Quaternary Science Reviews 112 (2015) 17–32

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Invited review

The role of palaeoecological records in assessing ecosystem services

Elizabeth S. Jeffers [a,*], Sandra Nogué [a,b], Katherine J. Willis [a,b,c]

[a] Long Term Ecology Laboratory, Biodiversity Institute, Oxford Martin School, Department of Zoology, University of Oxford, Oxford OX1 3PS, UK
[b] Department of Biology, University of Bergen, Allégaten 41, N-5007 Bergen, Norway
[c] Royal Botanic Gardens, Kew, Richmond, TW9 3AE, UK

ARTICLE INFO

Article history:
Received 10 July 2013
Received in revised form
12 December 2014
Accepted 19 December 2014
Available online

Keywords:
Ecosystem services
Palaeoecology
Long-term ecological records
Final ecosystem services
Ecosystem goods
Proxies
Dendroecology

ABSTRACT

Biological conservation and environmental management are increasingly focussing on the preservation and restoration of ecosystem services (i.e. the benefits that humans receive from the natural functioning of healthy ecosystems). Over the past decade there has been a rapid increase in the number of palaeoecological studies that have contributed to conservation of biodiversity and management of ecosystem processes; however, there are relatively few instances in which attempts have been made to estimate the continuity of ecosystem goods and services over time. How resistant is an ecosystem service to environmental perturbations? And, if damaged, how long it does it take an ecosystem service to recover? Both questions are highly relevant to conservation and management of landscapes that are important for ecosystem service provision and require an in-depth understanding of the way ecosystems function in space *and* time. An understanding of time is particularly relevant for those ecosystem services – be they supporting, provisioning, regulating or cultural services that involve processes that vary over a decadal (or longer) timeframe. Most trees, for example, have generation times >50 years. Understanding the response of forested ecosystems to environmental perturbations and therefore the continuity of the ecosystem services they provide for human well-being – be it for example, carbon draw-down (regulating service) or timber (provisioning service) – requires datasets that reflect the typical replacement rates in these systems and the lifecycle of processes that alter their trajectories of change. Therefore, data are required that span decadal to millennial time-scales. Very rarely, however, is this information available from neo-ecological datasets and in many ecosystem service assessments, this lack of a temporal record is acknowledged as a significant information gap.

This review aims to address this knowledge gap by examining the type and nature of palaeoecological datasets that might be critical to assessing the persistence of ecosystem services across a variety of time scales. Specifically we examine the types of palaeoecological records that can inform on the dynamics of ecosystem processes and services over time – and their response to complex environmental changes. We focus on three key areas: a) exploring the suitability of palaeoecological records for examining variability in space and time of ecosystem processes; b) using palaeoecological data to determine the resilience and persistence of ecosystem services and goods over time in response to drivers of change; and c) how best to translate raw palaeoecological data into the relevant currencies required for ecosystem service assessments.

1. Introduction

There is growing appreciation for the many goods and services provided to people by well-functioning ecosystems, including food, fuel, climate regulation and spiritual values. These goods and services are derived from ecosystem processes i.e. the physical, chemical and biological interactions between organisms and their environment (Fig. 1a). The Millennium Ecosystem Assessment (MA) evaluated the current state of ecosystem service provision worldwide and found that the majority of ecosystems are becoming increasingly degraded, which threatens the long-term supply of ecosystem service delivery (MA, 2005). Preserving (Chan et al., 2006) and restoring (Palmer and Filoso, 2009) ecosystems for the services they provide to people requires informed land and natural

* Corresponding author. Tel.: +44 1865 281 851.
E-mail address: elizabeth.jeffers@zoo.ox.ac.uk (E.S. Jeffers).

http://dx.doi.org/10.1016/j.quascirev.2014.12.018
0277-3791/

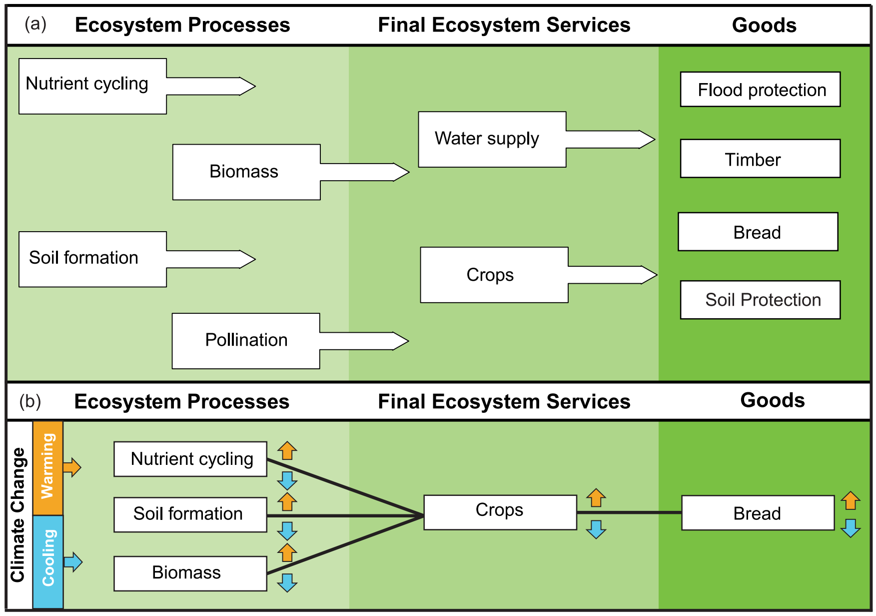

Fig. 1. Schematic of the ecosystem services framework used by the UK National Ecosystem Assessment to demonstrate the links between ecosystem processes, final ecosystem services and goods (a). Copyright 2011 UK National Ecosystem Assessment. Environmental change (e.g. climate warming) will alter the ability of ecosystems to provide goods and services. Predicting the impacts of environmental change on human well-being requires knowledge of how ecosystem processes respond to direct drivers of change and how these changes will cascade through each step in the production of ecosystem services and goods (b).

resource decision making, particularly in landscapes beyond protected areas, where human activities are reducing biodiversity and impeding natural ecosystem processes at increasing rates (Balmford and Bond, 2005).

Managing ecosystems for the continued supply of goods and services they provide for human well-being depends upon the availability of information about their variation across space (de Groot et al., 2010) and over time as systems respond to on-going environmental change and short-term environmental perturbations (Carpenter et al., 2009). Ecosystem management efforts are often being aimed at a moving target (Dawson et al., 2011) and therefore require an understanding of how ecosystem components and processes respond to direct and indirect drivers of change (Diaz et al., 2007; Tylianakis et al., 2008) and of the cascading effects these changes have on the supply of ecosystem services and goods to humans (Fig. 1b).

Since the publication of the MA, the field of ecosystem service research has made significant progress in developing methodological approaches for determining the variation over space in ecosystem service provision and how this might change in the future under particular management scenarios (e.g. UK National Ecosystem Assessment, UKNEA). In addition, attempts have been made to provide spatial displays of ecosystem service provision (Eigenbrod et al., 2010; Lavorel et al., 2011). Output from these exercises vary in complexity from simple land cover maps (e.g. Naidoo et al., 2008) to complex models incorporating interactions between ecosystem components and processes (e.g. Goldstein et al., 2012). The aim of these approaches is to identify hotspots of ecosystem service provision that should be protected from development (Fig. 2). However, these approaches represent ecosystem service provision at a 'fixed', static point in time. What is still lacking, and represents a significant knowledge gap is the continuity of these services over time (Dawson et al., 2011; Mace et al., 2012) particularly in response to drivers of change (e.g. species introductions, climate change, land-use change Nelson et al., 2005).

To understand ecosystem service provision over time and responses of different services to environmental perturbations requires knowledge of the baseline context of an ecosystem (if such a state exists), information on the alternative stable states of that ecosystem, and an understanding of what happens when the system is perturbed. Mapping dynamical ecosystem response to change therefore demands ecological records that span intervals in time where such responses can be observed. It has been acknowledged a number of times that palaeoecological records can provide some of these data (e.g. Dawson et al., 2011; Dearing et al., 2012) and some excellent case-studies have demonstrated the utility of palaeoecological records in this respect (e.g. Dearing et al., 2012; Colombaroli and Tinner, 2013; Gosling and Williams, 2013; McLauchlan et al., 2013a). But in order for palaeoecological records to become more widely used in the determination of ecosystem service provision over time, there are fundamental questions that the palaeo-ecological community at large need to ask. In some ways, these are similar to those asked when considering the use of palaeoecological records in biodiversity conservation and management (e.g. Willis and Birks, 2006; Froyd and Willis, 2008) and include *i*) what length of temporal record is needed? *ii*) what proxies should be used to reconstruct ecosystem processes? *iii*) what datasets should be utilised to reconstruct ecosystem service provision? *iv*) what is the relevant spatial scale at which to

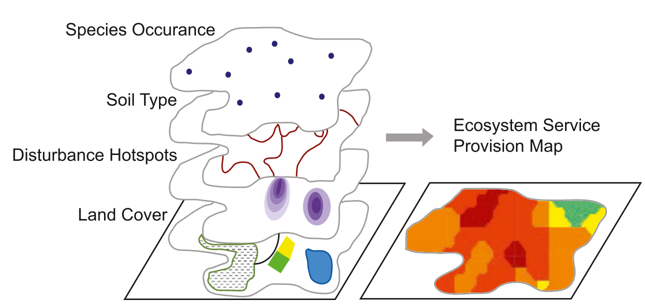

Fig. 2. Spatially-explicit biodiversity and ecosystem data are synthesized in order to generate maps of ecosystem service provision. These maps identify hotspots of ecosystem service provision that should be prioritized for conservation and ecosystem management action, modified from de Groot et al. (2010). Copyright 2010 Ecological Complexity.