Nature restoration legislation means redefining targets and forecasting progress

Running head

Nature restoration under legislation

Authors and affiliations

David Y. Shen[1, 2], Signe Normand[1, 2]

1. Center for Sustainable Landscapes Under Global Change, Department of Biology, Aarhus University, Ny Munkegade 114, DK-8000 Aarhus, Denmark

2. Section for Ecoinformatics & Biodiversity, Department of Biology, Aarhus University, Ny Munkegade 114, DK-8000 Aarhus, Denmark

Corresponding author

David Shen: david.shen@bio.au.dk

Author contributions

DS, SN conceived of the manuscript; DS wrote the initial version of the manuscript; all authors revised the manuscript

Abstract

Nature restoration is at a pivotal moment, driven by global initiatives like the EU Nature Restoration Law and the Kunming-Montreal Biodiversity Framework. These frameworks pose key challenges to how restoration targets are defined to ensure they are not only achievable and measurable but also resilient to future environmental changes. This requires addressing two key challenges: setting forward-looking restoration targets that account for dynamic environmental changes and developing methods to predict and forecast progress. We propose that restoration should focus on restoring ecosystem functions that represent the natural state based on current conditions, ecological history, and are resilient to future environmental change. Secondly, restoration efforts must be predictive, and we propose a two-stage process to predict outcomes prior to an intervention, and forecast progress over time. We argue that only by integrating these approaches, can restoration policies lead to large scale restoration for ecological recovery and long-term societal benefits.

Keywords

Nature restoration, restoration outcomes, biodiversity targets, temporal prediction, restoration legislation

Implications

- Large-scale and coordinated nature restoration driven by legislation should set targets for restoration based on missing ecological processes that are resilient to future conditions, rather than a historical or contemporary reference state
- Advancements in restoration prediction are urgently required so restoration measures and interventions can be evaluated so they lead to net positive outcomes
- Being able to quantitatively measure restoration success is crucial for accounting of restoration interventions towards national and international restoration targets

Introduction – International restoration targets

Ecological restoration, defined as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (Gann et al. 2019), has become a key aspect of international nature management and conservation strategies. Restoration is fundamental to transitioning towards a net positive outcome for nature by overcompensating biodiversity loss rather than simply preventing further decline (Bull et al. 2020). Restoration can counter climate change, restore natural capital and ecosystem services, and provide broad benefits to society and human health (Newbold et al. 2015; Breed et al. 2020; Bradbury et al. 2021). In recognition of these benefits, several global movements have pushed nature restoration into the spotlight, including the 2021-2030 UN declaration on the "Decade of Ecosystem Restoration" (UN General Assembly 2019), the 2022 Convention on Biological Diversity Kunming-Montreal Biodiversity Framework (KMBF) (CBD 2022), and most notably the EU Nature Restoration Law (EUNRL) in 2024 (European Commission 2024).

The EUNRL is unique in that it is a legal requirement, mandating each member state to restore 20% of total land area and 30% of "not in good condition" habitat area by 2030 (European Commission 2024), whereas previous commitments have been voluntary at best. The passing of nature restoration as a legal requirement makes successful implementation of passive and active restoration crucial from a political angle, in addition to the ecological perspective. Here we do not distinguish between active or passive restoration, in line with the EUNRL definition of restoration as "actively or passively assisting the recovery of an ecosystem" (European Commission 2024), and we use the term intervention to describe both.

For this law to be effective, it is necessary to reconsider the goals and strategies for restoration. Currently, the vast majority of restoration projects are site specific rather than at landscape level (von Holle et al. 2020). However, for these national and international restoration goals to be effective in transitioning society towards a nature-positive future, restoration needs to change to be part of a landscape-level and systematic process (Aronson et al. 2020). This is particularly important in the EU, where each member state has quantitative goals they must achieve and report on (European Commission 2024).

Additionally, both the EUNRL and KMBF refer to “restoration measures” and “effective restoration” to be in place by 2030 (European Commission 2024; CBD 2022). This leads to an important question of how the effectiveness of interventions can be measured, particularly considering that the ecosystem may take many decades to fully respond (Jones et al. 2018; Moreno-Mateos et al. 2020). Setting effective targets that are achievable and measurable is fundamental, as well as a way to predict the success of a restoration intervention so that it may be accounted towards the 20 and 30% targets set in the EUNRL and KMBF respectively (European Commission 2024; CBD 2022).

In this context, restoration under national and international goals should not be viewed as *the return* to a specific state of the environment. Instead, it should be seen as *the process* that guides an ecosystem towards a net positive and resilient state. This leads to two critical questions: how do we define what the targets for restoration should be, and how can we assess whether ecosystems are progressing in that direction?

Redefining targets - What should the end of the line be?

Targets and references are fundamental for restoration efforts as the success of a restoration effort can only be measured by comparing the current state, to the target or reference state. Traditionally, restoration has sought to return an ecosystem to a pre-disturbance or even pre-human state, evident in early definitions of ecological restoration defining it as “the intentional alteration of a site to establish a defined indigenous, historic ecosystem” (as cited by Aronson et al., 1993). However, over time this has shifted to be more inclusive of future conditions and the changing role of ecological restoration. The most recent definition by the Society for Ecological Restoration defines ecological restoration as “the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed” (Gann et al. 2019). The removal of references towards a “indigenous, historic ecosystem” broadens the scope of restoration to be any action that seeks to assist the recovery of an ecosystem, rather than returning to a specific historical state.

However, while the paradigm has started to shift in definition, in practice the use of present and past reference states is pervasive. A review by Shackelford et al., (2021) found that more than 90% of restoration efforts used contemporary references to measure success, and a mix of historical and contemporary references for goal setting. Only a tiny minority considered any kind of future states.

The question is then why is this an issue? This was discussed by Choi (2004) on what it meant for restoration to be "futuristic". Rather than setting goals based on the past or present, in the context of ongoing global change, restoration should seek to set dynamic goals for the future (Choi 2004). This was also discussed by Reyes-Aldana (2024), stating that the historic reference state, or "Pristine Reference State" (PRS) , sets an unrealistic and unachievable goal for restoration, disregarding the dynamic and variable nature of ecosystems. Instead, restoration should aim to create resilient, functional ecosystems using a more holistic approach (Choi 2007). This accepts that restored ecosystems may differ in structure and composition compared to the historical state, but prioritises functions that ensure their persistence in the face of future environmental changes and help mitigate global change (Choi 2007; Harris et al. 2006). This can be described as Futuristic Restoration, as coined by Choi (2004).

Futuristic Restoration is not to say the historical state should be disregarded. On the contrary, it is crucial that the historical state be considered to inform what the intervention should seek to recreate (Manzano et al. 2020; Higgs et al. 2014). The value of the historical state lies in its contextualisation of what should be considered natural for the local conditions (Willis & Birks 2006; Willis et al. 2007, 2010). This fundamentally differs to the philosophy of the PRS, where the historical state is assumed to be better purely because it is historical. Therefore, historical information is crucial for understanding what complexities and functions the restored ecosystem should reproduce, given the environmental context (Higgs et al. 2014; Fuller et al. 2017).

In the realm of endangered species conservation, Jachowski et al. (2015) operationalised a decision framework describing when the historical state should be pragmatically abandoned, to ensure long term species persistence into a changing future. We argue that such a framework should be adopted in ecosystem restoration, to help ecosystems persist into a changing future and maintain their functions. Among practitioners, views are already shifting towards supporting frameworks that take into account expected losses and greater ecosystem novelty (Hagerman & Satterfield 2014).

Achievability of restoration is also crucial from a legislative effectiveness lens. Both the EUNRL and KMBF have defined goals for restoration, targeting 20 and 30% respectively of land under restoration by 2030 (CBD 2022; European Commission 2024). Atkinson et al. (2022) found that globally, restoration efforts rarely ever reached their reference states, indicating that there is likely a mismatch between what is aspired to, i.e. historical or contemporary reference states, and what is achievable. If the restoration reference states are inherently unachievable, then this may damage the political effectiveness of the legislative efforts to spur restoration. By contrast, if the goals are to undertake achievable Futuristic Restoration, then the 20 and 30% area targets are more able to succeed in driving large-scale restoration.

In concert, these efforts to restore nature through futuristic and achievable interventions, informed through ecological history, enable directly actionable efforts for restoration. This provides an approach by which practitioners can modify degraded landscapes, and national and international governments to track and account restoration towards pre-defined goals.

Restoration predictions and forecasting - Predicting nature recovery over time

As previously discussed, ecosystems can take a long time to fully respond to restoration interventions, so while the intervention may happen immediately, the nature benefit may not materialise for many decades. However, if we can accurately predict that an intervention will eventually lead the ecosystem to a net positive outcome, the intervention should be considered successful. Article 4 of the EUNRL stipulates “restoration measures shall be put in place” by 2030 (European Commission 2024), and so for measures to count, outcome prediction is key.

For national governments to deem a restoration measure successful, predictive methods are needed to identify what sites are suitable for restoration, taking into consideration potential future conditions, as well as the likely success of an intervention. Inspired by the modelling cycle for restoration proposed by Brudvig & Catano (2021), we propose a prediction and forecasting framework, with the novelty of dividing the framework into two key predictive stages, to address the needs of legislation to be the most effective (figure 1).

The first stage is *a priori* “Restoration Outcome Prediction”, where the aim is to predict the likely outcomes of a restoration project prior to any intervention. Here, the current and future environmental conditions should be considered to evaluate likely outcomes possible for the restoration site, and what interventions could lead to desirable outcomes. This is where targets should be set, in line with the Futuristic Restoration perspective previously discussed. This form of prediction is particularly key for legislation effectiveness, as *a priori* Restoration Outcome Prediction can be used for restoration prioritisation; prioritising sites that that are likely to be the most positive for nature recovery, and have the lowest uncertainty for success. Communicating uncertainty is also crucial for legislation to be trustworthy, encourage local participation, and maintain political capital for restoration. Given limited financial, human, and political resources, efficiently prioritising restoration through *a priori* predictions is key for these legislative efforts to spur widespread restoration. In the case of the EUNRL specifically, evaluating the current and potential future environmental conditions will inform the type of habitats that can be restored, given the law stipulates the restoration of currently degraded habitats as defined in the EU Habitats Directive. Current methodologies for Restoration Outcome Prediction are limited, and should be a key target for future research.

The second stage is "Recovery Forecasting", with the aim of predicting the rates of recovery and trajectories post intervention and using ongoing monitoring information. With predictive forecasting, restoration efforts can be monitored to ensure that they are on track to reach the desired outcome based on targets set using Restoration Outcome Prediction. This is crucial information for the ongoing management of a restoration site; if the current intervention is unlikely to reach the desired outcome, management strategies can then be adjusted to change the rate and trajectory of recovery (Brudvig 2017). This also provides an opportunity for targets to be adjusted should the initially defined target be deemed infeasible due to ecological limitations or resource constraints. Methods for Recovery Forecasting already exist, such as those by Rydgren et al. (2019) using an ordination regression approach, and Sinclair et al. (2018) proposing a restoration index.

Brudvig & Catano (2021) describe the six key challenges currently limiting our ability to model restoration – 1. Unclear Goals, 2. Outcomes Vary, But Why, 3. Model Parameter Limits, 4. Model Uncertainty, 5. Scaling Up and Out, 6. Conditions Change Over Time – and we reiterate the need for these six challenges to be addressed. We argue that our approach for target setting adequately addresses challenge 1. The remaining challenges lay in the methodological realm, and so significant advancements could be made without the need for additional and bespoke data collection. Large databases of global biodiversity such as PREDICTS by Hudson et al. (2014) may be used to identify mechanistic drivers of restoration variability – Challenge 2 and 6, and hindcasting methods using existing restoration effort data may be used to test potential new methodologies – Challenge 3 and 4 in Brudvig & Catano (2021).

Conclusions

The push towards nature restoration since the 2020s, exemplified by the UN's Decade of Ecosystem Restoration and the EUNRL, marks a pivotal moment in the field of restoration ecology. These global movements require nature restoration to shift focus away from being a localised and ad hoc process, to being predictive and systematically planned; the articles within the EUNRL require habitats to be considered at landscape-level, requiring a high level of coordination.

Our suggested approaches for determining targets for restoration make a significant break from the current paradigm of comparing with contemporary and historical states, however we argue this enables more achievable restoration, as well as more resilient ecosystems in a changing world. Secondly, we argue that significant advances in predicting restoration outcomes both before and after an intervention are crucial to enable the scaling up of restoration and should be the key target for future research. By adopting a future-thinking and predictive approach like this, integrating ecological theory with natural history, these policies can lead to large-scale restoration, provide ecological and societal benefits, and help transition towards a nature positive future.

Acknowledgements

We thank Joe Atkinson, Jonas Trepel and Pablo Villalva for helpful feedback on an earlier draft of this manuscript. This work is a contribution to SustainScapes – Center for Sustainable Landscapes under Global Change (grant NNF20OC0059595 to SN).

Figures

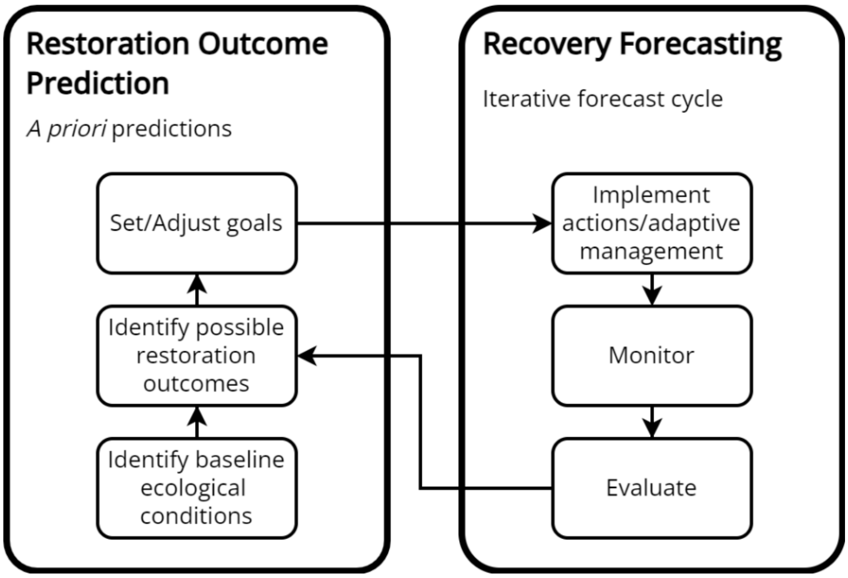

Figure 1 Flowchart of monitoring and adaptive management of nature restoration. Key is the division of the stages of adaptive management into: 1. An *a priori* stage for predicting the outcomes of restoration prior to the start of an intervention, and identifying potential outcomes and goals, 2. An *a posteriori* forecasting stage to monitor the effect of intervention actions, rate of recovery and ongoing trajectory. Monitoring and evaluation of restoration sites are important, however here we focus on how they link to the two stages of predictive modelling.

Literature cited

Aronson J, Floret C, Le Floc'h E, Ovalle C, Pontanier R (1993) Restoration and Rehabilitation of Degraded Ecosystems in Arid and Semi-Arid Lands. I. A View from the South. Restoration Ecology 1:8–17

Aronson J, Goodwin N, Orlando L, Eisenberg C, Cross AT (2020) A world of possibilities: six restoration strategies to support the United Nation's Decade on Ecosystem Restoration. Restoration Ecology 28:730–736

Atkinson J, Brudvig LA, Mallen-Cooper M, Nakagawa S, Moles AT, Bonser SP (2022) Terrestrial ecosystem restoration increases biodiversity and reduces its variability, but not to reference levels: A global meta-analysis. Ecology Letters 25:1725–1737

Bradbury RB, Butchart SHM, Fisher B, Hughes FMR, Ingwall-King L, MacDonald MA *et al.* (2021) The economic consequences of conserving or restoring sites for nature. Nature Sustainability 4:602–608

Breed MF, Cross AT, Wallace K, Bradby K, Flies E, Goodwin N, Jones M, Orlando L, Skelly C, Weinstein P, Aronson J (2020) Ecosystem Restoration: A Public Health Intervention. Ecohealth 18:269

Brudvig LA (2017) Toward prediction in the restoration of biodiversity. Journal of Applied Ecology 54:1013–1017

Brudvig LA, Catano CP (2021) Prediction and uncertainty in restoration science. Restoration Ecology e13380

Bull JW, Milner-Gulland EJ, Addison PFE, Arlidge WNS, Baker J, Brooks TM *et al.* (2020) Net positive outcomes for nature. Nature Ecology & Evolution 4:4–7

CBD (2022) The Kunming-Montreal Global Biodiversity Framework.

Choi YD (2007) Restoration Ecology to the Future: A Call for New Paradigm. Restoration Ecology 15:351–353

Choi YD (2004) Theories for ecological restoration in changing environment: Toward ‘futuristic’ restoration. Ecological Research 19:75–81

European Commission (2024) Nature Restoration Law PE-CONS 74/23.

Fuller RJ, Williamson T, Barnes G, Dolman PM (2017) Human activities and biodiversity opportunities in pre-industrial cultural landscapes: relevance to conservation. Journal of Applied Ecology 54:459–469

Gann GD, McDonald T, Walder B, Aronson J, Nelson CR, Jonson J *et al.* (2019) International principles and standards for the practice of ecological restoration. Second edition. Restoration Ecology 27:S1–S46

Hagerman SM, Satterfield T (2014) Agreed but not preferred: expert views on taboo options for biodiversity conservation, given climate change. Ecological Applications 24:548–559

Harris JA, Hobbs RJ, Higgs E, Aronson J (2006) Ecological Restoration and Global Climate Change. Restoration Ecology 14:170–176

Higgs E, Falk DA, Guerrini A, Hall M, Harris J, Hobbs RJ, Jackson ST, Rhemtulla JM, Throop W (2014) The changing role of history in restoration ecology. Frontiers in Ecology and the Environment 12:499–506

von Holle B, Yelenik S, Gornish ES (2020) Restoration at the landscape scale as a means of mitigation and adaptation to climate change. Current Landscape Ecology Reports 5:85–97

Hudson LN, Newbold T, Contu S, Hill SLL, Lysenko I, De Palma A *et al.* (2014) The PREDICTS database: a global database of how local terrestrial biodiversity responds to human impacts. Ecology and Evolution 4:4701–4735

Jachowski DS, Kesler DC, Steen DA, Walters JR (2015) Redefining baselines in endangered species recovery. The Journal of Wildlife Management 79:3–9

Jones HP, Jones PC, Barbier EB, Blackburn RC, Rey Benayas JM, Holl KD, McCrackin M, Meli P, Montoya D, Mateos DM (2018) Restoration and repair of Earth’s damaged ecosystems. Proceedings of the Royal Society B: Biological Sciences 285:20172577

Manzano S, Julier ACM, Dirk CJ, Razafimanantsoa AHI, Samuels I, Petersen H, Gell P, Hoffman MT, Gillson L (2020) Using the past to manage the future: the role of palaeoecological and long-term data in ecological restoration. Restoration Ecology 28:1335–1342

Moreno-Mateos D, Alberdi A, Morriën E, van der Putten WH, Rodríguez-Uña A, Montoya D (2020) The long-term restoration of ecosystem complexity. Nature Ecology & Evolution 4:676–685

Newbold T, Hudson LN, Hill SLL, Contu S, Lysenko I, Senior RA *et al.* (2015) Global effects of land use on local terrestrial biodiversity. Nature 520:45–50

Reyes-Aldana HE (2024) Restoration conundrum: between nostalgia and futuralgia, moving beyond the reference state. Restoration Ecology 32:e14071

Rydgren K, Halvorsen R, Töpper JP, Auestad I, Hamre LN, Jongejans E, Sulavik J (2019) Advancing restoration ecology: A new approach to predict time to recovery. Journal of Applied Ecology 56:225–234

Shackelford N, Dudney J, Stueber MM, Temperton VM, Suding KL (2021) Measuring at all scales: sourcing data for more flexible restoration references. Restoration Ecology

Sinclair A r. e., Pech RP, Fryxell JM, McCann K, Byrom AE, Savory CJ *et al.* (2018) Predicting and Assessing Progress in the Restoration of Ecosystems. Conservation Letters 11:e12390

UN General Assembly (2019) United Nations Decade on Ecosystem Restoration (2021-2030).

Willis KJ, Araújo MB, Bennett KD, Figueroa-Rangel B, Froyd CA, Myers N (2007) How can a knowledge of the past help to conserve the future? Biodiversity conservation and the relevance of long-term ecological studies. Philosophical Transactions of the Royal Society B: Biological Sciences 362:175–187

Willis KJ, Bailey RM, Bhagwat SA, Birks HJB (2010) Biodiversity baselines, thresholds and resilience: testing predictions and assumptions using palaeoecological data. Trends in Ecology & Evolution 25:583–591

Willis KJ, Birks HJB (2006) What Is Natural? The Need for a Long-Term Perspective in Biodiversity Conservation. Science 314:1261–1265