Title: The importance of long-term social-ecological research for the future of restoration ecology

Running head: Importance of long-term social-ecological research

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Abstract

In the face of rapid environmental and cultural change, long-term ecological research (LTER) and social-ecological research (LTSER) are more important than ever. LTER contributes disproportionately to ecology and policy, evidenced by the greater proportion of LTER in higher impact journals and the disproportionate representation of LTER in reports informing policymaking. Historical evidence has played a significant role in restoration projects and it will continue to guide restoration into the future, but its use is often hampered by lack of information, leading to considerable uncertainties. By facilitating the storage and retrieval of historical information, LTSER will prove valuable for future restoration.

Key words: long-term ecological research (LTER); long-term social-ecological research (LTSER); social-ecological systems; climate change; land use; human population growth

Conceptual Implications

- Rapid changes such as climate change and human population growth render long-term social-ecological research (LTSER) more important than ever to guide future restoration efforts.
- Historical knowledge in various forms (history as information and reference, history as revealing the future and history as enriching cultural connections) has played a significant role in restoration and will continue to be important for future restoration. This implies that LTSER will be important for restoration into the future through encoding and storing social-ecological memory.
- LTSER will inform effective integration of restoration as a management tool, which will need to be employed routinely in all aspects of human engagements to counterbalance inevitable extractive/destructive activities in a more intensely human-dominated future.

Introduction

The benefits of long-term ecological research (LTER) are widely acknowledged (Lindenmayer et al. 2012; Müller et al. 2010) and LTER contributes disproportionately to ecology and policy (Hughes et al. 2017). Monitoring the impacts of key environmental variables requires long-term studies partly because many variables change slowly, but also because spatial and temporal variability pose challenges distinguishing 'signal' from 'noise' (Singh et al. 2013) – particularly in dynamic environments such as drylands (Stringer et al. 2017). Moreover, long-term studies allow processes at multiple timescales to be captured, while complementing and providing more robust results than shorter-duration monitoring (Hughes et al. 2017). In 2003, recognition of the importance of integrating ecological and social dimensions led to the development of long-term social-ecological research (LTSER) (Singh et al. 2013; Dick et al. 2018). Here, we explore how LTSER will benefit future restoration following the historical knowledge typology outlined by Higgs et al. (2014): 1) history as information and reference, 2) history as revealing the future, and 3) history as enriching cultural connections.

History as information and reference

History has played in important role in restoration ecology and its significance is unlikely to diminish (Higgs et al. 2014). The role of history as information and reference includes history as range of variability (of system variables), legacy (signatures of influences of the past) and reference (information concerning past ecosystem states and trajectories). Regarding history as reference, long-term perspectives help to determine what is 'natural' and to disentangle natural variability from other, potentially significant trends; examples include animal population dynamics, biological invasions, climate variability, fire regimes and ecosystem health evaluations (Willis and Birks 2006). In each case, short duration studies are incapable of capturing longer-term trends and cycles that provide valuable information to guide restoration actions. LTSER also reduces susceptibility to 'shifting baselines' (Corlett 2016) and provides key information where contemporary reference ecosystems are lacking or where all ecosystems have changed. Long-term monitoring enables the characterisation of ecosystem dynamics and the definition of process-based and multifaceted reference models (e.g. Balaguer et al. 2014). LTSER will also help to elucidate legacy effects – the influence of the past on the structure and function of a social-ecological systems (SES) –, thus informing the prescription of restoration treatments that account for the constraints or challenges on future states or trajectories imposed by these legacies.

Unlike history as reference and legacy, historical range of variability (HRV) is expected to become less important to restoration due to rapid cultural and environmental changes (Higgs et al. 2014). However, HRV may continue to be valuable for future restoration i) in other locations that shift into a similar range of environmental conditions as a study site, or ii) where environmental variables return within a similar range in the same location. For history as information more generally, long-term monitoring will be critical for detecting small but significant changes and recording responses to infrequent, unexpected and potentially critical events (Mirtl et al. 2018; Hughes et al. 2017). For example, long-term studies revealed that short-term monitoring of plant community composition incorrectly predicted the success of restoration treatments that ultimately failed and vice versa (Herrick et al. 2006). Moreover, LTSER can play a significant role in assessing susceptibility to degradation and thus inform restoration planning, particularly in highly variable environments (Miehe et al. 2010). Similarly, LTSER also enables assessments of population declines and extirpation risk, which are crucial for targeting restoration efforts. Long-term monitoring is also required for tracking progress towards national commitments such as Sustainable Development Goal target 15.3 on land degradation neutrality (Cowie et al. 2018) and for restoration funding schemes based on payments for ecosystem services, such as Regen Network (www.regen.network). Furthermore, continuous monitoring will facilitate the prioritization process for targeting restoration investments (Dallimer & Stringer 2018), adjustment of restoration objectives, adaptation of management strategies and evaluation of restoration success (Herrick et al. 2006).

History as revealing the future

Long-term monitoring also augments the benefits of history as revealing the future, which includes history as scenario (past scenarios and actual events) and experiment (natural experiments). LTSER would improve scenario planning and prediction of SES dynamics under future conditions. Here we expand on two examples i) human population growth and land use change and ii) climate change.

Human population growth, increasing purchasing power and rising per capita consumption and land use change have negatively impacted biodiversity and ecosystem services (IPBES 2019). Although human population continues to rise, it is generally agreed that intensifying production on existing arable land is sufficient to meet humanity's future food demands (Cherlet et al. 2018). In fact, the global agricultural land share has been declining since 2000, while per capita food supply has maintained a positive trend (FAO 2017; Fig. 1). This indicates that increased efficiencies in food supply have allowed more people to be fed on less land, suggesting an increase in abandoned agricultural land, which creates opportunities for restoration if unexploited for other land uses (e.g. urban development) (Queiroz et al. 2014). More space-efficient intensive agricultural practices often have detrimental ecological impacts, which themselves necessitate the integration of restorative processes (e.g. to enhance biodiversity and ecosystem services). Changes in the share of agricultural land vary by country; parts of Europe and Oceania experienced the largest declines from 1996-2016 (Fig. 2a). The number of people living in rural areas is also projected to decline from 2020-2100 (UN-DESA 2018), which may create restoration opportunities in rural areas in which population densities are declining. These projections are also heterogeneous internationally (Fig. 2b); the rising rural populations expected in many African countries will likely pose challenges for restoration. In regions experiencing agricultural land expansion and rising rural populations (e.g. Tanzania, Niger), restorative agriculture, agroforestry and sustainable agricultural intensification is likely to take precedence over restoration in the coming decades. LTSER will help us identify restoration opportunities by increasing our understanding of how SESs are responding to these and other anthropogenic trends, such as technological development, female empowerment and climate change, as they unfold.

Similarly, LTSER will allow us to monitor the nature and rate of biodiversity change in response to climate change, thus guiding restoration planning. A well-designed network of long-term monitoring sites could act as a warning system for future climate impacts (Prach & Walker 2011). Unfortunately, the spatio-temporal resolution of current global climate projections is low, rendering site-level planning informed by climate projections difficult for restoration practitioners. Long-term records of climatic variables will be valuable for restoration planning by enabling global climate projections to be downscaled (Ekström et al. 2015). This is particularly pertinent in developing countries with low densities of climate stations and regions for which climate models show high uncertainty, or where contrasting climate trends are experienced at finer scales (e.g. Schmocker et al. 2015).

Regarding history as experiment, we extend its definition beyond natural experiments to include planned experiments and monitoring. Of course, natural experiments will continue to be valuable, particularly when documented through long-term observation, but rigorous long-term experiments will have several advantages including planned comparisons, replication and improved inference. A third aspect of history as revealing the future is history as virtue (the quality of being historical). If historicity indeed becomes 'restoration's virtue of the future' (Higgs et al. 2014), LTSER will be an effective means of facilitating the development of this virtue by storing social-ecological memory for future restoration ecologists and practitioners to access. This social-ecological memory will be valuable in guiding future restoration decisions.

History as enriching cultural connections

Generating social-ecological memory will also benefit history as enriching cultural connections, which includes history as place (reinforcing sense of place), governor (exercising caution in interventions and limiting exuberant actions) and redress (reinstating disturbance regimes). Of these, the last may be the most well recognised as it relates to the reestablishment of historical cultural practices and associated disturbance regimes. In this and other aspects of history as enriching culture, LTSER will be particularly important as it emphasises the integration of human dimensions into LTER by encouraging collaboration across multiple disciplines and knowledges (e.g. 'scientific' and 'local'). Unfortunately, history as enriching cultural connections has received little attention in restoration ecology thus far, but its prominence is likely to grow (Higgs et al. 2014). Another major gap is the diversity of LTER and LTSER sites, the majority of which are in the United States of America and Europe while very few are in developing nations (Singh et al. 2013).

Looking ahead

To summarise, the importance of the various facets of historical knowledge to restoration implies that LTSER will be a significant asset for future restoration, complementing other long-term approaches (e.g. paleoecology). Large-scale, long-term studies are of particular importance (Fischer et al. 2010) – these are becoming more common in invasion ecology and community ecology and are sorely needed for restoration ecology to graduate from a site- and situation-specific discipline to a more globally applicable science (Montoya et al. 2012). Restoration commands a growing share of peer-reviewed publications and the proportion of articles and reviews concerning restoration within leading conservation journals is also rising (Fig. 3). Restoration may yet come to dominate the field of conservation, as envisaged by Young (2000). Taking a long-term perspective, maintenance of diverse, productive and functional ecosystems requires that restoration is integrated into SES management as a continuous process rather than as a means to an end (i.e. a self-sustaining system requiring little/no intervention). For example, employing restoration to mitigate climate change may mark the start of the routine use of restoration as a tool for geo-climatic engineering into the future. Similarly, implementing restoration in areas experiencing high human population densities today will equip us with the techniques required to incorporate restorative activities ubiquitously in the more intensely human-dominated landscapes of the future; counterbalancing inevitable extractive/destructive activities. Finally, we will benefit from incorporating restoration principles into all aspects of human activities including product design, industry, architecture and urban planning.

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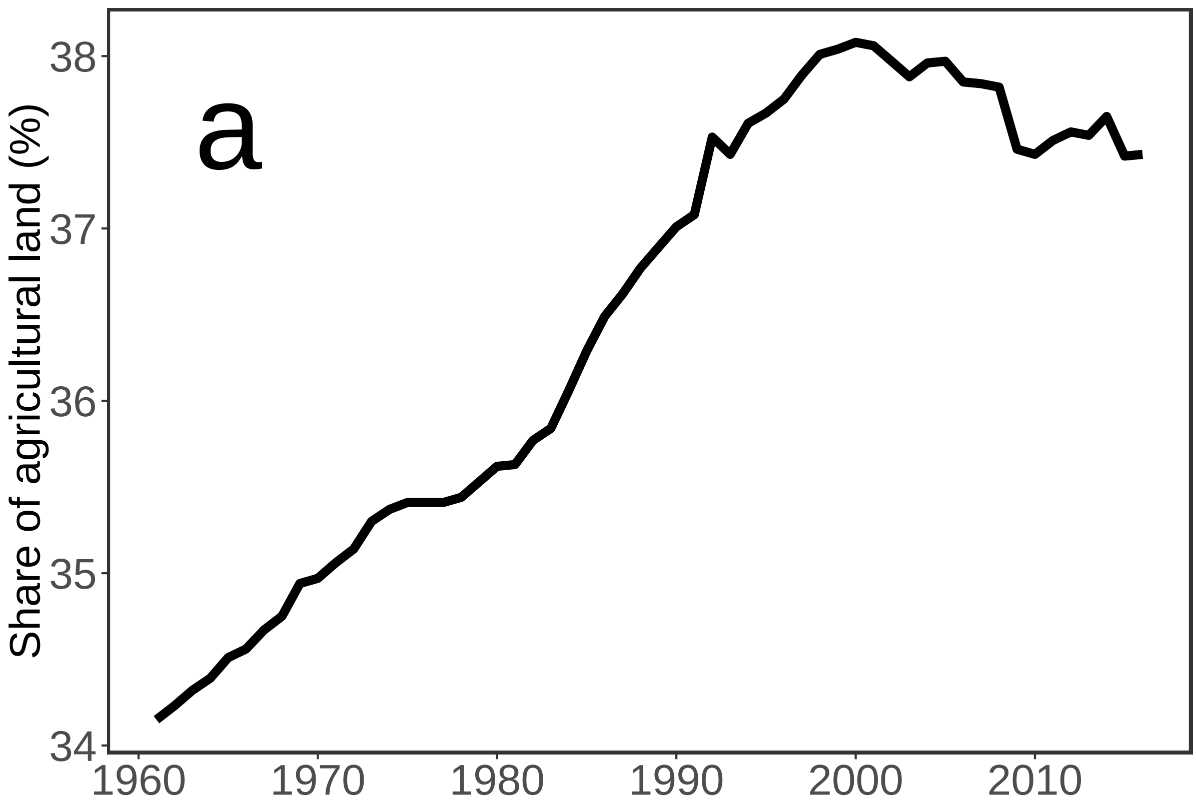
FIGURES



a
Share of agricultural land (%)
38
37
36
35
34
1960
1970
1980
1990
2000
2010

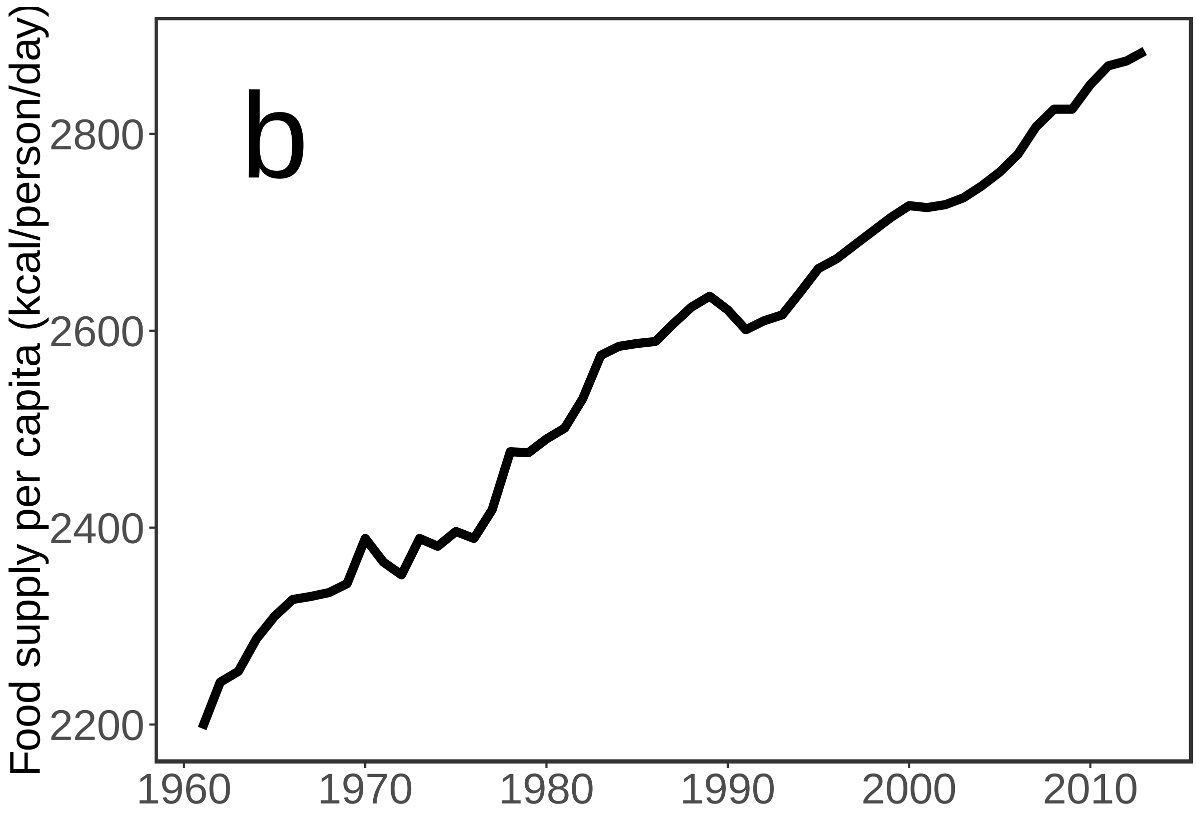


Figure 1. Global trends in the share of agricultural land (a) and per capita food supply (b) between 1961 and 2013. Data from FAO (www.fao.org/faostat/en/#data) accessed June 2019.

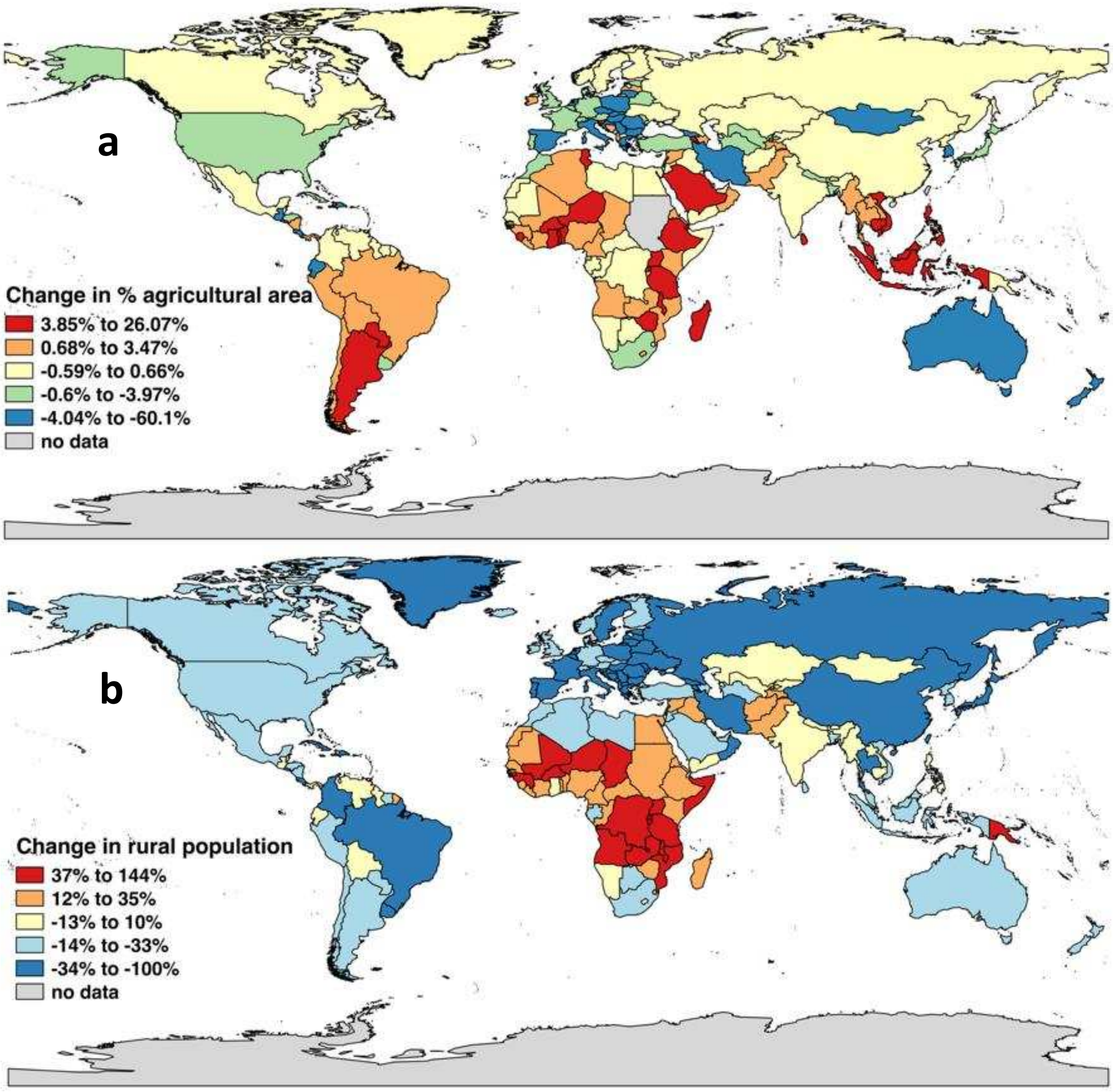


Figure 2. Maps of (a) change in share of agricultural land as a percentage of total land area between 1996 and 2016 (data from FAO (www.fao.org/faostat/en/#data) accessed June 2019), and (b) projected change in rural population from 2020 to 2050 (data from UN-DESA (2018) accessed June 2019).

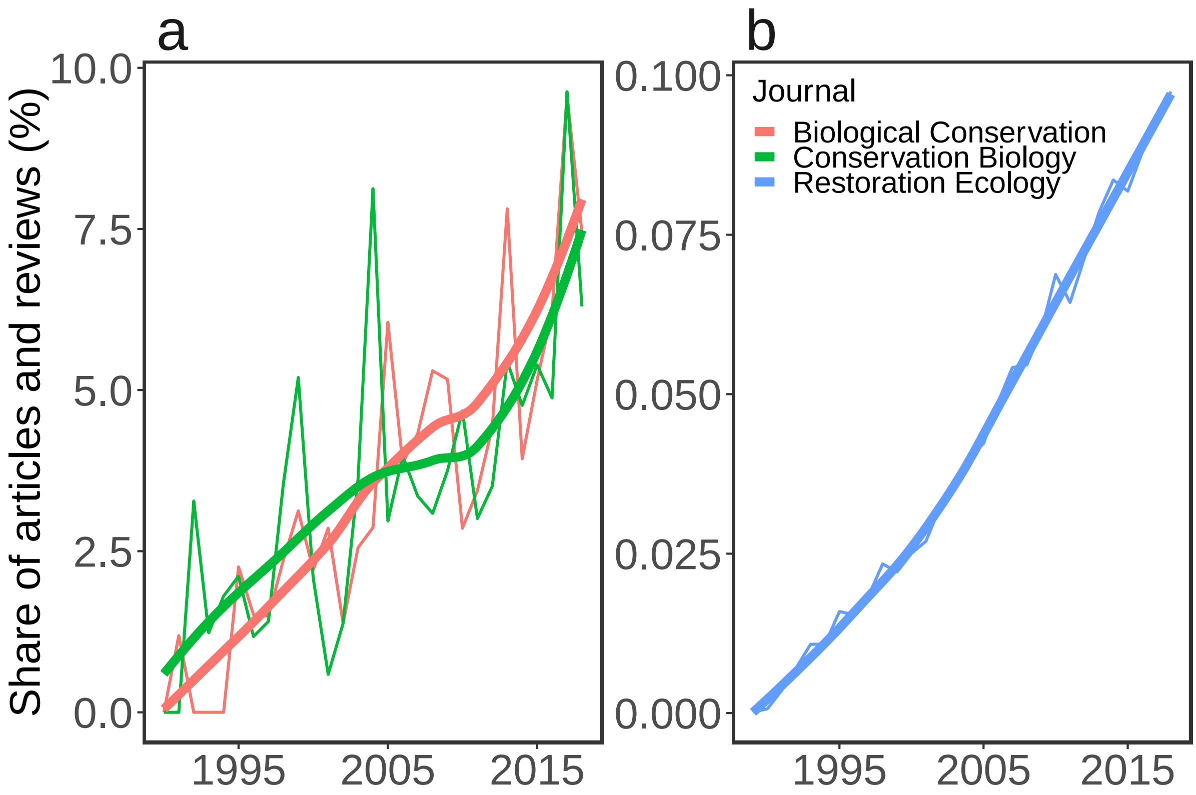


Figure 3. Increased interest in restoration from 1990-2018. The share of articles and reviews in Biological Conservation, Conservation Biology (a) and Restoration Ecology (b) in Web of Science using both 'restor*' and 'ecolog*' as search terms. Values are expressed as a percentage of total articles and reviews in each journal (a) or all journals (b). Thicker lines show loess regression trend lines.