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COMMENTARY

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Staged-scale restoration: Refining adaptive management to improve restoration effectiveness

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Abstract

1. Adaptive management (AM) was proposed as a rigourous and structured approach to natural resource management that increases learning and reduces uncertainty. It has been adopted as a guiding principle by agencies world-wide, yet its usefulness for guiding management continues to be debated. We propose a new strategy, which we term staged-scale restoration (SSR), to implement AM in a restoration setting while enhancing the scientific rigour, ecological effectiveness and overall efficiency of restoration efforts compared to traditional applications of AM.
2. The SSR approach includes three aspects: (1) experimentally assessing alternative restoration techniques directly on-site in replicated plots using operational-scale equipment, (2) staging, or the successive establishment and evaluation of treated areas over time and (3) scaling, whereby the most successful techniques identified during earlier stages are applied to increasingly larger areas in later stages. A case study illustrates how SSR was used to improve prairie restoration in western Washington, USA.
3. Staged-scale restoration provides several key advantages. It includes a robust experimental design and thus improves the scientific rigour of AM. It is conducted on-site using operational-scale equipment and thus increases the effectiveness of treatments while also providing a platform for refining existing treatments. SSR facilitates collaboration among researchers and managers. By promoting advanced planning and deferring much of the area to be treated to the latter years of a project, SSR reduces the risk of restoration failure. Finally, it is extremely flexible: it can be implemented at multiple sites or years, the number and types of treatments to be assessed can be customized and the pace of restoration can be varied.
4. *Synthesis and applications*. Staged-scale restoration addresses many of the criticisms that have been directed at conventional adaptive management (AM) and provides a scientifically rigourous strategy to improve restoration while customizing treatments for individual sites. It explicitly enables restoration projects to be conducted within an adaptive management framework, and clearly and intentionally integrates ecological research into restoration efforts. We urge the restoration community to explore the utility of staged-scale restoration in diverse socioeconomic circumstances and ecosystems.

KEYWORDS
adaptive management, adaptive restoration, collaboration, land management, randomization, replication, spatial scale, staged-scale restoration, staging

1 | INTRODUCTION

The concept of adaptive management (AM) was proposed several decades ago (Holling, 1978; Walters & Holling, 1990). AM seeks to increase knowledge and reduce uncertainty through a process that explicitly links management experimentation, hypothesis testing and observation of system responses. It has been adopted as a guiding principle by natural resource management agencies world-wide (Rist, Campbell, & Frost, 2012; Ruhl, 2008). However, perspectives differ about its usefulness for guiding management. Some authors maintain that AM is a well-developed theoretical approach and an effective and powerful framework to support the successful management of natural resources (Eberhard et al., 2009; Mackenzie & Keith, 2009), while others point to the scarcity of successful practical applications and to high-documented failure rates, particularly in large-scale applications (Allen & Gunderson, 2011; McLain & Lee, 1996; Rist et al., 2012).

One reason for these differences in opinion is that AM is not a panacea that is useful or appropriate in all management contexts. Rather, AM is particularly suited to natural resource management problems where uncertainty and controllability are high, and risk is relatively low (Allen & Gunderson, 2011; Gregory, Ohlson, & Arvai, 2006; Peterson, Cumming, & Carpenter, 2003). Under such conditions, the potential for learning is high, it is possible to manipulate major components of the system and the costs of failure are low. Examples of such problems include what methods of site preparation and seeding to use when restoring a plant community, and how to control invasive species. As these examples suggest, many aspects of ecological restoration are well suited to AM. We find this to be particularly true in herbaceous-dominated systems where succession and species turnover are relatively rapid, as treatments can be applied in an experimental context and results can be assessed relatively quickly (Dela Cruz, Beauchamp, Shafroth, Decker, & O'Neil, 2014; Healy, Rojas, & Zedler, 2015; Zedler, 2005). Working in ecosystems such as forests, where succession occurs more slowly, requires a longer term perspective, although aspects of work in these systems, such as comparisons of stocktypes, are amenable to AM.

A key issue in AM is the scale at which the management actions are performed. Managers are generally reluctant to work at small scales, as progress in restoring a site may be undesirably slow given the scope of restoration needs. However, evaluating alternative management actions at larger scales can be inefficient; areas treated with actions that end up being ineffective need to be retreated.

Here, we describe a new strategy, which we term staged-scale restoration (SSR), to implement AM in a restoration setting while enhancing the scientific rigour, ecological effectiveness and overall efficiency of the restoration efforts compared to more traditional applications of AM. During SSR, experimental treatments are applied at relatively small scales to generate site-specific information about their effectiveness, and this information systematically guides restoration in later stages and at increasingly larger scales elsewhere on the site. SSR uses a replicated experimental design that facilitates collaboration between practitioners and researchers, is flexible and can accommodate differences in spatial and temporal scale, resource availability and project objectives.

2 | THE SSR STRATEGY

The SSR strategy includes three aspects: (1) experimentally assessing alternative restoration techniques directly on-site in small, replicated plots, (2) staging, or the successive establishment and evaluation of treated areas over time and (3) scaling, whereby the most successful techniques identified during earlier stages are applied to increasingly larger areas in later stages. Together, these aspects distinguish SSR from traditional AM and alternative approaches that have previously been described (e.g. Dela Cruz et al., 2014; Zedler, 2005).

Staged-scale restoration is conducted by a collaborative team of practitioners and researchers. Management objectives should be clearly articulated based on organizational goals, current resources and constraints and future challenges such as climate change (Dunwiddie et al., 2009). The site or project area should be clearly defined. The more homogeneous the site, the more likely the outcome of actions in different stages will resemble one another. Drawing on their experiences, published literature and other sources, the team identifies several promising, scalable, restoration treatments to be tested on-site. An array of experimental plots is established, and each treatment is randomly assigned to multiple plots. This experimental array forms Stage 1 (Figure 1). The array should occupy a small proportion of the site, but the plots should be large enough to be treated using methods that can also be applied at larger operational scales. The location of the array is determined by the project team based on factors such as accessibility and landscape context. The number of plots is determined by the number of treatments being tested, the amount of replication desired and the homogeneity of the site. Plots can be arranged in a rectangular grid (e.g. Figure 1) or more organically to impart less rectilinearity to the restored site.

Treatment effectiveness is evaluated by monitoring plots in the array. The method, timing and intensity of monitoring can vary with management objectives, the desired level of difference detectable between treatments and available resources. For example, detailed monitoring such as counting seedlings or recording species covers is desirable sometimes but, in other situations, the differences between treatments may be striking enough that decisions could be based on visual or qualitative assessments. While treatments applied in Stage 1 are being evaluated, preparations are made for future restoration elsewhere on the site. These activities can include control of invasive species, site preparation and obtaining enough seed to support restoration at larger scales.

Based on evaluations of the Stage 1 array, the most successful treatment(s) are identified and applied to Stage 2 plots (Figure 1). How many Stage 2 plots to treat and how much larger they are than experimental plots is decided based on the size and configuration of the site, the relative success of the treatments in Stage 1 and the restoration timeline. The time interval between Stages 1 and 2 is determined based on the ecosystem, logistical constraints and the rates at which

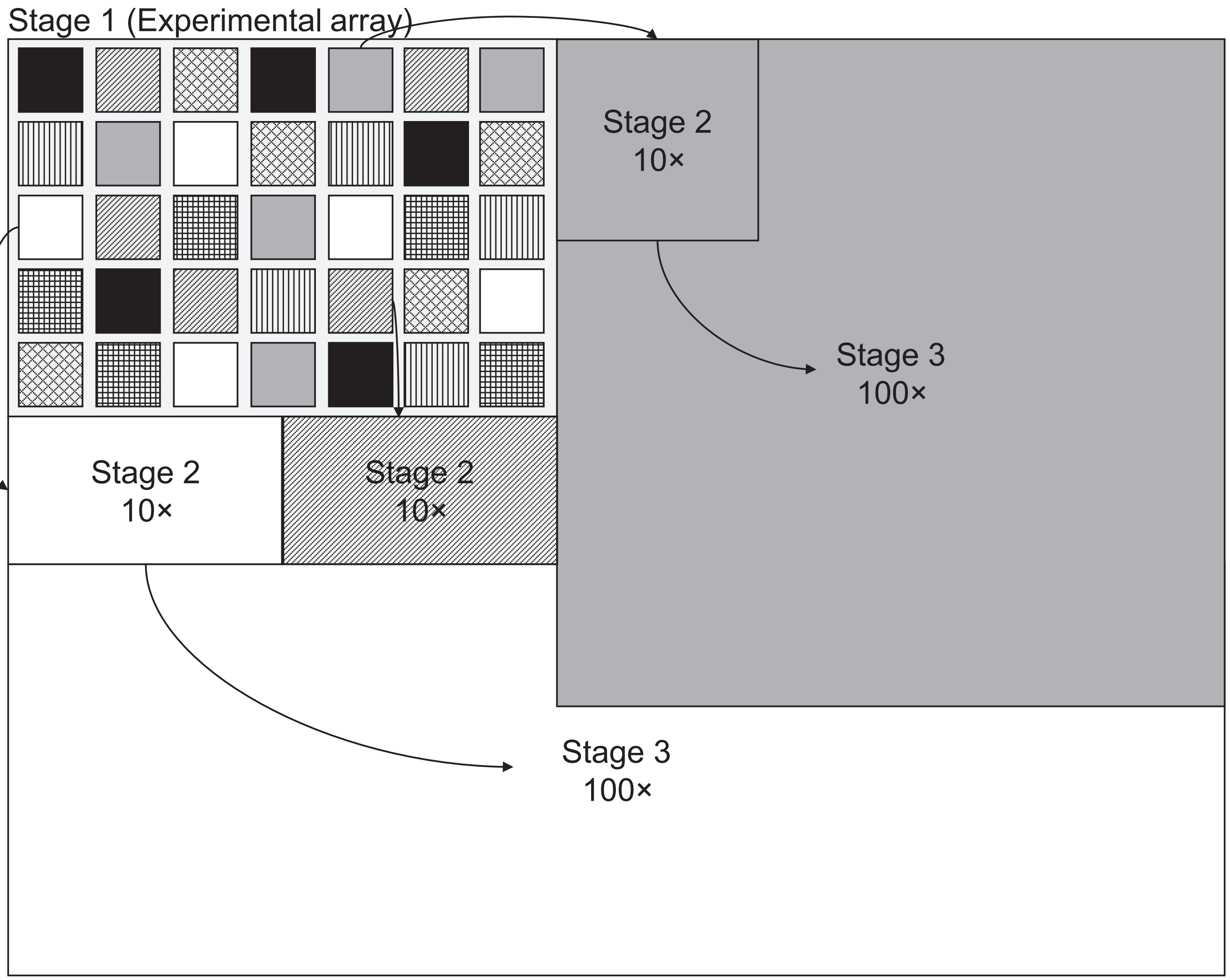

FIGURE 1 Conceptual design of staged-scale restoration. The different patterns in the experimental array (Stage 1) represent different treatments being tested. In this example, three of the treatments tested in Stage 1 are scaled to ten times larger plots in Stage 2, and two are scaled to 100 times larger plots in Stage 3. The scaling factor can be adjusted, along with the number of treatments scaled in later stages and the timing between stages. Furthermore, scaling of treatments can continue as appropriate based on the size of the site, observed results and restoration goals

demographic processes and community assembly occur. For example, stages could be implemented in consecutive years if community assembly occurs quickly and resources permit, or several years could elapse between stages to permit a longer term evaluation of plant communities in the experimental array before deciding which treatment(s) to scale up. Regardless of the interval between stages, treatments will be applied with more confidence in Stage 2 since they were already implemented on-site using operational equipment in Stage 1. Monitoring, at an intensity appropriate for the project, could focus on the Stage 2 areas and/or on the Stage 1 array to track ongoing dynamics within experimental plots.

Additional stages can follow, at similar or increasingly larger scales, until the entire site is treated. Decisions about which treatments to apply in later stages are based on monitoring of prior stages. Treatments may be modified over time, such as by diversifying a seed mix or utilizing new equipment. It may be valuable to also monitor these later stages to assess if such modifications produce different results, or if outcomes differ among treatments applied in different years (Vaughn & Young, 2010). The key concept is to use experimental plots to directly test treatments on-site and to apply and refine successful treatments in progressively larger areas until the entire site is treated.

3 | CASE STUDY

We tested the SSR strategy in Puget Lowland prairies of western Washington, USA. These prairies are highly endangered and provide habitat for several rare taxa. Previous work in this ecosystem focused on restoring degraded prairie remnants on relatively unproductive soils (Dunwiddie & Bakker, 2011), whereas we focused on productive deep-soil sites that had been cultivated and were dominated by perennial European pasture grasses. Since restoration under these conditions had not been attempted in this region, we did not know how to do so effectively or efficiently. Thus, this provided an excellent opportunity to test the SSR strategy.

One of our objectives was to examine spatiotemporal variation in plant establishment and community assembly, so we established several Stage 1 experimental arrays in each of four sites. We briefly describe these details here for completeness, although we note that the SSR strategy can be applied to a single site and does not require temporal replication of the array. Two sites were in each of two regions (North Sound, South Sound). In the South Sound, our study spanned three spatial scales (1×, 10× and 100×) and staging occurred over 5 years (2008–2012). In the North Sound, we worked at two spatial scales (1×, 10×) and staging occurred over 3 years (2009–2011). We began later and used smaller plots in the North Sound because seed and other resources were limited in this region. Sites differed in climate and soils, but there was little intra-site variation in edaphic conditions. The project area varied from 1.4 to 7.8 ha among sites.

A team of land managers and scientists identified treatments likely to create high quality, diverse native prairie habitat. Specifically, we desired to remove the perennial European pasture grasses that dominated each site, deplete the weed seedbank or suppress germination of weed seeds, create a substrate that facilitated germination of sown native seed, maintain conditions that favoured the growth and persistence of desired species and establish viable populations of golden paintbrush (*Castilleja levisecta*; federally listed as a threatened species). To ensure scalability, we only considered treatments that could be applied both to Stage 1 plots and to larger areas. We decided to test seven combinations of site preparation and seed mix, as detailed below.

Stage 1 plots were arranged in an array of 35 plots, each 25 or 40 m^2 (North and South Sound, respectively). Each treatment combination was randomly assigned to five replicate plots. Plots were separated by 2-m aisles kept bare by periodic herbicide applications. We applied a non-selective herbicide (glyphosate) across the array in early summer. Individual plots then received one of three site preparation treatments: Burning (prescribed fire in late summer), Solarization (plowing and rototilling the soil and installing a 2 mm clear plastic sheet from June to September to elevate soil temperatures and kill seeds) or Herbicide (glyphosate as needed to kill germinating or resprouting vegetation for two growing seasons). Because of the longer duration of the Herbicide treatment, these plots were seeded a year after the other plots in the array and only one seed mix (forb–rich; see below) was used with this treatment. We hypothesized that Solarization, an agricultural technique, would allow good seed-soil contact and result in the best establishment of native species, that treatments that did not disturb the soil (Burning, Herbicide) would most effectively limit the re-establishment of weeds because there would be less germination from the seedbank, and that Burning would favour establishment of golden paintbrush, based on previous observations.

Seed mixes were broadcast across the plots in early November. We tested three seed mixes with the same species richness (range 18–24 native prairie taxa per array) and similar seed densities (*M*: 682 seeds per m^2; range 542–955) but differing in the ratio of forb to grass seed (forb–rich: 98:2; mixed: 75:25; grass–rich: 50:50).

Plots were monitored each spring. Qualitative monitoring—visual comparisons of treatments within arrays—was conducted by scientists, land managers and members of the public. Quantitative monitoring—estimating cover by plant species and counting seedlings of sown species—was conducted by scientists in permanently marked quadrats within plots.

Scaling occurred over several years. We elected to scale treatments by a factor of 10: Stage 2 and Stage 3 plots were 10× and 100× larger than Stage 1 plots. This scaling factor was chosen because it was easy to communicate and because we felt these plots would be large enough to give a good sense of how restoration treatments would look when applied to even larger areas. We installed 3–6 Stage 2 plots per site. Stage 3 occurred only in the South Sound, where seed and other resources were sufficient to support restoration at this scale.

The SSR strategy allowed us to evaluate and customize treatments over time (Table 1). Although Burning resulted in the best establishment of golden paintbrush, a focal species, Herbicide was most effective in terms of overall establishment patterns. We more often scaled the Herbicide treatment, although we also began staging earlier so that areas received more years of weed control before seeding. Seed mixes changed somewhat over time based on availability—additional species became available in later years. The preferred seed mix varied among sites based on differences in plant establishment and in competing vegetation. For example, a problematic invasive forb (*Leucanthemum vulgare*) at one site required additional herbicide treatments so we sowed a native grass, *Festuca roemeri*, to occupy the site while providing management flexibility for controlling invasive species. Specifically, these areas could be treated with broadleaf-specific herbicides since no forbs were sown, and with grass-specific herbicides as these chemicals have minimal effects on *Festuca*. Two other sites had agricultural weeds, so we increased the overall seeding rate by adding more grass seed to the forb–rich mix.

TABLE 1 Site preparation treatments and seed mixes evaluated in Stages 2 and 3 at each site, and final site-specific recommended treatment combinations developed through the staged-scale restoration strategy. See text for details of the seven treatment combinations that were tested initially in Stage 1 arrays at each site

	Stage 2		Stage 3		Final recommendation	
Site[a]	Prep.[b]	Mix[c]	Prep.[b]	Mix[c]	Prep.[b]	Mix[c]
EL	B, S, H	F+, M	—	—	H+	F+
GH	B, S, H	F	H+, B	F	H+ or B	F
SP	H, B	F+, M	—	—	H+	F+
WR	H, H+, B	F, G+	H+	G+	H+	G+

[a]EL (Ebey's Landing), GH (Glacial Heritage), SP (Smith Prairie), WR (West Rocky).
[b]B (Burning), S (Solarization), H (Herbicide), H+ (Herbicide for > 2 years).
[c]F (Forb–rich; 98:2), M (mixed; 75:25), G (Grass–rich; 50:50), F+ (Forb–rich, with extra grass seed), G+ (*Festuca roemeri* alone).

4 | ADVANTAGES OF SSR

Staged-scale restoration addresses many of the criticisms that have been directed at conventional AM and thus enables AM to be applied with more confidence, effectiveness and efficiency. SSR also provides some unique advantages to AM.

Adaptive management has been criticized as lacking scientific rigour (e.g. Lee, 1999). For example, a common constraint of AM is that replication is not feasible when working at large scales (Schreiber, Bearlin, Nicol, & Todd, 2004); the lack of replication, randomization or other experimental design components could lead to erroneous conclusions. SSR addresses this issue by implementing a robust experimental design, including within-site replication and random assignment of treatments to plots. With sufficient replication and monitoring intensity, experimental results can be statistically analysed to provide rigourous quantitative support for observations and interpretations.

As customarily described and practiced, AM applies experimental treatments directly at operational scales. However, this means that large management areas within a site can be committed to treatments that yield uncertain or even undesirable outcomes. SSR lowers the risk of implementing unsuccessful treatments by reducing the area dedicated to uncertain experimental treatments. By experimentally evaluating treatments in small plots on the restoration site, SSR increases confidence that the chosen treatments will be successful when applied to larger areas of the site. Since all evaluated treatments are applied using operational-scale equipment, there should be few differences as a function of area treated. Furthermore, the lowered risks associated with SSR should translate into lower net costs. On a per-area basis, the cost of establishing replicate plots in the Stage 1 experimental array would generally be greater than that of conventional approaches. However, this experimental assessment will provide more confidence in the effectiveness of treatments applied to larger areas in later stages and thus would provide substantial cost savings compared to conventional AM approaches where previously untested methods are applied unsuccessfully to large areas that later have to be retreated.

Testing treatments directly at operational scales, as in conventional AM, also makes it difficult to evaluate refinements of those treatments and may even be a disincentive if the time and effort required to explore alternative treatments are perceived to be too large compared to the benefits of incremental improvements upon established practices (Hauser & Possingham, 2007). We also suspect that many practitioners underestimate the degree of uncertainty surrounding the success of established practices, such as by assuming that treatments will be equally effective on multiple sites or in different years (Vaughn & Young, 2010). Examples of treatments amenable to refinement include herbicide rates and formulations, mowing regimes, seed mixes, seeding techniques and combinations thereof (e.g. Stanley, Dunwiddie, & Kaye, 2011). These alternative treatments are easily evaluated within a Stage 1 experimental array. For example, a potential new seed mix and the standard mix could be applied to replicate plots and then directly compared. The Stage 1 array also allows qualitative or quantitative comparisons of treatment success in meeting restoration objectives. Furthermore, viewing replicate plots gives insight into how much spatial variation to expect within treatments.

Collaboration is critical for the success of any AM programme, and differing goals of researchers and practitioners are an area of conflict in AM (Gregory et al., 2006). The SSR strategy enhances collaboration for several reasons. First, it facilitates the incorporation of many research elements and goals without compromising larger, site-wide management goals. Second, the SSR strategy requires consultation among stakeholders right from the initial step of deciding where to work and which treatments to test. Third, multiple approaches are tested more quickly and rigourously than through traditional AM approaches, and thus, decision-makers and policy leads can be more confident in the likely success of future restoration efforts. Finally, the design encourages the evaluation of operationally realistic treatments in the experimental plots, informing managers of likely treatment outcomes at larger scales. The Stage 1 array is particularly notable for facilitating collaboration among individuals with different interests by allowing easy visual comparisons within and among treatments. Seeing treatments in proximity to the field also provide a platform for multiple parties to clarify restoration goals. Furthermore, individuals can compare treatments using the criteria that are most relevant given their interests—species richness, the presence or absence of key species, vegetation structure, etc.

The SSR strategy promotes advanced planning and reduces the risk of restoration failure. Knowing that restoration will be conducted in stages, and at increasing scales, motivates practitioners and researchers to establish a timeline and map to guide when and where restoration will occur and to work out the funding details to ensure continuity over the lifetime of the restoration project. This increases the efficiency of restoration by improving the planning process and identifying potential bottlenecks such as the availability of sufficient quantities of seed. Although the staged-scale approach means that much of the restoration acreage is deferred to the latter years of a project, the relatively small experimental arrays established in earlier years are also important to the overall restoration of the site. For example, these areas can enhance the overall heterogeneity and diversity of the site as plant establishment can differ as a result of interannual variability in weather, seed availability and the timing of seeding and other activities. Restoring a site in multiple stages can reduce the risk of failure due to extreme events such as droughts or fires that can be important aspects of climate change. Moreover, if these events occur during a SSR project, their effects can be evaluated on-site.

Finally, the SSR strategy is extremely flexible. It can be implemented at multiple sites, permitting techniques to be refined to the particular needs of each site, such as different suites of invasive species. To assess temporal variation, experimental arrays can be established at a site in different years. The number and type of treatments to be assessed can be determined by the management goals, context (e.g. area requiring restoration) and prior restoration experience at similar sites. Finally, the pace at which a site is restored can be altered by adjusting the amount of time that elapses between stages and the magnitude of the scaling factor applied between stages.

5 | LIMITATIONS OF SSR

Although the advantages of SSR are compelling, it also has some limitations. Many of these limitations can be mitigated through good communication and planning.

The formation of collaborative teams of practitioners and researchers could be challenging if practitioners and researchers do not interact professionally. Furthermore, relatively few funding mechanisms explicitly support collaborations that span the boundary between management and research. New funding mechanisms that require industry/research partnerships could increase opportunities for collaboration and improve the quality and scope of ecological restoration.

The ongoing management of the Stage 1 array should be planned for in advance. After several years, managers may want to integrate the array into the overall management of the site, whereas researchers may want to maintain the array to test further treatments or to study longer term results. The experimental array may leave a "grid" imprint on the site, particularly if aisles are maintained between plots or are not fully restored after the array is discontinued.

Although the plots are treated using operationally realistic equipment and therefore provide a reasonable picture of what to expect when treatments are scaled up, they are not perfect replicates of the larger site. For example, edge effects would be more pronounced in plots than in scaled-up areas. In addition, it is impossible to control all variables in field experiments. Experimental arrays and larger scaled-up plots could differ as a result of interannual variability in weather, differences in treatment implementation such as type of machinery and intra-site heterogeneity. However, as noted previously, such variability in outcomes may also be advantageous in promoting heterogeneity within a restored site.

The SSR strategy takes time: most of the area is treated during the latter stages of a project. If restoration funding is time sensitive, or is based on funding formulae related to area treated, this could limit the application of SSR.

Finally, the utility of SSR will likely vary among ecosystems and social contexts. We found it useful in grasslands and expect it to also be useful in other herbaceous-dominated systems, but its application to other systems may require additional evaluation. One starting point is to consider its utility for refining treatments, such as by comparing the performance of different stocktypes in forestry. As described here, SSR is focused on relatively homogeneous project areas (sites), although these sites are not of a predefined size and may be quite extensive. Its application to landscape-scale restoration efforts would depend in part on the homogeneity of the landscape. The best way to identify limits on the utility of SSR is to test the strategy broadly.

6 | CONCLUSIONS

Forty years after its introduction, AM is a well-established concept in natural resource management, yet there are relatively few examples where it has been successfully applied. SSR refines AM to improve restoration effectiveness in a scientifically rigourous way. Evaluating experimental treatments on-site allows the best-performing treatments to be identified relative to the needs of that particular site. By reducing the area dedicated to uncertain experimental treatments, SSR reduces the risk of implementing unsuccessful treatments and is more efficient than conventional AM. Importantly, SSR provides a platform for collaboration among practitioners, researchers and other stakeholders.

Use of SSR would explicitly enable restoration projects to be conducted within an AM framework and would clearly and intentionally integrate ecological research into restoration efforts. We urge the restoration community to explore the utility of SSR in diverse socioeconomic circumstances and ecosystems.

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AUTHORS' CONTRIBUTIONS

J.D.B. and P.W.D. conceived of the staged-scale restoration strategy and E.G.D. led its implementation in the case study. All authors contributed critically to multiple drafts of this work and gave final approval for publication of the final version.

DATA ACCESSIBILITY

Data have not been archived because this article does not use data.

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REFERENCES

Allen, C. R., & Gunderson, L. H. (2011). Pathology and failure in the design and implementation of adaptive management. *Journal of Environmental Management*, *92*, 1379–1384. https://doi.org/10.1016/j.jenvman.2010.10.063

Dela Cruz, M. P., Beauchamp, V. B., Shafroth, P. B., Decker, C., & O'Neil, A. (2014). Adaptive restoration of river terrace vegetation through iterative experiments. *Natural Areas Journal*, *34*, 475–487. https://doi.org/10.3375/043.034.0410

Dunwiddie, P. W., & Bakker, J. D. (2011). The future of restoration and management of prairie/oak ecosystems in the Pacific Northwest. *Northwest Science*, *85*, 83–92. https://doi.org/10.3955/046.085.0201

Dunwiddie, P. W., Hall, S. A., Ingraham, M. W., Bakker, J. D., Nelson, K. S., Fuller, R., & Gray, E. (2009). Rethinking conservation practice in light of climate change. *Ecological Restoration*, *27*, 320–329. https://doi.org/10.3368/er.27.3.320

Eberhard, R., Robinson, C. J., Waterhouse, J., Parslow, J., Hart, B., Grayson, R., & Taylor, B. (2009). Adaptive management for water quality planning – From theory to practice. *Marine and Freshwater Research*, *60*, 1189–1195. https://doi.org/10.1071/MF08347

Gregory, R., Ohlson, D., & Arvai, J. (2006). Deconstructing adaptive management: Criteria for applications to environmental management. *Ecological Applications*, *16*, 2411–2425. https://doi.org/10.1890/1051-0761(2006)016[2411:DAMCFA]2.0.CO;2

Hauser, C. E., & Possingham, H. P. (2007). Experimental or precautionary? Adaptive management over a range of time horizons. *Journal of Applied Ecology*, *45*, 72–81. https://doi.org/10.1111/j.1365-2664.2007.01395.x

Healy, M. T., Rojas, I. M., & Zedler, J. B. (2015). Adaptive control of *Phalaris arundinacea* in Curtis Prairie. *Invasive Plant Science and Management*, *8*, 363–373. https://doi.org/10.1614/IPSM-D-13-00106.1

Holling, C. S. (1978). *Adaptive environmental assessment and management*. New York, NY: John Wiley.

Lee, K. N. (1999). Appraising adaptive management. *Conservation Ecology*, *3*. https://doi.org/10.5751/ES-00131-030203

Mackenzie, B. D. E., & Keith, D. A. (2009). Adaptive management in practice: Conservation of a threatened plant population. *Ecological Management & Restoration*, *10*, S129–S135. https://doi.org/10.1111/j.1442-8903.2009.00462.x

McLain, R. J., & Lee, R. G. (1996). Adaptive management: Promises and pitfalls. *Environmental Management*, *20*, 437–448. https://doi.org/10.1007/BF01474647

Peterson, G. D., Cumming, G. S., & Carpenter, S. R. (2003). Scenario planning: A tool for conservation in an uncertain world. *Conservation Biology*, *17*, 358–366. https://doi.org/10.1046/j.1523-1739.2003.01491.x

Rist, L., Campbell, B. M., & Frost, P. (2012). Adaptive management: Where are we now? *Environmental Conservation*, *40*, 5–18.

Ruhl, J. B. (2008). Adaptive management for natural resources – Inevitable, impossible, or both? *Rocky Mountain Mineral Law Institute Proceedings*, *54*, chapter 11, 1–33.

Schreiber, E. S. G., Bearlin, A. R., Nicol, S. J., & Todd, C. R. (2004). Adaptive management: A synthesis of current understanding and effective application. *Ecological Management & Restoration*, *5*, 177–182. https://doi.org/10.1111/j.1442-8903.2004.00206.x

Stanley, A. G., Dunwiddie, P. W., & Kaye, T. N. (2011). Restoring invaded Pacific Northwest prairies: Management recommendations from a region-wide experiment. *Northwest Science*, *85*, 233–246. https://doi.org/10.3955/046.085.0212

Vaughn, K. J., & Young, T. P. (2010). Contingent conclusions: Year of initiation influences ecological field experiments, but temporal replication is rare. *Restoration Ecology*, *18*, 59–64. https://doi.org/10.1111/j.1526-100X.2010.00714.x

Walters, C. J., & Holling, C. S. (1990). Large-scale management experiments and learning by doing. *Ecology*, *71*, 2060–2068. https://doi.org/10.2307/1938620

Zedler, J. (2005). *Adaptive restoration*. Arboretum Leaflets 2005-04. Madison, WI:University of Wisconsin.

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