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Review

A quantitative review of relationships between ecosystem services

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ABSTRACT

Ecosystems provide multiple ecosystem services (ES) to society. Ignoring the multi-functionality of land systems in natural resource management generates potential trade-offs with respect to the provisioning of ES. Understanding relationships between ES can therefore help to minimize undesired trade-offs and enhance synergies. The research on relationships between ES has recently gained increasing attention in the scientific community. However, a synthesis on existing knowledge and knowledge gaps is missing so far. We analyzed 67 case studies that studied 476 pairwise ES combinations. The relationships between these pairs of ES were classified into three categories: "trade-off", "synergy" or "no-effect". We tested three hypotheses: (1) a dominant relationship between ES exists for each ES pair; (2) this relationship is influenced by the scale at which the relationship had been studied as well as by the land system the analysis took place; and (3), this relationship is further affected by the method applied to characterize the relationship. For the first hypothesis, we demonstrated a comprehensive matrix of pairs of ES. Most pairs of ES (74%) had a clear association with one category: the majority of case studies reported similar relationships for pairs of ES. A synergistic relationship was dominant between different regulating services and between different cultural services, whereas the relationship between regulating and provisioning services was trade-off dominated. Increases in cultural services did not influence provisioning services ("no-effect"). For the second hypothesis, our analysis showed that the overall pattern of ES relationships did not change significantly with scale and land system archetypes except for some ES pairs. The regional scale was the most commonly considered, and case studies were biased among different land system archetypes, which might affect our ability to find the effect of scale or land system archetypes on the pattern of relationships. The analysis for the third hypothesis showed that the choice of methods used to determine the relationship had an effect on the direction of the relationship: studies that employed correlation coefficients showed an increased probability to identify no-effect relationships, whereas descriptive methods had a higher probability of identifying trade-offs. Our results provide helpful information of which services to include in ES assessments for the scientific community as well as for practitioners. Furthermore, they allow a first check if critical trade-offs and synergies have been considered in an analysis.

Contents

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1. Introduction

Decision making on resource managements received worldwide attention in the past decades given the urgent need to preserve ecosystems and find a sustainable balance between long-term and short-term benefit and costs of human activities (Berkes and Folke, 1998; MA, 2005; Carpenter et al., 2009; Liu et al., 2015). However, a management decision can cause undesirable consequences if it lacks understanding of the complex nature of ecosystems which lead to the multi-functionality of land systems (Holling, 1996; Bennett et al., 2009). A land system does not provide only one function but combinations of a variety of overlapping functions (Bolliger et al., 2011, p.203), each of which provides different ecosystem goods and services to society. Land systems thus have a potential to provide multiple ecosystem services (ES) (Burkhard et al., 2009; Tallis and Polasky, 2009; Mastrangelo et al., 2014; Schindler et al., 2014). Due to functional trade-offs and synergies among the different components of this multi-functionality within the land, a decision potentially influences which services people can get or lose at the same time (Wiggering et al., 2006; Paracchini et al., 2011). Therefore, a comprehensive understanding of the multi-functional land system and of the different ES derived from it is crucial in natural resource management to avoid undesired and often unaware trade-offs and to enhance synergies among ES (Rodríguez et al., 2006; Hillebrand and Matthiessen, 2009; Bolliger et al., 2011; Mastrangelo et al., 2014). A key challenge that decision makers face now is to consider multiple ES and their potential consequences rather than focusing only on a few services in isolation (Cork et al., 2007; Tallis and Polasky, 2009).

The concept of multi-functionality has been originally developed at the landscape scale (Bolliger et al., 2011; Mastrangelo et al., 2014). However, it can be transferred to larger scales at which parts of the multi-functionality present at the landscape scale might be hidden due to aggregation effects. Likewise, the concept can be applied at smaller scales but one has to keep in mind that some functions might diminish at small scales such as functions that lead to water regulation, seed dispersal, pollination and pest control that connect different parts of the landscape. Therefore, interactions across multiple scales are important to be considered in decision-making (Willemen et al., 2012; Dick et al., 2014).

The global research community endeavors to elaborate the concept of ES both in theory and practice to preserve multiple ES (MA, 2005; Carpenter et al., 2009). The Millennium Ecosystem Assessment (MA, 2005) has raised the awareness of the importance of identifying multiple ES and their interactions (Raudsepp-Hearne et al., 2010; Willemen et al., 2012). The number of publication has risen rapidly in last decades on this issue (Bennett et al., 2009). Bennett et al. (2009) stressed the importance of understanding direct and indirect relationships among multiple ES. Recent studies focusing on multiple ES have taken several perspectives using various methodological approaches. The concept of "bundles" of ES has been commonly applied in the assessment of provisioning multiple ES in a landscape (e.g. Raudsepp-Hearne et al., 2010; Martín-López et al., 2013). This approach tries to identify groups of ES that co-occur repeatedly in landscapes showing patterns of the provision of ES derived from the different land use and land cover types (Raudsepp-Hearne et al., 2010; Turner et al., 2014). It is frequently based on a GIS analysis at the landscape or the regional scale (O'Farrell et al., 2010; Nemec and Raudsepp-Hearne, 2012). Often complementary statistical or descriptive analyses have been used to identify the bundles. Another research line tends to focus on ecosystem processes and functions that underpin ES (Dickie et al., 2011; Lavorel et al., 2011). The relationships among multiple ES are either identified by statistical analysis of field data or by the analysis of the output process models such as the Lund-Potsdam-Jena General Ecosystem Simulator (LPJ-GUESS) (Smith et al., 2001) or the Soil Water Assessment Tool (SWAT) (Arnold et al., 1999). Lautenbach et al. (2013) for example analyzed the relationships between bioenergy crop and food production, water regulation and water quality regulation using SWAT together with an optimization approach.

Relationships of ES pairs can be categorized into 'trade-off', 'synergy', and 'no-effect'. The term 'trade-off' in ES research has been used when one service responds negatively to a change of another service (MA, 2005). An attempt to maximize the provision of a single service will lead to sub-optimal results if the increase of one service happens directly or indirectly at the cost of another service (Holling, 1996; Rodríguez et al., 2006; Haase et al., 2012). When both services change positively in the same direction, the relationship between two ES is defined as synergistic (Haase et al., 2012) – this is also called a 'win–win' relationship (Howe et al., 2014). When there is no interaction or no influence between two ES, this is defined as a 'no-effect' relationship.

The relationship between a pair of ES can differ across different scales and across different socio-ecological systems (Kremen, 2005; Hein et al., 2006; Bennett et al., 2009). An example for this is the "externality" of a decision on a certain service as pointed out by Rodríguez et al. (2006): a decision that seems to influence ES positively for a specific region might cause substantial trade-offs in areas nearby or faraway (e.g. 'off-site effects' (Seppelt et al., 2011) and 'telecoupling' (Liu et al., 2013; Liu and Yang, 2013)). If the effects of this decision are viewed at a larger scale including all those negatively influenced areas, the relationship between ES might be characterized by a trade-off. Cimon-Morin et al. (2013) showed in their review study that the relationship between biodiversity and ES changes with scale and region. The relationship between carbon storage and habitat was, for example, described mainly as synergistic at the global scale, but at a finer scale regions of high biodiversity and high carbon storage might be disjunct leading to a trade-off relationship. Furthermore, the relationship can change in different land systems. Land systems are defined by the terrestrial components of environmental systems such as vegetation and soil type, as well as human-environment interactions such as land use intensity, socio-economic factors (Oliver et al., 2004; Dearing et al., 2010; Václavík et al., 2013; Verburg et al., 2013). A decision on increasing a service can affect the other services differently in different