Ecosystem Services ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser

Linkages between biodiversity attributes and ecosystem services: A systematic review

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ARTICLE INFO

Article history:
Received 3 March 2014
Received in revised form
21 May 2014
Accepted 23 May 2014

Keywords:
Biodiversity
Ecosystem service
Attribute
Trait
Ecosystem function
Network analysis

ABSTRACT

A systematic literature review was undertaken to analyse the linkages between different biodiversity attributes and 11 ecosystem services. The majority of relationships between attributes and ecosystem services cited in the 530 studies were positive. For example, the services of water quality regulation, water flow regulation, mass flow regulation and landscape aesthetics were improved by increases in community and habitat area. Functional traits, such as richness and diversity, also displayed a predominantly positive relationship across the services, most commonly discussed for atmospheric regulation, pest regulation and pollination. A number of studies also discussed a positive correlation with stand age, particularly for atmospheric regulation. Species level traits were found to benefit a number of ecosystem services, with species abundance being particularly important for pest regulation, pollination and recreation, and species richness for timber production and freshwater fishing. Instances of biodiversity negatively affecting the examined ecosystem services were few in number for all ecosystem services, except freshwater provision. The review showed that ecosystem services are generated from numerous interactions occurring in complex systems. However, improving understanding of at least some of the key relationships between biodiversity and service provision will help guide effective management and protection strategies.

1. Introduction

The significance and value of ecosystem services for human well-being is well known (e.g. Butler and Oluoch-Kosura, 2006; Costanza et al., 1997; Daily, 1997; de Groot et al., 2002; Harrison et al., 2010). Ecosystems provide four types of service: provisioning (e.g. food), regulating (e.g. water quality regulation and pollination), cultural (e.g. recreation) and supporting (e.g. nutrient cycling) (Millennium Ecosystem Assessment, MA, 2005). The importance of biodiversity in underpinning the delivery of both ecosystem services and the ecosystem processes that underlie them is well recognised (Díaz et al., 2006; MA, 2005), and our understanding of the nature of the biodiversity–ecosystem services relationship and the possible effects of biodiversity loss on the delivery of ecosystem services is increasing

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http://dx.doi.org/10.1016/j.ecoser.2014.05.006
2212-0416/

(e.g. Balvanera et al., 2006; Cardinale et al., 2006). Consequently, there is an increasing trend to integrate ecosystem service arguments within the management plans and strategies of protected areas (e.g. García-Mora and Montes, 2011), as well as the wider landscape (e.g. The Scottish Land Use Strategy, Scottish Government, 2011). However, ecosystem service-related argumentation is not undisputed (Schroter et al., 2014).

Early work on the biodiversity–ecosystem services relationship explored the contribution of habitats to different ecosystem services (Chan et al., 2006) and of individual species to the functional structure of ecosystems, as well as the impact of interactions, both between species, and between species and the environment, on ecosystem function (Balvanera et al., 2005). The link between ecosystem services and biodiversity has further been examined, not only in terms of species, but also genotypes, populations, species functional groups and traits in an ecosystem (Díaz et al., 2006).

Much recent work has focused on functional relationships between biodiversity and ecosystem services. Functional diversity is one of the most important biodiversity attributes affecting ecosystem services by impacting the underlying ecosystem processes (e.g. de Bello et al., 2010; Díaz et al., 2006). Research has focused on single species (Luck et al., 2009) and groups of species (Díaz et al., 2007; Hooper et al., 2005), in addition to a number of broader scale syntheses (e.g. Conti and Diaz, 2013). Other studies have tended to examine a small selection or individual ecosystem services (Kremen, 2005; Luck et al., 2009; Seppelt et al., 2011), with few spanning multiple ecosystems (Bastian, 2013; Lavorel and Grigulis, 2012). Trait[3] analysis (e.g. Balvanera et al., 2006; de Bello et al., 2010; Díaz et al., 2006; Hooper et al., 2005; Lavorel and Grigulis, 2012; Luck et al. 2012) has been shown to be useful in identifying specific links between species, ecosystem processes and ecosystem service delivery and can demonstrate the complexity of processes and interactions which occur in ecosystems (Fagan, et al., 2008; Gaston, 2000; Lavorel, 2013).

Population dynamics are another factor impacting ecosystem functioning and service provision. This was first highlighted by Luck et al. (2003), who proposed the concept of a Service Providing Unit (SPU) to describe the ecological unit which provides the ecosystem service. Subsequently, Kremen (2005) suggested identifying Ecosystem Service Providers (ESP) and the concepts were combined into the SPU–ESP continuum by Luck et al. (2009), showing how the ESP concept can be applied at various levels, for example population, functional group and community scales.

Knowledge on the links between biodiversity and the provision of ecosystem services is key for furthering arguments for ecological restoration (Rey Benayas et al., 2009; Bullock et al., 2011). It could also contribute to the management of protected and restored areas (Bastian, 2013) in order to meet the dual goal of optimising the delivery of ecosystem services and supporting biodiversity conservation (Palomo et al., 2014). However, despite a number of meta-analyses, and advances in research and understanding of this relationship (Balvanera et al., 2006; Bastian, 2013; Cardinale et al., 2006, 2012; Hooper et al., 2005; Luck et al., 2009; Mace et al., 2012) there remains much uncertainty over the effect of the complexity of biodiversity components on the ecosystem functioning that underlies service provision (Balvanera et al., 2014; Schroter et al., 2014). Current knowledge has been poorly integrated and few studies incorporate a wide range of both biodiversity attributes and ecosystem services. Also there are few studies using empirical evidence to examine the role of biodiversity in providing ecosystem services (Mertz et al., 2007), and the quantitative relationships between components of biodiversity and ecosystem services are still poorly understood (Carpenter et al., 2009; de Groot et al., 2010).

This review builds on current state-of-the-art concepts that link ecosystem service provision with biodiversity, particularly on the identification of ESPs. It examines the underpinning role of biodiversity for a range of ecosystem services from the provisioning, regulating and cultural categories (MA, 2005; CICES, Haines-Young and Potschin, 2013). We focus on the key biotic and abiotic attributes of individual ESPs and evidence of their influence on the delivery of particular services. We explore the direction (positive, negative or unclear) and strength (from very weak to very strong) of this influence in order to understand the multifaceted nature of the ESP-attributes-services relationships and indicate future research challenges. Our overall objective is to contribute to the understanding of the possible effects of biodiversity on ecosystem services and human well-being using network diagrams as an innovative approach to illustrate the complexity of interconnections. This also improves the scientific knowledge base allowing those biodiversity attributes that are crucial for the delivery of ecosystem services to be more effectively targeted in management plans. Importantly, unlike other similar studies, this review also documents possible negative effects of biodiversity on ecosystem service provision.

2. Material and methods

2.1. Data collection

Eleven ecosystem services were included in the review chosen to represent the key groups of services from the MA and CICES classifications (Table 1). In order to review and consolidate existing research on the linkages between biodiversity and these 11 ecosystem services, a literature search was conducted between July 2012 and August 2013 using Web of Science or Web of Knowledge. The primary aim of focusing on peer-reviewed academic literature was to find the best available knowledge reported by the scientific community. A systematic methodology was adopted in order to ensure that a rigorous and repeatable method was applied to each ecosystem service. The method consisted of three stages: (i) the generation of keywords, (ii) a systematic search, and (iii) extraction of the data.

Keywords were generated based on the results of a pilot test (conducted from February to April 2012) which showed that 'ecosystem services' is a relatively new term and, hence, only using this term in a literature search is likely to miss relevant papers. Thus, keywords specific to each ecosystem service were selected, accompanied by appropriate biodiversity terms which could be related to the given ecosystem service. We included both synonyms (i.e. the service) and antonyms (i.e. the disservice) in the search terms to enable negative, as well as positive, impacts of biodiversity on ecosystem service supply to be captured. Additional service-related terms were used if necessary to refine results when large numbers of papers were found for the initial search terms (see Online resources for a full list of search terms).

The objective was to find 50 relevant papers for each service in order to have a wide range of relationships and studies. For many ecosystem services, however, the number of relevant results using the above methodology was too few. In these cases, additional intelligent search approaches were utilised. These included: (i) searching the reference lists of relevant articles for secondary references which may be of interest (termed snowballing) and (ii) searching for papers that have cited the relevant papers (termed reverse snowballing). In total, 50 papers were found for all services except timber production and freshwater fishing, where only 35 and 45 papers could be found, respectively, after applying all search approaches. This reflects the

[3] Specific properties of species which define their ecological function and govern their impact on ecosystem processes and services (De Bello et al., 2010; Diaz and Cabido, 2001).