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Emerging approaches to successful ecological restoration: five imperatives to guide innovation

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As the science of restoration ecology and the practice of habitat restoration adapt to new sets of goals in a changing climate, we turn our attention to novel techniques and emerging approaches in the field. This special issue brings together eight papers that answer the question, "Given that we have defined our goals, can we find better ways to reach them?" From them, we derive five directives for ecologists and practitioners seeking to innovate with new methods, analyses, or applications: (1) ground the approach in ecological theory; (2) take advantage of the latest technology and models; (3) reject dogma; (4) subject the analysis to critique; and (5) be aware of time, budget, and expertise constraints faced by stakeholders and practitioners. Our five imperatives are illustrated by examples of papers from the special issue.

Key words: application, knowing-doing gap, land manager, method, practitioner, stakeholder, technique, theory

Implications for Practice

- Technological advances, a shift in restoration goals toward resilience and dynamism, and the need for efficient resource use have combined to create space for new techniques and approaches in ecological restoration.
- New methods will be most successful if they are grounded in ecological theory, adaptable in the face of setbacks and critiques, and sensitive to the constraints on managers' time, funds, and capacities.

Restoration ecology is a young discipline. Land management with restoration aims did not begin in earnest until the 1970s (Jordan & Lubick 2011); the Society for Ecological Restoration was founded in 1987; and the journal *Restoration Ecology* is less than a quarter-century old. The discipline is so young, and so unsure of itself, that only a decade ago, the flagship journal in the field could publish the article "Habitat restoration—Do we know what we're doing?" (Miller & Hobbs 2007)—and have it cited more than 200 times.

As befits a maturing discipline, there have been many papers over the years that question the directions the field is going, as well as periodic calls for new paradigms (Hobbs & Harris 2001; Choi 2007; Brudvig 2011; Shackelford et al. 2013; Perring et al. 2015; Martin 2017). In particular, the intradisciplinary handwringing has centered on questions of restoration goals: not only the need to be clear about defining goals, but more recently, the question of whether current goals are the right ones (Hobbs & Norton 1996; Ehrenfeld 2000; Hallett et al. 2013; Suding et al. 2015). Much of the recent debate has revolved around how future- or past-focused restoration should be: should restoration attempt to recreate—to the extent possible—the historic species assemblage in an area? Or should restoration create an ecosystem that will be functional and dynamic in the future, but not necessarily true to its origins (Harris et al. 2006; Choi 2007; Morse et al. 2014; Murcia et al. 2014)?

In this paper, we leave the question of restoration *goals* for managers to determine, and instead articulate a vision for developing new restoration *techniques*. This special issue of *Restoration Ecology* brings together eight disparate papers detailing novel approaches and analyses that will advance restoration goals in new ways. In other words, the authors featured here are all answering the question, "Given that we know what our goals are for this system—is there a better way to get there?"

Considering these papers as a group, we notice several themes that repeatedly emerge from the authors' embrace of new methods. In our view, truly innovative and useful approaches to restoration obey these five imperatives:

(1) They are driven by ecological theory.
(2) They harness technological advances.
(3) They reject dogma.
(4) They encourage self-critique.
(5) They respect stakeholder and practitioner limitations.

Here, we expand on these five imperatives and illustrate them with articles featured in the special issue. It is important to note that none of the individual articles represents the "last word" on how to do restoration in any particular system; nor is it necessarily the first time that these ideas have been articulated

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in the literature. We hope the reader will take inspiration from the entirety of the group of papers, as a first step in designing and refining future approaches to advance the field.

Driven by Ecological Theory

Although restoration techniques are fundamentally a facet of applied science, they should be thoroughly grounded in theory (Palmer et al. 1997; Wainwright et al. 2017). Young et al. (2017) drew heavily on community assembly theory, and the extensive ecological literature on priority effects in succession, in designing an experiment that manipulates priority as a restoration tool. Working in California grasslands, Young and colleagues gave a head start of as little as 2 weeks to native grasses and forbs over their competitors. They found that priority effects, though possibly short-lived, had profound impacts on the structure of grasslands communities, and generally favored the early arrivals, as predicted from theory.

In an agenda-setting paper tackling the thorny problem of dryland restoration, Hulvey et al. (2017) examine a technique with deep roots in ecological theory: restoration islands. The idea that restoration can take the form of planted or seeded vegetation islands that will "nucleate" to disperse propagules relies on the concept of ecological filters (Diaz et al. 1998) and owes a debt to the theory of island biogeography (MacArthur & Wilson 1967), as well as to facilitation and the nurse-plant concept (Callaway & Walker 1997; Bruno et al. 2003). Nucleation approaches have been highly successful in the tropics (Holl et al. 2011); in evaluating their potential in dryland systems, Hulvey and colleagues think ecologically about how islands work and how the technique might need to be adapted.

Laughlin et al. (2017), writing about trait-based models that can create novel species assemblages in restoration settings, see the ecological information going both ways: informing theory, and being informed by it. First, observation of the distribution of traits in naturally assembled communities helps guide the assembly of novel communities—that is a restoration goal. But in return, restoration sites where these communities are established are the testing ground for better understanding how interactions with the environment drive organisms' fitness.

Harnessing Technological Advances

In its early days, the practice of ecological restoration was sometimes dismissed as "glorified gardening" (Jordan et al. 1990). Emphasizing the theoretical basis underlying practice can help restoration ecology, as a discipline, to rise above that moniker (Weiher 2007). But so can a commitment to employing all the technological tools available to us. Advances in computing power and miniaturization have revolutionized every scientific field; restoration ecology has no reason to be limited to antediluvian approaches.

Remotely sensed data from Light Detection and Ranging (LIDAR), combined with sophisticated digital mapping, helped a group of Hawaii-based scientists make recommendations for where managers should pinpoint restoration activities at the Pohakuloa Training Area (Cordell et al. 2017). Understanding the interplay of topography and vegetation at the landscape scale, the team was able to identify areas with the highest suitability for reintroduction of rare or endangered plants, as well as where to locate greenbelts of native vegetation to decrease fuel load and reduce fire risk. In addition to presenting a useful case study, the paper serves as a lucid introduction to remotely sensed datasets for the uninitiated, with guidelines for how different sensors and platforms can be adapted to restoration challenges.

In Butterfield et al. (2017)'s "prestoration" approach, the power of ecological niche models (Peterson 2003) is utilized for choosing species palettes that are present now *and* are resilient enough to persist into the future. Using grasslands of the Colorado Plateau (U.S.A.) as a case study, they came to the unsettling result that sticking to the expert-recommended suite of native species would result in nearly half the habitat being lost within 80 years. By working with the latest and most powerful climate models, restoration ecologists can not only predict the right targets under future climates, but they can adaptively manage the process of species introductions as models become updated with more current information. The power of these computer simulations was unimaginable in the 1970s and 1980s, but today should be part of the everyday toolkit.

Rejecting Dogma

We define "dogma" here as restoration principles that are generally regarded as true, but that should not be slavishly obeyed. As one paper puts it, "Making prudent decisions … must start with challenging ourselves to question long-held perspectives" (Dunwiddie & Rogers 2017). This paper takes on the prescription to always use native species in restoration. Instead of a black-and-white world where natives are good and non-natives bad, Dunwiddie and Rogers see a spectrum of actions that range from merely tolerating hard-to-eradicate non-natives to actively introducing exotics for conservation purposes—or even creating a new "exotic" invasion through assisted migration. Examples range from the peaceful coexistence of invasive Mediterranean annuals and native giant kangaroo rats (*Dipodomys ingens*) in the western United States, to the possibility of moving Brewer spruce (*Picea breweriana*) outside its current range. Others have made a similar argument (e.g. Ewel & Putz 2004), but in presenting a range of examples that have already been implemented, the authors are highlighting the contribution of practitioners who do not adhere strictly to dogma in the service of restoration and conservation.

Meanwhile, Butterfield et al. (2017) reject the mantra of "local is best." They focus on ecosystem structure and function rather than the historic species assemblage. Looking to the future, when some local species will not be able to persist, their method identifies species that can fill functional and structural gaps and be resilient to future climate changes. And if there is gene flow from species adapted to warmer/drier climates into the local population? To their way of thinking, that is a feature, not a bug.

Encouraging Self-Critique

Science by its nature is self-critiquing and self-correcting. In seeking to test and adopt new restoration techniques, the discipline should require a healthy attitude of skepticism about its own practices, as well as a high standard for proof of concept. All the papers in this issue exemplify self-critique, from Laughlin et al. (2017) checking to see if trait-based models can adequately predict the past before trying them out on the future, to Young et al. (2017) presenting caveats about the long-term persistence of priority effects. But here we will first highlight the unusual approach taken in the paper by Corbin et al. (2017). This paper was a postmortem on a failed effort to control garlic mustard (*Alliaria petiolata*) along roadsides in a park. Corbin et al. (2017) did a retrospective analysis of this project to see if, in hindsight, its goals were achievable in the first place. They employed two decision analysis tools, IPMDAT and Weed-Search, neither of which was available at the time the project was started. In addition to discovering that the control effort was probably doomed from the start, the authors found that manipulating the decision tools made clear which factors most influenced the probability of success—e.g. the ability to detect 100% of adult plants at the time of control. This willingness to dig into a failed effort and learn from it is at the heart of the scientific endeavor, as well as the basis for adaptive management.

Respecting Stakeholder and Practitioner Limitations

There is a long-lamented gap between the cultures of academia and land management (Cabin 2007; Hulme 2011; Matzek et al. 2015) or between the "knowing" and "doing" sides of restoration (Gonzalo-Turpin et al. 2008; Dickens & Suding 2013). We were struck, reading these eight papers, at how often we saw evidence of deep understanding of, and sympathy with, the resource limitations and practical needs of land managers. One major goal of the new approaches was to maximize resource efficiency: focusing intensive efforts on a limited space (Hulvey et al. 2017), optimizing interventions for particular areas of the landscape (Cordell et al. 2017), seeking species assemblages that have the most long-term value (Butterfield et al. 2017; Laughlin et al. 2017). The paper by Schelfhout et al. (2017), which concerns *Nardus* grasslands in Belgium, creates a decision tool for managers to assess the most appropriate method of depleting P levels in these overfertilized grasslands. Having found that the current practice (haymaking) would require decades to bring P levels down to normal, the authors present a decision tree that allows managers to decide on the best approach in the context of their own budget and time constraints.

Another theme was restoring multifunctional landscapes with benefits to multiple stakeholders. For instance, the Cordell et al. (2017) paper focused on balancing the use of reserve landscapes by hunters with the need to restore and protect rare plants. The Schelfhout et al. (2017) contribution takes account of the balance between biodiversity and agricultural productivity. As further evidence of concern for practitioner needs, some authors were careful to point out where new approaches risked running ahead of managers' expertise or being blocked by structural constraints. Butterfield et al. (2017) warn that niche models are unlikely to be implemented by land managers without an academic partnership, and Dunwiddie and Rogers (2017) recognize that some government agencies, such as the U.S. Forest Service, forbid introduction of species from off-site.

In conclusion, these five imperatives can serve as a guide for those who would innovate a new restoration approach: let theory be the starting point; embrace powerful statistical models and technological advances; forget about dogma when a resilient solution is at hand; relentlessly subject the method to critique; and acknowledge both the values as well as the institutional and budgetary limits of the on-ground practitioner. With those guidelines firmly in view, the practice of ecological restoration can adaptively manage its own future.

LITERATURE CITED

Brudvig LA (2011) The restoration of biodiversity: where has research been and where does it need to go? American Journal of Botany 98:549–558

Bruno JF, Stachowicz JJ, Bertness MD (2003) Inclusion of facilitation into ecological theory. Trends in Ecology & Evolution 18:119–125

Butterfield BJ, Copeland SM, Munson SM, Roybal CM, Wood TE (2017) Prestoration: using species in restoration that will persist now and into the future. Restoration Ecology 25:S155–S163

Cabin RJ (2007) Science-driven restoration: a square grid on a round earth? Restoration Ecology 15:1–7

Callaway RM, Walker LR (1997) Competition and facilitation: a synthetic approach to interactions in plant communities. Ecology 78:1958–1965

Choi YD (2007) Restoration ecology to the future: a call for new paradigm. Restoration Ecology 15:351–353

Corbin JD, Wolford M, Zimmerman CL, Quirion B (2017) Assessing feasibility in invasive plant management: a retrospective analysis of garlic mustard (*Alliaria petiolata*) control. Restoration Ecology 25:S170–S177

Cordell S, Questad EJ, Asner GP, Kinney KM, Thaxton JM, Uowolo A, Brooks S, Chynoweth MW (2017) Remote sensing for restoration planning: how the big picture can inform stakeholders. Restoration Ecology 25:S147–S154

Diaz S, Cabido M, Casanoves F (1998) Plant functional traits and environmental filters at a regional scale. Journal of Vegetation Science 9:113–122

Dickens SJM, Suding KN (2013) Spanning the science-practice divide: why restoration scientists need to be more involved with practice. Ecological Restoration 31:134–140

Dunwiddie PW, Rogers DL (2017) Rare species and aliens: reconsidering non-native plants in the management of natural areas. Restoration Ecology 25:S164–S169

Ehrenfeld JG (2000) Defining the limits of restoration: the need for realistic goals. Restoration Ecology 8:2–9

Ewel JJ, Putz FE (2004) A place for alien species in ecosystem restoration. Frontiers in Ecology and the Environment 2:354–360

Gonzalo-Turpin H, Couix N, Hazard L (2008) Rethinking partnerships with the aim of producing knowledge with practical relevance: a case study in the field of ecological restoration. Ecology and Society 13(2):53. [online] http://www.ecologyandsociety.org/vol13/iss2/art53/

Hallett LM, Diver S, Eitzel MV, Olson JJ, Ramage BS, Sardinas H, Statman-Weil Z, Suding KN (2013) Do we practice what we preach? Goal setting for ecological restoration. Restoration Ecology 21:312–319

Harris JA, Hobbs RJ, Higgs E, Aronson J (2006) Ecological restoration and global climate change. Restoration Ecology 14:170–176

Hobbs RJ, Harris JA (2001) Restoration ecology: repairing the earth's ecosystems in the new millennium. Restoration Ecology 9:239–246

Hobbs RJ, Norton DA (1996) Towards a conceptual framework for restoration ecology. Restoration Ecology 4:93–110

Holl KD, Zahawi RA, Cole RJ, Ostertag R, Cordell S (2011) Planting seedlings in tree islands versus plantations as a large-scale tropical forest restoration strategy. Restoration Ecology 19:470–479

Hulme P (2011) Bridging the knowing-doing gap: know-who, know-what, know-why, and know-when. Journal of Applied Ecology 51:1365–2664

Hulvey KB, Leger EA, Porensky LM, Roche LM, Veblen KE, Fund A, Shaw J, Gornish ES (2017) Restoration islands: a tool for efficiently restoring dryland ecosystems? Restoration Ecology 25:S124–S134

Jordan WR, Lubick GM (2011) Making nature whole: a history of ecological restoration. Island Press, Washington, D.C.

Jordan WR, Gilpin ME, Aber JD (1990) Restoration ecology: a synthetic approach to ecological research. Cambridge University Press, Cambridge

Laughlin DC, Strahan RT, Huffman DW, Sanchez Meador AJ (2017) Using trait-based ecology to restore resilient ecosystems: historical conditions and the future of montane forests in western North America. Restoration Ecology 25:S135–S146

MacArthur RH, Wilson EO (1967) The theory of island biogeography, Princeton University Press, Princeton, NJ

Martin DM (2017) Ecological restoration should be redefined for the twenty-first century. Restoration Ecology 25:668–673

Matzek V, Pujalet M, Cresci S (2015) What managers want from invasive species research versus what they get. Conservation Letters 8:33–40

Miller JR, Hobbs RJ (2007) Habitat restoration—do we know what we're doing? Restoration Ecology 15:382–390

Morse N, Pellissier P, Cianciola E, Brereton R, Sullivan M, Shonka N, Wheeler T, McDowell W (2014) Novel ecosystems in the Anthropocene: a revision of the novel ecosystem concept for pragmatic applications. Ecology and Society 19(2):12. http://dx.doi.org/10.5751/ES-06192-190212

Murcia C, Aronson J, Kattan GH, Moreno-Mateos D, Dixon K, Simberloff D (2014) A critique of the "novel ecosystem" concept. Trends in Ecology & Evolution 29:548–553

Palmer MA, Ambrose RF, Poff NL (1997) Ecological theory and community restoration ecology. Restoration Ecology 5:291–300

Perring MP, Standish RJ, Price JN, Craig MD, Erickson TE, Ruthrof KX, Whiteley AS, Valentine LE, Hobbs RJ (2015) Advances in restoration ecology: rising to the challenges of the coming decades. Ecosphere 6: 1–25

Peterson AT (2003) Predicting the geography of species' invasions via ecological niche modeling. The Quarterly Review of Biology 78:419–433

Schelfhout S, Mertens J, Perring MP, Raman M, Baeten L, Demey A, Reubens B, Oosterlynck S, Gibson-Roy P, Verheyen K (2017) P-removal for restoration of Nardus grasslands on former agricultural land: cutting traditions. Restoration Ecology 25:S178–S187

Shackelford N, Hobbs RJ, Burgar JM, Erickson TE, Fontaine JB, Laliberté E, Ramalho CE, Perring MP, Standish RJ (2013) Primed for change: developing ecological restoration for the 21st century. Restoration Ecology 21:297–304

Suding K, Higgs E, Palmer M, Callicott JB, Anderson CB, Baker M, Gutrich JJ, Hondula KL, LaFevor MC, Larson BM (2015) Committing to ecological restoration. Science 348:638–640

Wainwright CE, Staples TL, Charles LS, Flanagan TC, Lai HR, Loy X, Reynolds VA, Mayfield MM (2017) Links between community ecology theory and ecological restoration are on the rise. Journal of Applied Ecology 00:1–12. https://doi.org/10.1111/1365-2664.12975

Weiher E (2007) On the status of restoration science: obstacles and opportunities. Restoration Ecology 15:340–343

Young TP, Stuble KL, Balachowski JA, Werner CM (2017) Using priority effects to manipulate competitive relationships in restoration. Restoration Ecology 25:S114–S123

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