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OPINION ARTICLE

Patterning ecological restoration after weeds

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The United Nations Decade on Ecosystem Restoration aims to prevent, halt, and reverse the degradation of ecosystems on every continent. Disturbances stemming from anthropogenic or natural causes make plant community restoration challenging. The introduction of fast-growing weeds that generate high biomass and produce copious seed is most threatening to plant communities. A paradigm shift in ecosystem restoration is needed that emphasizes traits and affected ecological processes similar to weeds. The repeated introduction of seed from native plants with weedy characteristics follows the propagule pressure and evolution of invasiveness hypotheses. In targeting areas with heavy weed populations, native plants could establish and more successfully develop into functioning plant communities.

Key words: annual grasses, community ecology theory, functional traits, invasive plants, management, seeding, woody plant expansion

Implications for Practice

- Weeds can have problematic and beneficial aspects depending on the context.
- Utilizing the beneficial aspects in restoration will require a paradigm shift in the approach taken by restoration practitioners, researchers, and native plant breeders and suppliers.
- By giving more attention to the beneficial aspects of weeds, practitioners can achieve greater success in restoration efforts.

Introduction

One of the principles for ecosystem restoration identified by the United Nations Decade on Ecosystem Restoration, 2021–2030 is to achieve a high level of recovery depending on the level of degradation. The goal is to sustain biodiversity, ecosystem health and integrity, ecosystem goods and services, climate-change mitigation, and human health and well-being at local, national, and global scales without replacing nature conservation, especially in areas with high ecological integrity and high value for ensuring ecological connectivity, as well as in other priority areas for conservation, including those within the territories of indigenous peoples and traditional communities. Management practices intended to be restorative should support and assist natural recovery processes and not cause further degradation. We focus on restorative or nature-based practices that support our core idea of modeling ecosystem restoration after weeds, which is simply to "take a page out of their own playbook."

Distribution of Weeds

Worldwide, weeds, heretofore including invasive and non-native plants, have been a focus addressed by many restoration efforts. Monocultures created by weeds have left lasting legacies through the inhibition and, in some cases, the elimination of native plant communities. The altered composition has changed the structure and resulting function of plant communities that has negatively affected basic ecological processes, such as hydrological cycles, fire regimes, and plant–soil feedbacks, and natural habitats that support wildlife, livestock, and multiple anthropogenic activities.

Weeds invade ecosystems without regard for geography or abiotic condition. The humid tropics harbor fast-growing herbaceous weeds, while perennial woody species, both those that readily establish from seed and those that rapidly propagate vegetatively, are considered weeds in temperate grasslands. Weeds can be found even in the harshest conditions, such as high elevation alpine forests and dry deserts. Over time, locations that were once considered uninhabitable are now being invaded by weeds

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due in part to anthropogenic activity and more recently, climate change.

Weeds take advantage of niches that naturally occur or are created within plant communities. Perennial bunchgrasses grow as individual plants spaced across landscapes. The openings within these native plant communities are natural and necessary for maintaining species health and supporting mesofauna complexes. In other systems that have average to high amounts of precipitation and Mediterranean or warmer temperatures, continuous canopy cover is common for plant communities. In both systems, disturbance events caused by changes in weather patterns, herbivore browsing, or human activities can expand naturally occurring niches as well as create new openings, thus allowing for weeds to invade and become established (Kolar & Lodge 2001).

Once weeds have established, expansion can occur quickly or be delayed for years. For the relatively small number of invasive plants that actually become established (e.g. roughly 10%, as suggested by Williamson 1999), the invasion process includes an exponential increase in individuals (rapid population increase), the establishment of monotypic stands with limited or no diversity (established local dominance), and dispersal from population(s) occurring in transition/disturbance-mediated areas affected by, e.g. humans, animals, wind, or water (rapid range expansion) (Gurevitch et al. 2011).

Weed Characteristics

The traits of weeds allow for successful invasion and establishment in native plant communities. The most aggressive weeds have three primary characteristics: rapid growth, high biomass, and seed production (Sutherland 2004). Weeds effectively compete for light and moisture aboveground and alter belowground microbial communities and nutrient cycles in ways that are different from native plants. Leaf area, growth rate, and leaf nutrient concentration are significantly higher in weeds compared to native plants and these traits, in particular, increase rates of litter decomposition and nutrient cycling (Allison & Vitousek 2004). Weeds often increase carbon inputs into the ecosystem as a result of greater primary productivity and thus alter processes governing carbon and nutrient cycles (Wolfe & Klironomos 2005).

Increasingly, weeds have contributed to the detriment of wildlife, eliminated native plants through intense competition, and reduced the viability of sustainable production systems (Doren et al. 2009). Weed establishment in these ecosystems can significantly alter ecosystem composition, structure, and resulting function. These impacts can occur at scales ranging from individual plant communities to watersheds to biomes with the common characteristics of rapid growth leading to high biomass and/or seed production.

Two common goals of restoration efforts are the establishment of native plant communities and the reduction or elimination of weeds. The traits common in the most aggressive and prolific weeds could be the answer to what is needed by their native counterparts in helping practitioners achieve restoration success. The first steps in a restoration paradigm shift include both short-term (massive introductions) and long-term (aggressive native plant breeding) approaches.

Application: Seeding and Breeding

Many models have been developed to demonstrate the process by which weeds establish, which is an appropriate application to native plants. If native plant propagules were thought of like weeds, seed would be continuously transported and deposited, except within and not outside of the native plant's home range. The location, when favorable for germination and recruitment, would allow for native plant expansion to occur over years or decades. In essence, restoration by repeatedly seeding native plants mimics the propagule pressure hypothesis, where a large input of seeds enhances the probability of overcoming the potential for failed establishment due to demographic, environmental, or genetic stochasticity of a location (Balestri et al. 2018).

By repeatedly adding large amounts of native seed to the soil in high enough quantities, populations can be created that are dense enough to outcompete and suppress weeds (Wilson 2015). Few practical examples of the excessive seeding approach exist, which may be due to (over) confidence in single-pass attempts or reliance on traditionally slow and steady growth by native plants. The cost of native seed can also be prohibitive in using an "excessive" amount. Land managers operate with limited budgets that must cover all restoration expenses, including seed, and using more than what is recommended by seed dealers and supported by traditional research could be viewed as unnecessary and wasteful.

In addition to practical challenges, other variables affect successful restoration. Weather is most often a limiting factor in restoration, especially in arid regions with infrequent precipitation and high summer temperatures. Competition from weeds is another important factor that leads to unsuccessful restoration, especially long-term. Seed placement, germination, and granivorous animals are added challenges that can lead to unsuccessful restoration. However, many of the known reasons for failure in establishing native plants can be addressed by repeated seeding, just like weeds.

The breeding of plants for harsh conditions allows for plant communities to not only tolerate drought and heat, but better withstand weed invasion. The most common desirable traits of early emergence, rapid growth, and high reproductivity in developing new native plant cultivars are the same as those found in weeds. An example is the exotic perennial bunchgrass, crested wheatgrass, which is capable of outcompeting weedy invasive annual grasses and can be used as a guide to select and develop native grass material that can go toe-to-toe with invasive annual grasses. Looking for other such "benchmark" plant species could help develop material in other ecosystems. In addition to aggressive plant breeding, development is needed for smarter, more rapid plant material selection tools.

Recent research using high-throughput genomics to develop predictive plant trait models shows considerable promise in rapidly accelerating selection and increasing the effectiveness of native plant materials (Jones et al. 2022). Such efforts need to be broadened, as traditional plant breeding approaches often fail

to release plant materials possessing the actual trait functionality needed to successfully restore degraded ecosystems (Garbowski et al. 2021). An important and critical caveat is that genetic variation must exist within (native) plant species to be able to select for the desired trait(s) and the stability of gene expression conferring the trait must be independent of the environment (i.e. G × E interactions) (Pozniak et al. 2022). Native plants bred to have invasive characteristics can be beneficial and detrimental. A faster emerging and more rapidly growing native plant has a greater chance of establishing and outcompeting weeds. Dense populations of quickly established native plants can stabilize soils prone to erosion by wind and water. Native plants provide habitat for wildlife to use in meeting the requirements for forage, protection, and nesting. However, instances of native plants becoming weeds, while few, do exist and present distinct effects on ecosystem structure and function, not to mention challenges in their management that should be considered when using weeds as models to follow in restoration.

Conclusions

Several approaches exist for restoring native plant communities that include the suppression of weeds. The most desirable are nature-based and rely on natural ecosystems and the delivery of environmental and societal benefits, which align with the United Nations Decade on Ecosystem Restoration, 2021–2030. The main approach of massive introductions and aggressive breeding of native plants to improve establishment success in weed-infested sites could help change current restoration practices to better mimic the processes that are already naturally occurring. Moreover, such an approach is more likely to restore the balance between the positive and negative species interactions underlying plant community resilience and resistance.

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