Improving biodiversity monitoring using satellite remote sensing*

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*Extended title: **Improving biodiversity monitoring using satellite remote sensing to provide solutions towards the 2020 conservation targets**

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ABSTRACT: The preservation of biodiversity has become a major challenge for sustainable development at national, European (Natura 2000 and Habitats Directive) and international levels (Convention on Biological Diversity, 2011-2020). To address the current conservation needs; there's a need to operationalise methods to assess the distribution of natural resources and produce detailed, high resolution habitat maps that integrate information on condition. In Europe in particular, the ambition is to develop such a detailed habitat map and use it as a strategic spatial tool to report on the conservation status of habitat and species of community interest within the EU; inform conservation planning; and support the assessment of ecosystem services. Nowadays, the use of satellite remote sensing approaches has become a key step to secure a standardised view of the natural environment at large spatial scales. Within this special feature we aim to highlight recent developments in satellite remote sensing techniques, and demonstrate through study cases how operational solutions can be designed and implemented to increase our understanding of natural systems and to improve our ability to manage them.

Key words: Biodiversity monitoring, biodiversity indicators, CBD, data fusion, RS-enabled EBVs, Remote sensing, spectral trait

Increased access to satellite imagery and new developments in data analyses can support progress towards biodiversity conservation targets by stepping up monitoring processes at various spatial and temporal scales. Satellite imagery is indeed increasingly being made accessible to all, while analytical techniques to capitalise on the information contained in spatially-explicit species data, such as Global Biodiversity Information Facility (GBIF), are constantly developing, offering a plurality of options for application. Free and open data policy is having a dramatic impact on our ability to understand how biodiversity is being affected by anthropogenic pressures, leading to increased opportunities to predict the consequences of changes in drivers at different scales and plan for more efficient mitigation measures.

Satellite remote sensing is however no panacea, and little can be achieved without a robust understanding of the socio-ecological system considered. Similarly, access to relevant field-based information is key for satellite imagery to be properly calibrated, analysed and validated. This need for close collaboration between ecologists, modellers and remote sensing experts to derive meaningful information can represent a serious challenge (Pettorelli et al. 2014). With this special feature, we aim to illustrate why tackling this challenge is worth doing, by demonstrating how the coupling of satellite remote sensing data with ground observations and adequate modelling can provide tangible operational solutions towards a better understanding and management of natural systems.

The contributions featured in this special feature result from targeted invitations to prominent satellite remote sensing experts, who have a known interest in applied ecology and are currently working on innovative applications and methodological development to improve environmental management outcomes. These contributions focus on three key conservation challenges, namely i) the monitoring of biodiversity; ii) the development of an improved understanding of biodiversity patterns; iii) the assessment of biodiversity's vulnerability to climate change.

Monitoring biodiversity

It is now clear that human activities have led to stress and disturbance to biodiversity and ecosystems from local to global scales. Reliably monitoring biodiversity globally is an important component of the grand plan required to prevent further biodiversity loss and restore healthy levels of biodiversity worldwide. Biodiversity is a multidimensional, complex concept that refers to all multiscalar and multitemporal structures and processes occurring at different levels of functional organization, that is from the genetic to the ecosystemic level. One of the most used methodologies to track changes in species composition and turnover is based on taxonomic approaches and community ecology theories, yet there are satellite-based alternatives to this common approach. Specifically, various studies have demonstrated how satellite remote sensing can be used to infer species richness but few have addressed the measurement of species compositional turnover from satellite imagery. This challenge is tackled in this special issue, by Rocchini and colleagues, who here provide an example of how compositional turnover (β-diversity) can be estimated from satellite imagery. This original work introduces a novel technique to measure β-diversity from airborne or satellite remote sensing, demonstrating how critical information on the distribution of biodiversity over wide areas can be garnered in a standardised way and in a reasonable time.

Knowing about where things are is sadly not enough; an understanding and consideration of changes in quality or condition is also necessary to assess how biodiversity is faring. While focusing on terrestrial systems, Lausch and colleagues compare different approaches to vegetation health monitoring, specifically in-situ species approaches and remote sensing techniques. While doing so, they provide an overview of in-situ species approaches, i.e. the biological species concept, the phylogenetic species concept, and the morphological species concept, as well as an overview of the remote- sensing spectral trait/spectral trait variation concept to monitor status, processes of stress, disturbances, and resource limitations affecting vegetation health.

Developing an improved understanding of biodiversity patterns

A key aspect of management is the need for developing an understanding of what’s happening, that is good enough to support the elaboration of realistic and scientifically-informed predictions. Satellite remote sensing has been extensively discussed in the context of biodiversity monitoring, yet one obvious contribution of this technology is in its ability to support the development and implementation of ecological models. For this special issue, Pasetto and colleagues provide a review that illustrate how satellite remote sensing has so far been used in ecosystem models, contrasting situations where satellite data have been used as (1) input to define model drivers; (2) reference to validate model results; and (3) as a tool to sequentially update the state variables, and to quantify and reduce model uncertainty. One key message from this contribution is that the synergetic use of satellite data and ecosystem models is far too uncommon, and likely to increase in scope and intensity as a broader range of satellite data become accessible.

Developing a global understanding of the factors driving changes in biodiversity requires access to comparable information about elements of biodiversity in various places on Earth. To this end, efforts over the past decade have focused on the identification of essential biodiversity variables (EBVs; Pereira et al. 2013), defined as variable or a group of linked variables that allows quantification of the rate and direction of change in one aspect of the state of biodiversity over time and across space (Pettorelli et al. 2017). EBVs are planned to harmonize assessment of biodiversity monitoring at any scales, and to support the aims of the Convention on Biological Diversity and IPBES. From the start, satellite remote sensing has been expected to be an impoirtant methodology for the derivation of EBVs, and indeed, satellite remote sensing EBVs (SRS-EBVs) have been conceptualized as the subset of EBVs whose monitoring relies largely or wholly on the use of satellite-based data. So far, there has been little agreement on what these SRS-EBVs should be (Skidmore et al. 2015) and most potential SRS-EBVS discussed rely on a single type of sensor (primarily optical). Alleaume and colleagues here introduce a generic remote sensing approach to derive operational SRS-EBVs for conservation planning. One interesting aspect of this work is that hybrid methods and data fusion using very high spatial resolution sensors are being explicitly considered and tested in different complex landscapes encompassing three French biogeographical regions.

Assessing biodiversity's vulnerability to climate change

Climate change represents a major threat to biodiversity and a challenge to improve efficient monitoring methods. The scientific community has so far devoted a lot of energy into developing methods and frameworks enabling the assessment of current and future species vulnerability to climate change, but much less has been done for ecosystems. Satellite remote sensing technology is expected to represent one of the most cost-effective ways to identify ecosystems put at risk from changes in climatic conditions, but this potential remains to be fully demonstrated. Focusing on a series of mangrove ecosystems around the world, Duncan and colleagues illustrate how to capitalise on the current availability and diversity of satellite products to (1) assess both coastal ecosystem resilience and resistance capacity to sea level rise, and (2) identify landscape-level and anthropogenic factors driving these capacities. It must be highlighted that coastal ecosystems, especially mangroves are of key importance for a variety of ecosystem services, however highly threatened by ongoing human activities. In that sense, the work presented in this feature by Duncan et al. addressed their importance while developed at the same time a rigorous novel remote sensing product for assessing coastal resilience and resistance capacity concerning seas level rise. Alarmingly low resilience and resistance across the study region could be seen and stressed the importance of regular remotely sensed assessment of these systems.

The developed approach provides a remarkable addition to the remote monitoring and assessment toolkit for adaptive coastal ecosystem management, providing a new opportunity to inform conservation and management priority assessments in data deficient regions.

Conclusions

The study cases featured in this special feature clearly demonstrate how satellite remote sensing data can support biodiversity monitoring and conservation at different spatio-temporal resolutions and scales, and how high level of integration between field data and satellite imagery can lead to significant improvements in our understanding of the natural world. They provide concrete examples of management relevant, satellite-based methodologies that are technically feasible, economically viable and sustainable in time.

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