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Dryland restoration needs suggest a role for introduced plants[☆,1]

Kirk W. Davies[a,*], Dustin D. Johnson[b]

[a] United States Department of Agriculture* - Agricultural Research Service, Burns, OR 97720, USA
[b] Oregon State University, Eastern Oregon Agricultural Research Center, Burns, OR 97720, USA

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ABSTRACT

Restoration of degraded drylands is critically needed to return lost ecosystem goods and services. Restoration practitioners often focus on restoring the historic native plant community to promote biodiversity and reduce the threat of invasion. However, success with native plants in drylands is often low, especially with altered climatic and disturbance regimes. Instead, we suggest that the focus should be on restoring ecosystem goods and services that are important to society. In other words, restoration goals should be the starting point for the restoration planning process. This may include using introduced (non-native) plants where they are likely to establish and meet ecosystem objectives determined important for society and pose minimal risk of further land degradation, but native plants are likely to fail. However, native plants should be used where they can be successful. We propose a decision tree to assist in determining if native, introduced, or mixes of native and introduced plant species should be used in restoration efforts. Restoration of degraded drylands at scales that will offset and reverse the current rates of degradation may require the use of both native and introduced plants. We do not make these arguments lightly, and are aware of the numerous challenges in the careful and successful use of introduced species in service of supporting ecosystems services and function without causing further, unintended degradation. However, we believe that the potential benefits are greater than the risk if done correctly and judiciously. We do not underestimate the complexity involved in following through with the decision tree we propose, but present it as a framework to guide this difficult work.

1. Introduction

Restoration has been defined differently by many authors (Gerwing et al., 2023). For the purposes of this manuscript, we use the restoration definition suggested by Martin (2017), “Ecological restoration is the process of assisting the recovery of a degraded, damaged, or destroyed ecosystem to reflect values regarded as inherent in the ecosystem and to provide goods and services that people value.”. This is in contrast with the more traditional view of restoration being the return to prior community composition and promoting native biodiversity (Gerwing et al., 2023). Utilizing a broader definition of restoration than simply to return to a historical reference is critical as restoration practitioners are dealing with unprecedented environmental changes and challenges (Miller and Bestelmeyer, 2016).

Restoration of degraded lands, which occupy >33 % of global land and affect billions of people (Abhilash, 2021), is critically

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* Correspondence to: EOARC, 67826-A Hwy 205, Burns, OR 97720, USA
E-mail address: kirk.davies@usda.gov (K.W. Davies).

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needed to return lost ecosystem goods and services. Drylands are temperate and tropical areas with an arid index of < 0.65, which include arid, semi-arid, and dry-subhumid ecosystems, are one of the most degraded biomes (Millennium Ecosystem Assessment, 2005). Restoration efforts in drylands focus heavily on native plants and the desire to reestablish historic plant communities. These efforts have generally overlooked that introduced plants may have values to restoration efforts. However, it is vital to differentiate between introduced and invasive plants. Introduced species are non-native species, i.e., they are species living outside of their native distribution. In contrast, invasive species are a subset of introduced species that spread widely or quickly and cause substantial harm to the environment (Davis and Thompson, 2000; Richardson et al., 2000). We are not suggesting using invasive plants for restoration as they will spread widely and quickly from where they are used and cause ecological damage.

However, non-invasive introduced (non-native) plants can provide important goods and services for fauna and humans (Trigger et al., 2008; Shackelford et al., 2013; Gérard et al., 2015; Alexandra, 2022). Introduced plants may be important for supporting pollinators over the long-term (Lybbert et al., 2022). For example, the non-native forb, lance-leaf plantain (*Plantago lanceolata*), has been seeded and planted as seedlings in prairies to provide a host plant for Taylor's checkerspot, an endangered butterfly (Dunwiddie and Rogers, 2017). The non-native woody species, tamarisk (*Tamarix ramosissima* Ledeb.) provides valuable breeding habitat for an endangered willow flycatcher in the southwest U.S. (Sogge et al., 2006). Reestablishing native taxa that formerly supported willow flycatchers may be difficult in many areas because of alterations to flooding regimes by dams (Schlaepfer et al., 2011). Introduced plants also provide important ecosystem services in California grasslands (Stein et al., 2014). The focus on native plants has, at times, circumvented developing specific ecosystem goals based on the capacity and capabilities of the land. Instead of identifying ecosystem goods and services that are important to society and selecting treatments with the highest probability for success in achieving those goals, reestablishing the historic plant community has often been the objective with the assumption that this will promote biodiversity and provide ecosystem goods and services. This, along with valid concerns of negative impacts from introduced species, which have been widely documented in the literature (e.g., Williams and Baruch, 2000; van Klinken et al., 2006: Ellsworth et al., 2014), has largely prevented restoration practitioners from considering if introduced species could be used to achieve ecosystem goals. Success with this native-centric strategy has not been high in dryland ecosystems with altered disturbance regimes (Shackelford et al., 2021). However, part of the problem may be that we are expecting native species to do things they are not adapted to do, such as establish from seed in any given year and grow rapid enough to occupy the site prior to invasive species dominance (Svejcar et al., 2017; Davies et al., 2021; Svejcar et al., 2023). Multiple years of seeding of native species to increase the probability that seeds of native species will be available when conditions are favorable for their establishment and additional inputs such as invasive species control may increase restoration success with native species (Davies et al., 2018; Svejcar et al., 2023). However, the probability of successful restoration with native plants will become even more unlikely with further climate change, more frequent and severe disturbances, and expanding invasive species (Walther et al., 2009; Butterfield et al., 2017; Svejcar et al., 2023).

If restoration is needed, unfavorable conditions likely already exist for the persistence of native plants, though past conditions or prior disturbances could have degraded the ecosystem. Unless the underlying conditions contributing to the loss of native species are addressed, attempting to reestablish native plants is illogical as the native plant community has already demonstrated its inability to persist. Thus, it is vital to determine if present conditions (e.g., degradation) present a barrier to native plant species establishment and persistence, and if present barriers can be resolved. Yet, how often do we examine if conditions are altered to the point that native species are unlikely to establish and persist?

When restoration is needed across large areas, rarely are these circumstances the product of just one causal agent that can simply be reversed. Multiple factors have often led to the degradation of these plant communities and the prevention of native species reestablishment. For example, in the Great Basin, USA, invasive annual grasses are highly competitive with native perennial species and their invasion can lead to the development of an annual grass-fire cycle that results in more frequent fire than most native species can tolerate, ensuring continued annual grass dominance (D'Antonio and Vitousek., 1992). Furthermore, highly variable weather patterns in many of these annual grass-invaded drylands are rarely conducive to native perennial plant establishment (Hardegree et al., 2018) and are likely to become even less so with climate change (Shackelford et al., 2021; Svejcar et al., 2023). In these situations, overcoming only one limiting factor is unlikely to allow native plants to establish and persist. Thus, before proceeding with native plant restoration, we need to carefully evaluate if the ecosystem will support native species under its current and projected climatic and disturbance regimes; if not, we should consider if introduced species could fill this need without posing a credible risk of further degradation. Integrating ecological niche modeling and predicted future disturbance regimes and climate can be one way to evaluate if native species will establish and persist in the future (Butterfield et al., 2017). When contemplating using introduced species, it is essential to ensure these species will not cause further ecological damage prior to incorporating them into restoration efforts. Both evaluating if native species will be successful or not and the potential for introduced species to have ecological damage may require extensive literature reviews, incorporation of local knowledge and experiences, and consulting with experts. Additional research into the use of introduced plants for restoration purposes, particularly long-term evaluations of the outcomes, would be valuable for decision making.

There are efforts underway to develop cultivars from native species that are capable of establishing and persisting under new climatic and disturbance regimes, but are these plants representative of the native populations or are they more similar to introduced species? This is not to imply that cultivars should not be used as they provide valuable ecosystem goods and services, but if they have been selected for traits that improve their abilities to succeed in a different environment (more competitive, establish better, grow faster, etc.), their relationship with other plants in the community has likely changed. Cultivars have substantially less genetic diversity than the populations they have been selected from and this may decrease restoration success (Espeland et al., 2017; Pizza et al., 2021). Even if genetic diversity loss is minimized, genetic shift is likely inevitable with the cultivation of native species (Chivers et al., 2016). At this point, could these genetically altered "native" cultivars be more similar to introduced species in their ecosystem roles than to their wild progenitors? Thus, if the restoration goal is to reestablish native species (often with the assumption that doing so will maintain biodiversity including genetics), do cultivars meet this objective when they have been specifically selected to have traits different than the general population? We would argue that, no, they do not meet this objective because they are not representative of the general population. Because they don't represent the general population and may hybridize with wild populations, some authors

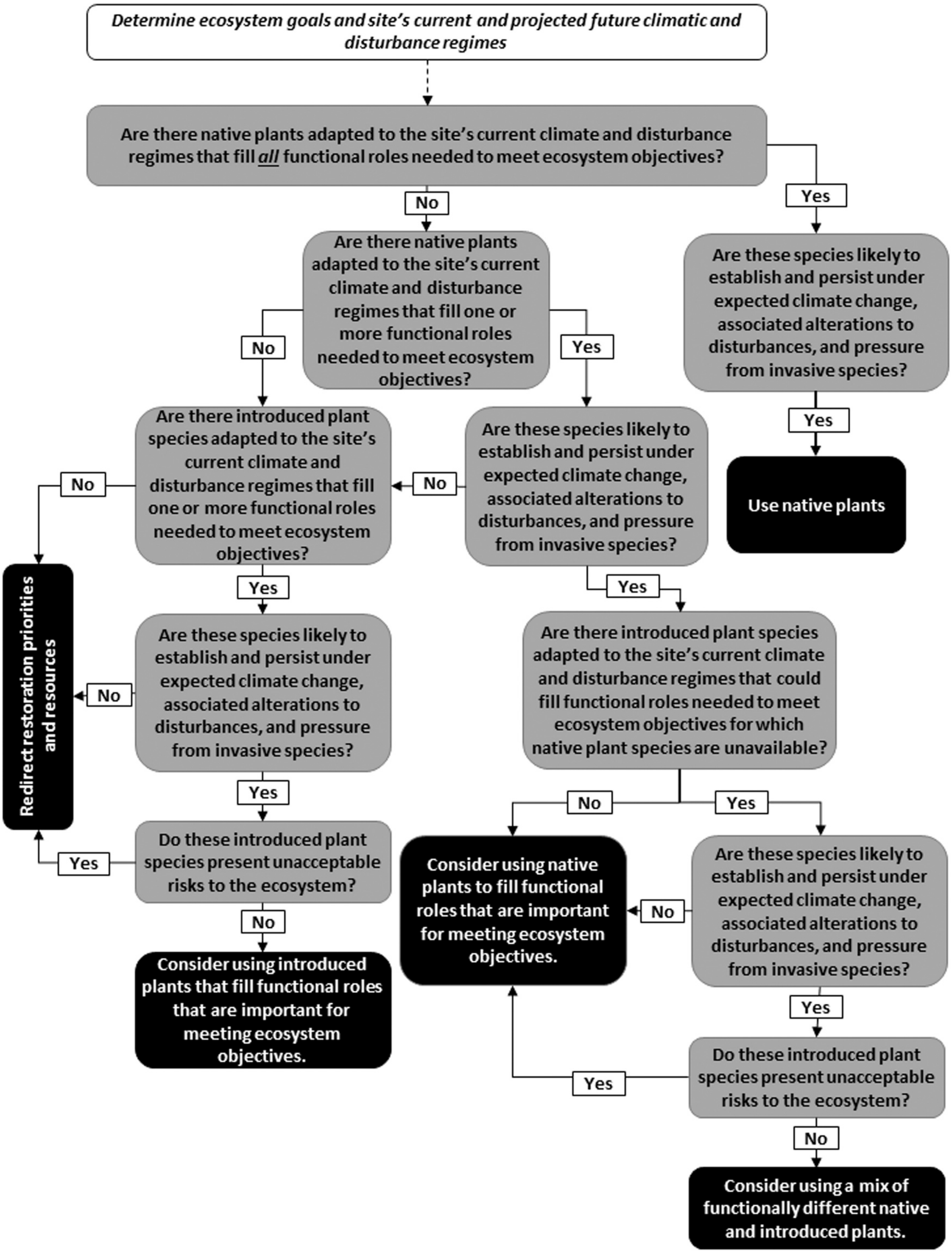

Fig. 1. Decision support tree for determining if native plant species, introduced species, or mixes of native and introduces species should be considered in dryland restoration efforts or if restoration resources should be redirected elsewhere.

have suggested that large-scale use of native cultivars should be avoided (e.g., Schröder and Prasse, 2013). In contrast, if the goal is to restore ecosystem services such as ground cover, forage production, or wildlife habitat, cultivars or introduced plant species could be used to achieve that outcome. Clearly there is a need for cultivars, especially those that are better adapted to current conditions than wild populations, and cultivars should be used over introduced species if they are likely to establish and persist. Hence, we whole-heartedly support efforts to develop and use native cultivars; however, we argue the need for cultivars also suggests a role for introduced species in dryland restoration.

Restoration practitioners and scientists need to take a critical look at how likely native plant species are to establish and persist and if that will meet ecosystem objectives. Too often, estimates of the likelihood of restoration success when using natives are overly optimistic and waste limited resources on efforts unlikely to succeed. Another difficult reality is that ecosystem objectives may be unattainable in some severely altered ecosystems (Davies et al., 2021), but this needs to be acknowledged so that resources can be focused where they can make a difference. In the following sections, we will highlight the need for considering introduced plants in restoration by discussing realistic ecosystem goals focused on the needs of society and addressing difficult realities based on the likelihood of native plant establishment. We recognize that using introduced species to achieve some desired outcome is not a novel concept and has had some serious ecosystem consequences (e.g., D'Antonio and Vitousek. 1992; van Klinken et al., 2006; Ellsworth et al., 2015). However, prior decisions to use introduced species have often been made in a vacuum, where only one interested parties' needs were considered, often at the expense of other parties' interests.

The idea that introduced species may have a role in conservation is not new (see Sagoff, 2005; Davis et al., 2011). There is disagreement, however, over the impact of introduced species with some (Sagoff, 2005; Davis et al., 2011) arguing that they typically increase species richness, rarely have negative impacts, and what negative impacts they have are at times exaggerated. While others (Simberloff, 2005; Simberloff , 2011) argued that introduced species threaten the environment and in some locales, as well as globally, decrease biodiversity. These contrasting views highlight the controversy surrounding introduced species, however, the need for restoration of vast areas of degraded drylands and high rates of failures with native plants suggest restoration efforts should focus on achieving ecosystem goals which may at times be achieved with introduced plants. We are proposing that restoration practitioners consider using introduced species in restoration efforts to meet ecosystem goals that are unlikely to be achieved with just native species and where introduced species pose little risk of further land degradation.

2. Establish ecosystem goals

The establishment of ecosystem goals should be the starting point for restoration planning efforts instead of the origins of plant species to be used. Restoration efforts may be improved if they focus on producing goods and services deemed important for society (wildlife habitat, soil stability, biodiversity, forage production, carbon sequestration and storage, etc.). Then potential restoration actions can be evaluated and compared based on their likelihood of achieving these ecosystem goals. The more specific and measurable the goals are, the easier it will be to select the appropriate restoration actions as well as evaluate restoration success.

Desired ecosystem goods and services need to be identified in conjunction with other interested parties (e.g., indigenous communities, governments, recreationists, environmental groups, livestock producers, wildlife enthusiasts, etc.). Buy-in by interested parties is essential for establishing the opportunities, momentum, and resources necessary for restoration projects. Accounting for sociological components of restoration is vital for community support of restoration plans (Choi et al., 2008). This can be particularly important for restoration projects that span multiple landownerships because what occurs on one property likely affects adjacent properties. The barriers to achieving the desired future state need to be carefully considered to evaluate the probability of success and to set realistic expectations. Unrealistic goals are counter-productive, and often lead to misuse of limited resources and disappointment among partners. This is why it is so critical that the potential for success with using native plants and the potential risk of using introduced plants are carefully evaluated prior to implementation of restoration endeavors.

Establishing ecosystem goals for restoration is a complex issue and requires careful consideration of numerous factors. It is even more daunting when considering that restoration is needed in areas that are fundamentally different than the recent past and are continuing to change with climate change and further degradation. For more information on developing ecosystem restoration goals see Ehrenfeld (2000), Hobbs (2007), Choi et al. (2008), and Hallet et al. (2013).

3. Selecting plant materials for restoration

Once ecosystem goals have been established then appropriate plant materials need to be selected for restoration efforts. Before using native plant species in a restoration project several questions need to be answered (Fig. 1) through published literature, expert opinion, and restoration experience. First, are there native plants that are adapted to the site's current climate and disturbance regime? Will these species persist under expected climate change, associated alterations to disturbances, and pressure from invasive species? Will restoration of these native plants provide the desired ecosystem goods and services? What is the likelihood of success with these native species? If the likelihood of success with natives is extremely low or the answer to any of the three prior questions is no, then we would not advise using native plant species alone. If the answers are yes for some native species that fill some of the functional roles needed to meet ecosystem goals but no for others, we recommend considering if a mix of native and introduced species may achieve the desired ecosystem outcome. This has been done in the Great Basin in locations where native bunchgrasses are unlikely to establish. Introduced wheatgrasses are seeded and then the native shrub sagebrush can be seeded or planted into these communities to create introduced wheatgrass-sagebrush communities that provide greater ecosystem goods and services than introduced grasslands (Davies et al., 2013; Davies et al., 2020). The same questions asked about native species need to be asked with introduced plants as well as considering if the risk with using introduced species is acceptable. Determining if the risk from using introduced species to the ecosystem is acceptable or unacceptable will not be an easy decision and is likely somewhat subjective. Hence, further research investigating the potential for introduced species to be used in the restoration context, in particular to develop quantitative measurements to determine the risk of introduced species causing ecological damage, is critically needed. We recommend considering the consequences of not restoring ecosystem goods and services with the potential risk posed by the introduced species as well as including all stakeholders and interested parties in the decision process. This will ensure that restoration is focused on restoring desired ecosystem goods and services, and will be more likely to succeed.

4. The hard truth

Achieving idealistic restoration goals may not be possible or desirable under current conditions in some ecosystems (Alexandra, 2022). Climate change, increasing atmospheric CO_2, species globalization, and altered disturbance regimes are rapidly changing drylands and altering what plant species can establish and persist (Walther et al., 2009; Butterfield et al., 2017; Weiskoph et al., 2020). At times, this may mean that the current or recently lost plant community may be an artifact of prior conditions. Attempting to restore an artifact community is highly likely to fail (Jones et al., 2015; Kane et al., 2017). These communities are likely lost, and this needs to be accepted because restoration resources are too limited to waste on futile efforts. We, the restoration ecology community, likely needs to move passed the idea that natives or locally-sourced natives are best adapted to these fundamentally altered sites; these sites may no longer reflect the environment that selected these plants' characteristics, i.e., native species may not be adapted to establish and persist in these altered environments (Walther et al., 2009). Restoration of these communities will require focusing on plant species that will establish and persist under the current and projected site characteristics (Butterfield et al., 2017) and provide the ecosystem goods and services desired (Davies et al., 2021). This may include using species that are native to the region, but not native to the specific location through assisted migration (Butterfield et al., 2017), though assisted migration has the same risks as the introduction of non-native species (Dunwiddie and Rogers, 2017), cultivars selected for these environments, introduced species, or some combination of these groups.

5. The future

Restoration is needed in many drylands and scientific advancements can increase the success with native plant species (Davies et al., 2021); however, this will likely not be enough to restore ecosystem goods and services everywhere needed because of fundamental changes to the environment (Walther et al., 2009). Native species should be used in restoration efforts where they can be successful; however, we, the restoration ecology community, need to be more realistic and flexible in our restoration efforts. The vast areas already degraded and at risk of being degraded from climate change, altered disturbance regimes, and invasive species (Abhilash, 2021), suggests that restoration practitioners will need the option of using either native, introduced, or combinations of native and introduced species as long as restoration actions cause no further environmental damage. This is not to dismiss that some introduced species may have major effects on biodiversity, ecosystem structure, and ecosystem function. Introduced species, as a whole, may be more likely than native species to become problematic invaders that cause environmental and economic damage (Simberloff, 2005; Simberloff et al., 2013; Paolucci et al., 2013). However, not all introduced species are going to have severe negative impacts (Davis et al., 2011). Introduced plants can serve an important role in restoring ecosystem goods and services (Ewel et al., 1999; Walther et al., 2009), particularly in communities where native species are unlikely to succeed. At the same time, it is critical to continue to conduct research to improve restoration success with native plants. Meaningful restoration of ecosystem goods and services at scales that will offset and reverse the current rates of dryland degradation will likely require the use of both native and introduced plant species.

CRediT authorship contribution statement

Dustin D. Johnson: Writing – original draft. **Kirk Davies:** Writing – review & editing, Writing – original draft, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Data Availability

No data was used for the research described in the article.

References

Abhilash, P.C., 2021. Restoring the unrestored: strategies for restoring global land during the UN decade on ecosystem restoration (UN-DER). Land 10, 201.
Alexandra, J., 2022. Designer ecosystems for the Anthropocene-deliberately creating novel ecosystems in cultural landscapes. Sustainability 14, 3952.
Butterfield, B.J., Copeland, S.M., Munson, S.M., Roybal, C.M., Wood, T.E., 2017. Prestoration: using species in restoration that will persist now and into the future. Restor. Ecol. 25, S115–S163.

Chivers, I.H., Jones, T.A., Broadhurst, L.M., Mott, I.W., Larson, S.R., 2016. The merits of artificial selection for the development of restoration-ready plant materials of native perennial grasses. Restor. Ecol. 24, 174–183.
Choi, Y.D., Temperton, V.M., Allen, E.B., Grootjans, A.P., Halassy, M., Hobbs, R.J., Naeth, M.A., Torok, K., 2008. Ecological restoration for future sustainability in a changing environment. Ecoscience 15, 53–64.
D'Antonio, C.M., Vitousek, P.M., 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annu. Rev. Ecol. Syst. 23, 63–87.
Davies, K.W., Boyd, C.S., Nafus, A.M., 2013. Restoring the sagebrush component in crested wheatgrass-dominated communities. Rangel. Ecol. Manag. 66, 472–478.
Davies, K.W., Boyd, C.S., Bates, J.D., Hamerlynck, E.P., Copeland, S.M., 2020. Restoration of sagebrush in crested wheatgrass communities: a longer-term evaluation in the northern Great Basin. Rangel. Ecol. Manag. 73, 1–8.
Davies, K.W., Boyd, C.S., Madsen, M.D., Kerby, J., Hulet, A., 2018. Evaluating a seed technology for sagebrush restoration efforts across an elevation gradient: support for bet hedging. Rangel. Ecol. Manag. 71, 19–24.
Davies, K.W., Leger, E.A., Boyd, C.S., Hallett, L.M., 2021. Living with exotic annual grasses in the sagebrush ecosystem. J. Environ. Manag. 288, 112417.
Davis, M., Chew, M.K., Hobbs, R.J., Lugo, A.E., Ewel, J.J., Vermeij, B.J., Brown, J.H., Rosenzweig, M.L., Gardener, M.R., Carroll, S.P., Thompson, K., Pickett, S.T.A., Stromberg, J.C., Tredici, P.D., Suding, K.N., Ehrenfeld, J.G., Grimes, J.P., Mascaro, J., Briggs, J.C., 2011. Don't judge species on their origins. Nature 474, 153–154.
Davis, M.A., Thompson, K., 2000. Eight ways to be a colonizer; two ways to be an invader: a proposed nomenclature scheme for invasion ecology. Bull. Ecol. Soc. 81, 226–230.
Dunwiddie, R.W., Rogers, D.L., 2017. Rare species and aliens: reconsidering non-native plants in the management of natural areas. Restor. Ecol. 25, S164–S169.
Ehrenfeld, J.G., 2000. Defining the limits of restoration: the need for realistic goals. Restor. Ecol. 8, 2–9.
Ellsworth, L.M., Litton, C.M., Leary, J.J.K., 2015. Restoration impacts on fuels and fire potential in a dryland tropical ecosystem dominated by the invasive grass *Megathyrsus maximus*. Restor. Ecol. 23, 955–963.
Ellsworth, L.M., Litton, C.M., Dale, A.P., Miura, T., 2014. Invasive grasses change landscape structure and fire behavior in Hawaii. Appl. Veg. Sci. 17, 680–689.
Espeland, E.K., Emery, N.C., Mercer, K.L., Woolbright, S.A., Kettenring, K.N., Gepts, P., Etterson, J.R., 2017. Evolution of plant materials for ecological restoration: insights from the applied and basic literature. J. Appl. Ecol. 54, 102–115.
Ewel, J.J., O'Dowd, D.J., Bergenson, J., Daehler, C.C., D'Antonio, C.M., Gómez, L.D., Gordon, D.R., Hobbs, R.J., Holt, A., Hopper, K.R., Hughes, C.E., LaHart, M., Leakey, R.R.B., Lee, W.G., Loope, L.L., Lorence, D.H., Louda, S.M., Lugo, A.E., McEvoy, P.B., Ricahrdson, D.M., Vitousek, P.M., 1999. Deliberate introductions of species: research needs. BioScience 49, 619–630.
Gérard, A., Goanzhorn, J.U., Kull, C.A., Carrière, S.M., 2015. Possible roles of introduced plants for native vertebrate conservation: the case of Madagascar. Restor. Ecol. 23, 768–775.
Gerwing, T.G., Hawkes, V.C., Murphy, S.D., 2023. Speaking the same language: aligning project designations to clarify communication in restoration ecology. Environ. Rev. 31, 498–508.
Hallet, L.M., Diver, S., Eitzel, M.V., Olson, J.J., Ramage, B.S., Sardinas, H., Statman-Weil, Z., Suding, K.N., 2013. Do we practice what we preach? Goal setting for ecological restoration. Restor. Ecol. 21, 312–319.
Hardegree, S.P., Abatzoglou, J.T., Brunson, M.W., Germino, M.J., Hegewisch, K.C., Moffet, C.A., Pilliod, D.S., Roundy, B.A., Boehm, A.R., Meredith, G.R., 2018. Weather-centric rangeland revegetation planning. Rangel. Ecol. Manag. 71, 1–11.
Hobbs, R.J., 2007. Setting effective and realistic restoration goals: key directions for research. Restor. Ecol. 15, 354–357.
Jones, T.A., Monaco, T.A., Rigby, C.W., 2015. The potential of novel native plant materials for the restoration of novel ecosystems. Elmenta 3, 000047.
Kane, K., Debinski, D.M., Anderson, C., Scasta, J.D., Engle, D.M., Miller, J.R., 2017. Using regional climate projections to guide grassland community restoration in the face of climate change. Front. Plant Sci. 8, 730.
van Klinken, R.D., Graham, J., Flack, L.K., 2006. Population ecology of hybrid mesquite (*Prosopis* spcies) in western Australia: how does it differ from native range invasions and what are the implications for impacts and management. Biol. Invasions 8, 727–741.
Lybbert, A.H., Cusser, S.J., Hung, K.J., Goodell, K., 2022. Ten-year trends reveal declining quality of seeded pollinator habitat in reclaimed mines regardless of seed mix diversity. Ecol. Appl. 32, e02467.
Martin, D.M., 2017. Ecological restoration should be redefined for the twenty-first century. Restor. Ecol. 25, 668–673.
Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Desertification Synthesis. World Resources Institute, Washington, DC.
Miller, J.R., Bestelmeyer, B.T., 2016. What's wrong with novel ecosystems, really? Restor. Ecol. 24, 577–582.
Paolucci, E.M., MacIsaac, H.J., Ricciardi, A., 2013. Origin matters: alien consumers inflict greater damage on prey populations than do native consumers. Divers. Distrib. 19, 988–995.
Pizza, R., Espeland, E., Etterson, J., 2021. Eight generations of native seed cultivation reduces plant fitness relative to wild progenitor populations. Evolut. Appl. 14, 1816–1829.
Richardson, D.M., Pyšek, P., Rejmanek, M., Barbour, M.G., Panetta, F.D., West, C.J., 2000. Naturalization and invasion of alien plants: concepts and definitions. Divers. Distrib. 6, 93–107.
Sagoff, M., 2005. Do non-native species threaten the natural environment. J. Agric. Environ. Ethics 18, 215–236.
Schlaepfer, M.A., Sax, D.F., Olden, J.D., 2011. The potential conservation values of non-native species. Conserv. Biol. 25, 428–437.
Schröder, R., Prasse, G., 2013. From nursery into nature: a study on performance of cultivated varieties of native plants used in re-vegetation, their wild relatives and evolving wild x cultivar hybrids. Ecol. Eng. 60, 428–437.
Shackelford, N., Hobbs, R.J., Heller, N.E., Hallet, L.M., Seastedt, T.R., 2013. Finding a middle-ground: the native/non-native debate. Biol. Conserv. 158, 55–62.
Shackelford, N., Paterno, G.B., Winkler, D.E., Erickson, T.E., Leger, E.A., Svejcar, L.N., Breed, M.F., Faist, A.M., Harrison, P.A., Curran, M.F., Guo, Q., Kirmer, A., Law, D.J., Mganga, K.Z., Munson, S.M., Porensky, L.M., Quiroga, R.E., Török, P., Wainwright, C.E., Abdullahi, A., Bahm, M.A., Ballenger, E.A., Barger, N., Baughman, O.W., Becker, C., Lucas-Borja, M.E., Boyd, C.S., Burton, C.M., Burton, P.J., Calleja, E., Carrick, P.J., Caruana, A., Clements, C.D., Davies, K.W., Deák, B., Drake, J., Dullau, S., Eldridge, J., Espeland, E., Farrell, H.L., Fick, S.E., Garbowski, M., de la Riva, E.G., Golos, P.J., Grey, P.A., Heydenrych, B., Holmes, P.M., James, J.J., Jonas-Bratten, J., Kiss, R., Kramer, A.T., Larson, J.E., Lorite, J., Mayence, C.E., Merino-Martín, L., Miglécz, T., Milton, S.J., Monaco, T. A., Montalvo, A.M., Navarro-Cano, J.A., Paschke, M.W., Peri, P.L., Pokorny, M.L., Rinella, M.J., Saayman, N., Schantz, M.C., Parkhurst, T., Seabloom, E.W., Stuble, K.L., Uselman, S.M., Valkó, O., Veblen, K., Wilson, S., Wong, M., Xu, Z., Suding, K.L., 2021. Drivers of seedling establishment success in dryland restoration efforts. Nat. Ecol. Evol. 5, 1283–1290.
Simberloff, D., 2005. Non-native species do threaten the natural environment. J. Agric. Environ. Ethics 18, 595–607.
Simberloff, D. and 141 others. 2011. Non-Natives: 141 scientist object. Nature 475:36.
Simberloff, D., Martin, J., Genovesi, P., Maris, V., Wardle, D.A., Aronson, J., Courchamp, F., Galil, B., García-Berthou, E., Pascal, M., Pyšek, P., Sousa, R., Tabacchi, E., Vilá, M., 2013. Impacts of biological invasions: what's what and the way forward. Trends Ecol. Evol. 28, 58–66.
Sogge, M.K., Paxton, E.H., Tudor, A.A., 2006. Saltcedar and southwestern willow flycatchers: lessons from long-term studies in central Arizona. In: Aguirre-Bravo, C., Pellicane, P.J., Burns, D.P., Draggan, S. (Eds.), Proceedings: Monitoring Science and Technology Symposium: Unifying Knowledge for Sustainability in the Western Hemisphere. RMRS-P-42CD. USDA-Forest Service, Rocky Mountain Research Station, Fort Collins, CO, pp. 238–241.
Stein, C., Hallet, L.M., Harpole, W.S., Suding, K.N., 2014. Evaluating ecosystem services provided by non-native species: an experimental test in California grasslands. PLoS One 9, e75396.
Svejcar, T., Boyd, C., Davies, K.W., Hamerlynck, E., Svejcar, L., 2017. Challenges and limitations to native species restoration in the Great Basin, USA. Plant Ecol. 218, 81–94.
Svejcar, L.N., Davies, K.W., Ritchie, A., 2023. Ecological restoration in the age of apocalypse. Glob. Change Biol. 29, 4706–4710.
Trigger, D., Mulcock, J., Gaynor, A., Toussaint, Y., 2008. Ecological restoration, cultural preferences, and the negotiation of 'nativeness' in Australia. Geoforum 39, 1273–1283.

Walther, G., Roques, A., Hulme, P.E., Sykes, M.T., Pyšek, P., Kühn, I., Zobel, M., 2009. Alien species in a warmer world: risks and opportunities. Trends Ecol. Evol. 24, 686–693.
Weiskoph, S.R., Rubenstein, N.A., Crozier, L.G., Gaichas, S., Griffs, R., Halofsky, J.H., Hyde, K.J.W., Morelli, T.L., Morisette, J.T., Muñoz, R.C., Pershing, A.J., Peterson, D.L., Poudel, R., Staudinger, M.D., Sutton-Grier, A.E., Thompshon, L., Vose, J., Weltzin, J.F., Whyte, K.P., 2020. Climate change effects on biodiversity, ecosystems, ecosystem services, and natural resource management in the United States. Sci. Total Environ. 733, 137782.
Williams, D.G., Baruch, Z., 2000. African grass invasion in the Americas: ecosystem consequences and the role of ecophysiology. Biol. Invasions 2, 123–140.