RESTORATION ECOLOGY
The Journal of the Society for Ecological Restoration

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POLICY ARTICLE

International principles and standards for the practice of ecological restoration. Third edition

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Abstract

Introduction: Growth in understanding of ecological restoration necessitates updated guidance for effective, equitable, and outcome-oriented restoration across terrestrial, inland water, and coastal and marine ecosystems. The third edition of the Society for Ecological Restoration (SER) International Principles and Standards for the Practice of Ecological Restoration provides an expanded, evidence-based framework for ecological restoration aligned with the United Nations Decade on Ecosystem Restoration and other global frameworks.

Objectives: This revision clarifies terminology, updates Principles with current science and practice, provides expanded Standards of Practice, and improves the Five-star System.

Methods: While key elements of the previous version were retained, substantial revisions were made.

Results: This document synthesizes eight Principles of ecological restoration and details Standards of Practice spanning assessment, planning, implementation, ongoing management, and monitoring and evaluation. Standards are applicable across ecosystems and biomes, sectors, and diverse social and cultural contexts. Included are: (1) a clarified definition of ecological restoration emphasizing recovery of native ecosystems; (2) refined terminology and updated Standards of Practice; (3) zero-star baselines and increased quantification of the Five-star System; (4) an

Author contributions: GDG, BW coordinated production of the document and solicited reviews of the first edition, second edition, and subsequent drafts; GDG, TM, BW, JA, CRN, JGH, MRG, EKG, FH, CE, DCB, MB, JC-S, RC, HK, KM, AM, SP, RY, KWD wrote sections of the text; JL, KD, ZEB, AC clarified sections of the text.

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doi: 10.1111/rec.70441

updated Restorative Continuum that refines the relationships between restorative activities and major restoration types and illustrates application to all major ecosystem types; and (5) expanded discussion of several complex topics.

Conclusions: Applying the SER Standards can help reduce risk and uncertainty and enhance ecological restoration outcomes, including creating synergies with other restorative and conservation activities.

Implications for Practice: Ecological restoration is inherently uncertain; applying best practices through standards can help reduce uncertainty and its associated risks, thereby enhancing outcomes. This is recognized in key guidance for the Kunming-Montreal Global Biodiversity Framework and other global restoration initiatives. The Standards include eight principles (Section 2), which help practitioners frame their work, while providing regulators, funders, and project owners with the foundational information needed to effectively direct and oversee projects. The Standards of Practice (Section 3) provide practitioners with detailed guidance for project assessment, planning, implementation, ongoing management, and monitoring. Section 4 expands on key topics, including developing reference models, landscape and seascape restoration, and restoration finance. Appendices address seed provenance and restoration supply chains.

Key words: ecological restoration, ecosystem restoration, Five-star System, native ecosystems, reference models, restoration projects, Restorative Continuum

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Front matter

The Society for Ecological Restoration (SER) is a global nonprofit organization that gives a voice to the field of ecological restoration, defines and drives its excellence, and provides leadership in all aspects of its development. With a dynamic global network of over 5000 members in more than 130 countries, SER establishes a forum to connect researchers, practitioners, land managers, community leaders, scientists, and decision-makers from diverse disciplines and backgrounds, fostering knowledge exchange and collaboration to restore ecosystems.

Through its publications, conferences, outreach, partnerships, resources, promotion of best practices and effective restoration policy around the world—as well as communication of leading-edge tools, technologies, and scientific findings—SER advances the science, practice, and policy of ecological restoration to sustain biodiversity, improve resilience in a changing climate, and reestablish an ecologically healthy relationship between nature and culture.

Partners. SER collaborates with a wide spectrum of partners to develop and deliver guidance to elevate standards-based ecological restoration. Key partners in the development of these Standards include SER-Australasia, The Institute for Regional Conservation, the International Union for Conservation of Nature (IUCN) Commission on Ecosystem Management, The United Nations Decade on Ecosystem Restoration task forces on Best Practices and Monitoring, The UN Convention on Biological Diversity Target 2 Roadmap, The Global Biodiversity Standard (TGBS), SCOR SE, and many author institutions.

Document development. The *International Principles and Standards for the Practice of Ecological Restoration* (the Standards) were originally launched in 2016 (McDonald et al. 2016a), followed by the second edition in 2019 (Gann et al. 2019). The second edition has been downloaded more than 120,000 times from the journal *Restoration Ecology*, the SER website, and other sources. It has been cited more than 2300 times (Google Scholar as of May 2026), and is a key document supporting the UN Decade on Ecosystem Restoration, Target 2 of the Kunming-Montreal Global Biodiversity Framework (KM-GBF), TGBS, and other key agreements, initiatives, and guidance.

The third edition of the Standards has been developed through ongoing feedback and review since the publication of the second edition, which has been supplemented by formal and informal consultation with restoration professionals within SER and across the global science, practice, and policy communities. Inputs for this third edition have been gathered at high-level events and fora, such as SER World Conferences on Ecological Restoration, regional fora (such as SER and partner regional conferences), training workshops, and direct email communications. In addition, feedback from published critiques in Restoration Ecology and other peer-reviewed outlets was recorded into a curated database by University of Victoria (Canada) students Lalena Dexter and Alex Vial, and then information in the database was used to identify major areas of work for this third edition.

The SER Science and Policy Committee (SPC) provided oversight of the revision process. This third edition of the Standards was approved by the SER SPC. As with previous editions, these Standards remain a living document. This version will be revised and improved as the ecological restoration discipline evolves through science, practice, and adaptive management, on a timeline of approximately 5 years to the next revision.

Background

The Standards expand upon and update SER's collection of foundation documents including the *SER International Primer on Ecological Restoration* (SER 2004), *Guidelines for Developing and Managing Restoration Projects* (Clewell et al. 2005), *Ecological Restoration—a Means of Conserving Biodiversity and Sustaining Livelihoods* (Gann & Lamb 2006), *Ecological Restoration for Protected Areas: Principles, Guidelines and Best Practices* (Keenleyside et al. 2012) and several books published in SER's book series on *The Science and Practice of Ecological Restoration* (Island Press; e.g. Palmer et al. 2016, Holl 2020).

The Standards also utilize SER's *Code of Ethics* (SER 2022) and specifically draw on material and models in the *National Standards for the Practice of Ecological Restoration in Australia* (McDonald et al. 2016b, Standards Reference Group SERA 2021). This third edition of the Standards incorporates new guidance published by SER and partners since 2019 including:

- *International principles and standards for native seeds in ecological restoration* (Pedrini & Dixon 2020);
- *Principles for ecosystem restoration to guide the United Nations Decade 2021–2030* (FAO et al. 2021);
- *Restoration project information sharing framework* (Gann et al. 2022);
- *International principles and standards for the ecological restoration and recovery of mine sites* (Young et al. 2022);
- *WWF-SER standards for the certification of ecological restoration projects for forests in Spain, V 4.0* (Colomina et al. 2023);
- *The Global Biodiversity Standard (TGBS): Manual for assessment and best practices* (Bartholomew et al. 2024);
- *Delivering outcomes for biodiversity and human well-being—Resource guide to Target 2 of the KM-GBF* (FAO et al. 2024);
- *Standards of Practice to guide ecosystem restoration—A contribution to the United Nations Decade on Ecosystem Restoration 2021–2030* (Nelson et al. 2024).

In addition to publications cited in the second edition, recent works published in *Restoration Ecology* and elsewhere, the SER Restoration Resource Center, and many other documents have also informed development of this edition (e.g. Falk 2017; Higgs et al. 2018; Young et al. 2019; de Siqueria et al. 2021; Chazdon et al. 2021; IPCC 2021; Valderrábano et al. 2021; Hua et al. 2022; Seidl & Turner 2022; Meli et al. 2023; Thorogood et al. 2023; Echeverria & Nelson 2024; Eisenberg et al. 2024; Liu et al. 2024; Maes et al. 2024; Mansourian

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et al. 2024; Chazdon et al. 2025; Holl et al. 2025; Peddle et al. 2025). Citations of published sources are minimized throughout the document, particularly Sections 1–3 to optimize readability by a non-academic audience. Several complex topics introduced in Sections 1–3 are expanded and cited in Section 4.

Since the second edition of the Standards was published in 2019, the UN Decade on Ecosystem Restoration (2021–2030) was launched. It is important to clarify that the Standards provide guidance and best practices specific to the practice of ecological restoration, the type of restoration that aims to recover native ecosystems, whereas ecosystem restoration includes a broad array of restorative activities as articulated in the Restorative Continuum (Introduction, Principle 8). As such, this third edition is drafted to be compatible with the broader guidance documents mentioned above that were co-produced by FAO, SER, IUCN, and others for the UN Decade including the Principles (FAO et al. 2021) and Standards of Practice (Nelson et al. 2024). The Standards are also compatible with broader guidance documents for conservation, including The Open Standards for the Practice of Conservation V 5.0 (Conservation Measures Partnership 2025).

Contributors. Justin Jonson was an author of the first and second editions; Nancy Shaw was an author of the second edition. Kayri Havens contributed to Appendix 1 on selection of seeds and other propagules for the second edition. We thank the following translators of the first or second editions: Claudia Concha, Marcela Bustamante, and Cristian Echeverría (Spanish—1st edition); José Ignacio Barrera Cataño, Lilia Lisseth Roa Fuentes, Germán Leonardo Jiménes Romero, Gildardo de Jesús Arango, and Ana Milena Lozano Melgarejo (Spanish—2nd edition); Ricardo Cesar (Portuguese—1st edition); Luiz Fernando Duarte de Moraes, Vera Lex Engel, Rafael Barreiro Chaves, and Jerônimo Boelsums Barreto Sansevero (Portuguese—2nd edition); Narayana Bhat (Arabic—1st edition); Jaeyong Choi (Korean—1st edition); Korean Nation Arboretum—Young-Eun Kim, Jae-Hyun Kim, Kae-Sun Chang, Sang-Jun Kim, Dong-Hak Kim, and Jae-Sang Chung (Korean—2nd edition); Junguo Liu, Delong Li, and Xuejing Zhang (Chinese—2nd edition); Jean-François Alignan, Julie Braschi, Élise Buisson, Jacqueline Buisson, Manon Hess, Renaud Jaunatre, Maxime Le Roy, Sandra Malaval, and Réseau d'Échanges et de Valorisation en Écologie de la Restauration (REVER) (French—1st edition); Alice Dubuisson, Julien Lassauque, and Stéphane Rivière (French—2nd edition); Melinda Halassy (Hungarian—2nd edition); Mykhailo Paslavskyi (Ukrainian—2nd edition); Mohammad Farzam (Farsi—2nd edition).

Jen Lyndall, Robert Cox, Stefanie Wacker, Jeff Cadry, Paula Capece, Akasha Faist, Elise Gornish, Kevin Gunnel, Dawn LaFleur, and Erin Shanahan contributed to the calibration of the Five-star System for specific ecosystems or biomes (Principle 6). Diana Colomina, María Melero, Natalia Cagide, and Juan Gorostidi Colás assisted with significant upgrades to Section 3. Stephanie Mansourian contributed to Box 11 in Section 4, Part 2.

Reviewers. Many international experts provided suggestions for the development of the third edition. The views expressed here are those of the authors, and not necessarily those of the reviewers. Karma Bouazza and Luiz Fernando Duarte de Moraes provided thoughtful reviews of the entire document. Meghan Dopping-Ward, Robert Heinzman, Karen Holl, Kundan Kumar, Harold Manrique Hernandez, Stephanie Mansourian, Sathya Raghu V Mokkapati, Nancy Shaw, Ryan Szuch, Ramesh Venkataraman, and Alvaro Zapata Cadavid contributed to or provided critical reviews of key sections. Martin Breed, Francis Kilkenny, Suzanne Prober, Maurizio Rossetto, and Cuauhtémoc Sáenz-Romero reviewed Appendix 1. The published manuscript greatly benefited from peer review by Donald A. Falk, especially in relation to better emphasizing the intrinsic value of Nature and clarifying ecosystem change and alternative states, and by an anonymous reviewer, especially in relation to marine ecosystems and scaling out, scaling up, and scaling deep in both marine and terrestrial settings.

Executive Summary

Ecological restoration, when implemented effectively and sustainably, contributes to protecting and recovering biodiversity; enhancing ecosystem integrity; improving human health and wellbeing; increasing food and water security; maintaining and augmenting the quality and quantity of ecosystem goods and services; contributing to economic prosperity; and

Box 1 Why Standards?

In response to rapidly growing demand for and uptake of ecosystem restoration globally, and the need for specific guidance to support the application of ecological restoration specifically, these Standards provide a foundation for and common understanding of ecological restoration. Application of these principles and standards can help increase the effectiveness of ecological restoration by establishing recommended practices across different contexts and ecosystem types. They also provide an adaptable framework that engages interested and affected parties and respects local social-economic and cultural contexts and needs so that restoration goals and methods are tailored to specific conditions within the area selected for restoration.

The Standards are aspirational and provide tools that are intended to improve outcomes, promote best practices, reduce risk and uncertainty, and deliver net global benefits for nature and people. The Standards underlie the practice of ecological restoration and help distinguish ecological restoration from other practices along the Restorative Continuum (Introduction, Principle 8). Unless legally required, following standards in restoration is voluntary. Standards are not intended to stifle or limit innovation and creativity, but rather to encourage anyone implementing restoration, anywhere along the continuum, to utilize globally understood and accepted approaches and practices as the common foundation underlying their work.

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supporting climate change mitigation, adaptation, and resilience. It is an evidence-based approach that addresses historical and ongoing degradation, repairs ecological damage, respects and engages Indigenous and local communities, and rebuilds healthy relationships between people and the rest of nature. When combined with conservation and sustainability, ecological restoration moves local, national, and global environmental conditions from a trajectory of continuing degradation to one of net positive improvement. This third edition of the *International Principles and Standards for the Practice of Ecological Restoration* (the Standards) presents a robust framework for ecological restoration projects to achieve intended goals; addresses challenges to effective assessment, planning, implementation, ongoing management, and monitoring; accounts for complex ecosystem dynamics (including in the context of climate change); and supports balancing tradeoffs associated with restoration decisions and priorities, such as potential conflicts between the recovery of biodiversity and the delivery of provisioning ecosystem services.

SER, together with partners, produced the Standards for adoption by practitioners, managers, scientists, educators, communities, industries, governments, policymakers, regulators, and funders to improve ecological restoration practice across all sectors and in all ecosystems, including terrestrial, freshwater or other inland waters, and coastal and marine. The Standards support the development of ecological restoration plans, contracts, consent conditions, and monitoring and auditing criteria (Box 1). Generic in nature, the Standards can and have been adapted to specific ecosystems, biomes, and landscapes; economic sectors; individual countries; and social and cultural contexts and systems. However, as an underpinning assumption to everything in these standards, it is critical to note that the *potential for ecological restoration should never be invoked as a justification for destroying, damaging, or unsustainably using existing native ecosystems*.

Section 1 describes the purpose, key definitions, and framework for ecological restoration, as well as the updates in this edition of the Standards. Section 2 outlines eight fundamental principles that guide effective ecological restoration practice. Principles 1 and 2 articulate the importance of effectively engaging a wide range of interested and affected parties and utilizing available Indigenous Knowledge (IK), Local Ecological Knowledge (LEK), practitioner knowledge, and scientific knowledge. Principles 3 and 4 summarize the central approach to ecological restoration by highlighting that the aim of ecological restoration is the recovery of native ecosystems informed by the use of reference models and emphasizing the imperative for restoration activities to address drivers of degradation and support natural recovery processes. Principle 5 underscores the need to set clear goals and objectives in restoration, and the use of measurable indicators to assess progress toward ecological and social goals. Principle 6 lays out the mandate for ecological restoration to seek the highest attainable and desirable level of recovery within the project's social-ecological context; this section also provides tools to track restoration progress in relation to key ecosystem attributes, which were first adapted in the *National standards for the practice of ecological restoration in Australia* (McDonald et al. 2016b) from a larger number of attributes originally published in the SER Primer (SER 2004). Principle 7 highlights the importance of implementing ecological restoration at larger spatial scales for cumulative gains. Principle 8 clarifies the relationships of ecological restoration to allied activities on the Restorative Continuum and within the broader context of ecosystem restoration.

Section 3 outlines Standards of Practices to guide practitioners in the assessment, planning, implementation, ongoing management, and monitoring of ecological restoration projects. Section 4 provides additional guidance on leading practices concerning the development of reference models, the integration of ecological restoration into landscape- and seascape-scale initiatives, and financing and delivering restoration across sectors. Section 5 comprises an updated glossary of key terms. The Appendices include (1) current guidance on provenance and genetic diversity of seeds and other regenerative units (propagules) under conditions of fragmentation and climate change and (2) the importance of scaling up and strengthening the supply chain of appropriate biological material needed for restoration projects.

At the midpoint of the United Nations Decade on Ecosystem Restoration (2021–2030) and the KM-GBF (Target 2 on restoration), the third edition of the Standards provides a framework to help ensure that ecological restoration achieves the highest possible potential in delivering ecological and social-economic benefits for nature and people.

Section 1—Introduction

The International Principles and Standards for the Practice of Ecological Restoration (the Standards) are a guide for practitioners, operational personnel, scientists, students, planners, managers, regulators, policymakers, funders, and implementing agencies involved in restoring degraded native ecosystems across the world—whether terrestrial, freshwater or other inland waters, coastal, or marine. The Standards place ecological restoration into a global context, including its role in enhancing **biodiversity** and overall **ecosystem integrity**, and improving **human health** and **wellbeing** in times of rapid global change.

Ecological Restoration as a Means of Enhancing Biodiversity, Ecosystem Integrity, and Human Health and Wellbeing

Humanity recognizes the planet's native ecosystems as having irreplaceable intrinsic, ecological, social-economic, and **cultural values** (bolded terms without italics are included in the Glossary). These include the **intrinsic value** of the biodiversity they contain and their cultural, spiritual, and esthetic importance, as well as their value as **natural capital** and the ecosystem goods and services (**ecosystem services**) that they provide to people. Ecosystem services include: (1) provisioning services such as food, fiber, fuel, and medicines, (2) supporting services including clean water and air and healthy soils, (3) regulating services such as pollination, flood, and erosion control, and (4) cultural services, such as recreation, cultural identity, spiritual connection, and tourism. All of these services are essential for human health, wellbeing, livelihoods, and thriving cultures as affirmed in a 2022 United Nations (UN) Human Rights Council resolution on the human right to a clean, healthy, and sustainable environment. This link is further emphasized by the UN Declaration on the Rights of Indigenous Peoples, which underscores the intrinsic connection between

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Indigenous Peoples' rights to land, territory, and resources, including their conservation and protection, and the culture, wellbeing, and health of Indigenous Peoples.

High-integrity native ecosystems, including natural, semi-natural, and traditional cultural ecosystems, can reduce the risks and effects of natural disasters such as wildfires, floods, and drought. In addition, native ecosystems can limit, mitigate, or contribute to adaptation to the impacts of accelerated climate change. When native ecosystems are expanded spatially through the practice of ecological restoration, these benefits are amplified. Ecosystem **degradation**, **damage**, and **destruction** (hereafter, collectively referred to as degradation) adversely impact the biodiversity, integrity, and, in some cases, the recovery of ecosystems, which in turn negatively affects the sustainability and resilience of **social–ecological systems**.

Protecting and sustainably managing the world's remaining native ecosystems is critical to conserving the world's natural and cultural heritage and must be prioritized. However, protection alone is insufficient, given the extent of past and ongoing degradation. Growing awareness of the need for ecological repair has led to a global escalation of ecological restoration and related efforts (Box 2). To sustain human health and wellbeing and recover depleted wildlife, native plants, and the complete web of life, *global society must secure a net gain in the extent and integrity of native ecosystems by investing not only in conservation but also in ecological restoration and other allied restorative activities*. This investment must be implemented at multiple scales to achieve measurable effects worldwide, as recognized by the United Nations Decade on Ecosystem Restoration, the Kunming-Montreal Global Biodiversity Framework (KM-GBF), regional initiatives such as the European Union (EU) Nature Restoration Regulation, and growing investments in restoration by governments, nonprofit and community groups, and the private sector. The concept of restoration in many of these initiatives and agreements is very broad and includes many approaches to **ecosystem restoration** and **sustainability**, all of which are valuable and can be synergistic. The Standards address the relationship between ecological restoration and other major **restoration types** along the **Restorative Continuum** (sustainability practices, remediation, rehabilitation; Fig. 1, Principle 8), and clarify the specific role of ecological restoration in the recovery and ongoing management of native ecosystems.

Need for Principles and Standards

Repairing degraded ecosystems is a complex task requiring significant time, resources, and knowledge. Many **ecological restoration projects and programs**, however well-intentioned, have underperformed. The Standards recognize that the following key factors contribute to improved outcomes:

- Appropriate assessment, planning, implementation, ongoing management, and monitoring;

Box 2 Key Global Restoration Guidance and Initiatives*

- The United Nations (UN) Sustainable Development Goals (SDGs) for 2030 call for the restoration of marine and coastal ecosystems (Goal 14), as well as forests and other ecosystems that have been degraded (Goal 15).
- The UN Decade on Ecosystem Restoration (2021-2030), led by the UN Environmental Programme (UNEP) and Food and Agriculture Organization of the UN (FAO), aims to prevent, halt, and reverse the degradation of ecosystems on every continent and in every ocean.
- The UN Convention on Biological Diversity (CBD) Kunming-Montreal Global Biodiversity Framework (KM-GBF), including Target 2, calls for all parties to the convention to begin restoration of at least 30% of their degraded terrestrial, inland water, and coastal and marine ecosystems by 2030.
- The Ramsar Convention on Wetlands decision XV.15 encourages increased wetland restoration investment, including through The Freshwater Challenge, which aims to bring 300,000 km of degraded rivers and 350 million ha of degraded wetlands under restoration by 2030, supported by more than 50 countries and the EU.
- The UN Convention to Combat Desertification (UNCCD) Strategic Framework 2018-2030 promotes land restoration and rehabilitation including to achieve Land Degradation Neutrality (LDN).
- The G20 Global Land Initiative aims to prevent, halt, and reverse land degradation and reduce degraded land by 50% by 2040.
- The Bonn Challenge and the New York Declaration on Forests seek to bring 350 million ha under restoration by 2030, largely through the Forest and Landscape Restoration (FLR) approach (Section 4, Part 2). Regional programs include Initiative 20x20 in Latin America and AFR100 in Africa.
- The Eighth Replenishment of the Global Environment Facility Trust Fund (GEF-8) supports 11 Integrated Programs, including the Ecosystem Restoration Integrated Program, including 20 countries in Asia, Africa, and Latin America working to restore degraded landscapes in support of the Bonn Challenge.
- Kelp Forest Challenge, a global initiative, aims to strengthen relationships with the ocean and safeguard and restore 4 million ha of kelp forests by 2040.
- The Coral Reef Breakthrough, a global initiative to protect and restore coral reefs, aims to secure at least $12 billion in investments by 2030 to safeguard 125,000 km^2 of reefs.

*The second edition of the SER Standards (Gann et al. 2019) underpins the strategic plan and key guidance for the UN Decade on Ecosystem Restoration (FAO et al. 2021; Nelson et al. 2024), the KM-GBF (FAO et al. 2024) and other key global guidance.

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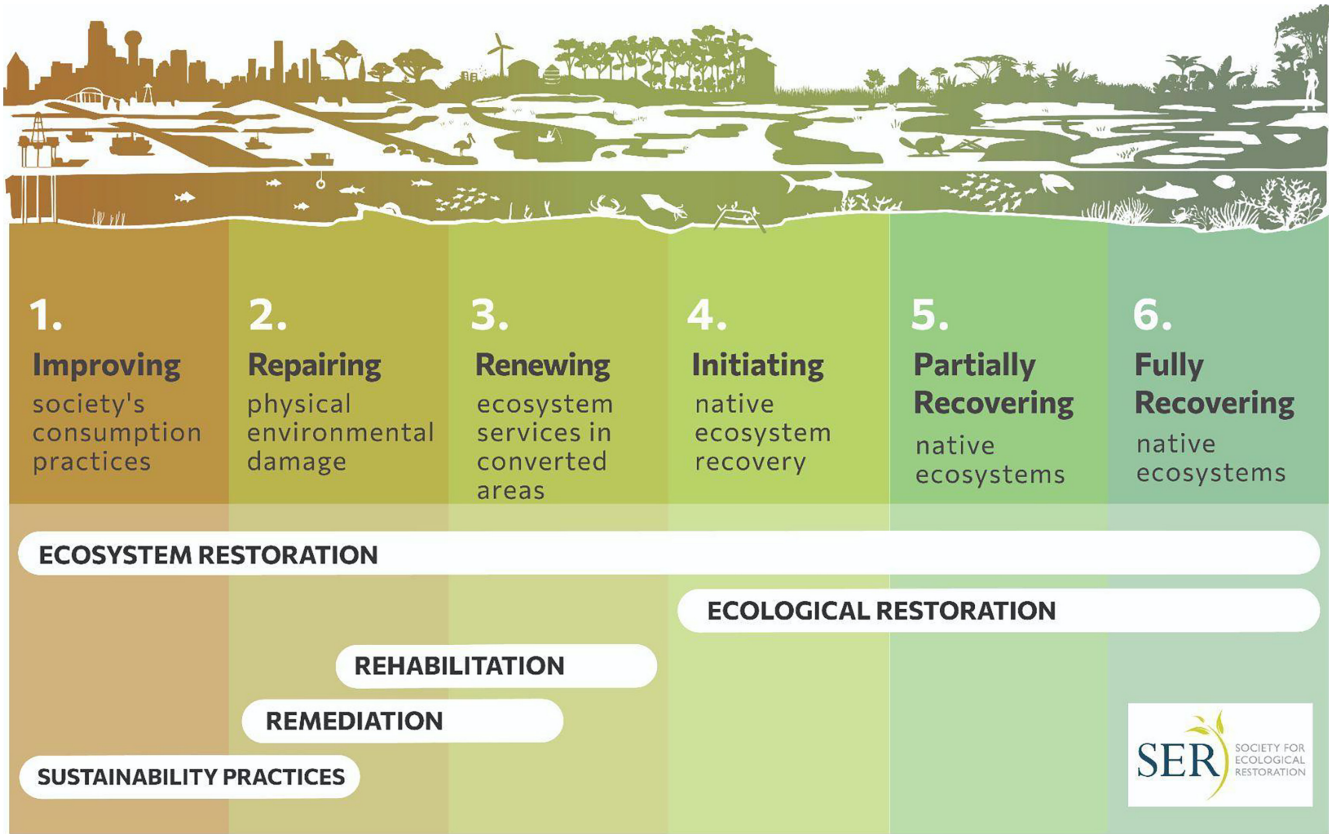


Figure 1. The Restorative Continuum includes a range of restorative activities and major restoration types (sustainability practices, remediation, rehabilitation, and ecological restoration) that, collectively, can reverse ecosystem degradation, leading to enhanced biodiversity, **ecosystem functions** and services, ecosystem integrity, and connectivity. The combination of ecological restoration and all other **restorative activities** along the continuum is accommodated under the UN's overarching term ecosystem restoration (UNEP 2021; Nelson et al. 2024). The continuum highlights interconnections among these different activities and restoration types and recognizes that the specific characteristics of the restoration **site** determine the best suited restoration activities. Note that ecological restoration can occur in urban, industrial, and agricultural landscapes as well as protected areas, and that some native ecosystems are also major production ecosystems (e.g. many grasslands, woodlands, and coastal, marine, and other aquatic ecosystems). These can be sustainably used with careful stewardship, but many require some form of restoration.

- Sufficient scientific, Indigenous, and local knowledge both informing and informed by restoration practices and outcomes;
- Relevant and ample skill, effort, and resources;
- Understanding of specific social-economic contexts and risks, particularly for vulnerable groups which may include Indigenous Peoples, women, youth, and traditional communities;
- Consideration of landscape and seascape contexts, including potential synergies with nearby ecological restoration and rehabilitation projects;
- Appropriate involvement of **interested and affected parties**; and
- Adequate monitoring, evaluation, and **adaptive management**.

Demand for and uptake of principles and standards for ecosystem restoration globally, and the need for specific guidance to support the practice of ecological restoration specifically, are growing rapidly across many sectors. Adoption of these principles and standards can help increase the effectiveness of ecological restoration by recognizing and incentivizing recommended best practices across different contexts and ecosystem types. They also provide an adaptable framework that engages interested and affected parties and respects social-economic and cultural contexts and needs, which can be applied to both voluntary and **mandatory restoration** (Section 4, Part 3).

The Standards can be used by a range of interested and affected parties to improve ecological restoration outcomes. For example, the Standards can be used to:

- Guide agencies, companies, organizations, community groups, and individuals in the delivery of all phases of ecological restoration;
- Provide a framework for regulators when developing agreements for mandatory restoration and assessing whether those agreements have been fulfilled;
- Support policymakers or funders in designing, supporting, financing, monitoring, and evaluating restoration projects at any scale;
- Support financial and insurance markets for restoration by reducing risk and uncertainty.

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What Is New in This Version Compared to the Second Edition?

(1) The definition of ecological restoration has been modified to include the word "native."
(2) The term "stakeholder" has been replaced with "interested and affected parties" as a means of promoting more equitable and inclusive language.
(3) For consistency with global fora such as the CBD and the World Commission on Protected Areas, we have clarified the use of the word "target." We have changed "target native reference ecosystem" to simply "native ecosystem" (i.e. the ecosystem to be restored); we have changed "target" used elsewhere in the second edition to "attributes" to align with the Five-star System (Principle 6), or simplified "targets, goals, and objectives" to "goals and objectives" or "goals." The word "target" is now reserved as an official term as used, for example, in the KM-GBF and the EU Nature Restoration Regulation.
(4) We have created zero-star values and constructed sub-attribute tables to support both the Social Benefits Wheel and Ecological Recovery Wheel (ERW) (Principles 1 and 6). We have improved quantification of values of attributes and sub-attributes, including elevating a Five-star condition within composition to 95% similarity to the **reference model**.
(5) We have modified the Restorative Continuum to refine the relationships between restoration approaches, clarify components of the continuum, and visually illustrate application to all types of ecosystems.
(6) To support good practice and project certification for ecological restoration, we have greatly expanded Section 3 on Standards of Practice.
(7) We have added a new section in leading practices on financing and delivering restoration across sectors.
(8) We have updated the glossary with important modifications to the definitions of rehabilitation, **substantive recovery**, and other key terms.

Key Definitions and Terms

SER defines **ecological restoration** as *the process of assisting the **recovery** of a **native ecosystem** that has been degraded, damaged, or destroyed* (hereafter, we use the term degradation in the broad sense as a catchall for degradation, damage, or destruction). It is distinct from **restoration ecology**, the transdisciplinary science that supports the practice of ecological restoration and other forms of environmental repair in seeking the recovery of native ecosystems and ecosystem integrity (see below this section). Ecological restoration aims to place degraded ecosystems onto **trajectories** of recovery that allow adaptation to local and global changes (including spatial shifts of species and native ecosystems) as well as persistence and evolution of component **native species**. The Standards accept **activities** with the goal or outcome of achieving the **substantive recovery** of ecosystems relative to appropriate native reference models as ecological restoration, regardless of the time required to achieve recovery. Many **semi-natural** and **traditional cultural ecosystems** are considered native ecosystems, and such ecosystems can be the goal of ecological restoration (Principle 3).

Ecological restoration is commonly used to describe both the process and the outcome sought for an ecosystem. However, the Standards reserve the term **restoration** for the *activity* and **recovery** for the *outcome* sought or achieved—whereby an ecosystem regains its integrity through a combination of human action and natural processes. Ecological restoration projects or programs identify one or more **native ecosystems** as the goal of restoration, **key ecosystem attributes** that characterize the native ecosystem to be restored (as informed by the reference model), and project **goals** that establish the level of recovery sought. **Full recovery** is defined as the condition whereby, following restoration, all key ecosystem attributes closely resemble those of the reference model (Principles 3 and 6). **Partial recovery** refers to situations where lower levels of recovery are planned or occur due to resource, technical, environmental, or social constraints. The difference between the level of recovery achieved and the reference model is termed the **recovery gap**. An ecological restoration project or program, at minimum, initiates substantive recovery of most of the key ecosystem attributes, including species composition, or otherwise accelerates or contributes to recovery in a significant way. When full recovery is the goal, an important benchmark is when the ecosystem demonstrates **self-organization**. If unexpected **barriers** or lack of particular species or processes take recovery off course, further restoration **actions** may be required to ensure that the ecosystem ultimately continues on a trajectory toward full recovery. Activities (e.g. to maintain **disturbance regimes**) applied after primary project implementation has concluded or following full recovery, are considered **ongoing management**. Specific activities, such as prescribed fire or the control of invasive species, may be used in both the restoration phases and ongoing management phases of a project.

Rehabilitation is one of several allied and complementary types of restoration that occurs along the Restorative Continuum. All restoration types across the continuum are fundamental to reducing the causes of degradation or reversing their effects, and thereby collectively contribute to **net gain** for biodiversity, ecosystem integrity, and **social-ecological resilience** (Principle 8). The goal or outcome of rehabilitation is not the recovery of a native ecosystem, but rather the recovery and reinstatement of a lost level of ecosystem functioning and the provision of a larger suite of ecosystem services flowing from highly modified or **converted** ecosystems (e.g. agricultural systems, mine sites, abandoned industrial sites; Box 8, Fig. 9). Native species can be supported or used in rehabilitation projects, but the substantive recovery of a native ecosystem does not occur. The terms reclamation, revegetation, and others relevant to mining and other industrial sectors are defined in Table 1 of Young et al. (2022); the term ecological reclamation was defined by Gerwing et al. (2021).

Ecological restoration projects are often carried out by **partners** in collaboration with other interested and affected parties. **Partners** are individuals, groups, or institutions whose active participation and support are essential for the successful implementation of a project or program and can include funders or

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donors, local communities or community groups, project managers, and **practitioners**. Interested and affected parties include individuals, groups, or institutions that have a vested interest in or can influence a project or that potentially will be affected by the project and have something to gain or lose if conditions change or stay the same; some interested and affected parties may be partners. **Rightsholders** are individuals or groups who have legal or customary title, tenure, or use of lands and waters or natural resources within the restoration area; they are inherently interested and affected parties but are optimally engaged as partners. **Knowledge holders** (see Principle 2), including **Indigenous Knowledge** (IK) holders and **Local Ecological Knowledge** (LEK) holders, are interested and affected parties and also can be rightsholders or partners.

Underpinning Assumptions

First, the restoration of most native ecosystems is a challenging process, and high levels of recovery usually require long periods of time. Consequently, ecological restoration projects, even when aiming for full recovery, may never achieve the high levels of biodiversity, ecosystem functioning, and delivery of services that may be aspired to (see recovery gap, above). Thus, while compensation may be mandated as a result of ecosystem loss or degradation (Section 4, Part 3), the *potential for ecological restoration should never be invoked as a justification for destroying, damaging, or unsustainably utilizing existing native ecosystems*. Furthermore, the potential to translocate rare species should not be used to justify the destruction of existing habitat. A critical point is that remnant native vegetation patches, even when highly degraded, have significant value within degraded and fragmented landscapes and therefore should be protected whenever possible, if not also prioritized as focal sites for ecological restoration.

Second, the Standards clarify that the aim of ecological restoration is the recovery of native ecosystems informed by the use of reference models (Principle 3, Section 4, Part 1). Reference models aim to characterize the state of ecosystems in the absence of degradation, accounting for ecological change. Appropriate reference models for ecological restoration do not characterize past ecosystem states, given that the goal of ecological restoration is not to immobilize an ecosystem at a fixed point in time or in a specific state. Instead, reference models reliably describe a range of variability of conditions within a high-integrity state. As such, they inform ecological restoration projects so that degraded ecosystems are assisted to move onto a trajectory of recovery to increase the potential for native species to recover, adapt, evolve, and migrate, allowing native ecosystems to reassemble.

Third, the Standards support the delivery of **effective restoration** as called for in the KM-GBF, which is defined as standards-based restoration, underpinned by agreed-upon principles, that results in appropriately balanced, sustainable net gain that benefits and enhances biodiversity, ecosystem integrity, and human wellbeing. This reflects a general understanding that all effective and durable restoration involves pursuing both ecological and social goals. The balance of ecological versus social benefits varies by restorative type and project, but all effective ecological restoration at a minimum benefits human wellbeing given the importance many people place in the intrinsic value and rights of nature and its recovery.

Finally, ecological restoration is part of a larger set of **ecosystem management** practices designed to conserve, restore, and sustainably manage native and production ecosystems at the landscape or seascape scale. These practices include Indigenous stewardship, regenerative approaches in agriculture, fisheries, and forestry, as well as ecological engineering. As such, *ecological restoration complements other conservation and sustainability activities* and vice versa (Principle 8, Section 4, Parts 2–3).

Section 2—Eight Principles for Ecological Restoration

Eight principles provide a framework to explain, define, guide, and measure the activities and outcomes of ecological restoration practice (Fig. 2). They represent a distillation of principles



Figure 2. Eight principles for ecological restoration. Each principle is fully developed in the text.

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and concepts presented in SER foundational documents, scientific literature, and practitioner experience.

Principle 1. Ecological Restoration Builds on Broad Societal Engagement

Ecological restoration explicitly responds both to the needs and aspirations of different segments of society. Humans benefit from a close and reciprocal relationship with nature. Participating in restoration projects can be transformative, for example, when people involved in restoration projects develop personal relationships with restoration sites, or when community volunteers seek new careers or vocational paths in restoration practice or science. Communities located within or near degraded ecosystems may gain health and other benefits from restoration that improves the quality of air, land, water, and habitats for native biota. In addition, restoration can provide short- and long-term employment opportunities in local communities, including low- and high-skill jobs, creating positive ecological and economic feedback loops. Indigenous Peoples and local communities (both rural and urban) benefit where restoration practices revitalize nature-based cultures, activities, and livelihoods (e.g. subsistence fishing, hunting, gathering, and their associated management and cultural practices), and strengthen their social bonds, sense of place, and individual and collective identity. Finally, ecological restoration enables many Indigenous Peoples who were dispossessed of their traditional lands and waters, independently or in partnership with others across cultures, to restore degraded landscapes from which Indigenous stewardship practices have been removed. In doing so, this helps to heal the damage done to Indigenous Peoples and their territories, and to restore ecological and sociocultural health to those landscapes and the human communities connected to them since time immemorial. These combinations of ecological, social-economic, and cultural benefits can lead to improved social-ecological resilience.

Ecological restoration projects are best conceived, co-created, and co-led by empowered local communities. They are carried out through partnerships that include regulators, land managers, practitioners, funders, scientists, Indigenous Peoples, local knowledge holders, and other interested and affected parties who are engaged and have a vested interest in the project and its goals and outcomes. Governments and the private sector also play critical roles in ecological restoration, particularly in providing policy support, legal frameworks, and finance (see Box 3, elaborated in Section 4, Part 3).

Interested and affected parties can make or break a project; recognizing their expectations and interests and directly involving them is key to ensuring that both nature and people mutually benefit. Interested and affected parties can help prioritize restoration actions across the landscape or seascape, set project goals (including desired level of recovery), contribute knowledge about ecological conditions and successional pathways to improve the development of reference models (Principle 3), and engage in **participatory monitoring**. Additionally, interested and affected parties can provide political, logistical, institutional, and financial support for long-term project sustainability, as well as help to resolve conflicts or disagreements that may arise. Managers of restoration projects should genuinely and actively seek the engagement of both local and distant interested and affected parties. Recognition of diverse forms of property ownership, user rights, reciprocal relationships with the land, management (government, private, and communal), land and other

Box 3 Expanding Restoration Finance

More than half of the world's gross domestic product (GDP) is moderately or highly dependent on nature. Native ecosystems and the services they provide underpin key economic sectors such as agriculture, forestry, fisheries, and tourism. However, recognition of ecological restoration's critical role in safeguarding economic health and sustainability has only recently gained traction among businesses, civil society, philanthropy, non-commercial banks, and governments.

Despite increasing awareness of the links between thriving ecosystems and robust economies, large-scale inaction persists. Many businesses overlook how ecosystem degradation heightens risks they face and creates substantial vulnerabilities, particularly with regard to their supply and value chains. This oversight creates a significant risk management gap. Similarly, philanthropy and civil society often undervalue ecological restoration's long-term benefits and the perils of inaction. This understanding and value gap can lead to a hesitation or reluctance to invest or engage in ecological restoration initiatives. Additionally, the monitoring, reporting, and valuation of restoration investments remain highly inconsistent across industries, ecosystems, and regions, further complicating efforts to mobilize public and private capital.

Effective engagement with the commercial and policy arms of society requires a robust business case for ecological restoration, one that highlights the importance of economic and social incentives, reduces perceived and real risks through targeted actions, and tailors approaches to specific sectors and geographies. Deepening understanding across economic sectors can foster greater confidence, mobilize investments, and help scale restoration globally. Importantly, this must incorporate equity considerations, such as integrating Indigenous and local knowledge systems and ensuring fair benefit-sharing to avoid exacerbating social inequalities.

Key drivers motivating public and private investment in restoration include: understanding the far-reaching benefits of restoration; improving policy; protecting supply and value chains; reducing risk; providing market incentives; refining philanthropic priorities; and developing a range of regulatory and public investment initiatives. All of these key drivers are examined in greater depth in Section 4, Part 3.

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resource tenure, and social organization is essential to this process. Special consideration should be given to understanding and upholding the rights of Indigenous Peoples and the interests of local communities in the specific sociocultural and historical context that shape those rights and interests (Box 3).

Timing and Continuity of Engagement. Ideally, engagement should occur at the conceptual phase or well ahead of project initiation, so that interested and affected parties can help define the project's scope, vision, goals, and **objectives**, as well as the methods to be used for implementation and monitoring.

Inclusive collaboration with local communities and authorities, including Indigenous communities, non-governmental organizations (NGOs), and individuals and organizations participating in community science to develop project plans can increase community investment in restoration and help bolster involvement in all stages of a project. This can empower on-the-ground actions and a sense of stewardship over a project site. Many Indigenous Peoples and local communities already act as stewards of their ecosystems. Existing restorative activities can serve as the basis for new ecological restoration projects, and the institutions that conduct them should be involved and empowered as knowledge holders and potential project partners.

Engagement and involvement must continue throughout the project to help meet and maintain social expectations, grow capacity, build a sense of belonging and individual and collective identity, and maintain support and positive input. Collaboratively building trust among key interested and affected parties fosters respect for different viewpoints and knowledge types and maintains interest and commitment during all phases of the project. Such collaboration can lead to more rapid and effective decision-making at local or across jurisdictional levels and can support social license to operate (SLO) in the private sector (Section 4, Part 3). In addition, managers of ecological restoration projects should actively seek the involvement of marginalized, diverse, and under-represented groups throughout the restoration process. Youth, women, and Elders, particularly in underserved communities, can be important participants, enabling them to act as powerful restoration agents and ambassadors. Continuous engagement over time is important for a variety of reasons including: (1) the possible reluctance or inability of some interested or affected parties to participate at the onset of a project or program, (2) a need to facilitate information sharing so individuals and communities understand the expected outcomes or changes to the **project scope**, and recognize their personal stake in the project, (3) a need to ensure that as many participants as possible remain engaged in the project over the long-term, and (4) the potential to develop a sense of pride and ownership and increase opportunities for public recognition of project successes.

Integrating Social Goals With Ecological Goals. Social goals, including goals that aim to reinstate or reinforce ecosystem services, must be identified alongside ecological goals during the planning stage of a restoration project (see Principles 5 and 6, including the SER ERW). The SER Social Benefits Wheel (Fig. 3), the associated **social Five-star System** attributes tables (Tables 1 and 2), and sub-attributes tables can assist in selecting social-economic goals (including cultural, economic, and human health and wellbeing goals) and in communicating progress (sub-attributes tables and templates for both wheels are located on the SER Standards Tools page online.) The visualization of the social Five-star System through the Social Benefits Wheel can enhance collective decision-making and effective communication to reach a shared understanding and optimize outcomes for all interested and affected parties. Although goals will necessarily vary among projects due to local contexts, multiple guidance documents can help in the development of relevant project goals and in enhancing community collaboration (e.g. Lynam et al. 2007; Keenleyside et al. 2012; Guariguata & Evans 2020; Shaver et al. 2020; Bliska et al. 2024; Mansourian et al. 2024; Nelson et al. 2024; Conservation Measures Partnership 2025; CIFOR-ICRAF's Multi-stakeholder platforms).

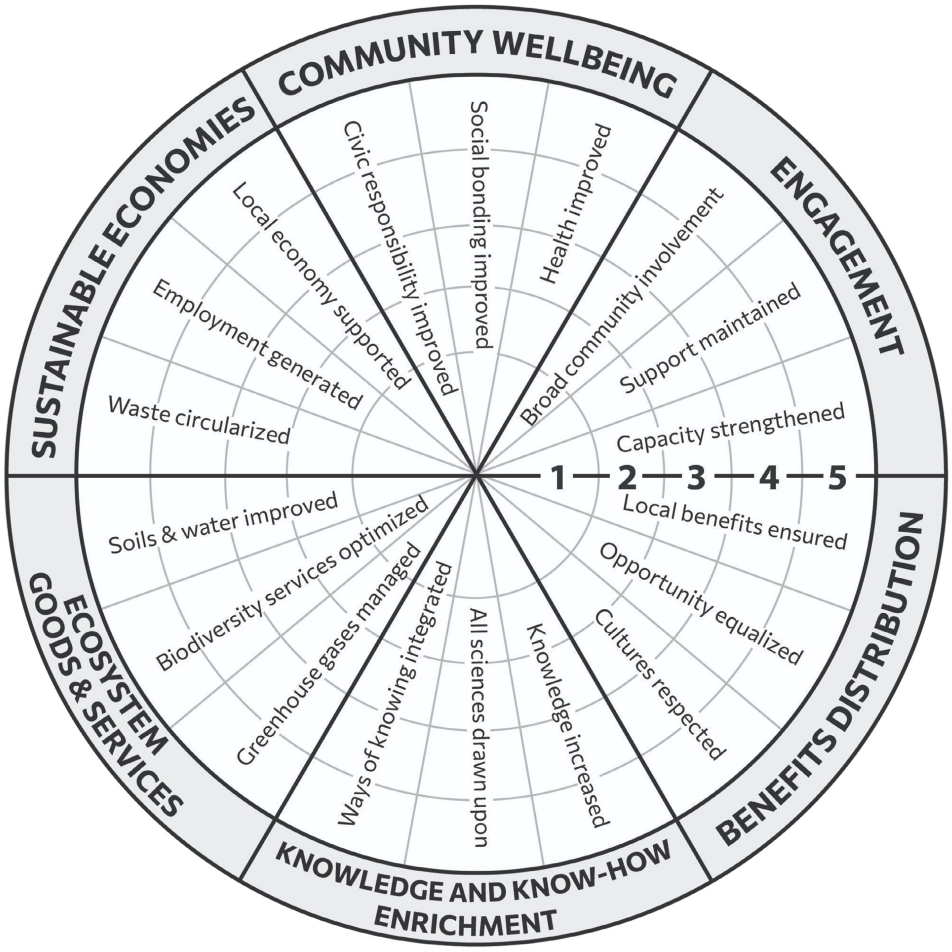
Consistent with the Standards, a number of ecological restoration strategies explicitly emphasize elevating social and cultural interactions to improve restoration outcomes. These include social-ecological restoration and **biocultural restoration**, which focus on enhancing the human and cultural values and relationships that strengthen and revive cultural practices along with the lands and waters with which local cultures are inextricably linked. These approaches can help support broader engagement and improve outcomes, including greater intercultural cooperation and learning. Valuing and elevating cultural understandings of, strong identity with, and connections to landscapes and seascapes, as well as emphasizing the restoration of lost or depleted cultural values, including Indigenous values and traditions, are essential for effective restoration. Moreover, sharing and comparing stewardship practices of Indigenous Peoples and local communities can provide critical insights for restoration practices, such as the shaping of natural disturbance regimes (Principle 2).

Principle 2. Ecological Restoration Draws on Many Types of Knowledge

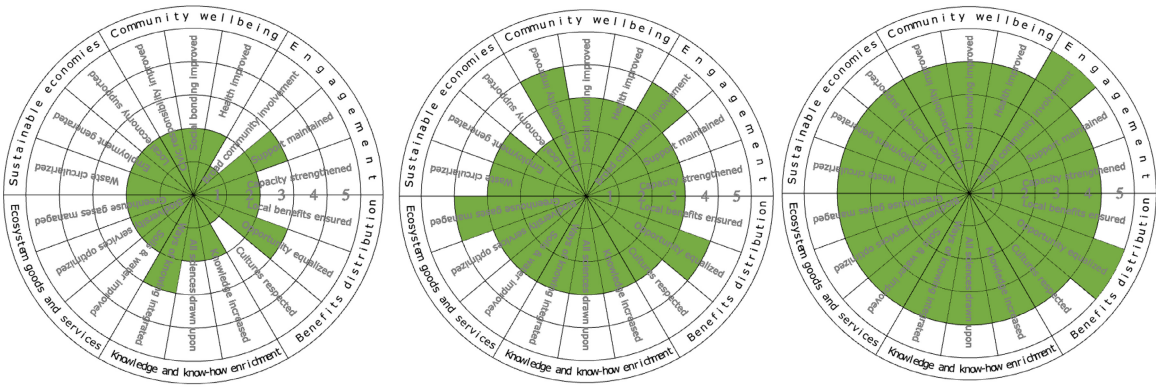
The best available knowledge should inform all phases of ecological restoration. This includes a high degree of ecological knowledge that can be drawn from practitioner experience (including technical knowledge), IK, LEK, and **scientific discovery**. Knowledge may be the product of observation, experimentation, and trial and error, whether formal or informal, or may be derived from a combination of sources.

All forms of knowledge hold intrinsic value. In ecological restoration, scientific knowledge has historically overshadowed other systems of knowledge; however, more inclusive approaches enhance the reliability and comprehensiveness of ecological understanding and its application to restoration practice. The inclusion of multiple forms of knowledge from diverse sources may provide a more holistic understanding of a site, landscape, or seascape, and a deeper appreciation of its context,

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(A) Social Benefits Wheel



(B) Example of using Social Benefits Wheel: (left to right) baseline, interim (current) condition, as compared to project goals

Figure 3. (A) Social benefits wheel; the Social Benefits Wheel (SBW) assists in both planning and tracking the degree to which an ecological restoration project or program attains its social benefits goals. (B) Example of using SBW. The left wheel shows sub-attribute conditions at the project's baseline. The middle wheel reflects interim progress. The right wheel illustrates the project goals, with over half of the attributes reaching four-star condition. The sub-attributes table of this wheel, as well as those in Table 2 and the online sub-attribute tables, can be customized to suit the specific goals and contexts of any ecological restoration project or program. For symmetry of design, six attributes and three sub-attributes for each are used in this example, but there may be more or fewer needed, depending on the project.

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Table 1. Characteristics of key social benefits attributes in a Five-star condition, considering local context.

Attribute	*Description of Five-star condition*
Engagement	The support, involvement, and number of interested and affected parties is optimal, appropriate to the stage of development and ambition of the restoration project, with transparent decision-making, self-management, and management succession arrangements in place.
Benefits distribution	Benefits to and opportunities for local communities and other interested and affected parties are distributed equitably, with optimal integration of appropriate cultural relationships with the site and its ecosystems.
Knowledge and know-how enrichment	Relevant sources of existing knowledge and knowledge-generation mechanisms are incorporated to a very high degree, with restoration outcomes evaluated, interpreted, and disseminated widely, including through education and training.
Ecosystem goods and services (EGS)	Management systems (policy and practice) are in place and restoration of natural capital is ongoing, resulting in a very high level of recovery of natural capital (healthy ecosystems, native biodiversity) with appropriate and balanced levels of EGS being delivered. Climate impacts (e.g. green house gases (GHG) management and hydrologic cycle) optimized.
Sustainable economies	**Sustainable businesses** and meaningful employment opportunities are developed, particularly for the local population, with very high levels of stability, delivering a mix of environmental, economic, and other social benefits.
Community wellbeing	A very high level of human health and wellbeing benefits are derived from the levels of participation and EGS that flow from the restoration site, ideally reflected in public acknowledgement of the importance of the site and its restoration.

history, use, and cultural values. It may also increase opportunities to improve restoration outcomes, including through the recovery or preservation of traditional practices in stewarding native ecosystems. Deep practitioner knowledge is derived from experience in repairing ecosystems, often over decades, and from formal training in a range of disciplines (e.g. restoration ecology, agronomy and seed production, botany, conservation biology, engineering, forestry, horticulture, hydrology, natural resource management, soil science, wildlife science, and zoology). Many practitioners are also LEK holders. IK and LEK experts (Box 4) can provide extensive and detailed information about sites and ecosystems drawn from their long-term relationships and connections to these sites and their ecosystems.

Scientific knowledge is generated through the process of systematic measurement and hypothesis testing. Restoration-relevant scientific knowledge comes from basic and applied research within a wide range of disciplines from economics to the social, physical, and biological sciences, including the subdisciplines of restoration ecology, ecosystem ecology, conservation biology, conservation genetics, and landscape ecology, among others. While there is an increasing body of knowledge about ecosystem degradation and repair, significant gaps remain in understanding the effectiveness (extent to which restoration goals and objectives are achieved) and impacts (abiotic, biotic, social-economic, and cultural responses to restoration interventions) of many restoration activities. Other gaps in scientific knowledge critical to successful restoration include understanding whether ecosystem recovery trajectories can be accelerated, species and ecological responses to climate change, and **climate readiness** (see also Principle 3 and Appendix 1). Scientific research can contribute to closing these gaps. In addition, scientific assessments of ecological restoration practice can address basic ecological questions, such as how ecosystems assemble and function, as well as social-ecological questions, such as the extent to which trust among members of the project team affects project outcomes. Generating new scientific knowledge may not be necessary or realistic in all ecological restoration projects, but it should always be considered, especially when little is known about treatment efficacy or where restoration interventions are extreme or highly risky (e.g. ecosystem reconstruction after mining).

Practitioner–IK–LEK–researcher collaborations of any combination can enhance scientific research by allowing for powerful research designs and improved ability to make inferences from assessments of restoration practice. Such research can increase innovation and provide additional guidance for restoration practice. Focused research can help practitioners overcome otherwise intractable problems (e.g. harsh substrate conditions, low reproduction rates, and inadequate supply and quality of germplasm). Additionally, research results can be shared and help to accelerate the dissemination of practical innovations and lower costs of other projects. Practitioners, IK, and LEK experts can play an important role in large-scale research projects by providing access to projects, identifying bottlenecks in capacity and gaps in information, and contributing logistical expertise. In addition, deep insights come from multigenerational connections to landscapes that transcend and complement scientific approaches in an essential manner.

By weaving practitioner knowledge, IK, or LEK together with mainstream scientific knowledge, restoration project managers can, for example, improve the development of reference models (Principle 3), rapidly identify and assess species and their suitability for restoration, and better understand key successional processes, stages, and species interactions. Further, restoration project designs and outcomes can be improved by utilizing the application of local cultural practices such as prescribed burning, rotational grazing, and water management.

The availability of evidence to monitor the effectiveness and the potential ecological and social impacts of restoration treatments should be determined early in the project planning stage, so that this evidence can inform adaptive management (Principle 5). Special consideration should be given to the differences in

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Table 2. Social Five-star System attributes for collaboratively evaluating progress toward social benefits at a restoration site. Not all sub-attributes (or all their suggested indicators) in this table will be relevant to all projects, and the table may be customized. The social Five-star System can be applied to small- or large-scale projects, with scale used as a multiplier of outcomes rather than being itself an attribute. More detail and suggested indicators are available in the sub-attributes table located on the SER Standards Tools page online.

Attribute	*Zero stars*	*One star (★)*	*Two stars (★★)*	*Three stars (★★★)*	*Four stars (★★★★)*	*Five stars (★★★★★)*
Engagement	Interested and affected parties not identified and engagement not initiated. Little to no external support and involvement (e.g. consultation, decision-making).	Interested and affected parties identified and made aware of the restoration and its rationale. Ongoing communication strategy prepared and in effect.	Some interested and affected parties committed but number of interested and affected parties, support, and involvement at a low level.	Many interested and affected parties committed but number of interested and affected parties, support, and involvement at an intermediate level.	Most Interested and affected parties committed and involved, appropriate to the stage of development of the restoration.	Number of Interested and affected parties, support, and involvement at an optimal level appropriate to the stage of development and ambition of the restoration project, with self-management and transparent succession arrangements in place.
Benefits distribution	No benefits to or opportunities for local community or other interested and affected parties negotiated. No incorporation of site-specific cultural relationships with the site.	Some benefits to and opportunities for local communities and other interested and affected parties negotiated, including identification of appropriate cultural relationships with the site.	Equitable distribution of benefits to and opportunities for local communities and other interested and affected parties at a beginning level, including appropriate cultural relationships with the site.	Equitable benefits to and opportunities for local communities and other interested and affected parties at an intermediate level, including appropriate cultural relationships with the site.	Equitable benefits to and opportunities for local communities and other interested and affected parties at a substantial level, including substantial integration of appropriate cultural relationships with the site.	Equitable benefits to and opportunities for local communities and other interested and affected parties at an optimal level, with optimal integration of appropriate cultural relationships with the site.
Knowledge and know-how enrichment	No relevant sources or knowledge-generation mechanisms identified for the site.	Relevant sources of existing knowledge and knowledge-generation mechanisms identified.	Relevant sources of existing knowledge and knowledge generation mechanisms incorporated to a low degree.	Relevant sources of existing knowledge and knowledge generation mechanisms incorporated to an intermediate degree.	Relevant sources of existing knowledge and knowledge generation mechanisms incorporated to a high degree, with restoration outcomes evaluated and disseminated.	Relevant sources of existing knowledge and knowledge generation mechanisms incorporated to a very high degree, with restoration outcomes evaluated, interpreted, and disseminated widely, including through education and training.
Ecosystem goods and services (EGS)	Lack of effective management to protect and enhance ecosystem integrity and prevent degradation. Natural capital depleted and virtually no EGS delivered. Site a GHG source.	Management systems (policy and practice) are being put in place to protect ecosystem integrity and prevent degradation. Natural capital largely depleted or altered, and only a very low or unbalanced level of EGS delivered.	Management systems in place and restoration of ecosystem integrity initiated, resulting in the conservation management and low level recovery of natural capital. A low or unbalanced level of EGS delivered. Some	Management systems in place and restoration of ecosystem integrity ongoing, resulting in the conservation management and intermediate level recovery of natural capital. An intermediate and balanced level of	Management systems in place and restoration of ecosystem integrity ongoing, resulting in the conservation management and high level recovery of natural capital. A high and balanced level of EGS delivered. GHG	Management systems in place and restoration of ecosystem integrity ongoing, resulting in effective conservation management and very high level of recovery of natural capital. Appropriate balanced levels of EGS delivered. GHG status at or very close to reference.

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Table 2. Continued

Attribute	*Zero stars*	*One star (★)*	*Two stars (★★)*	*Three stars (★★★)*	*Four stars (★★★★)*	*Five stars (★★★★★)*
		Site a GHG source or compromised sink.	recovery of GHG sink properties but far from reference.	EGS delivered. GHG improved.	neutral or sink status approaching reference.	
Sustainable economies	No consideration of or planning for sustainable businesses or meaningful employment opportunities.	Sustainable businesses and meaningful employment opportunities for the site are identified and designed.	Sustainable businesses and meaningful employment opportunities for the site initiated and tested.	Sustainable businesses and meaningful employment opportunities for the site developed showing intermediate levels of stability.	Sustainable businesses and meaningful employment opportunities for the site developed showing high levels of stability.	Sustainable businesses and meaningful employment opportunities developed, particularly for the local population, with very high levels of stability.
Community wellbeing	No or negligible human health and wellbeing benefits are being derived from the restoration sector of the economy and the EGS that flow from the site. Stewards are not identified and no meaningful individual or community connections to the site are evident.	A very low level of human health and wellbeing benefits are being derived from the restoration sector of the economy and the EGS that flow from the site. A very small number of interested and affected parties identify as stewards or have meaningful connections to the site. Community connection is still at a very low level.	A low level of human health and wellbeing benefits are being derived from the restoration sector of the economy and the EGS that flow from the site. A small number of interested and affected parties identify as stewards or have meaningful connections to the site. Community connection to the site is still at a low level.	An intermediate level of human health and wellbeing benefits are being derived from the restoration sector of the economy and the EGS that flow from the site. An intermediate number of interested and affected parties identify as stewards or have meaningful connections to the site. Community connection to the site is at an intermediate level.	A substantial level of human health and wellbeing benefits are being derived from the restoration sector of the economy and the EGS that flow from the site. A high number of interested and affected parties identify as stewards or have meaningful connections to the site. Community connection is at a substantial level.	An optimum level of human health and wellbeing benefits are being derived from the restoration sector of the economy and the EGS that flow from the site. There is an optimal level of interested and affected parties who identify as stewards and/or have meaningful connections to the site. Community connection is at an optimal level.

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Box 4 Indigenous Knowledge and Local Ecological Knowledge and Their Importance to Ecological Restoration

Indigenous Knowledge (IK) is defined as knowledge and practice passed on from generation to generation and informed by strong cultural memories, sensitivity to change, and values that include reciprocity. IK observations are qualitative and long-term, and often represent tacit knowledge preserved by people, not artifacts. Examples of IK that inform ecological restoration include knowledge derived from land-care practices such as prescribed burning, manipulating hydrological cycles to modify vegetation, conserving or recovering ecosystem engineers (beavers and elephants) or apex predators (wolves and lions), and marine IK systems such as rotational reef closures and traditional mangrove stewardship systems. Many Indigenous Peoples have used such practices over millennia to increase ecosystem productivity of food, raw materials for medicine, and ceremonial items for humans, while maintaining or improving habitat for other species. As such, IK involves respect and reciprocity between humans and the rest of nature. This includes the sharing of resources and human restraint to not overutilize, often sustained by spiritual beliefs that regard plants, animals, and other forms of life and nature as relatives. IK practices can increase biodiversity and improve ecosystem integrity by creating ecosystem mosaics across the landscape or seascape.

IK holders are often people engaged in subsistence practices including hunting, fishing, cultivating, and gathering. Most importantly, IK is inseparable from a culture's spiritual and social fabric. In many Indigenous worldviews, it takes all of what it means to be human—body, mind, heart, and spirit—to understand something ecologically. Consequently, IK offers important ecological insights, but also a web of knowledge that includes values that can help restore ecosystems. Within the holistic framework of IK is the specific subset of Indigenous science. **Indigenous science** describes the specific processes or methodologies that Indigenous Peoples follow within any experimentation, observation, or study. Leveraging IK, including Indigenous science, into ecological restoration practices can provide richer datasets and a more comprehensive understanding of conditions, ultimately enhancing the quality of restoration understanding, practice, and outcomes. Being open to diverse perspectives to foster a more complete understanding of environmental issues or projects aligns with **Two-Eyed Seeing**, which recognizes, considers, and weaves together mainstream science and IK. Co-creating projects by braiding together different knowledge systems, including LEK (see below), with all knowledge systems valued equitably, is essential for the effective and durable restoration of ecosystems within the context of biocultural and inter-cultural complexity. Such a strategy also builds community and long-term relationships, which are essential for the enduring success of restoration efforts in these contexts. Increasingly, national governments are recognizing Indigenous Peoples as members of their own sovereign nations that have distinct governments with the powers to regulate their own internal affairs; Indigenous rights are also recognized by the United Nations (2007). Any ecological restoration efforts involving Indigenous Peoples—whether on Indigenous land or waters or utilizing IK—must be carried out respectfully, ensuring that IK and data are treated as proprietary to the Indigenous partners. Data management practices, therefore, should uphold and protect Indigenous sovereignty rights. These rights include how knowledge and data are controlled, accessed, utilized, and managed. The principle of **Free, Prior, and Informed Consent** (FPIC) affirms that any research or data collection that involves Indigenous Peoples or their knowledge must happen with their full agreement and understanding.

Local Ecological Knowledge (LEK) is defined as practices and beliefs regarding place-based ecological relationships that are gained through extensive personal or cultural observations of and interactions with local ecosystems, and shared among local resource users. LEK about ecosystems, landscapes, or seascapes, obtained over decades, centuries, or millennia, can be used to manage or restore productive lands and healthy ecosystems, increase biodiversity, and improve ecosystem resilience. In regions where both Indigenous and non-Indigenous Peoples are present, IK and LEK can function together, although they may come from different cultural paradigms. In areas such as Europe, where few Indigenous Peoples have a presence, LEK includes pre-industrial farming, water management, and subsistence hunting practices, and may be known as **Traditional Ecological Knowledge**.

potential social impacts between genders, including that different evidence may be required to monitor any gender-specific social impacts. Where technical challenges arise, they need to be analyzed and alternative restoration interventions identified, using all forms of available knowledge. For mandatory restoration projects (e.g. in the mining sector; Section 4, Part 3), targeted research to address technical challenges should be undertaken to identify the most appropriate restoration interventions within reasonable time frames. If such research fails to provide solutions, other ways to satisfy legal requirements should be planned (see Principle 3 Fig. 4; Section 4, Part 3). Lack of substantive progress toward restoration goals, though, does not mean that restoration is not technically, practically, or economically feasible in the future. Lack of knowledge and technical competency may be overcome through adaptive management linked to focused, outcome-based research and monitoring. However, in mandatory restoration, knowledge and capacity should be acquired ahead of the project to ensure that legal requirements can be fulfilled.

Sharing, aggregating, and storing knowledge in accessible repositories is key to implementing restoration efficiently and effectively and to achieving restoration at scale. Leaving space for the evolution of restoration practice (**future practice**) is critical when it comes to collaborating with diverse partners and interested and affected parties, especially when considering both ecological and human health and wellbeing goals. As relationships and trust grow, so does the understanding of the diverse sources and types of knowledge that can improve and inform

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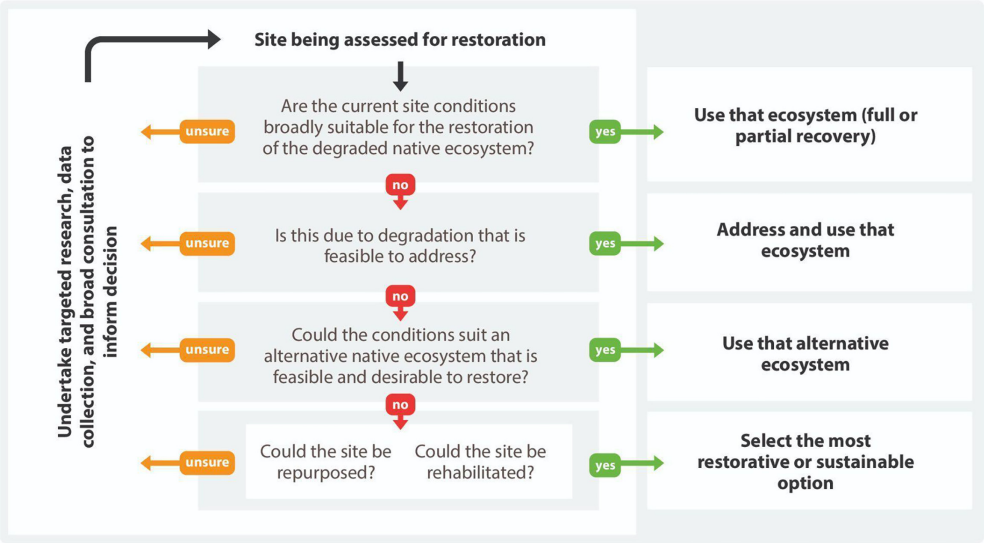


Figure 4. Decision tree to help answer the question "What is the most appropriate ecosystem to restore at a site?" Note that (1) the first row assumes we know what the ecosystem at the site was prior to degradation, and (2) the bottom left option assumes that, if the conditions cannot suit an alternative native ecosystem that is feasible and desirable to restore, then the final option is to either repurpose (convert to another use) or rehabilitate the site; in either case the most restorative or sustainable option should be selected.

ecological restoration practice. An important way to advance the science and practice of large-scale ecological restoration is to develop and promote bilateral and multilateral cooperation among and within countries (Principle 7; Section 4, Part 2). Sharing experience and expertise, co-financing, and co-development of new knowledge for more effective policy and practice should be encouraged among regions. **South–South cooperation** is especially important for knowledge sharing in technologically developing and newly industrialized countries of the Global South.

Principle 3. Ecological Restoration Practice Is Informed by Reference Models of Native Ecosystems That Account for Environmental Change

Ecological restoration is a place-based action that requires identifying the local **native ecosystems** to be restored and developing reference models to guide their restoration and support a shared vision of project goals. A reference model provides insight into the degree a degraded ecosystem deviates from the appropriate high-integrity condition and is ideally developed from an appropriate number of **reference sites** and other available information (Section 4, Part 1).

Optimally, native ecosystems that are the focus of ecological restoration are specific local native ecosystems (e.g. local variants of boreal forest, freshwater marsh, and coral reef). Importantly, over time humans have been natural components of virtually all native ecosystems. Indigenous Peoples have shaped virtually all terrestrial, inland water, and coastal ecosystems to a greater or lesser extent, not just for centuries or millennia but even up to tens of thousands of years. As such, native ecosystems include many semi-natural and cultural ecosystems (e.g. Camas prairies and Mediterranean dehesas; see below).

To the extent possible, reference models describe what the approximate state ecosystems to be restored would exhibit in the absence of degradation, accounting for past and anticipated environmental change. Reference models are based on multiple ecosystem attributes (Principle 6) and their variation within the native ecosystem to be restored. This state of the reference model is not necessarily the same as the historical state because all ecosystems (even those with high integrity) inherently change over time in response to shifting environmental conditions; turnover in native ecosystems over time is a natural, and indeed essential, ecosystem property (Box 5). In addition to changes in responses to external factors like climate and disturbances (fire, flooding, hurricanes, and rising sea level), ecosystems also change over time in response to internal factors such as biotic interactions that drive successional shifts in ecosystem structure and species dominance. Indeed, this capacity of ecosystems to respond to changing environmental conditions (due to natural or anthropogenic factors) is a fundamental expression of ecological resilience across levels of biological organization. For these reasons, therefore, reference models should not be misunderstood as an attempt to immobilize an ecosystem at a specific point in time, nor in any predetermined specific state, but rather should be employed to facilitate the development of restoration designs that assist native ecosystems to reassemble and allow local native species to recover, adapt, evolve, and migrate.

The quality of the reference model will vary among projects, based on project resources and the availability of reference sites and ecological information. Consequently, adequate investment in developing a reference model is an important consideration in project planning, timelines, and budgeting. Project managers

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Box 5 Reference Models, Climate Change, and Climate Change Adaptation

Continuous change in climate has occurred over millennia, resulting in changes in species dominance and ecosystem structure. These changes are evident throughout the paleoecological record, and demonstrate that ecosystems and the species that comprise them have responded to a changing climate throughout Earth's history. The occurrence of alternative pathways following disturbances or a changing climate is a natural phenomenon, and is an essential process allowing ecosystems to respond to changing environments. Anthropogenically-induced climate change, however, has altered average terrestrial and marine temperature maxima, disturbance regimes (e.g. droughts, fires, and flooding) and drastically increased the pace of change in many ecosystems worldwide through, for example, extreme weather events, sea-level rise, and ocean acidification. These changes are generally recognized as potentially leading to catastrophic consequences for many species and human communities, and are likely to be irreversible for the foreseeable future. Thus, urgent action is required by society, including working to improve the potential for restoration and other actions to slow human-induced climate change. Climate change, however, must be recognized as part of the current environmental background condition that drives shifts in species ranges (including regional or global extinctions in extreme cases and the continual reassembly of ecosystems). Similar to other degradation drivers (Principle 4), the reality of climate change increases the imperative for restoration. It should never be used as a justification to lower ambition.

When developing reference models, it may be necessary to consider anticipated gains or losses of species due to shifting climate envelopes (Section 4, Part 1, Appendix 1). Some degree of flexibility should, however, be built into the reference model to accommodate both the potential for species movement and the uncertainty of climate and species distribution models, although the certainty of models is improving over time.

Climate change necessitates goal setting informed by ongoing research on related anticipated effects on species and ecosystems. While uncertainty exists, we know that species turnover and ecosystem reassembly under climate change will result in large shifts in entire ecosystems in many geographic areas, although in some climatically buffered ecosystems, changes may be minimal. As the climate changes, climatic envelopes for individual species can shift spatially (Appendix 1). This means for an ecosystem at a given site, some species may be lost, while others may survive due to plasticity or ability to adapt to changes in environmental conditions, and still others will newly arrive.

Fragmentation is recognized as a form of degradation in its own right. However, it also exacerbates the effects of climate change on species and native ecosystems, both by isolating populations, which adversely affects genetic diversity and adaptation potential, and by limiting opportunities for species to disperse or migrate to climate-suitable habitats. Because of this, restoration interventions that optimize genetic diversity, improve the potential for populations to adapt, and prevent extirpations from current habitat areas are needed, as are evidence-based interventions that enable migration to new areas. Options include retaining and augmenting genetically diverse populations of existing native floral and faunal species, and ensuring that these populations exist in configurations that increase linkages and improve **gene flow** where appropriate to boost adaptability to changed conditions (Appendix 1). Fragmentation has many other negative impacts on ecosystems beyond effects on organisms and populations, including disrupting the continuity of essential ecological processes that occur at the landscape scale, such as wildfire and river flood regimes. Many ecological restoration activities (e.g. reintroductions of species or reinforcing populations) are implemented to overcome the effects of habitat fragmentation and degradation.

It is critically important to avoid taking actions that could end up exacerbating the effects of climate change, that is, translocating species where there is no evidence of natural migrations, or actions that might accelerate the conversion of biodiverse ecosystems already threatened by climate change, such as higher-elevation grasslands.

should aspire to create the best reference model possible given project constraints.

In some instances, the impacts of rapid or intractable environmental changes may warrant the focus of restoration to be an alternative native ecosystem to the one that was degraded (see also Box 5, Fig. 4). Alternative native ecosystems would be expected to be selected under certain kinds of changed conditions. Examples include sites where: (1) hydrology has shifted irreversibly from saline to freshwater or vice versa (due to changing stream flows, sea level rise), or mesic to arid (due to lowering water tables or complete dry-downs of rivers or lakes); (2) urban stormwater has produced new stream channels; (3) natural fire regimes or other **ecosystem functions** have been proven to be irreversibly altered; (4) nutrients have been added to soils and cannot be removed without extreme effort or resources; (5) substantial alterations in the geological profile have irreversibly impacted physical and chemical properties of the soils and water (e.g. from mining); and (6) unavoidable transformations of ecosystems have occurred, including species distribution patterns, in direct response to climate change.

Deciding when an alternative native ecosystem is appropriate as the focus of restoration depends on local conditions and the irreversibility of such conditions and requires skilled and informed ecological judgment. It is possible that more than one alternative native ecosystem may be appropriate to consider for restoration, for example, in urban and highly modified agricultural areas; careful selection is necessary to match the local social-ecological situation. In making such decisions, it is essential to appreciate that the appearance of a site may not be a reliable indicator of recovery potential. For example, in many cases,

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especially where restoration was assumed by some to be impossible, recovery has been achieved after application of skilled and informed approaches. Where potential for recovery is in doubt but recovery is highly desirable, a standard approach is to conduct trial treatments on a small area for a sufficient period to determine efficacy, species responses, and sustainability. Trial treatments are best designed as collaborations between scientists, practitioners, and other knowledge holders (Principle 2) and can help inform the appropriate choice of a native ecosystem to use as the basis for developing the reference model.

Once native ecosystems have been identified and selected for ecological restoration, reference models are developed using multiple sources of information, beginning with any formal descriptions of the ecosystem chosen for restoration. Best practice is to build empirical models based on information about specific ecosystem attributes obtained from multiple **reference sites** that align with these ecosystem descriptions. These sites are environmentally similar to the project site but optimally have experienced little or minimal degradation. Reference sites may be rare in regions that have few protected areas. In those situations, previously damaged sites that have had varying amounts of time for recovery (new protected areas, archeological sites, fenced military sites, or demilitarized zones) may indicate the trajectory of recovery of the ecosystem following a specified type of damage. Reference conditions may also be inferred from the portions of the site with the highest integrity, combined with other data.

Information on past and current conditions at the site as well as consultation with practitioners and IK and LEK holders can assist in developing reference models, especially where non-degraded local reference sites are unavailable. This information is usually collected during the site assessment or **baseline inventory** phase of the project (Principle 5). Other information used to develop reference models may include historical information, detailed ecosystem, biome, or physiographic descriptions, floristic and faunal lists, and tools that characterize ecosystem properties (see Section 4, Part 1).

A thorough reference model provides detailed information about all aspects of the site that the project proposes to restore. Importantly, reference models should be based on the specific ecosystem attributes to be recovered, and should account for both ecological complexity and temporal change (i.e. the successional or equilibrium dynamics of the ecosystem; see Section 4, Part 1 for discussion of these concepts). Six **key ecosystem attributes** relating to absence of threats, physical conditions, species composition, structural diversity, ecosystem function and **external exchanges** can be used to describe the reference model. Together, these six attributes contribute to overall ecosystem integrity, which arises from properties of diversity, complexity, and resilience inherent in functional native ecosystems and can be used to assess condition of a site prior to, during, and after restoration activities have occurred (Principle 6). Given the large range of ecosystem types for which ecological restoration is needed, these attribute categories are broad rather than prescriptive. In marine ecosystems, for instance, outcomes of restoration depend on oceanographic and climatic drivers, and thus reference models must integrate temperature, hydrodynamics, and salinity parameters.

Multiple reference models may be needed for a restoration project. First, large project sites or those with varied topography are likely to include a mosaic of ecosystems and their ecotones. Second, multiple or sequential references may be needed to reflect ecosystem dynamics or anticipated changes over time. Sites in successional ecosystems may be in the early phases of successional development immediately after restoration interventions and later advance to other successional stages, or they may start later in the cycle (in contrast, ecosystems that do not exhibit successional phases will not require sequential references—e.g. the hyper-diverse Cape Floral Kingdom of southern Africa or the Southwest Australian biodiversity hotspots that contain old, stable ecosystems developed on infertile substrates). For ecosystems with complex equilibrium dynamics, multiple successional pathways may exist and multiple models may be necessary to describe different possible restoration outcomes. Such alternative states arise in systems (e.g. coral reefs, grasslands, and forests in active volcanic landscapes) where the order of species arrival or stochastic events (including those related to disturbances) can affect **successional** trajectories. Additionally, reference models may need adjustment over time as informed by results of project monitoring, or by new knowledge or scientific insights.

Traditional Cultural Ecosystems and Semi-natural Ecosystems. Most native ecosystems worldwide have been shaped by human use, to provide food, construction materials, fiber, medicines, or other culturally important items (e.g. totems, spiritually significant tools). The traditional cultural ecosystems concept acknowledges that ecosystems are not just assemblages of organisms, but often reflect co-evolution of plants, animals, and humans in response to past environmental conditions. The extent to which native ecosystems are the result of human modification is variable and often unclear; but it is well understood that extensive modifications have occurred and been maintained by cultural practices that are similar to natural disturbances to which native species have adapted. For example, the existence of grassy openings found within forests is often attributed to cultural burning by Indigenous Peoples. Where such human-utilized grassland ecosystems exhibit species and biophysical characteristics similar to those occurring in natural fire-maintained savannas and grasslands, such human-utilized areas are considered native ecosystems. In these areas, cultural stewardship practices should be encouraged as a necessary part of maintaining ecosystem integrity. In fact, in many ecosystems, lack of cultural management (e.g. traditional burning, grazing, harvesting, planting, and seasonal flooding) disrupts ecological relationships that have often been in place for millennia, and drives degradation. Similarly, many of the ancient coppiced woodlands and unfertilized species-rich hay meadows of Europe and other ancient, human-modified ecosystems in the Mediterranean region and the Sahel can also be considered examples of native ecosystems and appropriate reference models for ecological restoration. In the EU legal context, these are specifically referred to as **semi-natural ecosystems** (not cultural ecosystems), and include chalk grasslands,

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wet and dry heathlands, woodland pastures, seasonal mountain pastures, grazed salt marshes, Mediterranean shrublands and dehesas, and mesotrophic fish ponds. Other countries or regions may have similar legal terminology for traditional cultural ecosystems.

Because of complex social-ecological histories of traditional cultural ecosystems, multiple complementary ecosystems may function as references for ecological restoration. In some cases, the restoration goal may be an early successional stage of an ecosystem, which will be maintained through cultural practices that may change and adapt over time (e.g. replacing hand cutting of biodiverse meadows in Europe with mowing by machines, modernizing cultural burning practices to conform to prescribed burning standards). It should be noted, however, that cultural ecosystems that are composed primarily of nonnative species, utilize artificial inputs (artificial fertilizers), or are structurally or functionally distinct from regional native ecosystems (e.g. formal botanical and zoological gardens) are not appropriate reference models for ecological restoration.

Principle 4. Ecological Restoration Addresses Degradation and Supports Ecosystem Recovery Processes

This principle highlights the importance of optimizing success in ecological restoration through site assessment, planning, and implementation that address (1) causes of degradation and (2) restoration approaches that harness and support the natural processes of recovery both at initial stages and during the extended recovery phase.

Activities that address these two aspects of a restoration project are planned and implemented with consideration of all available knowledge (Principle 2), a reference model for the restoration site (Principle 3), a baseline inventory of the ecosystem's condition prior to restoration (Principle 5), and agreed project goals and objectives (Principle 5). This integration between the principles will help to attain the planned degree of recovery of the local ecosystem attributes and properties including capacity for self-organization, self-perpetuation, and resilience to future stresses.

Addressing Causes of Degradation and Removing Obstacles to Recovery. The first aspect of this principle—assessing and addressing the underlying causes of degradation—is a pre-requisite for restoration success and foundational for all restoration design and planning. A preliminary step of restoration planning and implementation is therefore to identify and address specific obstacles that impede recovery processes. Sustainable ecosystem recovery will not occur without first removing, or reducing to a low level, the factors that *cause* the degradation—irrespective of how well other restoration interventions are planned and implemented to remove the *symptoms* of degradation (e.g. inappropriate substrates, invasive species, or low **propagule** availability).

Factors compromising the integrity of ecosystems are often referred to as **threats**, whereas the term **drivers** is used in this document to specifically refer to the sources of these threats, which are often processes that have complex causes. An analysis should be undertaken to identify **direct drivers** and **indirect drivers** (see Five-star System in Principle 6). Preliminary **restoration activities**, for example, may involve ceasing or substantially reducing direct drivers such as point sources of contamination and the sources or causes of **overutilization** (e.g. excessive grazing and excessive timber extraction), invasive species, or inappropriate hydrological, fire, or nutrient regimes.

Actions to remove such direct drivers may, in some cases, solely involve negotiations among interested or affected parties, or changes in law or policy (e.g. in some cases of overutilization); whereas others (e.g. contamination and altered hydrology) may require additional activities such as **remediation** or site engineering. In addition, consideration must be given to any indirect drivers that may be more distant causes or root causes of the direct drivers. In some cases, the task of addressing or reducing indirect drivers may be straightforward (e.g. to establish more appropriate social stewardship arrangements to secure long-term protection), whereas in other cases the task may be more complex (e.g. mitigating climate change that leads to ocean heat stress, reducing the social pressures leading to rapid increases in human populations—see allied practices in Principle 8). Whatever the case, one of the key principles underpinning the practice of ecological restoration is to strive for the highest practicable outcome (Principle 6), which means adopting the highest level of ambition feasible to address all drivers, however difficult or complex. In addition, sufficient long-term protection of the restoration site will be needed to ensure that degradation drivers do not recur and that recovery processes continue unobstructed.

Supporting Natural Recovery Processes Is Key to Effective Ecological Restoration. The second aspect to this principle—that is, optimizing natural recovery processes—is also a key objective of restoration. Restoration projects based on natural regeneration in various forms are being implemented at large scales around the world, including at terrestrial (e.g. rainforests, dry forests, grasslands, and deserts), inland waters (e.g. wetlands, lakes and streams), and coastal and marine (e.g. mangroves, saltmarshes, seagrass sites, kelp forests, coral and shellfish reefs) sites. See the many examples highlighted by the SER Natural Regeneration Network which consists of restoration scientists and practitioners who focus on harnessing the inherent capacity of ecosystems to recover, once degradation drivers have been addressed. Where natural recovery capacity is depleted, it is important that reintroductions are designed with long-term natural recovery as the goal.

Indeed, a key concept in achieving success in restoration is contained in SER's definition of ecological restoration as *the process of assisting the recovery of a native ecosystem that has been degraded, damaged, or destroyed*. This use of the term "assisting the recovery of" emphasizes that, while the activity of restoration is carried out by practitioners, the process of recovery itself is ultimately carried out by the biota as they interact with other components of the ecosystem and physical processes over time. This framework applies irrespective of whether the

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biota initially reestablish at the restoration site through **natural regeneration** or are added by practitioners (i.e. through **reintroduction** or **augmentation**).

Essential Components for Supporting Natural Recovery. The components needed to support recovery are established at the start of the restoration project. The most critical first steps, as mentioned above, are to ensure that direct and indirect degradation drivers are addressed to the extent possible. Ecological recovery, for example, may not occur until the physical conditions at the restoration site are similar enough to those of the reference model to allow for recovery to commence. At some sites, after removal of the direct driver (e.g. after exclusion of unsustainable grazing in rangelands), the physical conditions may be broadly suitable for long-term recovery such that little or no amendment is needed to attain the desirable physical or chemical substrate conditions for recovery. At others, substrates may need to be amended to an intermediate or high degree to adjust topography or remove overburden or contaminants (post-mining), to reconstruct more suitable substrates (e.g. shellfish reef restoration), to create windrows for water harvesting (e.g. in desertified sites), or to amend water chemistry (e.g. salinity levels in coastal wetlands).

For the recovery of native local species composition at a site, addressing the direct drivers of degradation may be sufficient to initiate at least some degree of natural regeneration of plants, animals, and other organisms through in situ mechanisms or colonization. This is because many native species have, through natural selection, evolved some capacity to resist, recover, and often proliferate in response to natural disturbances to which they have adapted over evolutionary time frames (e.g. herbivory, landslides, cyclones, wildfires, droughts, flooding, streambank erosion, and lava flows), as well as to short- and long-term variation in local climate. This capacity of individual organisms to resist and recover—sometimes referred to as a foundational level of **biological resilience**—will vary depending on the species, the types of disturbances involved, and the extent to which the human-induced degradation resembles the natural disturbance regime of the site. At the population level, such resilience can directly and positively contribute to ecosystem resilience. In some cases, however, this biological resilience can also lead to undesirable dominance of species or species groups. For instance, invasive nonnative species may have higher resilience to disturbances than native species; and, in cases where disturbance regimes are uncharacteristic of the ecosystem, some native species may become disproportionately represented.

Where potential for natural regeneration exists at a restoration site, allowing or facilitating natural regeneration is almost always the most reliable way to kick-start recovery, as this harnesses the capacity of any remnant biota to recover and can avoid any undesirable disruption of natural successional trajectories. For example, microorganisms may recover from residual on-site populations or recolonize from nearby areas, plant species may resprout from roots or germinate from seeds stored in soils or dispersed from nearby areas, while animal species may hatch from site-stored eggs, persist in juvenile forms, or recolonize from nearby populations if there is sufficient habitat connectivity. While colonizing species are often the first to emerge and may be more prevalent initially, other species may emerge over time or be stimulated by interventions variously designed to mimic natural disturbances, develop habitats, or encourage colonization. This initial recovery may reveal more diversity on site than previously evident (e.g. via germination of species that were present in the soil seed bank that were not anticipated or previously observed). Assessing early regeneration can confirm (or help refine) the reference model and demonstrate which species may be missing. It can also demonstrate potential for native species to recruit on the site in the future, assuming breeding and dispersal are effective.

Where potential for natural regeneration of native biota (i.e. from buried propagules or colonization from nearby sources) is lacking, however, relying upon natural regeneration alone would be ineffective. In such cases, reintroduction or augmentation may be necessary to compensate for missing propagules and thus support further recovery. The restoration approach to initiate species recovery, therefore, should be prescribed after careful analysis (through skilled site assessment) of natural regeneration potential, the limits of this potential, and the likely effectiveness of potential interventions. All of these steps draw upon different bodies of knowledge and skill (refer to *A continuum of approaches for recovering biodiversity*, below).

Best-practice restoration often deploys one or more of a range of restoration approaches to initiate biological recovery, each of which is matched to the degree of regeneration potential within the site. Very often, particularly at larger scales, a mosaic of approaches is needed because some less-degraded parts of a site may regenerate after the removal of threats alone, while others may require more intensive regeneration interventions or reintroduction of biota.

Supporting Natural Processes During the Recovery Phase. The recovery phase of a project extends from its inception to the point in the project where site properties and processes become highly similar to those of the reference model. It may be necessary over time to strategically work with natural processes to fine-tune and optimize outcomes relative to inputs. To optimize cost effectiveness, for example, restoration interventions can be started earlier in areas with higher **natural recovery potential** than those with lower potential. As these earlier-treated areas recover, they can progressively increase the potential for colonization of biota into adjacent areas with lower natural recovery potential, thus reducing the need for more resource-intensive interventions.

While the occurrence of natural regeneration does indicate potential for future **recruitment** under current environmental conditions, in cases of reintroduction or augmentation, the simple presence of the reintroduced individuals at a site, or even their successful growth, is not necessarily evidence of recovery of a species or population. Recovery should be determined based on evidence or prediction of population fitness (i.e. the ability of individuals in a population to survive and produce

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offspring). In addition, evidence of the return of ecosystem functions (such as decomposition, nutrient **cycling**), structure (such as spatial patterns of overstory trees or faunal marine structures), and other key ecosystem attributes need to be assessed, relative to the reference model, using a range of appropriate indicators (see Principle 5).

The trajectory of recovery at a restoration site is not always a linear or gradual process. That is, the rate and direction of recovery may fluctuate or stall because of internal dynamics or newly created barriers to recovery that may need to be overcome by further, targeted interventions. Restoration interventions designed to stimulate native species recovery, for example, may also result in a response from undesirable species present in the propagule bank or from the surrounding landscape or seascape, requiring invasive species control, culling overabundant native species, or other interventions to realign recovery toward project goals. In other cases, interventions may include: occasional disturbances, prescribed fire, or thinning (to attain the desired ratios of species); reintroductions of missing species or augmentation of a population's density or genetic diversity; or interventions that improve connectivity and provide additional habitat elements to attain appropriate ecosystem functionality (e.g. to attract pollinators, dispersers, or decomposers).

Because of the unpredictability of natural processes and our imperfect knowledge, it is prudent to see all restoration as experimental. While there are some best practice guidelines and often well-tested methods, there are no foolproof recipes for restoration. Practitioners must therefore be prepared to undertake additional activities such as those cited above, informed by field trials, research, monitoring, and adaptive management to help overcome barriers or constraints to natural regeneration that emerge during a project. Well-documented field trial results may improve the collective capacity to predict responses.

Preparing for Ongoing Recovery After the Preliminary Restoration Phase. Ideally, restoration projects should extend for periods of time that are ecologically and socially impactful. However, a restoration project rarely, if ever, attains full recovery within the period of restoration funding, even if all restoration interventions have been completed and a project is on a trajectory to full recovery. This is because ecosystems are complex assemblages of many species (and species groups) that can take many decades to reform, and achieving the status of old growth may take centuries. For these reasons, the design of restoration projects needs to be directed toward not only initiating substantive recovery but toward establishing conditions for attaining long-term maturation of an ecosystem. The biota must be able to interact with each other and **abiotic** components on an ongoing basis to drive further recovery of ecosystem attributes, ultimately rebuilding not only the ecosystem but also its resilience. Support for this includes ongoing protection from degradation and the provision of any ongoing management required, including natural disturbance regimes. Natural processes are not only a mechanism by which recovery occurs; their reinstatement is an ultimate goal of restoration and also an important measure of its success.

A Continuum of Approaches for Recovering Biodiversity. It is now well demonstrated that the potential of an ecosystem to recover from natural disturbances can also lend itself to recovery after human-induced degradation or stresses (to the extent the latter resemble the former). Correctly assessing the capacity of the ecosystem's biota to regenerate at a specific site, however, is necessary to enable selection of appropriate restoration approaches and treatments, thus enabling efficient use of financial and other restoration inputs.

Care needs to be taken to assess the degree of natural regeneration capacity at a site, and to ensure that whatever restoration approach is chosen does not harm existing native biodiversity or impede regeneration processes. Deciding upon an appropriate initial approach or combination is not always self-evident because stored regenerative units and colonization potential are often not visible. Hence, this assessment should be based on knowledge of the **functional traits** and adaptations (e.g. reproductive strategies, habitat needs and growth, and ecophysiology) of individual species likely to occur on or to colonize the site. These include capacity of plant species to form propagule banks onsite, regenerative unit flows from the surrounding landscape or seascape, and any barriers to natural regeneration, including the absence of dispersers or habitats favorable to symbiotic relationships with microbiota, or changes to natural disturbance regimes. The assessment should also be based on knowledge of how the ecosystem's potential resilience may respond to particular interventions. Where knowledge gaps exist, observing recovery responses in smaller areas is a key step prior to scaling out and up, and adoption of an adaptive management approach is recommended (e.g. allowing sufficient time to assess potential for natural regeneration prior to deciding whether reintroduction is needed).

Four Intervention Approaches. Four approaches are commonly applied to initiate the return of species to a restoration site. These approaches align along a continuum of natural regeneration potential remaining at a site—from high (aligning with the low degradation end of the continuum) to low (aligning with the high degradation end side). Being aware of this continuum can help restoration planners to avoid assumptions that traditional horticultural and agricultural approaches focusing on reintroduction are always necessary or desirable, thus avoiding inappropriate approaches that suppress natural regeneration. Regardless of approach, ecosystem recovery takes time. Hence, after the initial return of species, the more extended restoration phase will generally require adaptive management until recovery is attained, often on a **continuous improvement** basis. In many cases this will involve the repeated or incremental application of approaches 2–3 below.

(1) Natural regeneration that occurs spontaneously after removal of the drivers of degradation alone.

Where degradation is relatively minor, nearby populations are present, or sufficient time frames exist to allow longer distance recolonization, the ecosystem's characteristic species may be able to spontaneously recover after cessation of the causes of degradation alone (depending on the type and degree

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of the threats involved). Examples of this approach include discontinuation of low intensity agricultural production, removal of overgrazing pressure in grasslands and shrublands, regulation of over-fishing or over-hunting, and reinstatement of appropriate disturbance regimes. Examples of heavily degraded sites where this has been used include abandoned quarries or farmlands, where a long time frame has been available for recolonization. *Terms used to describe this approach include: spontaneous regeneration, unassisted regeneration*.

(2) Natural regeneration that depends on specific management interventions other than reintroduction or augmentation.

Restoration at sites of intermediate or greater degradation may require not only the removal of the causes of degradation but also specific management interventions to amend abiotic damage or to trigger biotic recovery. Examples include: removing competition from invasive and other undesirable species; actively remediating substrate chemical or physical conditions; reshaping watercourses and landforms (including bunding to harvest water); reinstating fish passage in estuaries and rivers; applying tailored disturbances such as fire or its surrogates or soil raking to break seed dormancy; and installing habitat features such as shellfish reef substrates, fauna watering holes, disperser perches or nesting features, and hollow logs, rocks, woody debris piles, and microniches for soil microbiota. *Terms used to describe this approach include: facilitated natural regeneration, assisted natural regeneration (without reintroduction)*.

(3) Combination of any natural regeneration approach with supplemental reintroduction or augmentation.

In some cases, natural regeneration alone is insufficient to return all focal species. In other cases, populations of organisms may be somewhat depleted and need augmentation to achieve desired abundance or genetic diversity. In these cases, natural regeneration approaches may need to be accompanied by supplementary reintroduction or augmentation through at least some soil microbial inoculation, direct seeding, planting of seedlings, dispersal of other regenerative units, or reintroduction of fauna by various means. This supplemental approach is optimally carried out after first testing the natural regeneration potential of the restoration site. Examples include: reintroduction of soil microbiota; reintroduction or augmentation of rare or threatened species; reintroduction of top predators or herbivores to readjust species abundances through trophic interactions (e.g. **rewilding** approaches); reintroduction of local native tree species that are dispersal-limited (e.g. plants with very large seeds or without extant dispersal vectors); and supplemental planting in areas of sparse or uneven natural regeneration. Other examples include framework plantings or **spatially patterned restoration** techniques where only a subset of species are initially augmented or reintroduced (e.g. reef-building coral species, structure-forming shellfish species, or native fruit-producing tree and shrub species to attract birds and bats that act as seed dispersers) after which other species are expected to colonize. *Terms used to describe this approach: reintroduction, combined regeneration, assisted natural regeneration (with reintroduction)*.

(4) Full or near-full reliance on reintroduction.

Where degradation is so severe that very little or no regeneration potential remains, not only do all causes of degradation need to be removed or reversed and all biotic and abiotic damage corrected to allow recovery toward the reference model, but also all or most of the desirable biota need to be reintroduced. The quality of that reintroduction, however, must be carefully planned to ensure that it results in sufficient species complexity, recruitment niches, and breeding potential (Appendix 1) to ensure that genuine ecological recovery occurs. The biota should have the potential to then interact with each other and abiotic components to drive further recovery of ecosystem attributes, ultimately rebuilding not only the ecosystem but also its resilience. In some cases where sequential recovery is a characteristic of the ecosystem or is needed (e.g. to help recovery of soils), earlier successional species may need to be reintroduced earlier than later successional species. Sequential reintroduction may also be beneficial in partially open ecosystems such as some woodlands where a herb-rich lower **stratum** may benefit from earlier reintroduction to form soil bud and seed banks before reintroduction of the tree stratum. In ecosystems that do not exhibit (or need) these successional patterns, however, all species are often best reintroduced from the outset. *Terms used to describe this approach: full reintroduction, reconstruction*.

Ongoing Natural Regeneration. Natural regeneration also occurs after any organisms introduced in initial restoration phases themselves successfully reproduce and expand. As needed and appropriate, techniques used for facilitating regeneration (e.g. manipulating competition and applying regeneration triggers) can be applied at later project phases, irrespective of the initial approach used.

Principle 5. Ecosystem Recovery Is Assessed against Clear Goals and Objectives, Using Measurable Indicators

In the planning phase of restoration projects, it is critical to establish the project scope, vision, and goals for ecosystem and social attributes (Box 6), along with objectives and specific **indicators** to measure progress. Indicators can then be used to monitor change over time and contribute toward the application of adaptive management approaches (Box 7). Adequate resources for monitoring must be allocated from the start of the project for effective monitoring to take place.

Ecological goals and objectives will be strongly informed by the baseline inventory (Section 3, Part 1.2) in combination with the reference model (Principle 3). The baseline inventory describes the current state and condition of the biotic and abiotic elements of the degraded site, including its compositional, structural, and functional attributes, as well as external threats (e.g. nearby invasive species sources) and beneficial external connectivity. The baseline inventory informs the selection of the native ecosystems to undergo restoration, the development of reference models, and the degree of recovery required for

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Box 6 Terms Commonly Used in Project Planning*

- The Scope is the broad geographic or thematic focus of a project.
- The Vision is a description of the desired state and ultimate condition that a project is working to achieve, associated with the project scope. A good vision is relatively general, inspiring, and brief.
- Attributes are elements chosen to represent key aspects of the overall ecosystem or social context to assist practitioners with the evaluation of project status and ecosystem recovery. Key ecosystem attributes are: absence of threats, physical conditions, species composition, structural diversity, ecosystem function, and external exchanges. Recommended social attributes are engagement, benefits distribution, knowledge and know-how enrichment, ecosystem goods and services, sustainable economies, and community wellbeing. These attributes and sub-attributes underpin the Five-star Systems that are used to populate the Social Benefits Wheel (Principle 1) and Ecological Recovery Wheel (Principle 6).
- Ecosystem attributes are assessed through the use of representative sub-attributes. It is recommended to use at least three sub-attributes to represent each key attribute in the Five-star System, but others can be added.
- Goals are formal statements detailing a project's intended impact on the desired future status of the ecosystem under restoration, with respect to its ecological and social attributes. Goals must be clearly linked to attributes and are specific, measurable, achievable, results-oriented, and time-limited (SMART).
- Objectives are formal statements of the desired interim results of a project along the trajectory of recovery. Objectives must also be SMART. If the project is well conceptualized and designed, the realization of a project's objectives should lead to the fulfillment of the project's goals and ultimately its vision.
- Indicators are characteristics of an ecosystem that can be used for measuring the progress toward restoration goals or objectives at a particular site. Indicators must have specific definable units (e.g. % cover, #/ha or categorical gradients) and be measurable with enough precision to assess the status of ecological and social attributes or sub-attributes over time, and thus to evaluate the effectiveness of restoration activities.

*Terms used here, with some adaptations, are based on those of the Open Standards for the Practice of Conservation V 5.0 (Conservation Measures Partnership 2025).

each attribute to approximate the reference condition. The inventory process is a key initial step to understand what is possible at a degraded site in terms of developing restoration goals and objectives.

A project's ecological goals should address the degree of recovery sought for each of the six key ecosystem attributes of the reference model (Box 6). Assessments of progress toward the ecological goals require the identification of specific indicators to help measure the state and condition of each attribute. These indicators should be used to conduct the monitoring before project initiation to establish the **baseline condition**, and to monitor recovery throughout the restoration process to evaluate whether restoration is progressing toward the project's ecological goals. To help deliver and evaluate recovery, each restoration goal should include the following for each of one or more specific indicators: (1) the desired level that will be measured (e.g. percent cover of native plants); (2) desired outcome (e.g. increase, decrease, and maintain); (3) desired magnitude of effect (e.g. 40% increase); and (4) time frame (e.g. 15 years) in which the outcome is sought. For projects where full recovery is the goal, the ecological goals for key attributes will align with the values of the reference model. However, for projects aimed at partial recovery, the goals may vary from the values of the reference model. For example, the ecological goals for the native ecosystem to undergo restoration may be to recover 80% of the species in the reference model or include nonnative surrogates of extinct species, or they may be modified to meet social needs (e.g. establishing mosaics of near full recovery patches and partial recovery patches in production landscapes).

The rating for an attribute is derived from the scores of the component sub-attributes, and in turn they are derived from the scores of their component indicators. A mechanism (e.g. calculation of the mean, median, or consensus score) is required to arrive at the attribute score. Indicators can also be weighted to account for their variable influence on ecosystem recovery.

Social goals vary widely among projects and arise from a variety of social considerations (Principle 1) and human wellbeing concerns. After meaningful consultation and in partnership with interested and affected parties, social goals are identified in the project plan including descriptions of the rationale for resolving tradeoffs between ecological and social costs and benefits. Project reports can then recognize and highlight the benefits to society and to native ecosystems that may flow from the project. As with ecological goals, the baseline condition for social goals should include specific indicators, desired outcome, desired magnitude, and time frame.

It is important to note that some restoration goals will be more critical than others. These can be identified through a risk-based prioritization process that can help allocate resources for appropriate monitoring (Young et al. 2019). This ensures that monitoring will focus on those goals where failure would cause the greatest risk to ecosystem recovery or human wellbeing. As ecological restoration continues, observable progress (or the lack thereof) should be documented to assess whether the project is on a trajectory toward the reference model and toward ecological and social goals.

Goals define the desired recovery outcomes, which may take decades to achieve. Objectives track progress by measuring

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Box 7 Monitoring and Adaptive Management

Monitoring plays a crucial role in:

Generating social learning. Participatory monitoring engages interested and affected parties in the collection, analysis, and collective interpretation of data gathered from restoration activities. This partnership approach can lead to improved collaborative decision-making (e.g. across governance levels) and strengthen capacity and empowerment. Successful participatory monitoring addresses the questions and needs of interested and affected parties in a timely way. Optimally, what to measure, as well as appropriate methods and indicators, are agreed upon collectively during the project planning process, are easy-to-use, and encourage social learning while building learning networks.

Answering specific questions. Monitoring answers specific questions that improve understanding of ecological restoration and inform restoration decisions. Major types of monitoring include (1) implementation or compliance monitoring (i.e. the degree to which restoration activities are implemented as planned), (2) effectiveness or performance monitoring (i.e. the degree to which restoration goals and objectives are achieved according to predefined indicators), and (3) impact monitoring (i.e. ecological, cultural, and social-economic effects, generally measured over the long term). Although not as formal, more cursory surveillance monitoring can be used to identify project challenges early on and take corrective actions through adaptive management.

To reliably answer monitoring questions, it is essential to select appropriate indicators, use a well-designed sampling approach and collect data with adequate levels of precision. To determine the extent of ecological recovery, best practice is to compare the restoration site to the baseline condition and to the reference model. However, this approach does not indicate whether the recovery (or lack thereof) is due to restoration interventions. To determine the effects of the interventions themselves, data should ideally be collected before and after treatment on a sufficient number of both control and treated sites (i.e. following the Before-After-Control-Impact—or BACI—design). Where possible, sufficient replication should be implemented to enable statistical testing of treatment effects. However, although considered best practice for determining the effects of interventions, a BACI design is often not feasible with limited project budgets. In these cases, impacts can be measured as changes from the baseline condition, although care should be taken to avoid interpreting as causation, as they may be entirely driven by temporal (e.g. year to year) variation and not by restoration activities.

Applying adaptive management. Adaptive management goes beyond "learning by doing" by using a systematic approach for improving the practice of restoration that strategically connects all project components in a structured way to enhance success. This includes directly linking monitoring questions to restoration goals and objectives. Importantly, adaptive management is not simply "trial and error." Properly applied, adaptive management improves our understanding of restoration by: (1) allowing interested and affected parties to explore alternative ways to meet restoration objectives if biophysical, political, or social-economic conditions change during project implementation; (2) predicting the outcomes of proposed alternatives based on the current state of knowledge; (3) implementing one or more of these proposed alternatives; (4) monitoring to learn about the implementation, effectiveness, and impacts of restorative actions; and then (5) analyzing the monitoring data and using the results to update knowledge and adjust restoration practices as needed. Adaptive management can and should be the standard approach for any ecological restoration project, irrespective of how well-resourced that project may be. Fully implementing a participatory adaptive management approach requires effective facilitation in meetings with interested and affected parties, effective planning and timely execution of the monitoring program, evaluation and dissemination of results, as well as funding for ongoing restoration.

Reporting. Reporting monitoring results in an accurate yet accessible manner, customized to the specific audience, is key to effective restoration. Reporting should specify the level and details of monitoring upon which any project evaluation is based. The Social Benefits Wheel (Principle 1) and Ecological Recovery Wheel (Principle 6) help to visualize project progress utilizing monitoring data.

Time-series monitoring provides evidence to interested and affected parties and regulators that goals are being met. For example, repeated photography or acoustic data collected at fixed locations may be used to provide visual or audio evidence, respectively. Condition mapping can also be applied as long as the condition categories being measured are rigorously defined, ecologically informed, and reproducible. At small sites, fixed points can be established on the ground, whereas for larger sites, remote-sensing techniques may be more efficient because of their ability to enhance spatial coverage. Technological approaches may also be used to extend monitoring beyond what humans can sense (see or hear), capturing evidence through methods such as infrared or thermal imaging, ultrasonic bioacoustics, and environmental DNA. Non-sensory data should be converted into sensory cues, such as graphs and visualizations, to make complex evidence accessible and interpretable for interested and affected parties, facilitating informed decision-making.

Data sharing, interoperability, and standardization. The sharing of monitoring data can contribute to the aggregation of data from many projects into national, regional, and global platforms and datasets. This allows for sharing of knowledge about where ecological restoration is taking place and its impacts. The sharing and exchange of data must take into account data sovereignty and security, which is essential to maintaining trust and collaboration with partners and interested and affected parties, including Indigenous Peoples. The Restoration Project Information Sharing Framework (ISF) (Gann et al. 2022), together with SER's

Continued

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Box 7 Monitoring and Adaptive Management—cont'd

Restoration Resource Center and FAO's Framework on Ecosystem Monitoring (FERM), facilitates data sharing and interoperability and thus contributes to tracking global progress and trends in ecological restoration (FAO et al. 2024). Numerous country-level efforts also support this work (e.g. the Brazilian Restoration Observatory).

Effective data and knowledge sharing require standardized monitoring methods to maintain consistency. While global and regional guidelines may provide frameworks, standardization efforts must also account for local ecological, social-economic, political, and legal conditions, as well as practical and financial constraints. Standardization of monitoring methods enables practitioners and local communities to develop, test, refine, and share methods, ensuring they remain scientifically robust, rigorous, comparable, and relevant. This improves cross-site learning, strengthens the evidence base for restoration, and helps inform meta-analyses and reporting to interested and affected parties at larger scales.

intermediate results along the trajectory of recovery according to a likely pathway of change. The theory of change clarifies assumptions about how restoration strategies contribute to recovery and how progress is assessed. Monitoring the trajectory of recovery helps identify when a project or its components deviate from expectations, signaling the need for adaptive management (Fig. 5).

Principle 6. Ecological Restoration Seeks the Highest Level of Ecological Recovery Attainable

An ecological restoration project strives to achieve the highest possible level of ecological recovery, relative to the six attributes described in the reference model. This process of recovery, whether full or partial, unfolds gradually and may be slow. In some cases, restoration requires a sustained, multigenerational effort. Thus, restoration project managers are encouraged to adopt a policy of continuous improvement, guided by effective monitoring and adaptive management. Such a policy can allow managers to continually upgrade and build on project goals to advance initial recovery toward progressively more impactful outcomes. One approach for tracking progress over time is to use the ecological Five-star System and Ecological Recovery Wheel (ERW).

Ecological Five-star System and Ecological Recovery Wheel. The **ecological Five-star System** (Tables 3–5) and the ERW (Fig. 6) are tools to provide a relative scale by which restoration practitioners can evaluate project progress at multiple intervals, along with intended goals. These tools can thus help managers, practitioners, and regulatory authorities establish, visualize, and communicate the level of ecological recovery aspired to (which star level for the six attributes), and to progressively evaluate and track the degree of native ecosystem recovery over time from the baseline condition toward these goals, always guided by the reference model. The idea is to aim high and show progress over time, even if full recovery is neither initially possible nor the project goal. Practitioners familiar with the project goals, objectives, site-specific indicators, and recovery levels shade the segments of the ERW for each sub-attribute after formal or informal assessment. Blank templates for the diagram and its accompanying form are provided in Appendix 3 and on the SER Standards Tools page. The ERW can be calibrated for specific biomes or restoration contexts (e.g. arid lands and mine sites) by modifying the sub-attributes, but all key ecosystem attributes should remain the same.

Notes for Interpreting the Ecological Five-star System. Since being described in McDonald et al. (2016b) and Gann et al. (2019), the Five-star System and companion ERW have been increasingly adapted and utilized by practitioners and scientists for a wide variety of ecosystems (e.g. rivers in the United Kingdom, coral reefs in Mexico, and forests, woodlands, and wetlands in Australia) and specialized applications (e.g. restoration in post-mining landscapes, certification systems) around the world. The following points answer some of the frequently asked questions about the ecological Five-star System.

- The ecological Five-star System was developed for implementation at the site level, but can be applied at the program level by separately evaluating sites using the Five-star System and then aggregating data from multiple sites to display degree of recovery (average, minimum, and maximum) for larger programs.
- Evaluation using the ecological Five-star System is based on average conditions at a site; at sites with high within-site variation for specific indicators, it may be necessary to conduct analyses at multiple subsites and average the values.
- The 18 ecological sub-attributes published in the second edition of the Standards have been widely used by many projects and are still recommended here. A 19th sub-attribute, Other Degradation Drivers, has been added in the Threats Attribute in this third edition of the Standards; it is also recommended for general use and has been incorporated into the ERW. Descriptions of additional optional sub-attributes (e.g. suggested for use for mining and arid lands) are described and available online on the SER Standards Tools page.
- The specific indicators and assessment methodologies selected for a project should be based on the project's ecological context, taking technical capacity and available resources into account. Bartholomew et al. (2024) and Nelson et al. (2024) provide additional context and applications of indicators including assessment methodologies.

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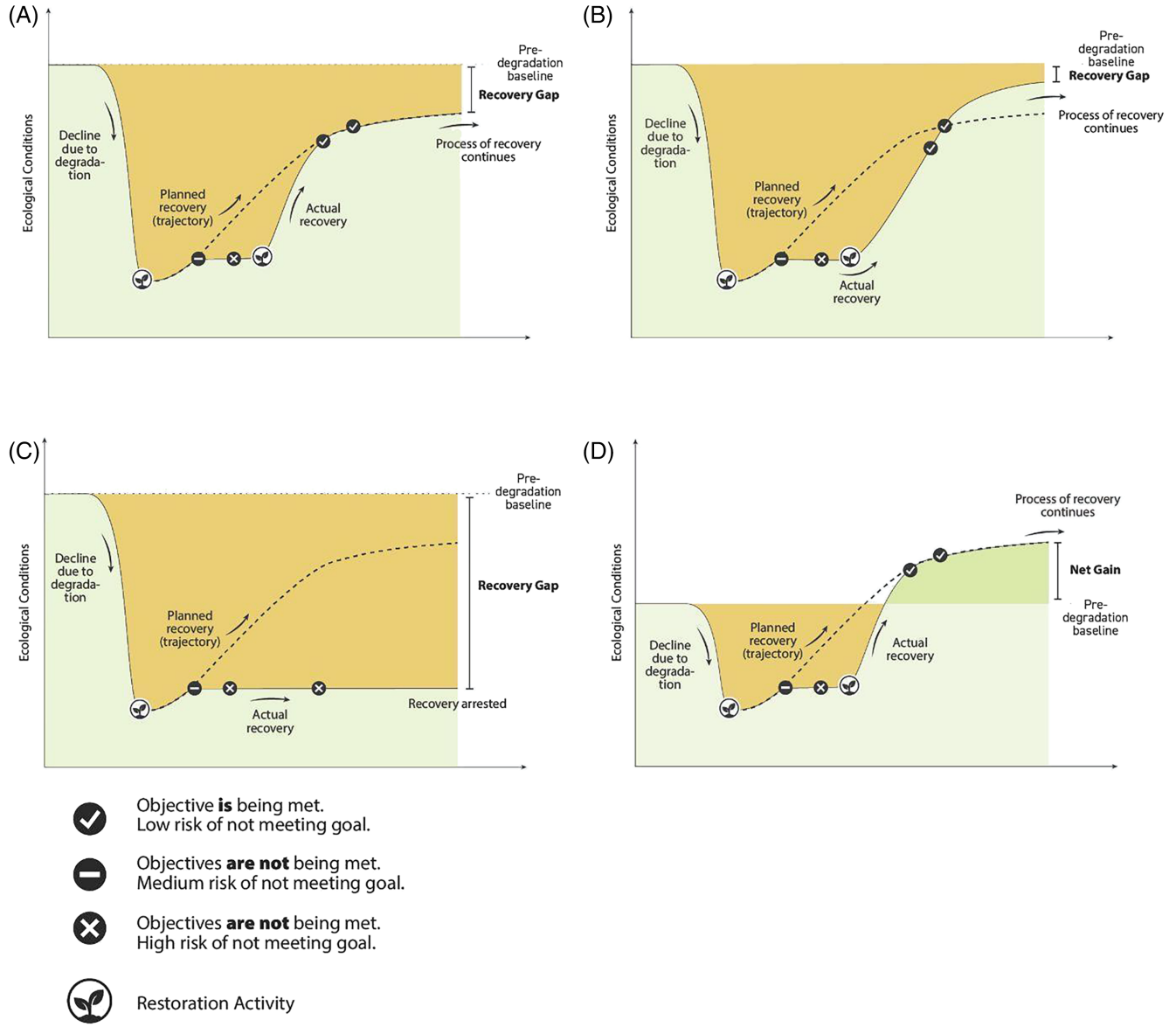


Figure 5. Hypothetical models showing a range of possible trajectories and the role of adaptive management when initial activities do not meet objectives (adapted from Young et al. 2022). The panels depict four scenarios incorporating different pre-degradation ecosystem conditions, initial ecological restoration activities, assessment, and the role of adaptive management toward achieving different levels of recovery: (A) degradation of a high-integrity native ecosystem and subsequent ecological restoration including adaptive management after initial objectives are not met; performance returns to intended restoration trajectory, (B) degradation of a high-integrity native ecosystem and subsequent ecological restoration including adaptive management; performance exceeds the expected trajectory (please note, an alternate outcome not pictured here would be performance approaching, but not fully reaching the intended trajectory), (C) degradation of a high-integrity native ecosystem and subsequent ecological restoration without adaptive management; performance does not meet the expected trajectory, and (D) new degradation of a previously degraded native ecosystem (or previously converted native ecosystem) and subsequent ecological restoration including adaptive management; net gain is achieved against the recent degradation.

- The Five-star System can be used as a framework for any quantitative or qualitative monitoring system as long as the monitoring system aligns with a scale of zero to five. The stars can be readily quantified using many monitoring systems and statistical approaches, for example response ratios (the ratio of the mean value of a sub-attribute at the restoration site compared to that of the reference model), which are commonly employed by scientists and practitioners to measure restoration outcomes. It is important to note that each attribute rating is derived from the ratings of its component sub-attributes, and in turn they are derived from the ratings of their component indicators.
- While quantitative data can be more powerful, qualitative data, consensus judgments, or expert opinion may be acceptable where these are reliable. Regardless of whether quantitative or qualitative approaches are used, it is imperative to be

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Table 3. Summary of generic standards for zero- to five-star recovery levels. The generic standards for zero- to five-star recovery levels are cumulative; each level builds on the previous one. While the table provides an example of a uniform one-star or three-star condition, it is essential to assess and track progress separately for each of the six key ecosystem attributes and their sub-attributes (Table 4). This is because most restoration sites will display varying star levels across the six attributes and their sub-attributes. In addition, where there is high within-site variation for specific indicators, it may be necessary to conduct analyses at multiple subsites and average the values.

Number of stars	*Summary of recovery outcome*
Zero stars	A high number or degree of direct degradation drivers threaten the site, representing a complete barrier to ecosystem recovery. Physical conditions are highly dissimilar to the reference model. While some ruderal or transient native biota may be present, there are no or few characteristic native biota present. Essential ecosystem processes, functions, and beneficial external exchanges typical of the reference model are missing.
1 star	Threats from some direct drivers are absent, but others remain high in number and degree. Physical conditions show some similarity to the reference model. A low number of characteristic native biota are present. Foundational level of ecosystem processes, functions, and exchanges are present.
2 stars	Significant threats from direct degradation drivers remain. The physical conditions can support some characteristic native biota, and a small subset are present and likely to be self-sustaining. Undesirable species are at intermediate levels. Low levels of ecosystem processes and functions are present. Positive exchanges with the surrounding environment have begun.
3 stars	Few threats from direct degradation drivers remain but with a moderate impact. An intermediate subset of characteristic native species is established and likely to be self-sustained, supported by intermediate levels of ecosystem processes and functions. Many species and processes are now engaging in positive exchanges with the surrounding environment.
4 stars	Threats from direct degradation drivers are few and have a minimal impact. Physical conditions closely resemble the reference model. A substantial subset of characteristic biota, spanning all species groups, is present, together with characteristic ecosystem structure. Key ecosystem processes and functions are established, supporting self-sustaining populations. Positive exchanges with other native ecosystems in the surrounding environment are occurring.
5 stars	Threats from direct degradation drivers are virtually absent. A characteristic assemblage of biota is present, displaying structural and trophic complexity that closely mirrors the reference model. All ecosystem functions and processes, including natural disturbance regimes, are present and characteristic resilience has been restored. Cross-boundary flows are functioning appropriately. The ecosystem is self-organizing and progressing toward full recovery.

transparent about the methods used, the level of detail, degree of formality, and reliability of the monitoring that informs the Five-star assessment. This transparency should be in the form of a statement included in any report where a Five-star assessment is employed.

- Applying the Five-star System requires careful consideration of sampling methodology to maintain reliable comparisons with the reference model. For example, species richness typically increases with area sampled. If there are differences in the sampling frame used at the project sites and in the reference model, impacts of restoration on species richness will be under- or over-estimated. Thus, when species richness is employed as an indicator, it is critical that the reference model developed for the site is based on a similarly sized area and assumes comparable monitoring methodologies, or that species-area relationships are accounted for. Existing monitoring tools can assist in accounting for spatial scale when assessing change over time relative to the reference model. Integrating such approaches may ensure consistent evaluations across sites of different sizes.
- Sub-attribute ratings assigned to restoration sites do not necessarily start at a zero or one-star. Sites with remnant biota and unaltered substrates will start with higher ratings for

Table 4. Characteristics of the key ecosystem attributes in a Five-star condition in comparison to the reference model.

Attribute	*Description of Five-star condition*
Absence of threats	Known threats from direct degradation drivers (e.g. overutilization, active contamination, sources of invasive species, and eroding land surfaces) are virtually absent.
Physical conditions	Environmental conditions (including the physical and chemical conditions of soil, water, and topography) required to sustain the ecosystem are present.
Species composition	A very high diversity and abundance of characteristic native species and genes are present, whereas undesirable species are minimal or effectively absent.
Structural diversity	Appropriate diversity of key structural components, including demographic stages, faunal **trophic levels**, vegetation or faunal strata (including nesting and denning habitat), and spatial heterogeneity are present.
Ecosystem function	Appropriate levels of growth and productivity, nutrient cycling, decomposition, habitat, species interactions, resilience, and natural disturbance regimes are present.
External exchanges	The ecosystem is appropriately integrated into its larger landscape and seascape context through positive abiotic and biotic flows and exchanges.

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Table 5. Sample zero- to five-star recovery scale interpreted in the context of the six key ecosystem attributes used to measure progress along a trajectory of recovery. This five-star scale represents a gradient from nil or very low to very high similarity to the reference model and is applicable irrespective of the level of recovery being aimed for. As this is a generic framework, users must develop indicators and monitoring metrics specific to the ecosystem and sub-attributes they identify.

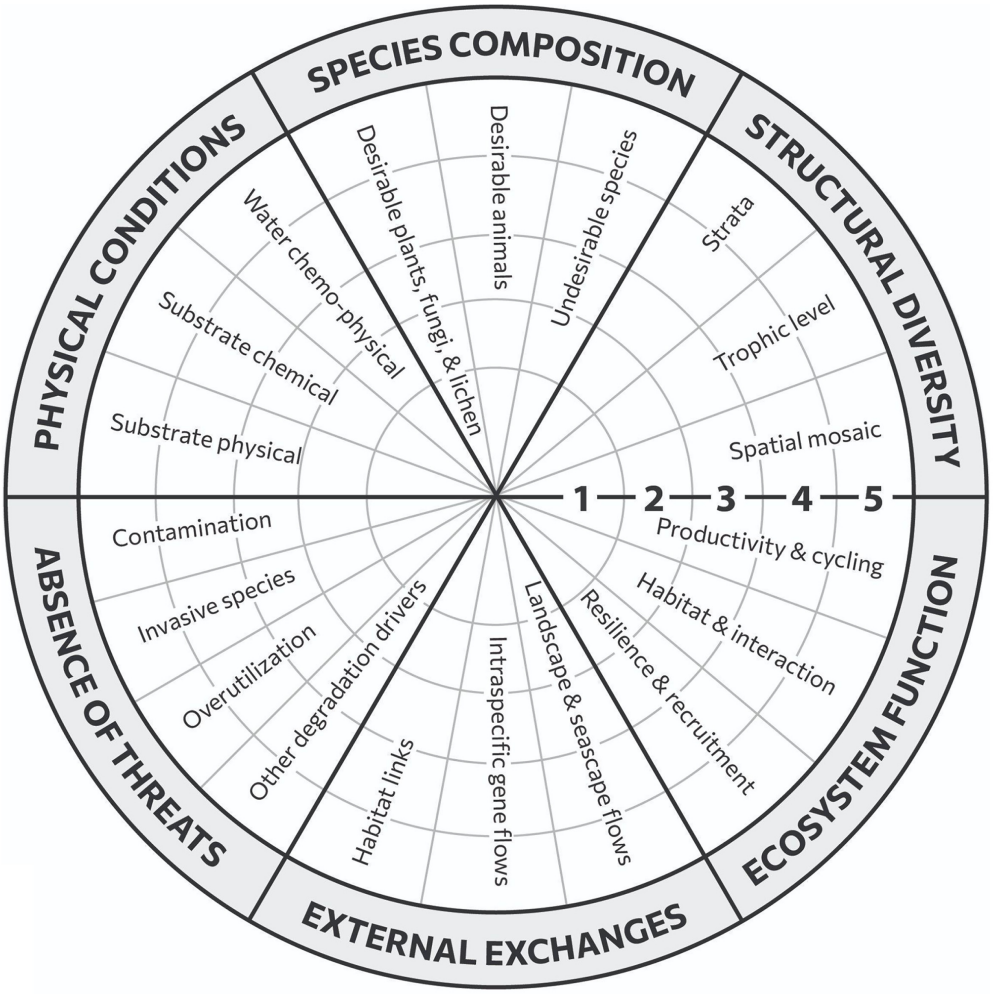
Attributes	*Zero stars*	*One star (★)*	*Two stars (★★)*	*Three stars (★★★)*	*Four stars (★★★★)*	*Five stars (★★★★★)*
Absence of threats	High degree or number of direct degradation drivers prevent any recovery (e.g. overutilization, active contamination, invasive species, absence of appropriate natural disturbance regimes). Protection status may not be secured.	Some direct degradation drivers absent and at least informal protection status secured, while others remain high in number or degree.	Many direct degradation drivers absent while others remain moderate in number or degree.	Number of direct degradation drivers low but some may remain moderate in degree.	Direct degradation drivers low in number and degree.	Known threats from direct degradation drivers are virtually absent.
Physical condition	Landforms and most physical and chemical properties of the site's substrates and hydrology (e.g. soil or other substrate structure, soil biota, nutrients, pH, salinity, depth to water table) are highly dissimilar to the reference.	Landforms and most physical and chemical properties of the site's substrates and hydrology still highly dissimilar to reference but some (e.g. topography, nutrients, and salinity) showing sufficient similarity for growth and recruitment of very low levels of characteristic native biota.	Landforms and physical and chemical properties of substrates and hydrology are at low similarity levels relative to reference but some (e.g. topography, nutrients, salinity) suitable for growth and recruitment of low levels of characteristic native biota of reference.	Landforms and physical and chemical properties of substrates and hydrology stabilized within intermediate range of reference and suitable for growth and recruitment of intermediate levels of characteristic native biota.	Landforms very similar to the reference, and physical and chemical properties of substrates and hydrology highly similar to reference and suitable for growth and recruitment of most characteristic native biota.	Landforms very similar to reference, and physical and chemical properties of substrates and hydrology very highly similar to that of the reference with evidence they can indefinitely sustain all characteristic species and processes.
Species composition	No characteristic native species present or their presence is negligible (<5% of the reference) or confined to ruderal or transient species. Extremely high abundance of nonnative, invasive or undesirable species (e.g. >75%	Ruderal or transient native species plus a very small subset (e.g. >5%) of characteristic (and genetically appropriate) native species of the reference present. Very high levels of nonnative, invasive or undesirable	A small subset of characteristic (and genetically appropriate) native species present (e.g. >25% of the reference) across the site. High to intermediate levels of nonnative invasive or undesirable species	An intermediate subset of characteristic (and genetically appropriate) native species present (e.g. >50% of the reference) over substantial proportions of the site. Intermediate to low levels of nonnative invasive or undesirable species (e.g.	High diversity of characteristic (and genetically appropriate) native species and genes present (e.g. >75% of the reference) across the site and representing a wide diversity of functional groups. Low to very low levels of nonnative invasive or undesirable species (e.g.	Very high diversity of characteristic native species and genes present (e.g. >95% of the reference), with high similarity to the reference and high potential for colonization of more native species over time. Very low to nil invasive or undesirable species

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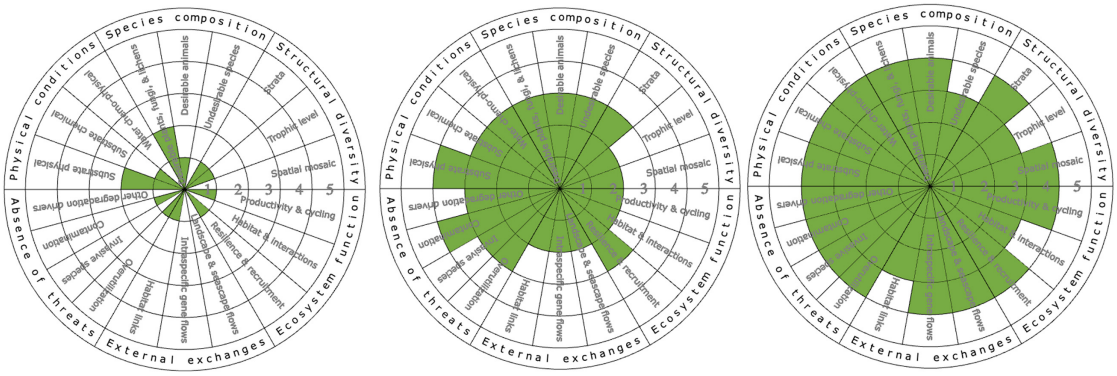
Table 5. Continued

Attributes	*Zero stars*	*One star (★)*	*Two stars (★★)*	*Three stars (★★★)*	*Four stars (★★★★)*	*Five stars (★★★★★)*
	relative cover of invasive plants).	species (e.g. >50% relative cover of invasive plants).	(e.g. >25% relative cover of invasive plants).	>10% relative cover of invasive plants).	>2% relative cover of invasive plants).	(e.g. <2% relative cover of invasive plants).
Structural diversity	No stratum of the reference represented, and **spatial patterning** and trophic complexity dissimilar or highly dissimilar to the reference.	At least one stratum of the reference present but spatial patterning and trophic complexity still largely dissimilar to reference.	Multiple strata of the reference present with some similarity of spatial patterning, mature growth forms, and trophic complexity relative to reference.	Most strata of the reference present and intermediate similarity of spatial patterning, mature growth forms, and trophic complexity relative to reference.	All strata of the reference present and substantial similarity of spatial patterning, mature growth forms, and trophic complexity relative to reference.	All strata present and at the appropriate proportions. Spatial patterning, mature growth forms, and trophic complexity high. Further complexity and spatial patterning able to self-organize to highly resemble the reference.
Ecosystem function	Processes and functions (e.g. water and nutrient cycling, habitat provision, natural disturbance regimes) absent or severely diminished compared to the reference.	Processes and functions only at a very foundational stage compared to the reference.	Low numbers and levels of physical and biological processes and functions relative to the reference are present (incl. plant growth, decomposition, soil processes).	Intermediate numbers and levels of physical and biological processes and functions relative to the reference are present.	Substantial levels of physical and biological processes and functions relative to the reference are present.	All processes and functions (including natural disturbance regimes) are present and show evidence of being sustained.
External exchanges	No or very limited positive exchanges and flows with the surrounding environment (e.g. species, genes, water, fire, other ecological processes).	Positive exchanges and flows with the surrounding environment in place for only very low numbers of species and processes.	Positive exchanges with the surrounding environment in place for a few characteristic species and processes.	Positive exchanges with the surrounding environment in place for intermediate levels of characteristic species and processes.	Positive exchanges with the surrounding environment in place for most characteristic species and processes and likely to be sustained.	Evidence that exchanges with the surrounding environment are highly similar to the reference for all species and processes and likely to be sustained.

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(A) Ecological Recovery Wheel



(B) Example of Using Ecological Recovery Wheel: (left to right) baseline, interim condition, and project goals

Figure 6. (A) Ecological recovery wheel; the Ecological Recovery Wheel (ERW) is a tool to assist with both the planning and tracking of the recovery progress of ecosystem attributes compared to those of a reference model, which is the Five-star condition (outer edge of the wheel); (B) Example of using the ERW; in this example, the left wheel represents the condition of sub-attributes assessed during the baseline inventory stage of the project. The middle wheel depicts the interim condition during the project's progression. The right wheel illustrates the goal of a project 10 years after initiation, where over half its attributes have attained a four-star condition. An editable version of the ERW is available on the SER Standards tools page.

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relevant indicators compared to sites with impaired substrates or missing native biota. Sites that rate at a zero star for a sub-attribute would have an empty cell in the ERW. Whatever the baseline condition of a project, the ERW can be used to demonstrate progress along the trajectory of recovery relative to the reference model.
- By adding different colors or patterns, or creating sequential ERWs, users can concurrently show the baseline condition, the proposed end condition based on project goals, and conditions at multiple points during the recovery process.
- The Five-star System is not intended to evaluate the performance of practitioners or the value of projects. Many projects, because of site constraints, cannot achieve five stars, or full recovery is not the goal. However, all recovery is valued, and even increasing by one or two stars has a significant positive impact and is encouraged. For example, if a project can only achieve three stars, a recovery wheel that largely shows achievement at the three-star level would demonstrate that the project has reached its intended outcome. A project that can achieve five stars and achieves only two stars, however, would indicate a need for adaptive management and modified interventions.

Principle 7. Ecological Restoration Gains Ecological and Social Values When Applied at Larger Scales

Both small and large ecological restoration projects can enhance biodiversity, ecosystem integrity, and human health and well-being. There are, however, often particularly advantageous outcomes associated with restoration efforts that occur at large spatial scales or where many small projects are coordinated to make a difference at larger scales. This is particularly true when integrated ecological restoration activities are planned and undertaken at large scales within a landscape or seascape following a social-ecological approach (see Section 4, Part 2, including concepts of scaling out, scaling up, and scaling deep). For many desired ecological outcomes, observed patterns of landscape- or seascape-scale biodiversity, plant and animal migration patterns, pollen and propagule dispersal, and biogeochemical cycles operate over, and are affected by conditions at large spatial extents, including interactions across the intersections of terrestrial, inland waters, and coastal and marine ecosystems. Concurrently, many social-ecological processes and challenges are generally understood and governed at larger scales where they can best be mapped and analyzed.

In the context of biodiversity recovery, numerous species of animals and plants, including many keystone species, have substantial minimum-habitat requirements that should not be ignored, and the patterns and dynamics of ecological communities and ecosystems across and between landscapes and seascapes are critical to maintaining and recovering biodiversity and ecosystem integrity. Landscape- or seascape scale influences are also often important determinants for the many ecosystem services that involve biological processes (e.g. soil health and water quality) or the exchange of matter (e.g. hydrological circulation and provisioning). Thus ecological restoration at large spatial scales can generate many additional ecosystem benefits. Wide-ranging wildlife, such as many carnivores, can drive the recovery of ecosystem processes such as tropic cascades, a key premise of rewilding. Native plants, including framework species, can benefit from healthy pollinator and disperser communities across ecosystem mosaics. Restoration of watersheds enhances the delivery of ecosystem services such as improved water quality and hydrologic function, and can help reconnect large landscapes through river meandering, wetland mosaics, and upland-wetland interfaces. Large landscapes and seascapes under restoration can better support or accommodate large-scale natural disturbance regimes like periodic fire and flooding, tropical cyclones, and marine upwelling events. They also support the functional ecotones and ecosystem mosaics that are essential for biodiversity and ecosystem integrity at the local, regional, and global scales.

Large-scale ecological restoration, even in fragmented landscapes or seascapes, can also increase synergies among projects within larger ecological **restoration programs** by considering landscape or seascape spatial patterns and social-ecological processes that are inherently scale-dependent or multi-scalar. It is also becoming increasingly apparent that implementing ecological restoration at large scales is critical for accommodating geographic changes in species ranges and climate envelopes driven by climate change. In some cases, large-scale restoration projects will be, or already are, critical to both buffer and encompass population migrations and community reassembly, especially when projects are linked with large protected areas that may offer improved migration corridors.

Longer temporal scales can also be associated with adding cumulative value to large-scale projects, such as through the maturation of trees suitable for cavity-nesting species, or the growth of coral structures required for conservative reef species. Adopting a process of continuous improvement can enable improved outcomes to be attained by leveraging multiple project budgets (Principle 6). Long-term commitment during and after the primary restoration project phase is a characteristic of successful ecological restoration at any spatial scale. To withdraw support at any stage risks regression into a degraded condition.

Due to the length of time and magnitude of required social investment, restoration projects or programs at large spatial extents must be forward-looking; that is to say, they must aim to recover the ecological capacity to satisfy the needs of current generations while ensuring the capacity of future generations to meet their needs. As such, planning ecological restoration at larger scales must ensure that ecological restoration efforts, together with other conservation, restoration, and sustainability measures, result in net-positive benefits for nature and people at the landscape level (Principle 8, Section 4, Part 2). This can only be accomplished if the drivers of degradation (Principle 4) are also addressed at the landscape or seascape level. Additionally, projects implemented at larger scales should ensure that the appropriate diversity of habitats and ecosystem types, including ecotones and mosaics, are adequately reflected in project planning, and that plans consider the social-ecological connections and interactions between these different elements of the landscape or seascape. It should be kept in mind, however, that large-scale planning often involves actors with competing values, aspirations, goals, and demands. Optimizing tradeoffs

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at the landscape scale requires the design and implementation of effective, equitable, and efficient platforms that include key interested and affected parties (Principle 1).

Challenges and Potential Solutions. Most of the social-economic challenges of large-scale ecological restoration are similar to those of landscape and seascape restoration which operate along the entire Restorative Continuum (Principle 8, Section 4, Part 2). For ecological restoration at the large-scale, the challenges are similar to those at the project level, but the scope is broader, more complex, and includes a wider suite of considerations, including, e.g. an increased need for adequate and interconnected financial, institutional, and infrastructural resources (Section 4, Part 3) and the need to identify relevant interested and affected parties at the local and regional level (Principle 1).

Very large ecological restoration projects may also create challenges for developing reference models due to their ecological complexity or the lack of appropriate reference sites (see Section 4, Part 1), although remote-sensing tools and other technological advances may help to overcome these challenges. For scale-sensitive and time-sensitive issues, treatments are best tested at a small scale prior to broader application. Investing in gradual improvements at larger scales (e.g. to control threats such as invasive species or non-point pollution) may, in some cases, achieve greater results than more intense work at smaller scales or over shorter periods of time. Increased scale of a restoration project confers an advantage, however, only where it represents an increase in the scale at which benefits increase (e.g. increased abundance of native species, decreased invasive species abundance, and increased connectivity). A range of potential co-benefits should be considered when predicting whether a project is likely to make a difference at larger scales (Table 6). It is important to note that cumulative value may only be achieved in the long term, meaning that those initially investing in restoration may not directly benefit. Finally, investment planning for large-scale restoration programs needs to take into account any opportunity cost of foregoing strategically important restoration of smaller-scale sites that may be of high biodiversity or ecological importance (e.g. small Key Biodiversity Areas).

Principle 8. Ecological Restoration Is Part of a Continuum of Restorative Activities

As ecosystem degradation continues globally, many countries and communities are adopting policies and measures designed to conserve biodiversity, recover ecosystem integrity and resilience, improve the quality and quantity of ecosystem services, and transform the way societies interact with nature. Ecological restoration is one of a range or family of restorative activities that, based on the SER Restorative Continuum (Figs. 1, 7, & 8), are collectively referred to as ecosystem restoration under the UN Decade on Ecosystem Restoration and Target 2 of the KM-GBF. A restorative activity is one designed to contribute to net gain for biodiversity, ecosystem integrity, and human wellbeing at the site, landscape, or seascape level. Conceptually, the Restorative Continuum offers a unified approach to reducing impacts and repairing the world's ecosystems (both native and production ecosystems), by enabling the most appropriate and effective treatments relative to local ecological, social-economic, and cultural contexts. To attain the six outcomes illustrated in the upper half of the Restorative Continuum figure, the lower half of the Continuum identifies four major categories of restoration types: (1) *sustainability practices*, for example, actions that reduce negative societal impacts through adoption of less damaging ways to consume products, harvest natural resources, and utilize ecosystem services across all sectors

Table 6. Project characteristics that contribute to a project's potential to improve ecosystem recovery at large scales. For optimal success, the project must be based on sound social-ecological information regarding local cultures, practices, and institutions.

Characteristic	*Examples*
Strategic location and timeliness	Restoration projects deploy strategies that make the most of scarce resources and known leverage points for effective restoration. Projects are prioritized in terms of: (1) potential to offer strategic linkages that would substantially expand habitats across the landscape or seascape, particularly for climate change adaptation; (2) goals with urgency or that accelerate the achievement of other goals; and (3) areas with high recovery potential.
Extinction risk reduction	Projects have added value when they reduce threats and help recover depleted populations, species, or ecosystems. This work can often be guided by formal species listings that already exist in many countries (national or subnational), usually linked to or consistent with International Union for Conservation of Nature (IUCN) Red Lists.
Threat pervasiveness	Projects addressing large-scale or pervasive threats and drivers of degradation can influence areas well beyond the project site. For example, projects that achieve substantial **carbon sequestration**, address fragmentation, reduce contamination into waterways, or control invasive plants or animals, can improve outcomes locally and contribute to improved outcomes elsewhere.
Security of institutional support	Large-scale projects need long-term security to ensure that benefits resulting from resources invested will persist over time. Formal protection of sites through legal tenure arrangements is ideal, as is ensuring that long-term political and economic commitments are made by major interested and affected parties, including public and private institutions at local, regional, or national scales.

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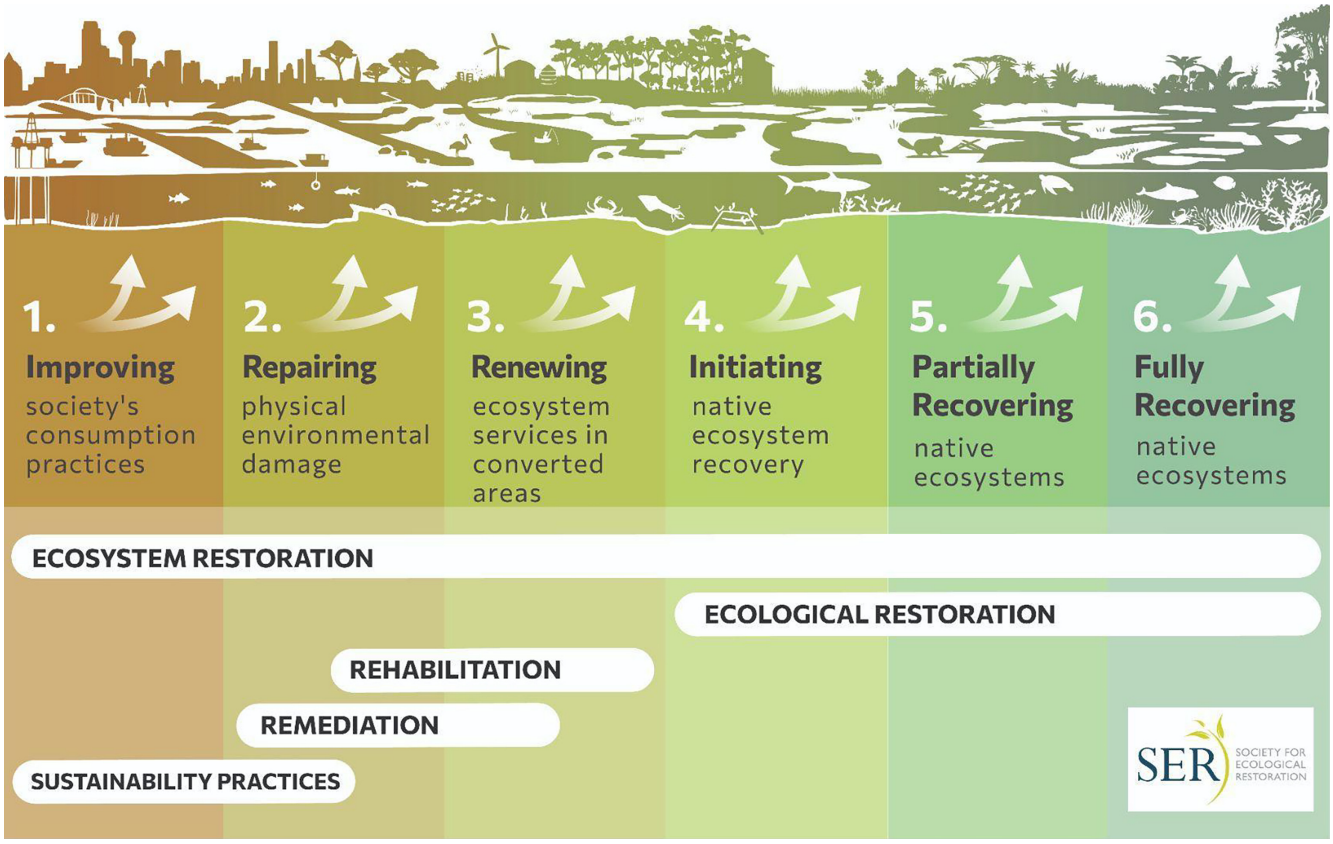


Figure 7. Seeking high ambition within and across the Restorative Continuum. To address the biodiversity extinction and climate change crises and recover the natural capital needed to provide for human health and wellbeing, ecosystem restoration projects and programs should strive for the highest ambition possible within each column of the Restorative Continuum, as illustrated by the upward arrows. The ambition to plan activities that enable further movement to the right on the continuum when possible and appropriate is illustrated by the rightward arrows. Ecosystem restoration is needed in all types of land use contexts, including in highly urbanized landscapes and intensive production ecosystems. Due to the widespread destruction of native ecosystems and the global collapse of biodiversity, ecological restoration is needed across hundreds of millions of hectares of coastal and marine, inland waters, and terrestrial ecosystems. Therefore, ecological restoration is recommended as the preferred choice wherever possible and appropriate.

(Box 8); (2) *remediation* of polluted and contaminated sites (Box 9); (3) *rehabilitation* of degraded urban, industrial, or production landscapes (Box 9); and (4) *ecological restoration*.

Sustainability practices, remediation, and rehabilitation practices are restorative to the extent that they reduce causes and ongoing effects of degradation, promote transition to sustainability, enhance potential for ecosystem recovery, and support or achieve recovery of individual native species. As such, they are also considered **allied activities** to ecological restoration. Activities that do not reduce negative impacts, improve ecological conditions, or that cause harm (e.g. **afforestation** of native grasslands that causes a net loss for biodiversity) do not qualify as restorative or ecosystem restoration. Ecological restoration and its allied activities should be viewed as part of an integrated whole within a broad sustainability paradigm (see Section 4, Part 2). One mechanism to scale up ecological restoration (Principle 7) is to ensure that, when possible, projects are strategically integrated within larger restoration programs that contain multiple projects involving a suite of other restorative activities carried out in different landscape units, with varying partners. These may consist of many restoration project sites that are functionally and physically linked. Examples include the Comprehensive Everglades Restoration Plan in the United States, the Altyn Dala project in Kazakhstan, and the Atlantic Forest Restoration Pact in Brazil, which are carried out by coalitions of governmental agencies, the private sector, NGOs, and research institutions.

Recommendations of performance measures for a range of industry, government, and community sectors or contexts are outlined in Table 7. Regardless of context, it is beneficial to adopt practices of continuous improvement, where restorative activities are cumulatively beneficial and improve outcomes from one level to the next; in China, for example, this process has been termed Stepwise Ecological Restoration. This approach facilitates adaptive management, enabling practitioners to refine techniques and strategies based on observed results, thereby enhancing the overall effectiveness of restoration efforts over time. The European Nature Restoration Regulation (NRR) also contains an explicit obligation for continuous improvement.

Wherever possible and appropriate, ecological restoration practice should aim to achieve the highest level of recovery possible (Principle 6). Where ecological restoration is not feasible (e.g. where remediation or minimizing harmful impacts may

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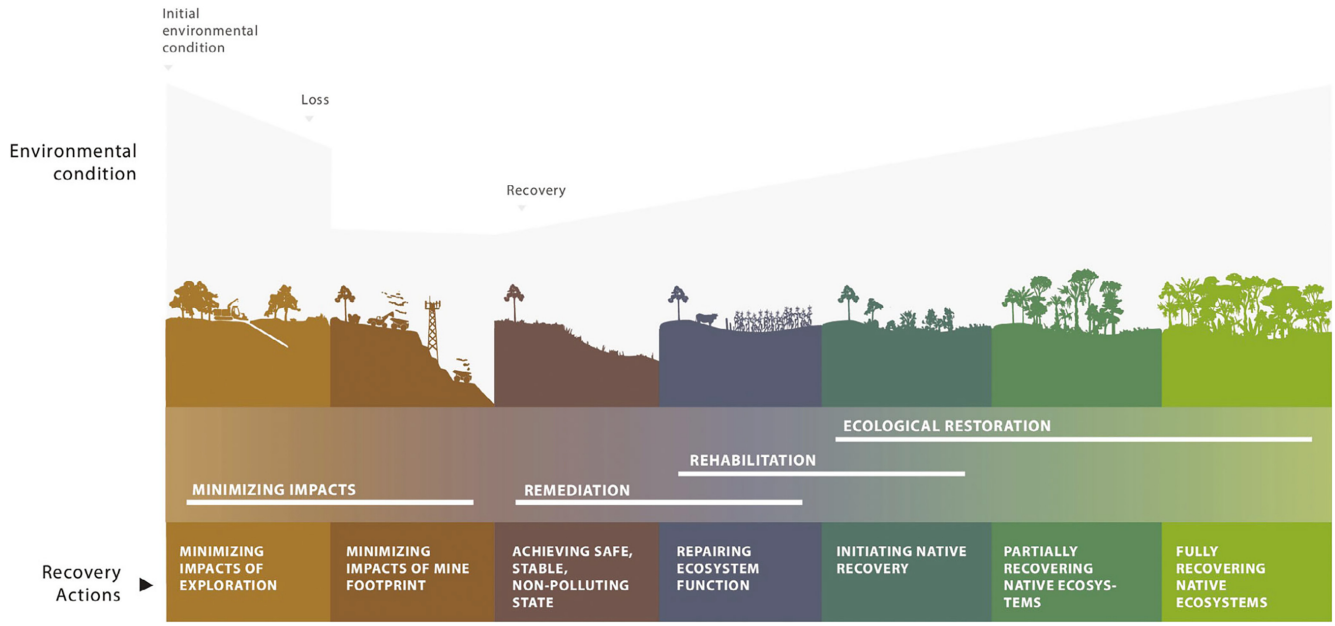


Figure 8. Recovery trajectory for mine sites, including associated categories of restorative activities at different life of mine stages, as an example of the Restorative Continuum calibrated for an economic sector or land use. Reprinted from Young et al. (2022).

be the only option) or when the primary goal is the production of goods and services that cannot accommodate ecological restoration, restorative efforts should also aim for the highest recovery level possible given the context (Fig. 7). It is important to note that the production of goods and services can also occur in native ecosystems (e.g. sustainable use including grazing in native grasslands, harvest of non-timber forest products, and fisheries). To facilitate use, the Restorative Continuum can be modified or calibrated for specific biomes, land uses, and economic sectors (e.g. for mine sites; see example in Fig. 8).

Section 3—Standards of Practice for Ecological Restoration Projects

The following section outlines specific standard practices which are recommended to be followed (where applicable),

Box 8 Sustainability Practices

In the context of global environmental degradation, it is urgent to find ways to reduce adverse environmental impacts that flow from the way societies extract, produce, market, consume, and dispose of ecosystem goods and services. A very broad suite of "sustainability practices", increasingly based on a growing body of research, has developed over recent decades as a result of the global endorsement of the UN SDGs.

Continuous improvement in the design and adoption of such practices has a foundational role to play in the Restorative Continuum. It is paramount, for example, to reduce the greenhouse gas emissions that are exacerbating climate change; one of the most important drivers of harmful impacts to biodiversity. On the consumption side, a combination of regulation and increasing social expectations is changing society's purchasing behaviors, particularly with respect to transition to renewable energy and minimization of waste, which in turn is affecting some manufacturing practices, service industries (e.g. transportation), and housing, particularly in urban areas where more than half of the world's population now resides. On the primary production side, changing regulations and improved practices, as documented through certification and verification standards in many regions of the world, are resulting in more ecologically informed and, therefore, less damaging farming, forestry, fisheries, and mining. Improved production methods have the potential to reduce negative impacts of contamination and pollution (including by greenhouse gas emissions), fragmentation or destruction of native ecosystems, overharvesting, and the spread of invasive species. Collectively, new and improved means of reducing environmental impact across economic supply and value chains demonstrate that production and consumption can align in a more nature-positive way. This alignment is critical, in combination with remediation, rehabilitation, and ecological restoration, to achieve net gain for people and nature.

(Note that this restorative activity is largely but not exclusively associated with minimizing the more widespread root causes of degradation at a societal scale—see also Principle 4. It does not include or replace the specific activities required to address more direct causes of degradation addressed within remediation, rehabilitation, and ecological restoration programs and projects.)

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Box 9 Remediation and Rehabilitation

Remediation includes activities that aim to correct physical conditions arising from degradation, such as the reshaping of highly disturbed soils, and the removal or detoxification of contaminants or excess nutrients from soil and water. Remediation is a common activity following mining to help achieve safe, stable, and nonpolluting sites. It is a pre-requisite for rehabilitation or ecological restoration on many heavily degraded sites including some urban areas, abandoned industrial sites, and heavily contaminated agricultural areas. Remediation in the mining sector may include modifications to the geomorphology of sites to create landforms that, as much as possible, mimic the topography, hydrology, and soils of the ecosystem to be restored. Where remediation projects not only repair physical and chemical conditions but also reinstate ecosystem functionality, there is an overlap between remediation and rehabilitation.

Rehabilitation, on the other hand, is a term used for ecological repair activities that restore ecosystem functioning (including through the use of nonnative biota) in production or other converted ecosystems. Rehabilitation is not intended to restore the biodiversity and integrity of a *native* ecosystem. While remediation and rehabilitation overlap, because rehabilitation is more prevalent, a greater focus is placed on rehabilitation in this box and in this Standards document as a whole.

Adapted from new guidance for Target 2 of KM-GBF for ecosystem restoration (FAO et al. 2024), rehabilitation is defined in the Standards as:

> Management actions that reinstate attributes of some physical properties (e.g. soils, water) and a level of ecosystem functioning on degraded or converted sites, along with a renewed or improved and ongoing provision of high quality and diverse ecosystem goods and services. Native biodiversity and ecosystem integrity are supported but actions do not achieve substantive recovery of a native ecosystem.

Rehabilitation activities are well suited to a broad range of land and water management sectors where substantial native ecosystem recovery is not possible or desirable due to competing and legitimate human needs. Examples of rehabilitation activities include regenerative agriculture, biodiversity-friendly agroforestry, and many mine site restoration projects. Ecological restoration is also sometimes carried out in association with these types of activities, and such higher aspiration is encouraged, particularly when a production area is decommissioned.

The progress of ecological recovery for many rehabilitation projects can be tracked against a native ecosystem reference model using the Five-star System and ERW, where improvements in one or more ecosystem attributes can be demonstrated to attain at least a one-star condition (see Bartholomew et al. 2024 for methods). Under the concept of continuous improvement, rehabilitation projects achieving some improvements in ecological conditions may be considered as having potential for transition to ecological restoration in the future. For instance, where **revegetation** of a degraded rangeland, or post-mine site (with a mix of native and nonnative plant species and native microsymbionts) has resulted in improved soil function, restoration plans can be developed that include harvesting nonnative species and ensuring their replacement by native species over time. Other actions can then be taken to assist the system in recovering to the state it would exhibit in the absence of degradation, taking into account environmental change. In some cases where soil has been stabilized with nonnative species, native species can be added (or helped to recover spontaneously) and nonnative species removed over time to ultimately transition the project from a rehabilitation project to ecological restoration.

particularly where professional staff or contractors are engaged, for five project components of ecological restoration: (1) Assessment; (2) Planning & Design; (3) Implementation; (4) Ongoing Management; and (5) Monitoring and Evaluation (M&E).

These Standards of Practice for Ecological Restoration Projects (Standards of Practice) fully align with SER's Code of Ethics (SER 2022) and Code of Conduct (SER 2024) and are consistent with the Principles and other guidance in the SER Standards as well as other more focused guidance SER has contributed to or led the development of (e.g. mine sites and shellfish reefs). These Standards of Practice also draw from broader guidance to which SER has contributed such as the UN Decade on Ecosystem Restoration Standards of Practice (Nelson et al. 2024) and the Resource Guide to Target 2 of the UN KM-GBF (FAO et al. 2024), which address restoration along the entire Restorative Continuum.

> *When utilizing these Standards of Practice, it is important to appreciate that they are intended to be flexible and therefore can and should be adjusted to fit the size, complexity, degree of degradation, regulatory status, and budget of any project; not all standard practices listed here will be applicable or appropriate for every project.*

It is also important to note that the sequence of the restoration project components stated above does not always reflect the order of activity in actual projects. For instance, M&E is sequenced here after Implementation and Ongoing Management; however, activities critical to M&E must begin before Implementation, because of the need to design monitoring plans, develop budgets, secure funding, and collect pretreatment data.

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Table 7. Recommended performance measures for restorative activities across a range of industry, government, and community sectors or contexts. Note: The star rating refers to the ecological Five-star System and the Ecological Recovery Wheel described in Principle 6. Unless otherwise specified, star ratings in this table are assumed to be an unweighted average of all six attribute scores.

Sector or context	*Restorative activity and recommended performance standard*
Protected areas	• *Native ecosystems with potential for full recovery*: Ecological restoration to five-star level • *Native ecosystems with potential for only partial recovery*: Ecological restoration ideally to four-star level, but minimum three-star • *Single species recovery programs or activities*: Recovery of highly valued individual species causes no collateral degradation and is integrated into ecological restoration projects that aspire to the highest standards
Urban conservation areas and green space	• *Native ecosystems with potential for full recovery for some attributes*: Ecological restoration to five-star level or the highest ambition possible • *Native ecosystems or areas adjacent to native ecosystems with potential for only partial recovery*: Ecological restoration to the highest ambition level practicable but minimum three-star level for biological attributes • *Converted parks and gardens*: Rehabilitation to minimum two-star level for the ecosystem function attribute or at least sustainable utilization with no deleterious effect on native ecosystems; if possible, provision of ecological benefits to adjacent or nearby native ecosystems
Forestry	• *Native forest restoration for biodiversity conservation*: Ecological restoration to five-star level • *Native production forestry*: Ecological restoration to four-star level (between logging cycles) • *Reforestation adjacent to native ecosystems* (e.g. for production or carbon sequestration): Ecological restoration to the highest aspirational level practicable but at least three-star level • *Reforestation primarily for ecosystem provisioning services*: Rehabilitation to minimum two-star level for the ecosystem function attribute, or at least sustainable utilization (between logging cycles) with no deleterious effect on nearby native ecosystems, preferably with added ecological benefits
Fisheries	• *Native ecosystems with potential for full recovery*: Ecological restoration to five-star level • *Native ecosystems with potential for only partial recovery*: Ecological restoration to the highest ambition level practicable but minimum three-star level • *Activities adjacent to native ecosystems*: Rehabilitation to minimum two-star level for the ecosystem function attribute, or at least sustainable utilization with no deleterious effect on adjacent native ecosystems, preferably with added ecological benefits
Utility corridors	• *Native ecosystems with potential for full recovery*: Ecological restoration to five-star level • *Native ecosystems or areas adjacent to native ecosystems with potential for only partial recovery*: Ecological restoration to the highest ambition level practicable but minimum three-star level at least for the biological attributes • *Within utility corridors (not native ecosystems)*: Rehabilitation to minimum two-star level for the ecosystem function attribute, or at least sustainable utilization with no deleterious effect, preferably with added ecological benefits for nearby native ecosystems
Agriculture and production horticulture	• *Native ecosystems with potential for full recovery*: Ecological restoration ideally to five-star level • *Native ecosystems with potential for only partial recovery*: Ecological restoration to the highest ambition level practicable but minimum two-star level for at least the biological attributes • *Regenerative and sustainable agriculture adjacent to native ecosystems*: Ecological restoration to the highest ambition level practicable but at least three-star level for the function attribute, preferably with added ecological benefits • *Regenerative and sustainable agriculture focused on production*: Rehabilitation to minimum two-star level for the ecosystem function attribute or at least sustainable utilization with no deleterious effect on native ecosystems, preferably with added ecological benefits
Mining, quarrying, and oil and gas drilling sites	• *When high-integrity native ecosystems are impacted (native ecosystems with potential for full recovery)*: Ecological restoration to five-star level • *When degraded native ecosystems are impacted (native ecosystems with potential for full or partial recovery)*: Ecological restoration to the highest ambition level practicable, that is three-star level or higher • *Impacts on already converted landscapes with high potential for native recovery*: Ecological restoration to the highest ambition level practicable, that is three-star level or higher • *Impacts on already converted landscapes with low potential for native recovery*: Rehabilitation to one- to two-stars level for the ecosystem function attribute, or at least sustainable utilization with no deleterious effect on native ecosystems and preferably with added ecological benefits

Crosscutting Subcomponents

The following subcomponents are relevant throughout all the phases of the restoration project, are woven into each phase of a project from the start, and are critical to the success and sustainability of restoration projects:

(I) Broad engagement and participation
  (A) Identify and engage with relevant interested and affected parties (e.g. Indigenous Peoples and local communities), ensuring that engagement is meaningful, informed, equitable, and reciprocal, and that gender

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equality and gender balance are promoted. Relevant interested and affected parties may include regulators, land or water owners or managers, industry interests, neighbors, and local communities. Some interested and affected parties may also be rightsholders.

(B) Where broad engagement with identified interested and affected parties is not possible, provide relevant details in the restoration plan.

(C) Identify interested and affected parties for involvement as active and collaborative partners in the project and facilitate their role in doing so.

(D) Obtain the FPIC of Indigenous Peoples as appropriate, and perform due diligence to ensure that all legal and customary rights, including IK data sovereignty, are understood and respected throughout the restoration process.

(E) Ensure that the knowledge, guidance, and concerns of interested and affected parties are acknowledged and incorporated in all project phases, and that interested and affected parties are invited and encouraged to participate in the project as partners from the start. Provide opportunities for participatory co-creation and weave in relevant and specific IK, LEK, and practitioner and scientific knowledge. Ensure that participation in knowledge sharing is meaningful, informed, and equitable.

(F) Record and evaluate any potential conflicts between interested and affected parties and develop mechanisms to resolve such conflicts.

(G) Ensure inclusive opportunities for co-management and the enhancement of livelihoods in all project phases, including local employment, training and capacity building, collaborative knowledge generation and dissemination, and participatory long-term monitoring and ongoing management.

(H) Develop a schedule for interested and affected parties' participation covering the entire duration of the restoration project.

(II) Interested and affected parties consultation and communication

(A) Ensure that the project managers hold open consultation periods during the various phases of the project, when appropriate.

(B) Provide interested and affected parties with communication channels to present their comments and suggestions to those responsible for the project. Ensure that there is an effective mechanism to receive and include comments and suggestions during each phase of the project.

(C) Ensure that project progress is regularly communicated to key interested and affected parties, preferably through a communications plan and integrated with any engagement activities with interested and affected parties or community science activities.

(D) Ensure that communication about the project reaches new generations, fostering appreciation for the project so that past investments are valued. For example, by:

(1) facilitating cultural activities that maintain the history of the project and celebrate its achievements; and

(2) reinforcing lessons learned including the need to carry out similar projects elsewhere.

(III) Adaptive management framework

(A) Ensure that an adaptive management framework is agreed upon and adaptive management activities are applied as appropriate throughout the course of the restoration project, informed by the results of monitoring.

(B) Ensure that the restoration project is modified in a timely manner when significant changes are detected through monitoring data or newly available scientific or programmatic information, including changes of direction to adapt to unexpected ecosystem responses (negative or positive) as well as the identification of additional work as needed. Where appropriate, undertake additional or new research to overcome restoration impediments or to take advantage of unexpected positive responses.

(IV) Record keeping and information sharing

(A) Incorporate information management and record-keeping practices that allow for transparent reporting and communication of activities in all project phases.

(B) Ensure there is the ability to share information to promote and sustain transparency, broad engagement and support; to facilitate understanding, implementation and evaluation of restoration activities; and to enable knowledge exchange, mutual learning, and adaptive management.

(C) Prepare accurate reports in a timely manner to enable clear and reliable communication of project achievements and lessons learned, and to reduce potential risks of misinformation and mistrust regarding the distribution of benefits of the restoration project.

(D) Ensure that adequate and secure records of all project data—including documents related to planning, implementation, monitoring, and reporting—are maintained to inform adaptive management and enable future evaluation of responses to treatments.

(E) Maintain all restoration intervention data for future reference, including details of restoration activities, number of work sessions, and costs, along with all evaluation monitoring records.

(F) Where possible, ensure there is the ability to share data more broadly so they can be aggregated with other data across projects. This is critical for tracking the impact of restoration at local to global scales and for documenting progress toward achieving national, regional, or global restoration goals (e.g. KM-GBF Target 2).

(G) Where appropriate, ensure data collected are available via open-access data systems, or results are submitted to open access repositories, such as SER's Restoration Resource Center or other national or international databases, with protected access given to sensitive proprietary data (e.g. restricted IK).

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(H) Ensure data are archived using secure storage and backups are created. Metadata describing the contents of each dataset should be included.

(1) **Assessment**

1.1 *Context Assessment*.

1.1.1 Define the relationship of the restoration project to regional and local conservation and sustainability goals and spatial planning processes. The restoration project should ideally align and integrate with the management of surrounding ecosystems, landscapes, and/or seascapes.

1.1.2 Assess the biophysical, environmental, social-economic conditions, policy and legal context, and cultural and historical influences of the site to undergo restoration. This assessment should identify the main economic activities and sources of income for communities, the current land tenure and use, and the cultural values held by local communities as they relate to the site.

1.1.3 This assessment should also include a gender analysis to fully understand gender roles and relations in the context of the restoration project. One example of well-established gender analysis is the Social Relations Approach, which has been adopted by the EU and the Center for International Forestry Research.

1.1.4 Assess the site being considered for restoration by compiling and developing contextual diagrams or maps of the site in relation to the surrounding landscape or seascape, including Geographic Information Systems (GIS) polygons and a description of that context. Clearly map all remnant native ecosystems.

1.1.5 Identify any site-tenure issues which may impact the ability to enable long-term restoration, including ongoing management and monitoring for the duration of the restoration project.

1.1.6 Assess ecological connectivity and identify ways to improve beneficial connectivity between native ecosystems at the restoration site, and increase beneficial ecological connectivity and external exchanges with other native ecosystems to improve landscape- or seascape-level flows and processes, including colonization, gene flow, and habitat linkages between and among sites.

1.2 *Baseline inventory*.

1.2.1 Document the causes, intensity, and extent of degradation, and describe the effects of degradation on the biota and physical environment, as well as other measurable indicators, as evidence relative to the six ecosystem attributes and to human health and wellbeing.

1.2.2 Document the pre-project condition and ecosystems of the area being considered for restoration relative to the key ecosystem attributes by using the relevant SER Five-star System to complete the SER Social Benefits Wheel and SER ERW. The baseline social context and ecological conditions should be determined for each distinct restoration site within the area (see also 1.2.5–1.2.9). Pre-project conditions are best measured, but can be estimated if necessary (e.g. if the project is already ongoing).

1.2.3 Identify past land and water uses of the site being considered for restoration and describe the temporal sequence of habitat loss and ecosystem conversion caused by previous land use changes including infrastructure development.

1.2.4 Describe the type and degree of direct and indirect drivers or threats that have caused degradation on the site in the past or may threaten the site in the future. Identify ways to eliminate, mitigate, or adapt to them (for a globally standard Threats Taxonomy, see Salafsky et al. 2024). Include an assessment of:

- historical, current, and anticipated degradation within and external to the site (e.g. overutilization, infrastructure development, damage to substrates, fragmentation, invasive plants and animals, hydrological degradation to water quality or hydrodynamics, contamination, and altered disturbance regimes) and ways to manage, remove, or adapt to them;
- any needs for genetic diversity supplementation for species reduced to non-viable populations due to fragmentation or other factors (see Appendix 1); and
- current and anticipated effects of climate change (temperature, rainfall, sea level, and marine acidity) on communities, species, and genotypes with respect to likely future viability.

1.2.5 For each distinct restoration area present, record the status of current physical conditions including dimensions, configuration, and physical and chemical conditions of streams, water bodies, water columns, topography, land surfaces, soils, or any other material elements relative to prior or changing conditions.

1.2.6 Identify all native and nonnative flora and fauna for each distinct restoration area within the project site, including ruderal and transient species, but particularly threatened species or communities and invasive species. Describe species richness and evenness.

1.2.7 Describe the characteristics and condition of vegetation strata, trophic communities, and spatial mosaics for each ecosystem present, relative to the reference model.

1.2.8 Describe the characteristics and condition of productivity and cycling, habitat provision and interactions (including soil habitats for microbiota),

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natural disturbance regimes (e.g. fire, flooding, herbivory, erosional processes, and extreme weather), community dynamics, resilience, and recruitment for each ecosystem present.

1.2.9 Identify the relative capacity of the biota on site and external to the site to commence and continue recovery with or without intervention. This includes undertaking an assessment that includes:

- the native species that have been recorded, those presumed absent, and those potentially persisting as stored or dormant propagules or occurring within colonization distance;
- a map of areas of distinctly varied conditions, including successional stages present, priority recovery areas, and any distinct spatial areas requiring different treatments;
- identification of the processes that may enable or limit the recovery of species persisting as propagules or other regenerative units on site (e.g. buried seeds or protected buds) or occurring within colonization distance; as well as opportunities to enhance natural regeneration through reinstating improved site conditions or applying germination triggers; and,
- prediction of the evolution of the degraded ecosystem without intervention considering the most likely ecological and social-economic scenarios. This alternative assessment includes changes in structure, composition, and functioning that will likely occur if no restoration activities are carried out and justifies the need for restoration and the proposed restoration activities.

1.3 *Native ecosystems and reference models*.

1.3.1 Use the baseline inventory to help identify native ecosystems that were historically present at the site or alternative native ecosystems that could be the appropriate focus of restoration.

1.3.2 Identify each native ecosystem to undergo restoration and develop an appropriate reference model, based on multiple indicators of the six key ecosystem attributes derived from a suitable number of reference sites and other information.

1.3.3 Ensure that each distinct restoration area identifies one native ecosystem to undergo restoration and therefore develop at least one reference model; in some cases (e.g. in cases of multiple successional stages) multiple reference models may be developed.

1.3.4 Develop reference models by:

- Mapping native ecosystems chosen for restoration to the Ecosystem Functional Groups of the IUCN Global Ecosystem Typology, and when possible, to the International Vegetation Classification's Macrogroup level or equivalent, and to national, subnational, or local ecosystem classification systems; and
- If feasible, identify and measure at least three indicators for each of the six key ecosystem attributes (ideally at least one indicator for each sub-attribute) that characterize the reference model(s). Plans should therefore document:
  (a) substrate characteristics (biotic or abiotic, aquatic or terrestrial);
  (b) major characteristic species representing all plant-growth forms and functional groups of micro- and macrofauna, including pioneer and threatened species, especially those requiring the use of multiple reference models;
  (c) vegetation strata, trophic communities, and spatial mosaics among and within ecosystems;
  (d) ecosystem functional attributes, including nutrient cycles, characteristic disturbance and flow regimes, successional pathways, plant–animal interactions, ecosystem exchanges, and any disturbance-dependence of component species;
  (e) habitat needs of focal biota including any faunal minimum ranges and responses to degradation pressures and restoration treatments; and
  (f) any ecological mosaics that require the use of multiple reference models for a site.
  (g) Any desirable ecological connectivity between the restoration site and the broader landscape to support gene flow for species diversity, allow species migration, and optimize other landscape flows.

1.3.5 Use the selection of native ecosystems and the development of reference models to develop restoration goals and intervention protocols, and to monitor restoration progress.

(2) **Planning and Design**

2.1 *Site tenure*. Before investing in restoration, provide evidence of the potential for the long-term management of the site. Restoration plans should therefore:

2.1.1 Ensure that the availability of the site to undergo restoration is documented with the owners or their authorized managers or agents, and an agreed-upon set of rights and responsibilities for each party is established. Such agreements must fully address all tenure-oriented aspects of the restoration project for its duration. Any documentation will ideally be in the form of legally binding agreements as they establish a greater degree of protection for these rights and responsibilities than informal agreements.

2.1.2 Ensure that access granted by the site owners or their authorized agents is documented through formal legally binding agreement(s) between the relevant parties and that the access granted

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allows for the carrying out of all aspects of the restoration project as described in the restoration plan.

2.1.3 Ensure that the rights of Indigenous Peoples, local communities, and other interested and affected parties to the site are identified, understood, and respected.

2.2 *Applicable laws and regulations*. Identify all laws, regulations, rules, or strategic instruments applicable to the restoration project. Ensure that the restoration project is consistent with and does not contradict such laws, regulations, rules, or strategic instruments and that all authorizations required for the restoration project have been obtained.

2.3 *Commitment to the restoration project and compliance with SER Standards*. Demonstrate a long-term commitment to the project (including the goals and objectives of the project) by developing strategies which enforce adherence to the SER Principles, and political and financial support to ensure sufficient funding has been secured or is probable for all planned activities, and for the project to be successful.

2.4 *Scope, vision, goals and objectives*.

2.4.1 Develop clear and measurable goals and objectives to identify the most appropriate actions, ensuring that all project participants have a common understanding of the project. Measure progress toward these goals and objectives (see Monitoring below).

2.4.2 Specify the scope of the project by outlining the broad geographic or thematic focus of the restoration project.

2.4.3 Craft a vision that is a general summary of the desired outcomes of the restoration project to be achieved.

2.4.4 Establish the ecological and social goals that specify the level of ecological recovery sought for each distinct restoration area (i.e. state and condition of the ecosystem attributes and social benefits to be achieved).

2.4.5 Ensure that the social goals are explicit and realistic, considering the time frame and social capital available in the area.

2.4.6 Ensure that ecological goals quantify, to the extent possible, the degree of the ecosystem attributes to be attained. In full recovery cases, ecological goals will fully align with the reference model, whereas in partial recovery cases, the goals will deviate from the reference to some degree.

2.4.7 Ensure that objectives, being formal statements of the interim results along the trajectory of recovery, are SMART and include indicators, specific actions, quantities, and time frames. If the project is well conceptualized and designed, the realization of a project's objectives should lead to the fulfillment of the project's goals and ultimately its vision.

2.5 *Restoration treatment specifications or prescriptions*.

2.5.1 Ensure that plans contain clearly stated treatment specifications or protocols for each distinct restoration area, describing what, where, and by whom treatments will be undertaken, and their order or priority.

2.5.2 Where knowledge or experience is lacking, ensure the use of targeted research that informs appropriate protocols within an adaptive management framework.

2.5.3 Where there is uncertainty, ensure that interventions are applied in a manner that reduces environmental risk.

2.5.4 Ensure that plans:

- describe actions to be undertaken to eliminate and mitigate, or adapt to, the degradation identified in the Assessment phase, and to foster the recovery of the ecosystem;
- justify the technical and ecological feasibility of the proposed actions and optimize the use of economic and technical resources;
- identify and justify specific restoration approaches (informed by the inventory of natural regeneration potential and limits identified during the site assessment phase), and corresponding descriptions of specific treatments based on existing, interim, and desired future conditions for each restoration area;
- describe what, where, and by whom treatments will be undertaken and their order of priority; and
- justify the human and financial resources for all actions.

2.5.5 Depending on the condition of the site, identify:

- amendments to the shape, configuration, chemistry, or other physical condition of abiotic elements to render them amenable to the recovery of target biota and ecosystem structure and functions;
- effective and ecologically appropriate strategies and techniques to control undesirable species and to protect desirable species, their habitats, and the site;
- ecologically appropriate methods to facilitate natural regeneration of desirable species or achieve reintroduction of any missing biota, along with management of regeneration niches for longer term recruitment;
- appropriate species selection, genetic sourcing, and procurement of biota to be reintroduced or augmented (Principle 4, Appendix 1) to ensure potential for breeding and recruitment of the site's biota; and
- ecologically appropriate strategies to address circumstances where the ideal species or genetic stock is not immediately available (leaving gaps for in-fill reintroductions in subsequent seasons).

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2.6 *Logistics and risk*.
- 2.6.1 Prior to undertaking a restoration plan, identify likely risks in relation to required resources, practical constraints, and potential hazards that may threaten the restoration project or its desired outcomes, and any strategies to manage or mitigate these risks.
- 2.6.2 Develop a restoration project budget which addresses financial needs for the Implementation, Ongoing Management, and M&E phases of the Restoration Project, identifying any financial risk factors.
- 2.6.3 Identify appropriately qualified personnel to participate in the restoration project, including the development of restoration treatment and monitoring specifications. Where knowledge or experience is lacking, ensure adaptive management or targeted research that informs appropriate prescriptions are described.
- 2.6.4 Ensure the prescriptions define the need for machinery, plant materials, and other physical resources. Ensure supply chains (e.g. plant material; see Appendix 2) and their temporal qualities, availability, and reliability are identified, described, and appropriately planned for.
- 2.6.5 Develop a project timetable and rationale for the duration of the project taking into account ecological, logistical, and regulatory constraints (e.g. faunal nesting, seasonal senescence in plant growth, seed-collection and nursery timelines, fire or flood risk).

2.7 *Ecological and social protections*.
- 2.7.1 It is required to acknowledge and describe the short-term negative impacts (erosion, sedimentation, impacts to fauna) that may occur during the implementation of restoration activities. Identify mitigation plans to reduce short-term impacts and avoid long-term impacts to the extent viable.
- 2.7.2 Ensure the justification for the use of synthetic chemicals, biological control agents, nonnative species, or genetically modified organisms according to regional and national regulations and internationally accepted scientific protocols.
- 2.7.3 Ensure that planned restoration actions respect natural processes and support the potential for natural and assisted recovery.
- 2.7.4 If hazardous chemical products are used, ensure that the restoration plan includes training requirements (consistent with those of the local jurisdiction) for personnel using the products and an emergency protocol that documents the actions for monitoring, controlling, and correcting potential hazards.
- 2.7.5 If relevant, ensure that the use of any biological control agent is selective, adjusted to the circumstances of the restoration project, and consistent with legal regulations.
- 2.7.6 If relevant, ensure that the use of synthetic chemicals in the restoration project is justified and minimized.
- 2.7.7 Avoid the use of nonnative species, except in cases which are strictly necessary and adequately justified in the restoration plan, and provided these species are not invasive or potentially invasive in the region.
- 2.7.8 Ensure that genetically modified organisms are only used in highly limited and scientifically defensible ways and within the legal framework of the restoration project area.

2.8 *Participation and communication*. Include a participation and communication strategy designed according to the restoration project's goals, scale, and intensity. Incorporate a broad diversity of partners and interested and affected parties as appropriate to create a shared vision, build trust, avoid problems related to project governance and design, and ensure that opportunities to benefit interested and affected parties, including employment and training opportunities, are considered as appropriate.

2.9 *Information management*. Define procedures to guarantee the accessibility, public dissemination, and custody of the information, including all relevant documentation.

2.10 *Restoration project plan review*.
- 2.10.1 Ensure that the plan includes a schedule and time frame to carry out review by interested and affected parties, and independent peer review as required.
- 2.10.2 Design and implement a plan review based on monitoring results and the principles of adaptive management that considers new knowledge, changing environmental conditions, and lessons learned.

2.11 *Ongoing management plan*.
- 2.11.1 Prepare an Ongoing Management Plan to ensure the project site does not regress into a degraded condition. Clearly state the ongoing management activities, including time intervals for management activities, and that are complementary to the rest of the Restoration Project Plan.

2.12 *Monitoring and Evaluation Plan*.
- 2.12.1 Prepare a M&E Plan to assess project implementation, effectiveness, and impacts (See also Box 7, Nelson et al. 2024), both social and ecological. Specific questions to be addressed through monitoring include: selection of measurable indicators; sampling design for collecting baseline, implementation, and post-treatment data; procedures for documenting and archiving collected data; plans for data analysis; and plans for communicating results to adapt management strategies on site and

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inform interested and affected parties of lessons learned.

2.12.2 Ensure that project monitoring is undertaken throughout the restoration project and incorporated into adaptive management decisions.

3 Implementation

3.1 *Site measures*.

3.1.1 Following the risk mitigation protocol included in the restoration plan, ensure that measures are taken to prevent, mitigate, or remedy potential adverse environmental and social impacts and liabilities of restoration activities, especially those causing long-term impact or with the potential of becoming permanent. Include impacts and liabilities that relate to physical damage (clearing, burying topsoil, trampling), chemical contamination (over-fertilizing, pesticide spills), or biological contamination (introduction of invasive species including undesirable pathogens).

3.1.2 Maintain a list of all chemicals and biological control agents used, and ensure information is collected on the positive and negative effects of their application. Ensure use of all chemicals and biological control agents, including methods, formulas, and application rates, is recorded in the daily progress reports.

3.2 *Support natural processes*.

3.2.1 Ensure restoration actions respect natural processes and prioritize the potential for natural regeneration through such actions as providing sufficient time after the removal of degradation drivers, installing dispersal attractants, ensuring suitable regeneration niches for ongoing recruitment, and applying appropriate disturbances to trigger germination of dormant seeds and other regenerative units.

3.2.2 Repeat any treatments as required to secure a stable ecological response, such as substrate, nutrient, or hydrological amendments; invasive animal or plant control; and application of appropriate disturbances, thinning, or biotic reintroductions.

3.2.3 Ensure that, where the recovery period is long (e.g. to attain growth of plant species or breeding of new populations), multiple additional (adaptive) treatments are planned for and implemented to reduce adverse effects that may arise over time (overabundance of species, nutrient influxes, and sediment inflows into streams). Follow up with repeat treatments as required.

3.2.4 Ensure that any species reintroductions are made sequentially in such a way as to create the proper conditions needed to support the subsequent reintroduction of beneficiary species.

3.2.5 Ensure appropriate aftercare is provided to any plants or animals translocated to support their establishment.

3.3 *Sustainability*.

3.3.1 Where possible, incorporate the use of sustainable materials and waste disposal processes into the restoration process.

3.3.2 Ensure that seeds or other regenerative units collected for restoration do not place undue pressure on natural populations.

3.3.3 Implement restoration plans to improve ecosystem resilience to current and future natural disturbances and anticipate environmental change by:

- when possible, ensuring appropriate species diversity from each functional group (consistent with the reference model) to replicate and support natural functional redundancy within ecosystems;
- when appropriate, establishing spatial and structural heterogeneity within the site to undergo restoration to support the persistence of a diversity of species occupying a range of successional and environmental niches; and
- considering the location of likely ongoing disturbances (such as historic floodplains), to ensure restored ecosystems are more adaptable to a range of potential site conditions; and
- integrating preventative measures over the course of project implementation to improve ecosystem resilience to changing disturbance regimes and environmental conditions.

3.3.4 Ensure fulfillment of planned considerations to account for community interests and pressures from the surrounding landscape when implementing restoration projects to support beneficial impacts on local assets and livelihoods and avoid unintended negative impacts on local assets and livelihoods and support project permanence.

3.4 *Engage appropriate personnel and participants*.

3.4.1 Involve appropriately qualified and trained personnel in the implementation of the restoration project.

3.4.2 Ensure that restoration treatments are carried out by, or under the supervision of, suitably qualified, skilled, and experienced people.

3.4.3 Support the participation of interested and affected parties, including community members, in project implementation activities when possible and appropriate.

3.4.4 If the project receives public funding, ensure that hiring conforms to the recruitment processes required by the funding agency.

3.4.5 When possible, prioritize local recruitment and training options to boost labor and social activity in local communities where restoration is carried out.

3.5 *Compliance with planning and design*.

3.5.1 Implement the project in accordance with the terms outlined in the project plans and according to any

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relevant contracts, agreements, regulations, or other conditions.

3.5.2 Ensure that the machinery and other material resources used on the project comply with any specifications in the project plan (e.g. cleaning to prevent transport of nonnative species propagules), except as approved by a manager where it is appropriate and reasonable to do so, in accordance with best practice.

3.5.3 Ensure that any modifications to the use of machinery and other material resources used on the project are to be recorded in the project daily progress reports.

3.5.4 Ensure that the receipt and handling of plant material on site are documented in the project daily progress reports.

3.5.5 Ensure that, to the extent any action deviates from the project specifications, the lead managers define any needed corrective measures and provide evidence that the modifications made, or corrective measures required, respect the project goals.

3.5.6 Ensure that all modifications or corrective measures comply with environmental, labor, and health and safety regulations, as required.

3.5.7 If modifications are made, including those based on adaptive management, ensure that the project plans are adjusted to reflect those modifications, including any needed adjustments to project goals, objectives, or monitoring.

3.5.8 Collect evidence confirming that each phase of the project has undergone rigorous quality control and assurance procedures, as appropriate, aligned with the specified project standards.

3.6 *Compliance with environmental, labor, and health and safety regulations as identified in 2.2*.

3.6.1 Ensure the project is implemented in compliance with all applicable environmental laws, regulations, and permits, including those related to soil, air, water, oceans, heritage, species, and ecosystem conservation.

3.6.2 Ensure compliance with all relevant labor laws, regulations, and permits, including those on prevailing wages, gender equality, and nondiscrimination.

3.6.3 Ensure that the project is in compliance with all applicable health and safety laws, regulations, and permits.

3.6.4 Ensure compliance with any applicable laws, regulations, and permits governing volunteers.

3.6.5 Ensure compliance with all safeguarding requirements, as related both to participatory engagement and employment, to protect children, youth, and adults at risk from all forms of exploitation, abuse, and harassment.

3.7 *Specific implementation phase communication*.

3.7.1 Ensure that interested and affected parties, including the local community, are informed of any actions that may affect their interests as the project progresses during the Implementation phase.

3.7.2 Ensure that interested and affected parties are recognized not just from a consultation perspective, but as potential paid or volunteer participants in the implementation phase.

3.7.3 Comply with information and public participation regulations during the implementation phase when applicable.

3.8 *Documentation*.

3.8.1 Ensure, as appropriate, that treatment data and supporting materials are recorded in daily progress reports.

3.8.2 Ensure, as appropriate, that daily progress reports are compiled into weekly, monthly, or other periodic summary reports.

4 Ongoing management

4.1 *Ongoing management plan*.

4.1.1 Expand and finalize the Ongoing Management Plan to reflect the outcomes of implementation and as informed by the results of monitoring. Ensure that management activities are undertaken in order to prevent deleterious impacts and to avoid regression into a degraded condition as well as to facilitate the natural recovery of the ecosystem.

4.1.2 Upon completion of the Implementation phase, ensure that the Ongoing Management phase is implemented in accordance with the Ongoing Management Plan.

4.1.3 Ensure that the Ongoing Management phase is appropriately budgeted and funded in the project budget.

4.1.4 Ensure permanent ongoing management tasks are minimized, except where appropriate (e.g. invasive species control, prescribed burning).

4.1.5 Conduct periodic surveillance of the site to check for re-occurrence of degradation and to protect the investment in restoration.

4.2 *Financial commitment*. Ensure there is a financial commitment to the implementation of ongoing management.

4.3 *Updates to Ongoing Management plan*. Ensure that the Ongoing Management plan is updated to reflect the ongoing experiences and knowledge generated during implementation as well as after major project activities are completed and following monitoring results. If modifications are made based on adaptive management, ensure the Ongoing Management Plan is adjusted to reflect those modifications, including any modifications to restoration project goals or objectives if needed.

4.4 *Communication*. Ensure that interested and affected parties, including the local community, are informed in advance of any actions that may affect their interests as the project progresses during the Ongoing Management phase. Ensure that interested and affected parties are recognized not just from a consultation perspective, but as potential paid or volunteer participants during the Ongoing Management phase.

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5 **Monitoring and Evaluation**.

Ecological restoration projects adopt the principle of observing, recording, and monitoring treatments and responses to determine whether a project is on track to meet its goals and objectives, or whether adjustment is needed. Projects are regularly assessed with progress analyzed to adjust treatments as required (i.e. using an adaptive management framework). Collaborations are fostered between researchers, local knowledge experts, practitioners, and participants in community-based science projects, especially where treatments are innovative or being applied at a large scale. Monitoring needs are reassessed throughout the project and resources reallocated or expanded accordingly.

5.1 *Monitoring Program*. Implement the monitoring program in accordance with the M&E Plan.
- 5.1.1 Schedule monitoring and collect data as outlined in the M&E Plan.
- 5.1.2 Use methods that are easy to use and implement through participatory processes when possible. When formal quantitative sampling is needed, the sampling design must include a sufficiently large sample size to enable statistical analyses and inferences. In all cases the methods should be detailed enough to be repeatable.
- 5.1.3 Use data collected during monitoring activities to inform and facilitate adaptive management, ensuring the implementation of effective responses to any significant unexpected ecosystem changes that are detected, positive or negative, including those caused by natural disturbances or climate change.
- 5.1.4 Report to interested and affected parties on project progress related to the goals and objectives identified at the start of the project.
- 5.1.5 Disseminate the restoration project outcomes to interested and affected parties.
- 5.1.6 Conduct periodic surveillance of the site to check for recurrence of degradation to protect the investment in restoration, ideally involving interested and affected parties.
- 5.1.7 Promote, as appropriate, collaboration with the scientific community.

5.2 *Intervention and control plots*.
- 5.2.1 Establish intervention and untreated control plots prior to treatment implementation and monitor these plots before and after treatments to determine treatment effects. The intervention plots should include all treatment alternatives.
- 5.2.2 Analyze data to assess project outcomes, compare alternative techniques, contrast the quality of the techniques, or monitor the trajectory of recovery or treatment impacts.

5.3 *Monitoring results*.
- 5.3.1 During the Implementation and Ongoing Management phases, use the SER Social Benefits Wheel and SER ERW (using the relevant SER Five-star System) to periodically analyze the progress of the project, including measuring the progress of the project toward its goals and objectives.
- 5.3.2 In addition to the SER Social Benefits Wheel and SER Ecological Recovery Wheel, use other multi-criteria analysis tools for evaluation as appropriate.

5.4 *Updates to the M&E Plan*. Ensure as appropriate that the Monitoring and Evaluation Plan is updated to reflect the ongoing experiences and knowledge generated during the course of the Restoration Project.

5.5 *Records and project data*.
- 5.5.1 Maintain project records, including all relevant data and metadata.
- 5.5.2 For wild collected organisms, include provenance data on location (preferably with coordinates), descriptions of donor and receiving sites or populations, and for plants, population sizes as well as numbers and spacing of mother plants.
- 5.5.3 For non-wild organisms, include documentation with reference to collection protocols, date of acquisition, identification procedures, and collector or propagator's name.

5.6 *Communication of results*.
- 5.6.1 Report through measurable indicators on progress toward the goals and objectives.
- 5.6.2 Inform interested and affected parties of the key results of monitoring and evaluation in an accessible way.
- 5.6.3 Provide the results to researchers and restoration experts via appropriate platforms (e.g. web platforms, brochures, congresses, and scientific publications).
- 5.6.4 Specify the level and details of monitoring upon which any evaluation of progress has been based.
- 5.6.5 Include training activities for the local community to encourage their engagement in long-term monitoring, collaborative knowledge cogeneration, and dissemination.

Section 4—Elaboration on Key and Leading Practices

Part 1. Developing Reference Models

As described in Principle 3, reference models are at the heart of ecological restoration. They allow assessment of the magnitude of degradation and the potential degree of recovery and help drive the establishment of restoration goals and objectives. Consequently, adequate investment in developing a reference model is an important consideration in project planning, timelines, and budgeting. However, the number of indicators used in a reference model and the model's ability to adequately capture all of the indicators' means and ranges will vary among projects based on resources, the availability of reference sites, and other relevant ecological information. Adequately resourced projects should develop thorough reference models that characterize all relevant aspects of the project site. Project managers should aspire to create the best model possible given project constraints.

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A first step in developing a reference model is to identify the native ecosystem to undergo restoration (Principle 3), using local data and any formal descriptions of the ecosystem chosen for restoration (e.g. NatureServe Explorer in North America, the interpretation manual of the EU Habitat types, many national or local classification systems; see also the Global Ecosystem Typology (Keith et al. 2022) and Faber-Langendoen et al. 2025). These classification systems and their descriptions can be essential in informing the selection of reference sites and providing other relevant data needed for developing reference models (Comer et al. 2025).

Identifying Indicators for Each of the Six Key Ecosystem Attributes. Reference models ideally incorporate a broad set of indicators for each of the six key ecosystem attributes and their sub-attributes (i.e. the variables measured and graphed in the recovery wheel, Principles 3 and 6). Some of these attributes, such as structural diversity and species composition are relatively straightforward to assess, whereas others, such as ecosystem functions, are more complex, but equally important. In addition to supporting ecosystem integrity, ecosystem functions provide the services required for life (food, fiber, water, and medicines) and their inclusion in reference models is essential. Further, the physical attributes of ecosystems and beneficial external exchanges (e.g. regenerative units) that flow across ecosystems are important to consider in developing references, as they are the context in which species interactions occur.

In addition to incorporating individual ecosystem components, reference models should reflect ecosystem complexity and the relationships among ecosystem components (Green & Sadedin 2005). For instance, plants and soils are tightly linked through a system of bioregulation (Perry 1994). Plants directly affect the chemical, physical, and biological properties of soils. Thus, the type of plants growing in an ecosystem affects all aspects of the soils in the system. Similarly, soil chemical, physical, and biological properties (e.g. symbiotic organisms) affect the types of plants that grow in an area. These relationships and bioregulation are not unique to terrestrial ecosystems. In aquatic systems, primary productivity (in which energy is fixed via photosynthesis) is tightly linked with productivity at higher trophic levels and drives the overall structure of the food web (Vander Zanden et al. 2006). Although explicit consideration of the entire suite of components and interactions in an ecosystem is impossible, the reference model should be developed with the aspiration of including as many components and interactions as possible, and if feasible should include at least three indicators for each of the six key ecosystem attributes (ideally at least one indicator for each sub-attribute). Projects that develop reference models based on a limited number of indicators, such as those that focus on a single ecosystem service (e.g. carbon sequestration), may lack critical information for setting goals and measuring recovery of overall ecosystem complexity. On the other hand, projects incorporating many indicators into their reference models and project goals may have a greater likelihood at restoring ecosystems that ultimately protect biodiversity, improve ecosystem integrity, and provide higher rates of ecosystem services and human wellbeing over the long term.

Incorporating Historical and Future Change. As outlined in Principle 3, all ecosystems, even those that have not been degraded, respond to changing environmental conditions. To account for background levels of change unrelated to degradation, the reference model is, in part, conceived as the state (i.e. ecological character) that the native ecosystem would exhibit in the absence of degradation (the high-integrity condition). Thus, the reference model does not represent (nor necessarily align with) any known or presumed past state. That being said, historical information is often very useful in the development of reference models, especially if modern reference sites are unavailable. When using historical data to develop reference models, however, consideration should always be given to the degree of background environmental change that has occurred (e.g. changes in temperature, precipitation, and soils).

Within this context, it is important to be aware of the concept of **shifting** (or declining) **baselines**, which considers that some ecosystems may be more degraded than they appear or were previously thought to be, or that current observers may view ecosystems as non-degraded that previous observers would view as degraded. The idea of shifting baselines has been particularly well studied in marine ecosystems and fisheries (e.g. Pauly 1995; Pinnegar & Engelhard 2008). Shifting baselines can have a profound impact on whether nearby local communities even see a need for restoration or agree on its goals. For example, in the absence of definitive reference information, many people make the default assumption that an ecosystem should look the way it did when they first encountered it, especially if it was early in their lives. The concept of shifting baselines must be considered when developing reference models, as reference sites may be perceived as non-degraded or minimally degraded, but may be missing important species or functions (Johnstone et al. 2016; Soga & Gaston 2018). Failure to consider that reference sites may be degraded could result in less accurate reference models. Given anticipated high rates of future environmental change (e.g. climate change), practitioners should also give consideration to developing reference models that take that change into account (see also Box 5).

Incorporating Ecosystem Dynamics. In addition to accounting for climate change, reference models must account for successional processes and equilibrium dynamics. For example, ecosystems that take 100s or 1000s of years to mature (e.g. 400-year-old coral reefs or 1000-year-old temperate forests) require multiple reference models representing multiple stages of development, which can align with long range project goals. In many types of ecosystems, there may be multiple potential outcomes of succession, often referred to as alternative states (Suding & Gross 2006). These alternative states arise when a site's environmental conditions can support multiple

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configurations of species, structures, and processes, depending on history and ecological feedback loops (Chase 2003). In an increasing number of cases, the potential for alternative states arises from uncharacteristic natural disturbances (wildfires, floods, and storm surges) or extreme departures from climate means (drought, heat waves, and pluvials) (Falk et al. 2022; Seidl & Turner 2022). When the ability of species to resist stressors has been exceeded and widespread mortality occurs, the community will reassemble based on the pool of available species. Substitution of one species for another with similar traits (e.g. nitrogen fixing or drought tolerance) often occurs in this process, resulting in a modified community with similar overall functions (Laughlin 2014; Laughlin et al. 2017).

The occurrence of alternative outcomes following disturbance or a changing climate is a natural phenomenon, and indeed has been an essential process to allow ecosystems to adapt to changing environments; indeed, the history of life on Earth is a history of change (Davis 1989; Jackson & Overpeck 2000). Thus, rather than assuming that the system will always follow a single successional trajectory, it may be important in some cases to develop a set of reference models for multiple potential trajectories. Incorporating information on such dynamics into reference models clearly makes restoration planning more complex. However, it also facilitates project success by giving practitioners and managers a more informed perspective on potentially suitable project outcomes or, when one of multiple potential alternative states is desired, helping practitioners avoid feedbacks that could drive the ecosystem in unintended directions (e.g. managing the order of species introductions or removing species that are likely to push the system in the unintended direction; Suding & Gross 2006).

Reference Sites and Other Sources of Information. Reference sites are real sites used to develop a reference model. Because no two sites are identical, best practice is to use multiple reference sites and other information to help develop the reference model. An inventory of one site will capture only a fraction of the range of ecosystem composition, structure, and functions and would be unlikely to represent the average characteristics of the ecosystem to be restored. Ecosystems that are highly heterogeneous will require more reference sites than those that are more homogeneous. Recent technologies like remote sensing facilitate developing reference models with high replication by integrating data at the landscape scale. For instance, LiDAR (light detection and ranging) data have been used to develop landscape-scale reference models for forested areas of western North America, with enough replication to have distinct models for different slope positions (Wiggins et al. 2019). However, remote sensing should be used to complement rather than replace field-based methods, as species composition and other characteristics need to be verified through on-the-ground observation.

As mentioned in the description of shifting baselines above, care must be taken to avoid using degraded areas as reference sites whenever possible. Standardized indices and protocols may be used to evaluate ecosystem conditions and level of degradation at potential reference sites to identify the best available examples of the ecosystem in question. Remote-sensing indices, such as the Normalized Difference Vegetation Index (NDVI), can also be used to assess the levels of **productivity** at a given site, which can be related to integrity for some ecosystems. If the reference site has been degraded for specific sub-attributes (e.g. lower than expected faunal richness or missing top predators), then this degradation must be accounted for in developing the reference model. Due to the high degree of native ecosystem alteration globally, many restoration sites may not have an adequate number of undegraded or minimally degraded reference sites, thus practitioners may need to supplement with or rely on successional models and other sources of information for developing reference models, as detailed below.

Several platforms compile information on reference conditions for ecosystem types (e.g. the IUCN Red List of Ecosystems; Valderrábano et al. 2021), which may be useful for informing local reference models. As a regional example, the Biodiversity Information System for Europe publishes ranges and thresholds for indicators that reflect the reference states of ecosystem types, which are essential to plan restoration measures and evaluate results in the EU (Box 10). While databases and other resource networks may not have information on reference sites within the same landscape as the project in question, practitioners can also pool data from similar ecosystems in other areas to help identify key indicators and other relevant undegraded ecosystem conditions.

In addition to information from reference sites, information from nearby residual native vegetation, the site baseline inventory, and indirect, secondary sources of evidence can assist with determining reference conditions (Clewell & Aronson 2013; Liu & Clewell 2017). Such sources can effectively help guide restoration planning (White & Walker 1997; Egan & Howell 2005). For instance, historical information obtained from natural archives and cultural records can provide valuable insights (Higgs et al. 2014). Geomorphological and historical information of many other varieties can also be brought to bear with very positive effects when assembling a reference model (Balaguer et al. 2014). Annual growth rings of older trees, for example, can reveal past incidences of drought and fire. The seed bank as well as pollen deposits in soil and sediments can be used to identify plant species that occurred at a site. Logs, large woody debris, and charcoal buried in wet soil or sediments can be excavated, identified to species, and reveal old-growth conditions that disappeared long ago. Cultural records comprising photographs (including aerial and repeat photography), landscape paintings, maps, diaries and books, and land surveys are possible sources of information about historical vegetation conditions. Older species descriptions in local floristic treatments generally include habitat information. Specimen labels in herbaria and museums identify species collected at specific sites many years ago and sometimes list other species occurring with them. Care must be taken when utilizing any of these sources of historical information, however, because historical conditions may be inadequate predictors of modern ones.

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Box 10 Favorable Reference Area and Reference Range Concepts in the EU

Fragmentation is a key driver of biodiversity loss and the degradation of ecosystem integrity (Box 5). For restoration planning at the local, national, or regional level, it is essential to assess the minimum area of an ecosystem at a particular site to ensure its long-term viability (In the EU Habitats Directive, the term "habitat" is used for what is commonly defined as an "ecosystem" in scientific literature.). In the EU, this is termed the Favorable Reference Area (FRA) (EU Commission Directorate-General for Environment 2023; European Union 2024, Art. 3[8]). This concept is conceptually different from the idea of a reference model or reference site as defined and used in the Standards.

The assessment to determine the FRA can be informed by the minimum size of existing high integrity (or minimally degraded) reference sites (the EU describes such sites as being in good ecological condition, which is analogous to high-integrity condition). In addition, historical distribution data of ecosystems and their typical component species (especially flagship species with large home ranges), in combination with an analysis of restoration potential, can help determine the FRA for a local restoration project and contribute to developing spatial targets for the restoration of specific ecosystems at the national or regional scale. An important consideration of this work is the genetic diversity of species metapopulations and long-term extinction risks of populations in fragmented landscapes (Appendix 1).

The EU has also developed the Favorable Reference Range (FRR) concept (EU Commission Directorate-General for Environment 2023), which considers that ecosystems at the border of their natural distribution, will often be more vulnerable to pressures and ecological degradation than those in the center of their range (e.g. due to climate constraints). In addition to helping achieve restoration goals in the EU, the concepts of FRA and FRR can help practitioners consider the full range of degradation drivers that may affect potential reference sites, so that they can be taken into account when developing reference models.

Additionally, natural archives and cultural documents each have their own biases and limitations that affect inferences. Finally, few ecosystems exist for which historical conditions are fully known. Even for locations where data are available, information may be limited to one or a few ecosystem components and processes.

Other information sources key for developing reference models include resources that characterize ecosystem properties (bioclimate or soil descriptions, rare species distributions, floristic and faunal lists), databases or online tools (the Global Biodiversity Information Facility [GBIF 2025], Plants of the World Online [POWO 2025], World Flora Online [WFO 2025]), and IK and LEK (Zedler & Stevens 2018). If only a few species are identifiable from these indirect sources of evidence, an ecologist familiar with the natural history of the region may be able to ascertain the estimated state of the ecosystems if degradation had not occurred and deduce species compositions.

For some ecosystems or locations reference sites and data may be scarce (e.g. threatened coastal forest ecosystems of Chile for which only a few small patches of forest remain; Echeverria et al. 2006). In most instances, project managers will have to navigate gaps in available information and resources using professional judgment. In all cases, the best available information should be combined with investigative work (Swetnam et al. 1999) to develop optimal reference models. Note that in some jurisdictions, reference models may have already been developed for some ecosystems (e.g. Kim et al. 2025) or are in the process of being refined (e.g. The Australian Ecosystem Models Framework being used to inform reference models for Australia's Nature Repair Market, Richards et al. 2020).

Part 2. Integrating Ecological Restoration into Landscape- and Seascape-Scale Restoration

The Imperative of Spatial Planning. As described in Principles 7 and 8, ecological restoration is part of a continuum of restorative activities and gains cumulative value when applied at larger scales. As such, the use of spatial planning is critical in planning for and implementing restoration across landscapes and seascapes in order to optimize ecological restoration in combination with other restorative and sustainability activities. This includes the increasing imperative to accommodate changes in species ranges arising from shifting climate envelopes, thus improving potential for native species to migrate and ecosystems to shift and reassemble (Principle 7). The KM-GBF, for example, finds integrated, deliberate, and comprehensive spatial planning important not only for determining where and what to restore (Target 2) or protect (Target 3), but also to address key drivers of degradation and therefore to drastically reduce the loss of biodiversity by 2030. KM-GBF Target 1 calls for Parties to: *Ensure that all areas are under participatory, integrated, and biodiversity inclusive spatial planning and/or effective management processes addressing land and sea use change, to bring the loss of areas of high biodiversity importance, including ecosystems of high ecological integrity, close to zero by 2030, while respecting the rights of indigenous peoples and local communities*.

Many different approaches can be used to integrate ecological restoration and other forms of ecosystem restoration, conservation, and sustainable production at the landscape or seascape scale. Spatial planning helps determine which areas to prioritize for restorative approaches and, within those areas, which should be targets for ecological restoration, and how to rebuild connectivity between them (Brodie et al. 2025). For individual sites, spatial planning can help determine the most appropriate

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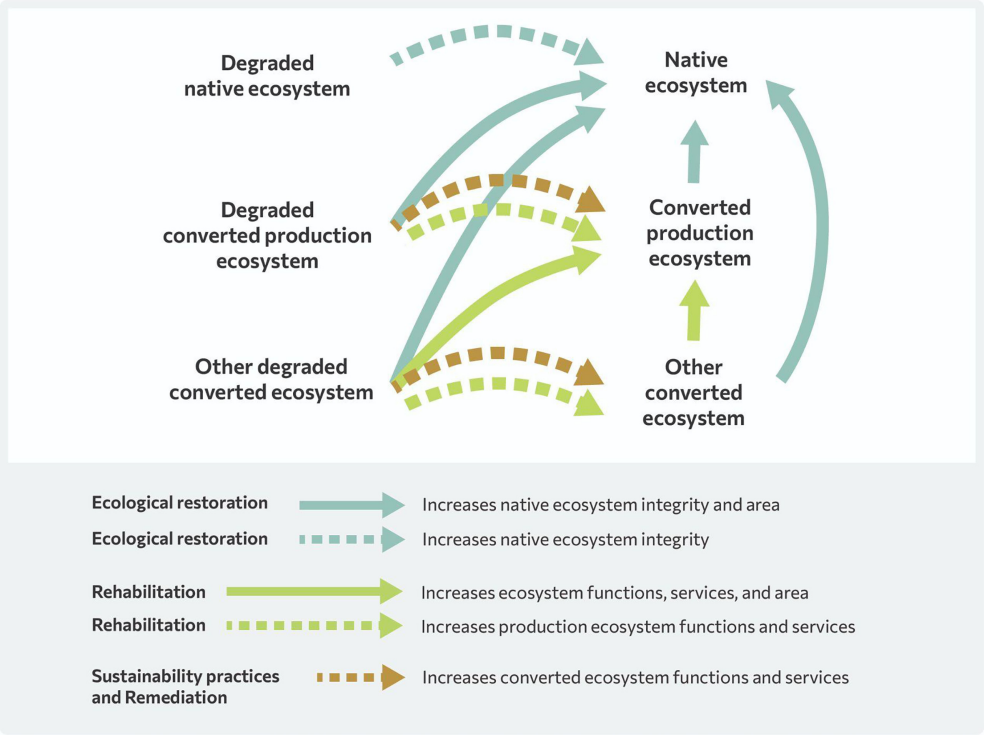


Figure 9. Relationships and transitions between major land use types and outcomes arising from implementing ecological restoration versus other major restoration types (adapted from FAO et al. 2024). Ecological restoration would be recommended in any situation where the intent is to restore a native ecosystem, whether or not that ecosystem is utilized for production or any other sustainable use. Rehabilitation is recommended when the intent is to improve a converted site that will continue to be utilized as a converted ecosystem, without substantive native ecosystem recovery (Table 7). In instances where a converted ecosystem is severely contaminated, remediation can be used to improve the condition so that the converted site becomes safe and can be repurposed for a sustainable use. Increasing sustainability practices can also increase ecosystem functions and services in converted ecosystems and reduce impacts to native ecosystems. Ecological restoration can be initiated from any starting point.

intervention along the Restorative Continuum and how different interventions interact and intersect with each other (see Fig. 9). For example, spatial planning can be used to determine where to focus rehabilitation to enhance production ecosystems while supporting the recovery of biodiversity and ecosystem services, as compared to where ecological restoration is best applied to recover native ecosystems. Understanding the spatial relationships between protected areas (Box 11), high-quality production landscapes and seascapes, urban and industrial areas, and highly degraded areas is key to optimizing restoration outcomes. Ecological restoration may be needed and can be applied in all these situations. Spatial planning is also important to help secure and focus public and private investment in restoration across the entire Restorative Continuum, and for both prioritizing and delivering restoration at scale, especially at the regional, national, and subnational levels.

Importantly, ecological restoration and other restorative activities influence land and water outside designated restoration sites; this is deliberately considered through spatial planning at the landscape and seascape level during the assessment and planning stages. The goal at the landscape level is to support biodiversity recovery and enhance the delivery of ecosystem services (Principles 7 and 8), including appropriate production agriculture and forestry (Hua et al. 2022). The net benefit of restoration can be amplified if it serves to enhance remnant but degraded native ecosystems or focuses ecological restoration on highly degraded, marginally productive production ecosystems.

The governance of large landscapes and seascapes is also inextricably linked to spatial planning. This includes the processes by which decisions are made locally; the institutional arrangements that govern them; the policy instruments that are employed; and the underlying values that guide the pursuit of biodiversity protection and recovery, the delivery of ecosystem services, and quality of life for the people affected. The planning and design of large-scale restoration must be a process of transdisciplinary co-creation, with participatory scenarios that consider the social-ecological patterns, connectivity, and functioning of biodiversity, native ecosystems, and local communities.

To effectively scale restoration involves more than spatial expansion or replication on new sites. Instead, effective and durable outcomes of scaling operations require three interrelated endeavors (Moore et al. 2015; Pienkowski et al. 2024): (1) Scaling out—expanding and replicating successful restoration activities across new sites, communities, and regions; (2) Scaling up—embedding restoration principles and standards within updated governance structures, policies, and legal frameworks,

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Box 11 Protected Areas and Ecological Restoration

The IUCN has defined a protected area as *A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values* (Dudley 2008). IUCN has designated six management categories to further describe these protected areas, including strict nature reserves, wilderness areas, national parks, natural monuments or features, habitat/species management areas, protected landscapes or seascapes, and protected areas with sustainable use of natural resources. In the CBD's Aichi Programme of Work (2011–2020), the term "other effective area-based conservation measures" (OECMs) was first mentioned to describe areas outside legally established protected areas that deliver effective and long-term in situ conservation of biodiversity. In addition, Indigenous and community conserved areas (ICCAs) also represent valuable areas for biodiversity and frequently overlap with protected areas. The term Protected and Conserved Areas (PCAs) encompasses all three of these designations.

Target 3 of the KM-GBF aims to protect 30% of terrestrial and marine areas, up from 17% for terrestrial and 10% for marine under the previous 2020 Aichi Target of the CBD.

- Over half of the world's ecoregions have at least 10% of their coverage designated as protected areas, encompassing two-thirds of the world's 15,000 key biodiversity areas (Secretariat of the CBD 2020; UNCCD 2022).
- Approximately 42% of terrestrial land is considered structurally and functionally intact; however, in 87% of ecoregions, the area of land that is simultaneously considered intact, unprotected, and projected to remain climatically stable is insufficient to reach a 30% protection target and will require including modified or degraded landscapes (Dobrowski et al. 2021; UNCCD 2022).
- Similar action will be required of inland waters and marine ecosystems:
  (a) An estimated 23% of rivers reach the ocean uninterrupted (Grill et al. 2019).
  (b) 15.5% of remaining coastal regions are considered under "low anthropogenic pressure" (Williams et al. 2022).
  (c) 13.2% of marine ecosystems have very low cumulative human impact (Jones et al. 2018b).

The close links between PCAs and restoration have not always been sufficiently considered despite existing guidance (Keenleyside et al. 2012) and recognition that conservation impact benefits from complementary protection and restoration measures (Mappin et al. 2019). While protected areas on average experience about half the level of human pressure placed on unprotected areas, a large portion of current protected areas nonetheless face some level of degradation (Jones et al. 2018a). However, current initiatives such as the UN Decade on Ecosystem Restoration and the KM-GBF emphasize the importance of ecosystem restoration in meeting area-based conservation targets including the following synergies between Target 2 on restoration and Target 3 on protected areas (modified from FAO et al. 2024):

- Legally recognized PCAs, including the lands of Indigenous Peoples and other collective customary rights holders, improve the institutional enabling environment for long-term restoration.
- T2 can increase the value of PCAs to stakeholders by increasing the delivery of ecosystem services (clean water, soil conservation, and coastal protection).
- T2 can strengthen the value of PCAs by increasing spatial ecological connectivity and by prioritizing the restoration of ecosystems that are poorly represented.
- T3 increases the spatial extent of effectively conserved and managed protected areas. Many new PCAs will require restoration.
- T3 and T2 both focus on enhancing and managing biodiversity and ecosystem functions. T2 can increase the value of PCAs through the restoration of depleted biodiversity and ecosystem integrity and function. Well-managed PCAs enhance T2 by increasing capacity for natural regeneration, both within and near protected areas.
- T3 and T2 share many common methods (e.g. control of invasive species) and tools (e.g. IUCN Red List of Ecosystems to prioritize areas for restoration) (see also the 30×30 solutions website).

In addition, because of their role in protecting high-integrity native ecosystems and rare biodiversity, PCAs can be a source of valuable data for ecological restoration including acting as reference sites for the development of reference models and helping to define priority species and other attributes (e.g. microhabitats) for restoration. Harnessing this information can contribute to defining restoration goals and methods. Equally, PCAs can provide an important source of appropriate native, genetically diverse, and locally adapted materials for restoration (Appendix 1). Ecological restoration can support ecosystems in PCAs by prioritizing processes such as pollination, reproduction, dispersal, and migration of species that are dependent on PCAs. Moving into the future, many PCAs will be unable to fulfill their objectives without restoration, and this will become even more relevant in the face of mounting threats such as climate change.

and funding mechanisms; (3) Scaling deep—fostering shifts in social norms, values, and stewardship ethics that sustain restoration outcomes (Moore et al. 2015; Pienkowski et al. 2024). These interrelated components or dimensions of the scaling effort are meant to interact through reinforcing feedback loops that enable not only broader adoption but deeper systemic transformation. This aligns with concepts of social-ecological restoration, where restoration leads to a paradigm-shifting social-ecological transformation (Fernández-Manjarrés et al. 2018; Tedesco et al. 2023).

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Enabling Conditions to Deliver Restoration at Scale. The implementation of large-scale ecological restoration initiatives necessitates the establishment of clearly defined institutional frameworks such as whole-of-government, whole-of-society, and multi-sectoral approaches. Furthermore, landscape- and seascape-scale restoration initiatives must be meticulously coordinated with both national and subnational policies, as well as with sectoral commitments and regulations. A participatory approach is recommended at all stages of the process and may require additional considerations as compared to the project level. For example, the scope and range of interested and affected parties are inherently larger and more complex when implementing restoration at the landscape scale. Engaging a diversity of partners is important to help develop a sense of responsibility for projects and to understand and address how different interested and affected parties view the potential for restoration, its costs and benefits, and the potential tradeoffs between desired services, biodiversity, and ecosystem integrity. From an enabling perspective, balancing tradeoffs and reducing conflicts is important to understand how degradation impacts and restoration goals are perceived by different interested and affected parties. Equally important is to link restoration actors across scales through information-sharing networks to build trust and address conflict in order to optimize the entire restoration process.

Social, ecological, and economic assessments and modeling are all valuable tools in landscape- and seascape-scale restoration. For example, habitat-suitability and connectivity modeling at large scales can identify areas where ecological restoration may reduce threats to species or actively restore their populations or habitats (Beatty et al. 2018a, 2018b; Brodie et al. 2025). Ecological economic analyses that consider ecosystem service and biodiversity benefits can contribute to understanding the total costs and benefits of specific restoration actions in particular areas.

Expanding ecological restoration to large scales also necessitates addressing cross-scale bottlenecks—challenges that arise when governance processes do not align across jurisdictions, along with the spatial or temporal dimensions of ecological processes (Gutierrez et al. 2025). Identifying these mismatches is crucial for effective restoration planning, implementation, and long-term sustainability.

Landscape and Seascape Approaches. Landscape and seascape approaches are integrated, holistic management frameworks that acknowledge the interconnectedness of ecosystems, requiring strategies that collectively consider ecological, social, and economic factors (FAO et al. 2024). They address the complex mosaics of natural areas, managed ecosystems, communities, uses, and infrastructures through an iterative and collaborative process in a consistent, coordinated, and locally sensitive manner, with the goal of restoring biodiversity, maintaining and enhancing ecosystem services, and supporting livelihoods and sustainable land uses that generate benefits for local communities across the entirety of the landscape or seascape. Ideally, this is integrated across the intersections of terrestrial, inland waters, and coastal and marine ecosystems, such as is practiced in Fiji and other nations in the Pacific (Fache & Pauwels 2022).

Landscape restoration refers to restoration approaches that take into consideration the ecological hierarchy within which ecosystems are embedded. It includes consideration of the types and proportions of ecosystems within landscapes, the spatial organization of these ecosystems, and the links among landscape composition, structure, and functions. Restoring functions, the "work" that ecosystems do, as well as flows of energy, nutrients, species, and other ecological processes throughout landscapes and larger regions may be equally as important as restoring the composition and structure of individual ecosystems, especially for the delivery of particular ecosystem services. For example, restoring hydrological processes and water movement among ecosystems is critical for streamflow regulation, which is one of the ecosystem services that often drives interest in restoration at the landscape scale.

Many large-scale restoration initiatives include opportunities to employ landscape restoration approaches. Landscape restoration involves practices based on the principles of both landscape ecology and landscape sustainability science (LSS; Frazier et al. 2019), in which a "landscape" is seen as a social-ecological system. LSS focuses on the dynamic relationship between ecosystem services and human wellbeing for improving social, economic, and environmental conditions. Consistent with the definition of landscape sustainability (Wu 2013), landscape restoration can be defined as a planned process that seeks to recover landscape-level ecosystem integrity and the capacity of such a landscape to provide the long-term ecosystem services that are essential for human well-being. Accordingly, landscape restoration involves both ecological and social goals (Principle 5). Planning and executing landscape-scale restoration projects requires deliberate and integrated spatial planning that assesses ecological degradation and restoration needs at the landscape scale, including biodiversity, ecosystem services, and production considerations and the tradeoffs between them. Restoration activities should be concentrated in strategic locations, with ecological and social benefits balanced (Doyle & Drew 2012) and delivered throughout entire watersheds or seascapes and beyond (IUCN and WRI 2014; Liu et al. 2017).

Additional approaches to large-scale restoration include the concept of **Sustainable Multifunctional Landscapes**, which are "landscapes created and managed to integrate human production and landscape use into the ecological fabric of a landscape maintaining critical ecosystem function, service flows and biodiversity retention" (O'Farrell & Anderson 2010). Conducting landscape restoration activities requires an in-depth understanding of landscape composition, structures, and functions, and the links between ecosystem integrity and meeting human needs (Wu 2013).

Seascape restoration aims to achieve sustainable and adaptive seascapes using an integrated approach. It takes place within large, multiple-use marine and coastal areas that are scientifically and strategically defined and managed. It emphasizes

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ecosystem-based management that includes ecological, social, cultural, and economic factors in order to conserve and restore marine biodiversity and abundance, while also promoting human wellbeing (FAO et al. 2024). Seascape restoration requires robust M&E frameworks to support effective governance structures. Seascape restoration approaches need to respect local cultures by requiring collaboration among a wide range of stakeholders, including governments, non-governmental organizations (NGOs), local communities, and the private sector.

Forest and Landscape Restoration (FLR) is *a planned process that aims to regain ecological integrity and enhance human wellbeing in deforested or degraded landscapes* (Mansourian et al. 2005). As forest ecosystems serve multiple functions and cater to multiple societal interests and needs (e.g. food and fiber, biodiversity, climate change mitigation and adaptation, local livelihoods, recreation), similar to other large-scale approaches discussed here, the implementation of FLR cuts across disciplines, sectors, and actors, thus making its implementation challenging. FLR incorporates many restorative interventions, including regenerative agriculture, agroforestry, and ecological restoration, and is widely recognized as an approach for delivering ecosystem restoration at scale. Collaboration is paramount to ensure that multiple environmental, economic, and social objectives encompassing a range of values are met, reconciled, and optimally mainstreamed through enabling policies and practices. Successful implementation of FLR hinges on negotiation and a common vision of often disparate objectives and perceptions within the landscape, inserted into an adaptive management context. This is of particular importance since the desirable outcomes of interested and affected parties continuously evolve over time, and as legal and normative contexts change for a given land use type within the landscape.

Many other site-based interventions and approaches can be delivered at scale or within large-scale restoration initiatives. Nature-based solutions (NbS), for example, are intended to be applied at the landscape scale (Cohen-Shacham et al. 2019; IUCN 2020). NbS serves as an umbrella for a wide variety of conservation and restorative approaches to solving environmental and ecological problems, including ecosystem restoration, **green infrastructure**, and agroecology. Conservation and restoration strategies that have emerged from the science of conservation biology, including rewilding and restoring connectivity, are generally applied at large spatial scales. Natural regeneration approaches, which can include both ecological restoration (Principle 4) and other restorative activities (e.g. Farmer Managed Natural Regeneration), are also often applied at large scales in response to land abandonment or economic necessity. Finally, there are many long-term, large-scale, regionally-based restoration programs around the world that can serve as examples for large-scale ecosystem restoration (see Principle 8).

All the above-mentioned ways to scale up restoration aim for a balance between social and ecological goals, often emphasizing the dependence of human wellbeing upon healthy ecosystems. It is important to recognize, however, that planning for ecological functionality and integrity in a rapidly changing global environment requires landscape planning to have a very strong and primary focus on ensuring the restoration and persistence of ecosystem integrity, structure, and function to the highest practicable extent. Because ecosystems cannot advocate for this themselves, negotiating a satisfactory outcome for the ecosystems upon which we all depend requires high levels of centralized planning, with strong willingness and cooperation among governments, industries, and communities.

Part 3. Financing and Enabling Restoration Across Economic Sectors

An estimated USD 44 trillion of economic activity, more than half of the world's GDP, is moderately or highly dependent on nature (WEF 2020; see Principle 1, Box 3). Despite this dependence, the role of ecological restoration in safeguarding economic stability and long-term sustainability remains underappreciated among businesses, civil society, philanthropy, non-commercial banks, and governments (Power 2010; Phelan et al. 2020; Löfqvist et al. 2023; Martin et al. 2025). A clear business case is therefore needed to show that ecological restoration, and related restorative activities, deliver measurable environmental benefits while also creating value for investors and corporations through stronger supply chains, innovation opportunities, improved resilience, and enhanced brand reputation. As consumers, communities, and other interested and affected parties demand environmental accountability, restoration offers a practical pathway to meet these expectations across sectors.

Traditional economic models often externalize environmental and social costs, framing restoration as an expense rather than an asset. In contrast, ecological economics and ecosystem services valuation frame restoration as a high-return investment that generates measurable public and private benefits. Growing evidence shows that restoring biodiversity strengthens ecosystem functions and services (Prangel et al. 2024). For instance, an EU study found that restoration in Europe returns 8–38 times the economic benefit as compared to the investment (European Commission 2022).

This section examines these dynamics in greater depth, with the discussion structured around eight key drivers that stimulate investment in restoration.

- International policy and law and corporate reporting frameworks.
- Protection of supply and value chains and strategic natural capital.
- Enhancing reputation and branding and reducing risk.
- Financial and market incentives.
- Evolving philanthropic priorities.
- Proactive restoration obligations.
- Mandatory restoration and offsetting.
- Emerging biodiversity and environmental credit markets.

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International Policy and Law and Corporate Reporting Frameworks. Numerous Multilateral Environmental Agreements (MEAs) and initiatives incentivize restoration directly or indirectly (see Box 2). The legal instruments underpinning these initiatives, binding or voluntary, are essential to creating national obligations and frameworks that enable governments, civil society, philanthropy, and businesses to assess needs, participate in implementation, and mobilize finance. Policy and regulation are necessary but alone are not sufficient. Voluntary corporate action complements legal frameworks by translating disclosure into targets and implementation. Two prominent mechanisms are the Taskforce on Nature-related Financial Disclosures (TNFD) and the Science-Based Targets for Nature (SBTN).

TNFD provides a standardized approach for companies to disclose their nature-related risks and opportunities, offering tools to assess not only their impacts but also their dependencies on natural capital. SBTN builds on such assessments to help companies set targets to avoid and reduce impacts on nature, restore nature, and address drivers of degradation. Together these tools span the Restorative Continuum (Principle 8). The two systems are well aligned, with TNFD supporting assessment and disclosure, while SBTN supports target setting and action planning.

As of September 2025, more than 620 companies and financial institutions in over 50 countries have adopted TNFD, representing more than USD 20 trillion in market capitalization and assets under management (TNFD 2025). TNFD supports KM-GBF Target 15 on corporate nature disclosures, emphasizing monitoring (or measuring), reporting, and verification (MRV) for private engagement. TNFD's LEAP (Locate, Evaluate, Assess and Prepare) Approach guides companies to: (1) locate nature interfaces; (2) evaluate dependencies and impacts; (3) assess risks and opportunities; and (4) prepare reports and responses, including allocating needed resources. Complimentary reporting platforms include the FAO-hosted Framework on Ecosystem Restoration Monitoring (FERM) and The Brazilian Restoration Observatory, which is interoperable with the FERM and gathers data on restoration efforts from companies, academia, governments, and civil society.

Advances in MRV can help support enabling conditions across sectors. Verification is particularly important to ensure submitted data are validated as reliable and accurate. Automated MRV (AutoMRV) approaches, for example using remotely placed sensors that automatically transmit environmental DNA data at regular intervals, can also support all three components of MRV. Wetland mitigation banking MRV provides an example where credits are only realized once a constructed wetland is verified as fully functioning and providing all of the intended ecological services of a wetland. Industry groups such as The Nature Tech Collective illustrate how entrepreneurial communities are applying lessons learned from the carbon market to the emerging biodiversity credit market (see below) in the context of MRV. These integrity safeguards are particularly important for private finance, given its stronger focus on return on investment and the heightened risk of market distortions if verification and governance are weak.

Box 12 Case Study of Restoration to Support Supply Chains—Mars Assisted Reef Restoration System (MARRS)

Mars, Inc. recognized that its cat food business relies heavily on healthy oceans, coral reefs, and fisheries supply chains. With 27% of tropical reefs already lost and another 32% projected to disappear by 2050 without intervention, restoring these ecosystems has become an urgent priority (Mars 2020; Smith 2020). In response, since 2006 the Mars Coral Reef Restoration Program has been active in the Spermonde Archipelago off the coast of Makassar, Sulawesi, Indonesia, one of the most biodiverse marine regions in the world. In 2017, Mars Sustainable Solutions (MSS) launched the Sustainable in a Generation plan, which includes a long-term coral reef restoration initiative that both restores coral reefs and supports sustainable economies for the local communities that depend on the reefs for their livelihoods and wellbeing.

The program utilizes MARRS, which employs locally fabricated steel structures known as Reef Stars. These are fitted with coral fragments and anchored together to form a stable web across damaged reef beds. Refined through over a decade of learning, the technique allows trained divers to deploy 300 Reef Stars (and about 4500 coral fragments produced in coral nurseries) across 400 m^2 of reef in a single day. By partnering with local communities, practitioners, and scientists, Mars is not only restoring reefs but also innovating reef restoration technology, engaging communities, and improving livelihoods in a manner that can be scaled, reducing its environmental footprint across its supply chain.

Protection of Supply Chains and Strategic Natural Capital. From a business perspective, ecological restoration reduces supply-chain vulnerability by restoring the ecosystems that underpin production and commerce (IPBES 2026). Targeted investments in restoration can strengthen business resilience to degradation risks (Box 12), support national restoration commitments (e.g. KM-GBF or other MEAs), and protect and enhance strategic natural capital, such as nature-based tourism assets. A practical example is the coral reef system near Cancún, Mexico, that underpins regional tourism. In 2018, governmental agencies, local businesses, the SwissRe insurance company, and The Nature Conservancy launched a parametric-based insurance product that pays out automatically when a storm of predefined intensity occurs (Green Finance Institute 2025). The rapid payout enables immediate actions within a narrow window when the corals can be successfully collected and reattached, improving the likelihood of ecological recovery and protecting tourism revenues. Insuring the reef helps ensure the long-term sustainability of the economically critical tourism sector in the area.

Dependencies on native ecosystems and their biodiversity are often underaccounted for in corporate planning, amplifying economic, operational, and commercial risks (IPBES 2026).

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Targeted restoration addresses these risks by reversing degradation and rebuilding essential natural capital and services that flow from it, including clean water, pollination, soil fertility, and carbon sequestration, benefiting both business and society.

Reputation, Branding, and Risk Reduction. Consumers increasingly reward businesses that go beyond reducing their environmental harm to also invest in nature-positive solutions, including ecological restoration. In certain sectors, especially mining, this type of reputational investment can be associated with the need to obtain and maintain a Social License to Operate (SLO) (Young et al. 2022).

As companies undertake their activities, it is in their best interest to secure the ongoing approval and acceptance by local communities and other interested and affected parties. Engaging in standards-based ecological restoration can be a powerful means of enhancing corporate reputation and securing and maintaining a SLO, especially in areas where businesses may be involved in resource extraction or land development, as it provides interested and affected parties greater confidence in the value and quality of the restoration project.

Restoration projects, particularly those that meaningfully engage local communities across all stages, from planning to implementation and monitoring, can help ensure that business operations contribute positively to local environmental and social outcomes. For example, Microsoft's Corporate Environmental Sustainability Program voluntarily invests in both tree-planting and ecological restoration in local communities (SER 2025). These Microsoft activities are specifically intended to improve environmental conditions in selected communities, in addition to other social investments (e.g. upskilling).

Box 13 The Global Biodiversity Standard

The Global Biodiversity Standard (TGBS) is a rigorous, high-integrity biodiversity standard using local expertise to certify and mentor projects that protect, enhance, and restore biodiversity. With local expertise supported by the Botanical Gardens Conservation International network of partners and its methodology underpinned by SER's ecological Five-star System (Bartholomew et al. 2024), TGBS evaluates restoration sites based on measurable changes to native biodiversity and ecosystem integrity. TGBS certification contributes to improved recognition, reduced risk for investors, and enhanced market opportunities. Furthermore, TGBS assessments and mentoring contribute to enhanced project design and implementation to elevate positive outcomes for people and nature. As an example, the Kasenene Restoration Site in Uganda, part of the Bugoma–Budongo chimpanzee corridor, which is being restored through a partnership between Ecosia, the Jane Goodall Institute, and a local forest management group, was awarded TGBS certification for meeting key ecological, social, site protection, and management criteria (TGBS 2025).

Product and project standards, verification, and certification (e.g. fair trade, carbon, and organic) influence consumer choices and investor confidence (Kemper et al. 2024). Consumers will often pay a premium for products backed by reputable certification or verification schemes. Certification and verification reduce investor risk by improving transparency and comparability. Emerging site-based project certifications like TGBS assess biodiversity outcomes from ecosystem restoration projects, including ecological restoration (Box 13). SER, with support from its partners, including SCOR SE, is also developing a more tightly focused ecological restoration project certification program that will assess both the restoration process and the outcomes achieved. SER has also collaborated with SCOR SE in developing customized project review standards for SCOR's Ecological Restoration Insurance Solution (see Financial and market incentives below as well as Box 14).

Offering modular biodiversity or ecological restoration certification or verification as additive values for carbon and other projects also has the potential to incentivize private capital for restoration based on improvements in reputation or brand valuation.

Financial and Market Incentives. There is growing awareness of ecosystem degradation and the importance of ecosystem

Box 14 The NatReCo Initiative by SCOR SE

The Initiative's first solution focuses on ecological restoration and insures projects throughout the duration of planning and implementation against both specific natural perils (such as fire, flood, storm, landslide, and lack of precipitation) and non-natural perils (such as aircraft, malicious damage, and impact). Unlike the parametric policy outlined above (Cancún, Mexico), SCOR's solution is impact assessment based (assessing the severity of the impact of an event because ecosystems have an ecological elasticity to their integrity levels). The NatReCo Ecological Restoration Insurance Solution aims to get a project back on track when its planned recovery trajectory has been adversely disrupted by a predefined peril. This gives the project greater security of initial investment, greater prospect of investment returns, and a greater prospect of completion which in turn increases the likelihood of achieving the intended outcome. This solution is only available to ecological restoration projects which sufficiently adhere (by achieving a Final Grade of A or above) to SCOR's project review standards, which were developed in collaboration with SER to be consistent with the Standards of Practice outlined in Section 3. The project review also acts as an assessment of the quality of a project, providing greater confidence to stakeholders, including potential investors. The benefits of increasing both the likelihood of project success and confidence in the quality of a project reduce financial risk and therefore facilitate project financing.

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integrity and resilience, yet available funding for restoration remains far short of global needs.

According to WRI (Ding et al. 2017), at least seven separate factors contribute to inadequate investment, including that the benefits of restoration are often public goods which are difficult to monetize, the incentives to degrade land outweigh the incentives to restore it, restoration projects are perceived as risky, and the long-term nature of restoration is not matched with investors' desire for liquidity. Return expectations also vary by financier and reflect the different risk appetites—generally the restoration of highly degraded ecosystems is riskier than the restoration of less-degraded ecosystems (FAO and UNCCD 2015).

Different actors pursue restoration for different reasons. Public or charitable organizations may prioritize public good and societal benefits, while corporations and financial institutions often focus on regulatory obligations, economic, or asset-related benefits. Real and perceived risks that hinder private investment include: the inherently unpredictable and dynamic nature of ecosystems and the drivers that impact them; risk associated with the stage of restoration (with early stages being more risky than later stages); uncertainty about returns on investments including the timing of returns; the lack of governance and standards around ecological restoration projects; and a lack of available data regarding project performance and investment returns.

Given the risks associated with investing in restoration, public financing to date has been the most dominant source of restoration funding globally, particularly through national public spending. Governments, either directly or via public foundations, are also uniquely situated to fund higher risk restoration (e.g. early stage restoration and innovative restoration).

Depending on the national context, public financing for restoration can take various forms including government-led restoration programs, government grants, development bank loans, and multilateral donations. National and subnational government-led programs, in particular, have driven many large-scale restoration efforts in numerous countries and will continue to play a key role in delivering restoration at scale. Government support for restoration is also critical in providing legal and policy frameworks, including by removing harmful incentives that cause ecosystem degradation in the first place and by providing beneficial financial incentives and technical support for restoration.

Financial incentives play an important role in funding restoration, whether through business, philanthropy, or civil society. These incentives can include a return on investment, sustainability linked loans, and green finance from lending banks. Another approach to incentives is related to permitting, wherein certified practitioners or projects may be conditions for reducing the regulatory burden which also reduces costs. Developing innovative solutions that reduce the risks associated with financing restoration projects can also play an important role in funding restoration. For example, in 2024 SCOR SE, a leading global reinsurance company with a Tier 1 franchise, launched its NatReCo Initiative, which offers proactive innovative (re) insurance solutions to support nature-resilient projects (Box 14).

While financial and market incentives are important, their effectiveness depends on enablers that make investment credible and scalable. Standards and certification increase assurance that restoration is delivering measurable ecological and social outcomes, and robust MRV systems enable transparency. Together these enablers strengthen confidence, unlock access to finance, and create market differentiation, increasing the likelihood that investments translate into verified restoration gains. Social enterprises are an additional enabler—by embedding environmental and social objectives into their business models, they channel revenue into public goods rather than private profit. For example, Ecosia reinvests its advertising income into ecological restoration and rehabilitation projects. By combining market reach with mission-driven reinvestment, social enterprises bridge the gap between philanthropy, public funding, and conventional markets.

Philanthropic Investment. Philanthropic capital is an increasingly important driver of restoration at the global, national, and local levels. Because philanthropic giving rarely requires a financial return, it is well suited to fund early-stage, higher-risk, or public-good restoration activities that private investors typically avoid. Standards-based restoration reduces technical and reputational risk for this type of investment by increasing the likelihood that projects will achieve intended outcomes.

Philanthropy is important for both partially and fully funding restoration projects. But it can be particularly important for three complementary needs: seed and early-stage finance for experimental or high-risk interventions; capacity building and technical assistance to develop platforms, MRV systems, and governance; and blended finance catalytic capital that leverages private investment through concessional capital or first-loss guarantees. Typical philanthropic mechanisms include:

- Blended finance: using philanthropic or government money as concessional capital or first-loss guarantees to attract private investment.
- Grants and technical assistance to build platforms, measurement systems, and tools that lower risk perceptions.
- Prize funds and competitions to spur innovation in restoration.
- Endowment models or impact-investing models that allow some return while emphasizing environmental and social outcomes.

Philanthropic giving can be prioritized at the local, subnational, national, or international levels and is aligned with the goals of the donor institution or individual. While some philanthropists are committed to restoration, others may be more focused on protection as a tool to prevent damage rather than investing in restoring ecological conditions. Donors motivated by biodiversity, climate, livelihoods, or social justice, however, may find restoration aligns with their broader mission, especially when framed through the lens of regenerative development, equity, or resilience. This creates an opportunity to increase understanding and awareness within the philanthropic community to increase investment in restoration. Philanthropic leaders can shape a new narrative around restoration, especially those of younger generations which are more

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focused on this issue area, not just as a cost, but as a strategic investment in planetary resilience. Building familiarity with standards and impact measurement can further build trust and increase capital flows into this essential work. Finally, younger donors are more issue-driven (favor causes over specific organizations), more transparent, and more concerned about environmental and social justice issues (Indiana University Lilly Family School of Philanthropy 2025), creating opportunities for intergenerational engagement.

Positive Restoration Obligations and Legal Support. Across the world, most mandatory legal obligations for restoration remain tied to compensatory restoration associated with new degradation (see below). Proactive, non-compensatory legal frameworks that require or enable restoration independent of new damage are an emerging and powerful tool to accelerate restoration implementation. Such proactive legislation addresses gaps left by compensatory mechanisms by addressing persistent environmental degradation, setting forward-looking targets, clarifying responsibilities, and creating predictable pathways for funding and enforcement.

Existing legal frameworks for restoration are fragmented, thus failing to create the enabling conditions necessary to achieve ecologically meaningful restoration goals, targets, or objectives (Bell-James et al. 2023). Proactive legislation should therefore: adopt clear, science-based definitions of restoration; set measurable targets and timelines; require MRV and public reporting; define roles and responsibilities across levels of government; and embed social safeguards such as FPIC, benefit sharing, and grievance and compliance mechanisms.

The EU's NRR (European Union 2024) provides a proactive legal obligation to restore previously degraded lands and waters. The groundbreaking 2024 regulation combines an overarching EU-wide restoration target for the long-term recovery of nature in the EU's land and sea areas with binding restoration targets for specific ecosystems, habitats of species, and certain species or species groups such as pollinators. The measures under the overall target should cover at least 20% of the EU's land and sea areas by 2030, and ultimately all ecosystems in need of restoration by 2050. The EU NRR also introduced the concepts of FRA and FRR, which are key to reaching a favorable conservation status of ecosystems and protected species (European Commission Directorate-General for Environment 2023; European Union 2024). The FRA considers historical distributions and projected changes to environmental conditions due to climate change, resulting in increased protected area size and connectivity needs.

National and subnational legal and regulatory mechanisms also proactively support large restoration programs, such as the Comprehensive Everglades Restoration Project in Florida, United States, which is a multi-decadal project that has enabled the flow of billions of USD in public sector financing to freshwater wetlands restoration. A second example is Brazil's payment for environmental services (PES) framework through Brazil's Federal Law No. 14.119/2021 including the Conservador da Mantiqueira, which was created in 2016 with a goal to restore 1.5 million ha in 425 municipalities in the Atlantic Forest in Southeastern Brazil. This program is based on the voluntary participation of farmers committed to restoring and conserving their forests.

Mandatory Compensatory Restoration. Mandatory compensation for environmental impacts has been a prominent form of obligating restoration and of generating restoration finance for decades (e.g. for wetlands or following mining). Businesses and other entities (in some cases government agencies) are legally obligated to compensate for regulated environmental damage, but in most cases the result is a net loss of native ecosystem spatial extent or a loss of ecosystem integrity. This is why an underpinning assumption of the Standards is *the potential for ecological restoration should never be invoked as a justification for destroying, damaging, or unsustainably utilizing existing native ecosystems*.

The Mitigation Hierarchy, which supports the mandatory compensatory restoration sector, calls for a stepwise process to minimize damage (avoid, minimize, rehabilitate or restore [on site], offset [off site]). Offsets are recommended only after the first three steps of the Mitigation Hierarchy, as it pertains to native biodiversity and ecosystems, have been thoroughly examined and proven to be ineffective and technically unachievable (Box 15).

Emerging Biodiversity and Environmental Credit Markets. The emergence of biodiversity and environmental credit markets reflects growing interest in market-based solutions to halt and reverse nature loss, with roots in mandatory offsets, corporate sustainability strategies, and carbon trading experience. They have the potential to act as important finance mechanisms to scale up restoration investment, provided they incorporate lessons learned from ecological offsets (see above) and the development and roll-out of carbon credit markets (Biodiversity Credit Alliance 2023). Demand for credits can be incentivized even in the absence of law or regulations, but market integrity depends on robust scientific metrics, transparent governance, and long-term monitoring. In the absence of these safeguards, biodiversity markets risk generating perverse outcomes, including biodiversity loss or social harms resulting from activities framed as compensation for ecosystem destruction or degradation or corporate environmental impact.

The Biodiversity Credit Alliance outlines High-Level Principles to guide biodiversity credits to deliver outcomes with ecological rigor, equity, and transparency. These principles emphasize that biodiversity credits must operate in addition to, and not as a replacement for, the mitigation hierarchy (Biodiversity Credit Alliance 2024). In this context, it is crucial that financing does not interfere with the intended vision, scope, goals, and the corresponding appropriate design of a given restoration project. Restoration projects must use robust, credible methods to quantify the gains in outcomes (i.e. the basis for calculating biodiversity, environmental, or restoration credits under the market context), and to install governance and

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Box 15 A Recommended Framework for Ecological Offsets

Offsets are measures and actions that attempt to compensate for planned losses in habitat, species, or ecological functions that are broadly applied across terrestrial, aquatic, and marine habitats. As it pertains to native ecosystems and biodiversity, offsets are recommended only after the first three steps of the Mitigation Hierarchy have been thoroughly examined and proven to be ineffective and technically unachievable on site. These first three steps are: avoidance, minimization, and restoration or rehabilitation on site.

There are major inconsistencies in offsetting policies and practices, and recent reviews (Samuel 2020) highlight that offsets applied in biodiverse regions rarely, if ever, achieve the ecological compensatory outcome of a net gain for the environment. Even in jurisdictions with strong environmental laws, averting loss using biodiversity offsets failed to deliver benefits, with offsets unable to show an effective replacement of lost biodiversity (Maron et al. 2015) and consistently failing to consider multiple ecological, regulatory, and ethical losses within the "no-net-loss" objective (Moreno-Mateos et al. 2015). Recent policy innovations such as the U.K.'s mandatory Biodiversity Net Gain legislation aims to move policy from no-net-loss to net gain, but the approach remains new and its ecological effectiveness is still being evaluated.

In cases where companies use plantings or natural regeneration as a mechanism for carbon emission offsets, ecological restoration should be engaged as best practice methodology to maximize net gain opportunities for biodiversity and ecosystem services values and to reduce the likelihood of unintended negative ecological consequences associated with carbon offsets. These additional benefits can be verified through outcome-based restoration certification (e.g. TGBS) or verification schemes to provide evidence of both best practice and achieved outcomes, and may increase the value of carbon credits traded on carbon markets (see financial and market incentives above). Engaging and embedding the Standards in this practice will reduce the risk of establishing systems that fail to recover ecosystem integrity. In these circumstances, it is particularly important to plan for and implement the very highest recovery interventions possible as these sites can get "locked-up" in permanency clauses (particularly where carbon mitigation might require decadal or longer periods of uninterrupted growth), which could prevent restorative actions based on the concept of continuous improvement from occurring onsite.

Model Legal or Regulatory Framework.

To facilitate effective offset practice in restoration:

(1) Offsets should be framed within an agreed international or national biodiversity offset framework that includes consistent principles and standards that provide proven net gain in biodiversity and ecological values.
(2) Where offsets include ecological restoration, appropriate fit-for-purpose standards are applied to guide planning, implementation, monitoring, and review practices noting that restoration should not be invoked as a justification for the destruction of nature.
(3) Offsetting methodologies including ecological restoration should be based on principles of continuous improvement (Principle 6) that include a commitment to adaptive research and adaptive management.
(4) Offset proposals requiring restoration must be independently peer-reviewed by restoration specialists and ecological subject experts with relevant knowledge and understanding of the appropriateness, feasibility, and risks associated with an intended offset to compensate for the impact.
(5) Offsets must deliver at a minimum demonstrable, like-for-like biodiversity and ecosystem integrity outcomes. Proven net-gain results relative to the pre-impact baseline condition of the impacted site is optimally the aim. Where equivalence is ecologically infeasible, offsets may only be justified if: a scientifically justified substitution hierarchy is applied; multipliers and risk buffers are used to account for uncertainty and temporal lag; and legally binding measures ensure permanence, liability, and independent verification.
(6) Companies, governments, and organizations causing degradation, damage, or destruction demonstrate competency in achieving successful ecological restoration prior to commencing work that causes destruction or degradation.
(7) Appropriate monitoring standards are adopted and implemented at appropriate time scales (years to decades) and where an offset deviates from the agreed trajectory (Fig. 8), mitigation and corrective actions based on adaptive management principles are implemented that are timely, proven to be effective, and enduring.

enforcement mechanisms to channel restoration toward positive outcomes.

In a review of eight of the world's largest nature markets, zu Ermgassen et al. (2026) noted that nature credit markets have operated for decades (mostly for wetlands, biodiversity, and land-based carbon) and outlined five rules for scientifically credible nature markets to overcome issues with: (1) the correlation between proxy metrics and desired outcomes, (2) additionality, (3) leakage, (4) independent verification, and (5) credible detection and enforcement of non-compliance. Similar to reviews of ecological offsets, their review found that all eight nature markets inadequately met at least one of these recommendations. In summary, while biodiversity credits and other environmental markets may form part of the solution to restoration financing

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challenges, their real-world impact will depend on addressing persistent weaknesses in market design and oversight.

Part 4. Conclusion

The world is entering an era with governments across the globe making impressive commitments to restore degraded ecosystems through a wide range of restorative activities at the ecosystem, landscape, and seascape levels. Standards-based ecological restoration is increasingly recognized as a critical tool for reducing risk and uncertainty, and increasing the likelihood of success in all restoration efforts as we collectively work to address past ecological harms and to mitigate and recover from the effects of environmental disasters, ecosystem degradation, biodiversity loss, and the impacts of climate change. By enhancing outcomes, standards-based restoration improves human wellbeing at individual, community, and national levels. When implemented effectively, ecological restoration can achieve profound ecosystem services benefits, ranging from the most basic needs like improving food and water security to reducing the spread of disease and improving individual physical, emotional, and mental health.

Ecological restoration must also be synergistically integrated with conservation and sustainable production to help move society, globally, from centuries of cumulative environmental damage to degradation neutrality (Box 2), and eventually to the ecological and social net gain needed to ensure a healthy, livable world for current and future generations of people and nature. Ecological restoration therefore promises a net gain in extent and functioning of native ecosystems, together with the delivery of critical human wellbeing benefits. However, achieving this promise requires standards-based restoration, the support of interested and affected parties everywhere, and a global commitment to and investment in all types of restorative activities, as encompassed in the United Nations Decade on Ecosystem Restoration. It will only work by recognizing the intrinsic value and importance of native ecosystems, and the unique role ecological restoration plays in recovering native ecosystems across the planet. Achieving restoration's promise requires that we recognize, support, empower, enable, and celebrate the global network of people—from local communities, Indigenous Peoples, governments, private sector, civil society, to youth and next generations—who are envisioning, funding, implementing, and assessing restoration work every day.

Section 5—Glossary of Terms

This glossary is adapted and expanded from McDonald et al. (2016b, 2016a) and Gann et al. (2019).

Abiotic: Non-living materials and conditions within a given ecosystem, including rock, or aqueous substrate, the atmosphere, weather, and climate, topographic relief and aspect, the nutrient regime, hydrological regime, fire regime, and salinity regime.

Action (intervention): A set of activities with a common focus that work together to achieve specific goals and objectives by targeting key intervention points, optimizing opportunities, and limiting constraints. A good action meets the criteria of being linked, focused, feasible, and appropriate.

Activity: A set of tasks undertaken by project staff and/or partners to help implement an action.

Adaptive management: The incorporation of deliberate learning into professional practice to reduce uncertainty in decision-making in complex or unpredictable systems such as ecosystems. Specifically, it is the integration of design, management, and monitoring to enable practitioners to systematically and efficiently test key assumptions, evaluate the results, adjust management decisions, generate learning, and ultimately improve outcomes.

Afforestation: The process of introducing a forest (usually either through planting or direct seeding) in an area where it did not exist in the historical past.

Allied activities: Restorative practices (including sustainability practices, remediation, and rehabilitation) that reduce the causes and ongoing effects of degradation and enhance potential for ecosystem recovery.

Attributes: Elements chosen to represent aspects of the overall ecosystem or social context to assist practitioners with project planning, project monitoring, and project evaluation. They include recommended social attributes and **key ecosystem attributes**.

Augment, Augmentation (of depleted populations): (also known as enhancement, enrichment, reinforcement, replenishment, or restocking) Adding seeds or individuals of a population to the same population, with the aim of increasing population size or genetic diversity and thereby improving viability; re-creating a recently extirpated population with individuals propagated from that population. In common practice, populations are often augmented with material from other nearby populations, not just the same population.

Barriers (to recovery): Factors impeding recovery of an ecosystem attribute.

Baseline condition: The condition of the restoration site immediately prior to the initiation of ecological restoration activities. The baseline condition includes both ecological and social attributes.

Baseline inventory: An assessment of current biotic and abiotic elements of a site prior to ecological restoration, including its compositional, structural, and functional attributes. The inventory is implemented at the commencement of the restoration planning stage, along with the development of a reference model, to identify ecosystem states and conditions and to inform planning including restoration goals, measurable objectives, and treatment prescriptions.

Biocultural restoration: The process of assisting the recovery of the biophysical and sociocultural components of dynamic, interacting, and interdependent social-ecological systems, including human health and wellbeing. Humans and their cultures are placed at the center of the process, and the work is conceived and managed from the inside out. Synonym: Ecocultural restoration. See also the term holistic restoration in Clewell & Aronson 2013.

Biodiversity: The variability among living organisms from terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems. In global

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environmental agreements and guidance documents, this term is most often used to refer to the Earth's native organisms and the native ecosystems of which they are part.

Biological resilience: The processes, largely derived from evolutionary adaptations, that enable components across biological levels to resist or recover from perturbations. This is expressed at the individual organism level as resistance adaptations (such as thick bark, hard coatings of seeds or eggs that protect buds, embryos and other reproductive parts) and recovery adaptations (such as responsiveness to cues for hatching, germination, resprouting, enhanced flowering, and adaptations that enhance propagule dispersal, e.g. winged or floating seeds, fleshy fruits, floating fragments).

Biotic: The living components of an ecosystem, including living animals and plants, fungi, bacteria, and other forms of life, and intraspecific and interspecific interactions among one another that affect survival, growth, and behavior.

Carbon sequestration: The capture and long-term storage of atmospheric carbon dioxide (typically in biomass accumulation by way of photosynthesis, vegetation growth, and soil organic matter buildup). This may occur naturally or be the result of deliberate actions to increase carbon stores to reduce the impacts of climate change.

Climate envelope: The climatic range in which the populations of a species are distributed. With climate change, the geographic locations of such envelopes are already shifting or likely to shift or uncouple from a species' or population's current range and may move, reform, or disappear entirely in unpredictable ways.

Climate readiness: Refers to a circumstance where genetic material has been selected, on the basis of climate science and genetics, to improve a species' likelihood of persisting under anticipated climate change.

Cultural values: The shared beliefs and priorities that influence the behaviors and decisions of members of a community or group.

Conservation (of nature, ecosystems, or resources): The practice of protecting and maintaining nature and natural resources, including native biodiversity, natural habitats, and ecosystems. In the broad sense, ecological restoration is part of conservation focused on recovering degraded ecosystem values. Effective conservation is collaborative, evidence-informed, and applies principles of adaptive management.

Continuous improvement: Strategy of enhancing restoration progress over time to take advantage of partial but ongoing logistical capabilities or budgets.

Converted ecosystem: A previously native ecosystem that has been reallocated by humans for specific anthropocentric uses (such as improved pasture, cropping, plantation forest, and urbanization) and where ecosystem functions and services are now at least somewhat provided by nonnative biota that dominate the site, or else has been covered over with gray infrastructure (e.g. concrete and asphalt). The terms transformed ecosystems or anthropogenic ecosystems are sometimes used, although these terms are broader and can convey a different meaning.

Cycling (ecological): The transfer (between parts of an ecosystem) of resources such as water, carbon, nitrogen, and other elements that are fundamental to all other ecosystem functions.

Damage (to ecosystem): A level of acute deleterious impact that is higher than degradation and lower than destruction.

Degradation (of an ecosystem): A level of deleterious human impact to an ecosystem that results in the loss of biodiversity and simplification or disruption in its composition, structure, and functioning and generally leads to a reduction in the flow of ecosystem services.

Desirable species: Species appropriate to the site that are included in the reference model. The corollary of desirable species is undesirable species, which are often but not exclusively nonnative species.

Destruction (of an ecosystem): When degradation or damage removes all macroscopic life and commonly ruins the physical environment of an ecosystem.

Disturbance regime: The pattern, frequency, timing, or occurrence of disturbance events that are characteristic of an ecosystem over a period of time. Examples include particular cycles of season, intensity and frequency of fire, grazing, and cyclones (e.g. hurricanes, tornadoes, typhoons) followed by adequate periods without disturbance allowing for recovery. Such cycles (including the rotation of various configurations of shifting states within an ecosystem) may be intrinsic to an ecosystem's normal dynamics, structural diversity, and **ecosystem resilience**, as well as essential to the perpetuation of its characteristic species.

Driver (of degradation): See **threat**.

Ecological recovery: See **recovery** (of native ecosystems from degradation).

Ecological restoration: The process of assisting the recovery of a native ecosystem that has been degraded, damaged, or destroyed. It differs from other ecosystem restoration activities along the Restorative Continuum in that it aims to recover a native ecosystem to the state it would exhibit in the absence of degradation, while accounting for environmental change. See also **ecosystem restoration**.

Ecological restoration activities: Any activity, action, intervention, or treatment intended to promote the recovery of an ecosystem or component of an ecosystem, such as soil and substrate amendments, control of invasive species, habitat conditioning, species reintroductions, and population augmentations.

Ecological restoration program: A larger composite of multiple restoration projects.

Ecological restoration project: Any organized effort undertaken to achieve substantive recovery of a native ecosystem, from the planning stage through implementation and monitoring. A project may require multiple agreements or funding cycles. A project may also be one of multiple projects in a long-term ecological restoration program.

Ecosystem: A dynamic complex of plant, animal, and microorganism communities and their non-living environment interacting as a functional unit. The term ecosystem can be used to describe a functional ecological assemblage, native or nonnative, of any size or scale. See also **native ecosystem**.

Ecosystem Attributes: see **key ecosystem attributes**.

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Ecosystem functions: The biophysical workings of an ecosystem arising from interactions and relationships between the biota and abiotic elements including ecosystem processes such as primary production, decomposition, nutrient cycling and transpiration, species interactions (e.g. competition and predation), and intrinsic properties such as resilience.

Ecosystem integrity: The degree to which an ecosystem's physical condition, composition, structure, and function are intact.

Ecosystem management: An integrated approach to the management of ecosystems and natural resources based on knowledge drawn from both science and practice. It aims to sustain the health, resilience, and diversity of ecosystems while allowing for sustainable use by humans of the goods and services they provide.

Ecosystem resilience: The capacity of an ecosystem to resist, recover, or reorganize in response to disturbance or other environmental stressors. Native ecosystems vary in their ability to resist or recover from disturbance, largely dependent on variations in their component organisms' **biological resilience**. When an ecosystem's resistance and recovery are exceeded, ecosystems naturally reorganize into new states. The inherent resilient capacity of ecosystems is ultimately the foundation of ecological restoration. See also **social-ecological resilience**.

Ecosystem restoration: The full spectrum of practices and activities along the **Restorative Continuum**, depending on local conditions and societal choice. These activities contribute collectively to halting and reversing degradation, resulting in improved biodiversity, ecosystem integrity, and ecosystem functions and services (modified from UNEP 2021; Nelson et al. 2024).

Ecosystem services (short for Ecosystem goods and services): The direct and indirect contributions of ecosystems to human health and wellbeing, including the satisfaction of spiritual, esthetic, recreational, economic, and other human values. They include the production and maintenance of clean soil, water, and air; moderation of climate and disease; nutrient cycling and pollination; and the provisioning of a range of goods useful to humans. These are commonly referred to as supporting, regulating, provisioning, and cultural services (Millennium Ecosystem Assessment 2005). Restoration goals may specifically refer to the reinstatement of particular ecosystem services or amelioration of the quality and flow of one or more services. Without natural capital there is no flow of ecosystem goods or services.

Effective restoration: Standards-based restoration underpinned by agreed principles that results in appropriately balanced sustainable **net gain** (project level) (i.e. that benefits and enhances biodiversity, ecosystem integrity, and human wellbeing). The concept of effective restoration applies to ecosystem restoration broadly and ecological restoration specifically.

External exchanges: The two-way flows that occur between ecosystems and their broader environment including flows of energy, water, fire, genetic material, organisms, and regenerative units. Exchanges are facilitated by habitat linkages.

Evidence: Relevant data, information, knowledge, and wisdom used to answer questions, test assumptions, and inform decisions.

Five-star System (Ecological): A tool used to help select goals and document the level of recovery attained by an ecological restoration project over time relative to the reference model and project goals. This tool provides a means to report changes from the baseline condition and to progressively evaluate and track the degree of native ecosystem recovery, potentially to full recovery. It can also be used to track improvements in the condition of rehabilitation projects to the extent site attributes overlap with those of a native ecosystem (Note: this system refers only to the recovery outcomes and not the restoration activities used to attain them).

Five-star System (Social): A tool used to identify the level of social benefits aspired to by a restoration or rehabilitation project, and to progressively evaluate and track the degree to which those benefits accrue over time relative to the baseline.

Fragmentation: A process characteristic of degraded lands and waterways where habitat destruction and barriers have isolated patches of remnant vegetation or disconnected aquatic habitats and which pose serious impediments to the movement of biota.

Free, Prior, and Informed Consent: A principle protected by international human rights standards that emphasizes the right of a person or community, including Indigenous Peoples, to give, withhold, or withdraw their consent regarding any action that may positively or negatively impact their lands, territories, resources, or knowledge. However, the person or community must have full information regarding the activity, must give consent before the activity begins, and must not feel any pressure or coercion to agree to the activity.

Full recovery: The condition whereby all ecosystem attributes closely resemble those of the reference model. It is preceded by the ecosystem exhibiting self-organization that leads to the full return and maturity of ecosystem attributes.

Functional traits: Morphological, biochemical, physiological, structural, phenological, or behavioral characteristics that are expressed in phenotypes of individual organisms and are considered relevant to the response of such organisms to the environment or their effects on ecosystem properties. Most often employed in relation to vascular plants.

Future Practice (of restoration): The acknowledgment that aspects of science, IK, LEK, on-site learning, and other knowledge sources that are not currently known or understood will inform, influence, and improve restoration practice and cost-effectiveness in the future.

Gene flow: Exchange of genetic material between individual organisms that maintains the genetic diversity of a species' population. In nature, gene flow can be limited by lack of dispersal vectors and by topographic barriers such as mountains and rivers. In fragmented landscapes, it can be limited by the separation of remnant habitats through **fragmentation**. Gene flow between introduced and native populations can have negative impacts, such as inbreeding depression.

Genetic swamping: Where small numbers of remnant individuals of a species are genetically overwhelmed by large

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numbers of introduced individuals of the same species that themselves have little, if any, genetic diversity or are inbred.

Germplasm: The various regenerative materials of plants and animals (embryos, seeds, and vegetative fragments) that provide a genetic source for future populations either on site or else for colonization of off site, potentially suitable habitats.

Goals (project): Formal statements detailing a project's desired impact on the desired future status of the ecosystem under restoration, with respect to its ecological and social attributes. Goals must be clearly linked to attributes and are specific, measurable, achievable, results-oriented, and time-limited (SMART).

Green infrastructure: A network of natural or semi-natural features (e.g. bio-swales, street plantings, green roofs, green walls, wetlands, urban forests, parklands) in **converted ecosystems**, that can help meet infrastructure needs as well as increase ecosystem services.

Habitat: The physical or potential living space of an organism or a population of a species, characterized by its particular environmental properties.

Human health: A state of optimal physical, mental, spiritual, and social wellbeing, where the body operates and continually adjusts as an integrated unit with the capacity to heal, adapt, and maintain equilibrium.

Impact: Refers to a measurable change—positive, negative, or neutral—in ecological conditions, processes, or functions resulting from a restoration activity.

Inbreeding depression: The reduced biological fitness in a given population as a result of inbreeding (i.e. breeding of closely related individuals).

Indicators (of recovery): Characteristics of an ecosystem that can be used for measuring progress toward restoration goals or objectives at a particular site (measures of presence/absence and quality of biotic or abiotic components of the ecosystem).

Indigenous Knowledge: Knowledge and practices learned from experience and observation, and passed from generation to generation informed by strong cultural memories, sensitivity to change, and values that include reciprocity. While IK is the preferred term, it is often used interchangeably with Traditional Ecological Knowledge (TEK), which specifically focuses on ecological and environmental knowledge but may convey the perception of an outdated or static knowledge system.

Indigenous science: Rooted in unique cultural practices and traditions, Indigenous science involves a systematic approach of observing, experimenting, and analyzing nature, specific to each community's knowledge system.

Initiating native ecosystem recovery: The location on the **Restorative Continuum** where recovery is at a low level and has potential for improvement but meets the minimum criteria for ecologically **substantive recovery** and thus ecological restoration. This level of recovery can also be considered as a subcategory of **partial recovery**.

Interested and affected parties: Any individual, group, or institution that has a vested interest in or can influence a project and/or that potentially will be affected by the project and has something to gain or lose if conditions change or stay the same. Interested parties are all those who need to be considered in achieving project goals and whose participation and support are crucial to its success. See Annex 2 for a more detailed definition. Compare with **partner** and **rightsholder**. Synonym: stakeholders.

Intrinsic value (of ecosystems and biodiversity): The value that an entity has in itself, for what it is, or as an end. The contrasting type of value is instrumental value. Instrumental value is the value that something has as a means to a desired or valued end. An emerging concept in social sciences is relational value.

Invasive species: A species whose presence in an ecosystem disrupts and degrades the composition, structure, functions, or physical conditions of that ecosystem. Invasive species often accomplish this by outcompeting other species or by preventing their recruitment or establishment. These species are often, but not always, nonnative species. However, not all nonnative species are invasive.

Key ecosystem attributes: A critical subset of attributes that enable the collective consideration of complexity, self-organization, resilience, and sustainability of an ecosystem. The six key ecosystem attributes are: absence of threats, physical conditions, species composition, structural diversity, ecosystem function, and external exchanges.

Knowledge holders: An individual within a community recognized for possessing and being a custodian over specialized knowledge and expertise, specifically related to their environment and cultural heritage (i.e. traditions, practices, and language). Includes **Indigenous Knowledge** holders and **Local Ecological Knowledge** holders.

Landscape: A bounded area (at any spatial scale) of interacting ecosystems with discrete ecological composition, structures and functions, and human communities with discrete social-economic and cultural characteristics. See also **seascape**.

Landscape and seascape restoration: Planned processes aimed at reestablishing the ecological integrity of landscapes or seascapes, including their long-term capacity to sustainably provide essential ecosystem services, thereby supporting human wellbeing.

Local Ecological Knowledge (LEK): Knowledge, practices, and beliefs regarding place-based ecological relationships that are gained through extensive personal observation of and interaction with local ecosystems and shared among local resource users.

Local provenance area or zone: A propagule or other regenerative unit collection area, generally the **natural genetic neighborhood** of a species, within which propagule transfer is thought likely to conserve any locally adapted traits. This area was assumed by restoration practitioners to be always relatively close to a restoration site, but this has been shown, through improved availability of genomic analysis, not to be the case. A related but distinct concept is the **seed transfer zone**.

Mandatory restoration: Restoration that is required by international, regional, national or subnational law, by courts, or statutory authority, which may include compensatory restoration including biodiversity offsets (i.e. restoration as compensation for damage to nature by plans or projects). Mandatory restoration may also include positive restoration uncoupled from new or ongoing degradation.

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Monitoring: The periodic collection and assessment of data to answer specific questions about a project's context, strategies, and effectiveness. Some people term the assessment of data as the "evaluation" component of M&E or monitoring, evaluation, and learning (MEL).

Native ecosystem: An ecosystem comprising organisms that are known to have evolved locally or have recently migrated from neighboring localities due to changing environmental conditions and have become a viable component of the local ecosystem. Some component organisms may be listed as globally, nationally, or locally threatened. In certain circumstances, **traditional cultural ecosystems** or **semi-natural ecosystems** are considered to be native ecosystems. The presence of nonnative species in native ecosystems is a form of degradation, and the presence of ruderal native plants or transient native animals would not, on their own, constitute a native ecosystem. Many native ecosystems, however, are themselves transient, pioneer, or early successional in nature.

Native species: Taxa considered to have their origins in a given region or that have arrived there without recent (direct or indirect) transport by humans. Among ecologists, debate exists over how precisely to define this concept.

Natural capital: (1) Stocks of natural resources that are renewable (ecosystems, habitats, native biodiversity, organisms), nonrenewable (petroleum, coal, minerals, etc.), replenishable (the atmosphere, potable water, fertile soils), and cultivated (landraces, heritage crops, and the know-how attached to them), and from which flow **ecosystem services**. (2) A metaphor borrowed from economics to denote the limited stocks of physical and biological natural elements found on Earth, some of which are of direct use to human society (then called resources) and others which are not.

Natural genetic neighborhood: Geographic extent of a continuous and uniform genetic group, distinct from **seed transfer zone** in that it is derived solely from genetic analysis, where there is naturally open gene flow and no genetic evidence of structure or differing local adaptation. See also **local provenance area or zone**.

Natural regeneration: Germination, birth, or other recruitment of biota including plants, animals, and microbiota, whether arising from colonization, dispersal, or in situ processes. It may occur spontaneously after the removal of the degradation causes or be assisted or facilitated through restoration interventions. The degree of natural regeneration potential in a degraded ecosystem will depend on the extent and duration of the negative impacts and whether they resemble states to which the ecosystem's species have adapted over evolutionary time frames.

Net gain (project level): A positive improvement from restoration's contributions to biodiversity, ecosystem integrity and human wellbeing, using the degraded state as a baseline, and measured at appropriate temporal and spatial scales. Measurement of net gain should include intended as well as unintended consequences of restoration activities, within and outside the restoration site. Because net gain at the project level by definition is measured against the degraded baseline, it only applies to ecosystems that have been degraded (i.e. it is not appropriate to measure net gain of non-degraded ecosystems).

Net gain (system level): The net positive result from restoration at broad temporal and spatial scales, as compared to the pre-restoration baseline at the same scales, after all gains and losses have been accounted for as measured by improvements to biodiversity, ecosystem integrity, and human wellbeing.

Objective: A formal statement detailing a project's desired intermediate result, such as reducing a critical threat. A good objective meets the criteria of being specific, measurable, achievable, results-oriented, and time-limited (SMART). If the project is well conceptualized and designed, the realization of a project's objectives should lead to the fulfillment of the project's goals and ultimately its vision.

Ongoing management: Ongoing activities, applied after primary project implementation has concluded, intended to counteract processes of ecological degradation, sustain the attributes of an ecosystem following partial or full recovery, and minimize the potential of regression into a degraded state. More extensive ongoing management activities are likely to be required at sites where higher levels of threats continue compared to sites where threats have been largely controlled.

Outbreeding depression: When offspring from crosses between individuals from different populations (from a remnant parent and an introduced parent) have lower fitness than progeny from crosses between individuals from the same population.

Outcome: The result or desired future state of an action, project, or program. Some practitioners distinguish between intermediate outcomes (intermediate results and their associated shorter-term objectives) and ultimate outcomes (positive impacts described by a project's goals).

Overutilization: Any form of harvesting or exploitation of a species or ecosystem beyond its capacity to regenerate. Examples include over-fishing, over-clearing, overgrazing, and over-burning.

Partial recovery: The state whereby some recovery has occurred at or beyond a 1-Star condition, but where not all ecosystem attributes closely resemble those of the reference model (see also the state of **initiating native ecosystem recovery**, which can be considered a sub-category of partial recovery).

Participatory monitoring: A system that involves interested and affected parties at multiple levels in monitoring design and the collection and analysis of data gathered from a given restoration activity. Effective participatory monitoring, like participatory planning, can lead to improved collaborative decision-making and improved community engagement and support.

Partner: Any individual, group, or institution including governments and donors whose active participation and support are essential for the successful implementation of a project or program. See also **interested and affected parties** and **stakeholders**.

Productivity: The rate of generation of biomass from the growth and reproduction of plants, animals, and other biota.

Project scope: The broad geographic or thematic focus of a project.

Propagule: Any biological material that functions in propagating an organism. Propagules are produced by plants, animals, fungi, and microorganisms. See also **regenerative unit**.

Provenancing: The strategy for selecting from where regenerative units are sourced to support genetic diversity, climate

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resilience, and long-term project success. See also **natural genetic neighborhood**, **local provenance area or zone**, **seed transfer zone**, and **climate readiness**.

Recovery (of species): The state attained by a species when it regains its presence and functionality (in part or in full) after release from a stress or disturbance. Return to functionality is measured in terms of such indicators as abundance, distribution, reproductive capacity, genetic diversity, and resilience compared to a reference state. In ecological restoration, the aim is to attain this state for a site's component species through the process of removing or managing threats and applying appropriate restoration interventions, followed by the appropriate ongoing management to protect species and their habitats on an ongoing basis.

Recovery (of native ecosystems from degradation): Describes the outcome of restoration where an ecosystem regains its integrity, including its composition, structure, and function, through the return of biota and interactions between them and their abiotic environments (as biota grow, breed, recruit, and ultimately build ecosystem complexity). In ecological restoration, recovery, relative to the levels identified for the reference model, is assisted by restoration activities and can be described as partial or full. A key indicator of recovery includes demonstrated or predicted capacity for self-perpetuation of the focal biota.

Recovery gap: a physical, biological, or knowledge impediment that cannot be overcome and reflects the discrepancies in biological and functional capacity between the pre-degradation state (the baseline), the reference model, and what is technologically possible given the best endeavors and science to achieve the reference condition. Even with the best outcomes from ecological restoration, a recovery gap almost always persists between the undegraded condition and the restored condition, and is one reason why restoration should never be used as a justification for destruction of ecosystems.

Recruitment: Production of a subsequent generation of organisms. This is measured not by numbers of new organisms alone (not every hatchling or seedling) but by the number that develop as independent individuals in the population.

Reference model: A model that indicates the expected state (in its highest integrity condition) that the restoration site would exhibit in the absence of degradation (with respect to flora, fauna and other biota, abiotic elements, functions, processes, and successional states), reflecting background and predicted changes in environmental conditions. It is not the historical state, nor the baseline condition, but represents a benchmark against which the condition of the site is measured prior to, during, and after restoration.

Reference site: Ideally, an undegraded or nearly undegraded extant site that has attributes and a successional phase similar to the restoration project site and that can be used to inform the development of a reference model. Ideally, the reference model includes information from a suitable number of extant reference sites.

Regenerative unit: Biological material used to reintroduce or improve the genetic diversity of plant, animal, fungus, and microorganism populations in restoration sites, including but not limited to vegetative material, seeds, spores, eggs, and live young. See also **propagule**.

Rehabilitation: Management actions that reinstate attributes of some physical properties (e.g. soils and water) and a level of ecosystem functioning on degraded or converted sites, along with a renewed or improved and ongoing provision of high quality and diverse ecosystem goods and services. Native biodiversity and ecosystem integrity are supported but actions do not achieve substantive recovery of a native ecosystem.

Reintroduction: The intentional return of biota, usually individuals of a given population or species, to an area where they previously occurred. This is carried out by restoration practitioners and can be done through a range of techniques suited to whether the organisms are plants, animals, or belong to other biological groupings.

Remediation: The repair of **damage** to the physical integrity of natural environments, particularly to ameliorate the physical degradation of substrates and to remove or detoxify contaminants or excess nutrients from soil and water, along with addressing the sources of that contamination. This activity is one of the categories of activities along the **Restorative Continuum**, distinguished from **rehabilitation** and **ecological restoration** in that it is not primarily directed to restoring ecosystem services or the recovery of native ecosystems, although it may be a precursor to either activity.

Resilience: See **ecosystem resilience** and **social-ecological resilience**.

Restoration: see **ecological restoration** and **ecosystem restoration**.

Restoration ecology: The branch of science that provides concepts, models, methodologies, and tools for the practice of ecological restoration, often in collaboration with other scientific and professional disciplines and cultural practices. It benefits from direct observation of and participation in restoration practice.

Restoration practitioner: An individual who applies practical skills, as well as knowledge from a range of sources, to engage in ecological restoration tasks at project sites. Practitioners may be adept at different aspects of restoration practice, whether planning, implementation, or monitoring, depending on training and experience.

Restorative Continuum: A spectrum of activities (including ecological restoration) that directly or indirectly support or attain at least some recovery of ecosystem attributes that have been lost or impaired (see Principle 8).

Revegetation: Establishment, by any means (e.g. regeneration, augmentation, or reintroduction), of plants on sites (including terrestrial, freshwater, and marine areas) that may or may not involve local or native species.

Rewilding: Some argue that rewilding is a form of ecological restoration that focuses on restoring ecosystem processes, in particular trophic cascades (e.g. Jørgensen 2015; Hayward et al. 2019), while others argue it may be a distinct practice (Pettorelli et al. 2018), or approach with a common scope and goals to ecological restoration (Mutillod et al. 2024). Carver

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et al. (2021) reviewed the history of rewilding and its evolution as a concept and suggested a definition. In the Standards, only rewilding projects aligned with the Standards are considered to be ecological restoration projects.

Rightsholder: An individual or group who has legal or customary title, tenure, or use of lands and waters or natural resources within an area. All rightsholders are also **interested and affected parties** in a project, but not all interested and affected parties are rightsholders.

Scientific discovery: Knowledge obtained from systematic observation, measurement, and the formulation, testing, and modification of ideas (hypotheses).

Seascape: A bounded area of interacting ecosystems (at any spatial scale) in marine environments, with discrete ecological composition, structures and functions, and human communities with discrete social-economic and cultural characteristics.

Seascape restoration: see **landscape** and **seascape restoration**.

Seed transfer zone: A defined geographic area, usually derived from relationships between traits of a species and environmental factors (with or without genetic analysis) to guide where seed may be transferred with little adverse fitness effects. See also **natural genetic neighborhood**.

Selfing: Self-fertilization (or in plants, self-pollination) as distinct from outcrossing. Selfing involves self-fertilization within the same lineage, reducing genetic diversity, whereas outcrossing species promote genetic diversity by mating between different individuals, particularly through mechanisms such as self-incompatibility.

Self-organization: A scenario or process whereby order, structure, or complex patterns emerge spontaneously, all the necessary elements are present, and the ecosystem's attributes continue to develop toward the appropriate reference state. Some restoration activities may still be required (e.g. species reintroductions or reinforcements), but ongoing management (e.g. support for natural disturbance regimes, invasive species surveillance and control) is almost always required.

Semi-natural ecosystem: In the EU legal context, biodiverse ecological assemblages co-created by human activities (e.g. grazed or mowed alpine meadows). They have evolved under traditional agricultural, pastoral, or other human activities that can be centuries old and depend on traditional management for their characteristic composition, structure, and function. These ecosystems are highly valued for their biodiversity and ecosystem services, and can be a reference for ecological restoration. They differ from cultural ecosystems created to provide ecosystem services (e.g. modern agricultural fields and urban ecosystems), which result in a higher level of ecosystem degradation with lower biodiversity values. See also **traditional cultural ecosystem**.

Shifting baselines: The phenomenon whereby current observers view particular ecosystems or ecosystem components (including species) as less degraded or even non-degraded because they have not witnessed the prior undegraded condition. This leads to a cumulative generational lowering of standards and a failure to recognize the magnitude of long-term loss and degradation.

Site: Discrete area or location defined in spatial terms. A site can occur at different scales but is generally at the patch or property scale (i.e. smaller than a landscape).

Social-ecological resilience: The capacity of a given integrated system—composed of ecosystems and human societies with reciprocal feedback loops at multiple scales—to absorb disturbance, adapt to change, and reorganize while retaining its function, structure, identity, and associated interactions. Resilience in social and **social-ecological systems** depends in large part on the capacity of humans, especially decision-makers and leaders of institutions, to anticipate and plan intelligently and skillfully for the future.

Social-ecological system: Complex, integrated, and linked systems of people and nature, at varying spatial scales. This term, commonly used in connection with **social-ecological resilience**, emphasizes that humans are a part of nature and part of ecosystems.

South–South cooperation: A broad framework for collaboration among countries of the Global South (also known as developing or low-income countries) in political, economic, social, cultural, environmental, and technical domains. Involving two or more countries or institutions in those countries, South–South cooperation can take place on a bilateral, regional, subregional, or interregional basis.

Spatial patterning: The spatial structure of ecosystem components (in a vertical or horizontal plane) that arises due to differences in substrate, topography, hydrology, vegetation, disturbance regimes, or other factors.

Spatially patterned restoration: A strategy that uses the establishment of patches of vegetation (often trees or shrubs) or populations of animals (corals, oysters) to serve as focal areas for ecosystem recovery by enhancing colonization or improving establishment and growth of native species.

Species: Used here as a generic term to represent an organism falling into the taxonomic unit of "species" or an infraspecific taxon, even if not formally described by science.

Stakeholders: see **interested and affected parties**.

Stratum, strata: Layer or layers in an ecosystem; often referring to vertical layering such as trees, shrubs and herbaceous layers at a terrestrial site and also sometimes used in descriptions of aquatic habitats (e.g. kelp forests), but can also be applied to marine faunal structure (e.g. coral formations).

Substrate: The soil, mud, sand, rock, shell, debris, or other medium where organisms grow and upon which terrestrial and many aquatic ecosystems ultimately develop.

Substantive recovery: The minimum level of improvement in ecosystem condition aimed for if a project is to be classified as an ecological restoration project. This level of recovery is defined by whether the recovery meets minimum fundamental ecological criteria or otherwise accelerates or contributes to recovery in a significant way. While the criteria cannot be tightly linked to a particular recovery metric, a minimum standard for initiating substantive recovery would be projects reaching at least a one-star condition for species composition and all or most of the other key ecosystem attributes. For that to be the case, however, there would need to be evidence or predictability that

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the reestablished biota (5–25%) of the reference model are likely to self-perpetuate and the project has potential for further improvement. See also **initiating native ecosystem recovery**.

Succession (ecological): Patterns of directional change in the structure, species composition, and abiotic components of an ecosystem over time after disturbance. Patterns of change and community development can differ markedly among ecosystem types, particularly after very large disturbances that remove all biota (i.e. primary succession), less so after smaller disturbances that do not remove all biota (i.e. secondary succession). Some ecosystem types exhibit earlier assemblages that facilitate the development of more complex assemblages over time, while others do not exhibit any such sequencing.

Sustainable businesses: Businesses (and economies) that encompass principles of economic and environmental sustainability, aiming for long-term ecological wellbeing, economic prosperity, and social equity as articulated in the concept of sustainable development. Outcomes measured include a business or economy's adoption of such sustainability practices such as minimizing resource consumption, environmental pollution, and waste generation to balance environmental and social benefits.

Threat: A factor, often a process, potentially causing or already causing degradation, damage, or destruction. A threat may be a direct driver of degradation (i.e. an event or process occurring at a restoration site) or an indirect driver (i.e. a process influencing the broader landscape or waterscape in which the ecosystem or site undergoing restoration is located).

Traditional cultural ecosystems: Ecosystems that have developed over long periods under the joint influence of natural processes and human-imposed organization to provide composition, structure, and functioning more useful to human exploitation. Those considered high-quality examples of native ecosystems can function as reference models for ecological restoration, whereas others converted primarily to nonnative species or are otherwise degraded do not function as reference models for ecological restoration. Note that traditional in the sense of this term is to emphasize long-standing cultural ecosystems and does not imply static or unchanging cultures or practices. See also **semi-natural ecosystem**.

Traditional Ecological Knowledge (TEK): See also **Indigenous Knowledge** and **Local Ecological Knowledge**.

Trajectory of recovery: A course or pathway of an ecosystem's condition (e.g. structure and function) over time. It may refer to a pathway of degradation, a static state, adaptation to changing environmental conditions, or response to ecological restoration—ideally leading to recovery of lost integrity and **resilience**.

Translocation: The intentional transporting (by humans) of organisms to a different part of a given landscape or aquatic environment or to more distant areas. The purpose is generally to conserve or recover an endangered species, subspecies, or population.

Trophic levels: Hierarchical categorization of organisms within ecosystems depending on their position in the food chain or food web. Levels include producers, consumers, predators, and decomposers, which represent the transfer of energy and nutrients through ecosystems.

Two-Eyed Seeing: Introduced by Mi'kmaq Elders, Murdena and Albert Marshall Sr., Two-Eyed Seeing refers to weaving together Indigenous Science, Knowledge, and place-based know-how with mainstream science and technology.

Undesirable species: Includes nonnative species (except in some cases where they may provide irreplaceable or temporary support for native biodiversity and ecosystem recovery), as well as native species that may be overabundant or otherwise considered to be out of place.

Vision: A description of the desired state and ultimate condition that a project is working to achieve, associated with the **project scope**. A good vision meets the criteria of being relatively general, visionary, and brief.

Wellbeing: A positive state experienced by individuals and societies, encompassing such factors as health, the basic material needs for a good life, good social relations, and personal security. Similar to health, it is a resource for daily life, is determined by social, economic, and environmental conditions, and has a strong relationship to the equitable distribution of resources and sustainability (adapted from Millennium Ecosystem Assessment 2005; WHO 2021).

Acknowledgments

D.C.B., G.D.G., and A.M. acknowledge funding from the Darwin Initiative Extra grant (DAREX001); J.C.-S. research is funded by Generalitat Valenciana, project Responses to Desertification (R2D, CIPROM/2021/001). E.K.G. thanks University of Victoria students A. Vial and L. Dexter for their review of over 700 academic articles citing version 2.0 of the SER Standards. Their work enabled us to incorporate scholarly critiques and practical applications from the literature into the development of the third edition. J.L. acknowledges the support from the United Nations Educational, Scientific and Cultural Organization (UNESCO) Chair on Stepwise Ecological Restoration of Watersheds. We thank Brooke Weiland Studios for updates to key figures, to S. Pedrini for the original editable online Ecological Recovery Wheel, and L. Gallet and S. Gallet for designing the updated Editable Ecological Recovery Wheel template available on the SER Standards Tools page. Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

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Appendix 1

Selection of Seeds and Other Regenerative Units for Restoration

This appendix is adapted and expanded from McDonald et al. (2016b) and Gann et al. (2019). While there are many considerations to be made when deciding on the selection of plant seeds and other regenerative units (e.g. vegetative material, spores, eggs, live young, soil transplants, and microbial inoculations) for restoration projects, genetic considerations can sometimes be paramount to ensure the resulting populations successfully reproduce and persist. These considerations are particularly important in fragmented landscapes, especially under climate change, and require particular care in cases involving threatened species (Falk et al. 1996).

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Genetic Considerations for Sourcing Seeds or Other Regenerative Units, Particularly Under Conditions of Fragmentation

Identifying appropriate sources of material for the **reintroduction** or **augmentation** of biota in ecological restoration—particularly under conditions of **fragmentation**—requires a balance of genetic risks: **inbreeding depression** (loss of fitness due to breeding between close relatives); **genetic swamping** (where the source material partially or fully replaces the local remnant populations, which can, over time, erode range-wide genetic diversity); and **outbreeding depression** (where there is loss of fitness due to breeding between distant relatives).

Inbreeding depression. Inbreeding depression can result from the mating of closely related individuals. It can occur in small populations where gene flow is restricted, and it represents a significant threat to restored populations sourced from a small number of parents. Inbreeding erodes genetic diversity overall and inbreeding depression can significantly reduce population fertility and fitness. Where **fragmentation** has occurred, small remnant ecosystem patches may be at risk of elevated inbreeding when populations drop below species-specific threshold numbers, especially for species that typically outcross as they carry elevated levels of recessive deleterious alleles that are not expressed without inbreeding (Breed et al. 2013). Obtaining regenerative units from such fragments alone may exacerbate inbreeding depression. This can reduce the function and adaptation capacity of populations and would therefore require supplemental genetic material from larger, more distant populations of the species, ideally from within the **natural genetic neighborhood**. The locations of these populations can inform the formulation of a **seed transfer zone**.

Genetic swamping. Genetic swamping can occur without outbreeding depression being involved at all, and is potentially a more important issue than outbreeding depression per se, particularly where small numbers of remnant individuals of a species are genetically overwhelmed by large numbers of introduced individuals of the same species that themselves have little if any genetic diversity or are inbred.

Outbreeding depression. Restoration practitioners have widely adopted the concept of confining the collection of regenerative units to a geographically narrow local provenance area in an effort to avoid loss of local adaptation through outbreeding depression. However, outbreeding depression is considered to have a lower likelihood and lower level of risk to species persistence than inbreeding depression (Frankham 2022, Wilder et al. 2025). It also needs to be noted that local adaptation is thought to exist in only approximately 50% of plant populations (Leimu & Fischer 2006).

Outbreeding depression may occur if the parents are adapted to different conditions, resulting in offspring of a cross between a remnant parent and an introduced parent being poorly adapted to the restoration site. In other cases, coadapted gene complexes can be disrupted, resulting in fitness loss (Rogers & Montalvo 2004). Outbreeding depression can be more likely in plants when populations of different ploidy (the number of chromosomes in the cells) are combined in restoration or in seed-production areas.

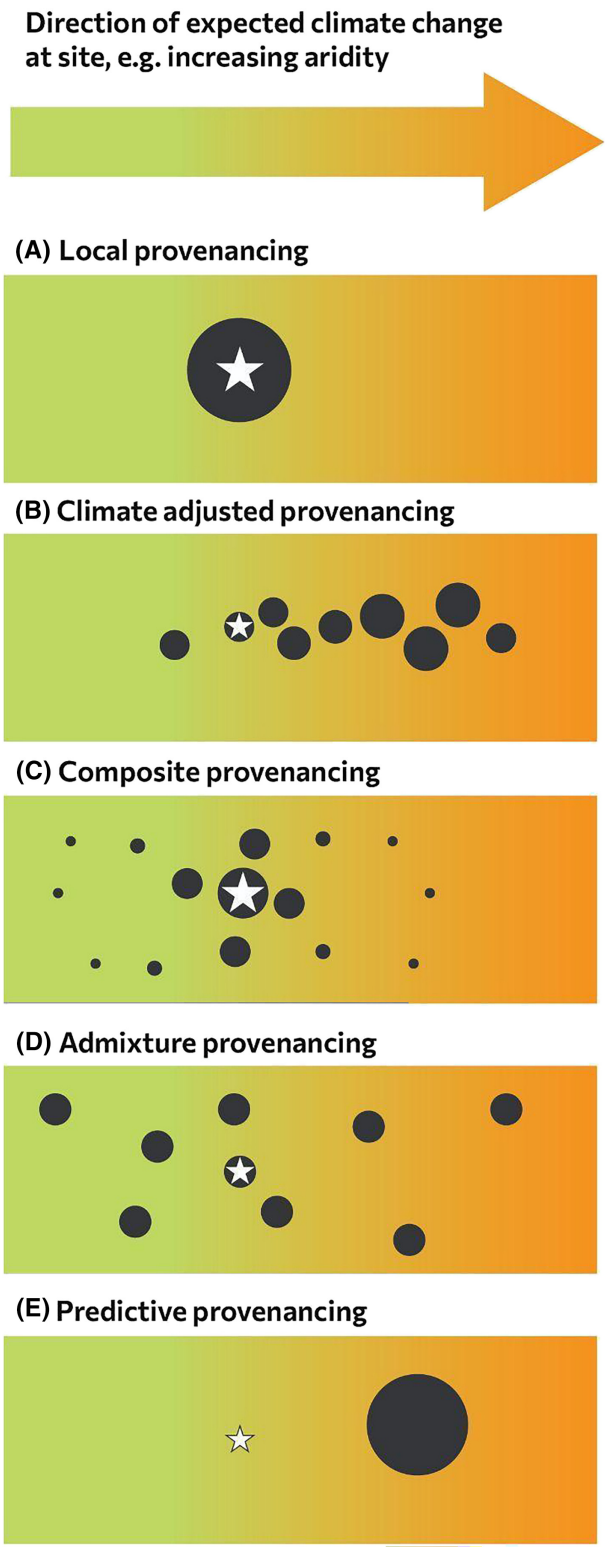


Figure A1. Provenancing strategies for translocations or regenerative units (adapted from Prober et al. 2015). Stars indicate sites where regenerative units are used and circles represent native populations used as germplasm sources. Circle size indicates the relative quantities of germplasm included from each population at the revegetation site. Note that climate-adjusted provenancing is not considered in Table A1.

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Best practice prescriptions to avoid all three genetic risks. Physically reconnecting fragments through ecological restoration should be a primary goal in fragmented landscapes. This requires some effort and the careful observance of genetic protocols, however, to ensure that individual organisms involved in restoration projects have the appropriate genetic makeup.

Collecting high volumes of reproductive units from single (or a few closely related) individuals—and the use of high performing selections or hybrids—should be avoided to lessen the risk of inbreeding and genetic swamping. Equally, a protocol of preferentially collecting units from a narrow zone close to the degraded ecosystem being restored is considered inappropriate as it can increase the risk of collecting from siblings and cause breeding failure. Collecting from a small and already fragmented donor site may also increase the risk of inbreeding depression. Close-proximity collection may also not be necessary to conserve local adaptation as genomic studies are showing that a "local" genetically distinct population can occur over a far broader **natural genetic neighborhood** than previously assumed (i.e. from 10s to 1000s of km^2), depending on the species and its biology (Fahey et al. 2025). These factors, coupled with the view that outbreeding depression is generally considered a lower likelihood than inbreeding depression (Frankham et al. 2011, Wilder et al. 2025), suggest that it is more important to select genetic material from multiple larger populations within a natural genetic neighborhood (and from widely spaced parents from locations with similar ecological conditions to the restoration site) than to collect within close proximity to the restoration site itself. This wider collection is likely to be necessary to capture sufficient genetic diversity and (if multiplied in production facilities) will allow sufficient volumes of units to rebuild functional, resilient communities (Bucharova et al. 2019), particularly when high genetic diversity is needed to optimize adaptability to climate change. Exceptions may include annual plants that are highly **selfing** (because deleterious alleles associated with inbreeding depression are likely to have been purged historically) and/or plants that historically have short-distance (specialized) dispersal or pollination patterns, especially those that have experienced recent range expansion (Hufford & Mazer 2003; Broadhurst et al. 2008). Practitioners are encouraged to seek evidence from any genetic genomic studies that exist for their species of interest and, where this evidence is absent, consider the species' natural dispersal and pollination range to gain some insight into the species or population's potential natural genetic neighborhood.

Table A1. Types of propagule sourcing, with their description, benefits, risks, and most appropriate uses. Modified from Havens et al. (2015) and Breed et al. (2013).

Propagule sourcing type	*Definition*	*Benefits*	*Risks*	*Best used when*
Strict local provenancing	Using propagule only from the site where restoration is occurring or populations within normal gene flow distance	• Little risk of maladaptation (at least short term)	• Narrow genetic base • Possible inbreeding • Genetic drift • Lack of adaptive potential	• Disturbance is minimal • Large local population present at or adjacent to restoration • Predicted distribution change is low
Relaxed local provenancing	Mixing propagules from geographically close populations with a focus on matching environment of source and recipient sites	• Little risk of maladaptation (at least short term) • Avoids inbreeding • Increases adaptive potential	• Can have narrow genetic base • Lack adaptive potential for the longer term	• Disturbance is minimal • Predicted distribution change is low
Composite provenancing	Mixing propagules from populations of close and intermediate distance (or environmental match) to mimic long distance gene flow	• Avoids inbreeding • Increases adaptive potential	• Maladaptation • Outbreeding depression	• Disturbance is minimal • Fragmentation is high • Predicted distribution change is moderate
Admixture provenancing	Mixing propagules from many populations of varying distances throughout the range of the species	• Highest adaptive potential	• Largest risk of maladaptation • Outbreeding depression • Possibly invasive genotypes	• Disturbance is high • Predicted distribution change is high
Predictive provenancing	Using genotypes adapted to predicted conditions (2050 climate projections) based on models and transplant experiments	• Deals best with changing conditions, if predictions are correct	• Projections may be wrong • Requires much research (high initial cost), although tools can help	• Disturbance is low to moderate • Predicted distribution change is high and well understood

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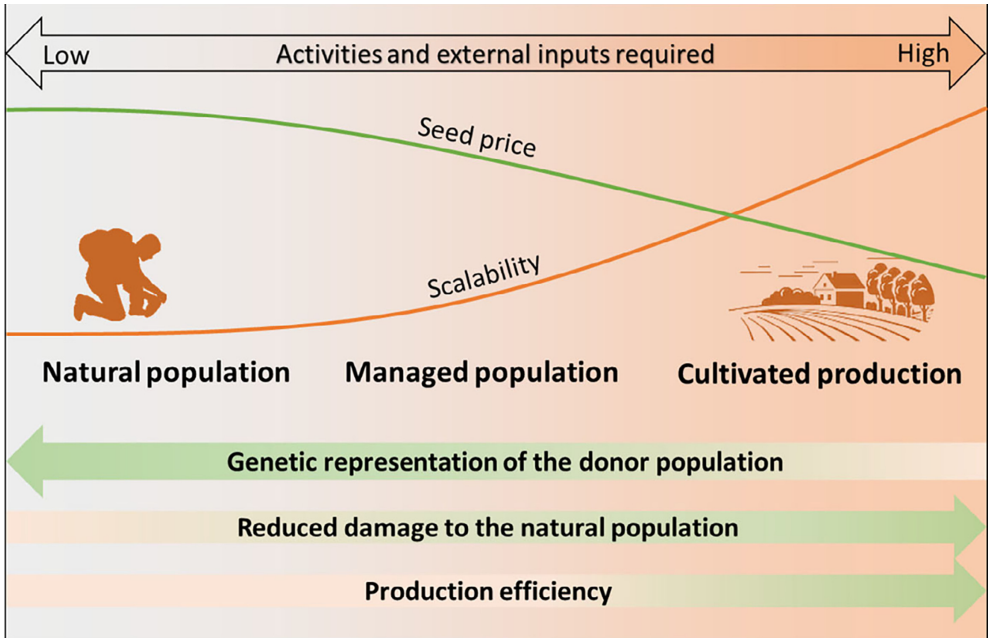


Figure A2. Native seed supply approaches for ecological restoration sit on a continuum of increased management activity intensity, from seed collection in unmanaged natural populations to highly controlled farm setups (e.g. weeding, fencing, irrigation, fertilization, and weed mat). Higher activity approaches might result in a lower representation of the genetic makeup of the population of origin due to involuntary selection; however, they can reduce potential damage to the donor population by reducing collection frequency and intensity, and increasing seed availability and affordability (image from Pedrini et al. 2020).

Material Sourcing and Climate Change

Setting the scene. The effects of fragmentation on genetic diversity are magnified under climate change, where connectivity is all-important for gene flow. The climate range in which a species or population exists is known as its **climate envelope**. As the climate changes, the climate envelope is likely to uncouple from a species' or population's current range and may move, reform, or disappear entirely in unpredictable ways. We can predict, however, that where conditions become hotter, the leading edge of a population may move further poleward or to higher elevations (where that movement is possible), while trailing edges of a population may decline. Climate envelopes may also be affected by changes in the patterning and amount of precipitation, with some areas becoming drier or wetter, not necessarily shifting location unaltered. Because precipitation is likely to change in even less predictable ways than temperature, it is likely that the modification of climate envelopes will be highly complex. These changes may also affect individual populations of a species at differential rates and in different ways, along with interspecific interactions within evolving ecosystems.

Although many species have endured climate changes in the historical past in their current region (e.g. some regions may possess populations with higher levels of in-built pre-adaptation than others, e.g. Hopper 2009), the current global acceleration of climate change (Hansen et al. 2025), compounded by fragmentation and anthropogenic barriers to migration, are unprecedented and may challenge the survival of many species (Baker et al. 2025). We cannot precisely predict the type and scale of risks that ecosystems face because only a small proportion of species have been studied. We know that some species or populations, however, may be lost from their current locations, particularly on mountain summits and coastal regions (due to lack of areas for migration or barriers to migration), with some becoming catastrophically affected by habitat alteration, such as episodes of coral bleaching (Baker et al. 2025). Others will colonize new areas, altering local species assemblages. Some may have sufficient **adaptive plasticity** to persist as climates change, as has been demonstrated from translocation experiments. For example, an individual plant may be able to adjust its form by mechanisms such as reducing its leaf size, increasing leaf thickness or altering flowering and emergence times. Animals may alter feeding choices (omnivorous bear species switching foods to plants more resilient to climate change). Generalist species of fauna will generally survive climate change better than specialist species. In most cases, persistence may depend on a species' capacity for adaptation, which in turn depends on the size and genetic diversity of individual populations, emphasizing the importance of optimizing genetic diversity in reproductive unit sourcing as outlined earlier. Species that have populations that are adapted to a narrow climatic space (so called specialists at population level) would be more at risk, since climate change would uncouple the individual populations from the climate to which they are adapted, even if some suitable climate persists for the species as a whole (Worral & Rehfeldt 2021).

Many factors will influence the ability of a population or species to adapt to new conditions or to migrate, including patterns of gene flow, geographic distribution, the heterogeneity of the

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Box A1 Seed Protocols and Certification Systems

General guidelines:

Restoration Ecology special issue on Standards for Native Seeds in Ecological Restoration https://onlinelibrary.wiley.com/toc/1526100x/2020/28/S3.

International principles and standards for native seeds in ecological restoration (Pedrini and Dixon 2020).

For translations into a range of languages see https://ser-insr.org/native-seed-standards.

Seed Collection Protocols.

Collecting plant genetic diversity: Technical guidelines. 2011 update. Crop Genebank Knowledge Base (International) (Bioversity International at al. 2011).

European Native Seed Conservation Network (ENSCONET) Seed collecting manual for wild species (ENSCONET 2009).

Florabank Guidelines—best practice guidelines for native seed collection and use (Australia) (Commander 2021).

Collecting and handling seeds in the field. In: Collecting plant genetic diversity: Technical guidelines. 2011 update (Hay and Probert 2011).

Technical protocol for the collection, study, and conservation of native plant seeds through the National Seeds of Success Program (BLM et al. 2026).

Bureau of Land Management (US), Seeds of Success Native Seed Collection Program.

Seed Certification.

Association of Official Seed Certifying Agencies. The AOSCA website describes the certification process for crop, horticultural, and native seeds in the United States.

Pre-variety germplasm program. This is the AOSCA program for certifying native seeds whether collected from native stands or grown in production fields.

Wildsamen und Wildpflanzenproduzenten. Website for one of the German certification programs. In the United States, the seedlot is certified. In Germany, the seed company is certified.

habitat and climate, and other biotic and abiotic factors including whether the species is early successional or late successional. Species or populations with less genetic diversity and low dispersal capabilities, or that occur in isolated patches, are likely to be less able to adapt or migrate in response to climate change. Those with large populations, high genetic diversity, long-distance gene flow, and naturally high reproductive and dispersal capabilities are likely to have a higher chance of adapting or migrating as their climate envelope moves. Nonetheless, even some open-pollinated forest tree species that have several of these traits are currently migrating at a pace slower than needed to keep up with the current speed of climate change (Peñuelas et al. 2007; Lenoir et al. 2008).

Dealing with uncertainty. Planning seed source translocations is more straightforward and reliable when there is abundant information about the amount of genetic differentiation among natural populations and for well-studied species with wide distribution and high economic value (St. Clair et al. 2005; Rehfeldt et al. 2014), as distinct from situations where there are few genomic studies (Ledig et al. 2010). There is reasonably good evidence from genomics and trait-based studies that widespread species harbor climate-adapted variability across their ranges (Steane et al. 2014, Prober et al. 2016). It is unclear, however, how quickly (i.e. how many generations are required for) such variation to increase by selection or develop as a new variation in a local population (with or without our assistance), particularly if they are present at low frequency (see Jordan et al. 2017). Indeed, it is even unclear how strongly any such variation relates to persistence of populations and maintenance of ecosystem functions under different climate scenarios.

As a consequence, there is a high degree of uncertainty about whether practices proposed to improve species adaptability under climate change are needed or will indeed assist. Failing to take action if there is a need, however, would be mismanagement. This means that the precautionary principle can be invoked to support both taking action (in case the actions are needed and have a positive effect) as well as refraining from taking action (in case they are not needed and have a negative effect). This suggests that where these practices are trialed, an appropriate level of caution is necessary, ensuring that practices are well-documented and that, ideally, they are designed as experiments retaining, as appropriate, large areas where these practices are not applied (Bailey et al., 2021, Jordan et al. 2024). Examples of such experiments include one that is drawing parent material from healthy genetic variants in Honduras to avoid the local extinction of a declining coral reef species in Florida, Elkhorn coral (*Acropa palmata*), that has experienced catastrophic decline from coral bleaching (Baker et al. 2025). Other experiments in Tasmania comprise transplant trials of a fairly widespread temperate eucalypt tree snow gum (*Eucalyptus pauciflora*) in an effort to better understand potential for such interventions to help conserve the species as the climate warms (Bailey et al. 2021).

Protocols, Tools, and Future Directions

Protocols for the selection of regenerative units to enhance a species' adaptive potential in restoration projects are being considered for experimental application in some regions. Care is required to ensure these actions solely result in the supplementation of local genes rather than over-dominance by selected

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Box A2 Restoring Connectivity and Assisting Migration

A beneficial impact of ecological restoration at a landscape scale is improved connectivity between native ecosystem patches that allows species to migrate more freely and evolve in the face of climate change. Some researchers have advocated that certain species will need to be actively translocated ("assisted migration"; Kramer & Havens 2009; Sáenz-Romero et al. 2016; Wang et al. 2019). Indeed, many of the plant propagule provenancing strategies discussed in this appendix could be considered a form of assisted migration at the population level. However, when and where this might be warranted, for both plants and animals, is subject to intense debate and comes with significant risks (hybridization with closely related species; species becoming invasive in the new environment). Augmenting species at the edges of their ranges, which may seem logical in many cases, may also be problematic as species may be rare along the edges of their ranges for ecological reasons that may be poorly understood. Additionally, populations along range edges are sometimes genetically distinct. Introducing germplasm from other populations could reduce climate readiness or lead to the extinction of the local population through hybridization. Often, range margins are irregular with many outliers, a condition not well illustrated by many distribution maps (maps using presence/absence by local political units). The question of when to pull species "up latitude and up slope" along those edges or continue to support populations at low latitudes and at the low-elevation edges of their ranges is complex and deserving of careful thought. Trailing edges of a distribution relative to climate change may be most vulnerable (Mátyás et al. 2010). Longevity, dispersal, breeding system, and other species traits determine the ability to adapt or migrate. When sourcing, it is important to consider material from currently adapted sources plus sources adapted to projected near-future conditions to hopefully balance the benefits of local adaptation with the ability to adapt to changing conditions. Evidence based on experimental studies is critical to evaluate when and if actions such as assisted migration should be considered and to assess the inherent risks. An example of species range expansion toward higher elevation is being conducted with Sacred Fir (*Abies religiosa*), aiming to create potential overwintering sites for the migratory Monarch butterfly (*Danaus plexippus*) populations under climates projected for the decade centered in 2060 in a high elevation volcano in central México (Sáenz-Romero et al. 2024). Also, the Western swamp turtle (*Pseudemydura umbrina*) has been experimentally translocated toward currently cooler sites in Australia, to bypass the complete impossibility of a natural migration overcoming a fragmented landscape by agriculture and highways (Bouma et al. 2020).

genotypes (through competition, genetic swamping, or outbreeding depression) arising from failures to give due attention to ensuring wide genetic diversity in the donor plants.

Where populations have been separated and reduced in size by fragmentation, a first priority should be to apply actions to restore connectivity along the climate change gradient where that is possible, and to increase gene flow and genetic diversity (as recommended above for fragmented landscapes) irrespective of the risk of climate change. This recommendation is made on the basis that larger and more genetically diverse populations are more likely to have useful adaptability to changing environmental conditions (Steane et al. 2014) even if the rate of that adaptive capacity may be unknown. Such improved connectivity between native ecosystem patches can also allow genes (and individuals in the case of animals) to migrate more freely and evolve in the face of climate change (see also Box A2).

As an additional precaution, or where the populations to be restored remain small and disconnected from gene flow from other populations, however, it is considered prudent by many geneticists to experimentally include some germplasm of the same species from a predicted future climate (i.e. a region with a climate similar to that predicted under a particular climate change scenario for the reference site) (Richardson et al. 2024). In such cases, researchers are encouraged to design protocols for trials or formal experiments integrated into low-risk restoration settings to avoid substantial risks that may exist due to unintended and irreversible outcomes. In higher-risk settings (e.g. areas with high endemism floras), strategies to appropriately reinstate gene flow and thus genetic diversity may be preferred. Application of any such strategy should therefore be supported by sound science, within a risk-management framework that considers the potential for unintended negative effects of genetic alteration of a population. Monitoring should be designed to record lessons to be shared with both practitioners and researchers in a manner that contributes to long-term knowledge generation. Before undertaking such experimentation, however, it is important to understand that, if genetic supplementation is shown to be negatively impacting a population or swamping local genetic variation, the effect may be difficult or impossible to reverse.

For low-risk scenarios, tools are available to help restoration planners undertake **climate readiness** analysis and incorporate appropriate experimental protocols at the planning stage. First and foremost, restoration practitioners should seek advice from or collaborate with field competent scientists to gain a better understanding of predicted responses of species to fragmentation and climate change, to identify any evidence-based need for intervention and evaluate the relative risks of options relating to the deliberate movement of genetic material to restoration sites. Researchers can also design the necessary experimentation protocols to ensure that lessons can be derived from the work should it go ahead (Sáenz-Romero et al. 2017, 2019, 2021).

With respect to reliable predictions of climate change for particular ecosystems of interest, web-based tools are becoming increasingly accessible in some countries to assist practitioners with identifying whether the species or population currently

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occurring near the restoration site will still be suited to climates predicted to occur at the site in the future. In North America, the Seedlot Selection Tool is very useful for trees, and the Climate Smart Restoration Tool is used for other growth forms of plants (St. Clair et al. 2022). In eastern Australia, the Restore & Renew web-based tool provides empirical genetic and climatic evidence to support decision-making on where to source material for establishing diverse and climate-ready populations. Guidance is provided across a continuously growing number of species along the eastern coast (currently well over 100 species).

A number of sourcing strategies to build climate readiness into restoration through ensuring genetic diversity have been hypothesized for careful consideration by researchers and practitioners. These include: relaxed local provenancing (Kaye 2001); composite provenancing (Broadhurst et al. 2008); admixture provenancing (Breed et al. 2013); predictive provenancing (Crowe & Parker 2008); and climate-adjusted provenancing (Fig. A1; Prober et al. 2015). Descriptions of each strategy along with the benefits, risks, and most appropriate uses are in Table A1. Most of the strategies emphasize a key role for local provenance sources and that "local" in Figure A1 represents distance from the restoration site only. In many cases, this is likely to be more geographically narrow than the distances to which we now understand a natural genetic neighborhood can extend.

Practitioners designing planting lists for restoration, even with the help of researchers, however, need to bear in mind that it is impossible to be certain of what changes will occur. Different species and populations will respond to climate change in different ways and currently there is no reliable or practical way to predict this. Furthermore, temperature and rainfall are not the only important predictors and are not the only selective factors that impact a species' success. A range of physical (substrates) and biological factors (dispersal, competition)—which themselves may or may not be affected by a changing climate—can also have important roles in influencing the distribution of a species, their competitive success, and capacity to survive climate fluctuations. Hence selecting material from multiple locations with similar ecological conditions within a population's natural range may be advisable (Kilkenny 2015; Richardson & Chaney 2018; St. Clair et al. 2022). While some caution will always be required, an empirical approach of testing different provenancing approaches in many areas around the world will help determine best practices. Every restoration project can be part of an experiment (either as treated sites or as untreated controls) if good records are maintained and results are monitored and shared. Such an approach is not only likely to improve restoration practices in the future but also to contribute to the process of generating new knowledge about species and ecosystems.

Implications for Plant Propagule Production

As restoration efforts ramp up across the world there is now a critical need to scale up native seed supplies to ensure that adequate species diverse supplies of good quality seed are available for restoration, and that these seeds are deployed efficiently and appropriately. To support this process, SER and colleagues have developed the International principles and standards for native seeds in ecological restoration (Pedrini & Dixon 2020). Consultation of this and other documents is recommended to inform practitioners about a range of protocols surrounding plant propagule production and processing, including those recording and labeling seed sources for individual and combined batches of seeds.

Multiplication of wild-collected seed in managed production systems (seed farms) relies on the manipulation of agronomic variables, such as water and nutrient availability, reduced weed competition, and higher plant density, to allow for more efficient seed harvesting and processing. Such an approach often allows for a drastic increase in seed availability and a reduction in seed cost compared to wild-seed collection (Fig. A2). Moreover, reducing reliance on wild-seed collection can reduce impacts on a population's reproductive capability that can be caused by overharvesting and other impacts such as trampling and the involuntary introduction of weeds and diseases.

Such expansion of seed availability of wild species needs to be coupled with studies of how to alleviate natural mechanisms of seed dormancy and methods of sexual and asexual propagation in nurseries. It is common that such knowledge is available for species usually produced in commercial or government sponsored nurseries, but not for wild species out of the commercial circuits. In that regard, studies like the one of Ruiz-Talonia et al. (2023) are highly valuable.

Native seed production systems are well developed in some areas such as the western and midwestern United States, and some European countries like Germany, Austria, and France, while in other regions, native seed production is limited or non-existent, relying almost exclusively instead on wild collecting (Pedrini et al. 2023a). Capacity building for nurseries providing seeds and propagules for both terrestrial and aquatic restoration should be a priority for all regions.

However, it is important to acknowledge that farmed seeds might be genetically less representative than wild-collected ones, as some involuntary selection might occur during production steps. Therefore, seed producers should strive to reach a balance between production efficiencies and ensuring genetic diversity. This can be achieved, for example, by limiting the number of generations a collection can be reproduced, and employing harvesting and processing techniques that limit or avoid involuntary selection of specific traits (plant height, maturation time, seed weight and size) (Pedrini et al. 2020). Seed certification standards have been developed for genera and species to help minimize loss of genetic diversity in seed fields (Box A1).

Improved varieties and cultivars. At times, seed producers have attempted to select native species for specific traits considered favorable for agronomic reliability, similar to improved varieties in production agriculture. However, ecological restoration is carried out for biodiversity recovery and such approaches are not recommended. Agronomically selected material should be avoided due to its risk of genetic or demographic swamping of native populations and the need to conserve and recover native genetic diversity. This includes the use of cultivars of native plants, whether derived from cuttings, division, tissue

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culture, or selected seeds (see Georgia Native Plant Society 2021).

Cuttings and divisions. Plants that produce low amounts or poor-quality seeds are often propagated from cuttings, divisions, or micropropagation (tissue culture). While the genetic principles regarding provenancing are similar regardless of propagule type, it is important to remember that genetic diversity is limited when vegetative propagation methods are used, and this might affect a population's ability to respond to future adaptive challenges. This general principle is also true for some animals, such as corals, where pieces of individuals or colonies are used as propagules in place of spores, eggs, or other modes of sexual reproduction. For this reason it is important to collect such propagation material from multiple widely spaced parents where these are available, particularly for potentially outcrossing species or where there is risk of inbreeding depression.

Appendix 2

Securing Robust and Reliable Supplies for Ecological Restoration

When practitioners develop a restoration plan, careful consideration must be placed on the supply of biological (seed, plants, animals, and topsoil) and manufactured material and equipment. Practitioners with limited experience in restoration planning and implementation might prepare a budget and timeline, assuming that all supplies could be acquired when needed from the market. However, while the material and tools required for building fences (wires and posts) can be purchased at a local warehouse or from wholesale suppliers at a relatively short notice, this is often not the case for the supply of specialized manufactured material and equipment and is rarely the case for biological material. Local supplies of sustainably sourced and genetically appropriate biological material (i.e. regenerative units) need to be identified and contracts secured before a project implementation, often years before the biological material is needed for use.

Supply of Manufactured Material and Equipment

Practical considerations regarding the type and quantity of equipment (tractors, excavators, and boats) and manufactured material (fences, wind barriers, artificial reefs, and nesting boxes) are needed to ensure that they are accounted for in the budget and available when required.

While most equipment and manufactured materials can be sourced quickly from other industries (such as agriculture, mining, and fisheries), specialized items required to handle complex and variable restoration scenarios may be more difficult to obtain or might not exist to desired specifications. This would require customizing existing equipment or manufactured material, or designing, developing, and testing new implements.

For example, seeding equipment used in crop farming can be adapted for native species; however, native seed mixes are composed of seeds of variable sizes and complex shapes that often do not easily flow through traditional farming implements (Shaw et al. 2020). Moreover, agricultural equipment is designed to operate on accessible and well-groomed fields, which is not always the case for ecological restoration. As such, a variety of approaches have been developed to either modify the shape and size of native seeds to fit existing agricultural seeders (Pedrini et al. 2023b) or to build ad hoc pieces of equipment to overcome such constraints (Masarei et al. 2019; Shaw et al. 2020). Depending on the complexity of the seed mix and resource availability, customized manufactured material and equipment can vary in cost and sophistication. At times, low-cost solutions can be as effective as highly engineered ones in overcoming logistical and biological constraints. The efficacy of solutions should be proven, and the science behind them understood before they are implemented at scale.

Restoration Bottleneck in the Supply and Deployment of Biological Material

While manufactured equipment and materials may not be easy to obtain, sourcing appropriate biological materials (e.g. seeds, plants, and animals) can be even more challenging. Sourcing a large quantity of seeds or seedlings (across many native species of high quality and appropriate origin) might take years to achieve. This is often a major obstacle to the timely implementation of ecological restoration projects that are biodiverse and representative of the native reference diversity.

Seed collectors need to identify and monitor suitable populations to ensure collections are sustainable and timed correctly (ENSCONET 2009; USDI Bureau of Land Management 2018). If sufficient seed cannot be collected from the wild, producing seed in farm settings can increase seed quantity (Pedrini et al. 2020; Zinnen et al. 2021); however, this may require several years and has genetic caveats as indicated in Appendix 1. Once collected, seeds need to be processed, tested, and stored appropriately to ensure they remain viable until they can be delivered to the restoration site (De Vitis et al. 2020; Frischie et al. 2020; Kildisheva et al. 2020).

Similarly, seedling production in nurseries requires appropriate origin biological material (seeds and cuttings) to be sourced from natural populations, propagated in trays or pots for months or years, and kept alive until the restoration site is ready for planting.

Numerous studies and surveys across many countries have identified native seed and plant shortages as a major bottleneck for restoration (De Vitis et al. 2017; Pedrini & Dixon 2020; Gibson-Roy et al. 2021; National Academies of Sciences, Engineering, and Medicine 2023). If the market is unable to supply enough genetically appropriate material when needed (see Appendix 1), practitioners may need to exclude taxa, thus reducing seed mix diversity, substitute with alternative taxa (if available), leave gaps for later infilling, or delay seeding or planting.

Seed dormancy (or lack thereof) may pose challenges in sourcing usable biological material for restoration projects as well. Some projects, particularly in tropical and subtropical regions, may face challenges with lack of seed dormancy (i.e. seed is unable to be stored for greater than 6 months). In contrast, some biodiverse regions such as in Australian temperate ecosystems

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have high levels of deep, often intractable dormancy (unable to be germinated on demand, Merritt et al. 2007) with no reliable means for reinstating species that may be common and necessary in ecological restoration projects.

Build Reliable and Robust Supply Chains

Native plant programs from local to subnational or national scales are being developed to improve the availability of key species for ecological restoration in areas of varying ecological, social, and economic contexts around the world. In countries such as Germany or parts of the United States, where clear specifications on quality and provenance are provided (seed transfer zones), a robust market comprised of hundreds of local native plant material suppliers helps to ensure that material is available for species in greatest demand ("workhorse species"). This also allows for the needs of large scale projects to be met at competitive costs (Pedrini et al. 2023a). Other approaches, including community-based seed networks, such as those developed in Brazil, can ensure a steady supply of seeds and plant material while providing employment opportunities to rural and Indigenous communities (Urzedo et al. 2022).

If infrastructure such as propagation nurseries, native seed, and other regenerative unit collection programs, and production and storage facilities is already in place, biological material for restoration projects may be acquired on-demand in a timely and cost-effective manner. Unfortunately, in many countries, such systems are either underdeveloped or non-existent. In such cases, regulators and restoration practitioners need to design and implement strategies to support the development of reliable supplies of biological material.

While this approach may be lengthy, failure to do so would result in most restoration projects failing to address the bottleneck of biological material supply and would drastically reduce the number of species used or the scale of the project.

Planning and Managing Supplies

As a practitioner developing a restoration plan, determining the type and quantity of biological material needed and identifying who can supply it is a key priority. A supplier does not need to be a private company. Institutions such as seed banks, zoos, Indigenous communities and organizations, community-run nurseries, conservation volunteer groups, and research centers might have the necessary expertise and resources to source and multiply sufficient biological material. Whenever possible, especially on large projects, engaging with more than one supplier is advisable to spread the production risk and increase the chance of at least some material being available when needed.

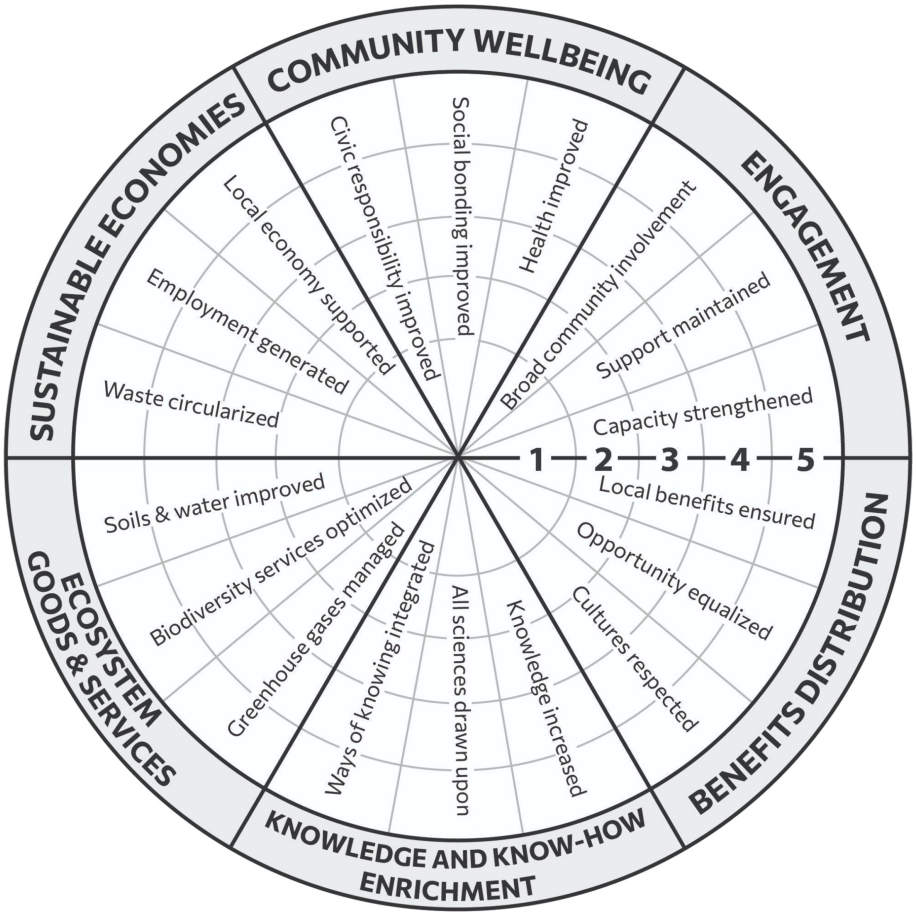
Realistic supply timelines are crucial and should be based on the supplier's ability to scale supply. As it can take years to obtain sufficient biological material, supply contracts should be secured early in the project. Moreover, some initially contracted taxa might prove too hard or impossible to supply during sourcing and production due to factors outside the supplier's control (lack of rain resulting in failed seed set). As such, a restoration plan should be adjusted to either replace the missing taxa or introduce them later in the project. Close collaboration and open discussion between practitioners and suppliers are critical for identifying realistic alternatives and solutions that allow projects to reach their ecological goals without compromising budgets.

In most cases, suppliers of biological materials are experts in the biota they supply, and their knowledge and insight can prove invaluable in supporting practitioners in the planning, implementation, monitoring, and management of restoration projects (see Principle 2). In the case of supplies from Indigenous communities and organizations, the expertise extends to traditional practices (medicinal and food plants) and cultural norms (totemic and cultural keystone species), which need to be understood and incorporated into the broader project plan. In these cases, the knowledge and expertise provided must be acknowledged and remunerated appropriately.

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Appendix 3

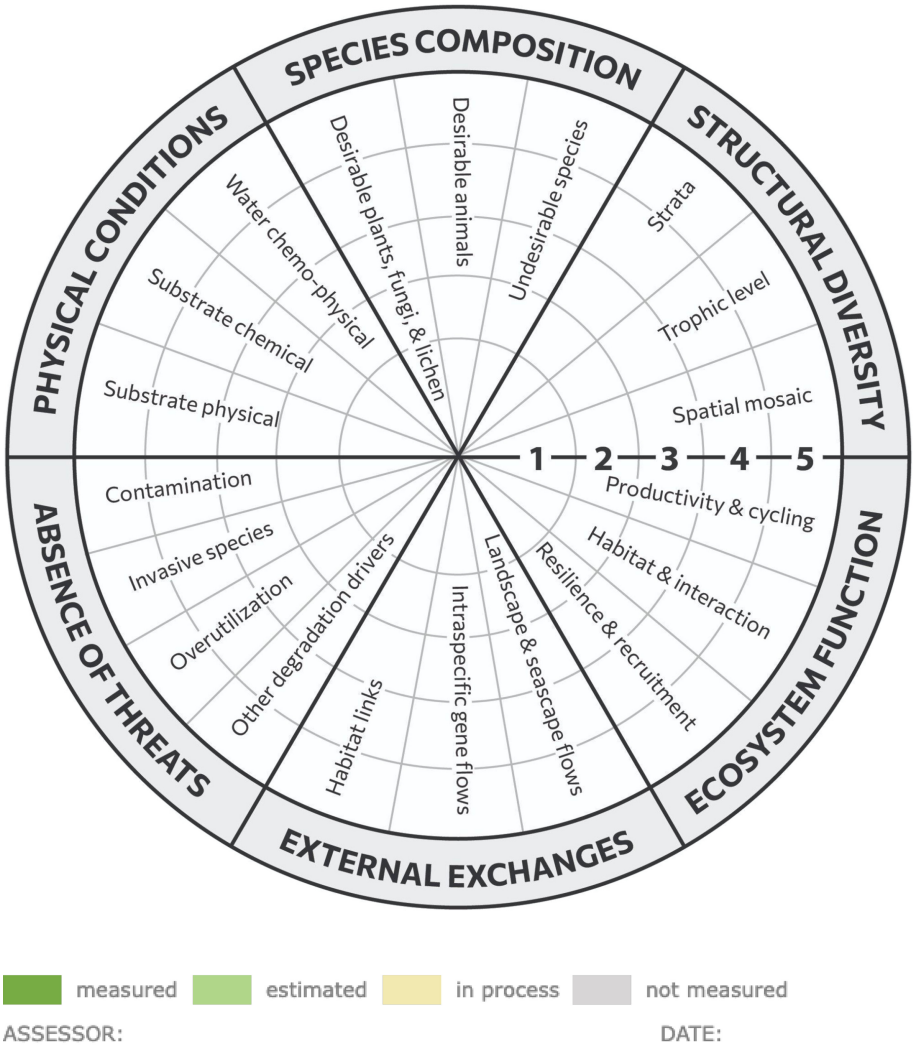
Blank Project Evaluation Templates



Social Benefits Wheel

Assessment phase: Baseline condition/Current condition/Project goals (select one)

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Ecological Recovery Wheel

Assessment phase: Baseline condition/Current condition/Project goals (select one)

Coordinating Editor: Valter Amaral

Received: 5 October, 2025; First decision: 18 December, 2025; Revised: 8 May, 2026; Accepted: 9 May, 2026

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