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REVIEW ARTICLE

Evaluating Ecological Restoration Success: A Review of the Literature

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Abstract

Assessing the success of ecological restoration projects is critical to justify the use of restoration in natural resource management and to improve best practice. Although there are extensive discussions surrounding the characteristics that define and measure successful restoration, monitoring or evaluation of projects in practice is widely thought to have lagged behind. We conducted a literature review to determine trends in evaluations of restoration projects and identify key knowledge gaps that need to be addressed. We searched the Web of Knowledge plus two additional restoration journals not found in the database for empirical papers that assessed restoration projects post-implementation. We quantified the extent that key attributes of success, including ecological (vegetation structure, species diversity and abundance, and ecosystem functioning) and socioeconomic, were addressed by these papers along with trends in publication and restoration characteristics. Encouragingly, we found the number of empirical evaluations has grown substantially in recent years. The increased age of restoration projects and number of papers that assessed ecological functions since previous reviews of the literature is also a positive development. Research is still heavily skewed toward United States and Australia, however, and identifying an appropriate reference site needs further investigation. Of particular concern is the dearth of papers identified in the literature search that included any measure of socioeconomic attributes. Focusing future empirical research on quantifying ecosystem services and other socioeconomic outcomes is essential for understanding the full benefits and costs of ecological restoration and to support its use in natural resource management.

Key words: diversity and abundance, ecological function, natural resource management, socioeconomic, vegetation structure.

Introduction

Ecological restoration has the potential to reverse land degradation, increase the resilience of biodiversity, and deliver important ecosystem services. The practice is being widely incorporated into natural resource strategies from the local to global level; however, there is still uncertainty as to how effective restoration programs actually are (Suding 2011). This can be partly attributed to the relative youth of the discipline compared with the timescale that ecological processes take to develop; however, a number of authors reflect that poorly defined targets and a lack of quality (or any) monitoring greatly inhibits our understanding of restoration (Bash & Ryan 2002; Miller & Hobbs 2007; McDonald & Williams 2009; Suding 2011; Parkes et al. 2012). Empirical assessments of restoration success are thus critical for the development of the practice and to justify the inclusion of ecological restoration into natural resource management policies. Identifying trends in where and how empirical evaluations are being conducted will help direct future research into areas where it is needed such that these aims can be achieved.

Evaluating restoration is not straightforward, with extensive debates surrounding what characterizes successful restoration and how best to measure it. Early in the development of the field, Hobbs and Norton (1996) provided a framework that helped define the practice of ecological restoration including the aims and the methodologies that can be used. Following this, Higgs (1997) argued the need to look beyond ecology and include historical, social, cultural, political, esthetic, and moral aspects in defining the targets for restoration. Since then debates have continued over the goals of restoration (Asbjornsen et al. 2005; Thorpe & Stanley 2011), the influence of climate change (Choi 2004; Fule 2008; Seabrook et al. 2011), and socioeconomic circumstances (Hull & Gobster 2000; Burke & Mitchell 2007; Hobbs 2009; Le et al. 2012). All of these issues affect how restoration success should be defined and measured, and synthesizing these debates may lead to development of useful indicators.

The Society for Ecological Restoration (SER) Primer is a key contribution to the field and aims to unite the discipline by delivering a practical overview of ecological restoration. It

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provides a standardized definition ("the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed"), basic guidelines for restoration planning, and a list of nine key attributes of successful restoration to help practitioners identify appropriate indicators of restoration success (SER 2004). The attributes cover three general ecological outcomes; vegetation structure, species diversity and abundance, and ecological processes (Ruiz-Jaen & Aide 2005*a*) which are commonly used to classify indicators of ecosystem condition in the literature (Noss 1990; Aronson & LeFloch 1996; Ruiz-Jaen & Aide 2005*b*).

Solely focusing on ecological outcomes of restoration, however, is insufficient for evaluating the success of restoration projects. Identifying and measuring the socioeconomic benefits provided by ecosystems have been key concerns of biodiversity conservation with substantial work on the economic value of ecosystem services as well as the effect on welfare and community development (Sachs et al. 2009; Cardinale et al. 2012). In the restoration literature, Bullock et al. (2011), Rey-Benayas et al. (2009), and Palmer and Filoso (2009) along with many others have discussed the benefit of assigning an economic value to ecosystem services recovered through restoration, whereas Geist and Galatowitsch (1999), Miller and Hobbs (2007), and Le et al. (2012) highlight the significant role of social influences in achieving restoration success. Indeed, Shackelford et al. (2013) argue that such is the importance of socioeconomic aspects to restoration success that an additional attribute encompassing social and cultural values should be added to the SER Primer.

Although the SER and other authors provide discussions of the ecological, economic, and social attributes for successful restoration and guidelines for assessing a project, it is not clear the degree to which these are reflected in practical evaluations of restoration. This article reviews empirical assessments of terrestrial restoration projects to investigate: (1) the extent to which ecological, social, and economic outcomes have been addressed by empirical evaluations; (2) the types of indicators used; and (3) general trends in the empirical research. Some reviews have already been conducted in the area, most notably those by Ruiz-Jaen and Aide (2005*a*) and Aronson et al. (2010). Ruiz-Jaen and Aide (2005*a*) similarly compared empirical work with the SER Primers, however, they did not look at socioeconomic attributes and it is expected that the empirical literature will have grown considerably since this review. The comprehensive review by Aronson et al. (2010) did focus on socioeconomic aspects of ecological restoration, however, it only briefly touched on the monitoring or evaluation literature and did not focus on whether socioeconomic outcomes are being measured in practice. Our review presents an important contribution to the literature by complimenting the work by Ruiz-Jaen and Aide (2005*a*) and Aronson et al. (2010) and provides a novel, focused look at the attributes addressed by empirical evaluations of restoration success as well as trends and gaps in the research.

Methods

A quantitative review was conducted of literature published up until November 2012 using the methods outlined by Pickering and Byrne (2012). A search of English, primary academic literature (i.e. not review papers or gray material) was conducted using the Web of Knowledge database. It was later found that two key restoration journals, *Ecological Restoration* and *Ecological Management and Restoration* were not included in this database and these were searched independently using the same methodology as outlined below.

The search terms used were: (restoration or restored) and (eco*) and (monitor* or success* or evaluat* or assess*).

Limiting the search to restoration or restored rather than including reforestation, regeneration, reclamation, or rehabilitation was done to focus on papers that were most likely to be in line with the SER definition. It is acknowledged that we may have missed articles by doing this; however, our experience with the literature indicates that most of the relevant papers that use these other terms also include "restoration" and would be picked up by the above search. We also chose to focus on terrestrial ecological restoration projects excluding all aquatic and borderline marsh, mangrove, beach-dune, and wetland systems. Although this will have affected our results, narrowing the scope of the paper allowed us to make more specific recommendations for practice. A similar review of aquatic restoration, however, would be a useful addition to the literature.

The search results were screened to identify papers that assessed the outcomes of restoration post-implementation. We only retained articles where active restoration was conducted including planting, weed control, fire replacement, and soil amendment, and excluded projects that were solely fenced or abandoned. In addition, papers were not included that only looked at the survival of plantings or where the restored site was used for production (i.e. forestry or grazing). Although survival is important for achieving success in restoration, we consider this an indication of the success of the planting method rather than the restoration of an ecosystem. Similarly, including projects with a dual productivity purpose would have introduced measures of success that were not necessarily representative of restoration success. Restoring productive land is an important aspect of restoration practice; however, increasing productivity on the site can be achieved at odds with the primary purpose of restoration as defined by the SER. It is acknowledged that this may have removed some economic focused papers, but we feel that the retained sample of literature is more representative of measures of ecological restoration outcomes.

The retained articles were classified using the criteria in Table 1 including publication details, background information on the restoration project, and details on the assessment methods used. We categorized the evaluation or monitoring methods as addressing ecological, economic, or social aspects. Within the ecological category we further categorized the indicators used into vegetation structure, diversity and abundance, and ecological processes, following the methodology of Ruiz-Jaen and Aide (2005*a*). Vegetation structure included measures

Table 1. Categories used to classify the articles found through the literature search.

	Categories for classification
Publication details	• Journal of publication • Year published
Restoration project characteristics	• Location • Ecosystem type • Type of degradation • Restoration method used
Evaluation/monitoring methodology	• Age of restoration • Use of reference site and type of reference used • Type of attributes assessed (ecological, economic, or social) and the indicator used

of plant growth such as height, canopy cover, biomass, basal area, and litter cover. Diversity and abundance included flora and fauna species, microbial and fungal diversity as well as functional and genetic diversity. Ecosystem processes included measures of reproductive success or dispersal, nutrient cycling, soil development, pollination, and other biological interactions. We also recorded the methodology used for assessing economic and social aspects of the restoration project.

Results

A total of 301 articles spanning 71 journals were identified using the search criteria. Almost half (49%) of these articles were published in just four journals: *Restoration Ecology*; *Ecological Restoration and Management*, *Ecological Restoration*; and *Forest Ecology and Management* (Appendix S1, Supporting Information). The number of publications increased over the 28-year time period that the search results covered (Fig. 1) and the majority of studies were published between 2008 and 2012. The restoration projects were located in 31 countries, although North America was by far the most studied region (Fig. 2). From the terrestrial literature that was surveyed, forests were the most represented ecosystem type (50%), followed by grasslands (22%). Woodlands, shrublands, and savannas were represented by 20% of papers, whereas 9% looked at restoration conducted in riparian zones. Agriculture and grazing of these ecosystems were the leading causes of degradation that led to restoration (44%) and planting was the most common method used to restore the ecological condition of the sites (63%).

Empirical assessments of restoration outcomes looked at projects ranging from 1 to 120 years old, although projects over 35 years old were uncommon (5%). Restoration sites of 1–15 years old were the most frequently studied (71%), with 5–10 years old the most common age group (Fig. 3). In conducting the assessments of these sites, the majority of studies included some form of reference or control site for comparison (74%). Of the 26% of papers that did not use a site for comparison, 68% tracked the development of the restoration site over-time instead. Within the studies that used a comparison site, around equal proportions of the literature used only positive target references (38%) or only negative controls representative of the pre-restoration degraded state (40%; Fig. 4). Surprisingly, only 44% of studies used a positive target reference.

Ecological attributes were by far the most common measures used for post-implementation restoration assessments (Fig. 5). Of the surveyed literature, 94% of articles only used measures of ecological attributes, and an additional 3.5% of papers also included social and economic attributes. Of the few papers that looked at social attributes, six papers looked at community engagement or participation in restoration, two papers investigated the links with education, and one paper conducted a survey of psychological benefits from volunteering in restoration. Most of the papers that included economic attributes focused on the cost or resource requirement of the restoration activity (eight papers) and the remainder looked at the impacts of restoration on the income of farmers involved (two papers) and job creation (two papers).

The three categories of ecological attributes were well represented in the literature. Vegetation structure was included in 118 papers although only 4% of papers that included ecological attributes used vegetation as their sole measurement (Fig. 5) and it was most commonly used in combination with diversity and abundance measures. Ecological processes were measured in 127 papers in total: 53 looked at nutrient cycling; 29 included soil structure or stability; 9 measured carbon storage; 17 addressed dispersal success or mechanisms; 6 included some measure of pollination; 12 looked at other forms of faunal activity within the site such as reproduction success or feeding; and 21 addressed other biological interactions or measure of ecosystem development. Diversity and abundance were the most frequently measured ecological attribute (Fig. 5) with 213 papers. Flora was used in 143 papers compared with 96 papers that measured fauna. Of the papers that looked at fauna diversity and abundance, invertebrates where measured more frequently than vertebrates with 48 and 34 papers, respectively.

Discussion

The number of empirical papers on the outcomes of restoration has grown considerably over the past 20 years, with the past three being the most prolific. This supports the notion that restoration is a rapidly developing field of research, with the outcomes of projects of significant interest. Although ecological restoration became prominent in the academic literature during the 90s, empirical studies of the outcomes of restoration are widely thought to have lagged behind. However, our results indicate that not only is the number of papers on the topic increasing, but the majority of these are looking at projects that are greater than 5 years old. This is a positive sign as it demonstrates post-implementation empirical research is catching up and the effects of restoration are being measured over a longer timescale, something which Ruiz-Jaen and Aide (2005*a*) and Tischew et al. (2010) highlight

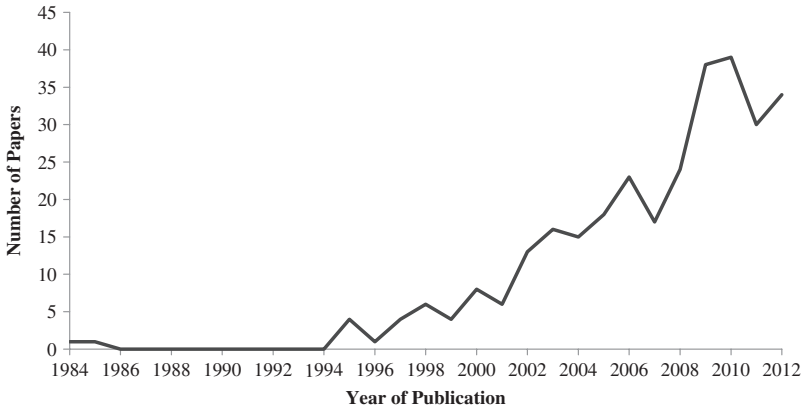

Figure 1. The number of papers identified through the literature search per year of publication. Note: 2012 does not represent the full year as publications were only searched up until November.

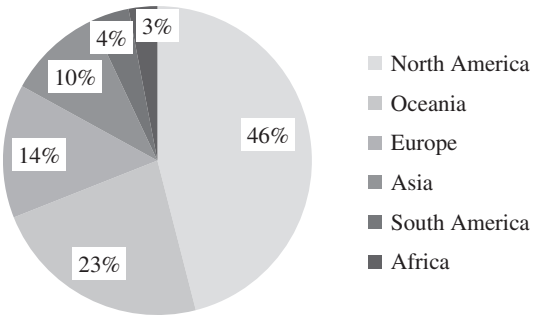

Figure 2. Geographic distribution of restoration projects evaluated in the papers identified through the literature search.

as critical for furthering the field. Despite this progress, we find that there are still limitations in the empirical research.

Location of Research

Part of the complexity in regard to understanding the outcomes delivered by ecological restoration is that the aim of the restoration project, the best methods to use and what can be achieved are often project-specific and subject to environmental and socioeconomic variables (Miller & Hobbs 2007). As such, the transferability of research from one region to another is likely to be low. Positively, our results show that empirical research into restoration outcomes covers a diversity of countries and ecosystem types which suggests that project and regionally specific knowledge are being developed. However, consistent with the findings by Ruiz-Jaen and Aide (2005*a*) the geographical distribution of the research is still heavily skewed toward North America. This is a notable limitation in empirical research because, as Aronson et al. (2010) points out, the high-income countries where the majority of restoration research is focused are not the areas of highest deforestation. Thus, there is still a large discrepancy between where restoration research is occurring and where restoration is most needed.

Reference Site

The SER Primer emphasizes that using a reference is a critical aspect of achieving restoration success as it provides a clear depiction of the goals of the restoration project and a development state to evaluate against. Despite this, we found that less than half of the surveyed literature actually used a target reference for comparison, although a significant proportion of papers used a negative reference or control. This is likely evidence of the experimental nature of the literature where experimental design often necessitates the use of a control. Restoration success though is more commonly defined as a shift toward an existing or pre-existing functional ecosystem (positive reference) rather than just a shift away from the degraded state. This is an area of ongoing debate though and the type of reference used should be a primary consideration in the design of empirical evaluation.

Ecological Attributes

The three types of attributes (diversity and abundance, vegetation structure, and ecological functioning) were all well addressed by the literature, although most papers only used measures of one or two attributes consistent with the findings of Ruiz-Jaen and Aide (2005*a*). Diversity and abundance measures were the most common suggesting that this is considered a primary objective of restoration success. These measures provide not only an indication of the suitability of the area as a habitat, but can also be a proxy for other outcomes. For example, species were also used to indicate the state of succession (Urbanska 1995; Dzwonko & Loster 2007; Courtney et al. 2010; Pais & Varanda 2010; So & Chu 2010; Burmeier et al. 2011), the dispersal mechanisms operating in the site (Sansevero et al. 2011), and ecosystem processes (Vallauri et al. 2002; Henson et al. 2009). In contrast, vegetation structure was used least in the literature and rarely used in isolation. Although vegetation structure is often portrayed as the most rapid and efficient means of assessing a site condition (Gibbons & Freudenberger 2006), there are questions as to how

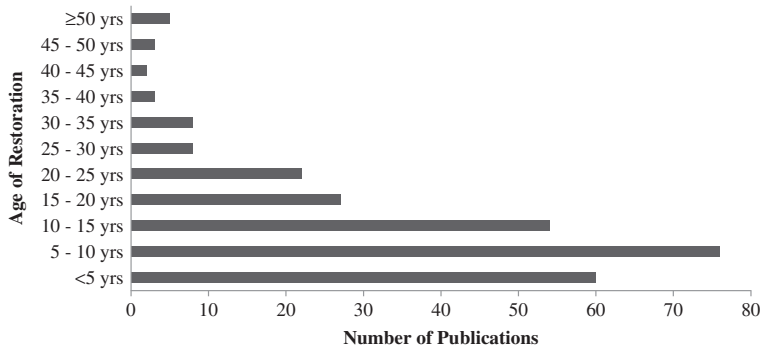

Figure 3. Maximum age of the restoration projects at the time of the empirical evaluation and the corresponding number of papers found in the literature search. Note: if the paper included multiple restoration projects of different ages or conducted the research over a period of time, only the highest age of a restoration project was used.

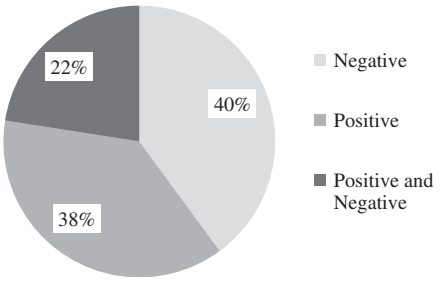

Figure 4. The percentage of papers that used a control (negative), a target reference (positive), or both when a comparison was included in the paper.

much can be inferred about an ecosystem from the structural attributes (Palmer et al. 1997) and recent studies have demonstrated results can vary considerably between observers (Cheal 2008; Gorrod & Keith 2009; Kelly et al. 2011). With limited resources, abundance and diversity measures may be favored given the additional information that can be inferred from the data.

Unlike Ruiz-Jaen and Aide (2005*a*), we discovered that measures of ecological processes or functioning were well addressed by the empirical literature. Ruiz-Jaen and Aide (2005*a*) identified two main reasons why ecological processes were under-represented in their review; that they take longer to develop than diversity and structure, and that they generally require more time and resources to measure. Our findings are likely reflective of the aging of restoration projects since 2005, with high time and resource requirement expected to still be an issue. This change indicates a positive development for restoration practice as an increased understanding of how restoration affects processes such as nutrient cycling, pollination, and erosion control is critical for the long-term persistence and stability of the projects, as well as understanding the role of restoration in the landscape context.

Socioeconomic Attributes

Very few papers looked at socioeconomic attributes of restoration post-implementation in the surveyed empirical

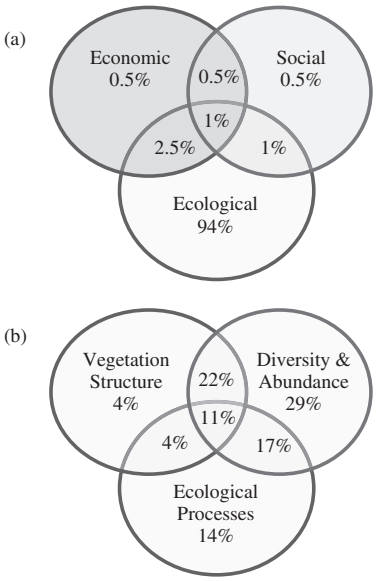

Figure 5. The breakdown of the attributes covered by the empirical literature: (a) the percentage of papers that addressed ecological, economic, or social attributes individually and in combination; (b) of the papers that included ecological attributes, the percentage that addressed vegetation structure, diversity and abundance, and ecological processes.

literature. Of the papers that did, the primary focus was on resource input into the projects or the extent of community involvement. These are very useful measures for the development of the practice of restoration as they provide evidence of the costs (both through resource input and volunteer involvement) and the successful engagement of the local community. However, we need to look beyond these measures to fully capture the socioeconomic outcomes that restoration delivers.

Interestingly, we found no economic measure of ecosystem services in post-implementation evaluations. This seems at odds with the findings of Aronson et al. (2010) who found ecosystem services addressed in 2.7% of the literature they surveyed from *Restoration Ecology* and 10.7% from other journals. There are likely to be a number of reasons for the difference. First, we excluded all projects that included

a dual production purpose as it was felt that these would have diluted the focus on restoration success, although these papers would likely have included more economic measure of ecosystem commodities. Second, there were a number of papers that looked at the improvement in ecological indicators that provide ecosystem services such as erosion control and carbon storage, but they stopped short of assigning an economic value. Finally, during the literature search we found a number of papers that estimated the provision of ecosystem services prior to the implementation of the project, rather than valuing the services that were delivered in practice.

The final point here was a common finding in regard to socioeconomic focused papers. A number of studies used various economic techniques to value future restoration projects including contingent value methods (Macmillan & Duff 1998; Desaigues & Ami 1999; Mitani et al. 2008; Johnston et al. 2012), opportunity cost (Dorrough et al. 2008), and cost-benefit analysis including ecosystem services (Currie et al. 2009; Birch et al. 2010; Suding 2011). Other studies looked at community attitudes to the environment and restoration to prioritize and guide the direction of future projects (Ostergren et al. 2008; Davies 2011) and their willingness to participate in programs (Januchowski-Hartley et al. 2012). Although clearly useful for planning restoration projects, these types of a priori evaluations are not a substitute for determining the realized socioeconomic outcomes or impacts of restoration.

Overall, empirical research into restoration outcomes is clearly expanding. As primarily an environmental endeavor, it is appropriate that most papers would evaluate restoration through ecological outcomes, particularly in the early development of the science and practice. However, given the call for greater attention to socioeconomic aspects of restoration in the literature and the recognized importance of these attributes to the overall success of restoration, there needs to be more research into the realized social and economic outcomes or impacts. With the addition of this research to the ecological focused studies, questions over the effectiveness of ecological restoration as a practice can be answered more comprehensively. This is essential not only for the development of the practice, but also to support the continued adoption of ecological restoration as a primary tool of natural resource policy.

Implications for Practice

- Empirical evidence to support the use of ecological restoration in terrestrial natural resource management is growing with long-term studies being conducted and more research into the recovery of ecological functioning post-restoration.
- There are still crucial gaps in the literature relating to the location of the empirical research and evidence of socioeconomic outcomes. Future work needs to focus on filling these gaps.
- Understanding the socioeconomic benefits/impacts of restoration is necessary to support the adoption of ecological restoration in natural resource management. We suggest socioeconomic measures should be incorporated into monitoring/evaluation practices as a key element of restoration success.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. List of journals where the papers identified through the literature search were published.