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Analysis and management of multiple ecosystem services within a social-ecological context

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ABSTRACT

The assessment of ecosystem services (ESS) requires approaches that are capable to deal with the complexity of social-ecological systems (SES). A new viewpoint is proposed, in which the social-ecological perspective of Ostrom's SES framework is used to describe the flow of ESS, through the identification of the social and ecological elements involved. Two types of ESS flow emerge from this analysis, depending on the way in which the elements of ESS supply (resource system and resource units) and demand (actors) interact: (i) a "direct flow type" in which the resource units deliver the ESS through some specific ecological functions (e.g. wetlands providing carbon sequestration), and (ii) a "mediated flow type" in which the resource units become themselves the ESS when "used" by means of human activities (e.g. fish harvested through fishing activities). The identification of activities is crucial to understand the interactions between ESS, because of the feedbacks they produce on the ecosystem functioning and thus on the provision of the same or other ESS. In addition, these feedbacks can depend on temporal aspects of ESS provision. On these regards, a hypothesis is proposed according to which a time lag can exist between the ESS supply-side and flow in human-modified SES. Altogether, this social-ecological analysis of ESS can contribute to focus the management strategies on the control of impacting activities and on the maintenance of those processes which underpin ESS' provision, thus contributing to the implementation of an ecosystem-based management of SES. These aspects are discussed in the light of the Venice lagoon example.

1. Introduction

Ecosystem services (ESS) have gained an increasing importance in the field of sustainability science and environmental management in the past decades (Burkhard et al., 2012; de Groot et al., 2010a, 2002; Millennium Ecosystem Assessment, 2005; Seppelt et al., 2011). ESS, being defined as the contributions of ecosystem structure and function – in combination with other inputs – to human well-being (Burkhard et al., 2012), result from the interactions between the ecological and social components of integrated social-ecological systems (SES) (Reyers et al., 2013), and thus their assessment requires an approach that takes into account the complexity of the SES by which they are generated.

The elements that make up the link between ecosystems and human well-being are often described by means of the "service cascade", a sort of production chain in which the biophysical structures and processes of the ecosystem are linked to the benefits (and values) they provide through a series of intermediate steps (Haines-Young and Potschin, 2010; Potschin and Haines-Young, 2011). A key role here is played by the anthropocentrically defined concept of ecosystem function, that is, the capacity of the ecosystem to do something that is potentially useful to people (de Groot et al., 2010b; Haines-Young and Potschin, 2010; Potschin and Haines-Young, 2011). This function is considered an ESS only if a human beneficiary exists (Potschin and Haines-Young, 2011). The cascade thus stresses the role of society as the beneficiary of ESS, but on the other hand it does not provide a way to represent the active involvement of humans in ESS generation.

The intervention of some anthropogenic factors in ESS delivery is an aspect that has been highlighted by several authors (Andersson et al., 2007; Bohnke-Henrichs et al., 2013; Burkhard et al., 2014; Fischer and Eastwood, 2016; Fisher et al., 2009; Jones et al., 2016; Queiroz et al., 2015). For instance, Fisher et al. (2009) specify that forms of capital other than natural can be required to realize benefits from ESS. These "additional inputs" (*sensu* Burkhard et al., 2014) refer to the anthropogenic contributions to ESS, which are recognized to be hardly separable from the ecosystem-based contributions in many human-influenced systems. The presence

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of additional inputs increases the complexity of ESS assessments (Burkhard et al., 2014), and a clear way to handle these inputs, both conceptually and in ESS assessments, is lacking.

A possible way forward is offered by the SES framework (McGinnis and Ostrom, 2014; Ostrom, 2009, 2007), aimed at providing a common language to organize findings and analyze outcomes at the SES level. According to this framework, *users* (later renamed as *actors*) extract *resource units* from a *resource system*, and this use is regulated by a *governance system* (McGinnis and Ostrom, 2014; Ostrom, 2009). The *outcomes* at the SES level are thus the result of the *interactions* among the four core variables of the SES (resource systems, resource units, governance system and actors). In a later revision of the framework, McGinnis and Ostrom (2014) open the way for its application to a broader set of situations, such as the cases in which the resources considered are ESS and public goods in general.

The use of ESS in environmental management, especially in the context of an ecosystem-based management, is becoming increasingly important (Agardy et al., 2011; de Groot et al., 2010a; McLeod et al., 2005). Management of SES faces the challenge to harmonize the provision and use of multiple ESS in a way that they become sustainable. Management focused on single ESS fails to capture the complexity of the system and can produce undesirable effects due to trade-offs between ESS, that is, a situation in which increased provision of one ESS can inhibit the provision of another ESS (Bennett et al., 2009; Meacham et al., 2016). Therefore, a deeper understanding of social-ecological processes involved in ESS provision is required also from a management perspective, for the implementation of strategies aimed at maintaining these processes to a level that is capable to provide sustainable levels of multiple ESS.

In the present work, a new viewpoint for the analysis of multiple ESS, based on the SES framework, is suggested. This approach is used to: (1) describe the social-ecological elements involved in the generation/use of ESS, (2) to categorize ESS, and (3) to explore possible implications in terms of management of multiple ESS. Finally, an example of application in the Venice lagoon is presented and discussed.

2. Analyzing ecosystem services through the social-ecological systems framework

2.1. Direct and mediated flow types

According to the SES framework, a general chain of elements is proposed, in which (1) ESS depend on *resource units* that are generated by the processes of a *resource system*; (2) the ESS provide benefits to some *actors,* and (3) their management is determined by the rules set by a *governance system* (Fig. 1). Here the resource units correspond to the elements of the system that actually provide the ESS, which, from a spatial perspective, represent the “service providing units” (*sensu* Syrbe and Walz, 2012).

The ESS flow (i.e. the *de facto* used ESS, Burkhard et al., 2014), results from the interaction between the ESS supply-side (*resource systems* and *resource units*) and the demand-side (*actors*). Here two types of interaction are distinguished, namely *ecosystem function* and *activity*, which generate two different types of ESS flow, which are named “direct” and “mediated”, respectively (Fig. 1A and B). In the “direct” flow type (Fig. 1A), the resource units generate an ecological *function* that is potentially useful to actors. Here the term function is used *sensu* Potschin and Haines-Young (2011), i.e. the capacity of the ecosystem to do something that is potentially useful to people. For example, energy dissipation is a function provided by coastal vegetation (*resource unit*), that underpins the disturbance prevention ESS. This function then becomes an ESS when and where it is actually beneficial to some actors (e.g. residents in the coastal area), with no need of a specific human input in ESS’s generation. In the “mediated” flow type (Fig. 1B), the interaction instead occurs in the form of an *activity* through which the resource units are “used” by actors. This *activity* is what makes beneficiaries “meet” the resource. The generation and availability of the resource units is dependent on ecosystem processes and functioning, however, the ESS directly depends on resources’ availability and use. Let us make the example of a forest (resource system), in which trees (resource units) provide two ESS, one is the raw material “timber” (mediated ESS) and the other one is erosion control (direct ESS). In both cases the presence of trees depends upon ecological processes occurring in the forest, such as soil processes, water and nutrient cycling, and plant growth. However, the timber ESS can be obtained only if trees are cut and timber is harvested, that is, if an activity turns the resource units into an ESS. It should be noted that this exploitation can be decoupled from ecological processes up to the point that the resource is depleted (e.g. cutting rate higher than growth rate). In this situation, this ESS is not sustainable, but it is still an ESS until there are resource units available. In order to be sustainable, the exploitation should balance the processes that generate the resource units, and this requires to move one step back in our “production and use chain” and identify the key processes and their trends. Therefore, ecological processes are crucial also for mediated ESS, but are “hidden” behind the availability of resource units. In the case of the erosion control ESS, the dependence upon an ecological function (soil retention) is straightforward, the provision of the ESS is directly proportional to the function and does not require any type of human input to turn the resource units into ESS.

The activities involved in the mediated flow type can produce feedbacks directly on the resource system (red arrows in Fig. 1B), resulting in negative effects on both the ESS itself and/or the flow of other ESS (ESS trade-offs). The identification of activities and their feedbacks is thus an important aspect that should be taken into account when analyzing interactions among ESS. The net result of all these interactions is the pattern of multiple ESS provided by the SES, which can be understood as an *outcome* of the SES.

Finally, this perspective allows to analyze the role of the governance system in the ESS delivery, which can be essentially of two types. In both flow types, the governance system should be responsible for the implementation of management measures aimed at the protection, maintenance or restoration of the resource system and units. In the case of mediated flow type, the governance system should come into play by setting rules that regulate the actors’ activities, in a way that minimizes the negative effects.

The flow types that apply to the various ESS groups, according to the Common International Classification of Ecosystem Services (CICES) version 4.3 (Haines-Young and Potschin, 2013), are proposed in Table 1.

2.2. Temporal aspects in human-modified social-ecological systems

Let us consider a SES in which society and ecosystems have coevolved over time: in such a system, ESS are provided by modified ecosystems and landscapes in which ecological and social elements are integrated. The elements of this SES are the result of processes at various temporal scales, which can influence the temporal aspects of the ESS provided. With a certain degree of simplification, we can make two hypotheses about the temporal aspects characterizing ESS in such systems:

- “short time scale” hypothesis (e.g. months, years), which represents the dependence of the current ESS provision on the “present” state and processes of the system;