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Restoration islands: a tool for efficiently restoring dryland ecosystems?

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Restoration islands are concentrated plantings in strategic locations, created to efficiently use resources to achieve restoration goals. These methods have been used effectively in mesic ecosystems, particularly tropical forests, where the goal of island plantings is often to "nucleate" across a degraded area, providing a seed source for spread outside the planted area. Here, we consider how an island strategy might be used to achieve restoration goals in dryland ecosystems, where limited resources and large areas of degraded land make restoration extremely challenging. In contrast to more productive areas, spread or "nucleation" from restoration islands in drylands may not occur or occur more slowly than required by most management time frames. Despite this, small-scale, more intensive island plantings may still be useful for achieving short-term goals, such as weed control, fire management, erosion control, and creation of wildlife habitat. Over the long term, island plantings could serve the same nucleation function as in other ecosystems and serve as repositories for genetic diversity within highly fragmented native systems. Here, we highlight the opportunities for using these high-intensity, targeted planting methods in dryland ecosystems, provide the guidelines for establishing islands to achieve short- and long-term restoration goals, and identify the areas where additional research is needed to understand the value of restoration islands in dryland ecosystems.

Key words: arid climate, ecosystem function, greenstrip, nucleation, restoration barrier, revegetation

Implication for Practice

- Although not widely tested as a restoration tool in dryland ecosystems, restoration islands can potentially increase restoration success if strategically situated in the areas with favorable biotic and abiotic conditions.
- Although the main use of restoration islands in more mesic ecosystems is as a center of habitat nucleation, in dryland ecosystems nucleation may be more limited or episodic, occurring under highly favorable weather conditions or over longer time frames.
- In arid climates, islands can serve as self-sustaining areas where ecosystem functions and services are restored and maintained in patches across the landscape.
- By focusing efforts on a limited area, managers can concentrate restoration resources in locations with a high potential for success or a high restoration priority.

Introduction

Climate change, species invasions, and changes in disturbance regimes are resulting in a rapid decline in the health and productivity of ecosystems across the planet (Rockström et al. 2009; Cahill et al. 2012), severely reducing their capacity to support social, economic, and ecological values. Resource-poor landscapes, such as water-limited arid and semiarid lands (i.e. drylands), are especially vulnerable to even small changes in the environment (Chabot 1985). Because of this, active restoration is becoming an increasingly critical component of efforts to limit the loss of biodiversity, stabilize sites after disturbances, such as fire, and enhance productivity across dryland ecosystems (Beyers 2004; Harris et al. 2006; Heller & Zavaleta 2009). Despite the enormous financial inputs and logistical efforts, current restoration approaches—including revegetation, soil remediation, and invasive species management—are still inadequate to stem plant extinctions, replenish species loss, and restore productivity and stability in drylands (e.g. Knutson et al. 2009; Moreno-Mateos et al. 2012). A focus on dryland restoration is critical because these ecosystems cover approximately 41% of the Earth's total land area, 10–20% of which is degraded as a result of human-caused disturbances (Safriel & Adeel 2005; Reynolds et al. 2007). Although land degradation has disproportional consequences in these dryland ecosystems (Chambers & Wisdom 2009), restoration success

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in arid systems is particularly difficult to carry out (Arkle et al. 2014; Hardegree et al. 2016), and novel methods may be needed to achieve management goals.

Restoration islands are increasingly being recommended as a novel strategy to efficiently and effectively restore degraded habitats (e.g. Corbin & Holl 2012; Rayburn & Laca 2013). Restoration islands are small-scale plantings of desirable species in strategic locations (Fig. 1A), created to efficiently use limited resources to achieve restoration goals (Fig. 1B). Also known as island plantings, assisted nucleation, or nucleation plantings, these plantings are intended to optimize cost–benefit ratios relative to alternative management options and, especially in mesic ecosystems, are expected to spread once established (Fig. 1C). Restoration islands have been shown to be ecologically successful and economically efficient for neotropical forests as well as some grassland ecosystems (e.g. Castellanos et al. 1994; Rubio-Casal et al. 2001; Franks 2003; Zahawi & Augspurger 2006; Schlawin & Zahawi 2008; Holl et al. 2011; Corbin & Holl 2012; Zahawi et al. 2013), but the potential benefits of using restoration islands in dryland ecosystems have not been critically considered (but see Reever Morghan et al. 2005).

To fill this gap, we explore the potential for restoration islands to be an effective restoration tool in dryland ecosystems. We first describe the concept of restoration islands, highlight the conditions in drylands that make these ecosystems particularly challenging to restore, and highlight how the restoration island use in drylands may differ from the use of other ecosystems. We present examples primarily from the Western United States, where much dryland restoration and vegetation management have occurred, with the goal of illustrating methods that can be generalized to dryland ecosystems globally. Finally, we outline the guidelines for the successful use of restoration islands in arid climates and suggest future research that could increase the success of island plantings in these ecosystems. Our goal is to encourage experimentation with small-scale, targeted restoration methods in arid systems, so that we can best understand how, and under what circumstances, island plantings succeed.

Island Plantings in Dryland Ecosystems

Island plantings are based on the premise that many ecosystems do not recover uniformly across landscapes after disturbance or degradation (Yarranton & Morrison 1974; Peterson et al. 2014). Rather, recovery tends to be spatially and temporally favored in patches that offer optimal conditions for plant regrowth (Yarranton & Morrison 1974; Franks 2003) or are in close proximity to patches of vegetation that escaped disturbance and provide a propagule source (Longland & Bateman 2002). The creation of restoration islands incorporates this pattern of landscape recovery into land management, enhancing initial establishment through targeted, sometimes high-input, plantings in the areas with an increased likelihood of successful plant establishment and persistence. This can involve seeding or planting transplants into remnant plant populations or creating new patches where remnant populations no longer exist (Huber-Sannwald & Pyke 2005; Corbin & Holl 2012; Corbin et al. 2016). A fundamental premise of most island plantings is that the initial patches of recovery will become sources of propagules that disperse outward across the landscape, facilitating additional recovery (Yarranton & Morrison 1974; Reis et al. 2010), thus the common terminology of "assisted nucleation" and "nucleation planting" (Corbin & Holl 2012).

The abiotic and biotic conditions of dryland ecosystems pose challenges to restoration practitioners. These ecosystems generally have low and variable rainfall and productivity, and nutrient-poor soils (Noy-Meir 1973; West 1983). Plant establishment can be episodic, and in many years, conditions are not amenable to successful recruitment (Maier et al. 2001; Meyer & Pendleton 2005). As a result, native communities are commonly dominated by long-lived perennial species (West 1983), which, upon disturbance, tend to become less resistant to invading annual species (e.g. Sheley & James 2010). Invasive annual species are highly competitive with seedlings of perennial species (e.g. Dyer & Rice 1999; Brown & Rice 2000) and also change disturbance regimes by increasing fire size and frequency, which limits plant recruitment and facilitates further invasion (Bradley & Mustard 2005; Alba et al. 2015). As a result, although efforts to restore arid systems are widespread, they too often fail (Duniway et al. 2015; Hardegree et al. 2016). An island approach allows managers to concentrate restoration effort into discrete patches that, if chosen strategically, may have a higher probability of success. Financial and other resources saved by reducing the spatial extent of a project can be employed to overcome common barriers faced in dryland restoration, including low seed germination/establishment, competition from invasive species, and fluctuating environmental conditions.

Because of abiotic and biotic constraints, some benefits of island plantings observed in mesic systems may not be immediately realized in dryland ecosystems. For example, rapid nucleation is a major goal of island plantings in mesic areas, but the factors that constrain restoration success in drylands (such as climate, invasive species, and frequent fire) are also likely to decrease successful establishment of propagules outside of island planting areas. In spite of this, given the episodic nature of favorable weather years for plant recruitment (e.g. Maier et al. 2001; Holmgren et al. 2006), islands of mature plants within a matrix of degraded dryland habitat could ensure that seed of desirable species is available to nucleate during excellent recruitment years. Thus, in dryland areas, nucleation may operate on a longer timescale than in other ecosystems. Ultimately, the ability of dryland islands to nucleate deserves more attention by researchers and practitioners.

Although island nucleation may not be possible in drylands or might only be realized in the long term, the island approach still has the potential to achieve many management goals. For example, managers could create a network of non-spreading, self-sustaining patches, strategically established to restore ecosystem functions and services in discrete areas across landscapes (Longland & Bateman 2002; Huber-Sannwald & Pyke 2005; Benayas et al. 2008). These non-spreading islands can provide "safe sites" (Rayburn & Laca 2013; Peterson et al. 2014) where the competition with non-native species, seed predation, and/or seedling herbivory is reduced (Rayburn &

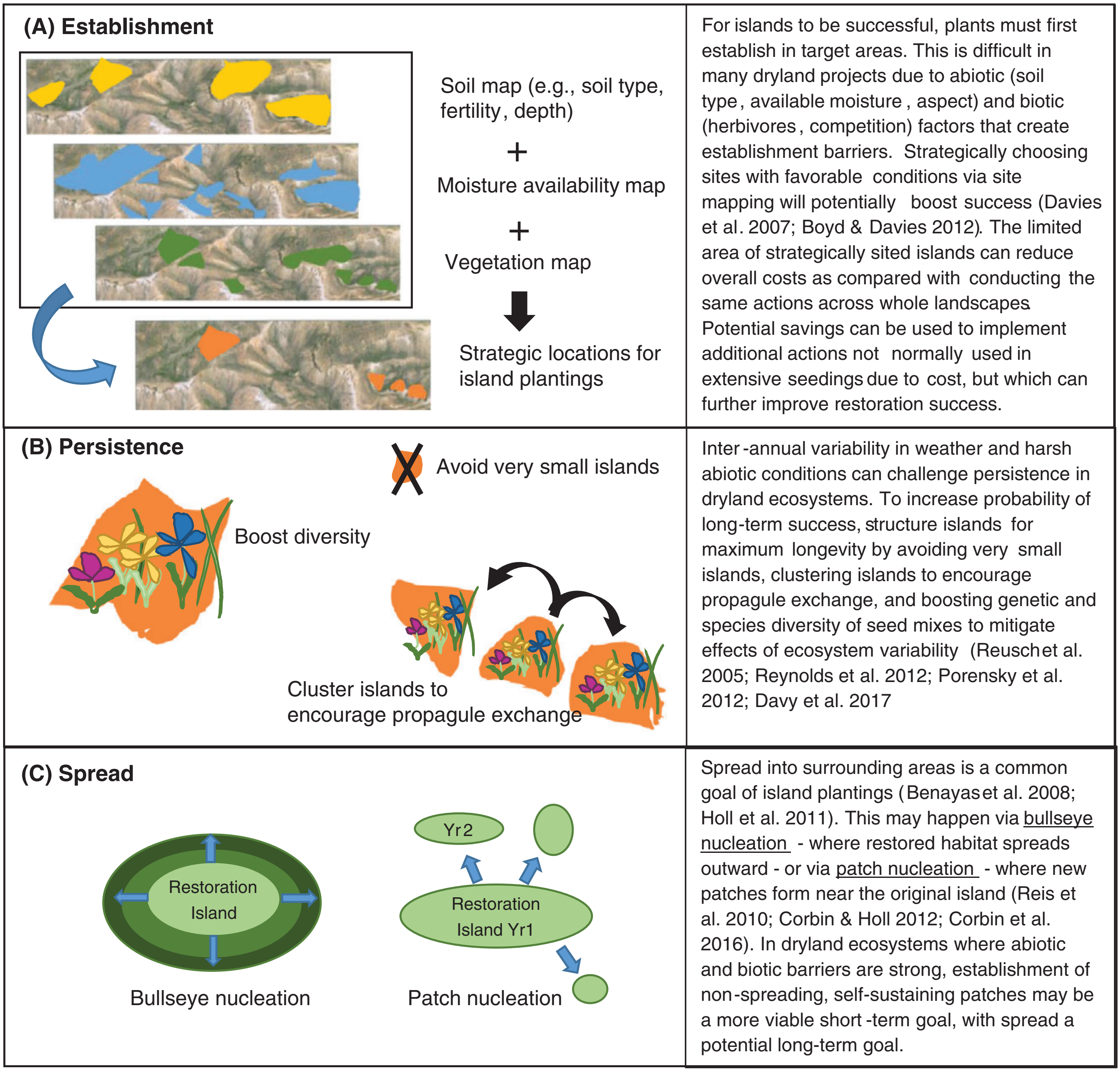

Figure 1. Restoration island basics.

Laca 2013). They can also serve as refugia and corridors within degraded or heavily disturbed landscapes by providing habitat and resources for target plant and animal species (Longland & Bateman 2002). Non-spreading islands can facilitate the establishment of species that would be restricted from establishing in non-vegetated openings, serving as nurse plants, and mitigating harsh abiotic conditions (Corbin & Holl 2012; Badano et al. 2016). Finally, non-spreading patches can provide benefits beyond restoration of habitat and biodiversity, such as firebreaks of less flammable perennial plants (Pellant 1990) in landscapes dominated by senesced annual plants. In all of these ways, islands can maintain populations of species that are negatively impacted by disturbance (Longland & Bateman 2002; Huber-Sannwald & Pyke 2005) or provide functions that benefit ecosystems and sustain ecosystem goods and services.

Using Restoration Islands to Address Dryland Management Goals

Goals Shared Across Mesic and Dryland Systems

Despite the differences in climatic conditions, dryland and mesic ecosystems have many overlapping restoration goals, including maintaining/enhancing plant community diversity, restoring habitat for valued wildlife, and controlling weeds (Table 1). Restoration islands may be able to achieve similar goals in arid climates, although additional consideration of how to successfully accomplish each goal is important. Here, we focus on the goals of promoting species diversity (Table 1, B) and supplanting invasive species with more desirable species (Table 1, F) to illustrate such considerations.

Promoting species diversity is a common restoration focus (Table 1, B), and adding species to existing vegetation can increase site biodiversity and habitat heterogeneity, benefiting pollinators and wildlife (Huber-Sannwald & Pyke 2005; Table 1, C). In drylands, focusing augmentation activity in locations that have retained native vegetation may be critical (Huber-Sannwald & Pyke 2005; Padilla & Pugnaire 2006). For example, in semiarid rangelands of the Great Basin, herbaceous vegetation cover and density are often greater under shrubs (Davies et al. 2007), and planting native grasses and forbs in preexisting stands of big sagebrush (*Artemisia tridentata*) can increase planting success (Huber-Sannwald & Pyke 2005). Harsh abiotic conditions (e.g. heat, wind, and water stress) are reduced by the preexisting big sagebrush stand, which functions similarly to a primary successional "island" (Davies et al. 2007). Manager-assisted secondary succession can facilitate success and lead to increased seed germination, seedling emergence, and survival of native grasses and forbs under protective shrub canopies (Temperton & Hobbs 2004; Poulos et al. 2014). At other times, however, established plants, even the desirable ones, can inhibit rather than facilitate the establishment of additional desired species (e.g. Porensky et al. 2014). In these situations, an island approach may provide opportunities for targeted, patchy removal of dominant plants in order to create space and resource availability needed to successfully restore desired species or genotypes.

Controlling non-native invasion and spread is another common restoration goal (Table 1, F). In drylands, invaders can alter the disturbance cycles by increasing fire size, intensity, and frequency, which can favor further invasion (D'Antonio & Vitousek 1992). In addition, many invaders have resource-use and reproductive traits that allow them to utilize the limited resources more quickly than resident species (Funk & Vitousek 2007), making it difficult to eliminate or even reduce the abundance of invasive species in dryland areas. Due to their constrained area, restoration islands cannot be used to control weeds across vast, invaded landscapes. However, the limited area of restoration islands allows managers to focus resources on weed control in specific locations. Such actions can include weeding or spot spraying with herbicide and may also include planting species that contribute to weed control and thus island persistence. A growing number of studies indicate that adding species with resource-use traits similar to potential invaders can reduce invasion by increasing the competition for limiting resources (Funk et al. 2008; Hulvey & Zavaleta 2012). For example, in California's Central Valley, increasing the diversity and abundance of species with functional traits similar to target invaders has been shown to increase the resistance (Young et al. 2009; Hulvey & Aigner 2014) via competition for limiting soil moisture resources (Hulvey & Zavaleta 2012). Using restoration resources to control weeds and simultaneously increase the seeding density of functionally similar, competitive species may contribute to island persistence. Such a strategy may be particularly useful when planted species are not competitive with weeds as seedlings, but become increasingly competitive as established plants, e.g. perennial bunchgrasses (Dyer & Rice 1999; Lulow 2006).

Goals Important in Dryland Systems

Restoration islands may also be employed to achieve important dryland management goals. Although not unique to drylands, these goals directly address common disturbances and restoration barriers encountered in these areas, which include the following: reducing fire risk, decreasing soil erosion, and creating seed sources for long-term nucleation.

Invasive species, land use changes, and climate change have altered historical fire regimes in many dryland ecosystems by increasing fire frequency and size (e.g. D'Antonio & Vitousek 1992; Brooks et al. 2004). Managers in such areas may be able to prevent the unabated spread of fire across large landscapes by configuring island plantings to interrupt the continuity of fuels (Table 1, G). An example of this strategy is greenstripping, where islands planted in linear strips produce firebreaks (Pellant 1990). Greenstrips can function either by resisting fire directly (e.g. plants remain green throughout the fire season) or by resisting invasion by other plants in order to create bare interspaces that reduce fuel loads and fuel continuity (Pellant 1990). Although greenstrips are a promising strategy and have received some attention from public land managers in the Intermountain West, little formal research has explored the best methods for creating successful greenstrips. As a result, fuel breaks created via herbicide (brownstrips) or by mechanical methods are still commonly used. The benefits of greenstrips will vary depending on the species planted, with common species being non-native perennials whose main role is to stop the spread of fire, although native species are sometimes used (Maestas et al. 2016). Even when greenstrips are composed of non-native species, these plantings still may provide an array of desired ecosystem services in addition to fire resistance, including increased soil stabilization, higher plant diversity, resistance to invasion, improved livestock forage, or enhanced wildlife habitat, relative to weedy communities (Schlaepfer et al. 2011).

Dryland islands may also be used to reduce erosion (Table 1, H). In some arid ecosystems, such as coastal areas characterized by substrate destabilization (Hesp 1991), choosing species that quickly develop extensive root structures can prevent erosion (Reubens et al. 2007). However, in many dryland ecosystems, plant growth may not be so rapid, and in these cases, additional actions that help plants establish might be needed. For example, high-input plantings (dense grass stands coupled with initial irrigation) have been shown to reduce wind erosion in central Nevada drylands (Porensky et al. 2014). Slow plant growth may also lead managers to rely on novel methods to spur successful establishment and thus prevent erosion. For example, erosion barriers have been used in drylands both in Kenya and in the Colorado Plateau in the Western United States to establish islands of vegetation that spread over time and

Table 1. Examples of goals for island plantings. Bold type indicates goals that commonly are important in dryland ecosystems.

Goal	Method	Examples
A. Increase forage production/ecosystem productivity	Plant heterogeneous patches of fast-growing palatable vegetation	Malmstrom et al. (2009)
B. Maintain/enhance plant community diversity	Stagger plantings of more/less competitive species to reduce competition during restoration	Porensky et al. (2012)
C. Maintain/enhance wildlife habitat size and quality	Plant natives that add diversity and structure and can serve as food resources	Huber-Sannwald and Pyke (2005)
D. Maintain/enhance pollinator habitat	Plant native forbs and appropriate host plants characterized by a wide range of flowering times	Dixon (2009)
E. Develop migration corridors	Use restoration to connect vegetation patches along favored routes	Fischer and Fischenich (2000)
F. Weed control	Plant species characterized by competitive traits and enhance trait overlap with invasives	Funk et al. (2008), Hulvey and Aigner (2014)
G. Fire management	Plant natives that are flame resistant, strategically located to protect intact habitat or prevent fire spread	Pellant (1990)
H. Erosion mitigation	Use erosion barriers to establish islands of vegetation; plant species with extensive root structure, rapid colonization ability, and/or traits that confer rapid recovery after disturbance	Beyers (2004), Fick et al. (2016), Kimiti et al. (2016)
I. Seed sources for long-term nucleation	Establish parent plants that can persist through dry years, and provide seed rain for establishment during favorable weather years	Perryman et al. (2001), Meyer and Pendleton (2005), Reever Morghan et al. (2005)

reduce the connectivity of bare ground (Fick et al. 2016; Kimiti et al. 2016). In many drylands, biological soil crusts also stabilize soils and protect against erosion (Belnap 2006; Chiquoine et al. 2016), and thus, restoring these crusts may offer additional stabilization. Studies investigating the use of field-collected topsoil or laboratory-cultivated inoculants to produce these stabilizing biological crusts are becoming more common (e.g. Bu et al. 2013; Chiquoine et al. 2016). Because biological crust establishment often increases with increased levels of water and nutrients (Maestre et al. 2006), employing restoration islands to increase these resources in target areas may be a strategic way to use the limited restoration funding and effort to benefit crust restoration.

Finally, despite the likely long-term timescale, restoration islands in arid climates may also be able to function as seed sources for nucleation (Table 1, I). To encourage this process, islands can be strategically placed throughout a landscape in the areas with biophysical conditions favorable for plant growth, such as soils with higher water-holding capacity, lower landscape positions that allow for water collection from the surrounding areas, or areas protected from fire by geologic features, such as rocky outcrops (Kolden et al. 2012). Such positioning may help ensure that seeds of native species are present on the landscape in years when conditions are favorable. For many dryland ecosystems, favorable weather years may simply be those with sufficient precipitation, but they also could be years when the timing of precipitation favors native perennial species over invaders (e.g. more late-season rain), or invaders are negatively affected by other factors, such as disease or herbivory. In a particularly dramatic example, the invasive plant *Bromus tectorum* periodically experiences large-scale "die-offs" or total stand failures caused by soil pathogens in the areas of the Great Basin (Baughman & Meyer 2013). Some areas are prone to repeated episodes of die-off (Weisberg et al. 2017), and establishing islands of native species within these areas could prime an area for nucleation due to periodic reductions in competition from invasive annuals (Baughman & Meyer 2013).

Recommendations for Creating Successful Restoration Islands in Dryland Ecosystems

Although much remains to be studied about effective methods for restoration island deployment in dryland ecosystems (see "Future Research & Conclusions" section and Table 2), here we adapt the current thinking on best practices in dryland ecosystem restoration to island plantings. Our goal is to highlight the practices integral to island establishment, persistence, and spread and describe how island plantings can be used to address the barriers to restoration in dryland ecosystems, including low moisture availability and fluctuating interannual weather conditions. We do not, however, focus on other important restoration strategies that are general to dryland restoration, such as decisions about which species, genotypes, and traits to include in island plantings. Although important for restoration success, we refer readers elsewhere for discussion of these topics (e.g. Abella et al. 2012; Leger & Baughman 2015; Bucharova et al. 2017).

Table 2. Questions to guide future research.

A. Ecological
- What conditions promote spread from restoration islands in arid ecosystems?
- How do we promote establishment in islands of less competitive species that can contribute ecosystem services?
- How do we create islands that contribute to multiple restoration goals? What are the trade-offs/benefits of such multigoal plantings?
- How long after establishment do you get service?

B. Economic
- What are the economic costs/benefits of using restoration islands compared to other restoration techniques?
- Is focusing dryland restoration efforts in small, focal patches more cost-effective than seeding an entire landscape or planting a large number of transplants?
- Will savings gained by such target planting be offset by increased planning costs involved with choosing target restoration sites?

C. Social/outreach
- How do we strategically situate islands across landscapes, so that they provide usable benefits to multiple stakeholders?
- What are the economic and ecological trade-offs when striving for multibenefit islands?

Primary Establishment

In arid systems, seedling establishment is often extremely low (e.g. Mazzola et al. 2011), but once established, plant survival probability increases significantly (e.g. Chambers 2000; Meyer & Pendleton 2005; Leger & Goergen in press). The limited planting area of islands allows managers to increase the initial establishment through a combined approach of strategic site selection and targeted resource deployment. We recommend the following strategies:

(1) *Be spatially strategic to overcome abiotic and biotic barriers*. Restoration studies in dryland areas highlight how variation in site conditions can drastically affect restoration success (Boyd & Davies 2012). In particular, topography, microclimate, the presence of competitive non-native species, and soil type will all affect the ability of islands to establish, spread (Prach & Řehounková 2006; Kimiti et al. 2016), and survive significant disturbance (e.g. Kolden et al. 2012; Levi & Bestelmeyer 2016). One advantage of island plantings, relative to spatially extensive plantings, is the ability to choose planting sites strategically to reduce some of this landscape-level variability. Here, we focus on choosing sites within particular landscapes, but acknowledge that prioritizing landscapes within vast areas of dryland ecosystems in need of restoration may be equally important, and similar considerations would apply.

Successful restoration island design and deployment can be supported by site mapping (Davies et al. 2007; Boyd & Davies 2012) that identifies locations best suited for plant establishment and persistence. For example, aspect, soil texture, fertility, and physical properties can all have strong effects on planting success and community trajectories (Ehleringer & Sandquist 2006; Lulow et al. 2007; James et al. 2011; Kulpa et al. 2012; Duniway et al. 2015), and thus, focusing plantings in the areas with appropriate soil conditions should improve establishment and ultimately survival. Because low soil moisture is a barrier to successful restoration in arid climates (Gornish et al. 2015), mapping methods that estimate the moisture availability from soil type and topographic position (e.g. Dilts et al. 2015) could reveal locations with higher restoration potential. Finally, because predicted shifts in the amount and season of precipitation due to climate change differ both by region and with regional-scale factors (e.g. topography) (Environmental Protection Agency 1998; Kueppers et al. 2005; Xie et al. 2015), regional-scale climate models could help inform island placement, allowing managers to avoid the most severely affected areas.

(2) *Use resources saved by limiting restoration to islands to employ additional management actions*. One of the largest advantages of the island concept is that because of the limited planting area, the overall costs can be reduced, and restoration may be more cost-effective than conducting the same actions across entire landscapes. For example, island plantings used for subtropical forest restoration have been found to reduce maintenance and planting costs by about 27% when compared to landscape-wide plantings (Holl et al. 2011). Similar economic studies of island plantings are needed in drylands, but the high costs of native seed and transplants ensure that smaller plantings will be more economical than the larger ones (Shaw et al. 2005; Rayburn & Laca 2013). Although the overall lower cost is a distinct advantage of this method, a secondary benefit is that resources saved through focused restoration actions can translate into more resources available per unit of planting area. This could be a distinct advantage in arid systems, as managers could take advantage of an array of approaches that have been shown to improve restoration success, but are not normally used in extensive seedings due to cost. These include the following:

- *Improving water availability*. Irrigation of newly created restoration sites can have long-term benefits in arid environments, increasing the establishment of both plants and biological crusts (e.g. Maestre et al. 2006; Porensky et al. 2014). For smaller islands, watering, the use of slow-release water gels, or irrigation methods designed specifically for arid areas (e.g. clay pot irrigation) may be worth the added expense (e.g. Bainbridge 2002; Abella et al. 2015). Investment in seed-coating technology that increases the effectiveness of available precipitation (e.g. Madsen et al. 2012) may also be considered.
- *Boosting the seed rate*. Increasing the seed rate may be one of the simplest options for improving establishment success (Aicher et al. 2011; Mazzola et al. 2011), but see (Wilson 2015). Quadrupling the seeding rate can result in

2–3 times as many seedlings (Hulvey & Aigner 2014), even in exotic plant-invaded, arid sites (Mazzola et al. 2011). Because the exact relationships between seeding rates and seedling numbers vary by species (Aicher et al. 2011), studies examining seed:seedling ratios for restoration species will be particularly informative for island plantings.

- *Reducing biotic resistance produced by competitive weeds or nontarget native species*. New seedlings are unlikely to establish within existing stands of highly competitive plants, whether they are invasive weeds or competitive native species (Levine et al. 2003). In dryland ecosystems where resources, such as soil moisture, are limited, the competition with established plants is especially problematic (Fowler 1986). In order to free up resources for new individuals, site preparation usually needs to include treatments, such as herbicides, targeted grazing, mowing, or mechanical plant removals, and often, results are improved if these treatments are applied multiple times or in combination before planting (e.g. John et al. 2016).
- *Creating favorable microsites*. Techniques, such as increasing soil surface roughness or installing snow fences and erosion barriers, may help to capture sediment, seeds, and moisture or to reduce soil loss, all of which can benefit establishing islands (Kinyua et al. 2010; Fick et al. 2016; Kimiti et al. 2016).

Island Persistence

Even if restoration islands are successfully established in optimal sites, interannual variability in weather and naturally harsh abiotic conditions are likely to challenge island persistence in drylands. To persist and regenerate, plants in arid regions typically employ numerous risk mitigation or bet-hedging strategies. For example, sagebrush shrubs produce many seeds every year, but in low elevation and dry locations, only a small percentage of years are favorable for recruitment (Maier et al. 2001; Perryman et al. 2001). To encourage dryland island persistence, restoration practitioners must seek to design islands, so that they can survive despite resource fluctuation and continual pressure from invasive species. We suggest the following strategies:

(1) *Dedicate resources to strategically manage variability inherent in dryland ecosystems by boosting genetic and species diversity and addressing priority effects*. High-diversity mixes may be too costly for large seedings, but, when used in restoration islands, will create buffering capacity that allows island communities to withstand years or events that are unfavorable for certain species or genotypes (Reusch et al. 2005; Reynolds et al. 2012). A more diverse seed mix that leads to a more diverse planting may also reduce invasion by non-native species (e.g. Naeem et al. 2000) and increase the chances of island persistence under uncertain future climates. It may also be possible to foster diversity and resist invasion through the creation of within-island temporal or spatial priority effects. Specifically, less competitive species can be planted earlier than, or spatially segregated from, more competitive species (Porensky et al. 2012; Vaughn & Young 2015; Werner et al. 2016), allowing the coexistence of ruderal and more slow-growing native species. When plantings are temporally segregated, initial fast-growing species could be a "first step" in a multitiered restoration process, reducing the competition from non-native species, stabilizing soils, and perhaps ameliorating site conditions for future target species (Leger et al. 2014; Uselman et al. 2014).

(2) *Structure islands for maximum longevity: Avoid very small islands, isolated islands, and islands with high edge-to-area ratios*. The risk of species extirpation is greater in small than large islands due to smaller population sizes that are more susceptible to inbreeding depression as well as population and environmental stochasticity (Ellstrand & Elam 1993; Morris & Doak 2002). If islands are also isolated from populations that can supply them with new propagules or pollination opportunities, their chances of persistence are lower if they are near other populations (MacArthur & Wilson 1967). When possible, locate islands close to an intact "mainland" to promote propagule immigration and associated gene flow (Hanski 1998; Corry et al. 2008). Alternatively, islands may be planted in clusters to increase the exchange of propagules among themselves. If restoration islands are placed immediately adjacent to remnant or previously restored areas, they could also extend the desired cover and provide a buffer against invasive species (Gascon et al. 2000). Finally, islands dominated by edge (e.g. long narrow strips) may have lower resistance to weed invasion and other processes that can degrade islands over time (Wilkerson 2013). If high edge-to-area ratios are required (e.g. greenstrip establishment), planned weed management (e.g. planting with species that compete with local invaders or applying targeted weed control) may be required.

(3) *Limit exposure to heavy herbivory and other disturbances*. Islands that include palatable plants may be targeted preferentially by herbivores, particularly when located within a matrix of unpalatable plants. Livestock grazing in the initial growing season(s) after planting can affect success (Davy et al. 2017). If possible, protect islands from herbivory during the seedling stage and avoid long-term, heavy grazing pressure (i.e. that which exceeds the community's capacity to recover). Similarly, islands planted with fire-intolerant species may be threatened by wildfires in landscapes where fuel loads and fuel continuity are high. Using herbicide to reduce biomass around established island perimeters may provide fire protection by creating a gap in fuel loads and may also foster island spread (see below). Targeted dormant-season grazing around islands may provide fire protection in some situations (Davies et al. 2016).

Spread

Although spread from restoration islands may be challenging in dryland ecosystems, there are some management actions that could increase the chance that islands serve as nucleating elements. We recognize that some of these recommendations run counter to those for enhancing island persistence (see above). However, there is rarely one perfect choice for management, and the goals for and constraints facing a particular site are important for selecting a particular strategy. Depending on the situation, managers may need to target islands either for persistence or for spread. Recommendations for nucleating islands include the following:

(1) *Make the matrix less hostile*. If areas outside of islands are already occupied with vegetation competing for resources, it may be difficult for seedlings to overcome biotic resistance (Fowler 1986). In order to foster spread, practitioners may want to consider targeted herbicide applications or grazing of existing plants surrounding islands. Similarly, it may be possible to defer grazing in the matrix after a natural recruitment pulse.
(2) *Facilitate dispersal*. To encourage spread, include species and genotypes with good dispersal abilities in islands. Consider including not just gravity-dispersed species, but also those dispersed via wind or animals. In the case of bird-dispersed species, it may help to create nearby perches that can serve as nuclei for new islands (Holl 1998).
(3) *Maximize dispersal: increase edge-to-area ratio and use island orientation*. If islands are able to resist weeds and other disturbances (see above), having a high edge:area ratio could benefit spread by increasing the amount of island-to-matrix contact (i.e. larger perimeter). In situations where long, narrow islands are possible (e.g. wind-dispersed forb or shrub seedlings planted into native perennial grassland), it may help to orient islands perpendicular to the prevailing wind direction in order to foster the dispersal of seeds into the matrix.
(4) *Arrange patches to maximize beneficial edge effect interactions*. For islands to nucleate, distances between nucleation foci must not be too large. Nucleation can benefit from interacting edge effects (Porensky & Young 2013), and therefore, it may be helpful to calculate edge effect depths and use this information to inform the spatial arrangement of island plantings.

Future Research and Conclusions

Despite the many potential benefits of using restoration islands to improve multiple outcomes in dryland ecosystems, questions remain as to how to use this tool most efficiently (Table 2). Many of these questions focus on the ecology of restoration islands, including how to best establish islands, while others look at the end goal of restoring the functions and services these islands will produce (Table 2, A).

Island restoration methods are only attractive if they are economically efficient. Island seedings in nondryland ecosystems have shown similar, if not greater, amounts of biodiversity and species density relative to broadscale landscape restoration efforts, with much lower implementation costs and faster recovery rates than passive restoration (Benayas et al. 2008; Corbin et al. 2016). Despite these potential benefits, we found no research on the economic benefits or trade-offs of using restoration islands in dryland ecosystems. Questions for future study thus include understanding when restoration islands offer economic benefits, as well as how restoration “bang for the buck” may differ between mesic and dryland ecosystems (Table 2, B).

Finally, island plantings allow for flexibility in large-scale restoration planning and landscape use (Benayas et al. 2008) that can benefit multiple stakeholders. As island plantings are small in extent and distributed throughout a landscape, the surrounding matrix can be targeted for other management goals, including agricultural land uses (Benayas et al. 2008). Studies examining how matrix management affects the achievement of island planting goals—e.g. long-term nucleation—will be needed to determine the compatible combinations of land uses. This approach of managing for landscape heterogeneity can provide opportunities to optimize multiple ecosystem services and accommodate a continuum of restoration and agricultural goals (Raudsepp-Hearne et al. 2010; Eastburn et al. 2017). Future research that examines how restoration islands can be strategically situated across ecosystems to provide varied benefits for multiple users (Table 2, C) will undoubtedly make this tool more appealing to land managers and landowners.

Ultimately, concentrating restoration efforts into high-input, strategically located, smaller areas may provide more satisfying outcomes for management activities in dryland ecosystems. Any researchers or managers who have had the all-too-frequent experience of planning, funding, implementing, and monitoring an unsuccessful dryland restoration project would agree that achieving smaller areas of success would be preferable to large-scale failure. Restoration islands can help management goals become more strategic and deliberate and may ultimately provide better long-term outcomes for restoration efforts in these challenging ecosystems.

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