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RE-New (Opinion) ARTICLE

Apps can help bridge restoration science and restoration practice

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Scientists need to find innovative ways to communicate their findings with restoration practitioners in an era of global change. Apps are a promising bridge between restoration science and practice because they apply broad scientific concepts to specific situations. For example, habitat connectivity promotes ecological function, but practitioners lack ways to incorporate connectivity into decision-making. We created an app where users calculate how habitat restoration or loss affects connectivity. By providing our app as an example and discussing the benefits and challenges in creating apps for practitioners, we encourage other restoration ecologists to similarly create apps that bridge science with practice.

Key words: digital tools, habitat connectivity, habitat restoration, network analysis, R shiny, web applications

Implications for Practice

- Creating apps can help ecologists present their findings to restoration practitioners.
- When creating apps, it is helpful to communicate with your target audience to understand their needs.
- Not all questions can be answered effectively in apps; it is necessary to understand the scope of your app.

Much of the work we do as restoration ecologists aims to inform restoration practices, and we can take more proactive steps to accomplish this. Scientific studies inherently focus on the big picture by conveying the general consequences of scientific findings. Restoration practitioners, however, often have specific, place-based questions about how these general trends will affect their work. Web applications (or "apps") have the potential to effectively bridge this divide, and, consequentially, they can help us better incorporate cutting-edge restoration science into contemporary restoration practice. By automating analyses and creating user-friendly interfaces, apps can widen the community of people engaging with our work. The usability of apps can help incorporate our findings into restoration practice, therefore increasing the likelihood that our science is used to create more effective restorations. As scientists hoping to affect change with our work, we can aid land managers by creating apps that allow users to interact with and manipulate data within defined parameter ranges. This enables restoration practitioners to engage with new findings in restoration ecology in more meaningful and specific ways because these tools can test the exact scenarios that are relevant to their concerns. Here, we discuss the benefits of creating apps to incorporate restoration science into restoration practice, using our own experience in developing such an app as an example.

One specific issue managers face is deciding where to restore land, as there are often several possible places to conduct restorations. Where we work in the American Midwest, remnant grassland habitat has been highly reduced and fragmented through conversion to agriculture. Ecological theory tells us that this habitat loss and fragmentation has negative consequences for ecological populations and communities because it disrupts connectivity; e.g. through loss of gene flow, population size decline, and decreased movement ability. Connectivity, or the extent to which organisms can disperse between habitat patches on a landscape, can be affected by the decisions we make about where to place restorations or further convert grasslands. Yet, we lack effective tools to translate ecological theory into practical application. Some organizations, such as The Nature Conservancy, do actively prioritize connectivity when planning new restorations. However, many groups that conduct restorations lack the institutional resources to make these kinds of management decisions based on ecological theory. Thus, it is difficult for them to anticipate the impact that restoration or habitat loss would have on connectivity. Further complicating this is the fact that connectivity has many aspects to it, which are each quantified using different metrics. For example, some metrics of connectivity focus on predicting a species' long-range movement ability for coping with climate

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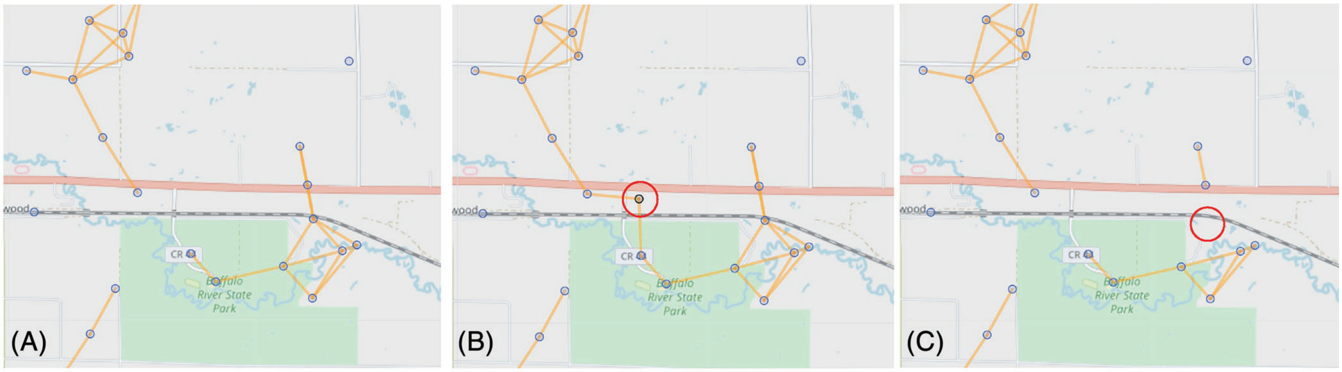

Current Connectivity

Total number of patches:	942
Number of components:	325
Avg patches per component:	2.8985
Max component size:	41
Transitivity:	0.5364
Number of isolated patches:	172

Projected Connectivity with Restoration

Total number of patches:	943
Number of components:	324
Avg patches per component:	2.9105
Max component size:	41
Transitivity:	0.5332
Number of isolated patches:	172

Projected Connectivity with Habitat Loss

Total number of patches:	941
Number of components:	326
Avg patches per component:	2.8865
Max component size:	41
Transitivity:	0.5357
Number of isolated patches:	172

Figure 1. Connectivity app examining different land use scenarios. This view from the app is of a portion of Clay County, MN. Note that connectivity metrics are calculated for the network over the entire county, even though only a portion of the county is shown. (A) Current connectivity. The app calculates and displays the current connectivity in MN counties. Blue circles are the centroids of existing grasslands of at least five acres, and orange lines represent counties that are connected at 1,000 m (defined by the user—not pictured). The data table summarizes the county's current connectivity using several connectivity metrics, which all describe different aspects of connectivity. (B) Projected connectivity with a restoration. When users change the land use scenario to "add" (not pictured) and click on the map, a restoration (black circle, inside the red circle) is added in that location and metrics are recalculated. (C) Projected connectivity with habitat loss. When users change the land use scenario to "loss" (not pictured) and click on an existing patch, that patch is removed (patch's former location marked by red circle) from the networks and metrics are recalculated.

change, while others focus on a species' local recolonization potential. As scientists who study the ecology and math of connectivity, we wanted to create a tool that would allow land managers to easily incorporate connectivity analysis into restoration decisions.

To do this, we created a connectivity app which allows land managers to ask specific questions about habitat connectivity in their region without needing to conduct network analyses (a method used to calculate connectivity) themselves. For example, if a land manager is interested in restoring a tract of marginal cropland into a grassland, they can use the app to quantify how this restoration would impact different aspects of connectivity across the landscape. The app can also be used to quantify the consequences of habitat loss, as many areas continue to lose grassland habitat via conversion to agriculture. Quantitative information on a patch's value to connectivity can be used to help make decisions about where to prioritize restoration or protection.

We created the connectivity app in R Shiny, and it utilizes network analysis to compute the connectivity of grasslands over the state of Minnesota. Users define their landscape of interest by clicking on a county, after which the app shows you the county's grasslands. Because the extent to which a landscape is connected depends on an estimate of how far a species can move, the user has the ability to set the "dispersal distance" from 50 to 2,000 m. Once these parameters—county and dispersal distance—are defined, the app draws connections between grasslands where dispersal is possible at that distance, and also presents the user with a table of metrics describing the connectivity of the created network (Fig. 1). Users can also toggle the land use scenario they are interested in displaying on the interactive map—they can plot the current extent of grasslands in the county, and then can either (1) click to add a grassland on the map (modeling the impact a restoration would have connectivity), or they can (2) click on an existing grassland to remove it (modeling the impact of habitat loss on connectivity). As users add and remove grasslands, they see connections re-forming on the map, and they can compare the county's current connectivity metrics to the projected metrics given these changes on the landscape (Fig. 1). The app addresses our need to maximize future connectivity and protect current connectivity, and to do this effectively we need to be able to anticipate the consequences of restoration or habitat loss in specific locations. With this tool, land managers are better positioned to incorporate connectivity into decisions about where to prioritize restoring or protecting land.

In order to design effective web apps, it is critical to understand the needs of the users. Our target audience for the connectivity app was people and organizations interested in restoring or protecting land. As such, we developed the app with organizations such as The Nature Conservancy, or the Minnesota Department of Natural Resources, as well as private citizens in

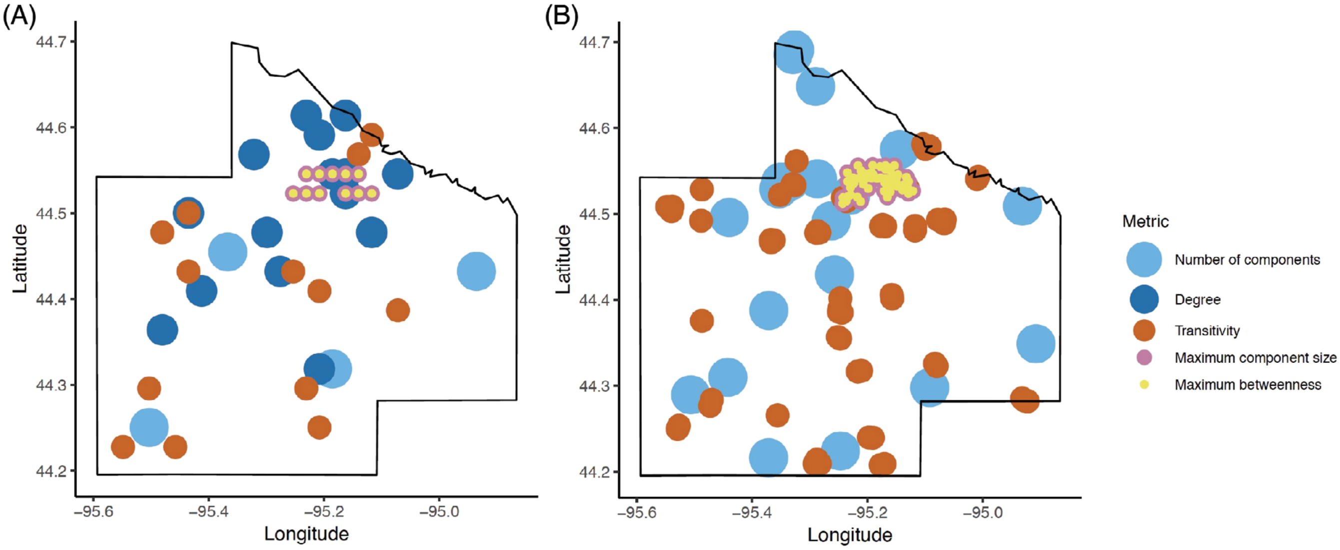

Figure 2. Locations of restoration and habitat loss that most increase and decrease connectivity, respectively. Note: size varies only for visualization purposes. (A) These points represent the locations that, out of all 500 sampled locations, resulted in a network with the optimal outcomes for each metric when they were added to the baseline network, as compared to baseline values. These optimal outcomes are quantified as the top or bottom, depending on which direction is optimal, 5% of all outcomes across the 500 sampled points. (B) These points represent the locations that, out of the 1,235 existing grasslands, resulted in a network with the worst outcome for each metric when they were removed from the baseline network, as compared to baseline values. These worst outcomes are quantified as the top or bottom, depending on which direction is worse, 5% of all outcomes across the 1,235 sampled points (see Appendix S1 for full description).

mind. For us, it was important that we create a tool that enabled people without prior technical experience to assess connectivity. Thus, we prioritized simplicity of the user interface and having informational pages about connectivity. We also wanted to engage with our target audience throughout the development process to make sure we were meeting the needs of the intended users. We gave presentations to our target audience to discuss how we could refine the app. This is a critical step to creating apps that bridge basic and applied science. For example, attendees at our meeting with The Nature Conservancy were interested in anticipating the effects of habitat loss, a direction we had not yet developed. As a result of this conversation, we developed the app's capability to remove grasslands, and the app is now more likely to be helpful in decision-making. This is a good reminder that if we as restoration ecologists want to ensure our work is helpful, we need to truly understand the needs of land managers.

Apps are a promising, innovative way to bridge restoration science and practice, but we need to think about the types of questions that apps can best address. Some analyses do not lend themselves to an app environment because they are too computationally intensive and would take too long to run, leading to a frustrating user experience. However, computational methods within an app can be used to answer these types of questions outside of the app environment. For example, when users tested the app throughout development, they often wanted to know the best place to put a restoration, or the worst place to lose a grassland, in terms of connectivity. These questions are a logical extension of the app but necessitate computing and comparing many hundreds of networks (each with a potential addition or loss). These computations would take hours to complete. To address this problem, however, we realized we could take a function we designed for the app that computes the connectivity metrics of a network and use it in base R to answer these questions. To do this, we (1) computed the resulting connectivity of individually adding hundreds of potential restoration locations to an existing network to find the locations that most maximized connectivity, and (2) computed the resulting connectivity of individually removing each existing grassland (one at a time) from the network to find which locations most decreased connectivity (Fig. 2). We have demonstrated this more complicated analysis with a case study of the grasslands in Redwood County, MN (Supporting Information, Appendix S1). This case study answers an interesting and important question, but one that would not have fit into the scope of our app. Our connectivity app is best used to answer a relatively simple question: What happens to connectivity if a single patch is added or taken away? These more-focused scenarios are better suited to apps, where the user expects output to be displayed promptly.

As restoration ecologists, we can gain a greater perspective of the applicability and efficacy of our science through the process of creating these types of apps. Communicating directly with restoration managers is beneficial for both parties. These conversations and collaborations can help direct our future ecological research, leading us to design studies addressing the gaps in our understanding that managers most need addressed. This will also afford us a better understanding of how our research fits into the process of restoration, helping us to better communicate the broader impacts of our findings and bringing our work to the attention of our target audience more effectively. Habitat restoration will play a key role in ameliorating the erosion of ecosystem functions and services resulting from centuries of habitat degradation and loss. To best do our part as restoration ecologists, we need to actively seek accessible and innovative ways, such as apps, to better communicate our science with those on the ground creating restorations.

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Supporting Information

The following information may be found in the online version of this article:

Appendix S1 Case study of grasslands in Redwood County, MN.

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