Ecosystem service trends in basin-scale restoration initiatives: A review

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Abstract

The integration of ecosystem services in ecological restoration projects presents an opportunity for enhancing benefits to human livelihood and funding sources as well as generating public support for such initiatives. This study reviewed the global trends in integrating ecosystem services in basin-scale restoration projects through bibliographic analysis. Few studies appear to incorporate ecosystem services, possibly due to the inconsistency and absence of the use of universally accepted classifications. Our review notes an increasing trend from 2006 onward towards the inclusion and citation of this concept, although its use is still limited. In this review, the supporting service was found to be the most cited (8), followed by regulatory (3), cultural (1) and provisioning (1) services. Identifying the number of services related to a restoration action was problematic when the services were not explicitly cited. We identify opportunities for increased integration of ecosystem services in basin-scale restoration projects, suggesting a conceptual framework following from new hierarchical maps. This is based on congruence between degrading processes or threat maps (e.g., thresholds of impacts) and ecosystem service maps. The resultant map will facilitate the targeting of threatened service supply at different scales from the basin scale to the scale of the restoration site. We urge the scientific community to standardize definitions and create methodologies and software tools that facilitate the incorporation of ecosystem services in large-scale restoration plans.

Key words: Environmental management, Ecological function, Landscape, Restoration of natural capital, Watershed, Ecological process.

1. Introduction

Human-induced changes and damage of the Earth's ecosystems make ecological restoration one of the key strategies of the present and beyond (Hobbs and Harris, 2001). Restoration is vital for stemming both the current loss of biodiversity and the associated decline of ecosystem services (Dobson et al., 1997; Millenium Ecosystem Assessment (MA), 2005). The purpose of restoration is to initiate, or accelerate, the recovery of an ecosystem with respect to its health, integrity and sustainability (SER, 2004). Ecological restoration and associated efforts are rapidly increasing and are being implemented throughout the world (Clewell and Aronson, 2007). This growth is supported by global and regional policy commitments, such as the Convention on Biological Diversity ([article 8(f)], 2007) and the Commission of the European Community (2008), among others. Restoration can be undertaken at different scales ranging from local and habitat-specific actions to the biome and regional levels. Although small-scale short-term projects can be valuable, these experiments do not resemble real-world ecosystem management. Many authors recognize the urgent need to greatly expand the scale of ecosystem restoration and conservation (Comin, 2010; Moreno-Mateos et al., 2012; Naveh, 1994; Palmer, 2009; Hobbs and Norton, 1996; Wohl et al., 2005). Large-scale ecosystem restoration is required to arrest and reverse the degradation of landscapes around the world, particularly focusing on biodiversity as a positive relationship has been observed between biodiversity and ecosystem services after restoration (Rey-Benayas et al., 2009). Also focus on river systems is encouraged as increasing evidence suggests that the biodiversity of freshwater ecosytems is among the most endangered in the world (Driver et al., 2005; Dudgeon et al., 2006; Jenkins, 2003; WWF, 2004).

The emerging policy focus on ecosystem services represents a significant shift in the objectives of restoration (Bullock et al., 2011). Economic valuation of ecosystem services has accentuated interest in using these services as a basis for restoration and conservation programs (Ehrenfeld, 2000). European Environment Agency (EEA) initiated the EURECA project which is intended to contribute to a European Ecosystem Assessment is strong evidence of the institutional interest in integrating ecosystem services in future socio-economic decisions. Recent progress in the assessment and evaluation of ecosystem services is likely to increase the inclusion of ecosystem services in restoration planning and implementation (Fiedler et al., 2008; Lopez-Barrera, 2008; Martinez and Naidoo et al., 2008; Moberg and Ronnback, 2003; Nelson et al., 2009; Reyers et al., 2009). While a single restoration project is unlikely to ameliorate the state of a large degraded basin, ecologists can help to identify combinations of projects that will best restore ecosystem services within watersheds. To obtain a full understanding of the services provided in a study area, research should ideally be conducted at multiple, nested scales, as environmental effects may be uncorrelated across scales (MA, 2003), although the large-size, long-term ecological services and functions constrain or control the small-size, periodical ecosystem services and functions (Limburg et al., 2002).

Such “strategic” restoration would prioritize the location, size and type of network of restoration projects needed for a watershed that can be compared with the stakeholder needs in order for it to provide optimal levels of ecosystem services (Zedler and Kercher, 2005). Biophysical and, increasingly, socio-economic values are currently used to define priority areas for planning conservation and environmental management measures (Raymond et al., 2009) as well as for evaluating the benefits of restoration projects (Aronson et al., 2010; Palmer et al., 2005). However, the degree to which ecosystem services have been incorporated into basin-scale restoration actions to date is unclear.

To address this knowledge gap, we conducted a survey of peer-reviewed international scientific literature to reveal global trends. Furthermore, we explored the emerging issues related to ecosystem service classification, mapping approaches, tools and software. We identified opportunities for the increased integration of ecosystem services in basin-scale restoration projects, suggesting a framework based on new hierarchical maps. This is based on congruence among threat maps (e.g., thresholds of impacts) and ecosystem service maps. The resultant new map will facilitate the targeting of threatened service supply at different scales. The inclusion of ecosystem services in restoration projects provides an opportunity for defining clear goals for generating public support and funding sources, which are necessary conditions to enhance the planning and implementation of restoration projects (Choi, 2007; Ehrenfeld, 2000; Hobbs, 2007).

2. Materials and Methods

2.1. Literature search

We follow the methodology of Egoh et al. (2007) in using the ISI Web of Science (http://www.newisiwebofknowledge.com) to search for peer-reviewed publications from 1998-2010 (February) written in the English language. We limited our search to 1998 and beyond because this is when the terminology “ecosystem services” was introduced in the published literature by Daily (1997). This publication, among others, created a clear increase in the number of studies citing ecosystem services (see Fig. 1 in Fisher et al., 2009). We searched for the term “restoration project” in an advanced search on ISI using the Boolean AND associated with a number of terms related to restoration (see Appendix).

2.2. Data extraction

We followed the data extraction methodology of Rey-Benayas et al. (2009) in part, examining the titles and abstracts of each reference to determine how closely they aligned with our selection criterion of ecosystem services classification based on MA (2005) within basin areas, thereby determining their inclusion in this review. If the manuscript reported on measures of one or more ecosystem services and/or biodiversity in relation to restoration at the basin scale, the study was included. Tools and techniques associated with the included services were also discussed to understand the best way to include services in restoration projects in the future.

3. Results

3.1. Inclusion and trends of ecosystem services in restoration.

Our search identified a total of 414 studies related to the selected search terms. However, only 45 of these studies involved research addressing basin-scale restoration and also made reference to ecosystem services either explicitly or implicitly. Analysis of the 45 studies showed a clear increase in the integration of ecosystem services (or processes resulting in these services) in basin-scale restoration studies from 2006 onward (Fig. 1). Of the 45 studies, only 13 explicitly referred to ecosystem services as being an integral part of basin-scale restoration studies. Among these 13 studies, eight investigated only one ecosystem service; four studies measured two; and one study measured three ecosystem services. In the remaining 32 studies, the reference to ecosystem services was implicit in their reference to ecosystem providers expressed as processes and functions.

3.2. Types of services that have been included

Four categories of services were addressed in the 13 studies that made explicit reference to ecosystem services: supporting, regulating, cultural and provisioning services. The supporting service was the most common (appearing in eight studies), followed by regulatory (three studies), cultural (one studies) and provisioning services (one study). We note that these categories are not mutually exclusive; most of the restoration studies potentially included multiple services that were not stated, thus preventing the positive results of restoration from being represented in their totality, downplaying the effort undertaken. The supporting service of habitat/refugia/nursery functions, which is generally linked to target species that benefit from habitat restoration, was the most common. Flood/drought prevention, water regulation and erosion control also received attention in restoration studies, either through their explicit inclusion or through the inclusion of ecological processes linked to them. The provisioning services addressed in the studies were focused on water production in a river basin, while the cultural services were focused on landscape restoration and the local inhabitants' perceptions of the projects, which were evaluated by means of local surveys (see table 1 in Appendix).

Our review indicated that no study at the basin scale explicitly mapped ecosystem services targeting restoration; instead, they identified and, in some cases, mapped processes and Ecosystem Service Providers (ESPs), which are mostly habitats, species and populations that are in some way responsible for the provision of services (see Table 1 in Appendix).

4. Discussion

4.1. Classifying ecosystem services

Despite the fact that ecosystem services now feature prominently in ecological studies and the many calls that have been made to introduce them into restoration plans (Dodds, et al., 2008; Ormerod, 2003; Peterson and Lipcius, 2003), prior to 2006, few peer-reviewed studies on restoration at the basin scale actually did so. Our review found an increasing trend from this date onward towards the inclusion of this concept (Fig.1). This growth may be due to an emerging societal consciousness that resources are becoming increasingly degraded and scarce (Costanza et al., 1997). The main reason for these declines is the rapid increase projected globally in the demand for food, fresh water, energy, and other resources over the next few decades, which implies greatly intensifying human impacts (Daily, 2000). But the great catalyst was the MA work which made a thorough effort to assess the effects of policies on ecosystem services and human well-being in 2005 (MA, 2005), and provided a base for further studies (Carpenter et al., 2009).

Notwithstanding the most difficult task in this review was the identification of ecosystem services, which was due to the lack of consistency and absence of the use of universally accepted classifications (e.g., Costanza et al., 1997; de Groot et al., 2002). Instead, the selected studies mostly referred to restoration of ESPs, ecological functions and processes to support biodiversity. This was a normal practice in past studies, where functions were identified and studied for years with no reference to services for humans, which they also provide (Fisher et al., 2009). Current debates about how to best define the distinction between ecosystem functions and services and how to classify the services to make them quantifiable in a consistent manner are ongoing (Fisher et al., 2009; de Groot et al., 2010). In a recent review, Rey-Benayas et al. (2009) also found that only a small minority of studies explicitly referred to the concept of ecosystem services, whereas a larger number referred to the concept of ecosystem function. In turn, Wallace (2007) found many relevant authors who examined the classification of ecosystem services combining means (processes) and ends (services) within the same category level, making the categories unusable for effective decision making. In our study case, for example, it was found that different services may be linked through processes, which may result in an unconscious double counting of services if services are not explicitly included in the study. The inconsistency in ecosystem service classification has been noted in many studies as Fu et al. (2011) highlighted in a recent review, causing uncertainty and a lack of reliability with respect to the estimation of the value of ecosystem services,.

4.1.1. Functions, processes and services?

Ecosystem services are generated by ecosystem functions, which, in turn, are underpinned by biophysical structures and processes classified in the MA (2005).

Moreover, biophysical processes are essential for the provision of ecosystem services, but processes are not synonymous with services (Tallis and Polasky, 2009). Processes and functions become services if there are humans that benefit from them (Fisher et al., 2009); nevertheless, it is common to find many authors who treat them as synonyms (Wallace, 2007). It is clear that a coherent and integrated approach for practical application of the concept of ecosystem and landscape functions in planning, management and decision making is still lacking (ICSU et al., 2008).

4.1.2. Missed opportunities

Every restoration project directly or indirectly aims to improve ecological processes, and based on the degree to which a degraded area is restored, it can potentially improve ecosystem services and create new ones, changing the conditions of degraded sites and improving the delivery of services. This is why some studies include multiple overlapping services, either intentionally or not. For example, in the present review, it was found that studies that attempt to restore habitat (see: Battin et al., 2007; Fullerton et al., 2006; Fullerton et al., 2009; Katz et al., 2007) for a target species (e.g., salmon) can be included among both supporting services (habitat provision) and provisioning services (food). Additionally, restoration of salmon habitat could enhance other services, such as regulating and cultural services (e.g., if the salmon are fished). However, the different services will often not be cited and are even less likely to be quantified. In studies addressing the dynamics of land use in a watershed, such as that of Rayburn and Schulte (2009), the addition of ecosystem service maps could complement, enrich and drive future land use scenarios as a basis for restoration planning.

Unfortunately, this lack of awareness regarding the use of ecosystem services is partially due to the poor understanding of the quantitative relationships between biodiversity, ecosystem components and processes and services. As de Groot et al.

(2010) highlight, criteria and indicators are required to comprehensively describe the interaction between the ecological processes and components of an ecosystem and their services. Reaching this point, it is extremely important to create standardized terms and definitions, eliminating any doubts and inconsistencies and standardizing the classification and the methodology. Despite the tremendous resources required for this ambitious approach (Kremen and Ostfeld, 2005), some progress has been made. If the opportunity to achieve concrete results is not to be lost, then it is time to standardize methodologies, definitions and key concepts to describe and quantify ecosystem services (de Groot et al., 2010; Wallace, 2007).

4.1.3. Learning from previous studies

Given the amount of attention that the ecosystem services concept has received in the past few years, it seems surprising that the services are not yet widely used to drive and target restoration projects (e.g., at landscape and basin scale). A likely cause of this oversight is the use of a traditional ad hoc restoration approach instead of a more holistic view, which constitutes the basis of sustainability. We therefore need to move away from the ad hoc site- and situation-specific approach that has been prevalent in restoration activities (Hobbs and Norton, 1996). For example, in a river restoration project, a broad knowledge of the characteristics of the watershed and river is required to identify not only environmental impacts but also their origins (Comín et al., 2009). In the present review, Fullerton et al. (2006) can be a good example of ecological data required for future translation from process into services. They used land use maps, aerial photos and field observations to map riparian areas according to their in-stream functions (organic matter inputs, filtration of pollutants and sediment, bank stabilization, temperature control), linking them with services such as disturbance prevention and nutrient cycling. Fewer explicit guidelines are available at the landscape/basin scale beyond non-quantitative generalities about size and connectivity. The global-scale ecological decline (Global Footprint Network, 2010) requires the development of general guiding principles for restoration projects to address the global challenges that humanity faces (Comin, 2010). Development of these guidelines should be prioritized so that urgently required large-scale restoration can be planned and implemented effectively (Hobbs and Norton, 1996).

4.2. Mapping ecosystem services

Unfortunately, the quantitative relationships between biodiversity, ecosystem components and processes and services are still poorly understood (de Groot et al., 2010). Current landscape maps normally include land cover and/or related uses. Quantifying ecosystem services in a spatially explicit manner and analyzing tradeoffs between them can lead to making more effective, efficient and defensible decisions related to natural resource.

Mapping ESPs is one of the most explicit methods for including ecosystem services in conservation activities (Egoh et al., 2007), though no consistent mapping protocol or official accepted framework exists that can be followed for this purpose. One of the main research questions to be resolved is how ecosystem services can be spatially mapped and visualized in a universal way (de Groot et al., 2010). In this review, ecosystem services were generally found to be both biotic (Grundel and Pavlovic, 2008) or abiotic (Fullerton et al., 2006; Nienhuis et al., 2002) attributes, such as vegetation type (Vesk et al., 2008) or scenic rivers being mapped (Junker and Buchecker, 2008). Mapping could also be applied in restoration planning, providing the opportunity to locate and quantify services for the purpose of making decisions and prioritizing future restoration activities. Unfortunately, the extent to which ecosystem services can be included in restoration studies remains largely untested, but there are some interesting new attempts focusing on some areas or some types of ecosystems of a territory (Orsi et al., 2011; Pert et al., 2010; Tong et al., 2007).

4.2.1. Prioritization through mapped congruence

Ecosystem services coupled with climate, demographic, economic and social models and data are becoming more common. The widespread use of geographic information systems (GIS), statistics and geostatistics currently provides a powerful and complementary suite of tools for spatial analysis in the agricultural, earth and environmental sciences (Burrough, 2001). Studies at the basin and landscape scales have begun to include ecosystem service mapping and evaluation into management and restoration plans (see: Egoh et al., 2011; Nelson et al., 2009; O'Farrell et al., 2010; Wendland et al., 2010). These authors follow the common framework of comparing services with one or more datasets, such as datasets addressing biodiversity conservation, vegetation diversity, needs of the local population, or commodity production. Following these examples of data intersection, we suggest a framework based on evaluation of the congruence among degrading processes or threat areas (e.g., erosion, deforestation, point and non-point pollution areas) and ecosystem service maps (Raymond et al., 2009) for the generation of new hierarchical maps based on thresholds of impacts (e.g., estimation of erosion limits for soil formation) and services (e.g., the number per area or level of importance required for the wellbeing of the beneficiary). Congruence among ecosystem services or ecological processes and threats areas will be exported as a new map which will facilitate the targeting of threatened services supplied at different scales from the basin scale to the scale of the restoration site. This systematic approach is well recognized as the essential next step toward informing decision making for a systematic approach that combines the rigor of small-scale studies with the breadth of broad-scale assessments (Tallis et al., 2009). The development and application of these hierarchical maps is a step in this direction, providing the opportunity to obtain an overview of the ecological state of a basin to understand and locate key ecosystem service priority areas for the purpose of maintaining, improving or restoring strategically identified targets. In these cases, the resolution of the available data is key for the downscale approach to be effective. Changing the spatial scale from a basin to prioritized areas requires optimum dataset support, depending on the scale of the target (e.g., at finer scales, a small pixel size is requested) to achieve more accurate targeting. Depending on the cell size of our maps, we would be able to downscale gradually from the basin to the subwatershed until we arrive at more defined and specific threatened areas (e.g., slopes, opencast mines, riparian areas, forest patches).

4.2.2. Data and planning tools

The planning of basin-scale restoration projects integrating ecosystem services still requires improvement. The amount of data available for mapping ecosystem services is growing. Some work in this arena is currently being conducted, including the creation of models such as InVEST (http://www.naturalcapitalproject.org/InVEST.html), which is aimed at spatially explicit modeling of multiple services, biodiversity and tradeoffs. We make a call for the creation of an operational model and software tools capable of include and evaluate congruence among degraded areas, threats and services. This will simplify spatial actions targeting future restoration projects. New data and techniques will be required to address the majority of ecosystem services. Critical data needs include comprehensive time series information on changes in land cover and land use (e.g. Costa et al., 2003) as well as biotic systems (e.g. Richards et al., 1996); the locations and rates of desertification (e.g. Geist and Lambin, 2004) and erosion (e.g. Trabucchi et al., 2012); the spatial patterns and changes of freshwater quantities and quality for both ground and surface waters; and data on stocks and flows (e.g. Le Maitre et al., 2007). These data will allow us to understand trends in human use and to perform economic evaluation of services. In addition to these core global datasets, indicators are required to bridge raw observations with scientific hypotheses or policy questions (Carpenter et al., 2009)

5. Conclusions

This review indicates that inclusion of ecosystem services in restoration studies at the basin-scale has increased since 2006 under the thrust of the MA, but the approaches adopted for this purpose are diverse. This is due both to the legacy of the use of ad hoc approaches in restoration plans in the past and to a nonexistent universal ecosystem service framework to be followed (based on universal definitions and methodology) that could make the quantification and localization of services simpler and straightforward. Including ecosystem services in basin-scale restoration plans represents a great challenge for the future. A more holistic approach will be allowed, enriching the ecological understanding of a whole basin and the services provided within it through integrating assessment, mapping and modeling approaches. Standardizing the mapping and methods used for integrating ecosystem services is a vital next step in moving this field forward. The creation of an operational model and software tools capable of planning ecosystem services able to evaluate congruence among threats and services will simplify spatial actions, targeting future restoration projects and specify their goals. This will have the additional effect of making basin-scale restoration plans more attractive with respect to receiving support and funding.

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