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The age of restoration: challenges presented by dryland systems

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Abstract Intact drylands are highly evolved and complex ecosystems, which allow them to be productive despite harsh environmental conditions. However, drylands are particularly susceptible to degradation, even after minor disturbance events. Conditions for natural plant recruitment in dryland systems are spatially and temporally irregular, which can create challenges for restoration. Large-scale restoration and rehabilitation of dryland ecosystems have become a global concern, prompted by ever-increasing anthropogenic pressure and associated degradation of these natural systems worldwide. The success of plant reestablishment programs in these regions is closely linked to both ecological and socioeconomic opportunities and limitations. This special issue brings together papers that discuss the roles which ecological and socioeconomic factors play in influencing dryland ecosystem restoration outcomes. We aim to (1) highlight the current status of recovery efforts taking place across a range of dryland ecosystems, emphasize advances in the region-specific understanding of plant community development, and (2) provide comparisons between the primary drivers and limitations to restoration that exist across dryland systems.

Keywords Arid lands · Desert · Ecosystem function · Environmental economics · Policy · Rehabilitation · Semiarid lands

Introduction

Dryland ecosystems occur throughout the world and occupy nearly half of the Earth's terrestrial surface (UNDP/UNSO 1997). They are defined as areas where

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the aridity index, or ratio of total annual precipitation to potential evapotranspiration, ranges between 0.05 and 0.65, and include arid, semiarid, and dry sub-humid regions (Reynolds and Stafford Smith 2002; UNCCD http://www.unccd.int). The global distribution of drylands is driven by atmospheric circulation patterns (Glenn et al. 1993) with the large majority of land areas occurring on the Asian and African continents, followed by the Americas, Australia, and Europe (Sivakumar 2007). These regions support in excess of two billion people and contain more than 30% of global biodiversity hotspots (James et al. 2013; Maestre et al. 2012; Reynolds et al. 2007; Verstraete et al. 2009). Current estimates of degradation and desertification extent vary based on the assessment method, and range from 20 million km^2 (Mabbutt 1994) to 32.5 million km^2 (Dregne 1983), representing between a third to more than half of dryland systems globally (UNDP/UNSO 1997).

In 2007, the United Nations recognized dryland degradation as one of the key ecological issues of the twenty-first century (Sivakumar 2007), largely due to the scale of disturbance and its impact on food security and environmental quality (MEA 2005; Ravi et al. 2010). The causes of dryland degradation are complex and typically are driven by a suite of interacting factors (e.g., changes in edaphic, climatic, and socioeconomic conditions) over many spatio-temporal scales (D'Odorico et al. 2013; Evans and Geerken 2004). Their interplay determines the extent of degradation and governs the methods necessary for subsequent ecosystem recovery (Boyd and Svejcar 2009; Hobbs and Norton 1996).

According to Hobbs and Norton (1996), the rationale for restoration can be largely broken into four general categories determined by the main drivers of restoration efforts. Specifically, according to the outlined framework, restoration can occur in order to (1) restore specific, highly degraded landscapes (e.g., mine sites, post-disturbance habitats), (2) enhance land-use productivity (e.g., increase grazing value, provide timber and non-timer products, reduce erosion), (3) improve the ecological/conservation value of protected areas (e.g., prevention of invasive species spread, exclusion of grazing, mitigation of pollution, and reduction in fragmentation), and (4) expand the ecological/conservation value of agro-silvo-pastoral landscapes (e.g., implementation of measures that improve habitat and enhance system biodiversity, structure, and function).

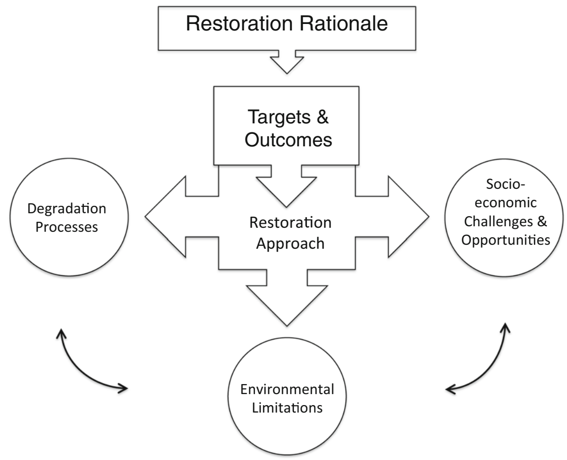

Fig. 1 A conceptual diagram describing the steps involved in determining ecosystem restoration planning and project execution. The restoration rationale concept, adopted from Hobbs and Norton (1996), can be broken down into four goal categories: (1) to restore specific, highly degraded landscapes, (2) to enhance land-use productivity, (3) to improve the ecological/conservation value of protected areas, and (4) to expand the ecological/conservation value of agro-silvo-pastoral landscapes. The specific rationale thus determines the explicit restoration targets and desired ecosystem outcomes. The approach chosen to best achieve the set target is consequently guided by the existing synergistic interactions between the region-specific degradation processes, environmental limitations, and socioeconomic factors

This rationale thus drives the formation of the explicit restoration targets and desired ecosystem outcomes (Fig. 1). The restoration approach required is then delineated by the existing synergistic interactions between the region-specific degradation processes, environmental limitations, and socioeconomic factors.

Traditionally, ecological restoration targets and outcomes are guided by a reference system, wherein a particular ecosystem or vegetation composition forms the target of restoration projects (SERI 2004). Reference ecosystems are often intact systems nearby, or are based on evidence for historic conditions, though a full understanding of the composition, structure, and function of these systems is not always available and is relative to the spatio-temporal scales for which restoration efforts are being developed (Hobbs 2007; White and Walker 1997). Furthermore, in many dryland systems, the extent and scale of degradation may mean that many of these systems will not be able to be restored to their reference state or may lack a clear designation. In other cases, the original biotic and abiotic conditions have changed to such an extent that they are no longer capable of supporting the reference system without major intervention, including environmental and edaphic amendments (Hobbs 2007; Suding and Hobbs 2009).

Finally, more often than not, it is difficult to fully curtail factors contributing to the degradation process; thus, the reference state cannot always be a fixed one. For example, transition from novel ecosystem to neo-historic condition, such as reversing shrub encroachment and enabling the reinstatement of a historic grassland system (Ravi et al. 2010), may be cost-prohibitive, practically unattainable, and lack long-term resilience (Hobbs et al. 2011). In cases where classical intervention is not feasible, "alternate" stable states must be established (Suding et al. 2004). The structure, function, and composition of these alternate states will be determined by management objectives and the site conditions (both environmental and socioeconomic). The modes of attaining the established restoration targets rely on our understanding of the drivers involved and may require additional inputs to modify the site's carrying capacity to allow new ecosystem development trajectories to emerge.

This special issue aims to explore the empirical and practical aspects of restoration in degraded dryland systems by (a) providing a snapshot of the current status of recovery efforts being carried out across a range of ecoregions, (b) highlighting advances in the region-specific understanding of plant ecology as it pertains to restoration practices and policy and (c) offering contrasts between key drivers of, and impediments to, restoration. In this context, we consider the term 'restoration' to follow the definition proposed by SERI (2004) as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed." Further, because of the high level of degradation experienced by the dryland systems discussed in this special issue, our definition expands to include efforts that would sometimes be described as 'rehabilitation,' which are primarily focused on the reestablishment of ecosystem function (in regions severely altered by degradation where full ecological restoration to a reference state is not immediately possible), so long as rehabilitation efforts support the maintenance of biodiversity and aim to propel ecosystem processes toward recovery.

The papers included in this special issue reflect the complexity of these factors in restoration efforts across a suite of degradation drivers, ecoregions, socioeconomic conditions, and political borders. For the sake of clarity, the papers are grouped geographically into Africa, Middle East and North/Central America regions, and comprise a discussion of restoration efforts in six nations.

Paper summaries

Africa

In their paper, Bourne et al. (2017) detail the significant degradation of the highly diverse vegetation of South Africa's Succulent Karoo as a result of decades of heavy grazing and fodder production. By combining two case studies, (1) outcomes of a local-scale restoration trial and (2) a cost–benefit assessment of regional-scale restoration efforts, the authors identify opportunities and challenges that face restoration in South Africa. Despite the high cost and low success rates reported, Bourne et al. suggest that a "holistic suite of land management actions" combining active management and oversight with investment in restoration efforts is paramount in ensuring that the ecological and socioeconomic stability of the region is maintained in the long-term.

Kimiti et al. (2017) describe the extensive degradation of the Ewaso ecosystem in North Central Kenya that has led to the increase of undesirable plant species cover and the expansion of barren lands. Together, this has resulted in the reduction of wildlife and grazing value, further exacerbated soil erosion rates, and reduced soil moisture content through decreased infiltration. Due to the nature of community-based land tenure, which supports both wildlife and nomadic pastoral use, effective land management of this system is challenging. The authors highlight the use of a three-pronged approach which combines (1) removing undesirable plant cover through mechanical means, (2) reseeding with native plant species, and (3) encouraging autogenic plant recovery (in a form of vegetation islands) through the reduction in grazing and trampling achieved using cattle enclosures. The results of these efforts, as well as recommendations for future objectives, are discussed.

Middle East

Kildisheva et al. (2017) describe drivers of forest degradation in Lebanon, highlighting that key historical barriers to reforestation success can be attributed to a lack of research-derived understanding of seedling morphophysiological development during nursery production, thus limiting the capacity to produce seedlings able to survive under harsh climatic and edaphic conditions. The authors provide recommendations for the use of tailored irrigation and nutrient application regimes to produce high-quality seedlings and demonstrate that the integration of locally and regionally based partnerships can result in the successful development of the necessary infrastructure, communication, and planning, and consequently improve long-term restoration outcomes.

Mayence et al. (2017) describe the synergistic influence of rapid urban expansion, the collapse of traditional grazing practices, changes in land tenure, and the increase in aridity on the ecological degradation of arid systems in Saudi Arabia. Recent efforts to mitigate degradation and create financial opportunities through tourism and recreation have resulted in the development of comprehensive plans aimed at establishing novel conservation and restoration programs, with the majority focused on *Acacia* woodland restoration.

The authors suggest that key ecological limitations to plant recruitment can be addressed by identifying optimal restoration microsites to extend the window of favorable conditions that support subsequent plant establishment and persistence.

North/Central America

Hruska et al. (2017) highlight the issue of extensive shrub encroachment in arid to semiarid grassland and savanna ecosystems along the US–Mexico border. Land management practices including excessive grazing, changes to fire regime, fragmentation, and the eradication of keystone animal species are considered to be the main drivers in the expansion of a shrub-dominated ecosystem state. Addressing these challenges in both the near and long-term requires a clear understanding of the social processes influencing land management, but this knowledge is currently lacking. In order to address this, the authors use the Chihuahuan Desert grasslands of the Janos Biosphere Reserve of Northern Mexico as a case study for elucidating the process of ecosystem change from a social–ecological perspective. Hruska et al. (2017) recommend addressing land degradation from both ecological and social perspectives and provide insights into how collaboration between researchers, land managers, federal and non-governmental organizations can be successful in engaging the local community to adopt novel management practices that improve the ecological value of these systems.

Finally, Svejcar et al. (2017) suggest that invasive exotic species and alterations in wildfire frequency are the two primary drivers of degradation in the Great Basin ecoregion of the Western United States. The authors discuss the environmental constraints to seedling recruitment, highlighting that plant establishment must occur before the onset of sub-zero winter temperatures or summer drought. To overcome these limitations, they argue that agronomic approaches, such as seed enhancement technologies, offer the potential to better match the time of seed germination and emergence with environmental conditions most likely to increase survival and persistence.

Conclusion

The discipline of restoration ecology has largely moved from an ad hoc site and situation-specific practice of the late 1980s and early 1990s (Hobbs and Norton 1996), to a more concerted theoretical and practical science addressing issues that impact entire regions (Aronson and Alexander 2013). However, due to the relative youth of the discipline (four decades), cohesion between restoration science and practice is often absent (Menz et al. 2013; Suding 2011). As such, there is an increasing need for the integration of empirically and practically based rationale to develop appropriate restoration modes and metrics required to ensure outcome success (Cabin 2007; Menz et al. 2013; Suding 2011). In addition, planning that acknowledges and accounts for the spatial and temporal time scales at which restoration practices are to be conducted is particularly critical (Hilderbrand et al. 2005).

The recognition of the need for a science-driven basis to support ecosystem restoration efforts is echoed through an increase in the publication of peer-reviewed scientific works that focus on the topic over the last decade (Appendix), although restoration in dryland systems comprises only a small portion of the total articles published (less than 5% over the past decade). This, in part, may be due to the lack of financial and institutional support, political stability, and biological understanding of ecosystem function in many of the world's dryland regions. Given the scale and degree of degradation experienced, there is a substantial need to increase the extent of international multi-institutional dialogue and collaborative efforts to enhance scientific capacity and support restoration across borders.

Despite the ambitious target proposed by UNCCD at the Rio+20 summit of attaining a land degradation neutral world by 2030 (UN 2012), it has become increasingly clear that ecological restoration will play an important part in managing the problem of chronic degradation in dryland systems (Aronson and Alexander 2013). Thus, wide-ranging international interest lies in the development of cost-effective restoration methods that are capable of functioning across political boundaries (Aronson and Alexander 2013), but systematic modes of achieving this remain limited. The extent to which systems can be restored depends equally on the environmental and socioeconomic factors governing the geographic region. Future efforts to move global dryland restoration forward will rely on a clear understanding of the key limitations presented across these different environmental, socioeconomic, and political systems, and on identifying effective solutions capable of functioning on a landscape scale.

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Appendix

See Fig. 2.

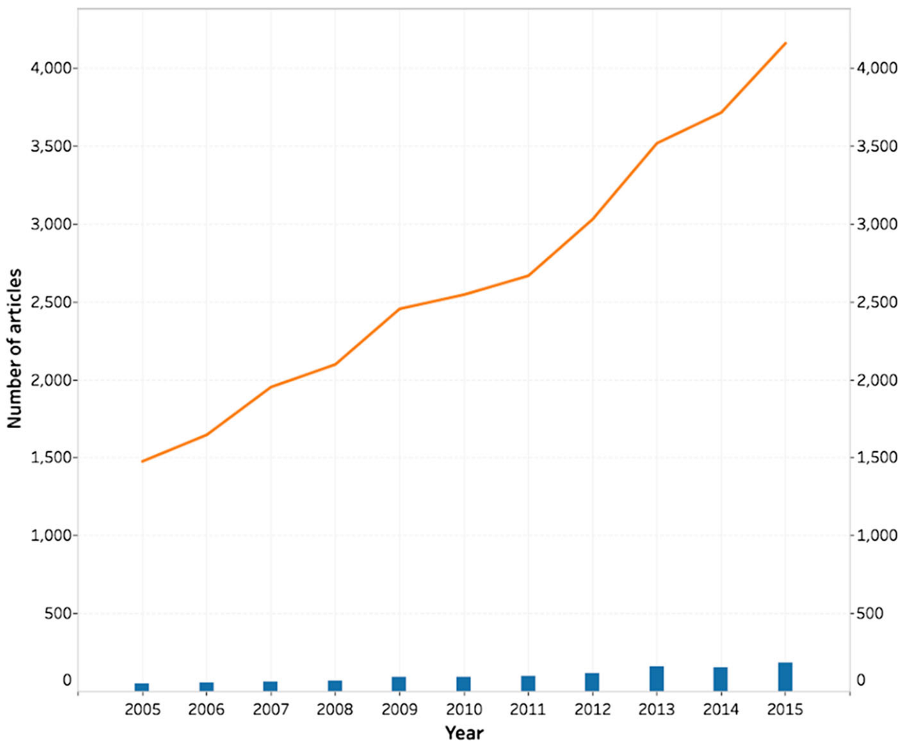

Fig. 2 Publication trends for articles published in the field of restoration ecology in dryland systems. Data were compiled from the ISI Web of Knowledge. *Blue bars* represent publications on dryland restoration by year, while the *orange line* represents articles published on restoration ecology in general. For articles on dryland restoration, the following topic search was used (restor* OR rehabilitation OR revegetation) AND (arid OR semiarid OR semiarid OR dryland* OR dry-subhumid) AND (ecol* OR environ*). For articles on general restoration ecology, the following topic search was used (restor* OR rehabilitation OR revegetation) AND (ecol* OR environ*). The *asterisks* represent a convention used for search terms with variable endings. (Color figure online)

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