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Perspective

Knowledge sharing for shared success in the decade on ecosystem restoration

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Abstract

1. The Decade on Ecosystem Restoration aims to provide the means and incentives for upscaling restoration efforts worldwide. Although ecosystem restoration is a broad, interdisciplinary concept, effective ecological restoration requires sound ecological knowledge to successfully restore biodiversity and ecosystem services in degraded landscapes.
2. We emphasize the critical role of knowledge and data sharing to inform synthesis for the most robust restoration science possible. Such synthesis is critical for helping restoration ecologists better understand how context affects restoration outcomes, and to increase predictive capacity of restoration actions. This predictive capacity can help to provide better information for evidence-based decision-making, and scale-up approaches to meet ambitious targets for restoration.
3. We advocate for a concerted effort to collate species-level, fine-scale, ecological community data from restoration studies across a wide range of environmental and ecological gradients. Well-articulated associated metadata relevant to experience and social or landscape contexts can further be used to explain outcomes. These data could be carefully curated and made openly available to the restoration community to help to maximize evidence-based knowledge sharing, enable flexible re-use of existing data and support predictive capacity in ecological community responses to restoration actions.
4. We detail how integrated data, analysis and knowledge sharing via synthesis can support shared success in restoration ecology by identifying successful and unsuccessful outcomes across diverse systems and scales. We also discuss potential interdisciplinary solutions and approaches to overcome challenges associated with bringing together subfields of restoration practice. Sharing this knowledge and data openly can directly inform actions and help to improve outcomes for the Decade on Ecosystem Restoration.

KEYWORDS
data synthesis, dissemination, ecological restoration, evidence-based knowledge, networks, open data, practitioner–scientist collaboration, restoration ecology

1 | INTRODUCTION

The United Nations' resolution for the Decade on Ecosystem Restoration (2021–2030) has the goal of raising awareness and action towards restoring upwards of 350 million hectares of degraded land. This could generate billions of U.S. dollars in ecosystem services and reduce several gigatons of greenhouse gases that contribute to climate change (UNEA, 2019). Although a primary means to achieve these goals will involve socio-economic factors that provide the engagement and incentives for restoration, successful ecological restoration will also require sound ecological knowledge and knowledge transfer to successfully restore biodiversity and ecosystem services in degraded ecosystems (Cooke et al., 2019; Temperton et al., 2019). However, restoration outcomes for biodiversity and ecosystem services are highly variable and contingent on the goals set, the approach taken and many ecological and socio-economic factors (Fischer et al., 2021; Miller et al., 2017; Suding, 2011).

Here, we emphasize the critical role of knowledge and data sharing, compilation and synthesis to help inform the most robust ecological restoration science possible in any context. Such synthesis is critical for helping restoration ecologists better understand how context affects restoration outcomes, increasing predictive capacity of restoration actions (Brudvig, 2017; Brudvig et al., 2017), informing evidence-based decision-making in restoration practice and scaling-up approaches to meet ambitious targets for restoration (Brudvig & Catano, 2021). Our advocacy towards data sharing and synthesis for restoration is inspired by other synthetic data compilations, such as the PREDICTS database on human impacts on biodiversity (Hudson et al., 2014), which played an important role in the Intergovernmental Panel for Biodiversity and Ecosystem Services (IPBES) global assessment (Díaz et al., 2018). Here, we detail how integrated data, analysis and knowledge sharing can lead to shared success in restoration. We also discuss interdisciplinary solutions to overcome challenges associated with these efforts.

2 | CURRENT STATE OF DATA AND KNOWLEDGE SHARING

To synthesize information on restoration and its outcomes, it is essential to develop a system where monitoring data from previous and ongoing restoration projects are shared and compiled. While data sharing in biodiversity science remains challenging (Poisot et al., 2019), there is a push towards embracing open data in the field. For example, there are now organized biodiversity monitoring schemes (e.g. GEOBON [https://geobon.org/]); new data-based journals (Biodiversity Data Journal, Scientific Data) and journals with data publication options (Ecology, Global Ecology and Biogeography); infrastructures and resources for data archiving (e.g. GBIF [https://www.gbif.org/], EDI [https://environmentaldatainitiative.org/], KNB [https://knb.ecoinformatics.org/]) (Powers & Hampton, 2019; Telenius, 2011; Whitlock, 2011); and growing numbers of compilations of biodiversity data from natural and modified ecosystems, such as PREDICTS (Hudson et al., 2017). However, at present, there are few schemes aimed specifically towards restoration monitoring data. Filling this niche would support restoration science and practice by advancing researchers' and practitioners' understanding and predictive capacity of outcomes across contexts.

Open-access tools and standards are becoming more commonplace, such as the FAIR principles, which aim to guide individuals through the process of making their data findable, accessible, interoperable and reusable (Wilkinson et al., 2016). Further, many journals, including those in applied ecology, are increasingly requiring that data associated with the results of papers are archived or made publicly available. Efforts to increase the standardization of data reporting and archiving, as well as concerted compilation and databasing efforts will further enhance the usability of these data (Groom et al., 2019). However, there are challenges to implementing these commitments, which we discuss below.

There is a great deal of existing restoration data that could be made available for shared learning in restoration. As with most fields, the number of restoration studies has grown exponentially, including many studies with experimental or monitoring protocols that would provide valuable information for restoration synthesis (Figure 1). Many studies that were published before data repositories (e.g. DRYAD, FigShare) became a leading standard can now be leveraged. There are many studies where raw biodiversity data and metadata are never posted anywhere, and become lost over time. Many other datasets are not archived, in particular for many restoration studies that do not end up in the published literature. Finally, even though it is becoming more commonplace (and often required by journals) to deposit data in repositories, the data are often quite heterogeneous, metadata standards are highly variable and data structures are not often interoperable. That is, even though Dryad, FigShare and other data repositories provide a great resource to the restoration research and practice community, the data therein are often not fully FAIR – in particular, they are not readily interoperable. This means that any synthesis activities would require a considerable amount of data harmonization effort in order to standardize and synthesize this existing wealth of data. Several of the co-authors of this paper are working towards this in the context of the Global Restore Project (GRP) (www.globalrestoreproject.com), which has a goal to bring together knowledge on the outcomes of active seeding and planting-based terrestrial restoration treatments to maximize evidence-based knowledge sharing within the restoration community. The data compilation efforts of the GRP will be released in the coming years as a series of data papers on different aspects of restoration.

In addition to data, knowledge sharing is also crucial for restoration synthesis. Restoration is, by necessity, a local action which requires intricate experience-based and site-specific knowledge. This includes qualitative detail and traditional knowledge that is not easily quantifiable and goes beyond what is captured in monitoring data. For long-term benefit and effectiveness, restoration efforts ought to be integrated into socially sustainable contexts and that consider the knowledge and needs of the people that depend on the vitality of restored ecosystems (Fischer et al., 2021; Perring et al., 2018). Quantitative and qualitative social and economic data can be integrated with ecological monitoring data to better understand these dynamics as we bring large ecological restoration data resources together across contexts. Multi-sectoral partnerships and platforms to integrate knowledge, including indigenous and local knowledge, would help to further facilitate knowledge transfer and understanding.

3 | OPPORTUNITIES OF DATA AND KNOWLEDGE SHARING

A commitment to knowledge sharing from the restoration community can offer an opportunity to better support interdisciplinary and cross-professional partnerships. Restoration needs strong two-sided partnerships to link scientific approaches developed in ecological restoration to their actual implementation in the field (Dickens & Suding, 2013). Partnerships between science and practice could support the exchange of knowledge on experimental design, and monitoring to help to understand these problems. Scientists can learn from practitioners about realistic goals and priorities, implications of findings and constraints on science-practice integration. Among networks and data sharing cultures, ecological restoration is unique in that much of the data that could be used for synthesis are generated by and belong to practitioners or in some cases, corporations or organizations (Shackelford et al., 2018). Working relationships between these groups are needed to embed experiments within all restoration actions (Gellie et al., 2018), which could strengthen connections between science and practice. This requires large-scale capacity building to reach the diverse types of restoration actions, activities, individuals and

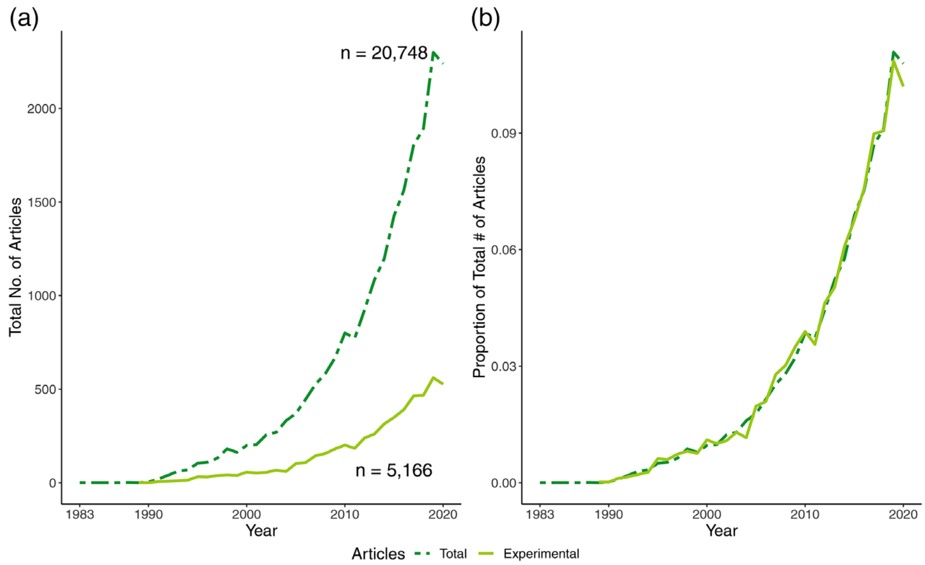

FIGURE 1 Following Young et al. (2005) and Brudvig (2011), we present research publication trends for restoration ecology. Data are from a Web of Science search conducted in December 2020. The dark green dashed line represents a search string of (topic = 'restor* AND ecol*'), and the light green solid line represents (topic = 'restor* AND ecol*') AND topic = (experiment* OR monitor*). (a) Total number of articles every year, and (b) proportion of the total number of articles every year for each search string category. *n*, the total number of articles across all years

organizations happening across the world. Extra capacity building will be required to face threats in data-deficient regions or ecosystems. There are many opportunities that currently exist for supporting knowledge exchange, but it is important to assess what barriers still exist, and how more capacity can be generated to better support the science and practice of restoration for every corner of the world.

4 | BARRIERS TO SHARING KNOWLEDGE

There are currently few shared standards for data and knowledge sharing in restoration. Time and resource constraints create barriers that prevent practitioners from broadly sharing results and experiences. These data are often summarized in reports used by regulators and site managers, and the data are often collected intermittently without standardized monitoring plans. Further, interventions are often based on ad hoc, local or expert knowledge. Reporting this knowledge in the form of case studies can be a powerful way to transfer knowledge and experience. While every case study is different, data associated with these case studies can also be integrated into synthesis efforts and directly contribute to improved understanding and predictive capacity of restoration actions. Reporting detailed knowledge and experience as metadata to accompany published case studies and data would further strengthen the contribution of every site-level case study. However, often there are organizational or corporate sensitivities that restrict participation in data and knowledge sharing such as data ownership agreements or concerns associated with public relations. Barriers to publishing scientific results in peer-reviewed journals include language, paywalls, the requirement for rigorous experimental design and analysis. In order to share valuable data, scientists, organizations and practitioners require assurance that their data will be held stably and used according to standards with which they agree. Such clear policies and standards often do not exist. Efforts to remove these barriers are still needed to reduce implicit biases and inequalities in knowledge sharing (Bezuidenhout et al., 2017), particularly for individuals and organizations who work in languages other than English, and in remote areas.

5 | NEEDS FOR DEVELOPMENT

Incentives may motivate researchers and practitioners to share knowledge and data openly. For researchers, there is currently little incentive to share data other than the requirements of some journals and funding agencies, which are still easy to avoid. In scientific research, the primary 'career currency' *(i.e. the recognition of career contributions) is authorship of peer-reviewed publications and the impact of those publications (Westoby et al., 2021). The data-index (Hood & Sutherland, 2020) and data contributions statements (Westoby et al., 2021) are two recent ideas that aim to promote recognition and value for data contributions within professional profiles. Additionally, many journals have begun to facilitate data citations so that data contributions are indexed in major indexing services, rather than in appendices where proper credit is often not provided (Costello, 2009). Clear incentives for data sharing among corporations, organizations and practitioners are still lacking, but such incentives would greatly facilitate knowledge transfer in restoration science.

A different set of incentives might be needed to enable practitioners to share knowledge and to better facilitate a two-way exchange of scientist–practitioner collaboration. A standardized place for facilitating and disseminating knowledge exchange between

TABLE 1 Existing examples of resources and tools that help to foster knowledge sharing, the purpose of each and how they can be leveraged, used and applied

Resource	Examples	Applications
Data sharing	DRYAD (https://datadryad.org) Environmental Data Initiative (https://environmentaldatainitiative.org) FigShare (https://figshare.com) Global Restore Project (https://www.globalrestoreproject.com) National Science Foundation (NSF) Long Term Ecological Research Network (LTER) (https://lternet.edu/using-lter-data) LTER-Europe (https://www.lter-europe.net) Open Science Framework (OFS) (https://osf.io/) U.S. Forest Service Research Data Archive (https://www.fs.usda.gov/rds/archive/catalog)	Sharing raw restoration monitoring via open access portals.
Habitat-specific knowledge sharing programs	Drylands (RestoreNet, 2021; GAZP, 2021; Shackelford et al., 2021), Grasslands (https://grasslandrestorationnetwork.org), Mangroves (Ellison et al., 2020; MAP, 2021; Million Mangroves, 2021), Oyster Beds (Baggett et al., 2015), Seagrass (Orth et al., 2020; Tan et al., 2020; WWF, 2021)	Networks of individuals and organizations working towards a shared goal.
Information platforms: Knowledge and experience sharing	British Ecological Society's (BES Applied Ecology Resources (AER) (www.appliedecologyresources.org) Restor (https://restor.eco) RiverWiki (https://restorerivers.eu) Society for Ecological Restoration's (SER) Restoration Resource Centre (RRC) (www.ser-rrc.org/) Project Database (https://www.ser-rrc.org/project-database) Webinar Library (https://www.ser.org/page/WebinarLibrary/)	Information, project descriptions, grey literature, reports and tools to learn about and explore other projects.
Society regional chapters	SER: African chapter (https://chapter.ser.org/africa/) Brazilian Network for Ecological Restoration (Isernhagen et al., 2017) SER: Netzwerk Renaturierung, a German-language chapter (https://renaweb.standortsanalyse.net/)	Regional networks of people with shared interests and goals.
Society thematic sections	SER: International Network for Seed-Based Restoration (INSR) (https://ser-insr.org/) SER: Large-Scale Ecosystem Restoration (LERS) (https://chapter.ser.org/lers/) Ecological Society of America (ESA): Restoration Ecology (https://www.esa.org/restorationecology/)	International networks to bring together people interested in similar contexts.
Standards and principles	IUCN: Restoration for Protected Areas: Principals, Guidelines, Best Practices (Cairns et al., 2012) FloraBank (Australian Government, 2021) SER: International Standards for the Practice of Ecological Restoration (Gann et al., 2019) SER: International Standards for Native Seeds in Restoration (Cross et al., 2020) United Nations Principles for Ecosystem Restoration (https://www.decadeonrestoration.org/publications/principles-ecosystem-restoration-guide-united-nations-decade-2021-2030)	Guidance for best practices based on knowledge gained so far.

Note: Examples of each type of resource are listed in alphabetical order. Not all examples given are exclusive to one category, for example, many Information Platforms also have the option to upload data. We list resources under the main purpose they self-declare. This list is not meant to be exhaustive.

researchers and practitioners would be ideal. The United Nations Decade on Ecosystem Restoration can provide a forum opening these discussions, but more capacity building to support these exchanges across sub fields, regions and borders is needed. Practitioners could share results that they would never consider publishing in peer-reviewed literature due to the constraints discussed above (Gellie et al., 2018). Conversely, researchers often carry out experiments based on theory, but have difficulty achieving applied uptake of their work (Cooke et al., 2018; Ormerod et al., 2002). Standardization of dissemination for practice could help to give individuals and teams a clear place to offer and find information.

The restoration community recognizes that shared tools and approaches are needed to advance understanding of variation in restoration outcomes across diverse ecosystems. However, a challenge remains as to who will organize and lead the development of new information sharing tools and approaches? Ecological societies, networks, standards of practice and newly emerging platforms can and are playing a key role (Table 1). Creative solutions and tools to help

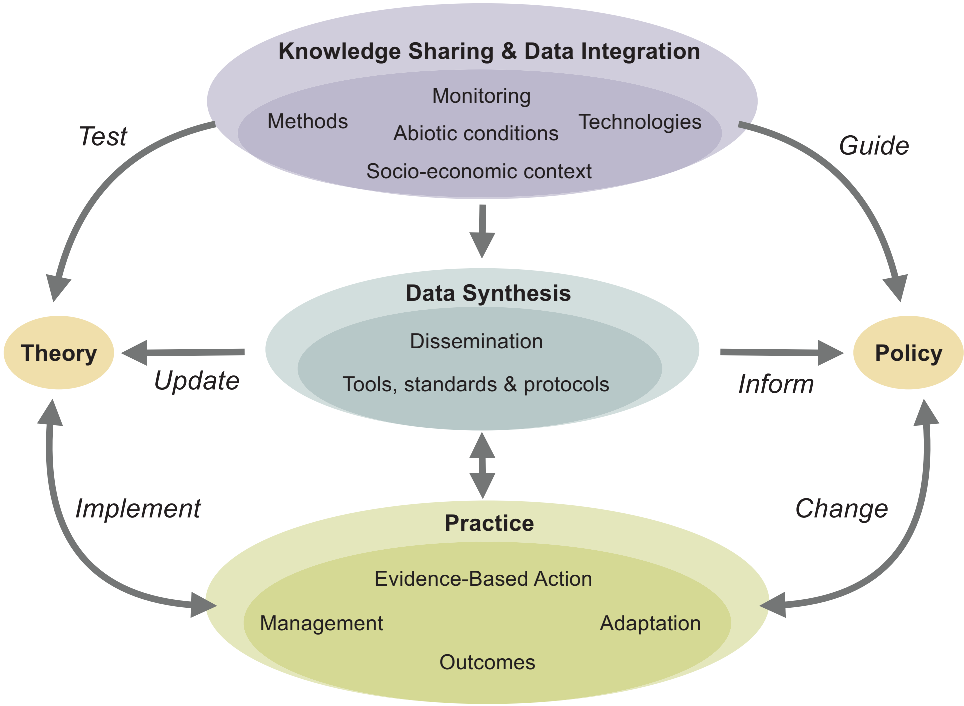

FIGURE 2 A conceptual figure showing the ideal workflow that links processes of knowledge sharing and data integration with theory, policy, dissemination and practice

provide baseline information to individuals in remote regions or on data-deficient regions generally are needed and synthesis could help contribute to this.

Featuring tools, standards and protocols in conferences through workshops and themed sessions is another important avenue for exchanging information. Applied journals can also help by giving practitioners more accessible forums to share practice, data and findings. By establishing and sharing developed tools and protocols, emerging technologies and the methods that employ them can be connected to monitoring data and restoration outcomes. However, tools that enable individuals and organizations to easily share, access and understand integrated open data resources on ecological restoration monitoring are still needed.

6 | KNOWLEDGE SHARING FOR SHARED SUCCESS

Open and integrated restoration knowledge and data can inform, test and update fundamental theoretical questions and, in turn, ecological theory can support restoration approaches and efforts (Temperton et al., 2004; Török & Helm, 2017; Walker et al., 2007; Young et al., 2001) (Figure 2). Community assembly is a clear example where theory provides a foundation for understanding restoration outcomes, and in turn, restored systems provide a rich testing ground for assembly theory (Delory et al., 2019; Grman & Brudvig, 2014; Martin & Wilsey, 2012; Young et al., 2001). However, connections between restoration ecology and other subfields of ecology, while potentially fruitful, remain sparse (Staples et al., 2019). With well-designed experiments and monitoring campaigns, data from restoration projects could in turn feedback to advance the development of new or updated theories and adaptive practical and empirical approaches in these subfields.

Knowledge sharing can help to directly inform restoration policy and decision-making, and policy can, in turn, support an open knowledge culture (Figure 2). Biodiversity trading programs (e.g. where restoration offsets are traded for habitat destruction) are being increasingly used as a policy tool, which increases restoration investment, but has uncertain outcomes (Bekessy et al., 2010; Suding, 2011), raising concerns about the practice as a policy mechanism (Curran et al., 2014; zu Ermgassen et al., 2019). Using data to test, for example, expected biodiversity outcomes based on standard restoration practice could better guide regulatory minimums. There also needs to be a clear message that restoration is not a 'magic bullet' for conserving biodiversity and functioning ecosystems (Cooke et al., 2018; Menz et al., 2013; Suding et al., 2015). Sharing restoration outcomes through both individual case studies and through synthesis of those case studies could normalize unexpected outcomes as learning experiences and encourage outcomes and monitoring that go beyond regulatory compliance in a development-offset context (Miller et al., 2017; Reid, 2018; Stevens & Dixon, 2017).

The goals of the Decade on Ecosystem Restoration are ambitious, requiring the synthesis of existing knowledge, strong partnerships and effective knowledge sharing. Sharing knowledge and experience requires us to commit to, incentivize and set-up systems for making data and knowledge accessible. Restoration networks are best placed to take a leading role in facilitating knowledge sharing across local, regional and international scales. Sharing this existing knowledge and data can directly inform actions and help improve outcomes for shared success. We call for all parties interested or engaged in restoration to consider the following action items:

1. Publish restoration project results and exchange knowledge and lessons learned no matter the outcome to normalize variable results;
2. Contribute raw data and metadata to an open-access global repository, even if it is not published in an academic journal;
3. Register your restoration project in the Society for Ecological Restoration (SER) Project Database (https://www.ser-rrc.org/project-database) so that others know about your work;
4. Promote funding opportunities for restoration science and long-term monitoring at large scales.

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CONFLICT OF INTEREST

The authors declare no conflict of interest. H.P.J. is a Lead Editor of Ecological Solutions and Evidence, but took no part in the peer review and decision-making processes for this paper. E.L. is on the board of the International Network for Seed-Based Restoration (INSR), a section of the Society for Ecological Restoration.

AUTHORS' CONTRIBUTIONS

E.L. and J.M.C. conceived the idea. E.L., J.M.C., N.S., G.P. and K.G. outlined contents of the manuscript. All other authors suggested ideas and helped shape the manuscript draft outline. E.L. wrote the first draft, and all authors contributed to rewriting and edits. E.L. retrieved data and performed analyses and made Figures 1 and 2.

DATA AVAILABILITY STATEMENT

Data from Web of Science (WoS) search are available from the FigShare Digital Repository: https://doi.org/10.6084/m9.figshare.17048207.v2 (Ladouceur, 2021).

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