Introduction to Part III: Trade-Offs and Synergies Among Ecosystem Services

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38.1 Introduction

Efforts are increasing to integrate the sustainable provision of ecosystem services into land management decision-making. These efforts, however, are challenged by (1) the variety of methods to map and quantify ecosystem services, and (2) the scarcity of knowledge on how environmental policies and management decisions affect relationships among ecosystem services. Changes in land management can alter the type of the main services provided (e.g., from regulating to provisioning services in the case of intensification of agricultural management) and the total amount and relative mix of services provided. Unknown relationships among ecosystem services might lead to unintentional effects of management that set the sustained provision of ecosystem services at risk. A better understanding of relationships among ecosystem services is therefore much needed. This chapter introduces the part of the Atlas framework (Fig. 38.1) that focuses on relationships among ecosystem services. It contains a typology and common definitions of different types of relationships (Sect. 38.2), provides a brief overview of the diversity of methods and approaches used (Sect. 38.3), includes a summary of empirical evidence (Sect. 38.4), and, finally, discusses implications for planning and management (Sect. 38.5).

38.2 Typology and Definitions of Ecosystem Service Relationships

The conceptualization of links between ecosystem services—which we term here *relationships*—is characterized by a persistent lack of consensus. The term *trade-off*—the counterpart of *synergy*—has become especially popular in the ecosystem service literature, but still lacks conceptual clarity. Recently, the idea of ecosystem service *bundles* has gained increasing attention as a way of describing ecosystem services co-occurring in space or time. See below for more detailed definitions.

38.2.1 Relevant Mechanisms

Two principle types of mechanisms lead to different forms of relationships among multiple ecosystem services [1]: (1) common drivers such as land use change, fertilization, and expansion of infrastructure; and (2) direct interactions among ecosystem services (Fig. 38.2). While drivers may in some cases affect only a single ecosystem service, they often have positive and/or negative effects on multiple services at once (e.g., fertilization may increase agricultural yield but at the same time decrease water quality). On the contrary, direct uni- or bi-directional interactions among ecosystem services often emerge from the same underlying ecological functions and ecosystem capacity that are relevant to several ecosystem services (e.g., carbon storage and water flow regulation can both be provided by intact forest ecosystems). Neighborhood effects also frequently play an important role in observed relationships (e.g., natural and semi-natural habitats increase numbers of pollinator species, and thus have positive effects on productivity of adjacent coffee plantations). While differentiating between the two mentioned mechanisms is also important when selecting appropriate methods (Sect. 38.3), we also find non-causal co-occurrence of ecosystem services ("no effect relationships") that may happen by chance or as an artifact of ecosystem service mapping techniques [2].

38.2.2 Trade-Offs and Synergies

Common drivers and direct interactions among ecosystem services can both drive service provision in the same or opposite directions, leading to positive (synergies) or negative (trade-offs) relationships [2]. The term trade-off generally describes a situation that involves losing one quality or aspect of something in return for gaining another. Trade-off situations hence require choices to be made between two or more alternatives that cannot be achieved at the same time [3]. Trade-offs and synergies can occur spatially

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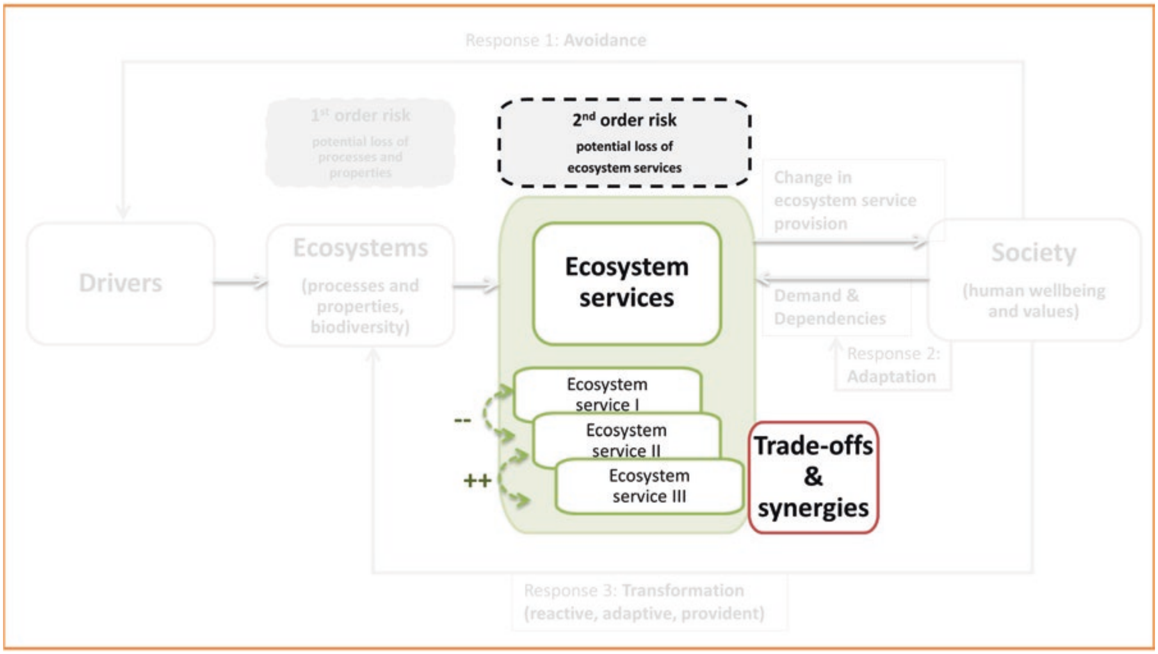

Fig. 38.1 Framework elements of the Atlas of Ecosystem Services addressed in this part

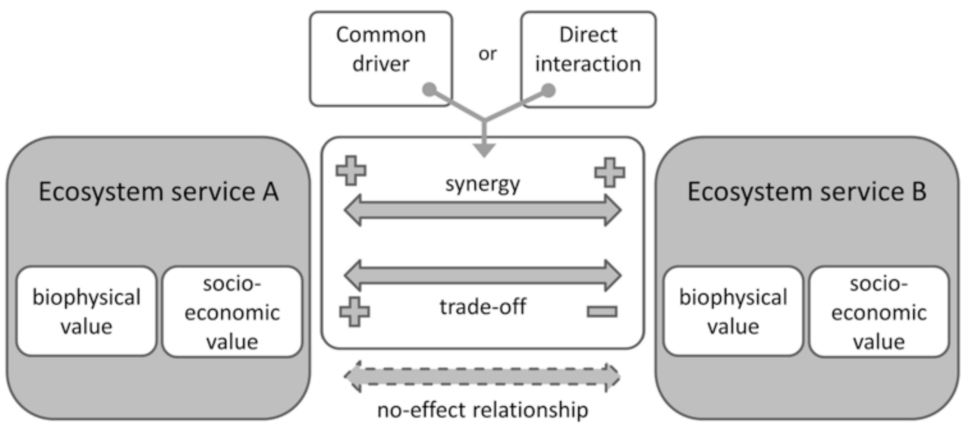

Fig. 38.2 Conceptual overview of possible relationships between ecosystem services

(across locations) or temporally (over time), and ecosystem service perturbations may or may not be reversible [4]. Further, they relate to both the biophysical provision of ecosystem services, as well as to the socio-economic and well-being benefits of different groups of people.

Based on Turkelboom and colleagues [3], we emphasize two major criteria for the occurrence of trade-offs and synergies among ecosystem services:

1. A causal relationship exists (i.e., there is a common driver or direct interaction between services). Hence we ignore non-causal co-occurrences of ecosystem services.
2. Demand for and use of the considered ecosystem services exist. Hence we ignore situations where an ecosystem is not somehow managed, altered, accessed, or experienced.

38.2.3 Ecosystem Service Bundles

Ecosystem service bundles are commonly defined as “sets of services that appear repeatedly together” [5], i.e., they represent patterns of spatially or temporally co-varying types of ecosystem services. As opposed to trade-offs and synergies, ecosystem services occurring within the same bundle are not necessarily causally linked. However, per definition, they are provided at the same time or in the same location/by the same spatial units.

38.3 Methods and Approaches

A range of qualitative and quantitative methods can be used to assess ecosystem service relationships (reviewed in Mouchet et al. [2]). The choice of appropriate method(s) depends on the research objectives [6], specific hypotheses to be tested, and compatibility with data availability and spatio-temporal scale. It may also have effects on the probability of finding trade-offs, synergies, or no-effect relationships [7].

38.3.1 Pairwise Correlations

The most popular quantitative method to assess relationships among continuous ecosystem service indicators are pairwise correlation coefficients. They are used in combination with statistical tests to identify the general direction and strength of ecosystem services relationships (e.g., Raudsepp-Hearne et al. [5]).

38.3.2 Factor Analyses and Clustering Approaches

Factor analyses and clustering approaches represent a better alternative when considering more than two ecosystem services. They identify similar ecosystem services (e.g., ecosystem bundles), are more flexible regarding the formalization of the ecosystem service indicator (i.e., continuous, nominal, or binary), and are able to handle a combination of quantitative and qualitative indicators simultaneously (e.g., Turner et al. and Queiroz et al. [8, 9]).

38.3.3 Regression-Based Methods

Regression-based methods imply causal relationships and emphasize the importance of mechanistic linkages among ecosystem services and of common drivers. Their use hence goes beyond simple detection. Still, they can get at causality only when the methodological framework is set to test for such causal relationships, i.e., by using experimental systems or predictors directly assessing the underlying mechanisms [2].

38.3.4 Multi-objective Optimization

Understanding ecosystem service trade-offs and synergies also plays an important role in studies that aim at exploring the biophysical and socio-economic constraints of landscapes and limitations to their multi-functionality. In this context, a promising approach is the combination of ecosystem service models with multi-criteria optimization methods to simulate a multitude of optimal solutions to land use or management problems. For example, while considering different crop rotations, Lautenbach et al. analyzed the trade-offs between conflicting objectives such as bioenergy production, food and fodder production, and water quantity and water quality [10].

38.3.5 Participatory Methods

Methods from the social sciences can help to understand how stakeholders perceive synergies and trade-offs that result from management decisions. Questionnaires, interviews, workshops, and focus-group discussions can help elucidate trade-offs across value domains, e.g., perceived social importance vs. economic values [11] or instrumental values against other moral values [12].

38.4 Results from Empirical Studies and from the Atlas of Ecosystem Services

The majority of case studies on relationships among ecosystem services focus on agricultural land use systems, particularly in North America and Europe. Such studies explore provisioning ecosystem services much more often than regulating/maintenance or cultural ecosystem services [13]. Typical and often-studied trade-off situations arise between timber production and carbon sequestration, as well as between food production and maintenance of habitats and biodiversity. Further, since research is mostly carried out on plot-to-regional scale, insights regarding potential trade-offs and synergies at larger spatial scales are for the most part missing. A recent global review of pairwise relationships between ecosystem services [7], however, showed that the majority of case studies reported similar relationships for pairs of ecosystem services, independent of the spatial scale considered and the land use system in which they were studied. Whereas the relationship between regulating and provisioning services are dominated by trade-offs, synergistic relationships are commonly observed different regulating services (e.g., flood protection, carbon sequestration, habitat protection) and different cultural services (e.g., spiritual experiences, recreation services). Increases in cultural ecosystem services, however, typically do not significantly influence provisioning services.

In this Atlas, Seppelt et al. (Chap. 39), conceptually synthesize the relationship between agricultural production and biodiversity under changing land composition, configuration, and landscape use intensity. Franko et al. (Chap. 40) show how a trade-off between two ecosystem services from agricultural areas arises in three federal states in Germany. They identify conflict areas in which soil organic matter, important for climate regulation, trades off with biomass for energy production. In the same vein, Majer et al. (Chap. 41) show areas in Germany where the use of straw creates a potential trade-off with the regulation of soil fertility and soil erosion. Haase et al. (Chap. 42) show how synergies and trade-offs among various urban ecosystem services arise under different land use policies.

Bundles of ecosystem services and their relationships with environmental and socio-economic gradients are assessed by Dittrich et al. (Chap. 43) for Germany. De Knegt (Chap. 44) presents bundles of ecosystem services for the Netherlands. This contribution shows the importance of distinguishing capacity to provide ecosystem services and actual use. It also investigates displacement of trade-offs between ecosystem services. Bennett et al. (Chap. 45) study bundles of ecosystem services for the past, present, and future for the Montérégie region in Canada.

Seppelt et al. (Chap. 46), finally, show simultaneous reaching of peaks of extraction of several provisioning ecosystem services on a global level.

38.5 Implications for Planning and Management

There is growing recognition among researches and decision-makers that considering multiple ecosystem services is crucial to inform balanced and sustainable land-use planning decisions [14]. For this purpose, relationships among multiple ecosystem services should be identified and assessed by integrated social-ecological approaches rather than with either social or ecological data alone [1]. So far, however, only a small portion of the literature dealing with ecosystem services in the context of environmental planning and management specifically takes into account synergies and trade-offs [15]. The goal of such studies is typically to find planning or management solutions that minimize conflicts between multiple uses and ecosystem service values. Examples of the evaluation of potential trade-offs and conflicts between multiple ecosystem services given alternative strategies range from managing protected areas [16] to marine spatial planning [17].

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