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Research paper

Spatio-temporal trends and trade-offs in ecosystem services: An Earth observation based assessment for Switzerland between 2004 and 2014

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ABSTRACT

Understanding and monitoring pressures on ecosystems and their consequences for ecosystem services (ES) is essential for management decisions and verification of progress towards national and international policies (e.g. Aichi Biodiversity Targets, Sustainable Development Goals). Remote sensing (RS) offers a unique capability to assess ES systematically and regularly across spatial and temporal scales. We aim to evaluate the benefits of RS to monitor spatio-temporal variations of ES by assessing several ES in Switzerland between 2004 and 2014. We coupled mechanistic ES models and RS data to estimate time series of three regulating (i.e. carbon dioxide regulation (CO_2R), soil erosion prevention (SEP), and air quality regulation (AQR)) and one cultural ES (recreational hiking (RH)). The resulting ES were used to assess spatial and temporal changes, trade-offs and synergies of ES potential supply and flow in Switzerland between 2004 and 2014. Resulting ES trends showed diverse spatial patterns across Switzerland with largest changes in CO_2R and AQR. ES interactions revealed a scale and elevation dependency. We identified weak to strong synergies between all ES combinations except for trade-offs between CO_2R–AQR and AQR–RH at Swiss scale. Spatially, all ES interactions revealed a heterogeneous mix of synergies and trade-offs within Switzerland.

Our results demonstrate the strength of RS for systematic and regular spatio-temporal ES monitoring and contribute insights to the large potential of RS, which will be extended with future Earth observation missions. Derived spatially explicit ES information will facilitate decision-making in landscape planning and conservation and will allow examining progress towards environmental policies.

1. Introduction

Safe planetary boundaries of several Earth system processes, in particular biogeochemical flows of phosphorus and nitrogen, land use change, climate change, and freshwater use have already been crossed (Steffen et al., 2015). Associated and often irreversible environmental change influences ecosystems and the services they supply in multiple ways. These modifications emphasize the need and importance of monitoring and protecting ecosystems and ecosystem services (ES) (MA, 2005). Additionally, assessing changes in ecosystem services has become crucial for current environmental policies like IPBES (Díaz et al., 2015), the Aichi Biodiversity Targets (Convention on Biological Diversity, 2010), the European Union Biodiversity Strategy (European Commission, 2011) and the Sustainable Development Goals (United Nations, 2015) that aim to ensure sustainable development of socio-ecological systems. Such environmental policies particularly require regular and systematic monitoring of ES to improve management decisions and to verify progress towards environmental policies and effectiveness of conservation measures and payment schemes (Scullion et al., 2011). However, required ES information is often complex as not only a single ES is of interest, but knowledge of multiple ES and their interactions is needed (Bennett et al., 2009). Additionally, appropriate methods linking ES to processes in ecosystems are still lacking (Lavorel et al., 2017). As consequence, dedicated monitoring systems for regular and systematic monitoring of ES are still missing.

One promising concept for assessing spatio-temporal changes in ecosystems and related ES to foster sustainable development is ecosystem accounting (European Commission et al., 2013). It is considered as an accounting framework that complements existing national accounts thereby acting as global comprehensive statistical standard for measuring economic activity. The development of ecosystem accounting as complementing framework to national accounts involves

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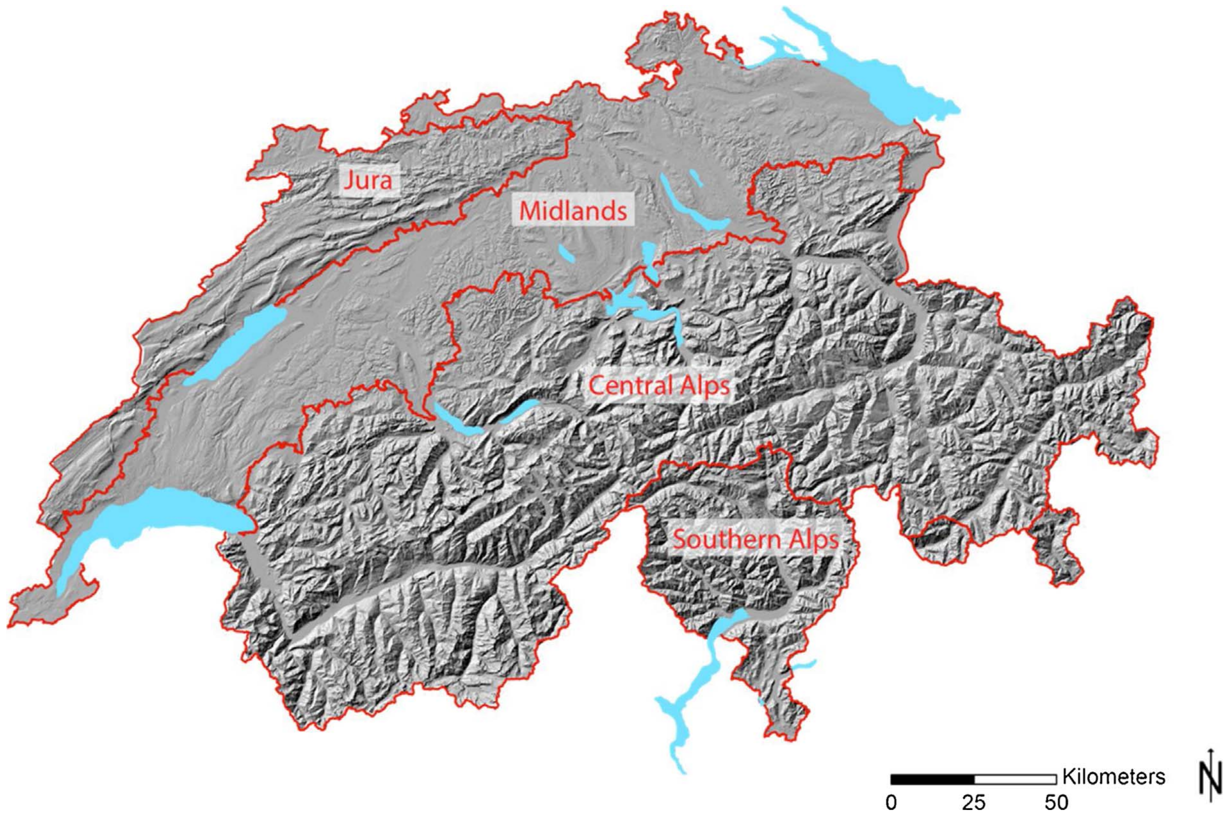

Fig. 1. The study area Switzerland with its different geographical regions. A digital elevation model is used as background and spatial data of Swiss lakes (courtesy of Swisstopo).

valuing the contribution of ES to human well-being in biophysical and economic terms. Ecosystem accounting relies on approaches to spatially measure and continuously monitor the conditions of ecosystems, their capacity to sustainably provide ES, and the effective flow of ES to society (Hein et al., 2015). Ensuring sustainable development of socio-ecological systems requires understanding and assessing the spatial and temporal changes in ES for improved management decisions and verification of progress towards national and international policies (e.g. Aichi Biodiversity Targets, Sustainable Development Goals). To accomplish this, the guidelines of the System for Environmental Economic Accounts Experimental Ecosystem Accounting (SEEA EEA) stress the need to capture spatial heterogeneity in ecosystems and related services (European Commission et al., 2013). The Ecosystem Accounting framework differentiates between ES flow, the amount of a service used by humans in a given time period, and potential supply defined as amount of a service generated by an ecosystem irrespective of its human use (Hein et al., 2016). Investigating both aspects is important to assess independently changes in ecosystem processes and in human use of ES.

Spatial ES modeling and mapping approaches have rapidly evolved in the past two decades covering a wide range of ES mapping approaches across various spatial scales (Burkhard et al., 2012; Maes et al., 2016; Malinga et al., 2015; Rabe et al., 2016; Schröter et al., 2014). Information of intra- and inter-ecosystem variability and related ES is essential to ensure sustainable development of socio-ecological systems, e.g. by improved management decisions and by the implementation of ecosystem accounting. However, there is a lack of accurate spatially explicit ES quantifications at larger scales (Lavorel et al., 2017). This justifies the request for new ES mapping approaches providing quantitative ES data compared to existing proxy indicators or models relying on land cover and expert judgments (Remme et al., 2014).

We argue that the use of remote sensing (RS) data offers new pathways for ecosystem accounting, particularly for the monitoring of status and trends in ecosystem conditions and ES across space and time. The large potential of RS for monitoring and mapping ecosystem services and biodiversity is already widely recognized (Cord et al., 2017; Cord et al., 2015; Pettorelli et al., 2016; Skidmore et al., 2015; Tallis et al., 2012). The integration of RS in ES models is, however, less elaborated compared to ES assessments without RS data. Three main gaps for ES monitoring can be identified: i) Land use and land cover are still the most common RS information used in ES models (e.g. InVEST (Sharp et al., 2016), ARIES (Villa et al., 2014)) (de Araujo Barbosa et al., 2015; Lavorel et al., 2017), often resulting in underestimated intra-class heterogeneity in ES supply due to the assumption of the same biophysical values per land cover class (Eigenbrod et al., 2010). Some recent studies started extracting the spatial explicitness of RS data to overcome this problem and consider spatial heterogeneity of ES in their mapping approaches (Braun et al., 2017; Remme et al., 2014; Schröter et al., 2014; Strauch and Volk, 2013). Nevertheless, there remains a lack of quantitative approaches that link ES to ecosystem processes at larger scales (Lavorel et al., 2017). ii) Many studies neglect the advantage of large temporal coverage by RS products. Nearly 30 % of ES studies using Earth observation data, are based upon monotemporal imagery and 56 % of the studies covered only 10 years or less (de Araujo Barbosa et al., 2015). iii) A particular lack is related to RS based assessments of multiple ES across space and time.

With this study we make a contribution to a requested paradigm shift in ES assessment from purely mapping to spatially explicit monitoring of ES (Cord et al., 2017; Cord et al., 2015; Karp et al., 2015; Tallis et al., 2012). In this study, we aim at demonstrating the contribution of RS to quantitative and spatially explicit ES monitoring for sustainable development and natural resource management. This is demonstrated by investigating spatio-temporal trends in potential supply and flow of ES in Switzerland between 2004 and 2014 using the ecosystem accounting framework. We applied mechanistic models in combination with RS data to estimate three regulating services, i.e. CO_2 regulation (CO_2R), soil erosion prevention (SEP), air quality regulation (AQR), as well as the cultural service recreational hiking (RH). We use