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RE-NEW (OPINION) ARTICLE

The power of data synthesis to shape the future of the restoration community and capacity

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Restoration efforts will be taking place over the next decade(s) in the largest scope and capacity ever seen. Immense commitments, goals, and budgets are set, with impactful wide-reaching potential benefits for people and the environment. These are ambitious aims for a relatively new branch of science and practice. It is time for restoration action to scale up, the legacy of which could impact over 350 million hectares targeted for the U.N. Decade on Ecosystem Restoration. However, restoration still proceeds on a case-by-case, trial by error basis and restoration outcomes can be variable even under similar conditions. The ability to put each case into context—what about it worked, what did not, and why—is something that the synthesis of data across studies can facilitate. The link between data synthesis and predictive capacity is strong. There are examples of extremely ambitious and successful efforts to compile data in structured, standardized databases which have led to valuable insights across regional and global scales in other branches of science. There is opportunity and challenge in compiling, standardizing, and synthesizing restoration monitoring data to inform the future of restoration practice and science. Through global collation of restoration data, knowledge gaps can be addressed and data synthesized to advance toward a more predictive science to inform more consistent success. The interdisciplinary potential of restoration ecology sits just over the horizon of this decade. Through truly collaborative synthesis across foci within the restoration community, we have the opportunity to rapidly reach that potential and achieve extraordinary outcomes together.

Key words: database, Decade on Ecosystem Restoration, global analyses, meta-analysis, networks, synthesis

Implications for Practice

- Data synthesis is complementary to field-based research in ecology, but could be further leveraged to improve predictive capacity in ecological restoration.
- Synthesis in restoration has the power to bring together the global restoration community, to find patterns linked to sharedpractices, and important gaps that need rapid attention.
- The Global Arid Zone Project and the Global Restore Project are two emerging examples of structured, curated restoration databases working together, aiming to bring together data and people to synthesize global restoration knowledge.

Introduction

Ecological restoration has rapidly become a recognized complementary conservation action (Young 2000; Possingham et al. 2015; Wiens & Hobbs 2015), climate change solution (Bastin et al. 2019), policy requirement to offset development projects, and tool to combat habitat loss and degradation (Bekessy et al. 2010; Maron et al. 2012). The Decade on Ecosystem Restoration has been declared by the United Nations as one of their key Environment Program developments (United Nations Environment Programme [UNEP] & Food and Agriculture Organization of the United Nations [FAO] 2019). Combined with previous initiatives such as the Bonn Challenge, goals are to restore over 350 million hectares of land globally by the year 2030 (Fig. 1) (Temperton et al. 2019). Restoration is now seen as a potential source for job and skill creation, food security, ecosystem stability, and poverty alleviation and will be a major sink for international environmental spending into the future (United Nations Environment Programme [UNEP] & Food and

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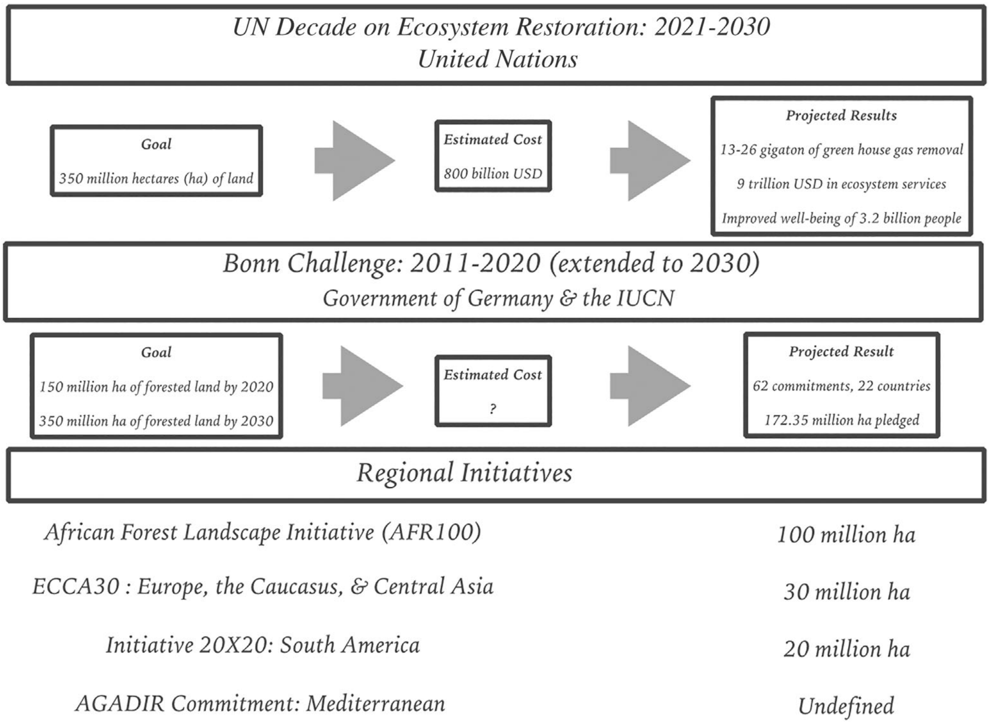

Figure 1. International targets that have been set for global restoration. Regional initiatives are land pledged to be restored as a part of the Bonn Challenge and the United Nations Decade on Ecosystem Restoration.

Agriculture Organization of the United Nations [FAO] 2019). Goals are ambitious and stakes are high. This scope of aspirations for restoration outcomes creates many roles to fill for a relatively new branch of scientific practice. There are questions as to whether many of these goals are achievable (Bastin et al. 2019; Temperton et al. 2019; Fagan et al. 2020) and both targets and approaches are being hotly debated. A call for public and intergovernmental action of this magnitude is also a call for science and practice to rapidly respond to fulfill burgeoning expectations (Suding et al. 2015).

Compiling and synthesizing data across projects and scales is a powerful approach that helps identify commonalities and knowledge gaps within broader restoration science, adding to the predictive understanding of successes and failures across a range of shared and diverging conditions (Brudvig 2017; Cooke et al. 2018). Restoration is, by necessity, a largely local action, but there is great variation among these small-scale outcomes (Stuble et al. 2017) that are not yet well-understood. To move forward, a global perspective of the current status of restoration project successes and failures (Reid et al. 2018), through the accumulation of data (Cooke et al. 2019), could be a powerful, complementary approach to local-scale projects and experiments. Research and practice can come together to collaboratively meet this challenge, through interdisciplinary approaches that bridge local expertise into global knowledge and shared advances (Palmer et al. 1997; Young et al. 2001; Temperton et al. 2004; Cooke & Suski 2008; Hallett et al. 2013; Wainwright et al. 2017; Hintzen et al. 2019; Staples et al. 2019).

The Role of Synthesis in Restoration

The strength of data synthesis to enhance local- and regional-scale actions is the ability for researchers and practitioners to compare restoration outcomes across common practices, similar treatments, environmental conditions, or restoration settings. There are several approaches that have been taken to synthesis in ecology; meta-analysis, database compilation, and coordinated experiments. The incredible power of coordinated experimental networks such as the Nutrient Network, a globally distributed nutrient addition experiment (Borer et al. 2014), has inspired emerging experimental examples such as RestoreNet (https://appliedeco.org/restorenet/), a distributed field trial network for dryland restoration, and DragNet (https://nutnet.org/dragnet), a distributed disturbance experiment. However, coordinated networks are difficult to launch and maintain, and often target a smaller subset of clearly defined questions. Data synthesis and database compilation are complementary to these coordinated efforts, and offer important and unique opportunities forward. Pooling data that assesses outcomes across a variety of temporal scales allows analyses beyond initial ecosystem dynamics into longer time settings (Crouzeilles et al. 2016). In doing so, common signals can be found across multiple scales and settings, providing a baseline set of predictors for restoration success (Cooke et al. 2018; Brudvig 2017; Suding et al. 2015, p. 201). Shared results can then be linked to historical contingencies, landscape context, or other site-level factors that can impact outcomes (Brudvig 2011). As restoration and pooled data resources expand in scope, the opportunities to investigate shared factors and outcomes expand as well.

Through collaborative synthesis, identifying gaps in restoration priorities, limitations in certain techniques or settings, and consistent leverage points for enhancing success can support strategic decisions ranging from the individual practitioner to regional biomes (Hulme 2014). Given the high cost and stakes for the restoration decade and beyond, identifying commonalities and gaps can guide strategic approaches to planning and reduce overall uncertainty, thus potentially maximizing resource use (Strassburg et al. 2019).

Meta-analysis and Synthesis

To date, there have been several powerful and informative meta-analyses and syntheses covering many aspects, systems, responses, and spatial and temporal scales in restoration (Jones & Schmitz 2009; Rey Benayas et al. 2009; Crouzeilles et al. 2016; Kollmann et al. 2016; Jones et al. 2018; Prach & Walker 2019) with more planned (Slodowicz et al. 2019). Meta-analysis can offer two powerful outcomes to science: to assess evidence for the effectiveness of particular interventions or hypothesized causal associations for a condition, or to reach broad generalizations to provide a more comprehensive picture than can be obtained from an individual study (Gerstner et al. 2017; Gurevitch et al. 2018). Meta-analysis is a particularly powerful tool as outcome magnitude (strength of treatment effects) and direction (positive or negative treatment effects) can be understood across response variables (Gerstner et al. 2017; Gurevitch et al. 2018) and across studies which otherwise might not be comparable due to differing methodology, temporal or spatial scales. However, meta-analyses are an analysis of analyses, in that they are reliant on effect sizes extracted from the analyzed results of each study. Where raw data are available, direct comparisons of outcomes allow more flexibility and nuance in both the questions posed to the data and the results extracted. These raw data can also be re-used and built upon for multiple syntheses, increasing value as a resource for the community.

Curated Databases

Over the last decade or so, structured database efforts in ecology and restoration have been on the rise. Notable examples include the U.S. National River Restoration Synthesis Database (Bernhardt 2005), the Restoring Europe's Rivers Database, the SER Restoration Project Database, the Australian Provenance Living Database, and the Land Treatments Digital Library (Welty & Pilliod 2013). The type of data included in these databases varies, from project descriptions and contacts through to raw monitoring data and detailed descriptions of restoration treatments. Information and conclusions gleaned from these databases has spanned both qualitative and quantitative spectra. Examples include important syntheses of project goals and budgets to assess priorities (Copeland et al. 2018), resource provision to community members (https://www.ser-rrc.org/project-database/), determining benchmarks for restoration references (Hering et al. 2010), and linking restoration success to key climate conditions at large scales (Pilliod et al. 2017). These advancements would have been unlikely without concerted efforts to accumulate data into curated repositories (Fig. 2). Yet the power of each effort has been limited by the data types available. The National River Restoration Synthesis Database found that of the 37,000 restoration projects collected in the database, only 10% recorded post-restoration monitoring data (Bernhardt 2005). The scope and breadth of restoration practices means that monitoring data are often sparse, rarely well documented, and difficult to standardize between disparate studies (Block et al. 2001; Bash & Ryan 2002; Herrick et al. 2006).

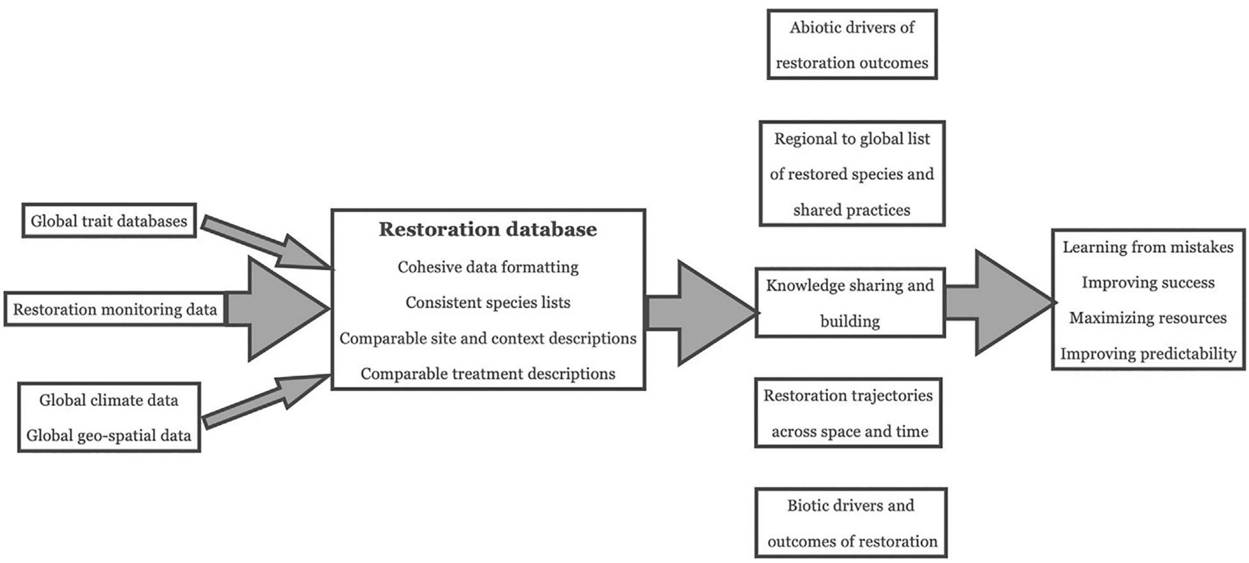

Figure 2. How data synthesis efforts in restoration can combine with other global data sources to gain predictive power in restoration, learn from mistakes, improve success, and maximize the use of data to strengthen predictive power.

Emerging Examples. Two emerging examples in restoration of structured, curated databases are the Global Arid Zone Project (GAZP) (www.drylandrestore.com) and the Global Restore Project (GRP) (www.globalrestoreproject.com). The GAZP began in 2018, and had the goal to bring together the restoration community operating in arid to semi-arid environments (~<750 mm average annual rainfall). The success of this project has been exceptional with over 160 participating restoration community members and 100 contributed datasets so far. The GRP began in 2019, and is focused on non-arid environments (~>750 mm average annual rainfall), with over 56 open access and contributed datasets included so far, and growing. These projects are commonly focused on restoration projects where seeding or planting has been applied as an active restoration treatment. Both projects are also integrating tandem active treatments (e.g. fire, weed control), as well as collecting both degraded and healthy reference site details and results wherever possible for a rich comparison framework. Both initiatives are maintaining separate operations and identities for the purpose of the communities on which they are based, but are working in partnership so that all data collected are formatted and normalized in the same way and can be analyzed together to ask a variety of questions across arid and non-arid environments (Fig. 3). These initiatives are modeled on the idea of usable, comparable, well-documented data with a long-term vision. The foundation of their growing success is a rich collaborative effort between restoration ecologists and practitioners, each of whom formats and contributes data from previous and ongoing projects.

Included in this data collection are detailed seeding treatment information, other active treatment details, and degraded and/or healthy reference site information (Fig. 3). This allows for questions to be asked focused on seeding success, but also community-based questions compared across treatments and to references. Taxonomic information is being normalized so that species-based questions can be asked. For example, in the existing GAZP database, there are clear commonalities in the species seeded into restoration projects. Though 40% of the 703 seeded species in the GAZP database are herbaceous forbs, that lifeform group represents only 22% of total seed input across all studies, likely due to the recognized difficulties in establishing forb species and relative expense of seed. There is opportunity to address filters to seed supply and use if biodiversity of keystone groups like perennial forbs are identified as a target of restoration projects (Ladouceur et al. 2018; White et al. 2018; Chapman et al. 2019).

User-friendly tools are under development that create links between contributed data and other global data sources, such as the TRY plant trait database (Kattge et al. 2011), the WorldClim (Fick & Hijmans 2017), and CHELSA (Karger et al. 2017) climate databases, as well as global topographic data. The result is a well-organized, relational database structure that allows flexible use, access, and expansion in the future.

Making the Most of Monitoring

Monitoring efforts within the restoration community are on the rise (McDonald et al. 2016) and there is increasing recognition that global syntheses are needed (Cooke et al. 2018, 2019). There is

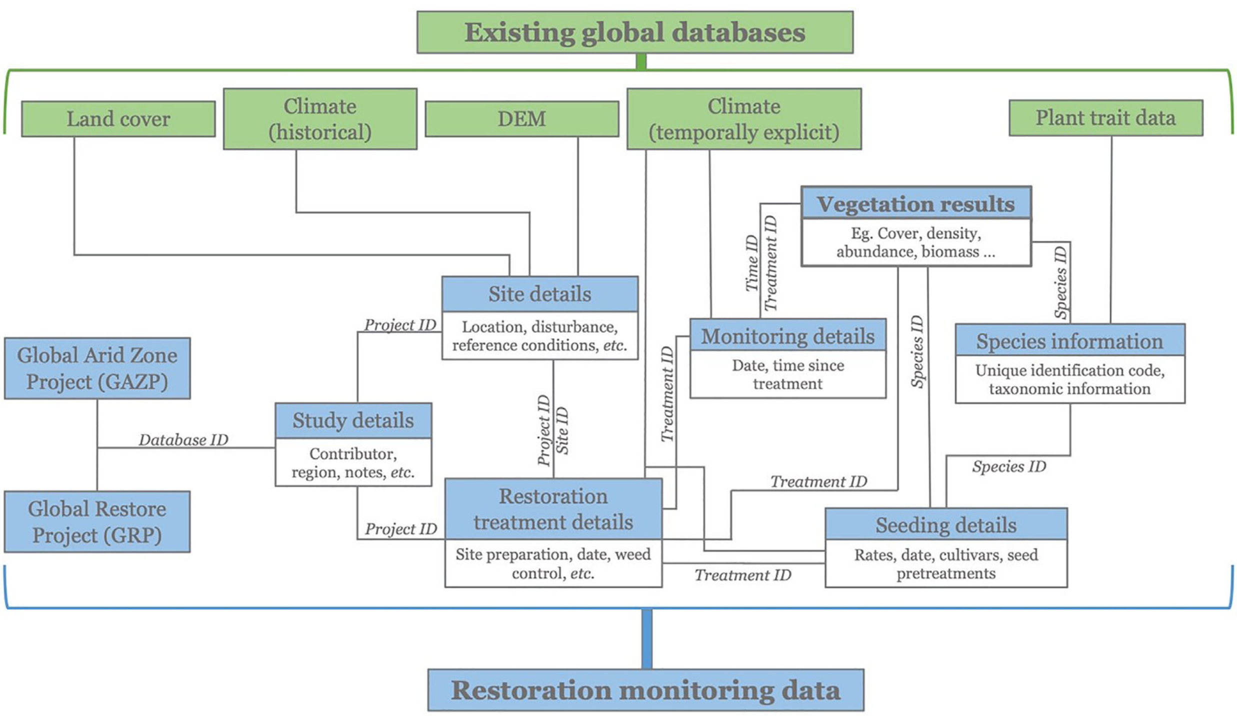

Figure 3. Two emerging examples of curated restoration databases are the Global Restore Project (GRP) and the Global Arid Zone Project (GAZP). This figure shows the coordinated consistent structure of each in blue and their coordinated connections to existing global databases in green.

now space and desire for the restoration community to curate data from multiple sources in order to maximize the learning potential of projects, monitoring, and ongoing efforts. Given the variety of restoration practitioners, from grassroots through to academia and government, there is potential to collect environmental and metadata that include failures (Suding 2011), which is underreported in scientific literature but provides key lessons in management practice about actions or conditions that may inhibit success. Additionally, data can span complex socio-ecological conditions, wide-ranging treatments, and varied budgets (Iacona et al. 2018). Biodiversity research has recently offered a prime example of a cohesive database with an ambitious and incredibly successful effort to compile and standardize local time series in order to track biodiversity change. The BioTime (Dornelas et al. 2018) database has collected over 8.5 million individual abundance records, comparable between time points, across studies, and across species. Analyses have emphasized disparate rates of biodiversity change between marine and terrestrial environments, and highlighted unexpected global patterns of biodiversity change (Blowes et al. 2019). Additional analyses have found increasingly rapid rates of both species loss and new establishment globally, and explored the balance of winners and losers in the Anthropocene (Dornelas et al. 2019). These kinds of databases, ranging from raw to transformed data, allow direct comparison across scales, offering some of the most powerful synthesis-based methods forward.

Future and Conclusions

To have data management with a long-term vision is to support the discovery and progress in science (Wilkinson et al. 2016). The FAIR data principles state that data should be (1) findable, (2) accessible, (3) interoperable, and (4) *re*-usable (Martone 2015). There are strategic ways to approach this, but seamless workflow solutions for this are still developing, and require extra effort from individual researchers (Reichman et al. 2011). It is important in a field such as restoration, where practice and science are deeply entwined (Cooke et al. 2018), that data also be accessible and usable for the non-academic community. Much of restoration practice and monitoring occurs outside of academic institutions, and ensuring a flow of knowledge with those sources will be pivotal to data-based advancement of predictive power in restoration science.

Taking a community-driven approach to these challenges would mean we can meet these challenges with the power of empirical evidence like never before. Linking data and knowledge resources through coordinated networks and global databases allows for collaborative, streamlined learning throughout the restoration community. Data are available, and underutilized, and with The Decade on Ecosystem Restoration upon us, the time is now to maximize understanding and predictive potential. Together, we can achieve extraordinary outcomes for the future of restoration science and practice, for over 350 million hectares of land, for the benefit of over 3.5 billion people, for future generations, and for climate.

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