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Prairie Reconstruction Unpredictability and Complexity: What is the Rate of Reconstruction Failures?

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ABSTRACT

The outcomes of prairie reconstructions are subject to both unpredictability and complexity. Prairie, tallgrass, and mixed grass reconstruction is defined as the planting of a native herbaceous seed mixture composed of multiple prairie species (10 or more) in an area where the land has been heavily cultivated or anthropogenically disturbed. Because of the unpredictability and complexity inherent in reconstructions, some outcomes end up being failures dominated by exotic species. We propose that these failures follow a fat-tailed distribution as found in other complex systems. Fat-tailed distributions follow the Pareto principle, where 80% of the time reconstructions work as expected but 20% of the time they are surprising and far from the typical response. Therefore, we suggest managers be informed that reconstruction failures follow fat-tailed distributions as opposed to assuming reconstructions are simple and predictable with few failures. Once managers realize failures are inherent in reconstructions, resources can be allocated to more effective methods of dealing with failures rather than working to perfect the predictability of reconstructions. We suggest implementing adaptive management, especially where unpredictability is high, as a way to learn from failures. Combining learning from adaptive management with a reconstruction design process, in which goals and constraints are iteratively adjusted, can be a way to deal with failures and develop better outcomes.

Keywords: adaptive management, design process, fat-tailed distribution, Pareto principle

Restoration Recap

- Prairie reconstructions are unpredictable and complex, requiring that practitioners be aware that past outcomes do not always inform future outcomes.
- The inherent complexity results in reconstructions following the 80/20 distribution rule in which 80% will be successes but 20% will be failures, known as a fat-tailed distribution.
- Accepting that failures are part of reconstructions should reduce the stigma of failure and instead lead to management directives that learn from unsuccessful attempts.
- Learning from failures through adaptive management can be used in reconstruction design processes in which goals and constraints are iteratively adjusted, leading to better outcomes.

Variability is inherent in ecological restoration in general (Suding 2011), and prairie reconstruction in particular (Brudvig et al. 2017). Prairie reconstruction is defined here as the planting of a native herbaceous seed mixture composed of multiple prairie species (10 or more) in an area where the land has been heavily cultivated or anthropogenically disturbed. We define a successful reconstruction in this paper as when the planted species dominate and a failure as when exotic species dominate. Our discussion of prairie reconstructions is restricted to the area occupied by tallgrass or mixed grass prairie. After planting, there are many alternative successional paths that reconstructions could take (Fagan et al. 2008, Brudvig 2011, Brudvig et al. 2017). The path taken is driven by management practices, but there is an opportunity for many other uncontrollable (or unforeseen) factors to shape the path (Perring et al. 2015).

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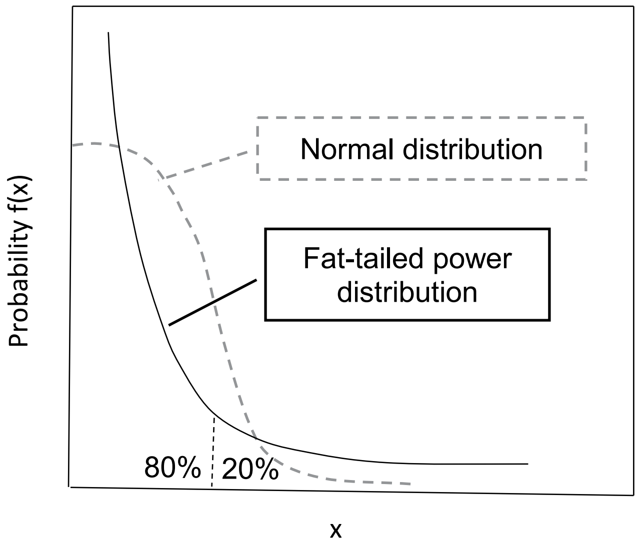

Figure 1. Graph shows the shape of a fat-tailed power distribution (Pareto), with the 80% and 20% area denoted, compared to a normal distribution. Complex systems that have fat-tailed distributions are stream-bank-erosion size, wildfire sizes, natural avalanches, controlled sand pile avalanches, floods, commodity markets, wars, and sizes of cities and firms.

Uncontrollable factors associated with reconstructions might include weather variables, pathogens, unintended anthropogenic effects (e.g., pesticide overspray, unintended defoliation), etc. These uncontrollable factors combined with variability signify that reconstructions function as complex systems (Suding 2011, Brudvig et al. 2017). Complex systems are those composed of many nonlinear interacting parts (plants, microbes, pathogen, predators) with feedbacks (e.g., competition, facilitation) that self-organize or promote emergent properties, and where there is a path dependency (Levin et al. 2013). Given these conditions, complex systems have limited predictability; i.e., "hindsight does not lead to foresight" (Snowden and Boone 2007, p. 3) and can be characterized by unpredictable, surprising events (unknown unknowns). Therefore, not only are reconstructions subject to that complexity but they intrinsically reintroduce complexity, and the unpredictability associated with that complexity, to systems that had become simplified by removal of original native vegetation (Perring et al. 2015, Brudvig et al. 2017).

Reconstructing prairies in the mixed and tallgrass landscapes often involves changing former croplands and pastures (monotypic, more simplified systems) into these more complex systems. The problem is that managers still think of reconstructions as simple (known knowns) or complicated (known unknowns) systems rather than complex (unknown unknowns [Snowden and Boone 2007]). Simple and complicated systems are predicable with cause and effect knowable (though in complicated systems understanding cause and effect may be a long process leading to competing, equally good answers). Variability in these systems is typified by known knowns, like soil class, and known unknowns, such as seasonal soil moisture, whereas complex systems have unknown unknowns, for example, past land use. Instead of managing reconstructions as simple or complicated systems, in which there are many competing right answers, one should be treating reconstructions as complex systems where unpredictability is inherent.

Such unpredictability was evident in a survey of 123 reconstructions conducted in eastern North Dakota and northwest Minnesota by Norland et al. (2015). The study only used reconstructions that were at least five years old. Best practices identified in the study were to use approximately 20 native species in the seed mix, to broadcast seed, and to perform seeding in the dormant season. Other factors, such as prior land use, weather, seedbed preparation, and post seeding management, varied across the reconstructions. Norland et al. (2015), using ordination and classification methods, found that reconstructions fell into two groups, one in which the planted species dominated (success), and the other in which exotic species dominated (failure). The analysis found that 80% of the reconstructions using identified best practices belonged to the group in which planted species dominated. The other 20% of reconstructions belonged to the exotic-dominated group and were classified as failures. The 20% failure outcome points to a situation in which even when best practices are followed, there is a high occurrence of failures. The level of reconstruction failures found by Norland et al. (2015) was similar to a review by Suding (2011). The first response to a high rate of failure is that we have not accounted for the necessary factors that lead to success. Only after further research on data gaps and investigation of the site and its history can we develop reliable predictions for reconstructions (Brudvig et al. 2017). The drivers of unpredictability that Brudvig et al. (2017) considered for further research are: land-use legacies, landscape variability, soil attributes, weather variability, consumer abundances, and interactions with the existing species in the surrounding landscape.

The promise that increased research and knowledge will reduce unpredictability of reconstruction outcomes ignores the high level of variability and lack of control found in these complex systems (Hilderbrand et al. 2005, Suding 2011). Previously identified drivers of unpredictability are often not under the control of managers. This lack of controllability, along with the other features found in complex systems (nonlinearity, feedback, self-organizing, and path dependency), leads to unpredictability as seen in other naturally occurring complex systems (see Figure 1). In these systems, the distributions of events that are far from the typical response (rare or extreme events) do not follow a normal distribution with thin-tails, but the distributions all have fat-tails (Harris et al. 2012). Fat-tails were first used by Pareto in 1896 to describe the situation in which 20% of the land owners controlled 80% of the wealth while the other 80% controlled 20% of the wealth (Dahlberg 2015). This 80/20 rule of thumb, or Pareto principle, is widely used in management and business literature as an explanation for how most outcomes (80%) are caused by a smaller percentage of factors or actors (20%); or put differently 80% of the problems are created by 20% of the customers (Cooke et al. 2014).

A recent study by Batt et al. (2017) confirms that fat-tailed distributions are present in ecosystems. They found there were "big" and surprising events in lake fish population sizes that were a product of nonlinear processes common in ecosystems and characteristic of complex systems. They concluded that "It is dangerous to consider the future as a set of norms from the past," and "forecasting future events, especially extreme events, is difficult" (p. 68). Thus, it seems logical that reconstructions in complex systems would also have fat-tailed distributions. The majority of the time, reconstruction outcomes are not so surprising (approximately 80%), but the rest of the outcomes would be categorized as surprising, or far from the typical response, and often classified as failures (between 5% and 20%) (Norland et al. 2015).

Not treating reconstructions as complex with fat-tails can lead managers to see the high level of failure as a product of their management errors, rather than a reasonable outcome of a complex system. Put another way, managers are using lessons learned from agriculture, a simple or complicated system, where plantings of ≤ 4 species are predictable, when they should be sensing that reconstructions are complex (Brudvig et al. 2017). Managers that expect complexity in reconstructions can then legitimately accept a certain rate of failure, such as less than 20% but more than 5% and the unpredictability is driven by unknown unknowns, e.g. land use legacies or interactions with newly introduced exotic species.

Accepting that failures are part of the reconstruction process, we suggest that managers do as Dahlberg (2015) advises and "plan for the predictable" but "prepare for the unpredictable" (p. 553). Realizing that failures will follow a fat-tailed distribution, managers can convey to others that a certain rate of failure is expected and this rate is not tied to traditional statistical distributions (such as a normal). Once this is understood, managers can reduce the need or imperative to further reduce failures. The realization that complex systems are inherently not able to deliver a very low failure rate will allow expectations to be changed and resources allocated to a more effective method of dealing with failures rather than working toward finding and controlling those last factors to create the perfect "secret sauce" for prairie reconstructions (Handel 2016).

Now What? Strategies to Reduce Failure

Acknowledging there will be prairie reconstruction failures is an essential first step, but perhaps as important is how to work effectively with failures. In complex systems, Snowden and Boone (2007) advocate a "probe, sense, and respond" strategy that is similar to adaptive management, in which "safe to fail" probes are initiated to discover (sense) the path forward (respond). Such a strategy will require patience to allow the probes to work and then sense that path from which an adaptive response can be formulated. Ideally, such adaptive management responses to failure should already be a concentrated effort; unfortunately, current efforts at adaptive management have often fallen short (Perring et al. 2015).

It seems intuitive that adaptive management should be a productive strategy in reducing failed reconstructions, but the success of an adaptive management process is hindered by our inability to produce realistic and testable models linking management to outcome (Williams and Brown 2016). When contingency is a major factor in each interaction modeled, competing models quickly become unwieldy and resist clear interpretation (Boyd and Svejcar 2009). Eviner and Hawkes (2008) along with Brudvig et al. (2017) have argued that it is possible to accumulate enough data on plant traits and their interactions with soil characteristics to improve reconstruction outcomes. While this is certainly true, especially in some very well studied systems, the investment in such detailed research and the necessary partnerships between practitioners and researchers to apply the data to management actions may not be practical in many situations. In many complex cases, the knowledge simply does not exist (Dickens et al. 2016). A bet-hedging strategy, such as planting over several years when weather is an important but unpredictable factor (Wilson 2015), can lead ultimately to better outcomes if used as a "probe, sense, respond" strategy.

It is also worth considering what the universe of acceptable outcomes looks like. The failed reconstruction may lack dominance by the desired native plants—that is, it is not a success but may nonetheless produce positive ecosystem functions (Matzek, et al. 2017). Managers develop objectives for a reconstruction based on expectations gleaned from the literature and previous experiences, which often include a dominance of native plants; however, other outcomes that relate to cost efficacies are also important to managers. Informal cost-benefit analysis, in which the negative impacts (e.g., export of weedy propagules) of the failed reconstruction are compared with the positive (e.g., nesting habitat for waterfowl or nectar plants for pollinators) will aid in prioritizing further management to push the reconstruction toward a desired end.

Another way of thinking about reconstruction is to treat it as a design process as advocated by Ross et al. (2015) with failure being a necessary part of the design process.

Design assumes that after trying something, you will learn from the failures, and in the next inevitable iteration you will make changes. This iterative process often leads to a change in goals or the realization that the constraints have changed. A change in goal may occur when a site has increased fertility through past manuring and fertilizer use causing typical prairie reconstruction seed mixes to be unsuccessful. A change in reconstruction goals to a novel or hybrid community is a way to deal with the higher fertility (Rohr et al. 2018). Design is thus a process that also adjusts endpoints so that the end may not be definable, but ever changing. Realizing that prairie reconstructions are a design process and subject to "causal thickets" (Harris and Heathwaite 2012) may preclude a clear link between management action and outcome. Thus, a strategy of iterative adjustments toward goals, with failures stimulating new learning and adjustments, can show the way forward without starting from scratch.

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References

Batt, R.D., S.R. Carpenter and A.R. Ives. 2017. Extreme events in lake ecosystem time series. *Limnology and Oceanography Letters* 2:63–69.

Boyd, C.S. and T.J. Svejcar. 2009. Managing complex problems in rangeland ecosystems. *Rangeland Ecology & Management* 62:491–499.

Brudvig, L.A. 2011. The restoration of biodiversity: Where has research been and where does it need to go? *American Journal of Botany* 98:549–58.

Brudvig, L.A., R.S. Barak, J.T. Bauer, T.T. Caughlin, D.C. Laughlin, L. Larios, et al. 2017. Interpreting variation to advance predictive restoration science. *Journal of Applied Ecology* 54:1018–1027.

Cooke, R.M., D. Nieboer and J. Misiewicz. 2014. *Fat-tailed Distributions: Data, Diagnostics and Dependence.* Hoboken, NJ: John Wiley & Sons.

Dahlberg, R., 2015. Resilience and complexity: Conjoining the discourses of two contested concepts. *Culture Unbound* 7:541–557.

Dickens, S.J.M., S. Mangla, K.L. Preston and K.N. Suding. 2016. Embracing variability: Environmental dependence and plant community context in ecological restoration. *Restoration Ecology* 24:119–127.

Eviner, V.T. and C.V. Hawkes. 2008. Embracing variability in the application of plant-soil interactions to the restoration of communities and ecosystems. *Restoration Ecology* 16:713–729

Fagan, K.C., R.F. Pywell, J.M. Bullock and R.H. Marrs. 2008. Do restored calcareous grasslands on former arable fields resemble ancient targets? The effect of time, methods and environment on outcomes. *Journal of Applied Ecology* 45:1293–303.

Handel, S. 2016. The seven habits of highly effective people who want to do ecological restoration. *Ecological Restoration* 34:171–172.

Harris, G.P. and A.L. Heathwaite, 2012. Why is achieving good ecological outcomes in rivers so difficult? *Freshwater Biology* 57:91–107.

Hilderbrand, R.H., A.C. Watts and A.M. Randle. 2005. The myths of restoration ecology. *Ecology and Society* 10:19.

Levin, S., T. Xepapadeas, A.S. Crépin, J. Norberg, A. De Zeeuw, C. Folke, et al. 2013. Social-ecological systems as complex adaptive systems: Modeling and policy implications. *Environment and Development Economics* 18:111–132.

Matzek, V., E.S. Gornish and K.B. Hulvey. 2017. Emerging approaches to successful ecological restoration: Five imperatives to guide innovation. *Restoration Ecology* 25:S110–S113.

Norland, J., T. Larson, C. Dixon and K. Askerooth. 2015. Outcomes of past grassland reconstructions in eastern North Dakota and northwestern Minnesota: Analysis of practices. *Ecological Restoration* 33:408–417.

Perring, M.P., R.J. Standish, J.N. Price, M.D. Craig, T.E. Erickson, K.X. Ruthrof, et al. 2015. Advances in restoration ecology: Rising to the challenges of the coming decades. *Ecosphere* 6:1–25.

Rohr, J., E. Bernhardt, M. Cadotte and W. Clements. 2018. The ecology and economics of restoration: When, what, where, and how to restore ecosystems. *Ecology and Society* 23:15.

Ross, M.R., E.S. Bernhardt, M.W. Doyle and J.B. Heffernan. 2015. Designer ecosystems: Incorporating design approaches into applied ecology. *Annual Review of Environment and Resources* 40:19–443.

Snowden, D.J. and M.E. Boone. 2007. A leader's framework for decision making. *Harvard Business Review* 85:69–76.

Suding, K.N. 2011. Toward an era of restoration in ecology: Successes, failures, and opportunities ahead. *Annual Review of Ecology, Evolution, and Systematics* 42:465–486.

Williams, B.K. and E.D. Brown. 2016. Technical challenges in the application of adaptive management. *Biological Conservation* 195:255–263.

Wilson, S.D. 2015. Managing contingency in semiarid grassland restoration through repeated planting. *Restoration Ecology* 23: 385–392.

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