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Satellite Earth observation data to identify anthropogenic pressures in selected protected areas

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ABSTRACT

Protected areas are experiencing increased levels of human pressure. To enable appropriate conservation action, it is critical to map and monitor changes in the type and extent of land cover/use and habitat classes, which can be related to human pressures over time. Satellite Earth observation (EO) data and techniques offer the opportunity to detect such changes. Yet association with field information and expert interpretation by ecologists is required to interpret, qualify and link these changes to human pressure. There is thus an urgent need to harmonize the technical background of experts in the field of EO data analysis with the terminology of ecologists, protected area management authorities and policy makers in order to provide meaningful, context-specific value-added EO products. This paper builds on the DPSIR framework, providing a terminology to relate the concepts of state, pressures, and drivers with the application of EO analysis. The type of pressure can be inferred through the detection of changes in state (i.e. changes in land cover and/or habitat type and/or condition). Four broad categories of changes in state are identified, i.e. land cover/habitat conversion, land cover/habitat modification, habitat fragmentation and changes in landscape connectivity, and changes in plant community structure. These categories of change in state can be mapped through EO analyses, with the goal of using expert judgement to relate changes in state to causal direct anthropogenic pressures. Drawing on expert knowledge, a set of protected areas located in diverse socio-ecological contexts and subject to a variety of pressures are analysed to (a) link the four categories of changes in state of land cover/habitats to the drivers (anthropogenic pressure), as relevant to specific target land cover and habitat classes; (b) identify (for pressure mapping) the most appropriate spatial and temporal EO data sources as well as interpretations from ecologists and field data useful in connection with EO data analysis. We provide detailed examples for two protected areas, demonstrating the use of EO data for detection of land cover/habitat change, coupled with expert interpretation to relate such change to specific anthropogenic pressures. We conclude with a discussion of the limitations and feasibility of using EO data and techniques to identify anthropogenic pressures, suggesting additional research efforts required in this direction.

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Introduction

Local scale anthropogenic pressures on the Earth have led to accelerated declines in biodiversity (Hooper et al., 2012), affecting the provisioning of ecosystem services essential for human wellbeing (Mace et al., 2012). Thus, international bodies such as the recently established Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) have stressed the need to assess human pressures on biodiversity and ecosystem services across all scales, including at local scales relevant to management intervention (Honrado et al., 2013).

Although protected areas constitute a cornerstone of local and international conservation approaches (Jenkins and Joppa, 2009), they continue to experience anthropogenic pressure (Nagendra, 2008; Vicente et al., 2013). For effective management response, spatial knowledge of the type and location of pressure is required. EO and airborne data from passive optical and active Synthetic Aperture Radar (SAR) and Light Detection and Ranging (LiDAR) are available at different spectral and spatial resolutions, and can be very useful for detecting land cover/use and/or habitat changes over time (Nagendra et al., 2013).

EO and associated techniques, coupled with landscape pattern analysis and habitat modelling of biodiversity distributions, can provide information on changes in the state/condition of biodiversity and ecosystems. These changes can be used to infer evidence of pressures. However, there is an urgent need to harmonize the technical terminology of experts in the field of EO data analysis and of ecologists, with the applied scientific terminologies of policy makers and management authorities. Policy makers and protected area management authorities use terms such as *impact*, *pressures*, *threats*, *drivers*, *state*, *stress–response* (Salafsky et al., 2008). It is difficult to directly relate these terms to corresponding indicators derived from EO data analysis, which mainly provides information on the extent and location of changes in land cover/use (Tarantino et al., 2007).

The aim of this paper is to harmonize the discourse between field experts, ecologists and protected area managers on the one hand, and EO experts on the other hand, by proposing a unified approach to facilitate the provision of value-added products from EO sources that can be useful for biodiversity conservation purposes. This is illustrated for selected protected areas, located in diverse socio-ecological contexts and representing diverse habitat types including wetlands, forests, grasslands and bogs subject to a variety of pressures, with two detailed examples provided. The paper concludes with a brief discussion of the advantages and limitations of EO data techniques for pressure assessment in protected areas.

This study was developed and tested within the European Union's Seventh Framework Programme (EU-FP7) project Biodiversity Multi-SOurce Monitoring System: From Space To Species (BIO_SOS), that aimed to develop tools and models for consistent multi-annual monitoring of protected areas and their surroundings by the integrated use of EO and in-field data.

Methods: definition and categorization of changes in state

We propose to build on the Driving forces, Pressure, State, Impact and Response (DPSIR) framework (EEA, 1995), defining four broad categories of changes in state which can be mapped and monitored through EO analyses. Changes in state are likely to be site- and habitat-specific (Nagendra et al., 2012). These are described, drawing on a systematic analysis based on literature review and expert knowledge (judgement), for a number of Natura 2000 sites in Europe and a protected area in southern India. The sites are further described in Table 1. European sites are located in countries belonging to the Mediterranean (Italy, Greece and Portugal) and Atlantic (Portugal, The Netherlands and Wales) biogeographical regions (Habitats Directive–92/43/EEC). For each site, interpretation from ecologists, drawing on field data, is used to link specific changes in state with the direct pressures considered as drivers in the protected area. Appropriate EO data are then used to analyse specific changes in state. Detailed examples are provided for two protected area sites, illustrating the use of EO data for detecting changes in state related to pressures.

Taxonomy for pressure assessment

A number of different terms have been used by researchers and conservation agencies to define pressures and consequent changes in state of habitats in protected area assessments. Perhaps the most widely used by policy makers and managers is the DPSIR framework, although there are a number of other frameworks and approaches such as strengths, weaknesses, opportunities and threats (SWOT) analysis (widely used in other contexts), the WCPA/IUCN framework for assessment and monitoring of protected areas (Hockings et al., 2006), and the work of Salafsky et al. (2008), reviewed further in Nagendra et al. (2012).

According to the DPSIR framework, *Drivers* of environmental change (e.g., urbanization) result in *Pressures* on the environment (e.g., discharge of industrial and domestic waste), which create changes in the *State* of the environment (e.g., water quality), creating *Impacts* (e.g., modifications of ecological functions and in ecosystem services provision) on ecology and society. This leads to *Responses* (e.g., policy/management responses) – which in turn feedback on Drivers, thus reinstating the overall cycle. Thus the DPSIR framework, through state and impact monitoring, allows for the assessment of response effectiveness and appropriateness within an adaptive management perspective.

Pressures in the DPSIR framework refer to processes of disturbance that influence changes in biodiversity and ecosystem state. It is difficult to directly detect pressures, or to assess impacts of such pressures on society and ecology through EO. EO can however determine changes in land cover/use or habitat e.g. in forest structure (state of the forest) as a consequence of pressure (Nagendra and Rocchini, 2008). Through expert knowledge, changes in state can be used to infer both the type of disturbance (e.g., wildfire, wind storm, pest infestation, silviculture, overharvesting) as a driving pressure, and the type of impacts likely to ensue, so that appropriate responses can be devised (e.g. Nagendra et al., 2010).

Broad categorization of changes in state

Based on literature review and the knowledge of ecologists, four broad categories of changes in state are identified, which can be mapped through EO data analyses, and related to causal direct anthropogenic pressures based on expert ecological interpretation. These are

1 Land cover/habitat conversion;
2 Land cover/habitat modification (e.g., in vegetation structure, as indicated by changes in density or cover, height);
3 Habitat fragmentation and changes in landscape connectivity;
4 Changes in plant community structure.

In some instances land cover/use classes (e.g. deciduous forest) coincide with habitat categories, but in general the definition of a habitat (*sensu* Bunce et al., 2013) is linked to that of an ecosystem, and includes additional ecological concepts and components (e.g., lithology, slope, water salinity).

Expert knowledge is crucial in the EO analytical phase. Ecologists and other field experts rely on processes of human discrimination