Title:

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

Running Head:

Five imperatives for innovative approaches

Authors:

Virginia Matzek, vmatzek@scu.edu, Dept of Environmental Studies and Sciences,
Santa Clara University, Santa Clara, CA 95053 USA

Elise S. Gornish, egornish@email.arizona.edu, School of Natural Resources and
Environment, University of Arizona, Tucson, AZ 85721 USA

Kristin B. Hulvey, kris.hulvey@usu.edu, Quinney College of Natural Resources,
Utah State University, Logan, UT 84322 USA

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25 **Abstract:**

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

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38 **Implications for Practice**

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

45

46 **Introduction Article**

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

54 As befits a maturing discipline, there have been many papers over the years
55 that question the directions the field is going, as well as periodic calls for new
56 paradigms(Hobbs & Harris 2001; Choi 2007; Brudvig 2011; Shackelford et al. 2013;
57 Perring et al. 2015; Martin 2017). In particular, the intradisciplinary handwringing
58 has centered on questions of restoration goals: not only the need to be clear about
59 defining goals, but more recently, the question of whether current goals are the
60 right ones (Hobbs & Norton 1996; Ehrenfeld 2000; Hallett et al. 2013; Suding et al.
61 2015). Much of the recent debate has revolved around how future-focused or past-
62 focused restoration should be: Should restoration attempt to recreate -- to the
63 extent possible -- the historic species assemblage in an area? Or should restoration
64 create an ecosystem that will be functional and dynamic in the future, but not
65 necessarily true to its origins (Harris et al. 2006; Choi 2007; Morse et al. 2014;
66 Murcia et al. 2014)?

67 In this paper, we leave the question of restoration *goals* for managers to
68 determine, and instead articulate a vision for developing new restoration
69 *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 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.

1. Driven by ecological theory

93 Though restoration techniques are fundamentally a facet of applied science,
94 they should be thoroughly grounded in theory (Wainwright et al. ; Palmer et al.
95 1997). Young et al. (2016) drew heavily on community assembly theory, and the
96 extensive ecological literature on priority effects in succession, in designing an
97 experiment that manipulates priority as a restoration tool. Working in California
98 grasslands, Young and colleagues gave a head start of as little as two weeks to native
99 grasses and forbs over their competitors. They found that priority effects, though
100 possibly short-lived, had profound impacts on the structure of grasslands
101 communities, and generally favored the early arrivals, as predicted from theory.

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

112 Laughlin and colleagues (2016), writing about trait-based models that can
113 create novel species assemblages in restoration settings, see the ecological
114 information going both ways: informing theory, and being informed by it. First,
115 observation of the distribution of traits in naturally assembled communities helps

guide the assembly of novel communities—that’s 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.

2. Harnessing technological advances

In its early days, the practice of ecological restoration was 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 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. 2016). 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. (2016)’s “prestorage” approach, the power of ecological niche models (Peterson 2003) is utilized for choosing species palettes that are present now *and* resilient enough to persist into the future. Using grasslands of the Colorado Plateau (USA) 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 ‘80s, but today should be part of the everyday toolkit.

3. 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 2016). 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 U.S., 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 don't adhere strictly to dogma in the service of restoration and conservation.

Meanwhile, Butterfield et al. (2016) 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's gene flow from species adapted to warmer/drier climates into the local populace? To their way of thinking, that's a feature, not a bug.

4. 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. (2016) checking to see if trait-based models can adequately predict the past before trying them out on the future, to Young et al. (2016) 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 and co-authors (2016). This paper was a

post-mortem on a failed effort to control garlic mustard (*Alliaria petiolata*) along roadsides in a park. Corbin et al. (2016) did a retrospective analysis of this project to see if, in hindsight, its goals were achievable in the first place. They employ two decision analysis tools, IPMDAT and WeedSearch, 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.

5. 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 in a limited space (Hulvey et al. 2017), optimizing interventions for particular areas of the landscape (Cordell et al. 2016), seeking species assemblages that have the most long-term value (Butterfield et al. 2016, Laughlin et al. 2016). 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. (2016) paper focused on balancing the use of reserve landscapes by hunters with the need to restore and protect rare plants. The Schlefhout et al. (2017) contribution takes account of the balance between biodiversity and agricultural productivity. As further evidence of concern for practitioner needs, the authors were careful to point out where new approaches risked running ahead of managers' expertise or being blocked by structural constraints. Butterfield et al. (2016) warn that niche models are unlikely to be implemented by land managers without an academic partnership, and Dunwiddie and Rogers (2016) recognize that some government agencies, such as the U.S. Forest Service, forbid introduction of species from off-site.

Together, 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.

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