Ecological Engineering 95 (2016) 542–550

Contents lists available at ScienceDirect

Ecological Engineering

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

Quantifying the impacts of grassland restoration on biodiversity and ecosystem services in China: A meta-analysis

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ARTICLE INFO

Article history:
Received 7 February 2016
Received in revised form 13 June 2016
Accepted 20 June 2016
Available online 12 July 2016

Keywords:
Ecological restoration
Biodiversity
Ecosystem services
Grassland
Spatiotemporal variability
Meta-analysis
China

ABSTRACT

Given the extent of global ecosystem degradation resulting from environmental changes and human activity, restoration efforts have increasingly focused on biodiversity and ecosystem services. Grassland, the largest terrestrial ecosystem globally and in China, has high ecological and economic value. We performed a meta-analysis to assess the impacts of grassland restoration on biodiversity and ecosystem services in China. The results showed that grassland restoration improved biodiversity by 32.44% and ecosystem services by 30.43%, although the restored grassland from degraded conditions failed to reach the level of non-degraded reference conditions for biodiversity and ecosystem services. The analysis of biodiversity and ecosystem services in the four ecological domains showed significant differences in restored grassland compared to the degraded and reference grassland. Restoration outcomes of biodiversity and ecosystem services were affected by different restoration approaches, but restoration age was not detected as significantly correlated with biodiversity and ecosystem services recovery. Biodiversity recovery, however, was positively correlated with ecosystem services recovery so far in our dataset. Despite this, these patterns require further elucidation and synthetic analyses must be conducted to assess and inform future restoration actions.

1. Introduction

Climate change, habitat loss, pollution, overexploitation, and invasive species are the main causes of biodiversity loss and ecosystem degeneration, leading to reduced provision of ecosystem services (Butchart et al., 2010; Millennium Ecosystem Assessment, 2005). Ecological restoration, designed to recover and reestablish the characteristics of an ecosystem that have been degraded, damaged, or destroyed, is now recognized as an important strategy to mitigate human pressures on natural ecosystems (Wade et al., 2008). Biodiversity and ecosystem services are two main goals of ecological restoration, which have drawn much attention from international initiatives. These initiatives include the Convention on Biological Diversity (CBD), the Millennium Development Goals (MDGs), the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), Atlantic Forest Restoration Pact, and the development goals of European Union (Calmon et al., 2011; Sachs et al., 2009). Evidence suggests that ecological restoration can enhance biodiversity and provision of ecosystem services (Benayas et al., 2009), but the degree of actual recovery of biodiversity and ecosystem services from those efforts remains uncertain and untested.

Many studies have indicated that increases in biodiversity correlated with enhancement of ecosystem services, but this relationship was complex and remained contentious (Benayas et al., 2009; Dodds et al., 2008). It is often assumed that biodiversity plays a key role in the provision of a range of ecosystem services, with the implication that recovery of biodiversity should accelerate ecosystem services recovery (such as enhancement of agriculture production, soil erosion control service, biomass production, and increased soil organic carbon) (Fu et al., 2011; Song et al., 2014). However, the relationship varies in a more complicated manner because of ecological complexity, which calls for a systematic and in-depth research.

Grassland, the largest terrestrial ecosystem in China, covers more than 40% (3.93 million km^2) of the total territory. About 78% of the grassland is found in arid and semiarid regions

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http://dx.doi.org/10.1016/j.ecoleng.2016.06.082
0925-8574/

(Kang et al., 2007). Grassland is, therefore, critical in regional climate, biodiversity conservation, provision of ecosystem services and socioeconomic development (Wen et al., 2013; Wu et al., 2014; Zhao et al., 2015). These grasslands have suffered severe degradation from long-term overgrazing, cropland expansion and extensive use, and climate change (Liu et al., 2015; Wu et al., 2010; Zeng et al., 2014). Sandstorms, desertification, and ecological refugees caused by environmental degradation have threatened animal husbandry, ecological security, and sustainable development in China (Jiang et al., 2006; Unkovich and Nan, 2008). Consequently, grassland restoration projects have been implemented to curtail degradation and to facilitate ecosystem recovery. Subsequently, grassland restoration has become a frontier and "hot theme" in ecological research and governmental policy.

Numerous studies have reported on changes in species diversity, soil carbon and nitrogen, vegetation, and soil properties during the restoration process (Shi et al., 2010; Zhang and Dong, 2010). However, few studies have systematically examined the effectiveness of restoration on biodiversity and ecosystem services recovery in grassland. A lack of scientific understanding of the effects of ecological restoration on biodiversity and ecosystem services limits their incorporation into grassland management and decision-making. Additionally, most studies of grassland restoration have been reported and published in the Chinese literature, so they are less accessible to the international community. To our knowledge, no meta-analysis has been performed to examine the effects of grassland restoration on biodiversity and ecosystem services across China. Given the high ecological and economic value of grassland, a comprehensive, evidence-based assessment of grassland restoration simultaneously examining biodiversity and ecosystem services could help inform future restoration efforts to achieve high effectiveness and sustainability.

In this study, we conducted a meta-analysis of the peer-reviewed literature to quantitatively assess how grassland restoration affects biodiversity and ecosystem services in China. Our goal was to address four questions: (1) how much biodiversity and ecosystem services can be recovered through grassland restoration; (2) how recovery of biodiversity and ecosystem services differs geographically; (3) whether the effectiveness of biodiversity and ecosystem services recovery is affected by factors such as restoration approach and restoration age; and (4) whether biodiversity recovery correlates with ecosystem services recovery.

2. Material and methods

2.1. Literature search and inclusion

To gather quantitative evidence from the literature on effects of grassland restoration on biodiversity and ecosystem services, we systematically searched the ISI Web of Knowledge (http://www.isiwebofknowledge.com) and the China National Knowledge Infrastructure (http://www.cnki.net/) on July 20, 2015, with no restriction on publication year, using the following search term combinations: (restor* OR recreat* OR rehabilitat* OR enhance* OR forest* OR reforest* OR afforest* OR recover* OR plant*) AND (ecosystem OR environment*) AND (biodiversity OR service* OR function* OR good*) AND (grassland OR steppe OR meadow OR lawn OR paddy). This resulted in a list of 2887 references. We then examined the titles, key-words, and abstracts of the references to assess their potential for meeting the selection criteria. We had three criteria for data inclusion:

(1) Articles must describe a grassland restoration project, reporting quantitative measures of variables related to biodiversity and/or ecosystem services under different restoration approaches and restoration ages.
(2) Studies used in the meta-analysis must present information comparing restored grassland with either degraded or reference (natural/undisturbed) grassland.
(3) Data reported in the selected studies must include sample size and standard deviation (or standard error/coefficient of variation), or this information could be extracted from the text and figures.

Qualitative review, modeling using empirical data, assessment based on RS and GIS, and studies without complete data for analysis were excluded from our selection. Finally, 70 studies were identified that met our criteria, and were used in the meta-analysis (see Supplementary data, Text A.1).

2.2. Database building

For each study, we extracted data on the Chinese province where the study was conducted, general properties of the study sites (longitude, latitude, and altitude), type of ecoregions, specific restoration actions, restoration age, variables of biodiversity and ecosystem services used to measure the impacts of grassland restoration (response variables). Separate databases were built for biodiversity and ecosystem services in which rows contained comparisons of the response variables between restored grassland and degraded or reference grassland. Each comparison was recorded as a separate row in the databases. Columns in the databases contained the properties of those comparisons (Supplementary data, Text B.1 and Table A.1).

We extracted data on variables relating to biodiversity, including density, abundance, richness, diversity index, and vegetation cover (Supplementary data, Text C.1). We categorized the broad biodiversity types as flora or vegetation, soil microorganism, invertebrate, and vertebrate. Response variables of ecosystem services were classified according to the four major categories proposed by MEA: supporting, regulating, provisioning, and cultural (Benayas et al., 2009; Meli et al., 2014; Millennium Ecosystem Assessment, 2005). The biophysical variables reported could be categorized as climate regulation, soil quality regulation, primary production, nutrient cycling, and forage and herbage; most of these were regulating and supporting ecosystem services. We assessed the ecosystem services by comparing response variables in restored and degraded or reference grassland. Only five comparisons from two studies reported on provisioning ecosystem services and none reported on cultural ecosystem services, so provisioning and cultural ecosystem services were excluded from the meta-analysis.

2.3. Overview of the selected studies

The 70 selected studies were mostly located in the northwestern and Tibet Plateau regions, which were dominated by temperate continental semi-arid monsoon climate and typical plateau continental climate. The mean annual precipitation of most of the study sites was less than 800 mm.

The selected studies were conducted in nine provinces: Inner Mongolia (33 studies), Ningxia (9 studies), Gansu (8 studies), Jilin (6 studies), Qinghai (6 studies), Xizang (4 studies), Yunnan (2 studies), Sichuan (1 study), and Xinjiang (1 study) (Fig. 1). From the selected studies, we extracted 1884 comparisons: 625 comparisons from 49 studies for biodiversity, and 1259 comparisons from 54 studies for ecosystem services. To investigate the spatial characteristics of biodiversity and ecosystem services recovery, we grouped the study sites into four ecological domains: Northern arid and semi-arid (1000 comparisons, 34 studies), Northeastern humid and semi-humid (447 comparisons, 20 studies), Tibet Plateau (403