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Fostering sustainability in European nature conservation - NATURA 2000 habitat monitoring based on Earth observation services

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Abstract: Earth observation, realized through satellite remote sensing and complemented by in-situ measurements provides the technological (and increasingly operational framework required for regular updated status information provision for setting up monitoring schemes for various domains of the civil society including sensitive ecological sites. Such information is required by the European Habitats Directive, which is implemented by the Member States to ensure sustaining biological diversity and favourable

ecological conditions within dedicated sites, but also on the entire territory. Remote sensing supported monitoring of status and trends will help keep such conditions in balance with favourable social and economic ones, and especially not to sacrifice the first for the latter. This paper discusses some of the first achievements in the operational use of latest generation satellite imagery for monitoring sensitive sites. Examples are presented from the project MS.MONINA, which develops services for providing geospatial information matching the specific requirements of the Habitats Directive on all levels of implementation,

Keywords: biodiversity; HabDir; habitat quality; satellite remote sensing; GMES

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1. Introduction

Since 1992, European Member States (MS) are committed to monitor the biodiversity on their territory and on designate areas of community interest for its protection. This is the success of the European Habitats Directive (92/43/EEC; HabDir), which established a network of NATURA 2000 sites, where trends in area and the quality of the protected habitats have to be observed and updates should be provided on a regular basis. The intention is not to stop any development within the sites, but to secure a favourable status under management strategies pursuing a sustainable development also in social and economic terms. Rich biodiversity is not only imperative from an environmental point of view, but also ensures sustainable social and economic conditions. To fulfil the Directive's reporting requirements, Earth observation (EO) techniques are regarded as a crucial additional data source, complementary to field-based inventories, to effectively map and monitor habitat status and dynamics. The derived information not only provides public authorities with a spatial overview of the habitats present and the past dynamics, but also enables the implementation of appropriate management strategies to sustain biodiversity in the future. On the level of EU MS, this information needs to be aggregated to conservation status reports, including information on range, area, quality, impacts and threats. The EU authorities subsequently compile a composite report to follow up on the conservation status of habitats and species over the whole of Europe, and assess the achievements of the HabDir within so-called biogeographic regions.

The shift from focussing on single species to protecting entire habitats has been a step forward towards sustaining the natural environment *sensu* nature conservation in several aspects: (1) habitats have a large umbrella function providing living space to entire communities of species and (2) habitat protection is area-effective, meaning that habitats have critical spatial parameters of their integrity (such as connectivity etc.), which are vital for the functioning of the ecosystem they are part of, and which can be assessed, mapped and managed. This results in a significant share of a country's territory being under direct concern.

2. Methods

2.1. Can Earth observation provide sustainable tools for nature conservation?

The potential of new concepts and methods combing EO data and in-situ measurements is currently investigated in the GMES (Global Monitoring for Environment and Security) project MS.MONINA

(*Multi-scale Service for Monitoring NATURA 2000 Habitats of European Community Interest*, www.ms-monina.eu), which aims at offering EO-based services to authorities on European, national and local level. The multi-scale approach embedded in the project (Figure 1) reflects both the specific information requirements on different (political) implementation levels of the Directive, as well as the ecological levels addressed, i.e. the level of single habitats, over habitat arrangements on site and range level, up to biogeographical regions.

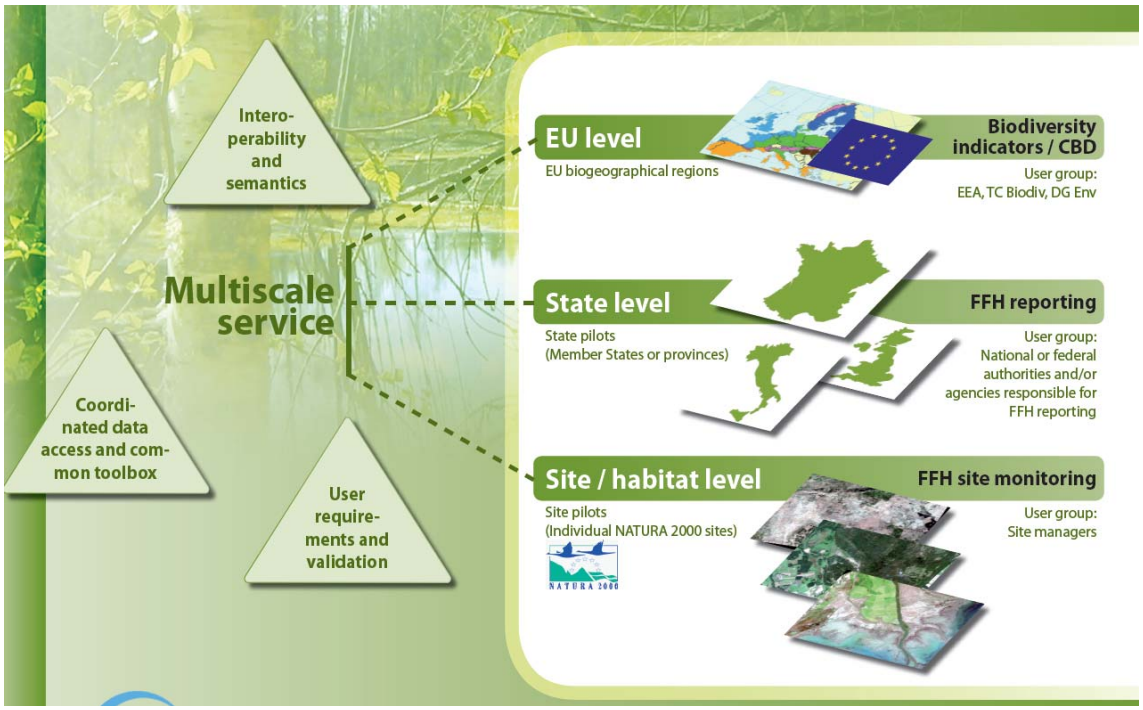

Figure 1. The three-level approach for EO-based biodiversity services in MS.MONINA (FFH = flora-fauna-habitat, HabDir)

Being included as a site in the NATURA 2000 network of sites implies the obligation to at least maintain, and possibly enhance, the biodiversity values for which the site was designated. In Europe, a continent dominated by landscapes shaped by often long-standing traditions of human land use, this entails in most cases the continuation or resumption of local management. But in order to evaluate its efficacy, monitoring of changes is indispensable. This also includes judging whether site conditions would improve or deteriorate. The latter triggers explicit management strategies in order to safeguard a favourable conservation status. Dependent on the occurring habitat types and pressures, specific information products are required from high-resolution satellite imagery. Building on the experience and knowledge of several national projects, product services are being developed that combine and integrate the potential of several recently developed mapping and monitoring methodologies (e.g. [4]). Such services will be provided in a high operational level in order to deliver the required information steadily and sound, but also with a specific user-oriented focus allowing output flexibility that meets the specific needs of a certain user. Several pilot sites all over Europe have been chosen in MS.MONINA to elaborate information products for different habitat types and user requirements. Heathlands, grasslands, estuaries, floodplains and riverine forests, as well as alpine meadows are among the habitats being addressed. The anthropogenic impacts include farming, settlements, intensive land use, land abandonment and tourism and many others.

On the level of federal states or MS, tools will be provided to monitor precious ecosystems related to the NATURA 2000 network of protected areas. Authorities are required to report on habitat range, area, quality, impacts and threats over the entire area, including habitats outside the network of protected areas. To reach from site level monitoring to MS relevant information, specific up-scaling methods need to be employed. Habitat modelling techniques will be integrated with satellite data at different spatial resolutions (very high to high), to arrive at a rule-based class model. Information extracted from dedicated satellite data can be used to provide indicators on habitat quality and, if coupled with distribution models, also on habitat range. This might for example include structural information from very high spatial resolution sensors (e.g. shrub distribution, farming machine tracks, distribution of open soil patches), temporal information from sensors with high temporal resolution (e.g. vegetation phenology, grassland mowing cycles) or hyperspectral information (material, plant distribution). If this information is stored in a standardised format (e.g. as raster data) it can be used as integrating information across different observation and reporting scales. Tying this information layers to evaluation criteria for specific habitats will enable a modular ‘toolbox’ of EO techniques.

2.2 Focus on habitats – where Earth observation meets ecological scale-specific knowledge

On either level, services based on dedicated EO-based data help foster a sustainable maintenance of precious ecosystems and reduce the loss of biodiversity. The habitat directive – as the name indicates - focuses a.o. on habitats as areal features. For these habitats, EO mapping and monitoring techniques can be applied to analyse their structural qualities and change dynamics [7] and thus support their conservation [9]. Each habitat type has distinctive structural and compositional features, which also relate to the conservation status of the habitat, requiring a dedicated set of EO data interpretation tools for each habitat type in order to extract the specific information products of interest for the habitat types at hand. In order for EO data analysis to be successful in providing Habitat Directive relevant information, the extracted information must be presented in a thematic context that is familiar to local, national and European public authorities. Likewise, for currently used habitat characteristics to be mapped with EO data, they must be distinguishable based on optical reflectance characteristics. Bringing these two views together is the essential step leading to EO-based information products for the monitoring within the context of the Habitat Directive, that: (1) will be used by public authorities because of the familiarity to their current data sources; and (2) are able to deliver relevant information due to the specific user-targeted output.

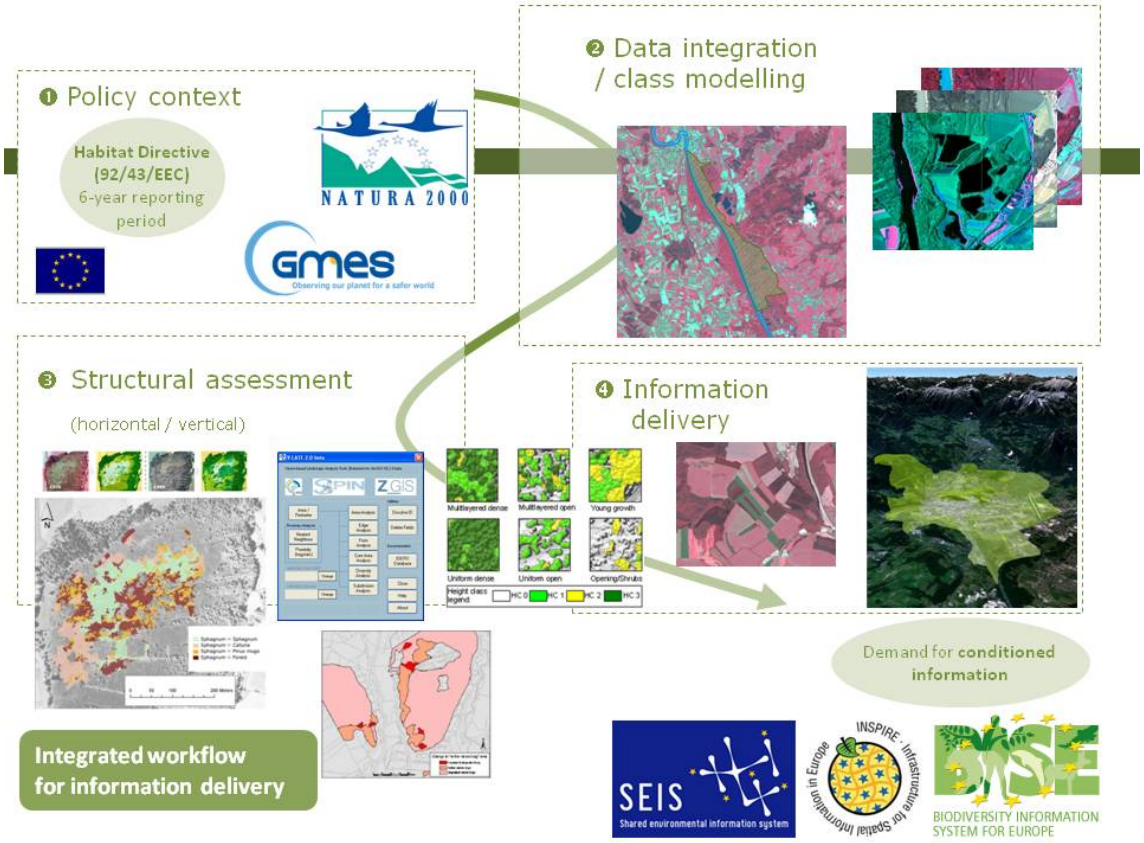

Figure 2. Service provision for biodiversity-related assessments and dedicated information delivery.

The administrative 'multi-scale' concept to a certain degree, reflects the ecological scaling ladder with a focal level embedded in nested hierarchical levels. A full match between administrative and ecological levels is unlikely, not in the least due to great variations in MS sizes, but up-scaling along a hierarchical ladder will support the 'conditioning' of biodiversity information on higher political levels with their specific requirements according to the HabDir.

3. Results

MS.MONINA takes into account both specificity and variety of habitats in different biogeographical regions. Several project partners are involved with local expertise in environments ensuring that particularities are considered such as seasonality, or variety in the configuration of habitats within conservation areas. Very high resolution data were obtained through the GMES data warehouse mechanism for approximately twenty NATURA 2000 sites, partly two-seasonal for 2011. For the coverage of state pilots high resolution data were provided in up to three time slices, multi-annual and multi-seasonal. The following three examples on site level show the variety of the potential usage of EO techniques:

The site pilot "Salzachauen" is located in a densely populated area in the pre-Alpine foothills at the Austrian-German border near the city of Salzburg. The focus area stretches along the regulated river Salzach and covers around 5 km^2. Dominating habitat types are *alluvial forests* (91E0) and *riparian mixed forest* (91F0) featured by rare geophytes, which consist of prevalent species as *Fraxinus excelsior*, *Alnus incana*, *Salix alba*, *Quercus robur* and *Acer pseudoplatanus*. One of the threats within

the site is the fragmentation of habitats by forest plantations with *Picea abies, Popolus canadensis.* Continuous urbanisation (and the demand for a bridge construction), the presence of invasive non-native species (neophytes) and fungal parasitism on ashes are further pressures on the natural distribution of potential habitat types. The change of the endangered habitat types is now detected by Worldview-2 satellite imagery composed of 8 spectral bands (with a spatial resolution of 1 m): Coastal (400 – 450 nm), Blue (450-510 nm), Green (510-580 nm), Yellow (585 - 625 nm)**,** Red (630-690 nm), Red Edge (705 - 745 nm)**,** NIR1 (770-895), NIR2 (860 - 1040 nm**)** and one PAN (delivered spatial resolution 0,5 m). Preliminary analysis results based on object-based image analysis (OBIA) are promising for species (appropriate to habitat types) and vitality detection by using a combination of Coastal, Green, Red Edge and NIR1.

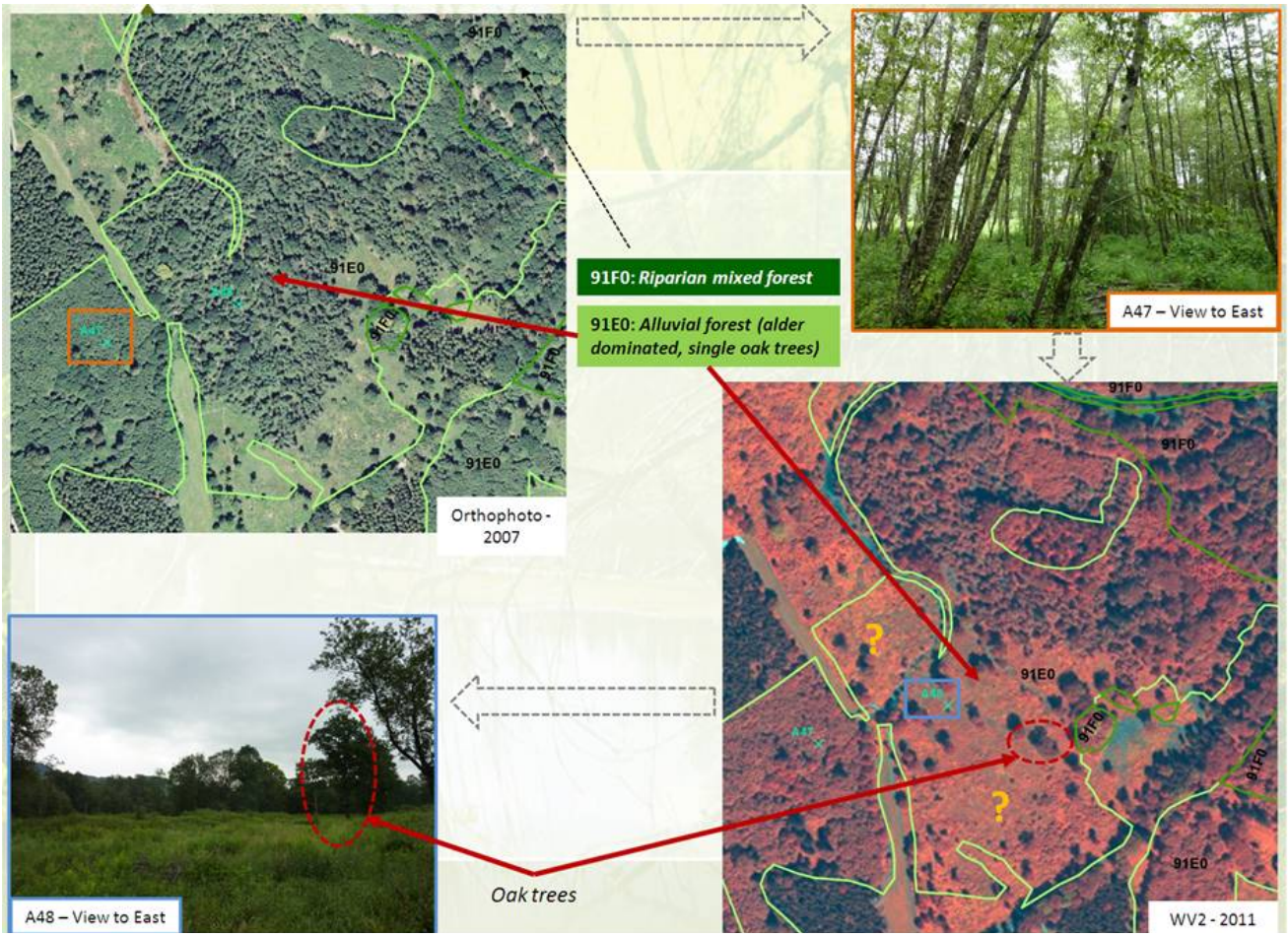

Figure 3. Changes in habitat type 91E0 indicated by analysis of recent Worldview-II imagery. Only larger oak trees remained after clear cut.

The site pilot "Döberitzer Heide" is situated in the north-eastern part of Germany, where former military training areas are now converted to nature protection sites. The result is a rich semi-natural landscape mosaic with mostly open-range areas, under rather dry and sandy natural conditions. Stretching over 60 km, it includes wood, dry sandy heaths, semi-natural grasslands, humid meadows and wetlands in flat terrain, some of which are not accessible due to remains of military munitions. In particular, semi-natural grassland and humid meadows comprise some species-rich and highly endangered NATURA 2000 habitats. For the classification approach, RapidEye imagery is utilised.

RapidEye is a German five satellite constellation launched in August of 2008. The system acquires images in five spectral bands: Blue (440-510 nm), Green (520-590 nm), Red (630-685 nm), Red Edge (690-730 nm) and Near Infrared (760-850 nm) with a spatial resolution of 6.5m. The available imagery was utilized to classify the study area by a spectral angle mapper (SAM) classification. First results show a good correspondence for well-defined plant compositions with clear phenological features. Plant compositions under strong anthropogenic influence (such as mowing regimes) showed lower accuracies.

Finally, the site pilot “Kalmthoutse Heide” is located in the north of Belgium, designated by the Flemish authorities as a part of the NATURA 2000 network since 1996. Its central heathland area is almost 1000 ha and contains a mixture of wet and dry heath, inland sand dunes and water bodies [2]. Due to its location near the city and harbour of Antwerp, and despite its protected status, the area is still affected by anthropogenic influences such as eutrophication, intense recreation and desiccation, resulting from drinking water extraction [3]. To counteract negative influences, dedicated management has been implemented since the 1970s. Nevertheless, atmospheric nitrogen deposition has accelerated dune fixation by the alien invasive moss species *Campylopus introflexus* (heath star moss) [8], and has led to an increased dominance of *Molinia caerulea* (purple moorgrass) in wet and dry heaths, at the expense of the former species diversity [1]. For the “Kalmthoutse Heide” study area, airborne high spatial (i.e. 2.4m) resolution AHS data were used to map and discern habitat types and conservation status indicators. Several output maps are generated, including amongst others: a detailed habitat patch map, a grass (mainly *Molinia caerulea*) encroachment map, and a bare sand map. More details on the methodology can be found in [6].

4. Conclusions

The paper has shown the potential of remote sensing techniques, especially the combination of recent very high resolution satellite imagery and advanced image analysis, for deriving crucial information on the conditions of habitats and sensitive sites in Europe. While there are scientific challenges yet to be overcome, sustainability is attained in at least two aspects: (1) in the purpose of the developed information services, i.e. to maintain and improve the conservation status of sensitive sites and the overall ecological conditions of the European Union and its biological diversity; and (2) in the way how these information products are steadily offered, namely by a tight relationship between service providers holding the technological capacity and the users satisfied when seeing their needs well represented in such products.

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Conflict of Interest

The authors declare no conflict of interest.

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