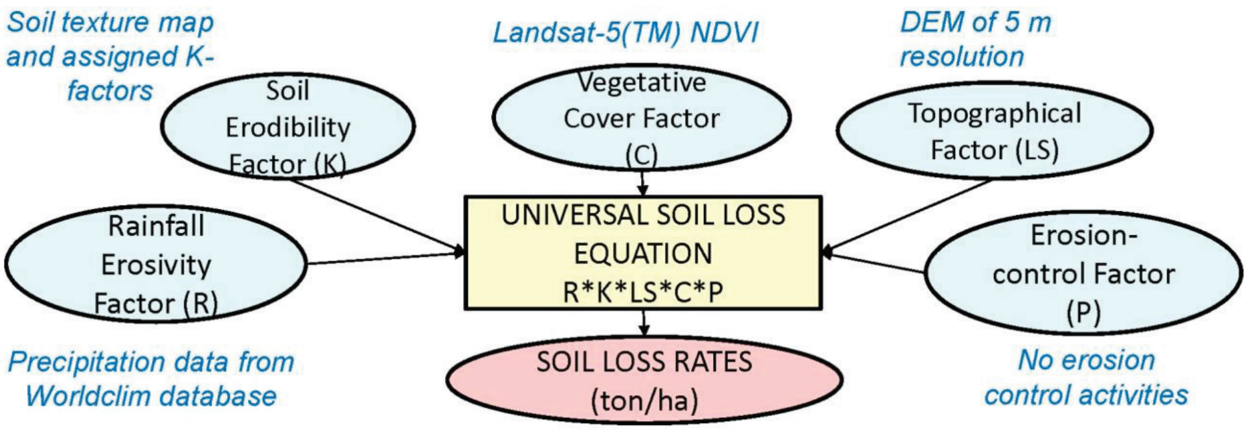

Fig. 4 The workflow for the USLE erosion prediction model

Table 1 USLE factors, equations and input data

USLE Factors	Equations	Input Data
Rainfall Erosivity (R)	$R = P_{eros}(0.119 + 0.0873\log_{10} I) * I_{30}$	Input Data: Rainfall (Worldclim Database) and recommended Rainfall intensity value by Hudson (1995) and (Wischmeier & Smith 1978)
Vegetative cover factor (C)	$C = \exp\left(-\alpha \frac{NDVI}{\beta - NDVI}\right)$	Landsat-5(TM) NDVI for 2010
Topographic Factor (LS)	$LS = \left(\frac{FlowAccumulation * CellSize}{22.13}\right)^{0.6} * \left(\frac{\sin Slope * 0.01745}{0.09}\right)^{1.3}$	DEM from 1:25000 topographic maps with spatial resolution of 5 meter
Soil Erodibility (K)	No equation	The recommended soil erodibility factor (K) recommended by Morgan (2005) assigned to the map of soil texture types developed by Schmidt (2005)
Erosion-control Practice Factor (P)	No equation	Since no erosion-control measures were taken in SNP, erosion-control practice factor was assigned to 1

4. RESULTS AND DISCUSSIONS

4.1 Vegetation Peak Season and Detected Vegetation Cover Changes of SNP

The results of the detection of vegetation cover peak season based on the MODIS 16-day composite NDVI time series data acquired monthly during 2010 demonstrated that the most suitable period for the selection of the archive Landsat-5 (TM) satellite images is during May. To the possible extent, the Landsat-5 (TM) satellite images were selected to fit to the determined frame of vegetation cover peak season during May. However Landsat-5 (TM) image for 2007 without cloudiness was only available for the beginning of June. The selected Landsat-5 (TM) multispectral images were acquired for the following dates: 2000-05-21, 2007-06-01, 2009-05-21 and 2010-05-24. It was concluded that a time-series of the 16-day composite MODIS 250m NDVI data had sufficient spectral, temporal, and radiometric resolutions for the determination of the vegetation peak season in SNP. NDVI changes for every month during 2010 are presented in the Figure 5 for two positions in SNP.

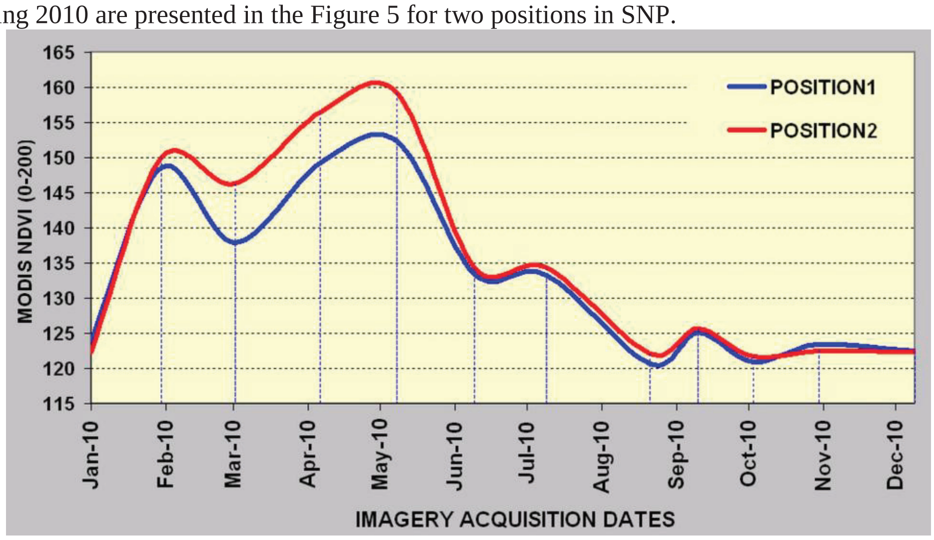

Fig. 5 Vegetation Peak Season in SNP

The modeling of NDVI for SNP revealed that the area of bare lands decreased from 2000 till 2010 (Figure 6(a-d)). 236 sq. km. of bare land in 2000 decreased to 142 sq. km in 2007, in 2009 to 103 sq. km. and in 2010 to 37 sq. km (Figure 7). It is also possible to observe in the Figure 8 that a count of pixels with NDVI values more than 110 corresponding to existence of ground cover increases towards 2010 year. This can be considered as a positive environmental spatiotemporal trend that can be related to a number of taken strategic restoration and improvement measures since SNP was established in 2003 as the first national park of Azerbaijan. Since 2003, livestock grazing was prohibited in SNP to improve the biodiversity conservation and ecosystem protection principles. It is possible to assume that the prohibition of livestock grazing contributed to the recovery of vegetation cover from overgrazing in SNP. In addition, the water treatment systems were installed at the entry of the irrigation collector and canal networks to the territory of SNP. This was performed to reduce the level of soil salinity around the Flamingo Lake and along the collectors and the canals passing over SNP. Wetlands were also developed in the territory of SNP for cleaning of domestic waste water. It is obvious that all of these infrastructure development projects and legislative landuse restrictions positively affected to the restoration progress of vegetation cover in SNP. However, the largest spatial distribution of bare lands was observed around the Flamingo lake in 2010. This provides the basis to assume that the soil salinity level is still increasing in these areas affecting to restoration progress of vegetation cover. Therefore the restoration activities should continue around the Flamingo Lake to reduce soil salinity and the root cause from irrigation collectors should be investigated.

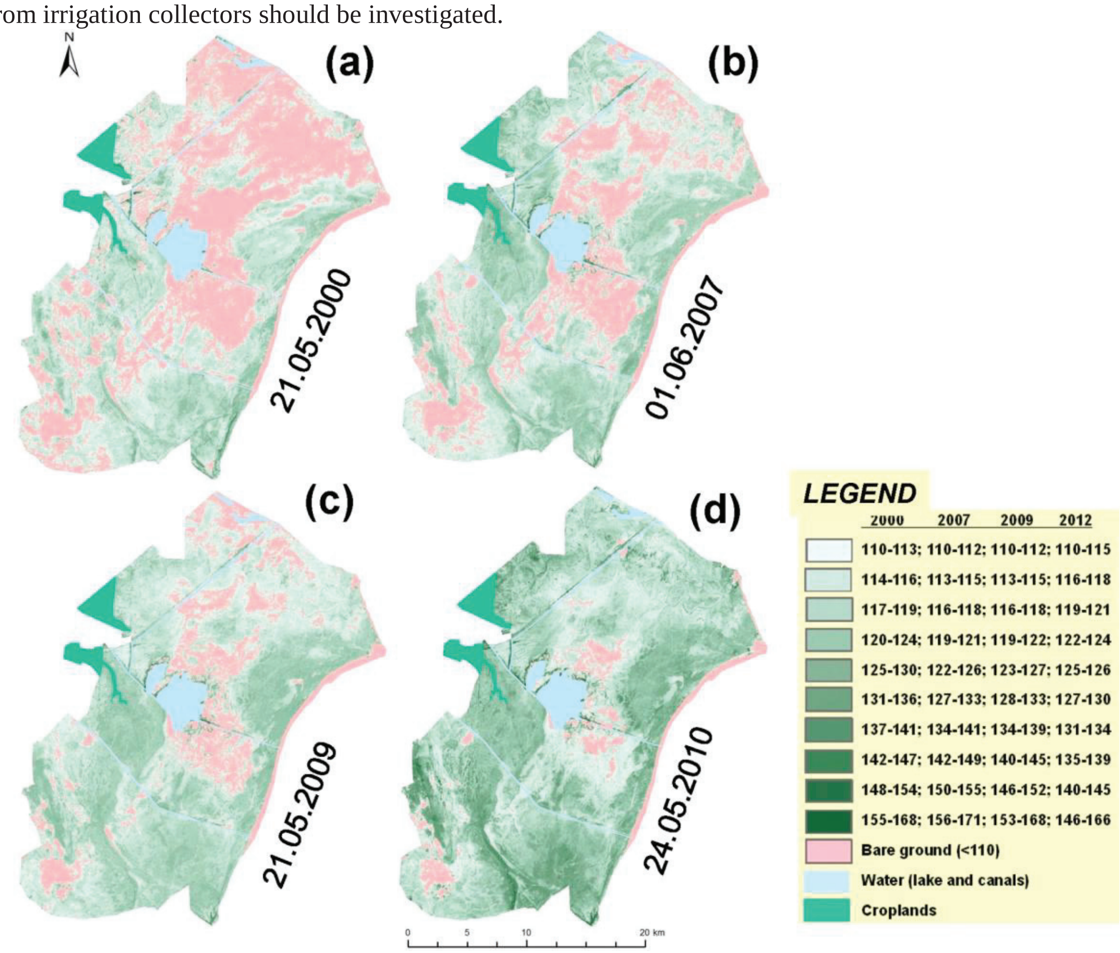

Fig. 6 NDVI Maps of SNP for: (a) May 2000; (b) June 2007; (c) May 2009 & (d) May 2010

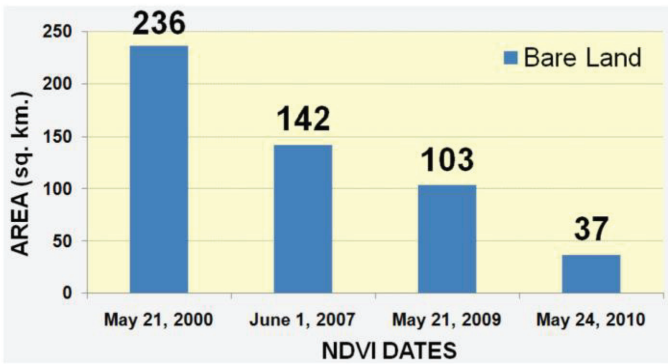

Fig. 7 Area of Bare Land in May 2000, June 2007, May 2009 & May 2010

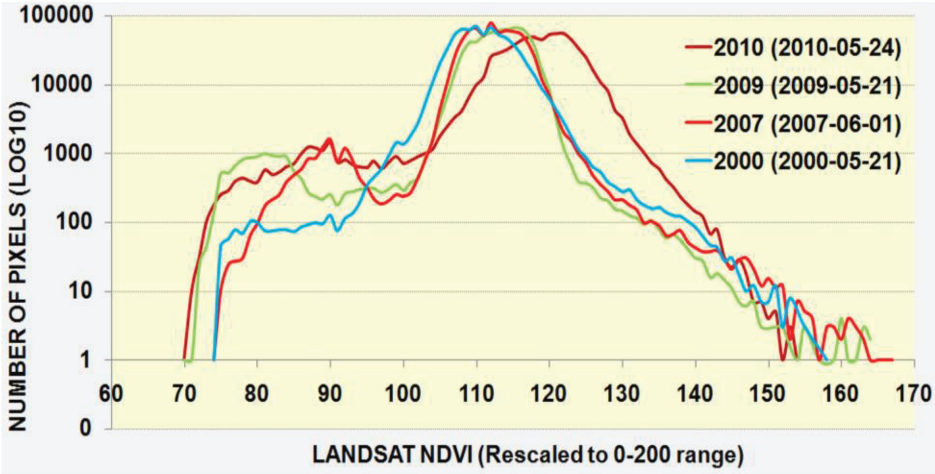

Fig. 8 Distribution of Count of Pixels of NDVI for May 2000, June 2007, May 2009 and May 2010

4.2 Predicted Erosion Prone Areas using USLE Erosion Prediction Model

The developed USLE factors for the prediction of soil loss rates are presented in Figure 9(a-d). The results of predicted soil loss rates by the USLE erosion prediction model are presented in Figure 10(a; b) and Table 2. USLE erosion prediction model was run twice with and without the vegetative cover factor (C) to understand how significant the role of vegetation cover in the protection of the soil cover and prevention from soil erosion processes is for SNP. In the first case when the C-factor was considered as '1' corresponding to the status of bare ground without vegetation cover, it is possible to observe in Figure 10(a) the larger spatial distribution of areas with the critical soil loss rates more than 10 ton/ha, whereas in the second case the USLE erosion prediction model with considered C-factor that corresponds to ground with vegetation cover in 2010 presented smaller spatial distribution of critical erosion classes more than 10 ton/ha (Figure 10(b)). This shows the significance of vegetation cover in SNP for the protection of soil and prevention of erosion processes in SNP. Besides, the comparison of two erosion prediction model runs allows to prioritize areas where the vegetation cover should be under more protected regime and where to continue the restoration activities of vegetation cover. Predicted soil loss results by USLE erosion prediction model may also be useful in the planning of field verification activities of potential erosion sites in SNP for the environmental restoration purposes. The results of the predicted erosion prone areas were not validated because of the absence of long-term erosion occurrences and field verification activities in SNP.

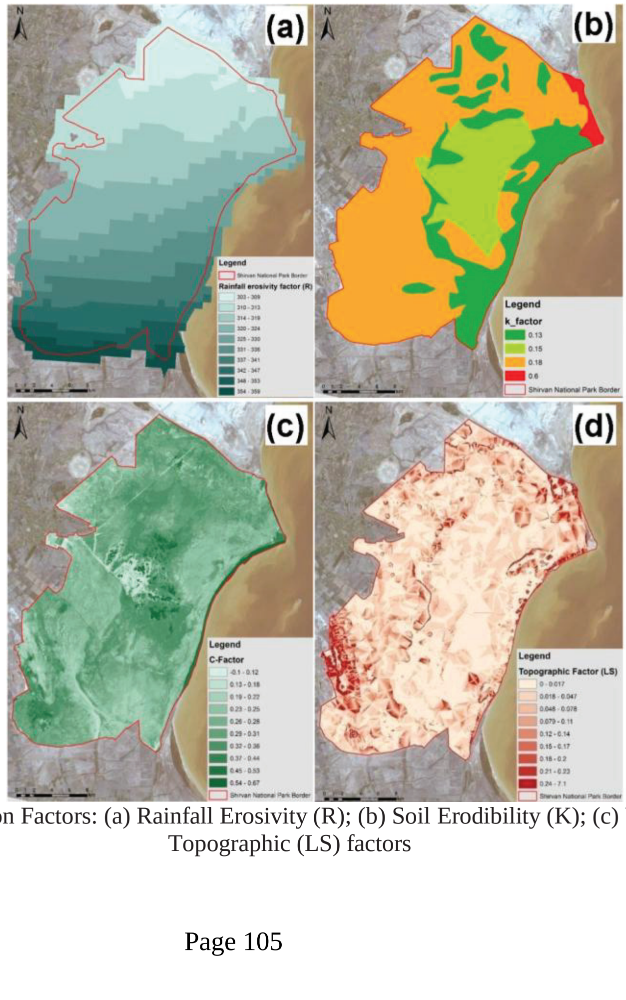

Fig. 9 USLE Erosion Prediction Factors: (a) Rainfall Erosivity (R); (b) Soil Erodibility (K); (c) Vegetative Cover (C); (d) Topographic (LS) factors

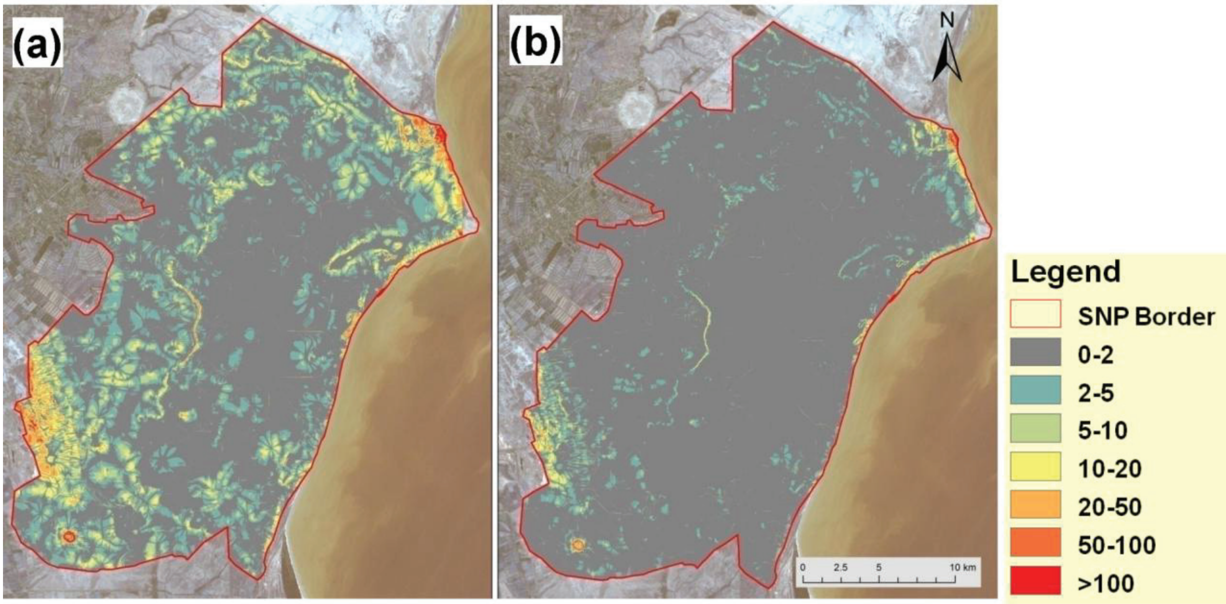

Fig. 10 Predicted Soil Loss (a) without C-factor; (b) with C-factor

Table 2 Predicted Areas of Erosion Classes

EROSION CLASS	DESCRIPTION	WITHOUT C-FACTOR (sq. km.)	WITH C-FACTOR (sq. km)
0-2	**Very slight**	407.38	589.43
2-5	**Slight**	145.74	42.32
5-10	**Moderate**	59.12	10.69
10-20	**High**	22.92	4.84
20-50	**Very High**	11.37	2.07
50-100	**Severe**	3.01	0.54
>100	**Very severe**	1.62	0.35

5. CONCLUSSIONS

This research focused on three main objectives: determination of vegetation peak seasons for SNP using multi-temporal MODIS NDVI images, monitoring of vegetation cover restoration progress from 2000 till 2010 using multi-temporal Landsat-5 (TM) satellite images, prediction of erosion prone areas using USLE erosion prediction model. The following conclusions were achieved:

1. The studies of vegetation peak season based on the multi-temporal images of MODIS allowed to determine that May is the month of the vegetation cover peak season in SNP.
2. The remote sensing analysis of NDVI derived from Landsat-5 (TM) multispectral images for SNP revealed that the areas of bare lands were decreasing in the period of 2000 - 2010. The 236 sq. km. of bare land in 2000 decreased to 142 sq. km in 2007, in 2009 to 103 sq. km. and in 2010 to 37 sq. km. This was observed as a positive spatiotemporal environmental trend that can be related to a number of strategic improvement measures since the establishment of SNP in 2003. The largest spatial distribution of bare lands was observed around the Flamingo lake. Therefore the restoration activities should continue around the Flamingo Lake to reduce the soil salinity and the root cause from irrigation collectors should be investigated.
3. The predicted soil loss rates by USLE model without consideration of the vegetative cover factor allowed to determine that critical soil rates more than 10ton/ha was 38.92 sq. km. whereas with the consideration of vegetative cover factor was 7.8 sq. km. This showed how critical the role of vegetation cover is for the soil protection in SNP.

This research demonstrated the role of the GIS and Remote Sensing for the quantitative assessment of SNP vegetation cover restoration status and prediction of the erosion prone areas.

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Perspectives: Remotely Sensing the Buried Past of Present Vegetation

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1. Introduction

This study is part of a research project (Landscape Archaeology on the Northern Frontier of the Roman Empire at Porolissum) that uses an interdisciplinary approach to explore the life and habits of the ancient inhabitants from the area of the Roman Empire LIMES situated on the present territory of Romania (Dacia Porolissensis). The comparative analysis of vegetation in different moments of time would allow the assembly of a more complete image of the Porolissum settlement since vegetation has directly influenced its organization and functioning.

Our goal is to map the distribution pattern of the current vertical structure of vegetation and to explore its correlation with the historical placement of structures within the Roman settlement. This would also make possible to detect traces of the ancient human impact from present vegetation structure and habitat quality. Since disturbance plays a fundamental role in determining the vertical structure of vegetation, knowledge of disturbance and land-use history and their legacies is vital for evaluating habitat resilience (Glenn et al. 1999, Foster 2003). This work is focused on contemporary landscape and forest habitat conditions derived from the analysis of certain LIDAR-derived data (Canopy Height Model-CHM) that is considered non-informational and “thrown away” by archaeologists, but often used in forestry for habitat structural features extraction, assessment and monitoring. Such information is important because characteristics associated with the 3D structure of forests are important factors that permit the estimation of habitat structure and quality. We explore if the buried Roman archeological remains modify the vertical structure of present forest growing above them. This approach goes beyond land cover and vegetation mapping to the next level of inferring habitats quality and conservation status from processing remote sensing and field data.

2. Study Area

The study area (Figure 1), covers 10 km² within the archaeological site from Moigrad-Porolissum (Sălaj County, Romania) - 47°11′49″N, 23°08′37″E, 504 m a.s.l., part of the Roman Empire Frontier fortification system (Figure 2), also called the Roman Empire LIMES. The remains of the LIMES today consist of vestiges of defense walls, ditches, forts, fortresses, watchtowers, civilian settlements and fortification structures that are hidden beneath forests. The climate is warm and temperate, the annual averages being a temperature of 9.2°C and 647 mm of precipitation.

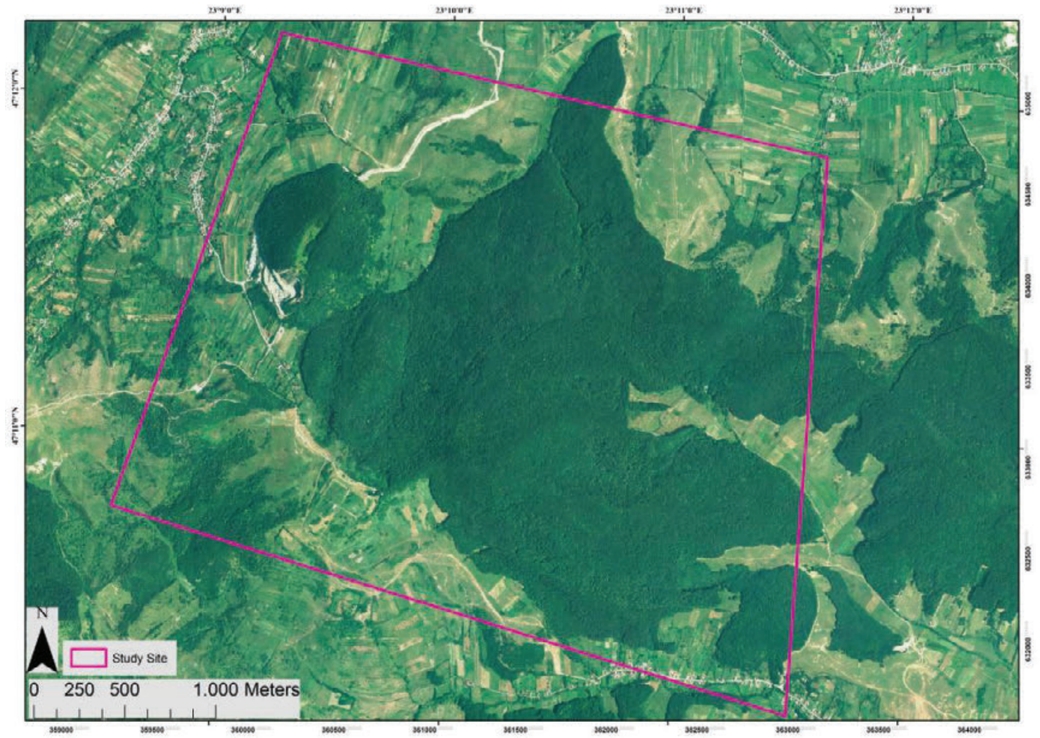

Figure 1: Aerial photography of the study area.

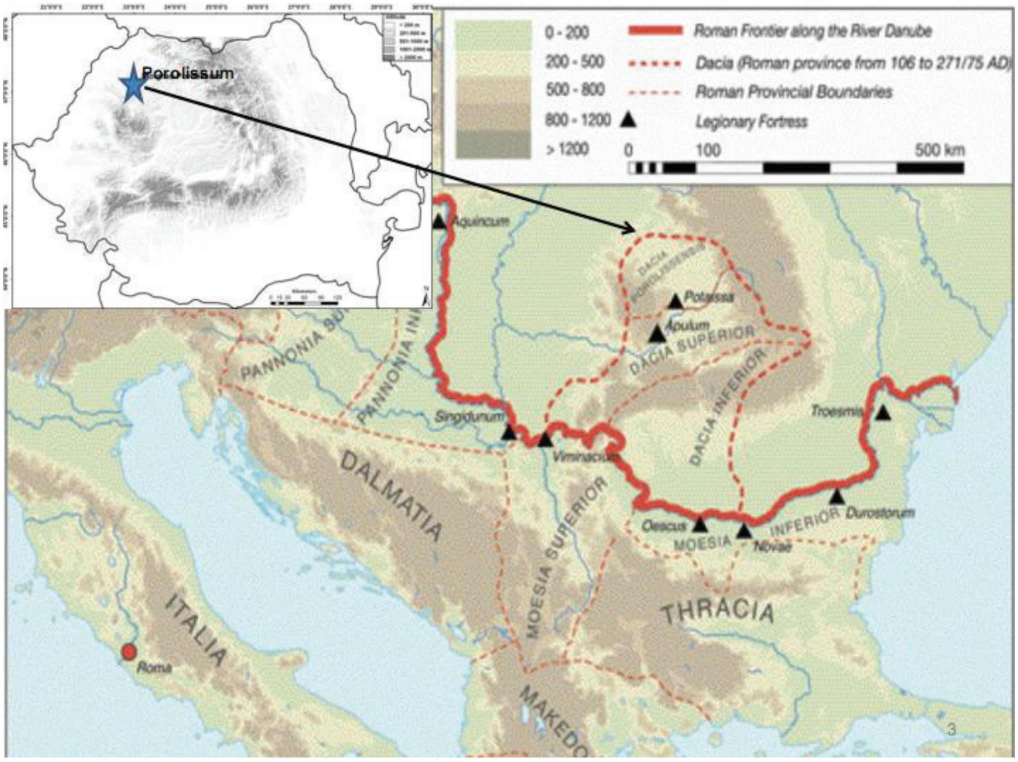

Figure 2: The Roman Empire LIMES (Breeze et al. 2009).

3. Materials and Methods

We used aerial photographs (pixel size: 0.5 m), taken in 2009, and field surveys of the surrounding vegetation (2012, 2013) based on an adapted version of the Braun-Blanquet method (1965) in order to generate the current vegetation map of the archaeological site. Recently, phytosociological methods have been used extensively for the purposes of plant community classification and vegetation mapping. A review of the relevé technique, its development and modification can be found in Kent (2012).

LiDAR data were collected in March 2013 (leaf-off season) using a D-EBMW/C207 helicopter equipped with Riegl's LMS-Q560 laser scanner, flying at an altitude of 600 m. The raw LiDAR data were used to create very accurate digital terrain models (DTM) and digital surface models (DSM). The set of XYZ files was converted to ASCII raster file, then to ESRI GRID, using XYZ2GRID 2.1 (Huang 2003). Subsequently, the CHM (computed as a difference between DSM and DTM) was visualized and analyzed with the FUSION software (McGaughey 2014).

4. Initial Results

The data from the vegetation field survey were mapped in ArcGIS 10 (ESRI 2011). According to the phytosociological relevés the forests belong to plant community *Lathyro hallersteinii-Carpinetum*, the shrubs to *Sambucetum ebuli* and *Pruno spinosae-Crataegetum*, and the pastures to *Festuco rubrae-Agrostietum capillaris*, *Trifolio repentis-Lolietum*, *Poo-Trisetetum flavescentis* (Figure 3). There is also an area covered by a successional stage dominated by oak (*Quercus cerris*), resembling the ancient forest type from Roman times (Şuteu et al. 1978).

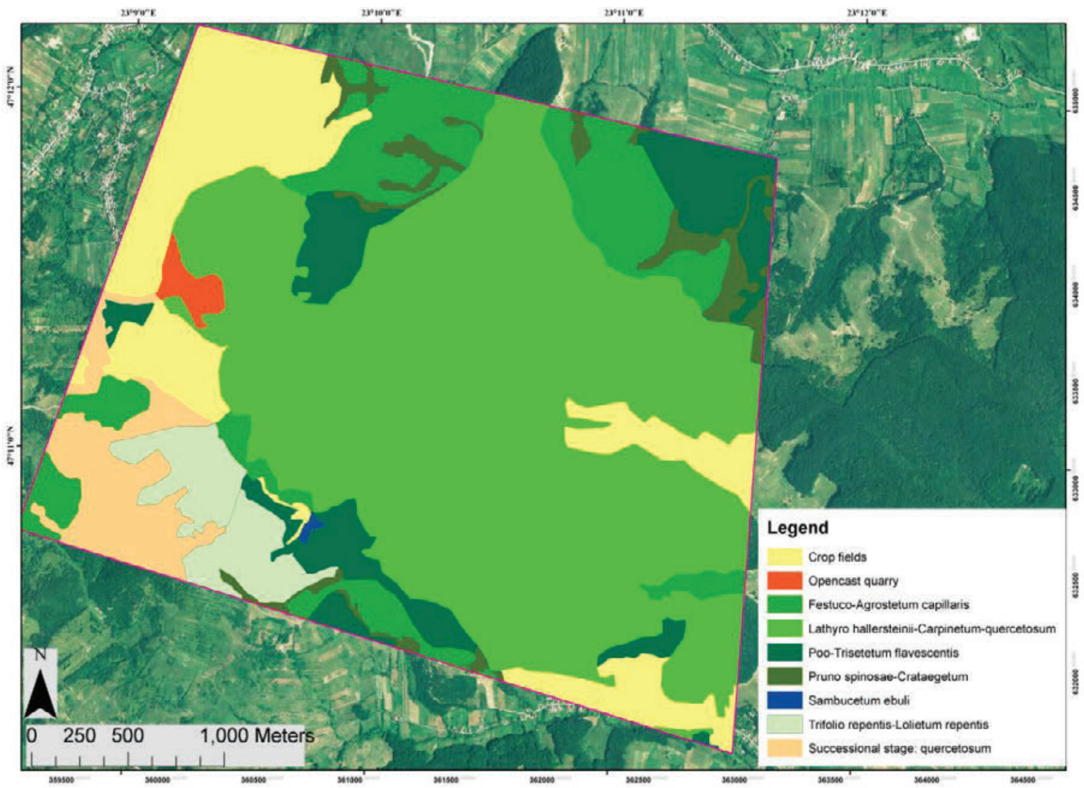

Figure 3: The current vegetation map at plant community level.

From LIDAR data we obtained very accurate (0.5 m ground resolution) DSM and DTM (Figure 4) that were used to extract key forest habitat characteristics such as tree heights and their spatial distribution.

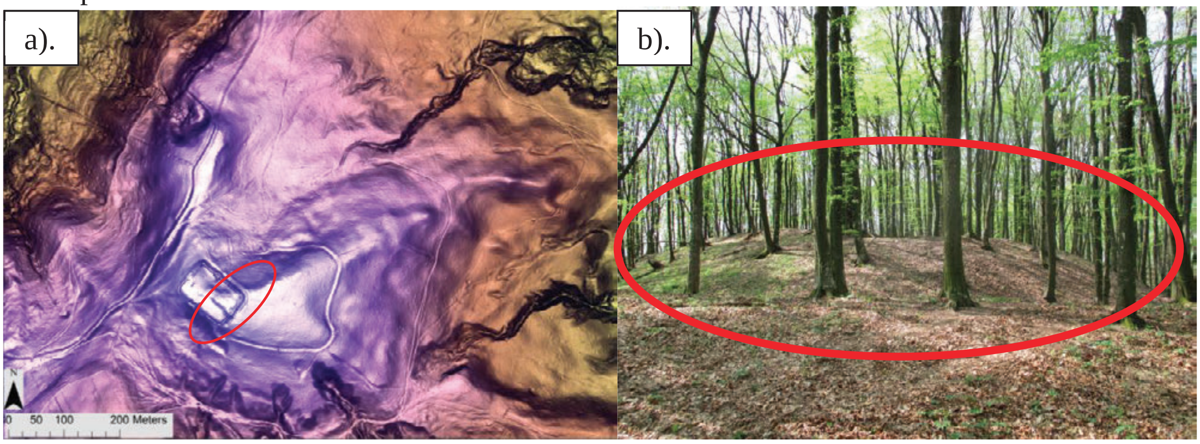

Figure 4: a). Aspect from the DTM revealing the archaeological remains, part of the Roman defensive system, confirming the deforestation of the area. b). The red oval indicates the area of the former Roman Fort, covered today by trees that display height patterns.

The tree height distribution (Figure 5) was visualized and analyzed with Fusion/LDV (McGaughey 2014). Obvious differences in tree height were noticed between the trees growing on the ancient structures and the surrounding canopy. This pattern needs to be confirmed through specific analyses after calibration of LIDAR–derived heights with control ground measurements.

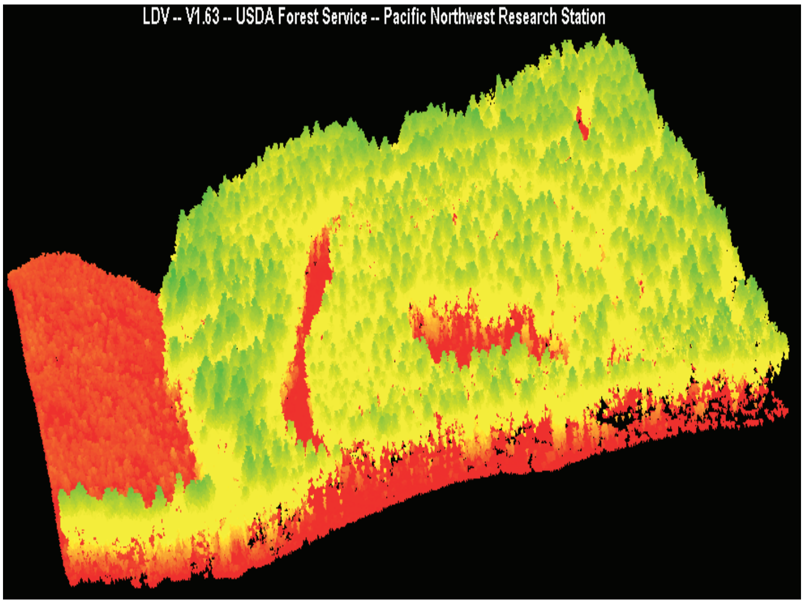

Figure 5: Visualizing the tree height patterns.

5. Discussions and Conclusions

The forest habitats from this area are dominated by oak species, beech and hornbeam (Figure 3), being similar to the ones that were found here during the Roman period (Nyárády et al. 1966, Raţiu 1966, Grindean et al. 2014). However, our LIDAR based research indicate that within this particular area of the Limes, there was extensive deforestation during the Roman period, required for strategic reasons (communication and early warning against barbarian attacks). Moreover, deforestation in the Roman has been a common practice for economic purposes (wood exploitation and clearings for agriculture). Therefore, in the 2nd century AD, within the Limes area at Porolissum, there was an open landscape with intense human military activity and defensive structures distributed over cca. 40 km², in contrast to the present forest habitat dominance. The buried remains of these structures have generated anomalies in the soil matrix that translate into human generated vegetation patterns that remain visible through the millennia. While these vegetation marks are well documented in grasslands and crop fields, we have detected them in the Canopy Height Model derived from LIDAR data, that, to our knowledge, has never been approached before.

Within this interdisciplinary study, phytosociological analysis and mapping together with active and passive remote sensing provides a base for combining the knowledge of plant ecologists, archaeologists and foresters in order to achieve a thorough analysis of the landscape and understand the interacting processes that influence habitat quality. Since such buried legacies from ancient settlements, although widespread, are easily overlooked especially in forest habitats, they are of particular interest to conservationists and land managers as well as to scientists. Consequently, we conclude that the historical perspective and the awareness of land-use legacies may be approached using the perspectives that remote sensing offers especially when inferring drivers that influence habitat quality.

Acknowledgements

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Modelling of soil properties in a NATURA 2000 habitat site in the Carpathian Basin

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1. Introduction

The flat areas of Carpathian Basin holds the most extent naturally salt-affected soils in Europe. These areas are typically covered by alkali grasslands. Natural salt accumulation due to continental climate and the special local hydro-geological conditions (e.g. closed evaporative basins) is rare in Europe. Due to their good nature conservation status, alkali grasslands have an important role in the European Natura2000 network. In these sites, detection of soil properties is difficult because of the complex horizontal mosaic structure. This task is especially challenging in mapping temporarily water covered areas. There are two types of salinisation in the Carpathian Basin: (1) solonchak (saline soil) with high amount of water soluble salts and (2) solonetz (alkaline soil) high alkalinity and high exchangeable sodium percentage (ESP) in the B-horizon. In Hungary the dominant soil type is solonetz. High exchangeable sodium saturation of heavy-textured soil with large amount of expanding clay minerals results in unfavorable soil properties - alkaline pH in B-horizon, swelling/shrinking colloids**,** degradation of soil structure**,** limited infiltration and leaching conditions, low water and nutrient storage capacity of the shallow A-horizon, which limit their fertility, productivity and agricultural utility.

Due to macro relief (catena) properties, salt affected soils are located in the transition zone between the high-and low-lying areas (Máté 1955). The correlation of micro relief and salt accumulation in micro depression in case of a solonchak soil was published by Mile et al. 2001. Nevertheless, according to Tóth (1999) and Blaskó (2004) in case of solonetz soils salt accumulation is not typical in micro-depression. Soil salinisation process is highly correlated with surface water and ground water moving. The vertical salt profile changes were published by the authors (Sigmond E. 1923, Tóth 1999, Mile et. al. 2001, Tóth et. al. 2001, Blaskó 2004, Novák 2008), but less emphasis was put on the horizontal variations. Because of horizontal variation depending on the micro topography. Next to it need to take consider soil properties, vegetation types and runoff properties.

2. Scientific Approach and Results

The main reason of this study is improving the inaccurate spatial modeling of an extremely flat area. The high-density point cloud data from 3D LiDAR remote sensing provides good quality input data to detect the micro heterogeneity surface very effectively. Airborne LiDAR, - also referred to as Airborne Laser Scanning - is widely used for high-resolution topographic data acquisition, offering a planimetric (<50cm) and vertical accuracy

(<20cm) suited for many applications (e.g. in natural hazard management, forestry) (Höfle et al. 2009). However this technology is also applied in nature conservation and environmental protection. This technology was used by ChangeHabitats2 project, which first aim was to monitoring NATURA2000 habitat sites in Europe. Our study area is Ágota-puszta - one of the four Hungarian sample areas of ChangeHabitats2. This is part of Hortobágy National Park- mainly characterized by salt affected soils, alkali grasslands, micro heterogeneity surface and micro watershed isolated. The aim of this study to using data of LiDAR technology to evaluate correctly these properties in this area.
The survey was made with Riegl LMS-Q680i laser scanner. This use full waveform analysis and echo digitization. The system is suitable for distinguish different echo signals, while scanning parameters are stored. Full waveform analysis contribute to evaluate different levels in the investigated environment (e.g. high vegetation, medium vegetation, ground, etc.) more effectively. Emitted laser beam has a certain footprint, so the laser shots different objects. Echo digitization operates based on the return time. Figure 1 presents points which reflected from the ground, which derive from the last echo in our study area.

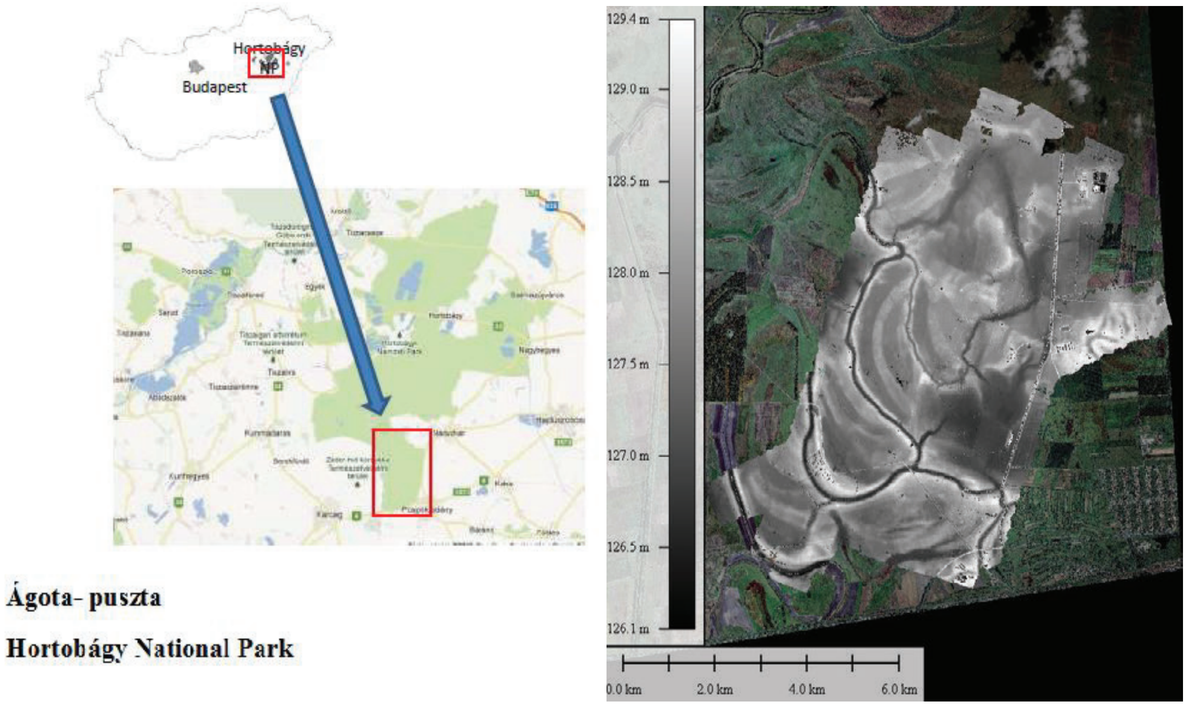

Figure 1: Ground points visualisation in our study area.

The purpose was to delineate impact of non permanent water pattern on salinisation. In the field survey mapping texture of different vegetation formations was performed by handheld GPS system unit. Measurement points were selected according to vegetation stratified sampling strategy and it was drilled depth of 0.6 m. In the 0.6 m range, the topsoil quality important from viewpoint of grasses could be characterized by soil texture. Furthermore soil laboratory tests have been conducted to determine the total salt content, pH value and texture of soils.
Furthermore DEM (Digital Elevation Model) was created in ENVI LiDAR 3.2 and the Global Mapper LiDAR module. Based on the DEM, the derived runoff model (which presents on Figure 2) of study area was created from the LIDAR point cloud by Tarboton algorithm

(Tarboton 1997) in ArcGIS 10.2 software environment. Whereas for determination of relationship between micro relief and soil characteristics statistics methods were used.

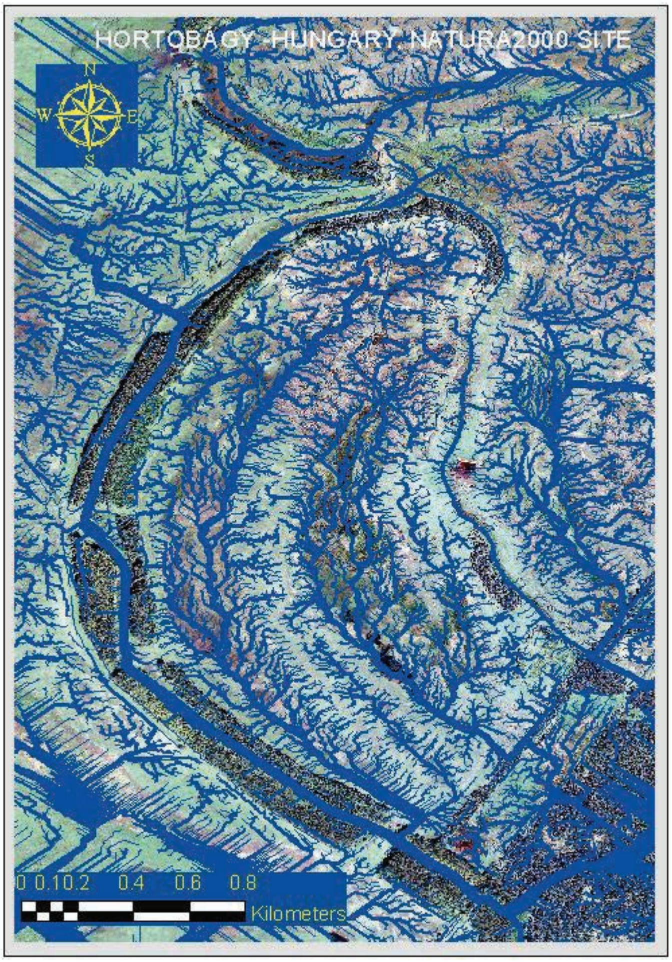

Figure 2: The runoff model of the study area.

The horizontal pattern of vegetation formation is largely depending on the movement of salt in soil profile, which is represented in the 3D DEM. In this way, it is possible to have a more accurate spatial analysis of correlation and understanding between movement of water and salt accumulation, micro-relief and vegetation. In the present study, we demonstrated monitoring Natura 2000 habitat site from LiDAR data processing to soil laboratory tests and field surveys.

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Combining object-based classification of IKONOS imagery and Habitat Suitability Index modelling for alpine rock ptarmigan (*Lagopus muta helvetica*)

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1. Introduction

The maintenance and restoration of high-quality habitats for wildlife species in alpine ecosystems are key issues in conservation biology. Grouse species listed in Annex II of the EU Bird Directive are indicators of ecosystem status and integrity (Storch 2007). The alpine tetraonid rock ptarmigan (*Lagopus muta helvetica*), preferring open subalpine and alpine habitats above the treeline, is an indicator species within this vulnerable ecotone.

Traditional methods for mapping and monitoring upland vegetation and biodiversity generally comprise field surveys or interpretations of aerial photographs, but both approaches are expensive and time consuming (Barrett and Curtis 1999). Addressing large areas of conservation concern and decreasing availability of the financial resources urgent need for technical tools supporting monitoring and management activities becomes obvious. A powerful suite of tools and data exists within programs that sense global environmental conditions remotely, the value of which is enhanced by the spatial and temporal consistency of satellite data and high cost effectiveness. Very high resolution (VHR) satellite images like IKONOS or Quickbird have become available recently, offering improved conditions for classification of land cover. Contrary to per-pixel approaches, object-based segmentation methods yield more reliable classification results for VHR images and this approach has already been used in a range of recent habitat mapping projects (e.g. Kobler et al. 2006). Once a classification of land cover types of interest is available, species-specific habitat models are required for further modelling procedures.

We newly developed a general habitat suitability model for rock ptarmigan that might serve as a decision support tool in regional monitoring and planning (Zohmann et al. 2013). We combined a novel conceptual HSI model with spatially-explicit land cover data derived from VHR IKONOS satellite images. To accommodate future variation in the environment due to changes in climate and land use, we developed a classification scheme that is transferable to satellite images in years to come. The small-scale approach presented in this paper should allow for regional habitat monitoring according to the EU Birds Directive. Both the simplicity of this modelling approach and its applicability in case of limited data on species' distribution allows for regional-scale applications that are appropriate for the management of wildlife populations.

2. Methods

The habitat suitability approach combined knowledge-based data on habitat requirements of rock ptarmigan with spatially explicit land cover data derived from satellite imagery to model the habitat suitability for the target species. The approach comprised the following steps (Figure 1): 1. Knowledge-based habitat modelling, 2. Object-based image analysis of IKONOS imagery, 3. Combining steps (1) and (2) for final habitat suitability model, 4. Model validation.

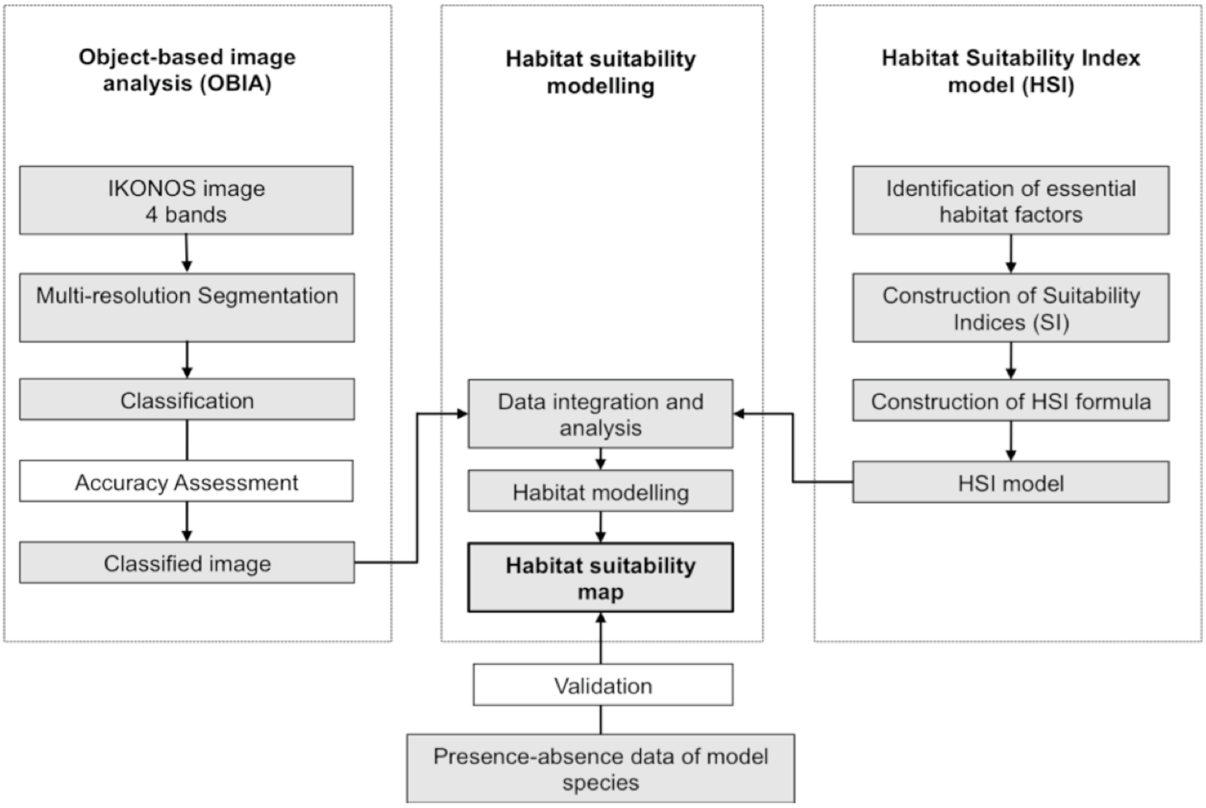

Figure 1. Workflow of the habitat modelling approach.

We applied the Habitat Suitability Index (HSI) approach (U.S. Fish and Wildlife Service 1980) to calculate summer habitat suitability for rock ptarmigan in terms of terrain and vegetation characteristics, representing food supply, cover and demands for rearing of offspring.

We used Definiens Professional 5.0© software for object-based image analyses, applying multi-resolution segmentation methods (Baatz and Schäpe 2000). This bottom-up, region-merging procedure using singlepixel segments (Definiens 2006) has successfully been applied to other mountainous regions (e.g. Dragut and Blaschke 2008).

We generated a classification hierarchy comprising the same variables of the HSI model. Image classification training for the nearest neighbour function was performed by labelled samples for each subset, respectively. For each class we selected representative sample image objects and an iterative classification process was performed.

We used accuracy measures to compare and evaluate the classification with respect to its suitability to specific applications. We assessed classification accuracies by Error Matrix based on TTA Mask, where test areas are used as a reference to check classification quality.

For final habitat suitability modelling, we used MapModels (Riedl et al. 2000, Riedl and Kalasek 1998), a flowchart-based modelling-tool implemented in Arc View® (ESRI 1996).

The model's key feature is the calculation of habitat suitability for rock ptarmigan within each grid cell using fuzzy membership-functions (Zadeh 1965). The scoring of habitat suitability between 0 and 1 was approached by Fuzzy Logic. For model validation, we compared presence–absence data and results of habitat suitability classification employing contingency tables and non-parametric correlations.

3. Results and discussion

We assessed classification accuracies, applying an Error Matrix based on TTA Mask. We reached an overall classification accuracy of 0.75 and a kappa statistic value of 0.70, the latter indicating good to very good agreement. The producer's accuracy of individual classes varied from 0.64 for scree to 0.89 for alpine to subnival grassland. The highest values for user's accuracy were assigned to clouds (0.95), dwarf pine (0.92) and alpine to subnival grassland (0.91). The classification results indicated that the object-oriented image classification approach using VHR data was appropriately used to create an adequate thematic map for further habitat modelling.

The habitat suitability model for rock ptarmigan yielded HSI values between 0.7 and 0.84; grid cells situated below 1400 m a.s.l. were assigned to the class of lowest suitability. In total, 20% of the grid cells were assigned to the class of "very high suitability" and 21% of the grid cells to the classes of "high" and "medium" suitability. 38% of the grid cells were assigned to the category "no/low suitability" (Figure 2).

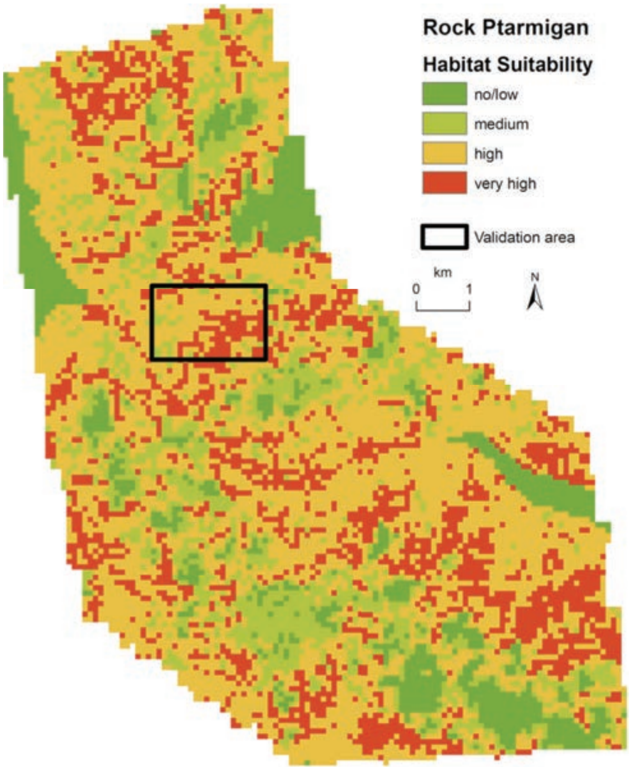

Figure 2. Map of habitat suitability (no/low, medium, high, very high) for rock ptarmigan.

To validate our habitat model we compared the model output with existing presence–absence data from the study area (Schweiger et al. 2012). Within this delimited validation area, HSI values ranged between 0.4 and 0.9. Re-standardized proportions of sample plots with rock ptarmigan signs significantly increased with increasing HSI class (Kendall's τ = 1.000, $p < 0.01$). There were highly significant differences in the re-standardized proportions of presence or absence plots over the HSI classes ($\chi^2 = 13.816$, df = 2, $p < 0.001$). Rock ptarmigan habitat use was closely related to habitat suitability**.**

The model approach we used is an effective tool for spatially explicit habitat suitability assessment and is well suited for regional monitoring, planning and decision support. Although being non-dynamic in structure, it can be used to assess temporal changes using spatial data of land characteristics collected at different points of time. Combining the modelled habitat suitability with presence–absence data of rock ptarmigan for different points of time, changes in habitat suitability and distribution can be evaluated over larger time periods.

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Towards an integrated assessment of protected riparian forests using EO-based indicators

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1. Introduction

Protecting habitats and areas of high biodiversity is an international commitment. Within the European Union this is supported by the EU Habitats Directive and the Natura 2000 network, where regular reporting and monitoring is mandatory (European Commission 2005). To preserve and improve the conservation status of such habitats, regularly updated spatial information on their quality and condition, as well as on existing threats and trends need to be collected (Lang et al. 2013). This information is essential for the development of adaptive local management strategies and policy decisions (Noss 1999; Vanden Borre et al. 2011).

It was often proposed to include satellite-based Earth Observation (EO) data in this task (e.g. Noss 1999; Gillespie et al. 2008), as it presents considerable potential for regularly monitoring the status and change of habitats. Today very high spatial resolution (VHR) EO data are capable of providing detailed information and characteristics, which are necessary for assessing habitat conditions on a local scale and advanced analysis techniques facilitate the extraction of thematic information on habitat conditions (Strasser et al. 2014). The area-wide coverage of EO data allows for seamless analysis of trans-boundary protected sites (Riedler et al. 2013) and the transfer of harmonized assessment methods (Vanden Borre et al. 2011) between sites that functionally belong to one single ecosystem but are subject to different national management strategies (Lang et al. 2013).

This abstract presents a study on the assessment of habitat quality of a Natura 2000 protected riparian forest with the help of EO-based indicators. The method was developed within the framework of the FP7 project MS.MONINA (www.ms-monina.eu). The aim of the study was to identify a set of indicators that cover different aspects of riparian forest quality and to compile these individual indicators into a single index (Nardo et al. 2008). This index summarizes the different aspects to support local site managers in the choice of management strategies.

2. Methods

This study was conducted in the Natura 2000 site Salzachauen, Austria (view details at http://natura2000.eea.europa.eu; area codes: AT3209022, DE7744371), which is located along the regulated river Salzach in a densely populated area of the alpine foreland at the Austrian-German border (Figure 1). According to the EUNIS classification scheme (Davies et al. 2004), the primary vegetation are *Riparian and gallery woodlands* (G1.1) and *Mixed riparian floodplain and gallery woodlands* (G1.2).

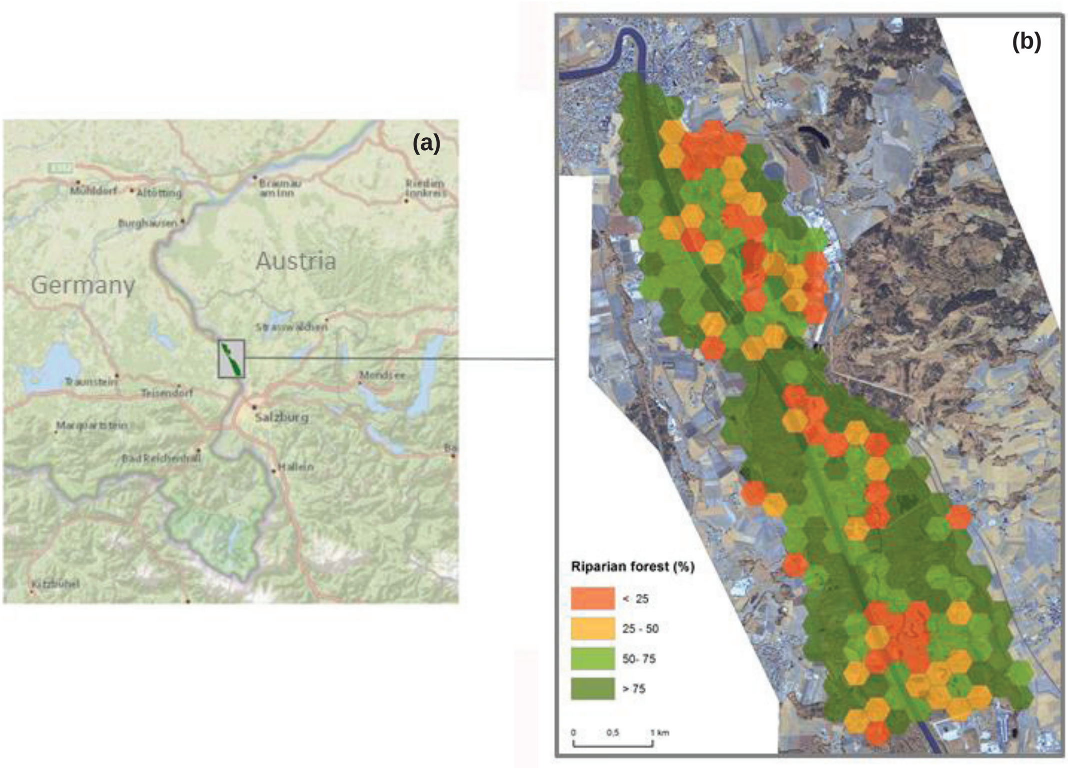

Figure 1: Location of trans-boundary flood plain Salzachauen (a), and coverage of riparian forest canopy (b).

VHR satellite imagery (WorldView-2, acquired in June 2012) along with a high spatial resolution digital terrain model (DTM) and digital surface model (DSM), both derived from airborne LiDAR data (acquired in April 2006), were used to derive a set of seven indicators. All indicators were summarised at the patch level of a semi-automated forest habitat delineation based on the WorldView-2 imagery (Strasser et al. 2014).

These indicators can be grouped to represent four different aspects of forest habitat quality: (1) the naturalness of tree species composition (Geburek et al. 2010), (2) the vertical forest structure (Noss 1999), (3) the horizontal forest structure (Noss 1999) and (4) the flood regime (Ellmauer 2005).

(1) The naturalness of tree species composition is approximated by

- the proportion of native key tree species (here *Alnus incana*, *Salix alba*, *Fraxinus excelsior*, *Quercus robur* and *Acer pseudoplatanus* derived from a semi-automated habitat model (Strasser et al. 2014) and
- the proportion of allochthonous tree species (here *Picea abies* derived from a semi-automated habitat model (Strasser et al. 2014).

(2) Vertical forest structure is described by

- the variance of the canopy surface model as approximation of the height structure, calculated by the standard deviation of height information of the DSM, and
- the number of old trees (heigher than 26 m), here extracted by calculating local maxima of the normalized DSM.

(3) Horizontal forest structure is indicated by

- the within-patch heterogeneity, using the spectral heterogeneity as an approximation for plant species diversity (Rocchini et al. 2004), here estimated from a measure of relative entropy (Dean and Smith 2003) and summarized as proportion per patch, and
- the shape index, describing the patch form complexity as an approximation for the occurrence of structural features (Riedler et al. 2013).

(4) The flood regime is described by

- the terrain roughness as an approximation for the soil wetness induced by perennial streams or channels that are activated through flooding, here calculated as the standard deviation of slope based on the DTM.

These indicators were aggregated into a composite index using geometric aggregation and expert-based weighting of the single factors (Nardo et al. 2008) The result of the composite index was compared to an existing conservation status map (REVITAL, 2014).

3. Results and Conclusions

The composite indicator provides an overview of the forest conservation status on local scale and thus allows the detection of hot-spots where management actions are needed to improve the conservation status (Figure 2a).

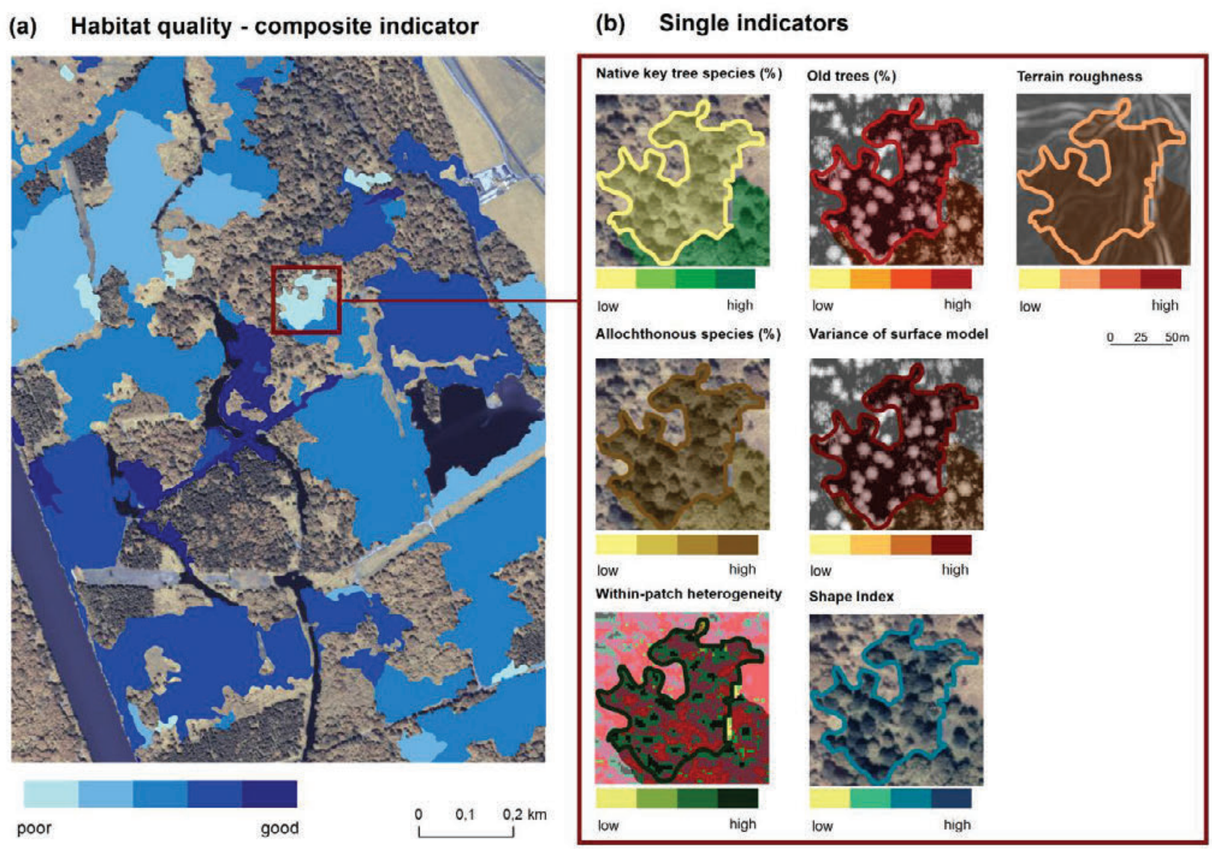

Figure 2: Composite indicator for describing the riparian forest quality (a). Seven single indicators were used for the calculation of the composite indicator (b).

This index can also be decomposed into its single indicators to identify aspects that need improvement in areas with poor quality. The poor conservation status in the chosen example can mainly be explained by a high proportion of allochthonous tree species and a low variance in terrain roughness (Figure 2b). A selective logging of *Picea abies* in addition to measures that increase soil wetness (e.g. the re-connection of dry channels to existing river branches), may be the most promising conservation measures here. Comparison of this patch with the conservation status map reveals that the overlapping area was also there graded as unfavorable-bad.

The use of the presented EO-based indicator approach complements classical field survey to assess the habitat quality status and to develop adaptive local management strategies and policy decisions independent of national and international borders.

Acknowledgements

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A Natura 2000 Monitoring Framework – Using Plant Species Gradients for Spectral Habitat Assessment

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1. Introduction

Natural habitats are multidimensional environmental spaces with characteristic ecological gradient compositions. Remote sensing often decomposes complex habitat configurations in order to find distinct spectral coherence for mapping approach. For habitat quality assessment, ecological relevant parameters are commonly defined a priori. As a result habitat features are often described and mapped as plant community or biotope classes (Kerr & Ostrovsky 2003, Xie et al. 2008) or multi species indicator approaches (Bock et al. 2005). Consequently, discrete habitat maps can only represent reduced aggregates of species environment. First promising approaches to describe habitats as ecological continua with hyperspectral reflectance signatures were achieved in heathlands and moist meadow areas (e.g. Trodd 1996, Schmidtlein et al. 2007). It was shown that reflectance signatures can predict continuous floristic transitions that are projected to an ordination space. However, the assessment potential by ordinated parameter aggregation for habitat type monitoring still remains unsolved in application.

Under the legal framework of the European Natura 2000 network habitat type and status has to be assessed and reported for large areas. In our study we developed a monitoring framework for an area-wide mapping of FFH habitat types and related assessment categories, using environmental space gradients. Therein homogenous as well as ecotone areas were modelled by means of plant species ordination. Based on ordination topology we introduce predictive aggregation techniques on habitat quality parameter for floristic and faunistic suitability indicators. It shall be demonstrated that habitat status can be assessed by ecological gradients that are translated to occurrence probabilities for habitat types and species, simultaneously. We can further prove significant relations on spectral variables to ordination dimension for a spatially explicit monitoring with hyperspectral imagery.

2. Conceptual Monitoring Framework

In Figure 1 the methodological framework for the spatially explicit derivation of FFH habitat parameters used for assessment is presented. On the basis of plant species assemblages a habitat assessment can be realized in an environmental continuum forming floristic composition or faunistic distribution pattern. We propose non variance explaining axes projection such as non-metric multidimensional scaling (NMDS) (Kruskal 19964) as ordination technique in order to project species variability into two or three dimensions for visualization. Plant cover values have to be collected over the whole range of habitats and transitions that are likely to occur in the study area. In order to find appropriate sample size, ordinated plot topology is tested on pattern significance and configuration stability (Pillar 1999). Ordination axes are subsequently modelled with spectral variables derived for field plots using Partial Least Squares Regression (PLSR) (Wold, 1966). Distinct spectral features for gradient description are extracted within axes models and finally used to transfer axes scores to image spectra.

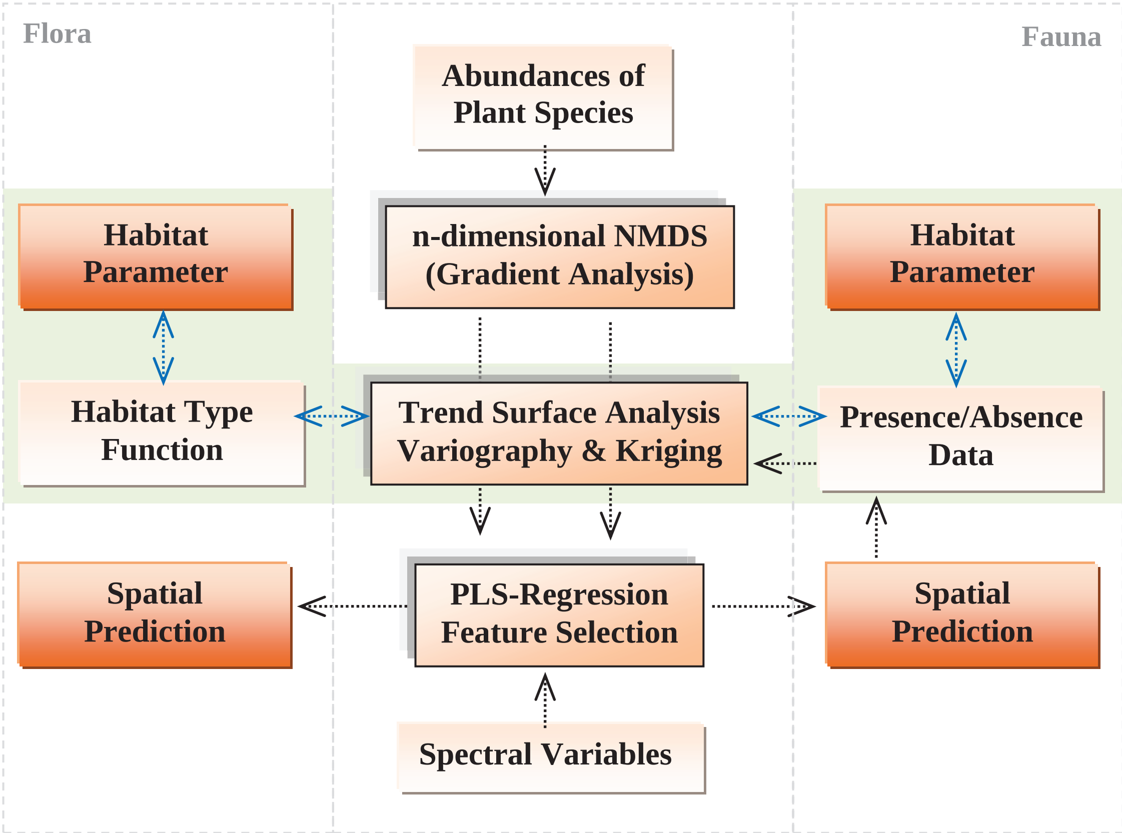

Figure 1: Conceptual framework for a remote sensing based monitoring of natural habitats using environmental space aggregation

The central embedding for habitat assessment is set in between ecological and spectral modelling approaches (Figure 1, green). It generates information for species distribution along abstract gradients and score values, respectively. Thereby floristic habitats can be described by plant species compositions that are aggregated under consideration of functional relations. Habitat type functions translate species complexes to type specific occurrence probabilities. Therein, single types or corresponding encroachments are defined over species occurrences. Their cover values can be projected to ordinated plot configuration. Subsequently, trend surface analysis on axes coordinates in combination with geostatistical Kriging (Hengl et al. 2007) are applied for the spatial interpolation of habitat functions.

In addition ordination space areas for faunistic habitats can be determined on presence/absence data that are superimposed with spatially predicted score vales on field survey locations. Logistic trend surfaces followed by residual Kriging of Indicators are then used to interpolate probability spaces for faunal occurrence in environmental space. Furthermore, habitat quality parameter examination can be realised by relating environmental variables on ordinated field plots to predicted occurrence probabilities.

3. Example: FFH-Habitat Type and Status Mapping of Dry Grassland

A FFH-habitat assessment using proposed approach was realised on a former military training area, “Döberitzer Heide”, located at 53° latitude and 13° longitude west of Berlin, Germany. Long term military use created dry open grassland communities comprising FFH-Habitat types 2330 (Inland dunes with open Corynephorus and Agrostis grasslands), 4030

(European dry heath), and 6120 (Xeric sand calcareous grasslands) on glacial ground moraine deposits. After abandonment of military use in 1992, habitats increased in small scale floristic heterogeneity due to natural succession processes and active management (e.g. grazing mammals).

3.1 Data

The fractional cover of 98 different plant species were collected on 58 field plots within all FFH-habitat types and successional transitions. Plot size of 1 m² was set into a 5 m² floristic homogeneous surrounding in order to assure appropriate image pixel representation. A 2-dimensional NMDS was performed to project species variability into ordination space. Habitat type and habitat quality functions were derived by standardized sums of weighted plant species cover according Table 1. Habitat probability ranges from 0 to 1. For the spectral assessment the status of an FFH-habitat is combined by a reduced set of positive and negative habitat factors compared to terrestrial assessment. The results are aggregated to habitat status A (excellent), B (good), C (middle to bad).

Table 1: Selected plant species for FFH-Habitat type definition (+) and quality assessment (-); species were aggregated into habitat functions and projected to ordinated plot location

FFH 2330		FFH 4030		FFH 6120	
+	-	+	-	+	-
1*Corynephorus canescens	1*Agrostis capillaris	1*Calluna vulgaris	1*Sarothamnus scoparius	1*Festuca ovina agg.	1*Sarothamnus scoparius
1*Bare ground	1*Festuca ovina agg.		1*Populus tremula	1*Koeleria macrantha	1*Populus tremula
0.3*Spergularia morisonii	1*Deschampsia flexuosa		1*Festuca ovina agg.	1*Dianthus carthusianorum	1*Arrhenatherum elatius
0.3*Polytrichum piliferum	1*Calamagrostis epigeios		1*Deschampsia flexuosa	0.8*Achillea millefolium	1*Tanacetum vulgare
0.3*Cladonia spec.	1*Rubus caesius		1*Nardus stricta	0.2*Agrostis capillaris	1*Calamagrostis epigeios

Spectral models were calibrated on ordination axes scores using spectral reflectance signatures that were acquired with an ASD filed spectroradiometer during an AISA DUAL imaging spectrometer airplane overflight. Internal leave on out validation was used to select spectral variables and model accuracy assessment. In order to transfer spectral models to hyperspectral imagery an Empirical Line correction was performed on image spectra.

3.2 Results and Discussion

The occurrence probability for all three FFH-habitat types could be modelled with distinct pattern into ordination space (Figure 2). Transition between types, as well as inner type variability can be visualized in adjacent ecological gradients. Spectral variables can explain 89 % of first score axes variance with 3 latent components resulting in a Root Mean Squared Error of prediction RMSEP = 7,6 %. Second axes variability is represent to 75 % in selected spectral variables using 5 latent components (RMSEP = 11.6 %). In Figure 2 habitat type probabilities are spatially predicted on the basis of axes models. Habitat types are extracted for a Natura 2000 quality assessment according individual occurrence thresholds. Dry grasslands and heathland communities are spatially well separated with good habitat status in core areas. In contrast, LRT 6120 show a widely spread distribution with mostly degraded habitat characteristics. They often exist within transition to heathland.

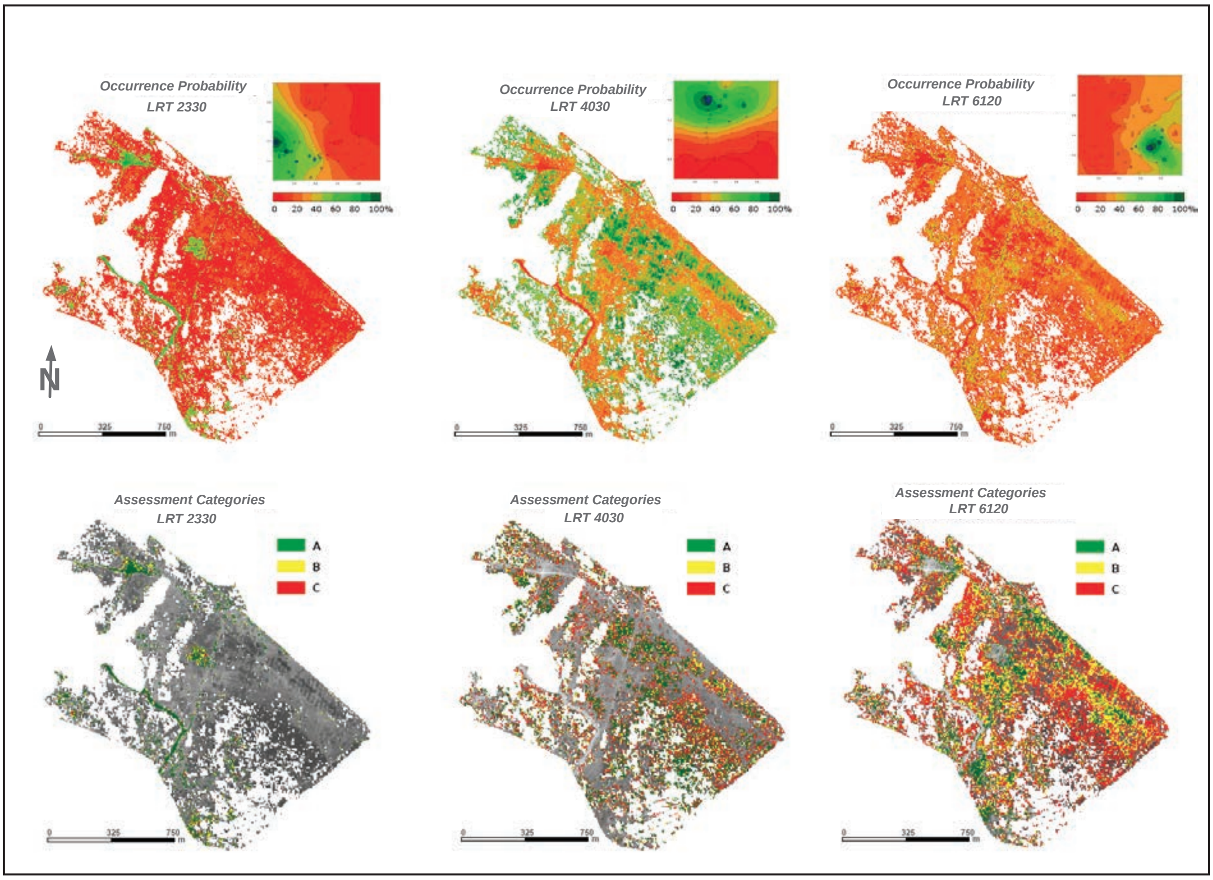

Figure 2: Spatial representation of ordinated FFH-habitat type occurrence probabilities and assessment categories

An external validation were performed on species transect comprising transitions between all three habitat types. In total the fractional cover of character species on 23 plots was correlated to habitat type probability. Calluna vulgaris was well correlated to LRT 4030 with $R^2 = 0.85$. LRT 2330 is mainly correlated to Corynephorus canescens ($R^2 = 0.79$) and bare ground ($R^2 = 0.84$). Xeric grasslands (LRT 6120) are more complex in species composition. Best correlation can be achieved with Festuca ovina agg. ($R^2 = 0.61$). It can be concluded that species rich environments are more difficult to aggregate in ordination spaces with regard to distinct parameter separation. Hence, a spectral monitoring must be reduced to highly diagnostic species concern spectral and ecological separable gradients.

4. Outlook

The proposed Natura 2000 monitoring approach can be further developed on different habitat type definitions (e.g. biotope, EUNIS). Its transferability to different landscapes should be assessed. Thereby its applicability on automated spectral library information extraction for hyperspectral imagery in varying phenological phases has to be tested.

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Natura 2000 Habitat Quality mapping in a Pannonic salt steppe from full-waveform Airborne Laser Scanning

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1. Introduction

Natura 2000 is the largest network of protected terrestrial habitats worldwide in terms of area, and is one of the most important conservation initiatives of the European Union. The Habitats Directive prescribes regular monitoring of habitat and species conservation status every six years to be undertaken by the corresponding member states. However, the sheer size of the habitats to be mapped, and the wide variety of assessment rules means that large areas are left unchecked, and the result of the evaluations is difficult to compare.

Remote sensing methods promise more standardized evaluation and better area coverage, especially in an optimal combination of sensor data processing and fieldwork.

In most cases, raw remote sensing data is used as an aid in field navigation and as a mapping background. Rarely, habitat mapping is supported by remote sensing-derived maps of the extent of specific habitats, or some environmental variables that influence habitat status. There are also some rare studies where remote sensing data was processed directly to the level of the habitat quality classification required by the directive, with encouraging accuracies.

With increasing point densities and the onset of full waveform processing and radiometric calibration, Airborne Laser Scanning (ALS aka. LIDAR) has capabilities to map not only vegetation structure but also a number of biotic and abiotic factors influencing habitat quality. By GIS analysis of these variables, it is possible to quantify conservation status of a study area.

In a general habitat mapping case, this would raise questions of which variables to take into account and how to weigh them against each other. The Natura 2000 habitat monitoring guidelines provide an answer to these questions, albeit from the perspective of terrestrial vegetation mapping and analysis.

1.1 Objectives

Our objective was to calculate Natura 2000 Habitat Quality for a grassland study site, adhering as closely as possible to the evaluation scheme of the local Hungarian grassland monitoring guidelines. This involved mapping all the variables listed by this scheme from sensor data, creating a GIS framework that compares and evaluates these datasets according to the Natura 2000 rules, and finally processing a habitat map theoretically ready for inclusion in a national report. We intended to test whether this is possible using only LIDAR data and field references.

2. Data and methods

2.1 Study site

Our study site was in Ágota-puszta (Hortobágy Special Area of Conservation Natura 2000 site) in south-eastern Hungary, which is characterised by Pannonic salt steppes and salt marshes (N2000 habitat code 1530). Additional Annex I habitat in the area – even with a smaller extent - is the Pannonic loess steppic grasslands (6250). Beside these grassland habitats planted forests, agricultural fields and wetlands are also present in the landscape. Micro-topography and soil conditions have an important effect on vegetation pattern, resulting in a very complicated mosaic of different associations.

2.2 Sensor data and field survey

Flight dates were timed to the peak of the biomass production before the summer droughts for leaf-on data, and very early spring for the leaf-off flight. A Riegl LMS-Q680 system was used, flown at an altitude of ca. 500 meters above ground. The sensor operated at the wavelength of 1550 nm with full waveform recording and a nominal ground point density of 22 pt/m^2.

The acquisition of field data was also carried out in several field visits, with most plots double-checked in an interval of several months. Habitat quality monitoring according to the standard Hungarian Natura 2000 protocol was carried out for 20 plots of 50×50 m, and in addition, patches of homogeneous vegetation were mapped with a differential GPS. Special attention was taken to represent the full spectrum of microhabitats as derived from the topography in transects perpendicular to the local slope. Reference points were also collected from anthropogenic features influencing habitat quality, such as vehicle tracks, trampling marks and crop fields, in a system of 60 micro-classes

2.3 Data processing and classification

Due to the final target of habitat quality mapping, we had to move beyond the classical raster model where one pixel belongs to one class. On one hand, this was due to the smooth transitions between different habitats (such as wetland and grassland), on the other hand, to the fact that not only vegetation was mapped. A single pixel was assigned a set of membership probabilities for different vegetation classes, but could also belong to e.g. a tread mark or have a certain coverage of weeds. This was solved by creating several different unique sets of classes (“scenarios”) for the same study area, each focused at different aspects of the habitat, (anthropogenic features, land cover, plant communities, tree species), and each processed both to single-class membership rasters and fuzzy class membership probabilities. Terrestrial data was split into calibration and validation polygons (50-50%), and classification was carried out by a random forest machine learning script working on data products of the LIDAR point cloud.

The main Natura 2000 habitats could be identified with accuracies around 75%, and the main plant associations within these classes could also be detected with considerable accuracy. Analysis of the Digital Terrain Model led to detection of micro-topographic features and human-induced erosion as well.

Based on the Hungarian Natura 2000 monitoring scheme for grasslands, a network of 50×50 m plots was established, and the following variables were evaluated in ArcGIS:

-Extent of alkali and loess grasslands within each plot was read from the respective hard classification rasters. Only plots with at least 5% of their area occupied by one of these habitats were further analysed.
-Naturalness of a habitat was calculated based on the fuzzy class probability rasters: if the probability of belonging to the grassland class was high, it was assumed that the species pool corresponds to the habitat.
-Patchiness of the habitat: the typical patch sizes and the patch diversity of each study plot were calculated from the classification layer representing the sub-habitat associations.
-Vertical structure: NDSM height and echo width values were averaged within each plot and positive scores were assigned to the plots where these were close to the mean value.
-Species pool: Information on the associations indicates the most typical species present, therefore the presence or absence of each association typical for the respective grassland habitat was checked, keeping in mind that this is only a proxy of the full species pool
-Erosion: for alkali meadows, the presence of erosion channels and salt flats resulted in a positive score
-Weeds: The proportion of the plot affected by weed probabilities above a threshold value was calculated
-Disturbance: Buffer distances were calculated for each anthropogenic disturbance feature, and a negative score was assigned to plots affected by the buffer
-Neighbourhood: The distance to the nearest similar habitat plot was calculated, and connecting features where checked including watercourses and wetlands
-Tree and shrub encroachement: Plots with invasive trees (*Eleagnus angustifolia, Tamarix tetrandra*) were given negative scores. Sparsely distributed non-invasive shrubs were considered positive, while dense shrubs and trees were assigned a negative score.
The output map of habitat quality (favourable, unfavourable, bad) was compared with the habitat quality surveys made in the field (which were not used to calibrate the algorithm), and the accuracy evaluated for the overlapping plots.

3. Results and discussion

The clearly and strictly defined rules of the Hungarian Natura 2000 mapping system together with the scheme of aggregating positive and negative scores was suitable for direct representation with GIS operations. The most important monitoring parameter, the coverage of different species could not be directly mapped by laser scanning, but the individual plant associations and communities which are the sub-units of the habitat types were detected, and this information was used to represent species composition.
While the accuracies of the input rasters are not always very high, the aggregation of spatial information from high resolution input data to the evaluation plots reduced noise. Since the evaluation scheme only contains three categories, it is not surprising that most reference plots were correctly categorized. However, the main benefit of this approach is that it delivers full coverage of the habitat map instead of the sampling plots typical for field studies. This allows understanding spatial trends in habitat quality, and selecting both the most threatened and the best preserved patches for conservation management.
Another important advantage is that for each study plot, the input maps allow checking why the habitat quality has been evaluated to the respective value. Vegetation classes, human influence, terrain properties and other factors can be checked in the respective raster products.

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What Remote Sensing Can Do and What Not for Habitat Mapping and Quality Assessment – Lessons from the "ChangeHabitats2" Project

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1. Introduction

The EU Habitats Directive (European Commission 1992) requests a regular monitoring of the status of habitats and species listed in its annexes. The current state of the art in EU habitat monitoring is time-consuming field work, involving many specialists working at a very detailed mapping scale, often in rather inaccessible or dangerous terrain. Based on the field mapping, conservation status is assessed and reported to the EU every six years. However, working all the Sites of Community Interests would take more than 10 years in all EU Member States. Furthermore, this traditional scheme of field mapping raises questions of repeatability (Hearn 2011), inter-observer variability (Spanhove et al. 2012) and is unfeasible over large or inaccessible areas. Thus the EU funded Marie Curie project "ChangeHabitats2 – Network for Habitat Monitoring by airborne-supported field work" aims to develop a cost- and time-efficient, airborne-supported approach using innovative image analysis and effective field work techniques for Natura 2000 assessment.

Presently, field work is supported by aerial photos (BfN 2009). Orthophotos might enable scientists to assign habitat types to photographic features; however, the procedure is still a very rough interpretation and does not replace field work at all. Satellite images are used as well, but they are usually at a lower spatial resolution; however, their high temporal resolution supports detection of various habitats based on seasonality (Förster et al. 2012).

As a more recent technique Airborne Laser Scanning (ALS aka LIDAR) is increasingly used for mapping terrain topography and vegetation cover. It relies on distance measurement based on the travel time of laser pulses, from which terrain surface and vegetation canopy elevation are derived. For many European states and regions, ALS data are already available or being routinely collected.

Thus the “ChangeHabitats2” project aims at integrating ALS-derived maps and indicators for supporting Natura 2000 habitat mapping and assessment. Since the laser pulse penetrates the vegetation canopy, vertical vegetation structure can be measured, and even features below a forest vegetation can be identified.

2. Parameters Used in Habitat Quality Assessment

When mapping habitat quality within the Natura 2000 framework a great number of parameters has to be collected, most of which can be assigned to one of the three categories: species, structure and disturbances. Among species those that are constitutive for the habitat type (dominating species, characteristic species or indicator species) and invasive species (both native and exotic) have to be mapped. The parameters which have to be recorded for habitat structure are obviously heavily dependent on vegetation formation. Specific parameters for habitat quality in forests are deadwood (both lying and standing) and trees as habitats, i.e. very old trees, trees with holes or big nests of e.g. birds of prey or black stork, or tinder fungus, bark fractures, living trees with fractured stems/crowns and upright root system of fallen trees. For grasslands the stratification, internal structure (e. g. percentage of tall and shorter growing grasses, cover of small herbs, herbs with rosettes) or the spatial vegetation structure (i.e. changes in sub-types on a fine scale, small-scale mosaic with other grassland habitats) are of relevance. The third parameter category is disturbance, both anthropogenic and by “natural” factors, like open soils, diggings of the wild boar, encroachment of species with ruderal or competitive strategies or certain life forms like tall grasses and shrubs, eutrophication, changes in water regime, roads, power lines, buildings and waste heaps.

Especially in silviculture there are a number of applications of airborne laser scanning to derive parameters for forest structure. Some studies have successfully derived structural parameters of forests relevant for habitat quality from LIDAR data, e.g. herbaceous layers (Vehmas et al. 2009) or understorey vegetation cover (Wing et al. 2012). Structural parameters have been applied as predictors for avian diversity in forests, like vertical distribution of canopy elements as an indicator for forest bird species richness (Goetz et al. 2007), indices for foliage height diversity predicting bird species diversity (Clawges et al. 2008), or statistics of canopy height distribution, vegetation layers and canopy openness for forest bird assemblages (Müller et al. 2010). Habitat suitability for individual species could be successfully predicted from LIDAR data for capercaillie (Graf et al. 2009: relative tree canopy cover, mean height of tree canopy, tree edge length) and woodpeckers (Garabedian et al. 2014: basal area, tree density). Habitat quality has been also inferred directly from LIDAR sensor data by Simonson et al. (2013).

3. Habitat Quality Assessment in the Light of LIDAR Data

As the examples from Section 2 show, previous habitat quality assessment approaches based on remote sensing are mostly founded on indirect parameters, often with a rather loose relationship to habitat suitability only. Two approaches attempting to use more direct parameters are (i) vertical heterogeneity (as derived from the absolute deviation of height LIDAR returns) as in indicator for snags (i.e. standing dead trees), which correlated well with habitat suitability indices as modelled from field investigations (Martinuzzi et al. 2009), and modelling of microtopographic features from LIDAR data as indicators of habitat factors (microclimate, soil moisture) for predicting optimum sites in the re-introduction of threatened species (Questad et al. 2014). Nevertheless, snags in the study of Martinuzzi et al. (2009)

were not identified directly, but rather derived from statistical correlations between LIDAR-derived measures of variation in canopy and snags mapped in the field.

For a more process-orientated approach which can be transferred to other sites and allows predictions of responses to changes in habitat quality, parameters which are more closely related to habitat quality and procedures to identify these parameters directly are needed. Thus, within the “ChangeHabitats2” project we attempted to identify some of the habitat features relevant for habitat quality assessment directly from LIDAR data, especially (i) lying and standing deadwood and dense shrub layers in forests; (ii) bare surfaces, field tracks and microtopography (e.g. erosion channels and erosion slopes) in (alkali) grasslands. We tried to follow the local Natura 2000 mapping scheme in this case as close as possible from the sensor data, attempting to identify every variable that the mapping scheme refers to.

An approach to derive information about the abundance of sub-dominant vegetation layers for forests was developed and tested in the Nagyerdö forest (East Hungary). The presence of shrub layers could be estimated with high accuracy. The identification of sub-dominant tree layers was also possible, but not as successful as for the shrub layers. In addition, a method to automatically detect deadwood in forests was developed. Via filtering the ALS point cloud according to surface roughness estimates we were able to remove echoes representing shrub vegetation effectively, thereby exposing objects underneath. Thus fallen trees could be identified very reliably. Also, the derived roughness parameters were found to be a useful indication on the decay level of the detected tree stems. However, no reliable estimator could be found for the identification of standing dead trees (Mücke 2014).

In the Pannonian alkali landscapes of the Hortobágy National Park (East Hungary) we tested the correlation between fine-scale differences in vertical position and vegetation pattern, using field vegetation data and Digital Terrain Model derived from ALS data. We demonstrated that main vegetation categories of alkali and loess grasslands are positioned along a vertical elevation gradient of a couple of decimeters. Microtopographic variables were more useful than even spectral variables — both derived from full-waveform ALS — for the classification of species and structures in these alkali and loess grasslands. Although comparisons with multi-spectral imagery have to be done, full-waveform ALS may have an edge over multi-spectral imagery for the mapping and habitat quality assessment of these habitats. The revealed elevation-vegetation correlations provide new perspectives in the ALS based vegetation mapping of alkali landscapes and also for other open heterogeneous habitat complexes such as large alluvial plains, sand dune vegetation or vegetation mosaics of fens and dry grasslands.

The extent to which such habitat quality parameters have been successfully identified and the potential of both successfully and not successfully identified parameters for representing ecological/habitat quality categories will be an important guideline for future research, not only for assessment of Natura 2000 conservation status to provide spatially explicit estimates of habitat quality over large areas, but also for other habitat quality assessment schemes like High Nature Value. Furthermore, parameters derived from high-resolution airborne laser scanning can be used for studying dynamics in plant communities like forest regeneration after disturbances and processes in ecosystems such as transfer of energy and dispersal of diaspores dependent on the three-dimensional spatial structure of system components.

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Can airborne laser scanning or satellite images, or a combination of the two, be used to predict the abundance and species richness of birds and beetles at a patch scale?

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1. Introduction

Management of forests for biodiversity conservation requires knowledge on the habitat needs of forest-dwelling species. Important habitat factors include local stand conditions such as forest structure and tree species composition as well as the amount and distribution of suitable local habitats in a surrounding landscape. Information at both these scales can be efficiently derived from remotely sensed data.

Focusing on the European boreal forest, this paper presents an analysis of the relation between the local-scale abundance and species richness of forest-dwelling birds and beetles on the one hand, and information derived from airborne laser scanning (ALS) data and satellite images on the other. The aim is to answer the following questions: 1. Can ALS-data or satellite image data or a combination of the two be used to identify important habitats for forest dwelling beetles and birds in boreal forest? 2. Which type of remote sensing data can best explain biodiversity patterns for beetle and birds species in boreal forest? 3. How accurate can different remote sensing methods predict biodiversity patterns at different spatial scales?

2. Materials

2.1 Study area and field data

The study area is a 30 × 40 km large forest landscape in the middle boreal zone (Ahti et al. 1968) in northern Sweden (64°05’ - 64°10’N, 19°05’ - 19°30’ E; Figure 1). During the summers of 2009 and 2010, we sampled stands in three age classes: young (10-25 years), middle-aged (40-60 years) and old (>80 years). The young and middle aged stands are regenerated with conifers after clear cutting, mostly Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*). The trees in the young stands are 1-6 m high. The middle aged stands include the oldest available stands which have been regenerated after clear-cutting, mostly in the 1950s-1960s. The older managed stands have been subjected to selective felling and thinning, but have never been clear-cut. In each study stand, three groups of species were sampled: birds (surveyed using fixed-radius point counts), flying beetles (captured using flight interception traps of the Polish IBL type) and ground-dwelling beetles (captured using pitfall traps). The species sampling was done at the scale of a 1 ha square. The correlation was high (0.67 - 0.81) between the observations of flying beetles and ground-dwelling beetles, suggesting that the two groups of beetles benefit from similar forest conditions. However, the correlation was lower (-0.04 - 0.28) between the observations of birds and the two groups of beetles.

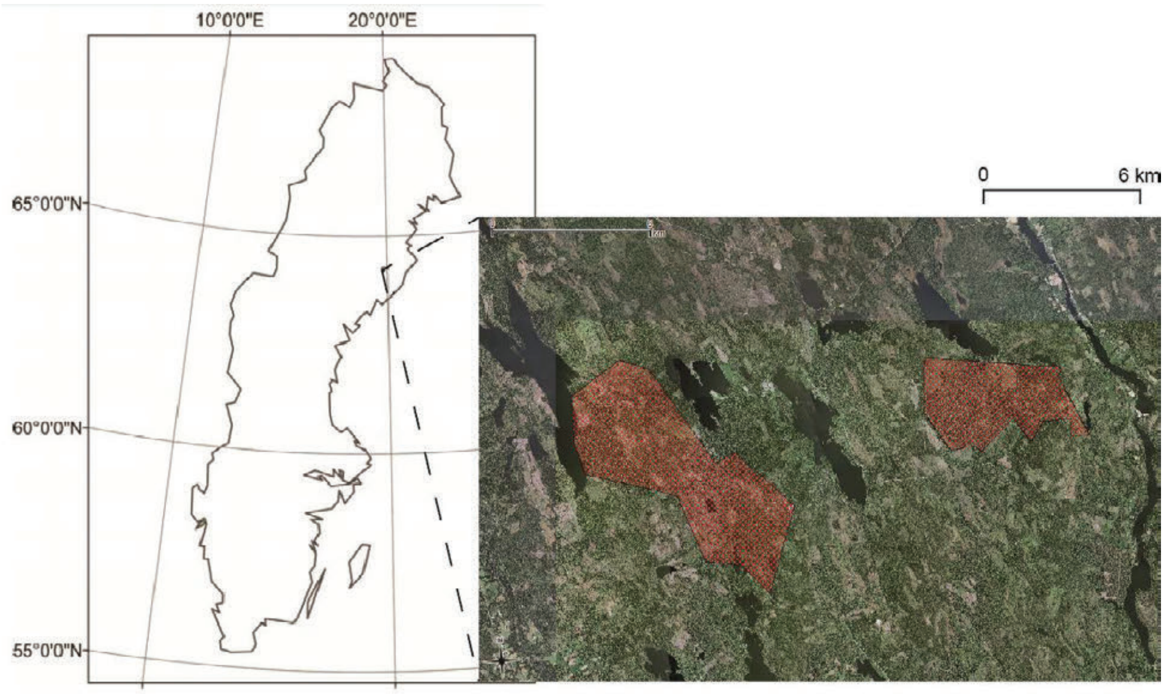

Figure 1: The position of the study area in Sweden and an orthophoto with the laser-scanned areas drawn in red.

2.2 Remotely sensed data

We extracted data from kNN-Sweden 2010, which provides information on forest age, tree height, total stem volume, and tree species composition in a raster with a resolution of 25×25 m (i.e., as a map). kNN-Sweden is based on forest data from the Swedish national forest inventory (NFI) combined with satellite images from SPOT 4 and SPOT 5 (Reese et al. 2003). Variables describing the forest conditions were derived as mean values of the 25×25 m raster cells in circles with 50 m and 200 m radius centred on the middle of the stands.
The ALS data were acquired on 3 and 5 August 2008, using a TopEye system S/N 425 with a wavelength of 1064 nm and a flying altitude of 500 m above the ground. The first and last returns were saved for each laser pulse and the average density of returns was 5 m^{-2}. Laser returns were classified as ground or non-ground and the ground returns were used to derive a Digital Elevation Model (DEM) with 0.5 m raster cells. Only study stands in the laser-scanned area were used for further analysis (Table 1).

Table 1. Number of study stands in different strata in the laser-scanned area; total number of study stands in brackets.

	Young forest	Middle-aged forest	Old forest	Total
Birds	17 (20)	16 (20)	14 (20)	47 (60)
Flying beetles	12 (14)	11 (14)	10 (14)	33 (42)
Ground-dwelling beetles	12 (14)	11 (14)	10 (14)	33 (42)

Metrics describing the height and density of the vegetation were calculated from the ALS data for each 10×10 m raster cell and the mean values were calculated within the 50-m and 200-m radii (Table 2).

Table 2. Summary description of the variables derived from kNN and ALS.

Variable	Description
kNN-based variables	
KNN_A	Mean forest age
KNN_H	Mean tree height
KNN_V	Mean total stem volume
KNN_P	Mean proportion of pine stem volume
KNN_S	Mean proportion of spruce stem volume
KNN_D	Mean proportion of deciduous (i.e. broadleaved) stem volume
ALS-based variables	
ALS _H95	Mean of the 95th percentile of height above the ground
ALS_HIGHR	Mean of the fraction of returns ≥ 3 m above the ground of all returns (higher vegetation ratio). This represents a general measure of higher-level foliage density, excluding bushes, short trees and branches below 3 m.
ALS_LOWR	Mean of the fraction of returns ≥ 0.5 m above the ground of all returns ≤ 3 m above the ground (lower vegetation ratio). This represents a general measure of lower-level foliage density.
ALS_SHANH	Mean of Shannon's diversity index for height. This provides an index of foliage height diversity (*sensu* MacArthur and MacArthur 1961).

3. Methods

Regression models were created for abundance and species richness as functions of variables derived from kNN and ALS data. For each response variable, three regression models were created for each of the two radii (50 m and 200 m): one with variables derived only from kNN, one with variables derived only from ALS, and one with variables derived from both sources. The independent variables for the final models were selected based on the Akaike information criterion corrected for finite sample sizes (AICc).

4. Results and discussion

Several of the regression models with the lowest AICc included the variables ALS_H95 or KNN_H (Table 3). These variables describe the mean height of the forest within the area, which generally increases with the age of the forest. The variables HIGHR and LOWR were also included in some regression models. They describe the mean density of the forest. The variable KNN_V was included in some regression models for the 200 m-radius. It describes the mean stem volume.

At the 50-m radius, all of the selected models included variables derived from ALS only. At the 200-m radius, 4 of the 6 best models included variables derived from ALS only, and 2 included kNN variables. The reason might be that the ALS data describe the forest better than the kNN data, especially for smaller areas.

For each of the 6 response variables, the model based on variables derived within the 50-m radius had lower AICc and better explanatory power than the model based on the 200-m radius. One possible explanation is that the habitats of the studied species depend mostly on local forest conditions (i.e., within the 50-m radius). However, other possible explanations could be that the forest conditions change too much within the 200-m radius and the derived variables don’t characterize the factors that are important at this scale.

Table 3. Regression models with lowest AICc.

	50 m radius			200 m radius		
	Regression model	Adjusted R2	AICc	Regression model	Adjusted R2	AICc
Bird abundance	~ALS_HIGHR_50	0.35	37.7	~ALS_H95_200 + ALS_LOWR_200	0.21	47.9
Bird species richness	~ ALS_H95_50 + ALS_LOWR_50	0.37	32.2	~ALS_HIGHR_200	0.18	43.8
Flying beetle abundance	~ALS_HIGHR_50 + ALS_LOWR_50	0.43	39.7	~ ALS_H95_200	0.28	46.0
Flying beetle species richness	~ALS_H95_50	0.38	9.4	~ALS_H95_200	0.24	16.3
Ground-dwelling beetle abundance	~ALS_HIGHR_50	0.53	73.7	~KNN_V_200	0.45	78.9
Ground-dwelling beetle species richness	~ALS_HIGHR_50	0.60	29.8	~KNN_V_200 + KNN_H_200	0.56	34.3

These preliminary results suggest that ALS data can provide a useful complement to satellite images for describing patterns of beetle and bird diversity in boreal forest. The best regression models for the different response variables were all based on variables derived from ALS data, meaning that variables derived from ALS data had a greater explanatory power than the variables derived from satellite images.

The best regression models were achieved for a smaller radius, suggesting that the effects of local conditions override those of the landscape surroundings in this system.

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eHabitat: Large scale modelling of habitat types and similarities for conservation and management of protected areas.

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1. Introduction

Protected areas need to be assessed systematically according to biodiversity values and threats so as to support decision making and fund allocation processes. Characterizing protected areas according to their species, ecosystems and threats is therefore required. While species based conservation approaches are the most commonly used, assessing natural habitats is also important. Among other ecosystem services, natural habitats offer refuge for species and can be mapped at a global scale by means of remote sensing in a harmonized way, not being biased by sampling efforts related to study location or taxa.

2. Methods

eHabitat, which is one of the services supporting the DOPA, the Digital Observatory for Protected Areas[1] (Dubois et al. 2013a,b), proposes a habitat replaceability index (HRI) which can be used for characterizing each protected area worldwide. More precisely, eHabitat computes for each protected area a map of probabilities to find areas within the corresponding ecoregion (Olson et al. 2001) presenting ecological characteristics that are similar to those found in the selected protected area. The HRI is then computed as the ratio between similar areas outside park and the park area itself.

Several environmental variables are used for identifying similar habitats through multivariate analysis using the Mahalanobis distance (Mahalanobis 1936): percentage of tree cover, percentage of grassland cover, elevation, slope, aridity, biotemperature, precipitation, Normalized Difference Vegetation index (NDVI) and Normalized Difference Water index (NDWI), some of the representing long term annual averages and all of them mapped at 1 km^2 globally (for more details see Dubois et al. 2013b).

There are two recent implementations of eHabitat, one programmed in R and a second one in Python. The first one uses some of the main spatial libraries in R, such as the 'sp', 'rgdal' and 'raster' libraries, has parallel computing capabilities and is integrated as part of some Web

[1] http://dopa.jrc.ec.europa.eu/

Processing Services (WPS)[2] (Skøien *et al*, 2013, Dubois *et al*., 2013b). The underlying codes are available online as an R library from GitHub[3]. The Python version, not yet integrated within the WPS, was developed for improving stability and increasing computational speed. It uses several numerical and scientific python libraries, such as NumPy, SciPy, Multiprocessing, Scikit-learn and the source code is also available online[4].

3. Improvements to eHabitat

One of the main limitations of the current eHabitat version is that protected areas with heterogeneous landscapes would lead to an overestimation of the probabilities to find similar areas elsewhere because the statistical approach considers an "average habitat" over the whole surface of the analysed protected area. The variables characterizing the "average habitat" may be represented by a range of values that is too broad, leading consequently to a high variance in the final results. This problem can be illustrated by computing the HRI over the Odzala-Kokoua National Park, a large (13,600 km^2) protected area located in the North of the Congo Republic.

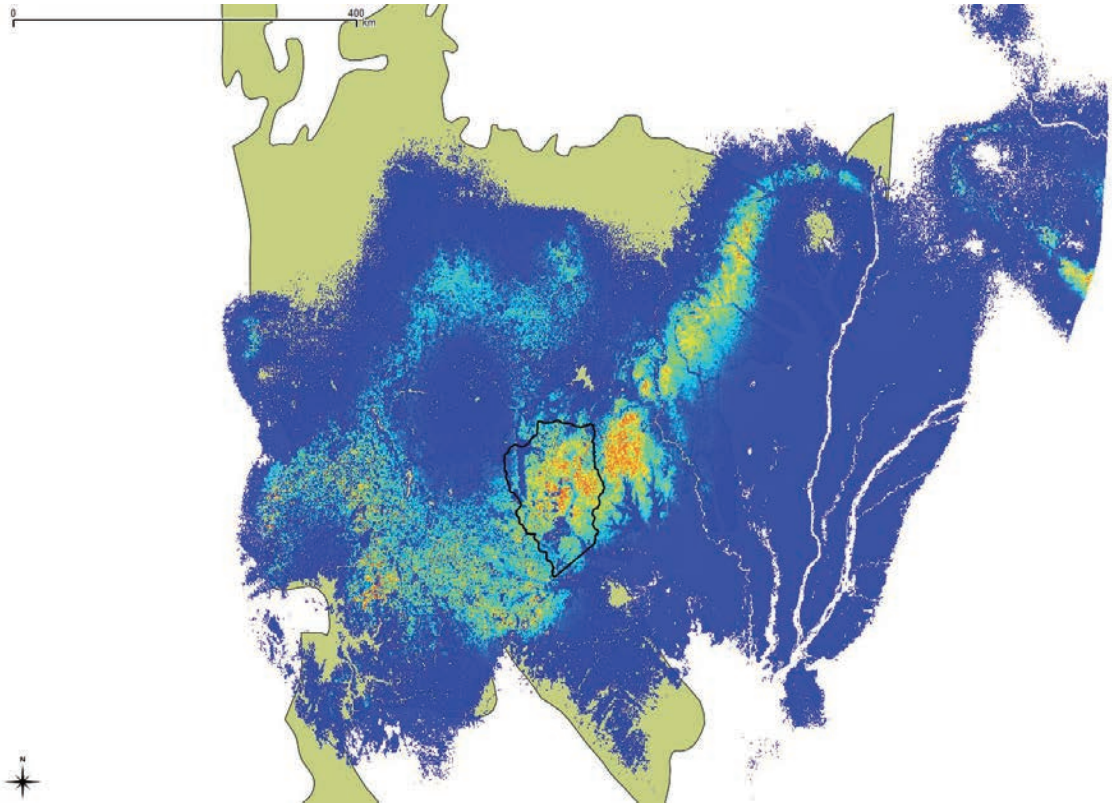

Figure 1: Map of habitat similarities to a protected area (delimited by the black central polygon boundary) within the Northwestern Congolian lowland forests ecoregion where it is present

[2] http://ehabitat-wps.jrc.ec.europa.eu/ehabitat/
[3] https://github.com/javimarlop/eHabitat
[4] https://github.com/javimarlop/eHabpy

(delimited by the green polygon). Similarity values range from 0 (blue; high dissimilarity) to 1 (red; total similarity).

The park, with a surface of 13,600 km^2, shows, according to Figure 1, that the northwest and the south of the protected area are dissimilar to the centre of the area. Continuity of the estimated “average habitat” outside of the park is shown along an axis of 30° across the ecoregion. A detailed analysis using land cover maps and expert feedback will confirm that the area is densely forested in the northwest while the south of the region presents a forest-savannah mosaic. The largest part of the park is covered by open forest in the south and the east. By implementing a preliminary segmentation step to eHabitat 2.0, we allow these main ecological features of the protected area to be identified automatically prior to a further individual processing for generating the similarity maps (Figure 2).

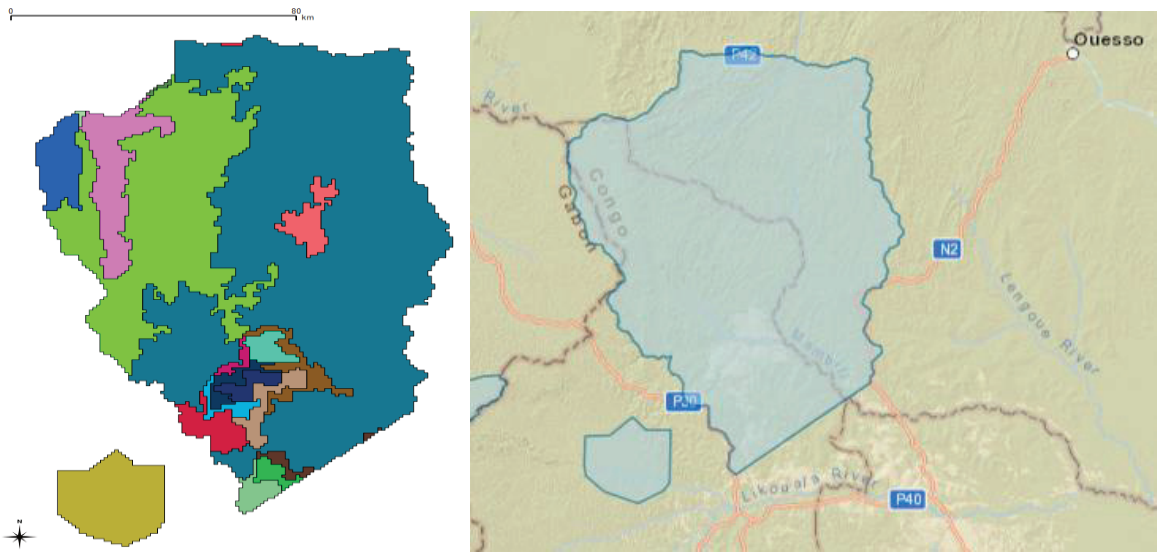

Figure 2: Automatic habitat segmentation (left) of the Odzala-Kokoua National Park (right) based on several environmental indicators using GRASS GIS 7 (using *i.segment* module).

The automatic segmentation of parks prior to HRI computation allows for a discrimination of different habitats types inside of protected areas. By reducing the variability within landscape patches, similarity values can be considered to be more accurate. This approach should also further improve the associated niche modelling tools as proposed by Skøien et al. (2013).

4. Further developments

The above method will still require case studies to be validated by means of expert knowledge (parks managers, research community) and comparisons with different regional, national and global land cover maps. Still, the underlying tools allow for the automation of large scale analyses using continent wide consistent datasets, allowing results to be easily compared.

In addition to the new automatic segmentation step implemented using GRASS GIS 7, various landscape metrics such as patch area, fragmentation and shape indices, are considered for further improving the characterization of each protected area.

Technically, our developments based on self-written codes used in combination with Free and Open Source Software tools, should benefit in the future from links with the rasterEngine R library, Scidb or Hadoop which could significantly reduce the processing time of large datasets and allow us to implement web processing services capable to provide such functions for larger datasets to a larger group of simultaneous end-users.

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Comparing instructions to assess Natura 2000 Habitat conservation status across borders

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1. Introduction

Natura 2000 is one of the largest international schemes for habitat conservation in terms of protected areas. It was established based on the EU Habitats Directive (European Commission 1992). This Directive also requests regular monitoring of the situation of species and Habitat types listed in its annexes. All EU member states are obliged to report on the current conservation status (A - favourable, B - good, C - insufficient) of the Habitat types occurring on their territory in a six years' period. While the Directive defines the way habitat quality is interpreted and lists the main variables to be monitored, it does not provide strict guidelines on the methodological details for monitoring. These are left to be decided by each member state, based on local knowledge and subject to local scientific and political discussion. This means each member state has its own monitoring rules for Natura 2000 habitat quality.

One goal of the ChangeHabitats2 project was to investigate the potential for manual and automatic derivation of habitat parameters relevant for Natura 2000 assessments from remote sensing data. Therefore, we first investigated the content of the Natura 2000 assessment schemes of different countries/regions to identify the features we are looking for in the remote sensing data. Additionally we analysed the influence of the applied instructions on the assessment results.

2. Methods

We systematically reviewed national/federal Natura 2000 assessment guidelines of four countries/regions – Hungary (Horváth et al. 2009), Austria (Ellmauer 2005), German Federal states of Brandenburg (LUGV 2011) and Saxony (LfULG 2009a, b) for our investigated Habitat types (forests: Natura 2000 Habitat Codes 9110/9130, 91G0, 91E0, 91F0 and 91I0; grasslands: 1530 and 6250). The features were compiled in a table and allowed a comprehensive comparison between the assessment schemes.

For a practical comparison study we selected exemplarily beech forest plots (Habitat types 9119 and 9130) in two of our study areas - Natura 2000 sites "Soproni-Hegység" in Western Hungary (N 47°41', E 16°34') and "Hardenbeck-Küstrinchen" in Uckermark region, North-eastern Germany (N 53°16', E 13°28'). For these plots, we carried out Natura 2000 assessments according to the corresponding local instructions but also according to the chosen rules of a comparable, mostly neighbouring country/region. This allowed for quantitative comparison between the rules, investigating whether the different guidelines result in different scores of the conservation status for the same area.

3. Results

There is a general difference in the method how to calculate the final assessment result between the Hungarian assessment scheme and the other three analysed rule sets. In Austria, Brandenburg and Saxony all assessment (sub-)criteria are already described in three classes that meet an A, B or C. There are different ways to aggregate them to the final assessment result. In Hungary, there is a point scoring system for all requested parameters and the sum of the points assigned for favourable and unfavourable conservation status decides upon the final A, B or C.

The layout of the field monitoring is also different between some states, with Hungary taking an approach with nested sampling plots. In the German federal countries the fieldwork is carried out on the whole habitat area, Saxony prescribes one or two plots inside the area only for the vegetation relevées.

Regarding the content of the assessments, our results show many similarities between all four compared schemes on a rough level. For our investigated forest types for example, all instructions require to collect and evaluate data regarding the structure of the forest stand (spatial structure of the living trees, deadwood), its species composition and the human influence. Differences on this level concern for example the involvement of the spatial extent of the habitat area (in Austria it is part of the assessment itself, Saxony has defined a minimum size for the habitat types, no requirements in Hungary and Brandenburg) information about the surrounding landscape (only in Hungary relevant), and the status of forestry management.

A more detailed view into the features and their definitions revealed a lot more dissimilarities between the compared guidelines. Criteria like the ‘structure’ of a forest are divided into different levels of detail for example, and contain different features. Even if similar features are listed, the details or definitions of the feature differ between the countries. Coarse woody debris for example is defined by different diameters (≥ 20, ≥ 30, ≥ 35, ≥ 40 cm in Austria, Hungary, Brandenburg and Saxony respectively) and has to be measured/counted in different units (volume/ha in Brandenburg and Austria, number/ha in Hungary and Saxony). Additionally the thresholds for a favourable, good and poor conservation status (A, B, C) can be on different levels in the compared countries (≥ 2 dead trees/ha = favourable in Hungary, in Saxony there must be ≥ 3).

Based on the many differences in the instructions we expect that for many of the forest plots we studied, assessment by the local set of rules results in a different final evaluation score for its conservation status compared to applying rules from neighbouring countries/regions.

4. Conclusions

Whereas some of the observed differences reflect the variations in the natural conditions of the countries/regions and were expected (as species lists for Habitat types or to a certain extend age and size categories for living trees) other differences or their range were rather surprising.

On one hand, the monitoring guidelines have to reflect the local conditions and local expert knowledge as well as fit the practice in science and/or nature conservation authorities of each particular state. On the other hand, such differences cause difficulties with the data fusion and comparability on a European level and are especially impractical if habitat evaluation is to be supported by remote sensing on a broader (e.g. European) scale. The structure of the schemes themselves are already considered Earth-Observation friendly and would allow the use of remote sensing applications if methods to extract the necessary information were available. We suggest that in the framework of the EU 2020 Biodiversity Strategy target "improve and streamline monitoring and reporting" these aspects should also be taken into account.

Acknowledgements

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Monitoring of Habitat Quality in Fruit Orchards – a promising Example for the Application of Remote Sensing and GIS

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1. Introduction

Traditional orchards have been typical elements of the cultural landscape in many regions of Central Europe for several centuries (Figure 1). They are characterized by fruit trees such as apples, pears, plums and cherries, and apricots or peaches in some regions, which are scattered on small-sized meadows or pastures, and in rare cases on arable fields. The landscape is dominated by many adjacent orchard parcels differing in age, size, fruit species composition and management intensity, especially in the vicinity of settlements. Due to this unique combination of a herb and a tree layer, both of which are traditionally used at low intensities, traditional fruit orchards provide habitats for a large number of plant, animal and fungi species and are therefore important for the conservation of biological diversity.

Figure 1: A typical traditional orchard with apple and pear trees of different age and structure on a low-intensity meadow (Saxony, Germany; photo: R. Achtziger).

Traditionally managed orchards in Central Europe have drastically declined in number in the last decades (up to 90 % in some regions) due to habitat destruction, and are threatened by intensification or – even more importantly – by the abandonment of the traditional management of both fruit trees and meadows. These processes have resulted in a decrease of habitat quality. Therefore, tree orchards are more and more the focus of nature conservation, and (effective) methods for the assessment and monitoring of orchard habitat quality are strongly needed.

Based on comprehensive studies of the relationships between structural features of orchards and various plant and animal communities in orchard-dominated landscapes in Northern Bavaria (Southern Germany), several key structures at the tree, stand, and landscape levels are presented which are used for a rapid assessment of orchard habitat quality in the field. Due to the characteristic structure of orchards consisting of discrete units (trees), orchards could be a promising example for the application of remote sensing techniques in order to support monitoring and assessment of habitat quality in the future. For this purpose, we propose structural parameters at the tree, stand, and landscape levels that could potentially be used for applying remote sensing techniques such as LiDAR, multispectral or hyperspectral imagery, and GIS to support the monitoring of habitat quality in orchard-dominated landscapes in the future.

2. Structural Indicators for monitoring Habitat Quality in Orchards

2.1 Indicators of Habitat quality of the tree layer

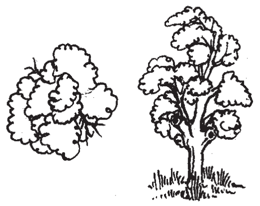
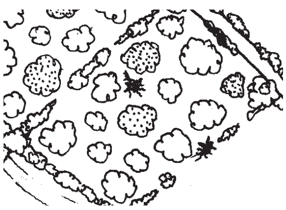
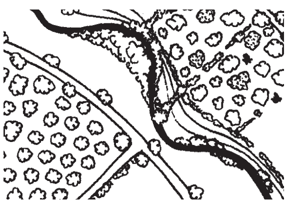
As has been shown by several studies on indicator groups such as birds, xylobiotic beetles, tree-dwelling bugs, leafhoppers and planthoppers, the high biodiversity of orchard habitats is the result of the occurrence, frequency and diversity of specific structural features at the tree, orchard (stand), and landscape levels (Table 1).

At the tree level specific structures such as tree hollows of different sizes, dead wood (stems, branches), epiphytes (lichens, mosses) and fungi as well as vitality, species identity, foliage architecture and density of the fruit trees are important indicators for habitat quality of tree-dwelling arthropods, small mammals or birds (Achtziger et al. 1999; Table 1). The amount and diversity of most of these structures are highly correlated with parameters of tree size and age. For example, tree caves suitable for the nesting of hole breeding birds occur on apple trees with diameters more than 0.25 m, which corresponds to an age of about 40 years (Achtziger et al. 2004). Besides size parameters such as height of the trunk, diameter at breast height, or crown diameter, the vitality and condition of a tree (see Table 1) is important for the structural diversity and hence the biodiversity of different tree-dwelling species groups: For example, we found the maximum number of xylobiotic beetle species in dead trees, whereas insects living on the foliage, or breeding birds showed the highest species richness in older, over-aged trees.

At the single orchard (stand) level the number and diversity of tree species, tree vitality and age classes (from young and newly planted to dead trees), tree density, distance between trees and specific structures such as stacks of wood, heaps of stones, and lying dead wood are important habitat structures (Table 1).

At the landscape level, landscape structure, isolation, and connectivity between single orchards or connections with adjacent habitats are important for the colonisation of newly planted orchards and for species groups with larger spatial requirements such as bats or birds (Table 1, Bailey et al. 2010, Horak et al. 2013).

Table 1. Structural parameters for the assessment and monitoring of habitat quality at the tree, stand and landscape levels in traditional orchards (tree layer only, data from Achtziger et al. 1999, 2004, Wiche 2011, and unpublished reports) with suggestions for suitable techniques to estimate these parameters (L = LiDAR, M = Multispectral imagery, H = Hyperspectral imagery, G = GIS, * = Not directly; may be possible to find indicators)

Level	Structural parameter indicating habitat quality	L	M/H	G
Single tree				
	Size parameters (e.g., height, crown diameter, height of crown base)	✓		
	Age and vitality class	✓	✓	
	Foliage density	✓	✓	
	Amount of dead wood	✓		
	Number of tree caves	*		
	Amount of epiphytes, fungi, small hollows filled with rotten wood	*		
Single orchard				
	Total number of trees	✓		✓
	Density of trees	✓		✓
	Number and proportion of different fruit tree species			✓
	Number, proportion and variability of tree vitality classes (e.g., proportion of dead vs. young trees)			✓
	Spatial distribution of trees (aggregated vs. regularly)			✓
	Average distance between trees			✓
	Amount of specific structures (e.g., lying dead wood, stacks of wood or brushwood, anthills)			✓
Landscape				
	Number / proportion of neighboring orchards vs. other habitat types	✓	✓	✓
	Proportion of orchards	✓	✓	✓
	Amount of fragmentation, connectivity			✓
	Proportion of abandoned orchards vs. newly planted	✓	✓	✓
	Other landscape metrics			✓

All the structural features of trees and hence the habitat quality of orchards are of course correlated with management intensity (e.g., cutting of trees for fruit yield increase, removing dead branches or epiphytes, replacing dead trees by new ones, frequency of fertilisation and mowing). It could be shown that an intermediate management intensity (i.e. moderate removal of dead wood or trees and moderate but continuous replacement of some dead trees by young ones) is important for a long-term and sustainable preservation of structural diversity and habitat quality in orchards.

2.2 Application of Remote Sensing and GIS Techniques for Monitoring Habitat Quality

Due to their characteristic structure – spatially separated trees – monitoring of habitat quality of orchards may be a promising example for the application of remote sensing and GIS techniques. Jang et al. (2008) were able to quantify the number of trees in an orchard and several other tree characteristics related to parameters such as crown density and vitality by using a combination of airborne LiDAR and multispectral sensors. Several of these structural parameters are indicators of habitat quality at the tree level, and can be used in a GIS to estimate the parameters at the stand and landscape levels (Table 1). Warner and Steinmaus (2005) used high spatial resolution panchromatic imagery to classify a landscape into orchards, vineyards and non-orchards with 95% accuracy. Remote sensing and GIS techniques can therefore support habitat quality assessment and monitoring based on structural parameters in traditional orchards.

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User Needs, Possibilities and Limitations of Remote Sensing for Natura 2000 Habitat Monitoring - Results from the European MS.MONINA Project

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1. Introduction

As part of the implementation of the Habitats Directive (92/43/EEC), member states throughout the European Union have selected outstanding natural areas on their territory to become part of a Natura 2000 network of protected areas. The aim of this directive is to reach and maintain a favourable conservation status for the most typical or most threatened habitat types and species in Europe, listed in the annexes to the directive. To monitor progress towards this aim, member states are required to deliver six-yearly reports on the conservation status of each habitat and species (Art. 17 of the directive), based on sound monitoring data covering their whole territory (Art. 11). For habitats, such data not only include the range and area, but also an assessment of the habitats' specific structures and functions and their typical species, or in short, their quality.

2. Habitat Quality Monitoring Needs

To monitor a habitat's specific structures and functions, several member states have drawn up lists of indicators that can be used to assess the quality of a habitat patch in the field. Indicators that are typically evaluated comprise structural characteristics (e.g. proportion of dead wood in a forest), disturbance-related criteria (e.g. grass and tree encroachment in open habitats), characteristics related to the floristic composition (e.g. number of key species present) and landscape configuration (e.g. connectivity and isolation) (Bock et al. 2005, Tiner 2004). Vanden Borre et al. (2011) provide an example from the Flemish habitat quality assessment manual (T'jollyn et al. 2009). Given the diversity and the large number (currently 231 on the Annex 1 of the directive) of the habitats, it is no surprise that the list of indicators is very long. Moreover, many indicators apply to only one or a few habitat types (Figure 1). If one adds to that the large set of site-specific requirements from site managers in the frame of appropriate conservation management (Art. 6 § 1 of the Habitats Directive), the need for data in this field becomes extremely huge and diverse.

Remote sensing has repeatedly been suggested as a highly suitable tool to cover these data needs (e.g. Nagendra 2001, Kerr and Ostrovsky 2003, Turner et al. 2003, Gross et al. 2009). But despite several studies aiming at developing practical applications of remote sensing in Natura 2000 monitoring, the step towards actual operational use apparently still is a big hurdle to take (Vanden Borre et al. 2011).

3. Remote Sensing Applicability

MS.MONINA (*Multi-scale Service for Monitoring Natura 2000 Habitats of European Community Interest*, http://www.ms-monina.eu) was an FP7 project in the frame of Copernicus (formerly GMES), aiming to develop dedicated earth observation based services to help authorities and managers at European, national (EU member states) and local (protected sites) level comply with their monitoring and reporting obligations on habitats under the Habitats Directive (Lang et al. 2012). Within the local-level oriented work package, project partners gathered their collective experience in the form of 16 mostly pre-existing methods for habitat mapping or monitoring through remote sensing, together with existing data on their targeted habitat types and preferred study sites. An analysis of the user requirements for these sites showed that only very few requirements ('indicators') are sufficiently widely used and potentially suitable for the development of a more generic remote sensing approach (e.g. shrub and tree encroachment in open habitats). This is not necessarily problematic, since Spanhove et al. (2012) showed that indicators often are correlated with one another, and that fine-scale, difficult to record indicators can be modelled to a certain extent using coarse-scale, more easily assessable indicators.

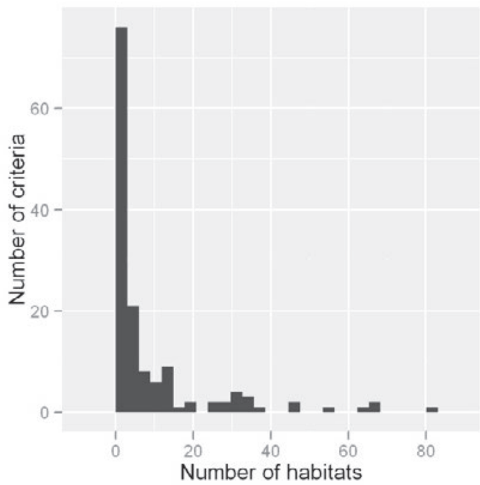

Figure 1: Histogram of the number of habitats in which a given criterion ('indicator') is used in the Flemish manual for habitat quality assessments (T'jollyn et al. 2009). The majority of the criteria are used for a few habitat types only.

But even if remote sensing focuses on these suitable indicators, the question remains whether developed methods are effectively widely applicable. Figure 2 shows the assumed applicability of a set of six remote sensing approaches, each used to assess shrub and tree encroachment in open habitats, as perceived by the developers and/or providers of the method. The graph illustrates the providers' optimistic viewpoint on the broad usefulness of their methods across a wide range of habitats (black and orange dots), but it should be noted that actual testing has only been done on a limited number of habitats and biogeographical regions (green dots).

Therefore, in MS.MONINA, we set up some tests of transferring and applying methods to different settings, i.e. other study sites than the ones for which they were developed. Although a quantitative analysis of the results was not possible, it was clear that some techniques did well, but many others failed or needed at least substantial adaptations. Several factors may be contributing to this low transferability: variations in user needs, characteristics of the sites, habitats and species composition, timing and quality of the imagery, training data requirements of the algorithm, etc. Despite the huge potential of remote sensing, the lack of transferability of some remote sensing methods is undoubtfully a major obstacle towards operational systems. New method developments will need to take care to avoid this pitfall. Meanwhile, when existing methods are transferred to other settings, it should be taken into account that adaptations to the method will generally be unavoidable.

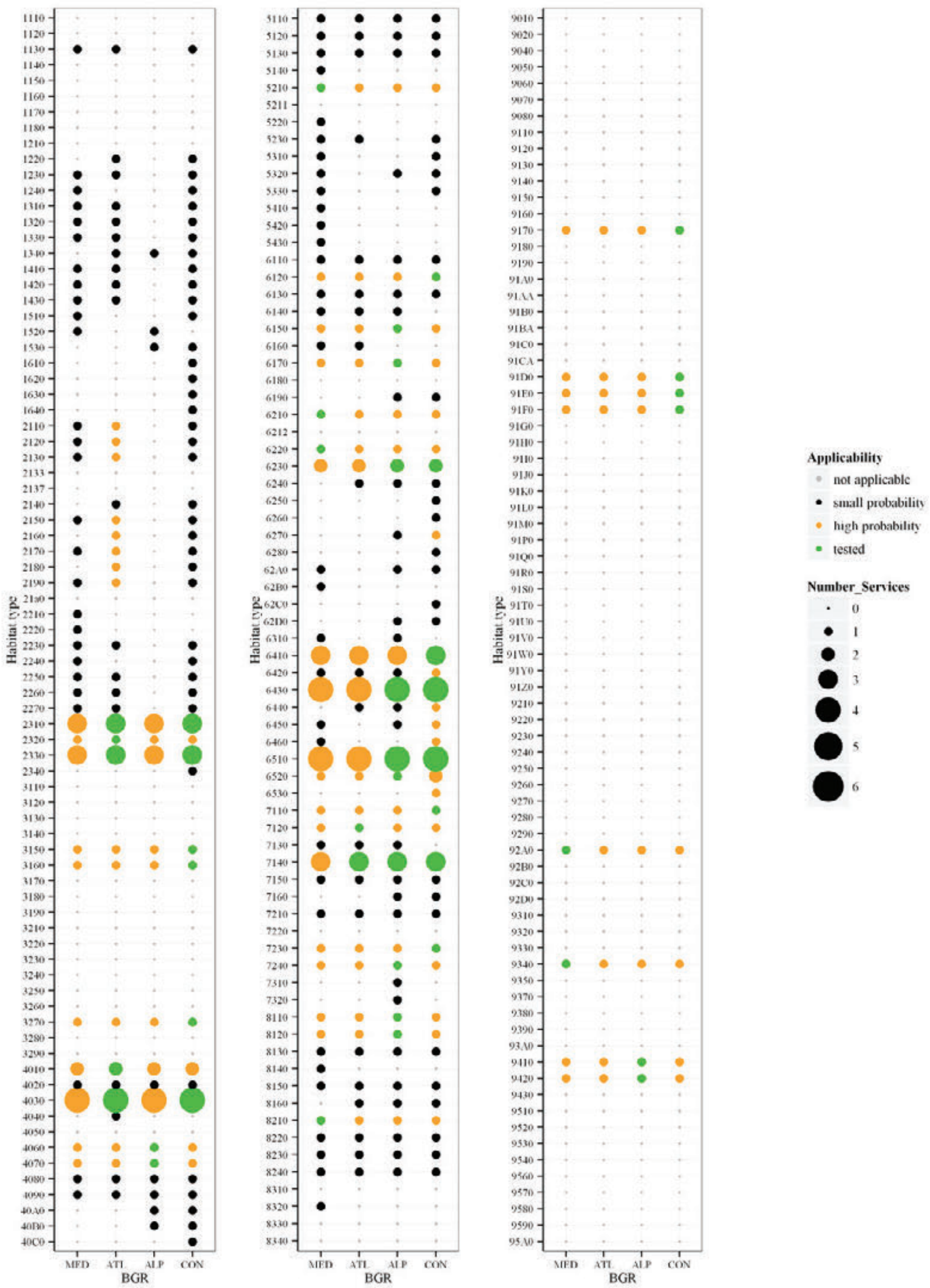

Figure 2: Assumed applicability of six ‘shrub and tree encroachment’ methods across habitat types (four digit codes, *y*-axis) and biogeographic regions (BGR, *x*-axis, MED: Mediterranean, ATL: Atlantic, ALP: Alpine, CON: Continental), based on expert judgements by the service providers. For simplicity, the colour only reflects the highest assumed applicability probability and ignores the opinions of service providers that gave a lower probability.

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Mapping of habitat type and quality with the Natura 2000 habitat monitoring service of North Rhine-Westphalia (Germany)

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1. Introduction

In the last decade, numerous studies (e.g. Bock et al. 2005, Förster et al. 2008, Vanden Borre et al. 2011, Spanhove et al. 2012) and related international projects (e.g. MS.MONINA, BIO_SOS) have shown that remote sensing (RS) data can be used for habitat mapping. At present though, there is no systematic use and integration of RS in the Natura 2000 habitat monitoring procedures in most of the German Federal States. This fact is due to the discontinuous availability of cost-efficient RS data for Federal authorities and a lack of standardized procedures. Moreover, Federal authorities often do not have the technical knowledge for RS data analysis.

The European Copernicus program, and especially the Sentinel satellite missions, will provide earth observation data from different sensors with high revisiting times under a free and open data policy. To facilitate a systematic integration of earth observation data and analysis into federal Natura 2000 habitat monitoring procedures in Germany, the North Rhine Westphalian State Agency for Nature, Environment and Consumer Protection is developing in collaboration with the technical partner EFTAS the pilot service “Natura 2000 habitat monitoring North Rhine-Westphalia”. This service will be able to analyse RS data and combine the resulting information with available geodata (e.g. Digital Surface Model, Digital Terrain Model, Soil Type) to provide useful information for subsequent terrestrial habitat mapping. Upon completion, the pilot service will be made available to all other German Federal States.

2. The pilot service

The core of the pilot service is the application and further implementation of the Information Layer Concept, which was developed by the MS.MONINA project (Buck et al. 2013, Lang et al. 2013). Within known segments, e.g. cadastral areas or areas delimited in former terrestrial habitat mapping campaigns, the analysis tool searches for information indicators. These indicators may be for example the portion of the segment covered by woody species, the height of vegetation or the variability of biomass throughout the year. Every indicator is then expressed as a separate raster information layer based on the input RS data or other ancillary geodata. These information layers are the first output of the service and may then be directly used for supporting terrestrial mapping.

Moreover, the tool combines all created information to give indications on the habitat type and quality present in the analysed segments. This is done by the application of pre-defined expert class models.

3. Indicators for habitat type and quality

The pilot service will include a set of information indicators for both habitat type and habitat quality evaluation. To determine relevant indicators a first screening was carried out of all criteria and sub-criteria currently used by national and regional authorities to classify habitats and to evaluate their quality. This screening checked which of these criteria and sub-criteria could be described by indicators for interpretation derivable from RS data analysis.

Second, from the remote sensing perspective we identified additional indicators for interpretation which up to today have not been used by terrestrial habitat mapping. For this a first user workshop was held in April 2014, bringing together monitoring experts from eleven Federal States in Germany. This led to a set of indicators, that is currently assessed for their inclusion in the above mentioned information layer approach.

4. Perspectives

With a successful development of the monitoring service, the Federal States of Germany will be able to reduce the costs of Natura 2000 monitoring because RS-derived information on habitat type and quality can reduce terrestrial mapping efforts. Especially the use of change detection analyses tools should enable focussed terrestrial mapping campaigns on those areas where changes in habitat type and/or quality actually occurred. In addition, RS-derived information can be used for data quality control.

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Semi-automated mapping for the National Inventory of Landscapes in Sweden (NILS) using Landsat and LiDAR data

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1. Introduction

The National Inventory of Landscapes in Sweden (NILS, http://www.slu.se/nils) is a sample based landscape inventory used to monitor biodiversity on a continuous basis. NILS is carried out by the Swedish University of Agricultural Sciences (SLU) on behalf of the Swedish Environmental Protection Agency. NILS captures vegetation data for all terrestrial environments: agricultural lands, wetlands, urban environments, forests, and coastal and alpine areas. Thus, NILS complements the National Forest Inventory (NFI; also carried out by SLU), which has an emphasis on productive forest land.

NILS is based on a nationwide stratified sample of 631 squares (Ståhl et al. 2011). For each sample location, a 1 * 1 km square is photo-interpreted and 12 plots within this square are inventoried in the field. There are 39 variables with sets of classes to be estimated for the delineated polygons. By using variables instead of predefined habitat classes, the data are more likely to be compatible with other programs, such as those for surveillance and monitoring of European habitats.

An outer 5 * 5 km square around each 1 * 1 km inner square is presently used for special inventories by different authorities. An example of such an "add on" survey to NILS is collection of data on small biotopes and their management in rural landscapes which is financed by the Swedish Board of Agriculture. There is a need to create wall-to-wall data within the 5 * 5 km area so that the measurements in the inner square and the special inventories can be analyzed in a landscape perspective. The mapping of the 5 * 5 km square should be done with automated remote sensing methods, possibly in combination with complementary photo-interpretation. The aim of the development project presented here is thus to establish a method for semi-automated mapping of vegetation type, vegetation height and cover within the 5 * 5 km^2 squares. Earlier research has shown that 3D data from airborne sensors and multispectral satellite data complement each other when used for vegetation mapping (Nordkvist *et al.* 2012; Reese *et al.* 2014). The primary method investigated in this project is therefore to combine LiDAR data (from an ongoing national airborne laser scanning carried out by the Swedish mapping authority) together with Landsat 8 images. Since the aim is to develop methods that can be used operationally in a nationwide application, we try to use existing field plots from NILS and the NFI as reference data in the final product. Here we present intermediate results from classifications with these data sources. The ongoing national laser scanning is not expected to be repeated in the foreseeable future. The possibility of replacing the laser data with 3D point clouds obtained by matching digital aerial photographs will therefore also be studied in the project.

2. Material and methods

The national laser scanning, acquired primarily for the construction of a new elevation model, has a posting density of 0.5 – 1 laser returns / m^2. The scanning is divided into blocks of 25 by 50 km. In order to obtain a sufficient number of field plots from NILS and the NFI as training data, the remote sensing datasets should cover large areas, encompassing many field plots. We are therefore using Landsat 8 images (185 x 185 km) in the present project, while waiting to use Sentinel 2 data (290 x 290 km) in a future operational phase.

To combine 3D datasets of different extents and properties together with satellite images, a stratified approach is tested. Forest variables can be estimated from smaller areas due to a relatively dense sample of field plots in the NFI. Predictions of canopy cover and basal-area weighted mean height are made based on regression models built using the NFI plots and a 25 x 50 km LiDAR block. A minimum of 200 field plots inventoried within a five-year period from the LiDAR scan date are used. Field plots from adjacent LiDAR blocks with similar properties might be needed for obtaining a sufficient number of reference NFI plots. Using predictions based on the LiDAR data trained with NFI plots, the 5 * 5 km NILS squares are stratified into forest and non-forest, where forest is defined as areas with more than 20% canopy cover and having trees more than 3 m tall. Within these two strata, separate classifications are made of the Landsat 8 data. The training of the subsequent satellite data classification will be done with NFI plots in the forest strata and NILS field plots in the non-forest strata, but in the development phase, subjectively chosen photo-interpreted plots were used for training of the field layer classification. The forest strata is classified as coniferous or deciduous, based on the majority of basal in the plots used for training these two classes

3. Early results

Initial tests show that canopy cover predictions from LiDAR had an acceptable error level when using photo-interpretation as training data, but had higher error levels when subjective field judgments of canopy cover was used as training data. Tests also show that accurate measurements of canopy cover are best obtained from the NFI plots by using the measured stem diameters in combination with functions for the relationship between stem diameter and crown diameter (Jakobssons 1970). The RMSE for basal area weighted tree heights obtained when using NFI plots for training data was 9-11 %, when evaluated at plot level.

Furthermore, a classification system for field and bottom layer vegetation suitable for the NILS inventory is currently being tested. Results for the classifications are expected at the time of the conference.

Table 1. Error matrix for forest strata from a test site in southern Sweden, using random forest on a balanced training data set of NFI plots and OOB estimate of error.

	Coniferous	Deciduous	Producer’s accuracy
Classified as coniferous	99	10	90.8 %
Classified as deciduous	11	94	89.5 %
User’s accuracy	90 %	90.4 %	Overall accuracy: 90.7 %

An early tests has also been made where the use of 3D point clouds from digital photogrammetry where compared with the use point clouds from laser data, in both cases using colour information from a SPOT HRG image. Training data was in this test obtained by photo interpretation. For classification into four classes: coniferous forest, deciduous forest, vegetation outside forest, and water were 88% overall accuracy obtained with only SPOT data and 93% with using SPOT data in combination with either digital photogrammetry or LiDAR data.

4. Discussion

Monitoring and assessing habitats needs not only information of site quality but also landscape context information at various scales. The NILS inventory gives information on plot level via a field inventory, and detailed information on the local context via manual interpretation. A very real aim of the inventory program is to optimize the relationship between workload, time consumed and statistical soundness of the data collected. Taking the work load into account, use of automated remote sensing methods and existing field data from the NFI and NILS inventories for the provision of context information on a larger scale seems feasible. Preliminary results show sufficiently good results for forested lands, and a potential vision for forested lands could be to provide new classifications based on the combination of optical satellite data and 3D data from laser scanning or digital photogrammetry.

Acknowledgements

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Airborne Optical Imaging in Support of Habitat Ecological Monitoring of the Austrian Reed Belt of Lake Neusiedl

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1 Introduction

The reed belt of Lake Neusiedl is one of the most important habitats of the National Park Neusiedler See - Seewinkel. The Austrian and Hungarian parts of the reed belt extend over approximately 181 km^2 and represent the second largest contiguous reed population in Europe. These vast reed areas provide a unique ecotope which is a multifunctional core area of the National Park region. However, there are relevant conflicts between the interests of tourism and reed harvesting on the one hand and the objectives of nature conservation and ecological management on the other. A habitat ecological approach to an inventory of the reed belt is urgently needed and should be performed in regular intervals. In the frame of the research project „Schilfkartierung Neusiedler See" airborne optical scanner data of the Austrian part of the reed belt was acquired beginning of August 2008. In order to fully preserve the specific structural varieties of reed areas which are of initial importance for a habitat ecological inventory object-based image analysis was adopted via adaptive segmentation and subsequent classification. A detailed data base mirroring habitat ecological characteristics of more than 100km^2 of reeds allows for subsequent sub-regional monitoring of relations between species-related population dynamics and habitat structures. Operationality of homogeneous data collection and data analysis points towards the establishment of crossborder periodical monitoring based on airborne optical imaging as a precondition for fulfilling respective national and international directives.

2 Motivation

Lake Neusiedl is characterised by a very shallow lake basin, which allows optimum conditions for reed growth. Reed (*Phragmites australis*) extends over approximately 181 km^2 and thus represents the second largest contiguous reed area in Europe. The reed belt is a unique diversely structured ecotope. Conflicts between ecological and economical interests drive permanent discussion about strengths and weaknesses of regional development measures which often directly interfere with measures of protection and conservation. Therefore a detailed updated spatial data base on distribution, extent and structure of the reeds of the Austrian part of Lake Neusiedl was urgently needed. The habitat ecological spatial inventory is a precondition for establishing a fully-operational reed information system for the whole lake basin in support of planning and management for nature conservation.

3 Data and methods

Airborne colour-infrared (CIR) imagery was acquired on 8 August 2008. After ortho-rectification 132 .tiff images with respect to the geodetic datum MGI were available, each covering an area of 2,5 km x 2 km and consisting of 10 000 x 8 000 pixels, thus providing a ground resolution of 25cm.

2.1 Segmentation

After preprocessing, explicitly radiometric correction and similar, segmentation was performed to preserve the specific habitat ecological structures of the reed belt. Input was image data of three spectral bands (near infrared, red and green) as well as the Normalised Difference Vegetation Index (NDVI). In average around 3 000 to 4 000 segments were created per image in order to preserve a maximum of richness of detail. Anyhow expert-based editing proved to be inevitable because selection of representative habitat structures is not related to criteria such as smallness or largeness, but depends on specific habitat functions. Often very small objects like areas of open water inside the reed belt which are exactly detected by the segmentation algorithm have to be preserved and larger objects in closed reed areas which are characterised by changes of the vegetation continua type have to be merged. After expert-based treatment around 1.000 to 1.500 segments per image were available for subsequent classification (Figure 1).

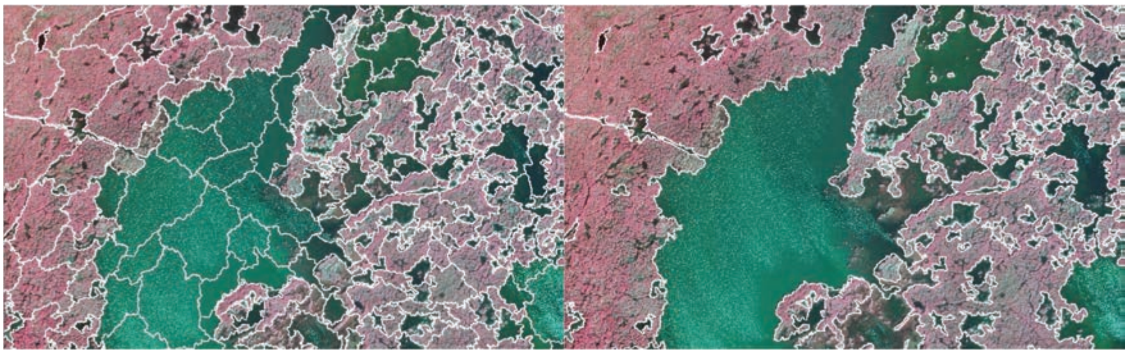

Figure 1 Reed area after segmentation (left) and after expert-driven merging (right).

2.2 Ground truthing

In September and October 2008 GPS-supported ground-truthing was performed at 45 randomly selected circle-shaped sample locations along vertical transects in 5m and 10m distance from the centre and at the centre itself. Nine measurements per sample of vegetation density and vegetation height, amount of collapsed reed, thickness of reed stems and amount of young reed (of the recent year) as well as - in case of occurence of water surface – amount of coverage and water depth were collected. Field data collection was following criteria of habitat ecological inventories regarding habitat preferences of different reed birds (Dvorak et al. 1995; Nemeth et al. 2001).

2.3 Classification

Based on in-depth ground-truthing and on-screen interpretation training a classification key was developed which mirrors the capacity of very-high-resolution CIR-image analysis to classify reeds towards habitat ecological characteristics, explicitly by application of separation criteria of horizontal structure (density, fragmentation, heterogeneity), vitality (age distribution) and growing height (stereo-imaging). A respective interpretation key has been established at the occasion of the first full-coverage mapping of the Austrian reed belt in the early 1980s (Csaplovics 1982). The recent classification key separates between pure reed and mixed reed classes, open water, channels, fillings and tourism facilities. There are five distinctive reed classes which are differentiated by the criteria density (structure) and age (vitality) of reed cover, patchiness (open water) as well as the distribution of other plants. The mixed reed classes consider the distribution of sedges (mostly *Cladium mariscus*) as well as mixed marshland in general (Márkus et al. 2009). Anyhow, as the „Hungarian classification key“ was solely developed based on occurrence of respective reed classes in the Hungarian reed belt, the „Austrian classification key“ had to be amended and extended in order to take into account the distinctive variations of reed growth (Schmidt et Csaplovics 2012).

3 Results

In the northwestern part of the reeds near the Wulka inflow a large homogenous area of old reed is prevalent. Further to the south the density of reed decreases and an increasing amount of water (“Braunwasser”) is characteristic. It is obvious that areas dominated by sparse old reed prevail in the Austrian part of the reed belt (Figure 2). Reed classes III.A, IV.A and V.A extend over approximately 69 km², while vital, young, dense reed covers only about 20 km². Mixed vegetation of reed and sedges (classes I.B through V.B), partly dispersed over marshland, represents about 16 km². A significant amount of the inner parts of the reed belt, explicitly 12.5 km², is covered by open water (reed water, *Braunwasser*). Along the open-water reed edge vital, dense, young reed prevails. The landward transition zone is dominated by a mixture of young, vital reed and marshland as well as abundance of sedges, often distributed along vegetation continua gradients.

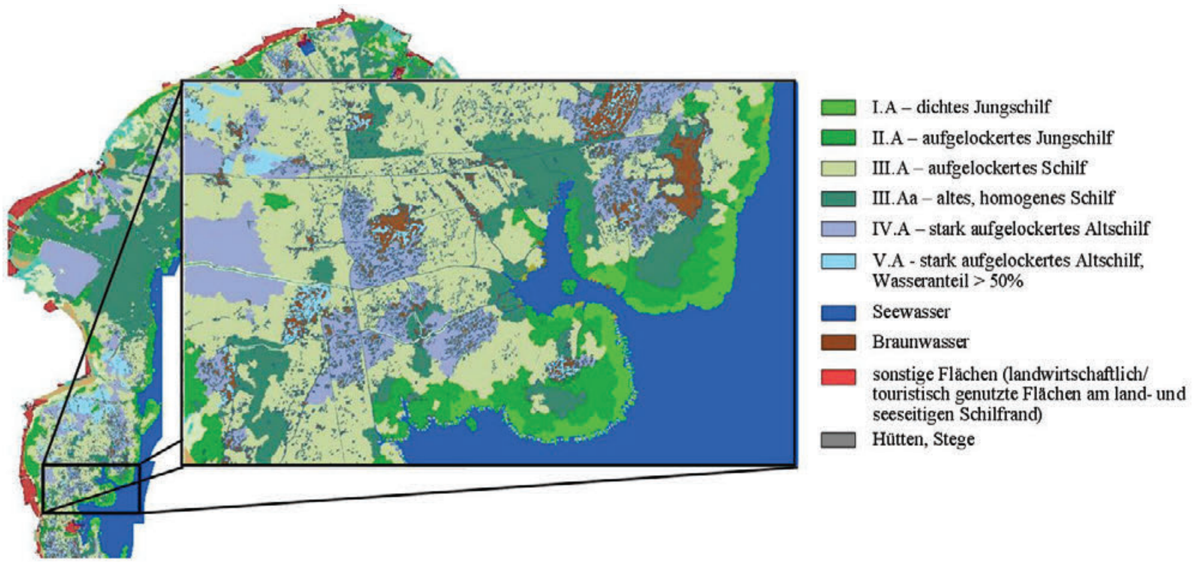

Figure 2 Habitat-ecological map of the reed belt of the Austrian part of Lake Neusiedl (detail) (Csaplovics et Schmidt 2011).

Habitat-ecological interpretation of reed classes relies on the fact that preferences in habitat choice of reed birds are significantly correlated with adequate reed structure as well as with variations in water level inside the reed belt. The reed belt hosts bird populations of international significance. In total 35 species are found along the edge and inside the reed belt which are listed as species of priority following the European Birds Directive (Species of European Conservation Concern SPEC, categories 1-3). Habitat selection of wading birds (herons and similar), but especially of small birds is to a large extent determined by structural parameters of the reed areas. While the Moustached Warbler *(Acrocephalus melanopogon)* and Little Crake *(Porzana parva)* prefer open reed areas with a large amount of collapsed reed, the Great Reed Warbler (*Acrocephalus arundinaceus*) is found in areas characterised by significantly dense and strong reed stems. Habitat-specific parameters of reed structure and amount of open water areas inside the reed belt are perfectly assignable to classes derived from colour infrared aerial image analysis. Prediction of the occurrence of bird species in relation to specific parameters of reed structure and patchiness in core areas of the national park is possible. The Water Rail (*Rallus aquaticus*) colonises along the reed edge both landwards as well as towards the open water in areas with predominantly thick reed stems (Figure 3).

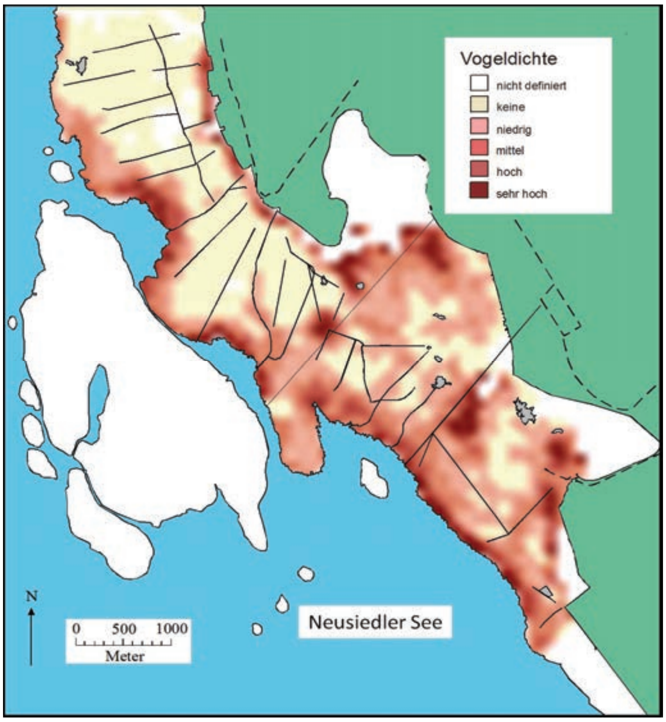

Figure 3 Distribution of the occurrence of Water Rail (*Rallus aquaticus*) in the core area of the National Park Lake Neusiedl based on reed of significant vitality and low density of open water patches (Nemeth et al. 2001).

4 Conclusion

The Austrian-Hungarian reed belt of Lake Neusiedl/Fertö covers an area of approximately 181 km^2 including the reed-land transition zone (effective 2008), with the Hungarian part of about 64 km^2 and the Austrian part of about 117 km^2, thus representing the second largest contiguous reed area in Europe (surpassed only by the reeds of the Danube Delta). It is remarkable that reed areas with densities of reed growth lower than 70% cover an extraordinary large area of approximately 35% of the Austrian reed belt and that more or less distinct open water areas inside the reeds cover about 15% of the Austrian reed belt. A comparison with the distribution and extent of open water areas described by the „historical“ inventory of 1979 proves for a tremendous increase from $2.5km^2$ to $12.5km^2$ (Csaplovics 2012). Comparative analysis of changes in reed extent and reed structures in relation to the prediction of population densities of reed birds and other rare faunistic species creates a sound baseline for crossborder ecological monitoring and management of reed habitats of Lake Neusiedl in concordance with European regulations and directives.

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The EAGLE data model - concept for parameterized data collection on habitat characteristics

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1. Abstract

Increasing commitment to preserve natural values from pressure by human activities has lead over the last decades to a variety of national and European initiatives with the aim to monitor changes of landscape, expressed as land cover (LC) and/or land use (LU). The variety of applications has resulted in the development of numerous classification systems to systematically describe LC/LU (many achieving an operational implementation status e.g. CORINE Land Cover, LCCS). Each of these emphasizes different aspects of land surface. Different semantic borders between class definitions hinder data exchange and restrict comparability between systems.

Recent trends in remote sensing, like free data access to opened LANDSAT archives, the launch of SENTINEL series, advances in data analysis techniques and increasing computing capacities pave the way to new opportunities in gaining knowledge about the environment. Besides long-term and dense historical time series and steadily incoming new satellite imagery, a broad variety of thematic datasets provide rich sources of information on land. The challenge of today is therefore to optimize data collection, systematically extract information from existing and available data sources (data mining) and utilize it in an efficient way to respond a broad range of application requirements. The INSPIRE directive is also pointing in the direction of interoperable data sharing and exchange of information.

The EAGLE group (Eionet Action Group on land Monitoring in Europe), nested in European Environment Agency's Eionet network sees a response to this challenge in building a new concept of land description that can help to handle the situation and utilize opportunities described above.

The EAGLE concept (Arnold et al. 2013) is based on an object-oriented data modelling approach. It describes land surface through land surface units (polygons, grid cells), which contain one or several Land Cover Components (LCC). One or many Land Use Attributes (LUA) can be attached to these components and land surface units, which then are described with further Characteristics (CH), such as spatial and temporal pattern, land management practices, bio-physical parameters, species types, ecosystem structure information a.o. The approach allows a parameterized description of land instead of classifying it to a limited number of pre-defined classes. By preserving elementary descriptive information on each single land unit, users of data are not bound by restrictive and inflexible class definitions, but are free to re-combine information to fulfil their application requirements.

The decompository approach of EAGLE model enables it to be used

a) for semantic analysis of class definitions,
b) as a semantic-based translation tool between classification systems,
c) as guideline for systematic collection of land- and habitat related information,
d) as an analytical tool to link user requirements to existing data,
e) as conceptual basis for a harmonized future European Land Monitoring Framework.

The EEA and Eurostat expressed interest in the potential contribution of the EAGLE concept to the long-term strategy of Copernicus land monitoring (CLC/HRL) and LUCAS. The concept has been integrated into the Copernicus work programme and already welcome in selected European Member States, assisting and fostering the harmonization of national land monitoring programmes in place. It was successfully applied for the enhancement of the CORINE Land Cover nomenclature guidelines.

The thematic content of the data model is not restricted to a specific manner of data capture; both remote sensing data and in-situ mappings and measures can be the source of information. Due to its conceptual basis and flexibility to enclose any kind of information on land surface as new model element, EAGLE model is seen to be able to respond the needs of harmonization and data exchange arising in the field of habitat monitoring. With few modifications the core EAGLE data model that is suited to serve rather general multi-purpose application can be extended to match the requirements of habitat and ecosystem monitoring.

Therefore the EAGLE data model is tested against the General Habitat Categories (GHC) system to estimate its usefulness for habitat monitoring purposes. Preliminary results has lead to the conclusion that extended with a limited number of parameters EAGLE model can be suitable particularly for

- improving habitat nomenclatures through systematic decomposition of class definitions, resulting in identification of semantic gaps/overlaps/inconsistencies within or between classes,
- identification of individual descriptors in existing habitat nomenclatures,
- translating between classes of different habitat classification systems,
- serving as a data model for collecting information on status of habitats.

In particular, the following issues are considered as most relevant subjects of ongoing research:

- combined analysis of EAGLE data model and GHC-classification system according to their contribution for the proposed essential biodiversity variables (EBV) like taxonomic diversity, net primary production, habitat structure and ecosystem functional types;
- to analyse the completeness and suitability of the data model regarding habitat characteristics/parameter relevant for the monitoring requirements of the Habitats Directive (Bock, Dees 2006);
- combined analysis of EAGLE data model and the European Nature Information System (EUNIS), which aims to facilitate the harmonized description and collection of data across Europe through the use of criteria for habitat identification.

An additional benefit for habitat description is seen in the manner the EAGLE model tackles temporal aspects of land. Beside the typical classification of ecosystems the assessment of their condition (ecosystem state) receives increasing attention as a result of the Biodiversity Strategy 2020. One target of the biodiversity strategy calls for a restoration of 15% of degraded ecosystems. Therefore the aim of every monitoring programme is shifted towards documenting the change of ecosystem condition over time. The proposed EAGLE data model is able to differentiate between various temporal dynamics over time (a.o. frequency, duration, time interval) by using ISO’s temporal schema (ISO 19108:2002) and extends these recommendations to overcome the shortcomings of existing models, and is compliant to INSPIRE Directive Annex II – Land Cover.

The oral presentation and paper aims at introducing the EAGLE concept by describing 1) the criteria behind development, 2) structure and content of the data model, 3) foreseen uses, 4) example of successful application, 5) potential benefits for habitat mapping. The authors also intend to foster further discussion between the land cover mapping communities and habitat monitoring experts to find solutions for common challenges regarding data harmonization and optimisation of data collection..

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The EAGLE concept in its current form is the result of a joint voluntary work of the EAGLE group.

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Unified fusion of satellite imagery for seasonal terrestrial habitat mapping in Hong Kong

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ABSTRACT

Current satellite sensor systems have two major technical limitations: (1) the incoming radiation energy to the sensor, and (2) the data volume collected by the sensor [1]. These lead to the dilemma that improving a satellite sensor's spatial resolution may only be achieved at the cost of losing some other advantages of satellite instruments, such as spectral resolution, temporal resolution, and radiometric resolution. Consider the Landsat 7 ETM+ sensor and the MODIS (Moderate-resolution Imaging Spectroradiometer) sensor as an example. The ETM+ data possess high spatial resolution (30 meters), low temporal resolution (16-day revisit cycle), and low spectral resolution (bandwidth of approximately 70-200 nm in visible and infrared (VIR) bands). By contrast, the MODIS data possess low spatial resolution (250/500/1000 meters), high temporal resolution (daily revisit cycle), and high spectral resolution (bandwidth of approximately 10-50 nm in VNIR bands). However, the remote sensing data that are available to researchers may not be the data they actually need [2].

One possible solution to this problem is data fusion. Since the 1980s, numerous spatio-spectral fusion methods have combined multispectral (MS) bands with a panchromatic (PAN) band image to produce MS images with the spatial resolution of PAN. Reviews of these pan-sharpening methods can be found in [5]-[9]. These methods have also been extended to merge hyperspectral images with a PAN band [10]. Similarly, to obtain images with both high spatial and temporal resolution, many spatio-temporal fusion methods applied to different

sensors have been developed since the 1990s [11]-[13]. However, little work has so far been done to explore a unified fusion of satellite images to generate high spatio-temporal-spectral resolution simultaneously.

By formulating the spatio-temporal fusion and spatio-spectral fusion into one general problem, i.e. super resolving a low spatial resolution image with a high spatial resolution image acquired under different conditions (e.g. at different times or in different acquisition bands), we propose a notion of unified fusion that can accomplish both spatio-temporal fusion and spatio-spectral fusion in one process. An image super-resolution method is, thus, developed to perform both spatio-temporal fusion and spatio-spectral fusion in a similar manner.

The proposed method has been applied to generate Landsat 8 – like satellite images with the temporal resolution and spectral resolution of MODIS. These images were then used to produce seasonal habitat maps in Hong Kong [14]. Twenty five habitat categories were defined; they are Fung Shui Forest, Montane Forest, Lowland Forest, Mixed Shrubland, Freshwater/Brackish Wetland, Natural Watercourse, Mangrove, Seagrass Bed, Intertidal Mudflat, Shrubby Grassland, Baeckea Shrubland, Plantation or Plantation/Mixed Forest, Fishpond/Gei Wai, Sandy Shore, Rocky Shore, Cultivation, Bare Rock or Soil, Grassland, Modified Watercourse, Artificial Rocky/Hard Shoreline, Golf Course/Urban Park, Quarry, Rural Industrial Storage/Containers, Landfill, and Other. To produce the habitat maps with twenty five categories, the PAN band (15 meter spatial resolution) of Landsat was fused with the multi-spectral bands of Landsat, and so the satellite images used for classification had the spatial resolution of 15 meters. Such images were also fused with MODIS images so that the images at four dates in 2013 representing the four seasons were generated with the fine spectral resolution of MODIS to improve the habitat classification accuracy. In the afore-mentioned way, the seasonal habitat maps can then be generated and their associated habitat quality evaluated. Given the seasonal maps, the change of habitat quality over different seasons can be viewed. In the presentation, we will report to you the process and methods of generating the seasonal habitat maps and the accuracy associated with the maps. We will elaborate the impossibility without the use of unified fusion. In other words, the advantages of the unified fusion will be demonstrated and highlighted.

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Monitoring and Mapping for biodiversity using remote sensing: a case study from Norfolk

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1. Introduction

Due to legislative obligations included in the EC Habitats Directive, as well as domestic commitments to provide audits of ecosystem function and service provision, information on location and condition of semi-natural habitats in the UK is required. Earth observation (EO) has been identified as an important monitoring tool for conservation bodies and DEFRA, helping to meet surveillance standards under resource constraints.
"Making Earth Observation Work for UK Biodiversity Conservation" is a three part project, designed to establish the practical role of EO in surveying UK priority habitats designated under the UK Biodiversity Action Plan (BAP) and Annex I habitats.

1.1 Phase I – Review and Scope Potential (Completed)

Reviewing recent activity, Phase I (Medcalf et al. 2012) demonstrated the potential contribution of EO techniques combined with geoinformatics to the surveillance of habitat extent, composition and condition on an operational level. A user guide, the "Crick Framework", was developed, wherein habitats were grouped into five tiers representing the current likelihood of the habitat being identified using EO techniques.

1.2 Phase II – Pathfinder Projects (Completed)

By carrying out projects in a pilot area of Norfolk, Phase II tested the application of EO techniques in operational surveillance for biodiversity in the UK and assessed effectiveness, practicality and cost-performance-ratio. During this phase, the Crick Framework was updated.

1.3 Phase III – Influencing (Current Phase)

Phase III is intended to develop a common research agenda between the UK and other European Member States utilizing EO. Herein research needs, identified both during Phase I and during EO application for biodiversity surveillance in Europe, should be addressed utilising data supplied through EU and MS programmes (particularly GMES/Copernicus).

2. Findings

2.1 Implementation and Evaluation of a Pilot Project

During the pilot study in Phase II further development of an "object based image analysis" (OBIA) habitat mapping approach was required. In this approach, the knowledge of landscape context is applied to image classification, allowing for spectrally similar vegetation to be distinguished on the basis of the different settings it occurs in. For the successful application of OBIA, Ordnance Survey MasterMAP (OS MM) and digital terrain models proved to be essential, both at landscape (wider countryside, including agriculturally managed and semi-natural habitats) and site scale (localised, e.g., nature reserves). In order to identify small objects (e.g., scattered scrub) and linear features, ultra-high resolution imagery obtained through an Unmanned Aerial System (UAS) was incorporated, which aided in the delineation of habitat extent and in the identification of features relevant to Annex I SAC sites.

2.2 Implications of Phase II for Senior Policy Makers

It was demonstrated that EO techniques provide a good cost-performance ratio for the mapping of Annex I and priority habitats: 1/3rd of these habitats can be mapped directly, while key data sets for the identification of the remaining ones are provided. The efficacy of EO techniques is added to by their applicability to large or difficult to reach areas and the capacity to improve mapping accuracy at individual sites. A further advantage of EO techniques is that the rule bases and processed imagery and data, once developed, can be built upon and adapted to provide additional outputs, meeting the needs of other policies utilising habitat mapping. Consequently, follow-on work can be carried out at very low costs, compared to techniques requiring re-surveying or manual re-interpretation of imagery.

Supporting and augmenting current techniques, the main fields of application identified for EO techniques include, on the countryside-scale, filling of knowledge gaps regarding habitats and the generation of maps for approaches to biodiversity delivery, as well as, on smaller scales, the development of management plans, particularly for discrete areas, the identification of threats to habitats and the monitoring of mitigation measures put in place.

2.3 Implications of Phase II for Habitat Practitioners

Based on cover forming species present, the EO techniques can distinguish a range of high priority habitats at accuracies greater than 78%. Habitats distinguished on the basis of small or understorey species cannot be separated; however, the identification of broader habitats can be used to target field survey work to identify specific habitats. Additionally, measures difficult to obtain from the ground, such as "the extent of stands of negative indicator species", can be obtained as part of the EO process.

The resolution and temporal frequency of imagery required for EO techniques to be applied successfully depends on the habitat: Patchier habitats require higher spatial resolution imagery while habitats undergoing frequent changes associated with their biogeographical, agricultural and habitat system context require higher temporal frequency imagery. The EO process itself requires a combination of EO and ecological expertise, as well as GIS and geoinformatical knowledge. Particularly relating knowledge of the ecology of the site to the imagery is integral to creating the rule base for map creation.

The end product is a high-quality, site-based habitat map that can be used in monitoring, surveying and site maintenance and an adaptable dataset; continuous improvement upon the rule base is possible, the data can be used to apply a different classification system or to provide a more detailed assessment of one particular area.

3. Conclusions

Overall, Phase II of the research has established the practical role EO can play in addressing habitat monitoring and surveillance needs in the UK for priority habitats designated under UK Biodiversity Action Plan (BAP) and Annex I habitats.

Accuracy assessment, feedback from local habitat practitioners and assessment by the research team of how well the techniques worked suggest that the EO techniques developed can support the mapping and surveillance of high priority habitats. Work in Norfolk and Wales demonstrates that the techniques are capable of consistent implementation and evidence suggests that the technique is transferable for application in the UK, and abroad. The approaches can support and augment current surveillance techniques in a practical way, sometimes improving upon the accuracy of habitat mapping or providing a better performance-cost-ratio.

3.1 Future Research

Future research needs identified during the project include assessment of the suitability and potential role for satellite radar in an OBIA approach and further vegetation structural features that can be described by LiDAR. Measures (indices) to assist with the site-based assessment of the condition of Annex I habitats need to be researched and formulated.

Further widening the applicability of EO techniques will require knowledge transfer with conservation agencies to create image analysis classification systems suited for particular habitat mapping needs.

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Nature without barriers – Natura2000 sites as Green Infrastructure in the Austrian-Hungarian transborder region Fertö-Hansag-Neusiedlersee

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Abstract

Many ongoing processes in today's landscapes impact our environment considerably. Thus, it is enormously important to gather information on qualitative characteristics of our landscapes in order to effectively counteract the negative development. Structural functionality as proxy for the assessment of habitat quality and species patterns has already proven potential to successfully describe ecological values. Completed by the measurement of green infrastructure information for a defined profile of a functional trait, a rapid and rough assessment of the qualitative state of habitats seems feasible. We therefore present in this study (i) an assessment of structural functionality based on the statistical analysis of landscape metrics, (ii) the measurement of green infrastructure and travelling costs for the ecoprofile of Disturbance Sensitive Group and (iii) an investigation if functionality and green infrastructure change between different types of landscapes and protection status. In the region of Neusiedler See (Austria), we selected 41 landscape samples based on a stratified random process. Based on orthophoto interpretation, we calculated landscape metrics with FRAGSTATS and reduced them to a core set of 13 indices by combining statistical results with literature review. Their relation to main ecological processes determined if the individual metric related positively or negatively with the land cover category and structural functionality was given by the average value of the landscape metrics. Green infrastructure was allocated with GUIDOS, whereas the travelling costs to move between the infrastructure was calculated with PATHMATRIX Landscape elements of valuable matrix and connecting corridors ranked highest in structural functionality based on the calculated landscape indices but showed large differences between different land use regimes. Correlation and regression analysis confirmed the dependence of Green Infrastructure elements as well as travelling costs to functionality values. Protection status of the landscape samples proved to be a determining factor because functionality values as well as Green Infrastructure differed significantly (both with a p-value < 0.05) with the exception of dissecting corridors, stepping stones and travelling costs. We conclude that one simple guideline for a holistic assessment of structural functionality is hardly reachable but we set up a comprehensive rule set. Based on a transparent sampling procedure, a qualitative assessment of habitats and landscapes can easily be conducted. The complementary use of an ecoprofile enables the valuation of green infrastructure elements and the identification of major driving forces along with scenario development for sustainable landscape planning.

Keywords

Landscape metrics, morphological spatial pattern analysis, nature protection, travelling costs, landscape pattern, Fertö-Hansag-Neusiedlersee

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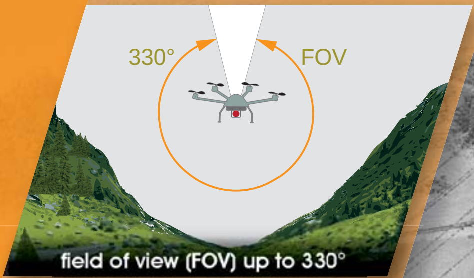

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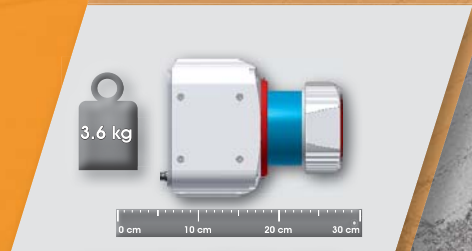

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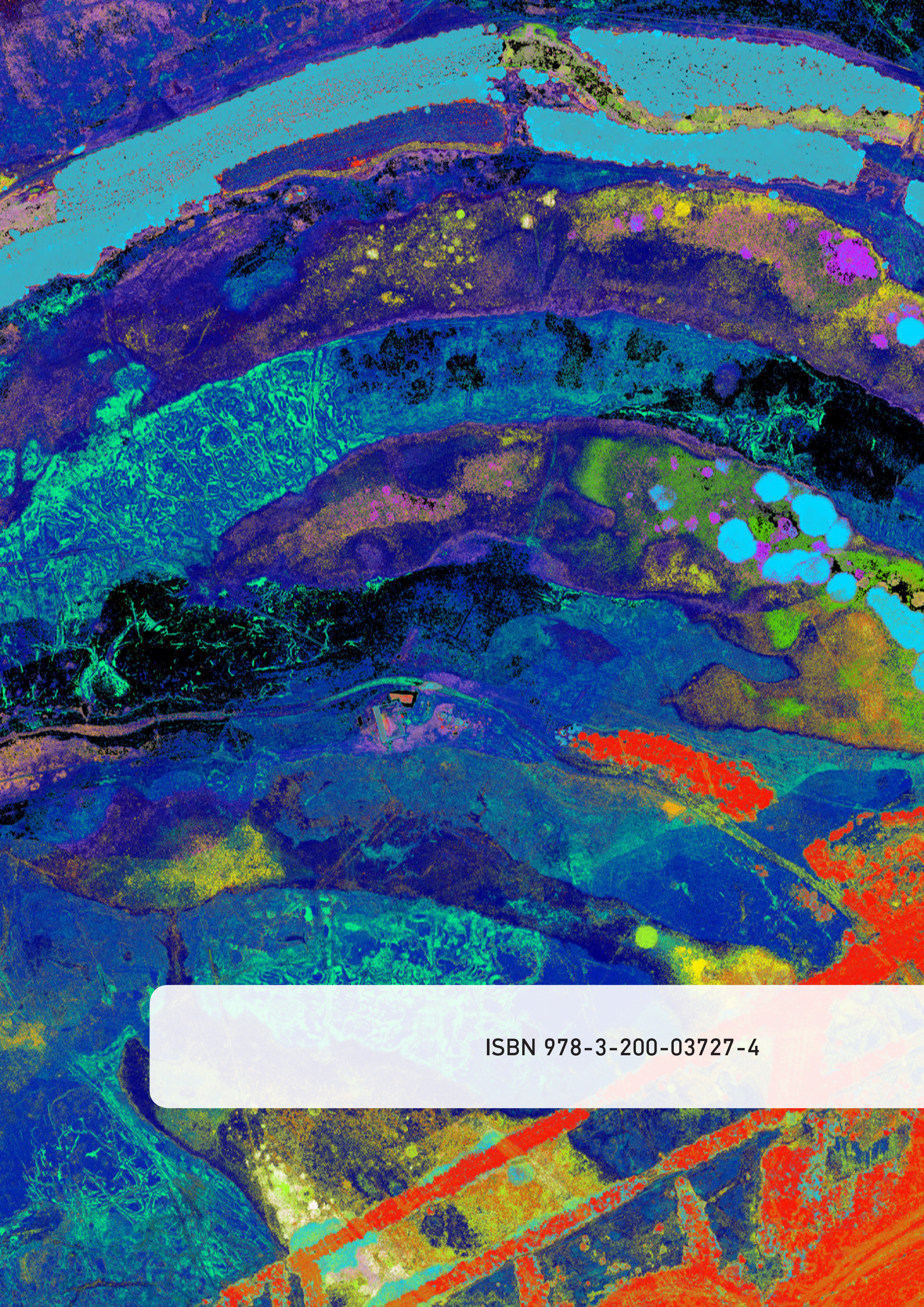

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