Using ecosystem risk assessment science for ecosystem restoration

A guide to applying the Red List of Ecosystems to ecosystem restoration

Marcos Valderrábano, Cara Nelson, Emily Nicholson, Andrés Etter, Josie Carwardine, James G. Hallett, James McBreen and Emily Botts

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Clearing of natural mangrove forests. Irrawaddy Delta, Burma. *Photo: NASA image by Robert Simmon, based on Landsat-7 data from the USGS Global Visualization Viewer.*

Executive summary

Global efforts for ecosystem restoration

Recent global initiatives in ecosystem restoration offer an unprecedented opportunity to improve biodiversity conservation and human health and well-being. In recognition of this opportunity, in 2021, the United Nations (UN) launched the Decade on Ecosystem Restoration. The Decade is a call for countries, practitioners, scientists, local and indigenous communities, and other stakeholders to work together to reverse ecosystem degradation and improve ecological integrity for generations to come.

Ecosystems form a core component of biodiversity. They provide humans with multiple benefits – a stable climate and breathable air; water, food and materials; and protection from disaster and disease. Ecosystem restoration, as defined by the UN Decade on Ecosystem Restoration, includes a range of management interventions that aim to reduce impacts on and assist in the recovery of ecosystems that have been damaged, degraded or destroyed. However, restoration projects and programmes are often implemented without strategic evaluation of the degree of urgency for restoration among ecosystem types.

As we expand our ambitions for restoration over the coming decade, and move to the restoration of entire ecosystems, landscapes and seascapes, the complexity of the questions we need to answer increases accordingly. This guide was developed to promote the application of the science of ecosystem risk assessment, which involves measuring the risk of ecosystem collapse, in ecosystem restoration (Figure 1). It explores how the IUCN Red List of Ecosystems and ecosystem restoration can be jointly deployed to reduce risk of ecosystem collapse.

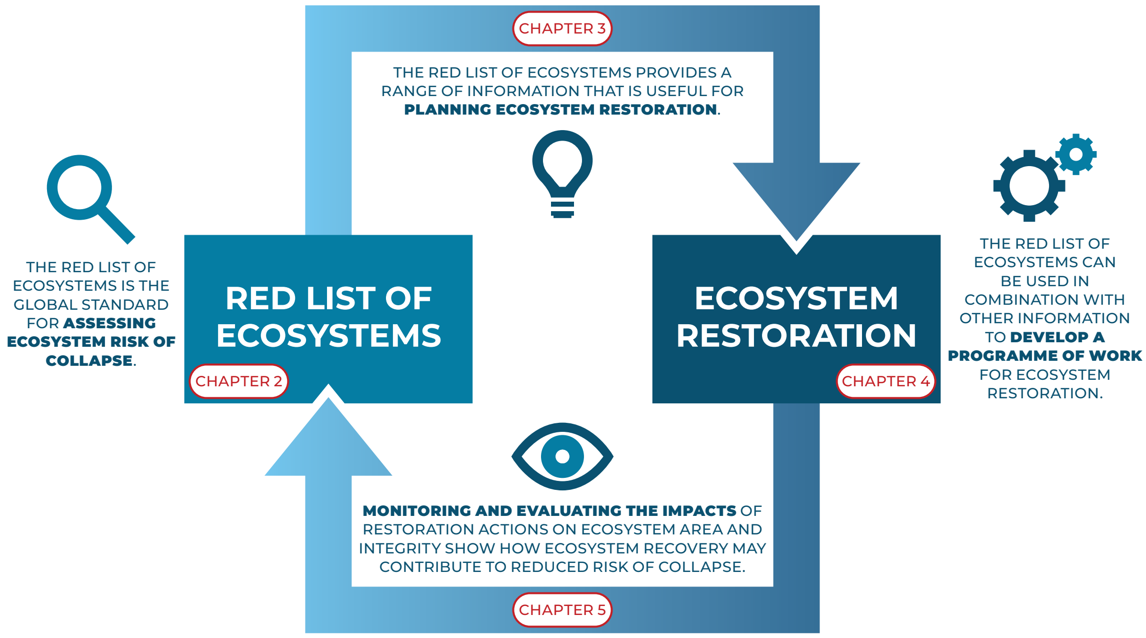

Figure 1: Overview of how to integrate ecosystem risk assessment into restoration projects and programmes, and how to use it to measure restoration progress. *Source: Compiled by the report authors.*

The Red List of Ecosystems is the global standard for ecosystem risk assessment

In 2014, IUCN formally adopted the Red List of Ecosystems as the global standard for ecosystem risk assessment. The Red List of Ecosystems assesses the risk of ecosystem collapse, which is the endpoint of ecosystem degradation and loss, where an ecosystem loses its defining features and identity. By mid-2019, over 2,800 ecosystems had been assessed in more than 100 countries and on all continents, with demonstrated impacts on conservation policy and practice.[11]

Ecosystem types are the unit of assessment in the Red List of Ecosystems. The assessment process brings together all relevant knowledge about the target ecosystem types, including spatial maps and time-series data for ecosystem features. One of the most important steps of an ecosystem assessment is to diagnose the cause of change and choose quantitative indicators that are most relevant to measuring change of the ecosystem.

The Red List of Ecosystems assesses the risk of collapse based on five criteria: A) change in ecosystem distribution; B) restricted distribution; degradation of C) the abiotic environment, or D) biotic processes; and E) the probability of ecosystem collapse estimated using a quantitative model. Ecosystems are placed in easy-to-understand categories of relative risk ranging from *Least Concern*, to *Critically Endangered*, and ultimately, *Collapsed*.

The Red List of Ecosystems informs restoration planning

The Red List of Ecosystems provides a wealth of data for restoration planning. The strengths of the Red List of Ecosystems for guiding strategic planning of ecosystem restoration are its structured framework to assess how risk is impacted by threatening processes, as well as the biophysical description and associated spatial datasets for each ecosystem type.

Preparing a Gnetum (okok) nursery. Lekié, Cameroon. *Photo: Ollivier Girard/CIFOR.*

There are two broad contexts through which the Red List of Ecosystems can be applied to identify where restoration needs to be carried out:

- **Areas where ecosystems have been lost** and replaced by different land cover, which require action to restore the ecosystem and increase ecosystem area, combined with the abatement of ongoing threats in those areas. The Red List of Ecosystems helps to identify areas where there has been historic or ongoing loss of the original distribution of an ecosystem type.

- **Degraded areas of remnant ecosystems**, which require restoration to improve ecosystem integrity, including the abatement of threats. The key information from the Red List of Ecosystems that is most useful in this process is an understanding of what threats affect the risk category of the ecosystem types and how.

The fundamental starting point to using the Red List of Ecosystems in restoration is the categorisation of ecosystem risk of collapse, since for any ecosystem restoration activity to be considered restorative, it must be implemented in an area that has been degraded. Thus, the increasing risk categories inform the urgency for ecosystem restoration. However, the most at-risk ecosystems, or all areas of an ecosystem at risk, may not all be equally sensible places to conduct restoration. As a result, additional information will need to be combined with the data from the Red List of Ecosystems, such as information on the costs, the social and technical feasibility of restoration, and the stakeholders' interests.

A now widely accepted approach for identifying restoration objectives, considering alternatives and evaluating them from the perspectives of different stakeholders is multi-criteria decision analysis. The Red List of Ecosystems can form part of the evidence-base for this analysis. In addition to ecosystem information, information can also be included on ecosystem goods and services, cost-effectiveness of different restoration strategies, and social and institutional considerations, to prioritise and assess the feasibility of different options. Multi-stakeholder participatory processes, such as the Restoration Opportunities Assessment Methodology (ROAM), allow collaboration among stakeholders, which is fundamental to develop a shared understanding of the value of restoration in multi-functional landscapes or seascapes.

From the perspective of the Red List of Ecosystems, restoration has two main outcomes: achieving the down-listing of an ecosystem to lower risk categories or preventing ecosystems from being up-listed to higher risk categories. Quantitative restoration targets can be set to achieve these outcomes, by increasing the area of an ecosystem and/or improving its ecological integrity.

The Red List of Ecosystems informs restoration action

Restoration activities are initiated according to the plan of work devised after stakeholder consultation, and the determination of resources and workforce available. The approaches to restoration will vary with type and degree of degradation. When remnants of native ecosystems exist, removal of threats may allow natural recovery of the ecosystem. This cost-effective approach may require some additional assistance, for example, in removal of weedy species. Severely degraded areas will require the greatest inputs of resources (for example, reintroduction of biota or soil amendments). Interventions can also be designed to abate threats to ecosystems and restore degraded processes. Restoration activities should be implemented following recognised standards of best practice, including achieving the highest level of restoration possible, applying adaptive management and considering post-implementation maintenance.

Little Karoo region. South Africa. *Photo: Jomilo75.*

The Red List of Ecosystems informs monitoring of restoration success

A monitoring programme will greatly assist in judging whether or not restoration has had a positive impact on ecosystem area, integrity and, ultimately, risk of collapse. To monitor whether restoration interventions are effective at achieving objectives, the objectives need to be clearly described, with specific measurable indicators that include the type and amount of change desired and a specified timeframe. The Red List of Ecosystems defines indicators for ecosystem types that are used to assess risk. The same indicators can be used to monitor the recovery of ecosystems over time in response to restoration activities.

There are three general types of monitoring that need to be done to optimise the use of ecosystem risk assessment for ecosystem restoration, determine the degree of project and programme success, and enable adaptive management. Each type addresses a different monitoring question:

- **Implementation monitoring** addresses the question of whether restoration activities were implemented as planned.
- **Efficacy monitoring** assesses the extent to which an area has been restored relative to the reference state or other pre-defined performance targets.
- **Effects monitoring** assesses the direct effects of the restoration activities on indicators of ecological integrity by comparing the magnitude of change (from before to after treatment) between treated and untreated control areas.

It is important to remember that the timeframe required to observe changes in risk of ecosystem collapse may be considerable. For this reason, despite recovery of multiple indicators of ecosystem integrity, it may take years or decades for an ecosystem to pass thresholds for different risk categories.

Ecosystem restoration is an experimental endeavour. Evidence for restoration effectiveness can be drawn from controlled trials and empirical monitoring that measures the relationship between restoration activities and improved ecosystem area and integrity.

However, wide-scale success in restoration will depend on the extent to which evidence from past projects is applied to ongoing and future ones. The recent development of internet platforms to share lessons learnt and best practices presents a powerful opportunity to advance understanding of restoration methods.

Conclusion

The vital need for restoration has coalesced into several global initiatives, notably the UN Decade on Ecosystem Restoration from 2021–2030. Ecosystem restoration is gaining an ever-increasing part in building a sustainable future, and it is likely to guide priorities for years to come. Ecosystem risk assessment science provides a wealth of information that is useful across the entire cycle of a restoration project or programme, from building knowledge, through planning and decision making, to implementation on the ground, monitoring and learning, and finally, in global, national and regional policy.

Coral reef and mangroves. Raja Ampat, Indonesia. *Photo: Alex Mustard/Ocean Image Bank.*

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List of acronyms and abbreviations

AOO	Area of Occupancy
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
CO	Collapsed
CR	Critically Endangered
DD	Data Deficient
EN	Endangered
EOO	Extent of Occurrence
FAO	Food and Agriculture Organization of the United Nations
FLR	Forest and Landscape Restoration
GDP	Gross Domestic Product
ICRAF	World Agroforestry
ICRI	International Coral Reef Initiative
IKI	International Climate Initiative
IPBES	Intergovernmental Panel on Biodiversity and Ecosystem Services
IUCN	International Union for Conservation of Nature
LC	Least Concern
NE	Not Evaluated
NT	Near Threatened
PRAGA	Participatory Rangeland and Grassland Assessment
PTM	Priority Threat Management
RCC	Restoration Resource Centre
REDD+	Reducing Emissions from Deforestation and forest Degradation
RLE	Red List of Ecosystems
ROAM	Restoration Opportunities Assessment Methodology
SANBI	South African National Biodiversity Institute
SEEA EA	System for Environmental Economic Accounting – Ecosystem Assessment
SER	Society for Ecological Restoration
STAR	Species Threat Abatement and Recovery
TNC	The Nature Conservancy
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UKCEH	UK Centre for Ecology and Hydrology
UNEP	United Nations Environment Programme
UNEP-WCMC	United Nations Environment Programme World Conservation Monitoring Centre
UNFCCC	United Nations Framework Convention on Climate Change
VU	Vulnerable
WCS	Wildlife Conservation Society
WOCAT	World Overview of Conservation Approaches and Technologies

Rocky Mountain National Park, Colorado, United States. *Photo: Kent Kanouse*.

Chapter 1: **Introduction to applying ecosystem risk assessment to ecosystem restoration**

Marcos Valderrábano, IUCN
Cara Nelson, University of Montana and IUCN Commission on Ecosystem Management

This guide was developed to promote the use of ecosystem risk assessment science in ecosystem restoration. Ecosystem restoration is now a dominant conservation activity across the globe. As defined by the UN Decade on Ecosystem Restoration, it includes a range of management interventions that all aim to improve environmental condition, reverse ecosystem degradation, enhance adaptation to climate change and improve human well-being.[34] Recent ambitious global initiatives in ecosystem restoration offer an unprecedented opportunity to improve ecological integrity, and associated human health and well-being.

Repairing degraded ecosystems is, however, a complex task that requires a strategic agenda. Part of that agenda involves deploying restorative activities in the ecosystems that are most in need of restoration. Despite this, restoration planning to date has often been done without consideration of the degree of ecosystem risk. Including ecosystem risk assessment in restoration planning would allow practitioners to explicitly consider the degree of risk to different ecosystems in their evaluation of restoration opportunities. One increasingly utilised tool for ecosystem risk assessment is the IUCN Red List of Ecosystems, a standardised global approach to assess the ecosystems at greatest risk of collapse. A Red List of Ecosystems assessment illuminates the areas where reducing risks to threatened ecosystems is a priority, and which may have the greatest need for ecosystem restoration. The Red List of Ecosystems can provide a range of valuable information for planning where to implement restoration activities and monitoring restoration impacts.

This guide explores how ecosystem risk assessment science and ecosystem restoration can be jointly deployed to reduce the risk of ecosystem collapse. Specifically, it demonstrates why it is essential to include ecosystem risk assessment when planning ecosystem restoration projects and programmes, and how to integrate the Red List of Ecosystems into spatial planning exercises. It also explores moving from planning to restoration action, where monitoring can use the Red List of Ecosystems indicators to evaluate the extent to which ecosystem restoration can contribute to reducing the risk of ecosystem collapse.

A global agenda for ecosystem restoration

The UN Decade on Ecosystem Restoration views **ecosystem restoration** as involving a wide range of actions from removing threats in production landscapes or seascapes (remediation) to partially or fully recovering native ecosystems (*ecological restoration*). It is an expansion of the field of *ecological restoration*, which has been recognised as a distinct field of practice since the mid-1980s. *Ecological restoration* projects in the early years were mainly done at small spatial scales, focusing on recovering native ecosystems and initially grounded in plant community ecology and soil science, among other disciplines. In just a few decades, however, the potential for restoration to repair degraded ecosystems led to a global movement (Box 1). Restoration initiatives grew from small local projects to programmes aimed at restoring millions of hectares to recover biodiversity, ecological integrity and human well-being. Accordingly, restoration practice is grounded not just in the science of restoration ecology, but also in conservation biology and landscape ecology.

As interest in repairing degraded ecosystems has grown, the term 'restoration' has been used in global initiatives to refer to a wide range of management activities beyond *ecological restoration*. *Ecological restoration* is a well-defined practice that aims to remove degradation and assist in recovering an ecosystem to the trajectory it would be on if degradation had not occurred, accounting for environmental change.[34] In contrast, **ecosystem restoration,** as currently defined by the UN Decade on Ecosystem Restoration, is much broader and refers to a wide range of management actions, from reducing societal impacts on ecosystems to partially or fully recovering native ecosystems through *ecological restoration*.[86]

Halting ecosystem degradation, and reversing the global trend that is moving many ecosystems to the edge of collapse, is a massive task of unprecedented dimensions. Structuring a transformative agenda that can support ecosystem restoration requires significant political will.

The period between 2021 and 2030 has been identified as the UN Decade on Ecosystem Restoration. It is a call for countries, practitioners, scientists, local and indigenous communities, and other stakeholders to work together to reverse ecosystem decline and degradation. Mechanisms for knowledge exchange have been put in place to foster shared learning among restoration practitioners from different countries. The end of the Decade in 2030 also coincides with the deadline to fulfil the Sustainable Development Goals. A concerted effort towards restoration will help to achieve the goals through the human benefits that arise from restored ecosystems that function and provide services.

As restoration gradually increases its scale of ambition from individual sites to synergistic plans to repair ecosystem types, and is integrated into public policies for spatial planning, it becomes necessary to consider ecosystem dynamics and trends. The information from ecosystem risk assessment is then an essential part of ecosystem restoration planning and monitoring.

Box 1: Global ecosystem restoration initiatives

The UN Decade on Ecosystem Restoration is an umbrella initiative, under which many other global restoration initiatives can be aligned and coordinated. Key restoration-relevant initiatives at the global scale are listed below:

The **Sustainable Development Goals** (SDGs) are part of the 2030 Agenda for Sustainable Development adopted by the 193 member states of the United Nations. They are a call "to end poverty, protect the planet and improve the lives and prospects of everyone, everywhere". Preventing ecosystem degradation and undertaking ecosystem restoration are essential to achieving these goals.[85]

The **Global Biodiversity Framework** is the strategic plan of the Convention on Biological Diversity. It envisions a world where "biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people".[19] Ecosystem restoration will contribute to meeting many of the Global Biodiversity Framework's targets for 2030.

The **Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services** (IPBES) is an intergovernmental body established to assess the state of biodiversity and of the ecosystem services it provides to society. Its assessment reports recognise that land, freshwater and marine degradation are pervasive across the globe and that restoration is an urgent priority to protect biodiversity and ecosystem services.[39,40]

The **Bonn Challenge** is a global goal to bring 350 million hectares of degraded and deforested landscapes into restoration by 2030. Since its launch in 2011, 61 nations, eight states and five associations have taken up the Bonn Challenge, committing more than 210 million hectares to the world's largest Forest and Landscape Restoration initiative and forging ahead with restoration planning and implementation.

The **United Nations Convention to Combat Desertification** (UNCCD) is the sole legally binding international agreement linking environment and development to sustainable land management. Its current Strategic Framework is heavily engaged with Land Degradation Neutrality in order to restore the productivity of vast expanses of degraded land.

The **Paris Agreement** is an agreement under the United Nations Framework Convention on Climate Change (UNFCCC) to limit global warming to well below 2°C, preferably to 1.5°C, compared to pre-industrial levels. Protecting and restoring ecosystems can contribute significantly to climate change mitigation and adaptation.

Reducing Emissions from Deforestation and forest Degradation (REDD+) is a mechanism for climate change mitigation that offers incentives to developing countries that reduce carbon emissions from deforestation and forest degradation. Efforts to reduce degradation and restore forested landscapes can have benefits beyond climate change mitigation.

The **International Blue Carbon Initiative** is "a coordinated, global program focused on mitigating climate change through the conservation and restoration of coastal and marine ecosystems". It recognises that coastal ecosystems like mangroves, tidal marshes and seagrasses are vital for providing many ecosystem services. The initiative supports research, policy and restoration activities in 'blue carbon' ecosystems.

In addition to ambitious global initiatives, there are numerous **regional initiatives**, like the Great Green Wall, an African-led movement across the entire width of Africa, and ecosystem specific initiatives like the Global Mangrove Alliance, which intends to increase the surface of mangroves by 20% by 2030.

What is an ecosystem?

Biodiversity is "the variability among living organisms from all sources including, inter alia, 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".[17]

Biodiversity can be understood as a hierarchy, with a number of different levels of organisation, ranging from entire landscapes or seascapes, to species, populations and genes (Figure 2). Ecosystems form one level of this hierarchy.

At each level, biodiversity can have attributes of composition (the identity and variety of elements), structure (the patterns of physical organisation) and function (ecological processes and nutrient cycles).

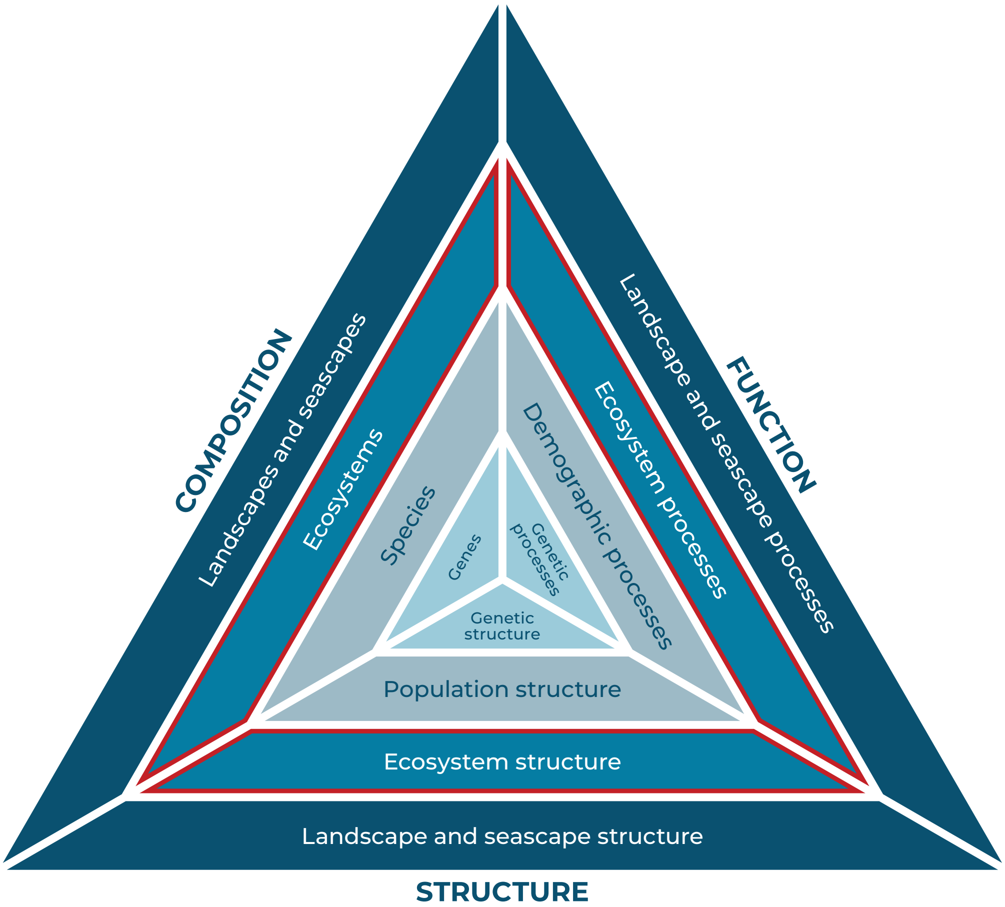

Figure 2: Biodiversity can be understood as a hierarchy of levels of organisation, each with attributes of composition, structure and function. Ecosystems are one level of the hierarchy.
Source: Modified after Dale and Beyeler (2001).[22]

Ecosystems are made up of living components (assemblages of species and biotic complexes), the abiotic environment, the processes and interactions within and between the biotic and abiotic, and the physical space in which these operate.[10,46]

Ecosystems form a core component of biodiversity. They provide habitat to the rich diversity of life on Earth and support complex interactions among species. They also provide many contributions to human health and well-being. Ecosystems are vital to our physical health, by providing an essential diet of nutritious foods, supplying a significant proportion of global medicinal resources, regulating pollutants in air and water, and controlling disease vectors.[40] Intact ecosystems are also important for our mental health, by providing opportunities for recreation, learning and inspiration, granting a sense of place, and giving expression to cultural values and identity.[40] Despite their importance to people and nature, anthropogenic factors have led to substantial ecosystem degradation across landscapes and seascapes. Following from this widespread degradation is an inevitable decline in the contributions that people receive from ecosystems, which threatens human quality of life.[40]

Ecosystem integrity is the degree to which an ecosystem's physical condition, composition, structure and function are intact (that is, have not been degraded). Measuring ecosystem integrity is complex and requires understanding the range of states an ecosystem would have been in had degradation not occurred (see Context for ecosystem restoration). Assessments of ecological integrity should ideally be based on a sufficient number of indicators of physical condition, composition, structure and function. The inverse of ecosystem integrity is ecosystem degradation.

Ecosystem integrity varies greatly across landscapes and seascapes, from ecosystems with high integrity in wilderness areas, to completely transformed systems in areas, such as cities, where little of the natural ecosystem remains.[69] Between these two extremes are a wide range of 'managed ecosystems' which are transformed in different ways and to varying degrees. These include agricultural landscapes, freshwater diversions and utilised seascapes. In managed ecosystems, ecosystem functioning continues to provide benefits to people, such as forage for livestock, water supply, pollination, fish nurseries and much more. The aim of restorative management activities in these areas may not be to fully recover a native ecosystem, but rather to achieve a sustainable balance between ecosystem integrity, human well-being and climate change adaptation.[69]

Tea Plantation. Ren'ai, Taiwan. *Photo: Metamorfa Studio.*

Assessing risk of ecosystem collapse is critical for ecosystem restoration

Ecosystems across Earth are being degraded and some have completely collapsed or disappeared, challenging attainment of the Sustainable Development Goals. In the face of widespread anthropogenic impacts, restoration has become an essential tool for natural resource management and to mitigate negative effects of land use and climate change. The core aim of ecosystem restoration is to guide the repair of degraded ecosystems and avoid further decline. Yet, despite this goal, restoration projects and programmes are often implemented without strategic evaluation of the degree of urgency for restoration among ecosystem types.

To assess risk – the probability of an adverse outcome over a specified time frame – it is necessary to specify the adverse outcome.[11] For species risk assessment, this is extinction, which is the loss of the last individual of a species. For ecosystems, it is the risk of ecosystem collapse.

Ecosystem collapse is the endpoint of ecosystem degradation and loss, where an ecosystem loses its defining features and identity, and is replaced by a different ecosystem type.

Risk assessment science deals with the methodologies and protocols for measuring risk. In this guide, ecosystem risk assessment refers specifically to the risk of ecosystem collapse, and should not be confused with 'risk' in other contexts, such as financial risk or project risk.

The **IUCN Red List of Ecosystems** is a tool for assessing the risk of ecosystem collapse. Like extinction of a species, collapse of an ecosystem means the loss of Earth's biodiversity. Some ecosystems are disproportionately impacted, resulting in higher risk of collapse. These highly threatened 'at risk' ecosystems may, in some cases, be obvious targets for ecosystem restoration. The Red List of Ecosystems is a useful tool to assess ecosystem risk, and examine the underlying causes of that risk. Consideration of ecosystem risk, when fully included into the restoration process, can provide valuable information to support spatial planning and monitor restoration activities.

Ecosystem restoration seeks to overcome the negative consequences of anthropogenic degradation, and enhance ecosystem integrity. The Red List of Ecosystems is based on an understanding of those intrinsic processes, and evaluating past and future trends to determine risk. As a result, the Red List of Ecosystems makes it possible to adapt restoration responses to specific degradation pathways, according to the nature of the degradation. Habitat loss and fragmentation, changes in abiotic conditions, or modification of biotic processes within an ecosystem, will require different restoration responses. The analysis of ecosystem-wide temporal trends provided by the Red List of Ecosystems helps to set up restoration goals and targets, as well as monitor the impact of restoration activities in reducing ecosystem risk.

Stark contrast between the forest and agricultural landscapes. Rio Branco, Acre, Brazil. *Photo: Kate Evans/CIFOR.*

What is ecosystem restoration?

Ecosystem restoration is defined as "the process of halting and reversing degradation, resulting in improved ecosystem services and recovered biodiversity. Ecosystem restoration encompasses a wide continuum of practices, depending on local conditions and societal choice."[84]

Ecosystem restoration differs from *ecological restoration* in that it refers to a broader array of management interventions aimed at ecosystem repair that fall along a restorative continuum (Figure 3). One end of this continuum includes management activities aimed at reducing societal impacts, such as runoff into urban streams, and mitigating threats such as contaminated soils. The other end of the continuum includes *ecological restoration*, a management practice that aims to not just remove degradation but also to assist in recovering an ecosystem to the trajectory it would be on if degradation had not occurred, accounting for environmental change.

The Red List of Ecosystems is helpful in supporting the recovery of native ecosystems, or in guiding the repair of ecosystem functions (Figure 3), for example in production areas where restorative activities can be prioritised to improve ecosystem integrity. However, since the Red List of Ecosystems has a biodiversity focus, it has some limitations to address ecosystem restoration in very artificial systems where it should be complemented with other tools. Ecosystem restoration can be used to improve the integrity of degraded areas, which can lead to an overall increase in ecosystem area.

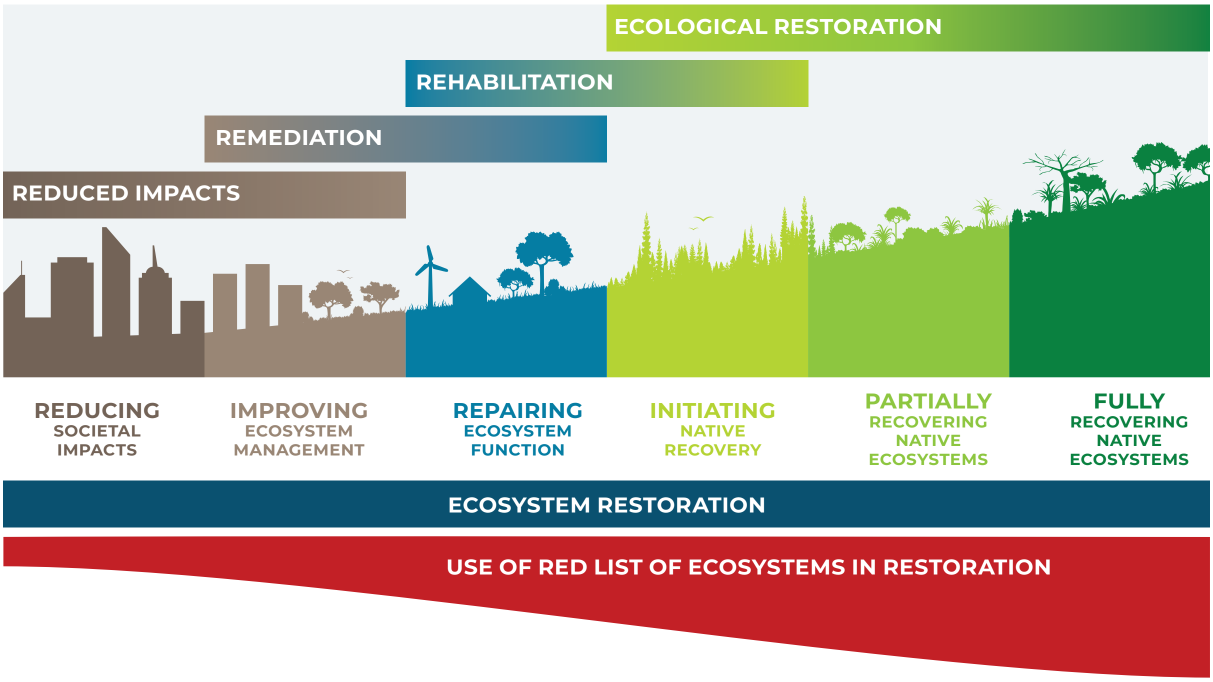

Figure 3: Ecosystem restoration includes a continuum of restorative activities from reducing societal impacts, such as contaminants, to repairing ecosystem function in areas managed to produce goods and services, to full recovery through ecological restoration. This diagram does not imply a linear pathway of restoration, instead it visualises the different types of restoration activities across a continuum. Since the Red List of Ecosystems has a biodiversity focus, it has greater relevance to repairing ecosystem function and recovering native ecosystems (right side of continuum). *Source: Modified after Gann et al. (2019).*[34]

Box 2: The principles of ecosystem restoration

Principle 1. Ecosystem restoration contributes to the UN Sustainable Development Goals and the goals of the Rio Conventions.

Principle 2. Ecosystem restoration promotes inclusive and participatory governance, social fairness and equity from the start and throughout the process and outcomes.

Principle 3. Ecosystem restoration includes a continuum of restorative activities.

Principle 4. Ecosystem restoration aims to achieve the highest level of recovery for biodiversity, ecosystem health and integrity, and human well-being.

Principle 5. Ecosystem restoration addresses the direct and indirect causes of ecosystem degradation.

Principle 6. Ecosystem restoration incorporates all types of knowledge and promotes their exchange and integration throughout the process.

Principle 7. Ecosystem restoration is based on well-defined short-, medium- and long-term ecological, cultural, and socio-economic objectives and goals.

Principle 8. Ecosystem restoration is tailored to the local ecological, cultural, and socio-economic contexts, while considering the larger landscape or seascape.

Principle 9. Ecosystem restoration includes monitoring, evaluation, and adaptive management throughout and beyond the lifetime of the project or programme.

Principle 10. Ecosystem restoration is enabled by policies and measures that promote its long-term progress, fostering replication and scaling up.

Source: FAO, IUCN CEM & SER (2021).[33]

The global community agreed, in September 2021, on the principles for ecosystem restoration (Box 2), recognising the valuable contribution it can make to global goals (Principle 1). These principles create a shared vision of the types of activities that fall along a restorative continuum (Principle 3). Importantly, ecosystem restoration activities must include participatory governance, and result in social fairness and equity (Principle 2), and be based on all types of knowledge (Principle 6). Ecosystem restoration activities must strive to achieve the highest level of recovery possible for both ecosystem integrity and human well-being (Principle 4). This means

Tehuacán-Cuicatlán Valley. Puebla and Oaxaca, Mexico. *Photo: IUCN/Thora Amend.*

that ecosystem restoration must address the drivers of degradation (Principle 5) and result in net gain for biodiversity, ecosystems and people.

The planning of ecosystem restoration must include measurable objectives and long-term goals (Principle 7). These objectives and goals must be detailed enough to allow for monitoring and evaluation of project success, and ultimately adaptive management (Principle 9). Ecosystem restoration projects and programmes can be undertaken at scales ranging from less than a hectare to large landscapes or seascapes. Regardless of size, however, both the local and broader context must be considered in project planning and evaluation (Principle 8). Finally, ecosystem restoration requires scaling-up interventions up, to ensure that in the long term, successful practices have a broad influence and that relevant policies and measures are mapped, adopted and integrated (Principle 10).

In addition to conserving biodiversity, ecosystem restoration is also an important way to regain the many benefits that people receive from functioning ecosystems. It has significant potential to contribute to Nature-based Solutions (NbS) for societal challenges, including mitigation and adaptation to climate change (Box 3). Restoration is also playing an increasingly important role in mitigating impacts of development (Box 4).

Box 3: Restoration – A pathway for achieving Nature-based Solutions

Restoration is one of the three pathways for achieving Nature-based Solutions (NbS) for societal challenges, as stated in its definition – "actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits".[15] The core of NbS is to provide solutions to address today's major societal challenges, while using ecosystems and the services they provide. NbS will result in benefits for both biodiversity and for human well-being. Importantly, while restoration can be a means to improving a wide range of ecosystem services, it can only contribute to reducing ecosystem risk of collapse under the Red List of Ecosystems if the restoration approach aligns with the Ecosystem Approach[78] and aims to recover native biodiversity and ecosystem integrity.[79,91]

Forest and Landscape Restoration (FLR) is an example of an NbS that aims to revive ecosystem function as well as enable ecosystem services to be derived. Work done through The Bonn Challenge[23] and other large-scale restoration efforts have documented such human well-being benefits – employment creation, food security through increased yields and diversification, reduced siltation of waterways, adapting to climate change and sequestering carbon. In order to minimise trade-offs between biodiversity, climate change responses and human well-being benefits, FLR should employ sound biogeographic science, grounded in the Red List of Ecosystems.[79,91]

Restoration for NbS has also been a post-disaster response, for future risk reduction. Following Hurricane Katrina, the United States Congress approved US$ 500 million for the restoration of its coastal national parks and salt marshes, following evidence that these features had mitigated the damage.[65] Similarly, the Government of Japan prioritised the expansion of its coastal forests, in the form of the Sanriku Fukko Reconstruction Park, as these forests had helped reduce the impacts of the tsunami caused by the Great East Japan Earthquake in 2011.[72] Restoration will be critical to the success of NbS, and NbS provides the opportunity to mobilise large-scale, long-term restoration opportunities for addressing biodiversity, climate change and human development needs.

Source: Andrade et al. (2020).[3]

Jean Lafitte National Historic Park and Preserve (JELA NHPP) after Hurricane Katrina. Louisiana, United States. *Photo: GULN/NPS*.

Box 4: Restoration as part of the mitigation hierarchy

Restoration is part of the four main elements in the mitigation hierarchy, whereby the biodiversity impacts from development should first be (1) avoided, then (2) minimised, before considering options to (3) restore, or then (4) offset.[83] Impacts of development that cannot be avoided or minimised may thus be remedied through restoration. The aim is often to return areas that have been impacted to a functioning natural state, although the complexity of biodiversity can seldom be fully restored. The increasingly stringent use of the mitigation hierarchy in international performance standards and by development funders means that rehabilitation efforts are escalating.

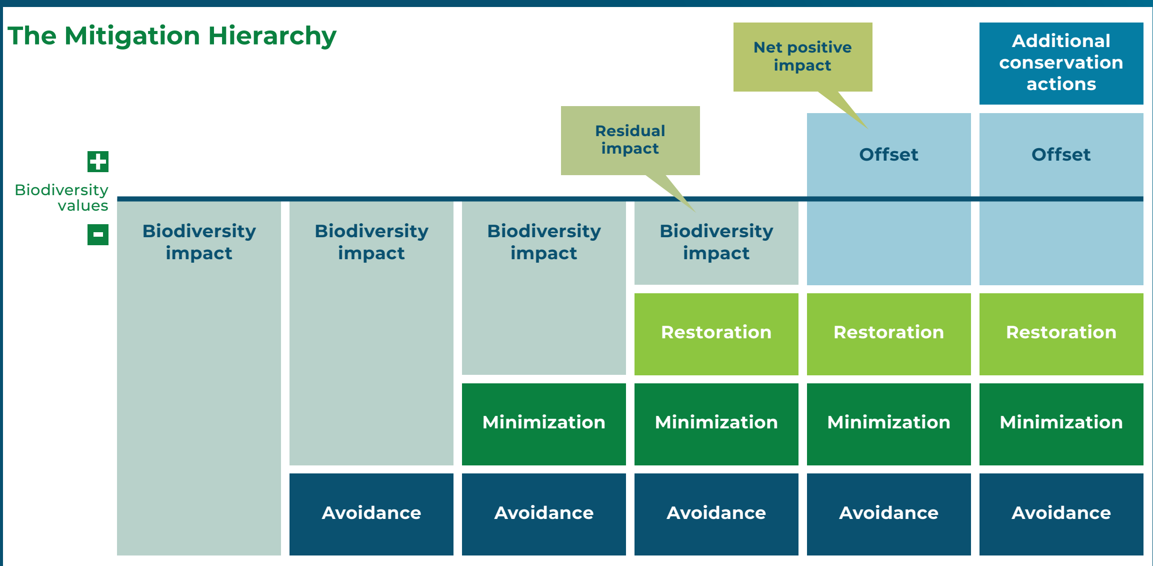

Figure 4: Restoration is one of the four main elements of the mitigation hierarchy. *Source: Modified after UN Global compact and IUCN (2012).[83]*

Context for ecosystem restoration

The **reference state** defines the condition that an ecosystem would be in if degradation had not occurred, accounting for environmental change.[34] It describes the physical condition, biota, functions and the interactions between these. In ecosystems where local or traditional human uses are part of the system (such as cultural landscapes), the reference state may include a specific intensity of human pressure.[34]

Given that ecosystem restoration aims to reverse degradation, a key step in planning is to determine the reference state.

Reference states are identified through the development of reference models (Box 5). Because ecosystems are dynamic and can follow more than one pathway of change, often with multiple alternative states, it is sometimes necessary to identify multiple alternative reference states and models.[34] Reference states and models are used to measure the degree of degradation, set restoration goals and evaluate project success. However, depending on the type of ecosystem restoration activity being implemented, the goal may not be to achieve the reference state.

Box 5: Developing a reference model

Developing a reference model is complex, in large part because ecosystems are highly dynamic over time. Given continual changes in climate and biophysical conditions, the condition of current ecosystems – even those that have experienced minimal anthropogenic degradation – deviate from historic ones.[59] Increasing recognition that change is an inherent characteristic of all ecosystems has underscored the fact that restoration should not aim to hold ecosystems stable at any prior point in time.[37,34] Rather, it should remove degradation and allow the system to recover within current biophysical envelopes. Thus, reference models for ecosystem restoration should not be based on historic condition but rather should approximate the condition that the project site would be in if degradation had not occurred, accounting for environmental change.[57,34] This condition is best modelled through the use of modern analogues – contemporary sites that are similar to the project site but that are still relatively intact.[34] In semi-natural or cultural ecosystems, the reference state would include human modifications of ecosystems that are not considered as having adverse ecological consequences.

Ecosystems are comprised of both biotic and abiotic components that interact in complex ways.[47] This means that reference models will not adequately describe the target ecosystem unless they include a wide enough array of metrics to measure ecosystem integrity. An exact determination of how much complexity is enough may not be possible.[48] Best practice is to include at least several metrics each of physical condition, composition, structure and function[35] at both the ecosystem and landscape or seascape scale.[34,94]

Because no two sites are exactly identical, even if they fall within the same ecosystem type, it is necessary to include multiple reference sites when developing reference models. Due to the high rates of degradation, there are many ecosystems for which a suitable number of reference sites, or even a single one, may not be available. In these cases, managers need to be creative in assembling a reference model based on all sources of available information and successional models. Because of the inherent uncertainties of determining reference conditions, the best models will combine data from multiple sources with best professional judgment to determine the approximate ecological trajectory of the system, if it had not been degraded, damaged or destroyed.[34]

Appalachian Mountain stream, USA. *Photo: Samuel H Austin, Virginia Water Science Center.*

The term **landscape** or **seascape** can be used differently in ecological and management contexts. From an ecological perspective, a landscape or seascape is an area composed of multiple interacting ecosystems. Landscapes and seascapes have the following elements: composition, which refers to the type and abundance of ecosystems of which they are composed; structure, which refers to the spatial arrangement of ecosystems, patches and connectivity; and function, which refers to the flows of energy, nutrients and biomass among patches (Figure 2). In contrast, for management purposes, landscape or seascape is often used interchangeably with large spatial scale where a spatial planning process occurs. In this sense, planning landscapes or seascapes may be defined by administrative boundaries, from the scale of national jurisdiction to provinces or villages, and as such could sometimes be relatively homogenous in their distribution of ecosystems.

Ecosystem restoration involves levels of the biological hierarchy above the ecosystem scale and specifically an explicit consideration of composition, structure and function at the landscape or seascape scale (see Figure 2).[98] Restoring functions, flows of energy, nutrients and other subsidies through the landscape or seascape may be as, or more, important than restoring composition and structure, especially for the delivery of ecosystem services.

Understanding the landscape or seascape context is essential to prioritise where, what, how and with whom to implement restoration, including types of management actions needed. For instance, in some cases, proximity of the project site to remnant intact ecosystems can indicate whether propagule sources are available for natural regeneration or whether active reintroduction is required.[28] The landscape context must also be considered in evaluating the feasibility of restoration success, since if threats from the larger landscape, as well as connectivity and habitat fragmentation, are not addressed restoration investments will be short lived. Similarly, the effects of some restorative activities, such as reducing sedimentation into aquatic systems, can only be evaluated at the landscape scale.

Purpose and structure of this guide

As we expand our ambitions for restoration over the coming decade, and move from local sites to the restoration of entire ecosystems, landscapes and seascapes, the complexity of the questions we need to answer increases accordingly. In a world with limited resources, it is now vital to carefully plan restoration priorities, define restoration targets and measure progress.

This guide provides restoration planners, practitioners and decision makers with a comprehensive overview of how to integrate ecosystem risk assessment into restoration projects and programmes, and how to use it to measure restoration progress (see Figure 1). The information will also prove useful for funders, spatial planners or technical advisors in deciding spatial priorities for restoration across terrestrial, freshwater and marine ecosystems.

Releasing coral larvae onto sections of Wistari Reef off Heron Island. Queensland, Australia. *Photo: Southern Cross University.*

The key questions that this publication aims to address are:

Which ecosystems are most at risk and why? The Red List of Ecosystems is a scientifically robust, transparent, evidence-based tool for assessing the risk of ecosystem collapse, and the consequent loss of biodiversity and ecosystem services. It enables integration of ecosystem dynamics into decision-making tools.	**Chapter 2** provides a basic overview of the Red List of Ecosystems and the methods for assessing ecosystem risk based on the Red List of Ecosystems categories and criteria.
Which ecosystems should be a focus for restoration? It is essential to understand the root causes of ecosystem risk, and to use that understanding to determine which types of ecosystems are most in need of ecosystem restoration.	
What changes can be achieved through restoration? Setting targets at ecosystem level, that reflect what changes are intended through restoration, is essential for subsequent monitoring and evaluation.	**Chapter 3** explores how the Red List of Ecosystems, coupled with other information through multi-criteria analysis, can support the analysis of opportunities for addressing ecosystem risks and identify strategic priorities for restoration.
Where should restoration be prioritised in the landscape or seascape? Once ecosystem-level targets have been determined, it is now necessary to decide where to act within the landscape or seascape. Competing land uses, local views from a wide range of stakeholders and spatial patterns make the planning process especially complex, with potential conflicts. A participatory process, such as the Restoration Opportunities Assessment Methodology (ROAM), can engage with decision makers and stakeholders in identifying where and how to implement restoration.	
What types of restoration activity would be most effective depending on the context? The type of restoration activities that will be more effective will depend on local context, in terms of both local species, and human presence and cultural practices. It is not the intention of this publication to provide detailed guidance on what restoration activities to conduct in each context, but rather to highlight the types of restoration activities that may be appropriate to achieve the highest level of recovery possible for ecosystem health and human well-being.	**Chapter 4** covers how to integrate information from the Red List of Ecosystems into the implementation of restoration action on the ground.
How should success and progress be measured? Because all restoration activities are experimental, monitoring and evaluation are necessary to assess their efficacy and effects. This includes assessing the efficacy of the spatial prioritisation process, as well as the effects of the restoration activities themselves in increasing ecosystem area, improving ecosystem integrity and decreasing risk of collapse.	**Chapter 5** considers the processes for monitoring and evaluating restoration progress, and the ways in which the Red List of Ecosystems can be used to measure and report on ecosystem recovery due to restoration activities.

Further reading:

Becoming #GenerationRestoration: Ecosystem restoration for people, nature and climate.[86] https://www.unep.org/resources/ecosystem-restoration-people-nature-climate

International principles and standards for the practice of ecological restoration.[34] https://onlinelibrary.wiley.com/doi/10.1111/rec.13035

IUCN global standard for Nature-based Solutions.[3] https://www.iucn.org/theme/nature-based-solutions/resources/iucn-global-standard-nbs

Jodogahama beach. Iwate, Japan. *Photo: KO-TORI.*

Chapter 2: **Identifying which ecosystems are most at risk using the IUCN Red List of Ecosystems**

Emily Nicholson, Deakin University

This chapter presents an overview of the methodology used to assess ecosystem risk of collapse using the IUCN Red List of Ecosystems. It summarises the assessment process, data needs, the criteria and how risk categories are assigned.

Introduction to the Red List of Ecosystems

The IUCN Red List of Ecosystems is the global standard for ecosystem risk assessment. The Red List of Ecosystems addresses risks to biodiversity at the ecosystem level, rather than for individual species (as in the IUCN Red List of Threatened Species™). The Red List of Ecosystems uses criteria to place ecosystems in a category of relative risk that is meaningful and easy to understand. The five criteria assess:
A) change in ecosystem distribution;
B) restricted distribution;
C) degradation of the abiotic environment;
D) disruption of biotic processes; and
E) the probability of ecosystem collapse estimated using a quantitative model.
The Red List of Ecosystems can be applied to any ecosystem across marine, terrestrial and freshwater realms.

The Red List of Ecosystems was developed in response to a need for a global standard for ecosystem risk assessment. During the 1990s and early 2000s, many countries, non-governmental organisations and researchers were developing their own approaches to ecosystem risk assessment to support legislation, planning and conservation priorities.[66] The scientific basis for a Red List of Ecosystems was published in 2013,[46] and in 2014, IUCN formally adopted the Red List of Ecosystems as the global standard for ecosystem risk assessment. Since then, there has been wide uptake of the Red List of Ecosystems across conservation, non-government and research communities. Likewise, many countries have integrated the Red List of Ecosystems into their legislative, regulatory and policy frameworks. By mid-2019, over 2,800 ecosystems had been assessed in more than 100 countries and on all continents, with demonstrated impacts on conservation policy and practice.[11] Uses of the Red List of Ecosystems include legislation, land-use planning, protected area management, monitoring and reporting, ecosystem restoration, and management.[11,1]

A diverse range of tools are available to support Red List of Ecosystems assessments, including guidelines, a growing set of case studies from around the world (and associated community of practitioners), technical tools to support data analysis, and training materials (including free online courses). The Red List of Ecosystems database holds many of the ecosystem assessments, including strategic and systematic assessments at global and sub-global levels. These resources are available through the Red List of Ecosystems website.

The Red List of Ecosystems assessment process

The assessment process of the Red List of Ecosystems brings together all relevant knowledge for the target ecosystem type or types. A successful Red List of Ecosystems assessment will be underpinned by a strong understanding of ecosystem processes and dynamics, considering processes over different timescales, and thinking about the mechanisms that make an ecosystem function. This requires assessors to think broadly, bring in experts and diverse knowledge types, search fastidiously for information, and be creative in applying the criteria with different types of available data. The steps and elements of an assessment are outlined in Figure 5. Typically, ecosystems are expected to be reassessed every 5–10 years.

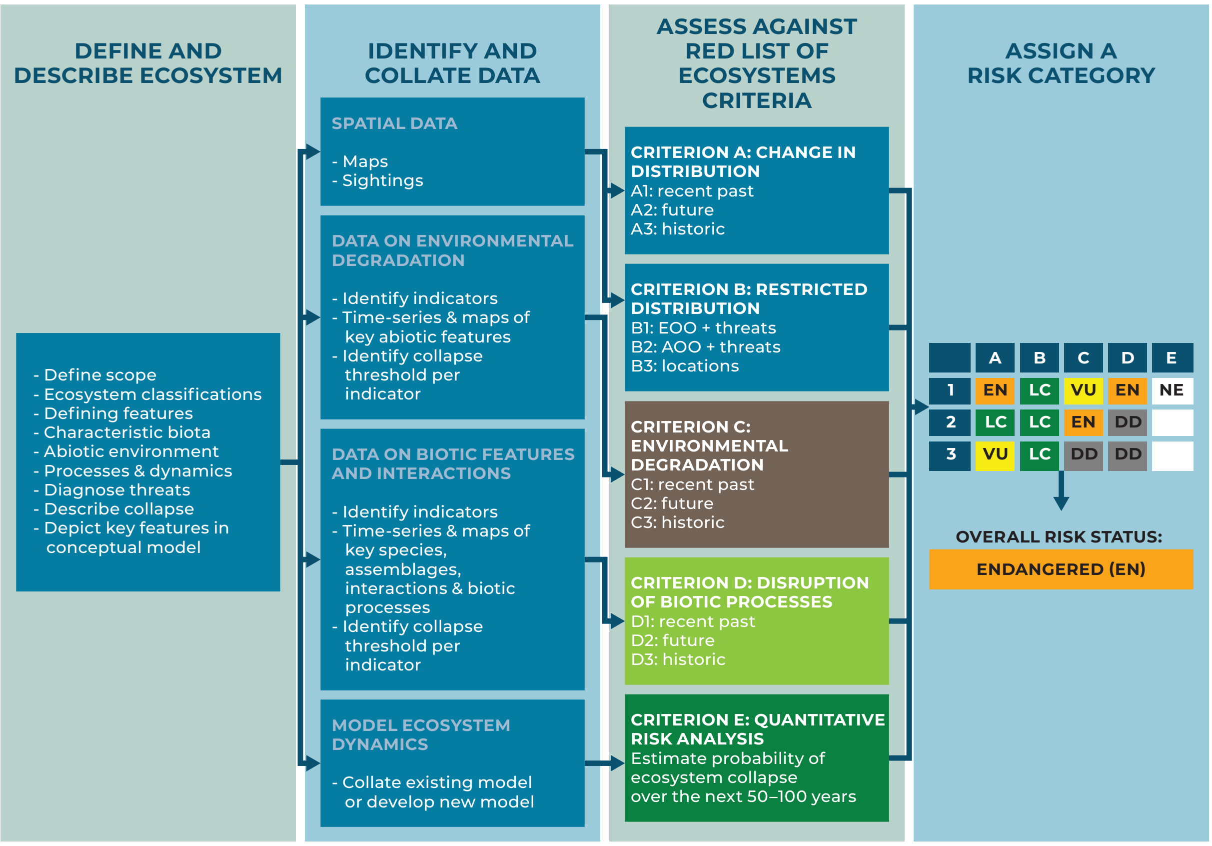

Figure 5: The stages and data requirements for a Red List of Ecosystems assessment, the five ecosystem risk assessment criteria, and how the overall risk category is assigned (the highest amongst the criteria). It may not be possible to assess some criteria due to data limitations, but assessors should aim to assess as many criteria as possible. **AOO** = Area of Occupancy, **EOO** = Extent of Occurrence. *Source: Compiled by the report authors.*

Eastern Andes Mountains. Caquetá, Colombia. *Photo: Juan Carlos Isaza (Fundación Natibo/WWF).*

Scope and scale

The Red List of Ecosystems framework and criteria were designed to be applicable at a range of scales, from global assessments (for example, the coral reefs of the Caribbean[46]) to local assessments at the sub-national scale (for example, the Coorong Lagoon in Australia[46]). Typically, the whole range of the ecosystem should be considered in the assessment process, even if only a portion is formally assessed (for example, if the range extends into another country).

Broadly, there are two types of assessment:

1. **Systematic assessments**, when all ecosystem types within a region, country or group are assessed – for example, the national assessments of Colombia (terrestrial ecosystems[28] and coral reefs[90]), or the assessment of the forest ecosystem types of the Americas.[30] The aims of these assessments typically include understanding relative risks of collapse to inform priorities, underpin legislation and guide conservation planning and restoration. Systematic assessments are usually performed by governments or non-governmental organisations, often in partnership with academic institutions, in consultation with experts. For example, the national assessment of Finland was led by the government's environment agency and undertaken by teams of experts on particular ecosystem groups from different institutions.[49]

2. **Strategic assessments**, where one or a few focal ecosystem types are assessed, typically in greater detail than in systematic assessments, which can inform specific ecosystem management or policy. Examples include the coastal upland swamps near Sydney, Australia, which informed management under national regulation,[46] and the Indian Sundarbans mangrove forests.[80] Many strategic assessments have been undertaken by one or a few experts, in consultation with discipline experts (for example, the Meso-American Reef[12]).

The scope and scale of assessment affect how finely ecosystems are classified (for example, whether all seagrass types are assessed as one ecosystem type, or divided by dominant species or depth). This in turn influences the spatial scale of data available, the types of indicators that can be used to assess change and thus the information that is available to ecosystem restoration.

Coorong National Park. Southeastern Australia. *Photo: Rene Kisselbach.*

Defining and describing ecosystem types

Ecosystem types are the unit of assessment in the Red List of Ecosystems. They are differentiated from one another by their unique composition, structure, ecological processes, and ecosystem dynamics and functions.[46]

An ecosystem type should be characterised based on key diagnostic features of the ecosystem:

- The **characteristic biota**, or living parts of the ecosystem (plants and animals), and structure that differentiate it from other ecosystem types.
- The **abiotic environment**, including soils, water, climate (rainfall and temperature), flow or flood regimes for aquatic ecosystems, or water depth for deep sea ecosystems.
- The **interactions** between species, among abiotic components, and between the species and the physical environment.
- The **spatial location** where the ecosystem exists, which usually takes the form of a map.

Box 6: The IUCN Global Ecosystem Typology

The IUCN Global Ecosystem Typology[44] was developed by a global network of cross-disciplinary specialists. It is a systematic and hierarchical classification that encompasses all of Earth's ecosystems, representing the diversity of both ecosystem function and biodiversity. In its upper levels – comprising realms, biomes and ecosystem function groups – the typology defines ecosystems by their ecological functions. In its lower levels, it distinguishes ecosystems with different assemblages of species involved in those functions. The aim of the typology is to provide a framework for understanding and comparing the key properties of functionally different ecosystems and their drivers, which is essential to support ecosystem management to improve outcomes for both biodiversity and ecosystem services.

The typology is the reference classification system for the Red List of Ecosystems and the System for Environmental Economic Accounting – Ecosystem Accounting, see Box 15). The typology can support the development of new classifications (such as the national ecosystem classification in Myanmar[63]) and is designed to enable integration of existing finer-scale classifications (for example the national classification in South Africa[24]).

While the Global Ecosystem Typology includes anthropogenic ecosystems (including heavily transformed urban and agricultural ecosystems), the Red List of Ecosystems tends to focus on the non-anthropogenic ecosystems (that is, more natural ecosystem types) because it aims to address risk of biodiversity loss, with some notable exceptions in Europe (for example, Norway[4]). Many ecosystems have been shaped by people over millennia, for example through cultural practices, such as fire management in Australia and traditional farming methods in Europe. The biodiversity of these ecosystems has adapted to such management over hundreds or thousands of years, and are now at risk of being lost to colonisation and industrial transformation.

The ecosystem description should place the ecosystem type within the context of other ecosystem classifications, including the IUCN Global Ecosystem Typology (Box 6). The similarities, differences and boundaries between related ecosystem types need to be included in the ecosystem type description, along with the variability in expression and dynamics of the ecosystem.

Conceptual models are recommended when describing the ecosystem in a Red List of Ecosystems assessment. Conceptual models are representations of ecosystems, usually through a diagram that identifies the most important processes and relationships in an ecosystem, including its defining features and key threats (for example, Figure 6). These models communicate shared knowledge, clarify assumptions and help to identify key indicators for measuring ecosystem change. There are many ways to draw conceptual models. Causal models, which show how different components of a system affect one another, including threatening processes, are the most common types of conceptual models used in ecosystem assessment. Others include state- and transition-models, which describe different states of the system and pathways between them, and are often used in management, while stylised sketches can support communication.

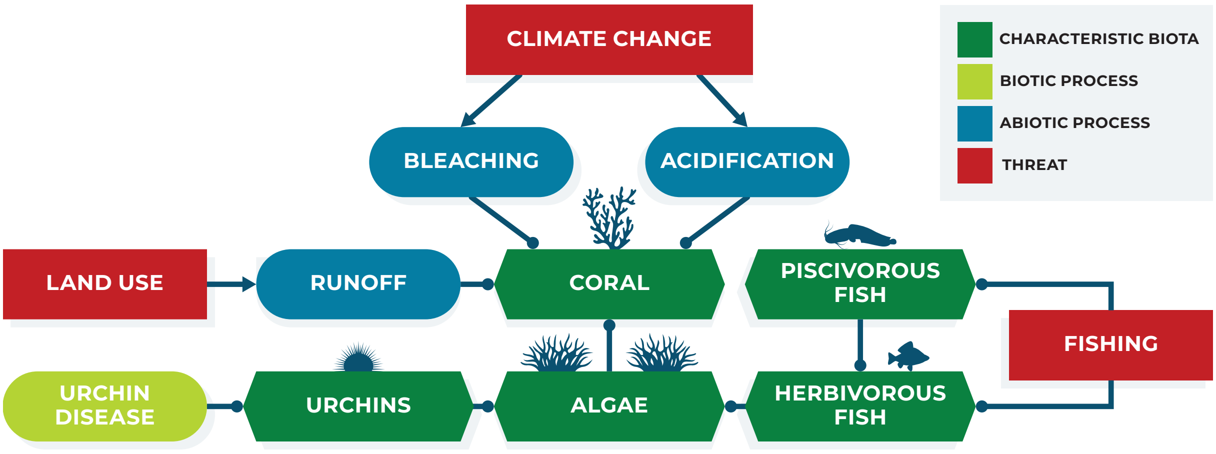

Figure 6: A conceptual model of a coral reef, showing how key features of the ecosystem interact, how threats affect ecosystem components and thus pathways to degradation and collapse. The model is a simplification of complex ecosystem dynamics that supports assessors to identify the most important processes and features, and therefore relevant indicators of ecosystem degradation. Here, it is clear that coral (measured by live coral cover) is central to the ecosystem persisting, but is threatened by multiple threats, including climate change (via the processes of bleaching and ocean acidification). Pointed arrows indicate positive effects, and rounded arrows indicate negative effects. *Source: Modified after Bland et al. (2017).*[12]

Ecosystem collapse is the endpoint of ecosystem degradation and loss, where an ecosystem loses its defining features and identity, and is replaced by a different ecosystem type. Collapse can occur locally, where an ecosystem is lost from an area or country (analogous to local extinction or extirpation of a species), or globally, where the whole extent of the ecosystem type is lost. Typically, in the Red List of Ecosystems, collapse refers to global collapse (that is, throughout the range of the ecosystem type, unless otherwise specified). Describing ecosystem collapse is a key part of the Red List of Ecosystems, and calls for a general description of the state of collapse and pathways to collapse, as well as thresholds for key indicators which represent collapse. Collapse thresholds are often uncertain, because the concept is complex, and because our knowledge about when collapse occurs is imperfect. One way to deal with that is to examine a range of values where an ecosystem could be considered collapsed (for example, collapse in a coral reef may lie between 1% and 5% live coral cover[11]). The impact of this uncertainty can be tested by comparing alternative collapse thresholds, to see if it affects the overall risk status. Different pathways to collapse, and the impacts of threatening processes and interactions between them, can be clarified by the conceptual model of the ecosystem.

Identifying and selecting indicators of ecosystem change: One of the most important steps of an ecosystem risk assessment is to choose indicators that are most relevant to measuring change in defining features of the ecosystem type. These are vital for assessing criteria C and D (Table 1). The Red List of Ecosystems uses quantitative measures (or indicators) of ecosystem change, in contrast with most previous ecosystem assessment methods that used qualitative estimates (for example, descriptions like ‘highly modified’) which may be poorly defined and difficult to replicate. Importantly, the Red List of Ecosystems protocol is designed to be flexible, so that assessors can use the indicators that are most relevant to the ecosystem type, rather than using pre-defined indicators that may not be relevant or may not measure the key features of a given ecosystem. Conceptual models can help identify the key elements of the ecosystem and appropriate indicators to measure them.

Criteria for selecting indicators include:

- Relevance to key ecosystem features and processes identified in the conceptual model.
- Data availability and quality over the relevant timeframes (see Criteria and data needs) to estimate current and past or future values.
- The ability to identify a suitable threshold representing ecosystem collapse.[12]

Ideally, indicators for assessing degradation should measure how the internal ecosystem state – such as species diversity, invasive species cover, abundance of keystone or foundation species, or river flows – changes in response to external threats (see Figure 7). However, where data for direct measures of the ecosystem state are lacking, measures of threatening processes (such as level of harvest of fish, water or timber) can be used, provided thresholds of collapse can be identified.

Table 1: Example indicators for criteria C (abiotic) and D (biotic) that have been used in Red List of Ecosystems assessments, including relevant references.[75]

Abiotic indicators		Biotic indicators	
Category	**Examples**	**Category**	**Examples**
Water (physical or chemical)	Mean annual salinity[46] Water table depth[27] Sea surface temperature[12] Change in hydroperiod[55] Stream flow[46]	Composition	Waterbird abundance[46] Invasive species abundance/cover[46,27] Abundance of tigers[80] Sea otter abundance[46] Kelp density[46]
Climate and atmosphere	Days of cloud cover[5] Annual rainfall[27] Annual temperature[27] Climatic moisture[46] Climatic suitability modelling[46,92,13]	Structure	Shrub cover/encroachment[97] Proportion of old-growth trees[13] Mangrove canopy density[80] Spatial pattern in overstory trees[95]
Disturbance (e.g. fire, climate extremes)	Change in fire interval[6] Hurricane frequency/intensity[12]	Function	Live coral cover[12] Seedling recruitment[55] Predation by invasive species[5]
Substrate	Soil carbon[58] Volume of sand sediment[76]		

Criteria and data needs

The Red List of Ecosystems framework comprises five ecosystem risk assessment criteria, with sub-criteria, that reflect different symptoms of ecosystem degradation and loss, and pathways to collapse (Figure 7). Usually, there are insufficient data to assess all of the criteria, but because they represent different ways in which an ecosystem can be threatened, as many of the criteria as possible should be assessed. Ideally, at least one of the spatial criteria (criteria A and B) and one of the criteria that address ecosystem degradation (criteria C and D) should be assessed. The five criteria are:[10]

A. Reduction in geographic distribution: Identifies ecosystem types undergoing loss in area such as forest conversion to agriculture.

B. Restricted geographical distribution: Identifies ecosystem types with small distributions that are inherently susceptible to spatially explicit threats or catastrophes.

C. Environmental degradation: Identifies ecosystem types threatened by change in their abiotic environment, such as water extraction, sea-level rise, or reduction in rainfall.

D. Disruption of biotic processes or interactions: Identifies ecosystem types that are losing characteristic species, biotic assemblages, or loss of biotic interactions or processes, such as decline in foundation species or functional groups, or change in trophic structure.

E. Quantitative risk assessment that estimates the probability of collapse: Allows for an integrated evaluation of multiple threats, symptoms and their interactions.

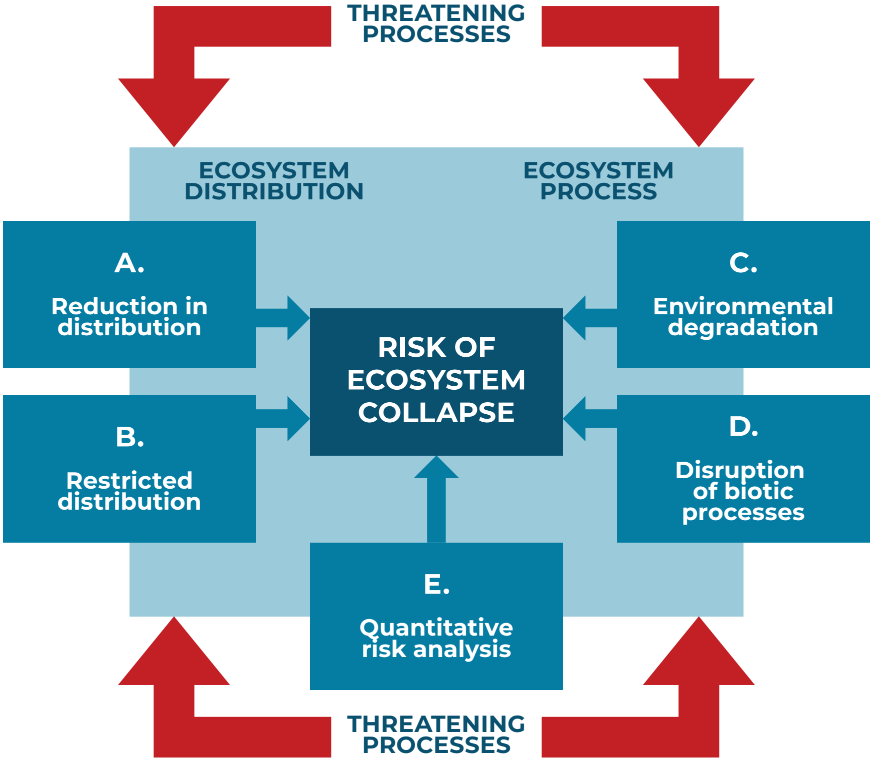

Figure 7: The five Red List of Ecosystems criteria represent different symptoms of ecosystem decline and pathways to collapse. *Source: Modified after Keith et al. (2013).*[46]

Change is assessed over three time frames, forming the sub-criteria for criteria A, C and D (see Figure 5):

1. Trends in the recent past (last 50 years)
2. Projected change up to 50 years into the future (or 50-year window, including past and future)
3. Compared with an historical baseline (approximately 1750, or pre-industrialisation).

The sub-criteria for criterion B are different metrics of distribution, along with evidence of ongoing threats:[10]

1. Extent of occurrence (EOO).
2. Area of occupancy (AOO).
3. Number of threat-defined locations.

Different types of data are required to assess the criteria (see Figure 5).

The **initial state** refers to the value of any given indicator at the beginning of the assessment period (for example, 50 years ago). The initial state is used simply to measure change through time. It may differ from the reference state described for restoration, either because the ecosystem was already degraded at the beginning of the assessment period, or because the environmental conditions have changed over this timeframe (for example, if the assessment period was 1750 to present).

Trends in ecosystem area: The two spatial criteria rely on maps of the current distribution (for criteria A and B), and past and/or future projected distributions (for criterion A). Past distributions may be mapped through modelling of historical distributions[82] using old maps (for example, of army surveys of tidal mudflats[64]), or satellite remote sensing, which in some cases reaches back 30–40 years and can be extrapolated to estimate change over 50-year timeframes.[64] Future projections of distribution can be estimated using models, for example under different climate change scenarios.[13]

Trends in ecosystem degradation: The data needed for criteria C and D are time series for the indicators for key ecosystem features (identified through the selection process outlined above). Criteria C and D assess change over two dimensions: the relative severity of degradation (magnitude of change in the indicator); and the proportional extent of the ecosystem's distribution affected by degradation. It is very rare for data to be available through time (for example, 50 years) and space (across the whole extent of the ecosystem) for any indicator. So assessing criteria C and D often requires extrapolation and expert judgement about how representative the available time series are for the whole distribution or timeframe, or how spatial maps of degradation relate to the reference time frames (for example, assuming no degradation in pre-industrial times).

Relative severity is assessed by normalising the indicator against two points: the initial state (for example, 50 years ago, for sub-criterion 1); and the collapse threshold, which is the point for that indicator where the ecosystem is considered collapsed (for example, where live coral cover is 1%,[12] or where less than 1% of old-growth forest remains[13]). For more examples of collapse thresholds, see the Red List of Ecosystems guidelines[10] and case studies on the Red List of Ecosystems website. Relative severity allows assessors to understand how close the ecosystem is to collapse, for example, 50% relative severity means that the ecosystem has moved halfway towards the collapse threshold in the last 50 years.

Process-based ecosystem models: Criterion E requires a stochastic ecosystem model, which in turn requires extensive data and knowledge. Although there are some examples of ecosystems assessed under criterion E, such as the Coorong Lagoon[46], the Meso-American Reef[12] (see Figure 6) and the mountain ash forests of south-eastern Australia,[13] these are currently rare. Although such models can be useful for restoration planning (for example, to compare river flow regulation under different

Parque Nacional El Palmar. Argentina. *Photo: Ariel Amoroso.*

climate scenarios in the Coorong Lagoon[46]), because they are rarely applied, they are not discussed further in this guide.

Assessing ecosystem risk

Quantitative thresholds for each criterion allow assessors to place ecosystems into risk categories. Details can be found in the IUCN Red List of Ecosystems guidelines[10]. For example, criterion A assesses change in geographic distribution. The thresholds for change are shown in Table 2. For example, if an ecosystem's area has declined 72% over the last 50 years, it is Endangered (50–80%). Sub-criterion A3 has higher decline thresholds to account for the longer timeframes over which it is assessed.

Criteria C and D assess change over two dimensions: the relative severity of degradation; and the extent of the distribution affected by degradation. This makes assigning a risk category slightly more complex, as risk is a combination of extent and severity (Figure 8).

For example, an ecosystem with a very high level of degradation (more than 80% relative severity) over the great majority of its extent (more than 80%) in the last 50 years is considered Critically Endangered (red square in Figure 8). In contrast, there are two ways an ecosystem can be Endangered (orange, Figure 8): more than 80% relative severity over 50–80% of its extent, or more than 50% relative severity over more than 80% of its extent.

Table 2: Thresholds for assigning an ecosystem to a risk category under criterion A, change in geographic distribution.[10] CR = Critically Endangered, EN = Endangered, VU = Vulnerable.

Sub-criterion	Timeframe	CR	EN	VU
A1	Recent past (over the past 50 years)	≥80%	≥50%	≥30%
A2	Future (over next 50 years, or a 50-year period that include past and future)	≥80%	≥50%	≥30%
A3	Historical past (since approx. 1750 or industrialisation)	≥90%	≥70%	≥50%

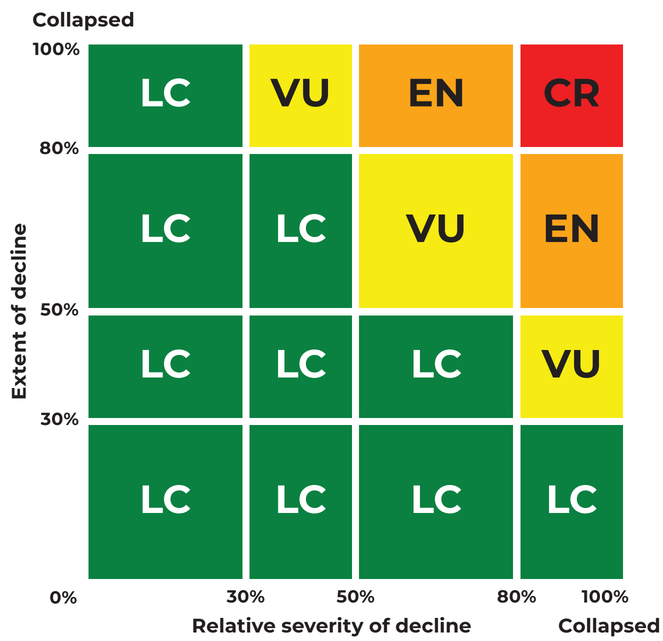

Figure 8: Thresholds for change in indicators of degradation under criteria C and D (sub-criterion 1, change over the last 50 years). Only the thresholds for C1/D1, change over the past 50 years, are shown – see the IUCN Red List of Ecosystems guidelines for more details.[10] *Source: Compiled by the report authors.*

The risk categories scale from the highest category of *Collapsed* (CO), through three threatened categories – *Critically Endangered* (CR), *Endangered* (EN) and *Vulnerable* (VU) – to the non-threatened categories with the lowest risk of collapse – *Near Threatened* (NT) and *Least Concern* (LC) (Figure 9). An ecosystem is *Data Deficient* (DD) when there is not enough information or data to assign a risk category (for example, if no data are available, or data are too uncertain to be informative). *Data Deficient* is not a category of threat, and does not imply any level of collapse risk, but indicates that the ecosystem has been reviewed and requires more information. If the criterion or ecosystem has not been assessed, it is *Not Evaluated* (NE).

The overall risk status for the ecosystem is the highest risk category for any one of the criteria or sub-criteria (Figure 5 and Box 7). The highest risk category is used because each of the criteria (and sub-criteria) represent different symptoms of ecosystem change and pathways to collapse. Any one of them represents a way in which an ecosystem can be at risk of collapse.

CO	Collapsed	Defining features lost, key biota no longer sustained	
CR	Critically Endangered	Extremely high risk of collapse	THREATENED
EN	Endangered	Very high risk of collapse	
VU	Vulnerable	Very high risk of collapse	
NT	Near Threatened	Does not qualify as threatened, but close or will be in the near future	
LC	Least Concern	Does not qualify as threatened; includes widely distributed and relatively undegraded ecosystems	
DD	Data Deficient	Inadequate information to assess risk of collapse	
NE	Not Evaluated	Ecosystem or criterion not yet evaluated against the criteria	

Figure 9: The Red List of Ecosystems risk categories. *Source: Compiled by the report authors.*

Box 7: Case study: IUCN Red List of Ecosystems assessment of the floodplain ecosystem of river red gum and black box, south-eastern Australia

This ecosystem type occurs in the floodplains of the Murray-Darling River Basin, Australia's largest river system. It is dominated by two main tree species, the river red gum (*Eucalyptus camaldulensis*) and black box (*Eucalyptus largiflorens*), with density varying from closed forest in the east to open woodlands in the west across a rainfall gradient, and shrubby, sedgy and grassy understoreys. Its dynamics are driven by the episodic flooding of the rivers, with its biota adapted to inundation. However, river regulation and water extraction has greatly reduced the frequency, extent and duration of flooding. For example, extensive flooding in the Barmah Forest has reduced from 46% to 25% of years, while flow has reduced by 50%. This has been compounded by climate change, droughts and other threats, such as timber harvest, land clearance, overgrazing and invasive species.

Because the floodplain ecosystem is threatened by water diversion and climate change, river flow was selected as a suitable variable for assessing the relative severity of environmental degradation under criterion C, with a collapse threshold between 0–10% of historical flow (giving rise to uncertainty in the risk category in criterion C, as shown in Table 3). Key variables for biotic degradation were declines in remotely-sensed condition, and multiple measures of the native bird assemblage, including number of species, abundance and breeding activity. Future potential distribution under various climate change scenarios was also projected using a correlative model (criterion A2).

The ecosystem was found to be Vulnerable, triggered by three sub-criteria (Table 3): projected declines of future distribution of >30% (criteria on A2); reduced river flow over the last 50 years (C1, with 30–60% relative severity over 79% of the extent); and projected future river flow (C2). Although declines in condition are extensive (79%), the relative severity of decline in bird abundance, richness and breeding activity were not high enough to trigger a threatened status under criterion D. Because the distribution remains large, the ecosystem is Least Concern under criterion B. The lack of an ecosystem model means that it is Data Deficient (DD) under criterion E.

The analysis highlights the need to restore flood regimes and water flow to the river to recover this ecosystem. Locally, removing threats of overgrazing (by domestic stock and invasive species) would reduce degradation, particularly in areas predicted to be most suitable for the ecosystem under a changing climate, from the model of future distribution used in criterion A2.

Table 3: Red List of Ecosystem assessment for the floodplain ecosystem of river red gum and black box. The ecosystem was found to be Vulnerable based on three sub-criteria.[46]

<table>
<tr><th>Criteria</th><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th><th>Overall</th></tr>
<tr><td>Sub-criterion 1
• A, C, D: past 50 years
• B: Area of Occupancy</td><td>LC</td><td>LC</td><td>VU
(LC-VU)</td><td>LC</td><td rowspan="3">DD</td><td rowspan="3">VU</td></tr>
<tr><td>Sub-criterion 2
• A, C, D: future 50 years
• B: Extent of Occurrence</td><td>VU</td><td>LC</td><td>VU</td><td>LC</td></tr>
<tr><td>Sub-criterion 3
• A, C, D: historical (~1750)
• B: number of locations</td><td>LC</td><td>LC</td><td>LC
(LC-VU)</td><td>LC</td></tr>
</table>

Source: Mac Nally et al. in Keith et al. (2013).[46]
For more information: IUCN Global Ecosystem Typology: TF1.2 Subtropical/temperate forested wetlands

Further reading:

The IUCN Red List of Ecosystems website, https://iucnrle.org/, contains many resources, including guidelines, assessments and free online training material.

Guidelines for the application of IUCN Red List of Ecosystems Categories and Criteria.[10] https://iucnrle.org/resources/guidelines/

Scientific foundations for an IUCN Red List of Ecosystems.[46] https://doi.org/10.1371/journal.pone.0062111

The IUCN Red List of Ecosystems: Motivations, challenges, and applications.[45] https://doi.org/10.1111/conl.12167

Tundra vegetation at Sydkap, inner Scoresby Sund. East Greenland. *Photo: Hannes Grobe.*

Chapter 3: **Using ecosystem risk assessment to guide strategic restoration planning**

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This chapter explores how the range of information provided by the Red List of Ecosystems can support the analysis of opportunities for addressing ecosystem risks through restoration. The risk of ecosystem collapse should be a key factor in setting priorities for restoration at the national and regional levels of planning. However, restoration opportunities are often assessed without considering the risk of collapse of ecosystems or the underlying causes of ecosystem risk.

Information from the Red List of Ecosystems assessment, coupled with multi-criteria analysis, can be used to identify strategic priorities for restoration, based on the potential benefits, feasibility and relative value of restoration for reducing the risk of collapse for an ecosystem type. Such high-level analysis of ecosystem restoration potential across landscapes and seascapes provides critical information for strategic restoration planning, including setting targets for ecosystem restoration.

Post-disaster restoration of mangroves project, a Red List ecosystem with Endangered (EN) status. East Tortola, British Virgin Islands. *Photo: Susan Zaluski.*

Information from the Red List of Ecosystems to inform strategic restoration planning

The Red List of Ecosystems is highly informative for assessing strategic opportunities and priorities for ecosystem restoration. It identifies the types of ecosystems at risk of collapse, and provides a diagnosis of the underlying causes of risk for each ecosystem. It is also useful in identifying the portions of an at-risk ecosystem that have been cleared, or have lost their integrity through degradation. These are potential areas to focus restoration aimed at increasing ecosystem area and integrity, once costs, feasibility and other human-use values have been considered.

The strengths of the Red List of Ecosystems for guiding strategic planning of ecosystem restoration are its structured framework to assess how risk is impacted by threatening processes, as well as the biophysical description and associated spatial datasets for each ecosystem type. The amount of information available in Red List of Ecosystems assessments and its applicability for strategic restoration planning will depend on the type of assessment (see Chapter 2: Scope and scale), as well as the spatial scale of available supporting data.

Descriptive information: Each Red List of Ecosystems assessment begins with a description of the ecosystem type in terms of its characteristic composition, structure and function. The ecosystem description includes information about its characteristic species, abiotic environment, ecological processes and spatial distribution (see Chapter 2: Defining and describing ecosystem types). The IUCN Global Ecosystem Typology (see Box 6) provides comparable ecosystem information across countries and regions that will help compare restoration under similar ecological settings. Information from the ecosystem description can be used to identify key species and abiotic processes that need to be resumed to restore an ecosystem. The ecosystem description can also identify important stressors such as water scarcity and substrate fertility conditions. These data are useful to help consider the key diagnostic features of the ecosystem and how to define a preferred restoration strategy.

Conceptual models: A conceptual model is part of the ecosystem description for each Red List of Ecosystems assessment (see Figure 6). Conceptual models clarify the cause-effect processes of ecosystem collapse, as well as key components, limiting resources and feedbacks. They can show how ecosystem risk accumulates with different threats. This knowledge is crucial to understand the options for ecosystem restoration, determine the feasibility of restoration success and identify the best strategies for the restoration process.

Spatial information: A crucial spatial output of the Red List of Ecosystems is the map of threatened ecosystems, which is foundational information to guide assessment of restoration opportunities. It shows where threatened ecosystem types occur within the landscape or seascape and their extent. Maps of current ecosystem distribution can inform planning for connectivity. Additional supporting maps and spatial data used in the Red List of Ecosystems assessment can also be valuable inputs towards restoration. Maps of the past distribution and extent of ecosystem types prior to anthropogenic degradation can identify locations that have the potential for restoration. Temporal map series showing the loss or degradation of ecosystem types over different timeframes can help to understand when and how impacts occurred (Figure 10), and how they may be redressed. Maps showing the location, extent or relative intensity of threats associated with ecosystem risk can show where, within remnant parts of ecosystems, there is a need for threat abatement. Finally, maps of potential future distribution for an ecosystem under anticipated future climate can guide where restoration is most appropriate under a range of climate scenarios (see Box 8), especially to identify areas previously occupied by an ecosystem type that may no longer be suitable as the climate changes.

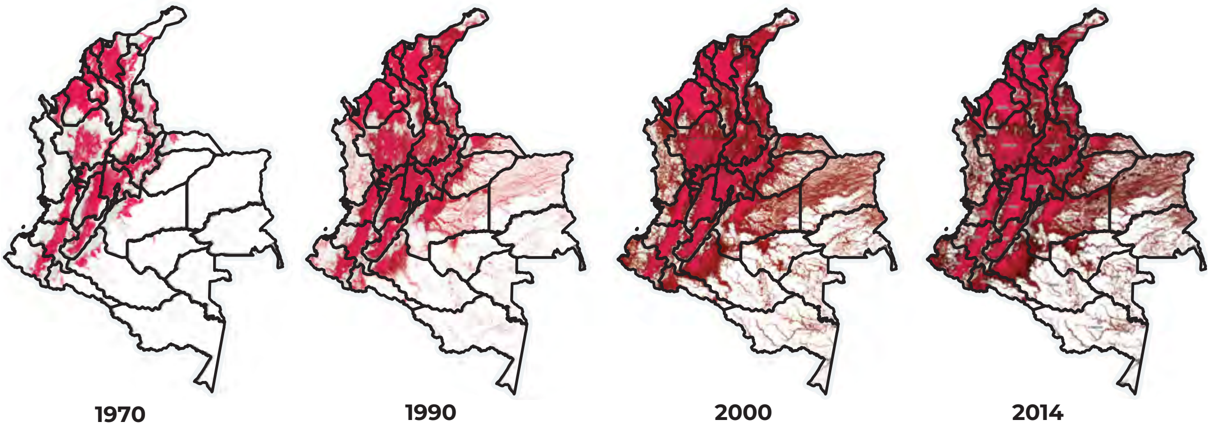


Figure 10: An example of a multi-temporal map series of transformation from Colombia. The systematic Red List of Ecosystems assessment for Colombia gathered a series of maps that show how the conversion of natural ecosystems to other land uses has taken place over 45 years, from 17% of the country in 1970 to 34% in 2014 (graded shades of red). *Source: Modified after Etter et al. (2020b).*[29]

Information about threats: Central to ecosystem risk assessment in the Red List of Ecosystems are data describing the characteristics of threats, their occurrence and intensity. Each assessment includes information on links between threats and ecological processes leading to ecosystem risk of collapse (Figure 11). This information is essential to planning restoration as it can help to determine the appropriate restoration strategy by identifying which threats need to be addressed to restore an ecosystem in a location. Because ecosystem threats are often due to cumulative effects at the landscape or seascape scale, they must be included in high-level spatial planning processes. An important aspect of threat to ecosystems is climate change because it may determine the future spatial displacement of climate envelopes where ecosystems can occur (Box 8).

Damaged dragon blood trees after cyclones hit. Socotra Archipelago, Yemen. *Photo: Ismail Mohammed/IUCN.*

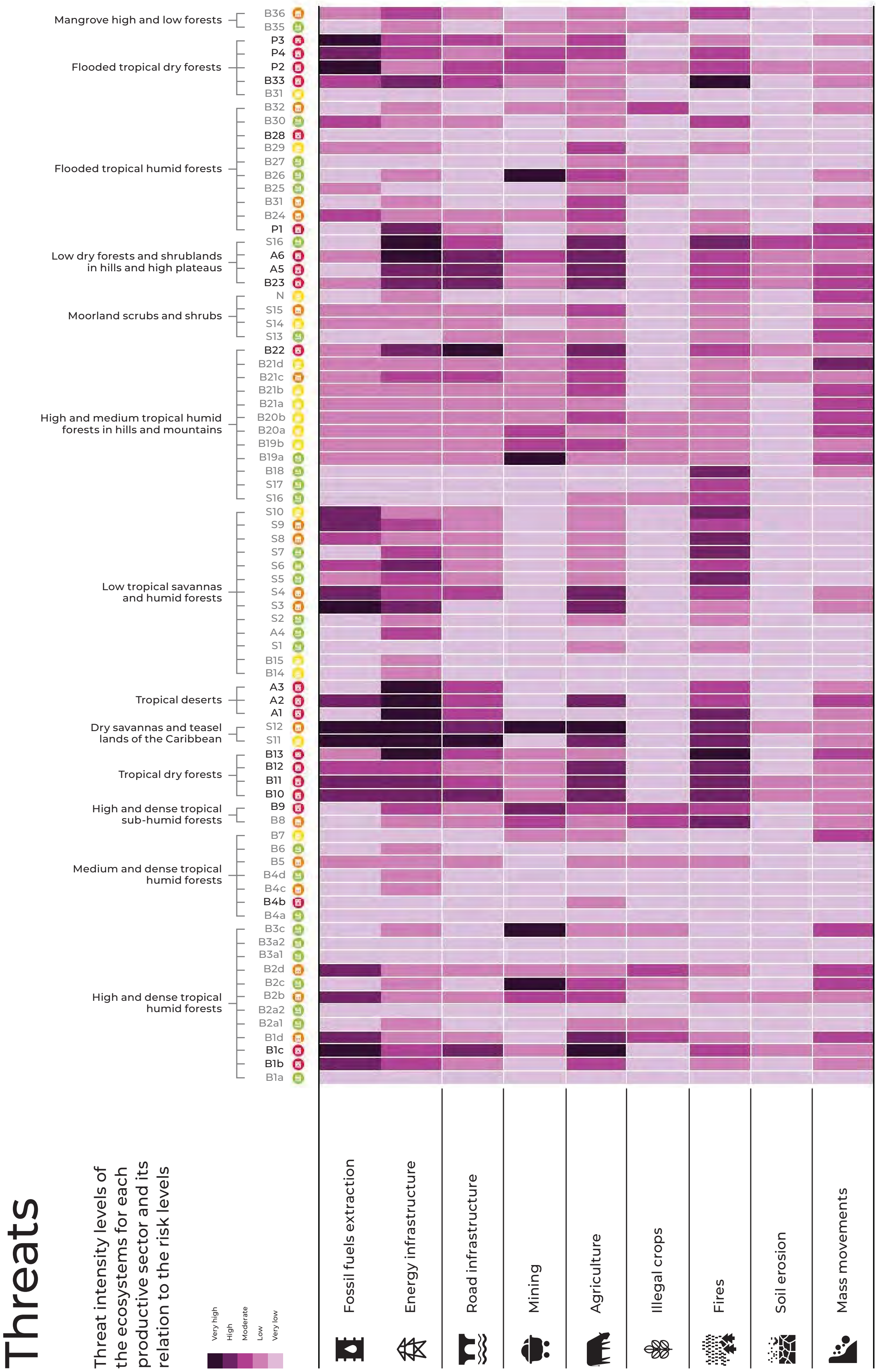


Figure 11: Threats from different productive sectors, their occurrence and intensities across different ecosystem types in Colombia. Each ecosystem type is categorised by its risk category. For example, the Critically Endangered Llanos foothills tropical forest ecosystem type (B1b) is under high threat from fossil fuel extraction, and moderate threat from energy infrastructure and agriculture. *Source: Modified after Etter et al. (2020b).*[29]

Box 8: Considering climate change in ecosystem restoration

Restoration planning should ideally consider the foreseeable effects of climate change (for example, changes in temperature, rainfall and disturbance regimes), which could affect the feasibility of locations and actions for restoration.

An inherent property of ecosystems is that they change over time in response to changing climate and environmental conditions. Even in the absence of localised threats, the composition, structure and function of ecosystems change over time. For this reason, ecosystem restoration should not aim to recreate past conditions, but rather to remove degradation and enable the ecosystem to return to the condition it would have been in had degradation not occurred, accounting for environmental change.[34]

Anthropogenic climate change presents a unique challenge for the practice of restoration, as it is both a degrading force, but also the background stage in which ecosystem dynamics occur. This means that restoration must include adequate consideration of environmental change. Understanding how climate change will determine future threats, their impacts, and the likely changes in species distributions and community assembly, is fundamental in deciding where and how to restore an ecosystem. Some ecosystems may even collapse due to rising temperatures such as high mountain ecosystems in the tropics that have no place to move. In other cases, species may need assistance in migrating from areas that no longer fall within their environmental envelope, causing ecosystems to disaggregate and reaggregate with new communities.

Climate change is an important component of the Red List of Ecosystems framework because future threats (50 years into the future) inform the risk status of ecosystems under several criteria (see Figure 5). The Red List of Ecosystems recognises the role climate change plays in the ecological integrity of an ecosystem in the future, by impacting the environmental envelope, and changes to species and linked ecological processes.

The emergence of novel ecosystems is also likely, given that anthropogenic degradation may result in irreversible changes in species assemblages.[37] Learning how to manage existing ecosystems in new places, and to enable current ecosystem locations to transition to new functional ecosystem types, will be a steep learning curve and likely require experimental adaptive management and monitoring approaches.

Time-series information on ecosystem and threat trends: The Red List of Ecosystems allows for assessment of risk over different time periods (past, present and future), providing rates of change and trends in ecosystem integrity, threats and processes. Time-series information may show trends of ecosystem degradation from past to present, and also forecast into the future (for example, deforestation or species invasions). It may also show trends in degradation of abiotic components or biotic processes and their interactions (Figure 12), or trends in threatening processes (such as overexploitation of fish or timber, salinisation, sea level rise). Time-series information allows visualisation of the timing and rates of degradation of an ecosystem, or the temporal dynamics in the intensity of threatening processes.

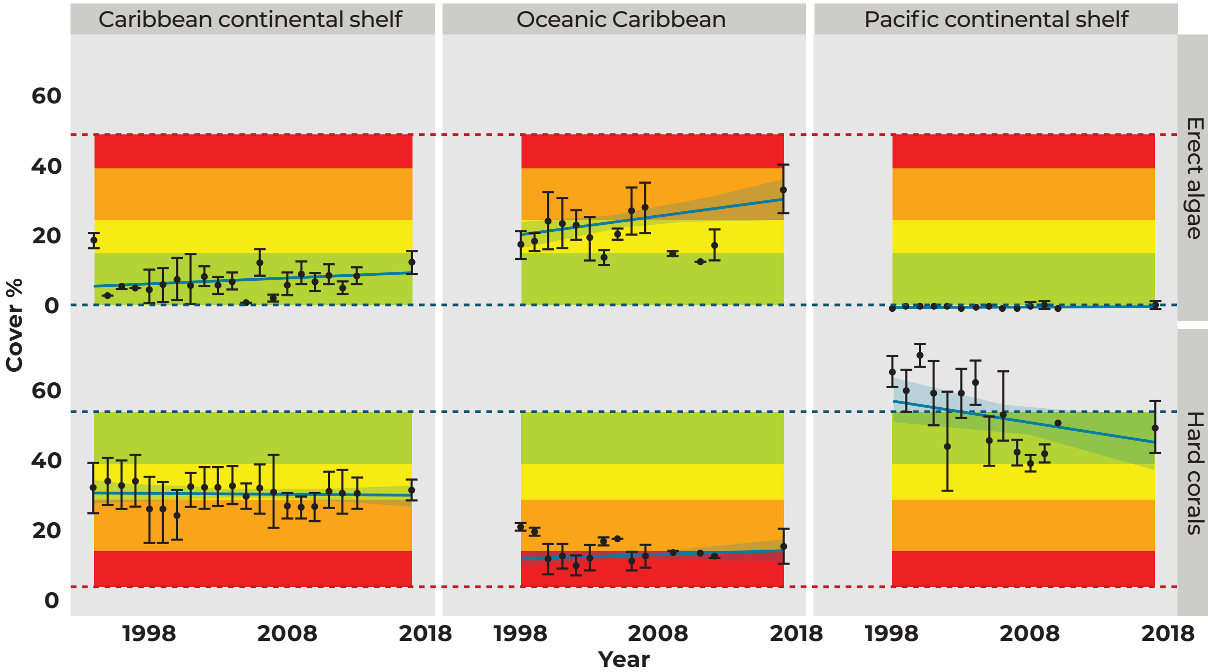


Figure 12: Trends in coverage of algae (upper panels) and hard corals (lower panels) in Caribbean ecosystems of Colombia between 1994 and 2018, and the impact on ecosystem risk. Colours refer to the risk category imposed by the condition: Red = Critically Endangered, Orange = Endangered, Yellow = Vulnerable, Green = Least Concern. *Source: Modified after Uribe et al. (2020).*[89]

Identifying ecosystem types and locations where restoration can be most useful

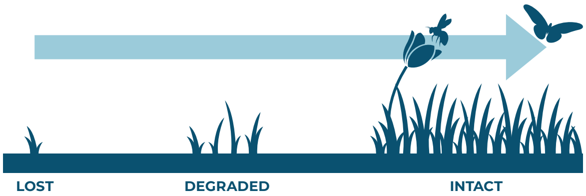
The fundamental starting point to using the Red List of Ecosystems in restoration is the categorisation of ecosystem risk of collapse (such as Critically Endangered, see Figure 9). This is the logical starting point because for any ecosystem restoration activity to be considered restorative, it must be implemented in an area that has been degraded. Thus, the increasing categories inform the urgency for ecosystem restoration. The risk category is particularly relevant in countries where there are statutory obligations to manage and restore threatened ecosystems. Depending on the policy objectives of restoration, decisions about the categories of risk that would benefit most from restoration can be made.

Arguably, the ecosystems most at risk (Critically Endangered, Endangered or Vulnerable) are the most immediate targets for restoration because they are in more imminent danger of collapse. However, it may not always be feasible to restore the most threatened ecosystems. Furthermore, restoration may, in some cases, be important for reasons other than risk reduction, for example to retain locally valued biodiversity and ecosystem services, such as in mangroves for coastal protection, or peatlands for carbon storage potential. Thus, there is not always a direct relationship between the degree of ecosystem risk and priority for restoration.

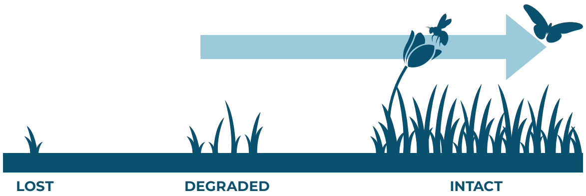
Knowing which criterion triggered the risk status is crucial as it gives a 'diagnosis' about why the ecosystem type is at risk and allows restoration efforts to be targeted effectively. It gives an understanding of the root causes of risk and how these might be overcome by restoration to reverse the trends that are threatening the ecosystem. For example, is a threatened ecosystem at risk due to loss of area or degradation? Which changes in components of the ecosystem are producing the highest declines in function? How can restoration activities reduce those risks most effectively? Are there feasible actions that can be taken that will address the underlying risk?

There are two broad contexts for application of the Red List of Ecosystems assessment in identifying where restoration needs to be restored as listed below (also see Figure 13):

1. **Areas where ecosystems have been lost** or extirpated and replaced by a different ecosystem type, which require restoration to return the ecosystem.



2. **Degraded areas of remnant ecosystems**, which require restoration to improve ecosystem integrity and prevent future loss of area.



Deciding which to pursue will depend partly on the relative cost effectiveness and feasibility. Generally, recovering areas that have been lost will require more effort and resources than reducing threats. Furthermore, the outcome is usually much less certain because restoring all of the ecological values of an intact system is difficult and success cannot be guaranteed.

However, in some cases, it may be more effective to restore lost areas, for example where it is the only option available or there are compelling social reasons to attempt full restoration. Ideally, restoring a threatened ecosystem will address both degradation in remnant areas, as well as restoring the lost areas of an ecosystem.

The old city of Quito. Guagua Pichincha Volcano, Ecuador. *Photo: Ricardo Jaramillo.*

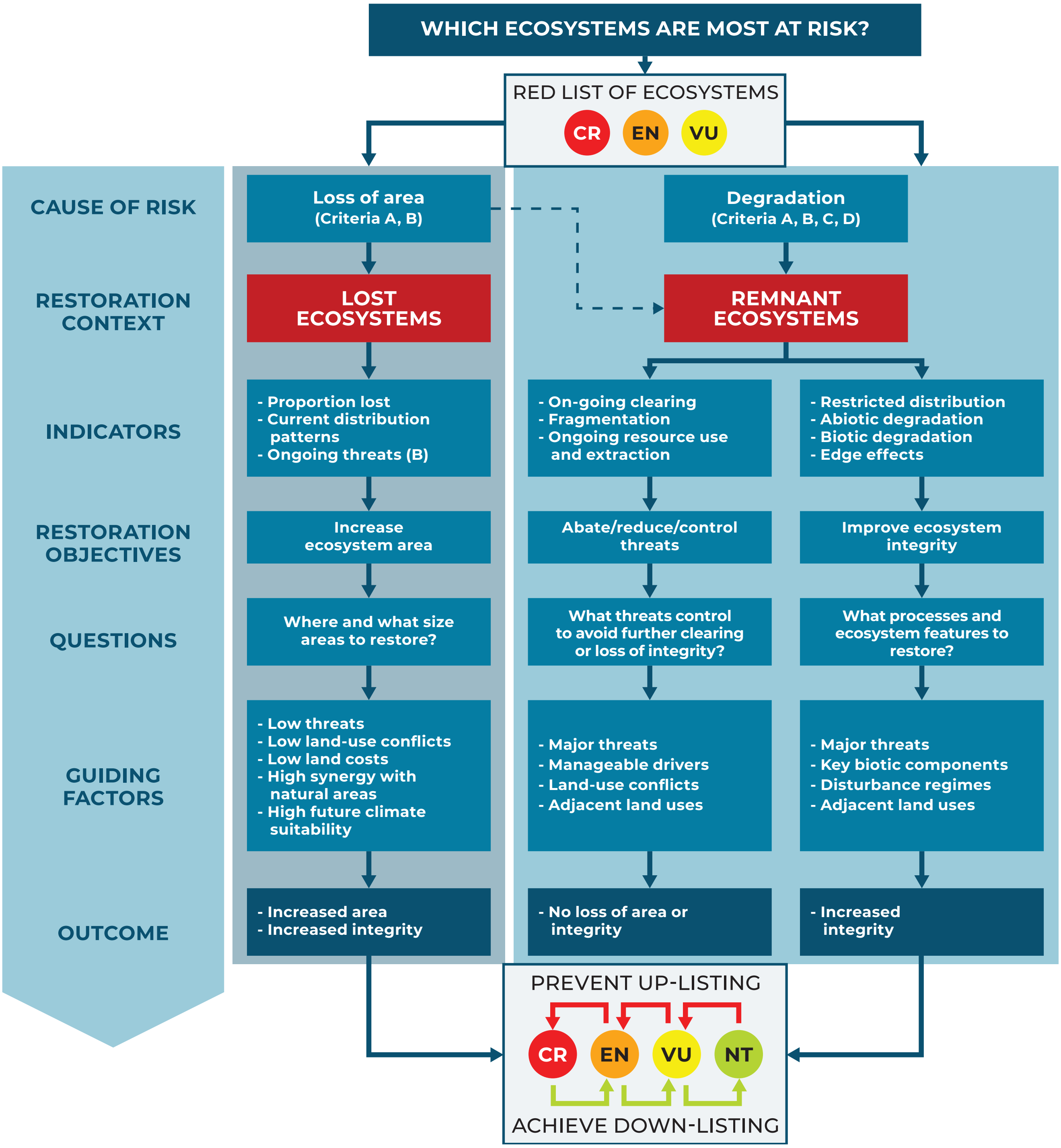


Figure 13: The application of the Red List of Ecosystems to ecological restoration in the contexts of loss of ecosystem area and degraded remnant ecosystems. *Source: Compiled by the report authors.*

Restoring ecosystems where they have been lost

One goal of ecosystem restoration is to re-establish ecosystem types in locations where they have disappeared. The Red List of Ecosystems, specifically criterion A, measures the reduction in geographic distribution of an ecosystem type over various timeframes (see Figure 5). This permits the identification of areas for possible restoration where the ecosystem type occurred in the past (Figure 14).

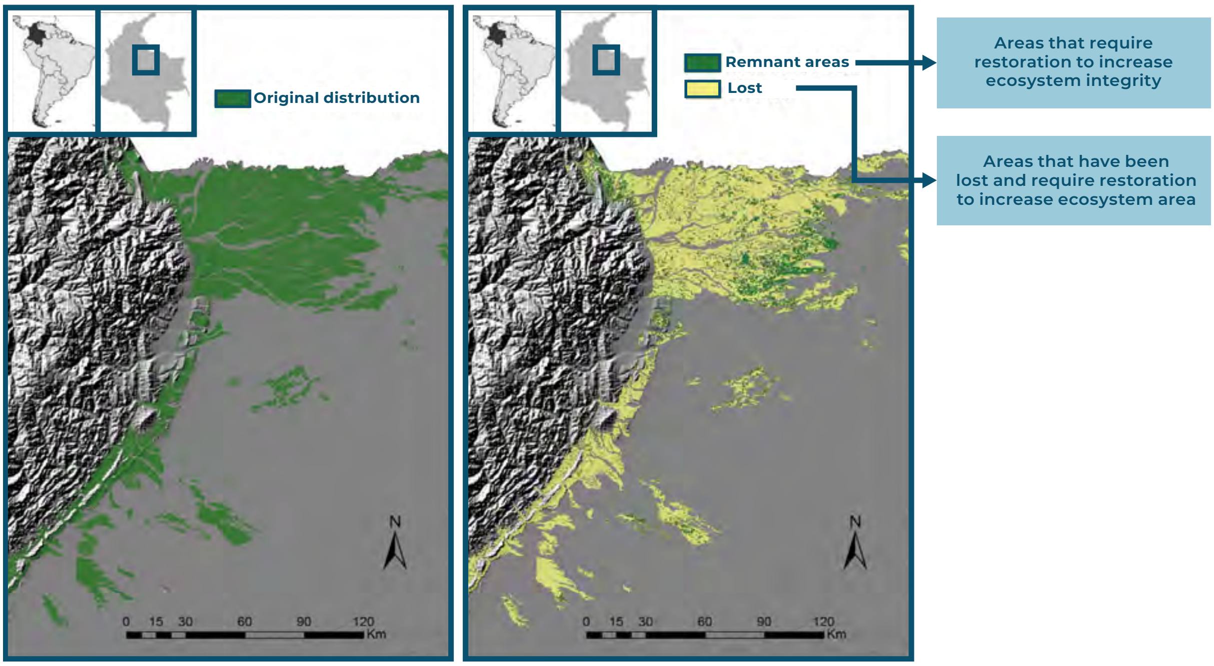


Figure 14: Spatial information that shows (a) the original extent of a Critically Endangered ecosystem type, the Llanos foothills tropical forests in Colombia; and (b) areas where the ecosystem type has been lost and the remnants that remain. *Source: Modified after Etter et al. (2020a).*[28]

To guide priorities for restoration in areas where ecosystems have been lost, relevant information can be drawn from the Red List of Ecosystems, such as:

- The risk category and criteria evaluated for the ecosystem type.
- The past distribution of the ecosystem type. Understanding where it was originally distributed is a basic consideration to select areas to re-establish parts of the ecosystem that have been lost.
- The loss of ecosystem area over different timeframes, or specifically time since clearing or conversion, may determine suitability for restoration of the site, because it may affect the soil fertility and propagule availability.
- The historical and projected rates and trends of loss, showing where the risks of future loss are highest.
- The areas where climate change may impose severe threats to the current ecosystem range in the future (see Box 8).
- The spatial structure and metrics of its remnant distribution (for example, fragmentation, connectivity, patch sizes).
- The ongoing threats affecting regeneration of the ecosystem.
- Other ecosystems that are spatially or functionally related in a critical way.

Restoring integrity of degraded areas of remnant ecosystems

The other application of the Red List of Ecosystems is to identify priority areas for ecosystem restoration that will reduce threats and improve ecosystem integrity in remnant areas of threatened ecosystem types (Figure 13). Information from the Red List of Ecosystems that can help in the selection of potential restoration areas where remnant ecosystems have been degraded includes:

- The relationship between threats, and ecosystem composition, structure and function provided by the conceptual models that synthesise the knowledge about the ecosystem in question (see Figure 6).
- The characteristics of threats, such as type, temporality and locations.
- Known or potential synergies between different threats.
- The values of components and processes that characterise high levels of ecosystem

integrity, and their relations with described threats.

- The areas where climate change may impose severe threats in the future to the ecosystem range (see Box 8).
- The spatial structure and metrics of the remnant distribution (for example, fragmentation, connectivity, patch sizes).
- The threats affecting the capacity of the ecosystem to recover.

Multi-criteria approaches to assess restoration opportunities

The Red List of Ecosystems assessment provides information on the degree of ecosystem risk, rate of loss and degradation. However, to identify the most effective locations for restoration, information on ecosystem risk must be combined with multiple other sources of additional information (see 'Guiding factors', Figure 13) to determine where restoration is most likely to generate the maximum net gain. Determining where it is more sensible to conduct restoration also requires additional data on socio-economic conditions and any possible barriers to restoration that would affect the likelihood of success.[28] These include:

- Current distribution of land uses and management, as well as land productivity and possible conflicts with restoration. This information is important because seeking to change land uses (for example, reduce pollution or improve drainage), or human-driven activities (for example, hunting or species invasions), may be socially challenging.
- Cost of the land across potential restoration areas, land ownership and administrative boundaries.
- Degree of degradation of the biophysical conditions (soils and water), as this may determine the type of restoration activity needed and incur additional cost if degradation is severe.
- Technical capability of achieving different degrees of restoration (partial to full recovery) at different scales.
- Distance to natural areas or protected areas that may serve as a source of regeneration and offer further security to restored areas.
- Spatial distribution of ecosystem goods and services valued by stakeholders, such as carbon storage, reduction of natural hazards, and water quality and quantity.
- Information on how ecosystem restoration may also benefit threatened species (Box 9)

Removing *Salvinia molesta* from Ranupani Lake. East Java, Indonesia. *Photo: Titik Kartitiani.*

- The availability of funding and relative costs of proposed restoration activities, including comparisons between return on investment of alternative restoration activities and risk of restoration failure (no change in ecosystem risk).
- Social and institutional considerations, including employment and income, cultural values, and willingness of people to displace their homes or economic activities.

Incorporating this multiplicity of information requires multi-criteria decision frameworks (Figure 16). Such frameworks allow a large number of factors to be included in assessing spatial priorities, with each factor having a different level of influence on the analysis according to its assigned weight (Figure 17). Multi-criteria decision analysis begins with a clear articulation of the problem, which can include, for example, the prioritisation of areas for restoration or abatement of threats.

Box 9: Species Threat Abatement and Recovery (STAR).

STAR provides a spatial analysis of the impact that restoration activities could have for threatened species. STAR analyses data from the IUCN Red List of Threatened Species™ to assess the potential contribution of specific actions at specific locations in reducing species extinction risk.[54] STAR estimates the contribution of two kinds of action to reduce species extinction risk – threat abatement and habitat restoration.

STAR values are mapped on 5 by 5 km pixels across the world. Adding together the values of individual pixels contained within a site permits the calculation of potential contributions of habitat restoration and threat abatement at the site. The pixel values are based on the IUCN threat categories of the different species found in the pixel, and the proportion of the species' range covered by the pixel (Figure 15). This makes it possible to assess the potential impact across a project portfolio or compare among spatial options.

The information from STAR can be integrated into the multi-criteria analysis for ecosystem restoration.

For more information, see the IUCN STAR website and STAR on the Red List website.

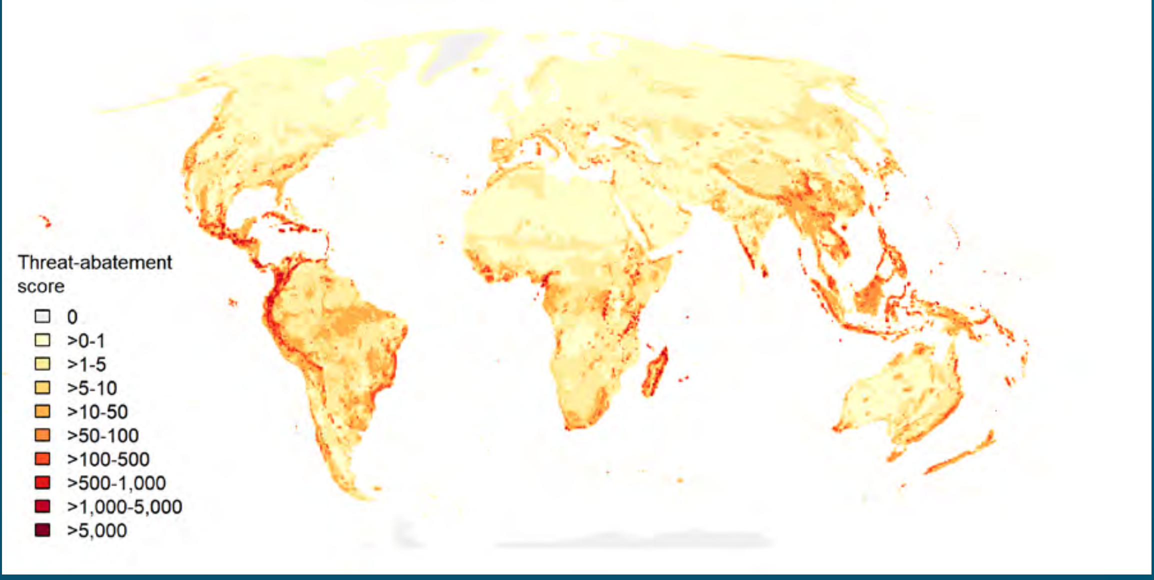


Figure 15: Global Species Threat Abatement and Recovery (STAR) scores for amphibians, birds and mammals (at a 50-km grid cell resolution). *Source: Mair et al. (2021).*[54]

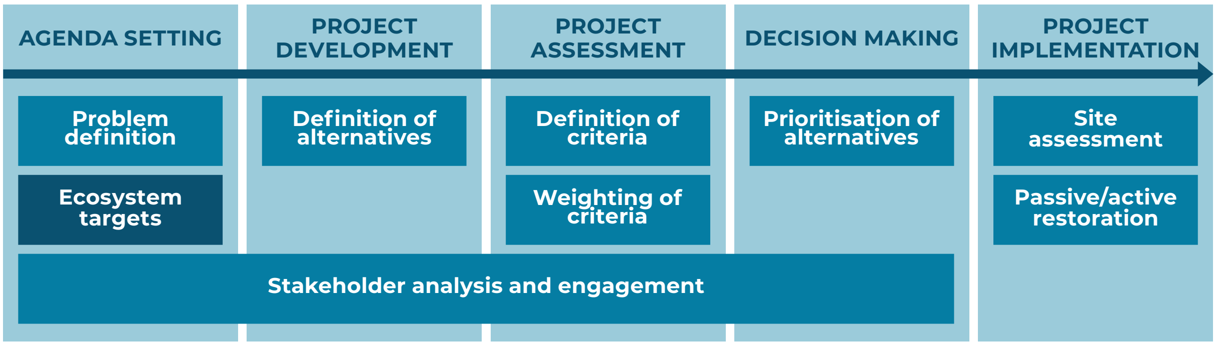


Figure 16: Idealised multi-criteria decision framework. *Source: Modified after Langemeyer et al. (2016).*[50]

Waste covers the river in Bandung. West Java, Indonesia. *Photo: Rony Ariyanto Nugroho.*

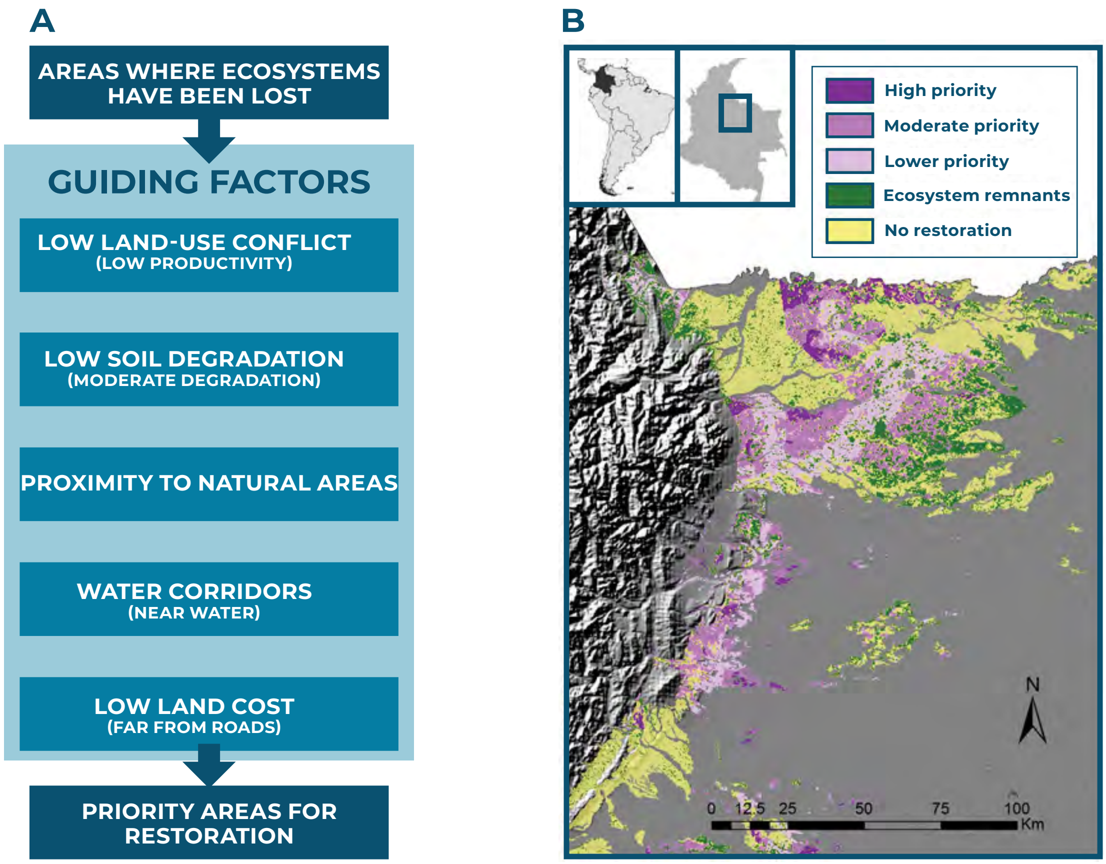


Figure 17: Identification of areas where restoration of at-risk ecosystems will be more suitable based on a multi-criteria approach. In this case showing the location of focus areas for restoration of the Critically Endangered Llanos foothills tropical forests of Colombia, based on a range of guiding factors used to select priority areas. *Source: Modified after Etter et al. (2020a).*[28]

Participatory planning

The coarse-filter priorities that have been identified must then be adjusted for the specific restoration project by incorporating a fine-filter ('bottom-up') approach to reflect, for example, the desires of stakeholders, current capacity for implementation, or anticipated consequences within and outside the restoration area. Just as the landscape or seascape has to be assessed, so too does the local capacity for implementing restoration. This includes traditional and local knowledge of the ecosystems that is important for understanding natural processes. The ability of local land users or practitioners to potentially modify their land-use practices, conduct restoration activities and protect restored areas will also affect outcomes. Balancing the needs of stakeholders for livelihoods or ecosystem services will at least partially determine the restoration activities that will be needed.

The support and cooperation of stakeholders can often determine whether restoration will reach its objectives, so thorough analysis of stakeholder interests in restoration outcomes must be conducted. Stakeholder engagement should be maintained from initial definition of the restoration problem (see Figure 16), through prioritisation of alternatives and ultimately implementation of restoration. The definition and prioritisation of possible alternatives should reflect the viewpoints and opinions of stakeholders. These alternatives could be in conflict and their resolution requires the complete transparency afforded by this process. This information is considered together in the multi-criteria framework to assign priority values for each stakeholder group. The outputs should point to areas of agreement or disagreement and preferred alternatives. One such framework for conducting multi-criteria analysis with stakeholders is the Restoration Opportunities Assessment Methodology (ROAM, Box 10).

Importantly, although they ultimately decide on restoration objectives and degree of recovery, stakeholders will not be able to make a truly informed decision, unless the planning process includes all required information to evaluate the range of alternatives with respect to both ecological and socio-economic outcomes.

This implies that regardless of stakeholders' objectives (from full recovery of native ecosystems to maximising goods and services), the process of restoration planning should be similar and include data on ecosystem risk, along with restoration feasibility and socio-economic factors.

Box 10: The Restoration Opportunities Assessment Methodology (ROAM)

ROAM is a tool for planning Forest and Landscape Restoration (FLR) that integrates the needs of stakeholders within an understanding of the landscape context.[43] ROAM identifies landscape restoration opportunities that are science-based, inclusive, demand-driven and country-owned. ROAM equips decision makers and stakeholders with critical knowledge and evidence on where and how to implement restoration and sustainable land management actions. Restoration practitioners – from governments to the private sector, communities, individual farmers, non-governmental organisations and international organisations – use ROAM to make restoration actionable at scale. To date, over half a billion hectares of land across the globe have already been assessed for FLR opportunities using ROAM, with more than 170 million hectares primed for restoration in 65 jurisdictions.

ROAM analyses and prioritises deforested and degraded areas to restore, responding to the benefits identified (such as biodiversity, water, food security, energy security) as a result of stakeholder and decision-makers' dialogues. Restoration activities are then selected based on participative multi-criteria mapping, using best science and knowledge contextualised to the local situation (from the perspective of degradation and landscape restoration objectives), combined with economic analysis.

Landscape restoration can be conducted at different scales, including national, sub-national, watershed, community and district planning units. ROAM combines a situation analysis of degradation with spatial analysis and biophysical and economic modelling, within a framework that assesses the social, political and institutional readiness to implement restoration. A ROAM process is designed to answer several important questions relevant to restoration, including:

1. Where is restoration socially, economically and ecologically feasible?
2. What is the total extent of restoration opportunities in the country/region?
3. Which types of restoration are feasible in different parts of the country/region?
4. What are the costs and benefits, including carbon storage and ecosystem services, associated with different restoration strategies?
5. What policy, financial and social incentives exist or are needed to support restoration?
6. Who are the stakeholders to engage?
7. What options exist to unlock finance for restoration?
8. How can restoration be scaled up?

Where available, ecosystem risk could be integrated into planned ROAM processes. This will enhance the evidence-based decision making for restoration activities and facilitate the ability to use restoration as a tool to reduce loss of ecosystem area and integrity. It will allow practitioners to measure and report the changes in ecosystem risk that result from restoration. In turn, the Red List of Ecosystems can benefit greatly from integration within a multi-stakeholder driven approach.

A range of information resources, guidelines and tools on ROAM are available at www.iucn.org/ROAM.

Setting ecosystem targets for strategic restoration

Restoration targets are important for guiding planning and decision making, as well as informing monitoring and evaluation at a later stage (see Chapter 5). Ideally, targets should be kept as simple as possible to ensure they are easily understood by decision makers and managers. Strategic targets should be set for ecosystem types, and should also include the reduction of the associated threats and impacts on the ecosystem. Such targets need to account for the processes that are placing ecosystems at risk, and be linked to reversing or preventing collapse. From the ecosystem risk perspective, restoration has two main outcomes: achieving the down-listing of an ecosystem to categories with lower risk, or preventing ecosystems from being up-listed to higher risk categories (Figure 13). These outcomes can inform target setting, and imply three overall types of targets for restoration (Figure 18):

1. Increasing area by gaining back portions of the ecosystem that have been lost.
2. Improving the integrity of remnant portions of the ecosystem.
3. Reducing threats and associated impacts (societal and from production) that may affect area or integrity of the ecosystem to minimise further degradation in the locations where the ecosystem still occurs.

Targets should be observable trends in improving the integrity and area of ecosystem types. For example, a target for a quantitative area that should be restored to a given reference state over a defined timeframe, or the degree of repair to a particular process in a remnant portion of an ecosystem type. The indicators established during the Red List of Ecosystems process (see Table 1) can provide quantitative targets that link directly to the risk categories (Table 4).

Construction barge unloads rock for reef restoration (see Box 11 for more details). Australia. *Photo: Adam Bolton.*

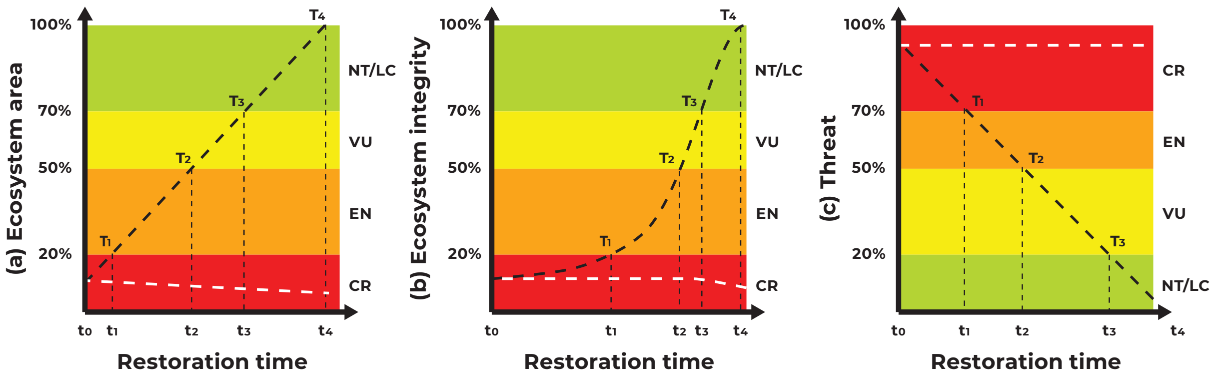


Figure 18: Types of targets to be addressed by restoration to achieve the down-listing of threatened ecosystems: (a) increase in ecosystem area; (b) improvement of ecosystem integrity; and (c) reduction of threat/s. Targets (Tn) and timeframes (tn) to reach stepwise down-listing of an ecosystem by improving the indicator. White lines indicate a trend with no restoration action. *Source: Compiled by the report authors.*

Because of the long timeframes involved to reach the ultimate outcomes of down-listing an ecosystem, targets should be progressive across different time intervals. For instance, the process of restoration may attain progressive levels of increased species numbers, biomass, soil quality, productivity and total area restored (Figure 18). The use of predictive modelling based on the function of the ecosystem, can account for non-linear behaviours of recovery to establish more realistic timeframes to reach recovery targets.[73]

Ecosystem targets can then be used for setting targets for local projects where this ecosystem is found. Local targets for specific restoration programmes might depend on what is feasible within an available budget, or on what aligns with the other objectives of the restoration programme.

Table 4: Example showing the area of the Critically Endangered 'Tropical lowland rainforests of the Llanos foothills' ecosystem type in Colombia that needs to be restored to reach each target that will result in a change in ecosystem risk (also see Figure 14 and Figure 17).

Ecosystem	Risk category	Original area (ha)	Remaining area (%)	Target 1: To reach EN		Target 2: To reach VU		Target 3: To reach NT/LC	
				(ha)	(%)	(ha)	(%)	(ha)	(%)
Tropical lowland rainforests of the Llanos foothills	CR	1,413,163	19.5	148 382	30	431 015	50	713 645	70

Box 11: Case study: Establishing ecosystem restoration targets for shellfish reefs in Australia

Contributed by Ashley Whitt (The Nature Conservancy)

Recent international initiatives, such as the UN Decade on Ecosystem Restoration, have highlighted opportunities to scale-up ecosystem restoration from the site level to whole systems, revitalising ecosystem services and public benefits and recovering whole ecosystems. One example of a globally relevant ecosystem type undergoing large-scale restoration are shellfish reefs, which are being restored at dozens of sites across Europe, Asia, Australia, New Zealand and the Americas.

To support local decision making on shellfish reef conservation in Australia, The Nature Conservancy conducted an IUCN Red List of Ecosystems risk assessment of Southern and Eastern Australian shellfish reefs, focusing on two community sub-types established primarily by Sydney rock oyster (*Saccostrea glomerata*) and Australian flat oyster (*Ostrea angasi*).[36] These shellfish reefs were categorised as Critically Endangered, largely due to severe historic decline in ecosystem extent (criterion A) and disruption of biological processes (criterion D) over the past 200 years, as well as low area of current occupancy (criterion B).

Insights from the ecosystem risk assessment were utilised to inform national restoration targets with the ultimate goal of down-listing the ecosystems from Critically Endangered to Vulnerable and ultimately reducing the threat of total ecosystem collapse. For instance, determining the number and extent of restoration sites was guided by criteria A and B. Analysis of historical records indicated that reefs were previously present in at least 200 locations across Australia, with only seven extant sites remaining (a threat category of Critically Endangered). A Vulnerable category could be achieved by restoring 30% of the historical distribution, translating to a national target of 60 sites for restoration. Principles from criterion B and knowledge of reef connectivity guided the definition of sites and spatial separation. A successfully restored site needed to comprise of multiple patch reefs occurring over at least a 5 ha area (to define multiple patches within a site). A notional distance of 10 km (aligned to grid size in Area of Occupancy measures) between sites was used to distinguish independent sites. The concept of area of extent, and susceptibility to spatially explicit threats, was used to consider the need for sites across the full historic distribution of the ecosystem, rather than a concentration of project sites in one jurisdiction (which is logistically easier). Criterion C, environmental degradation, was used to support site selection including the development of restoration suitability models. Lastly, the ecosystem model, in addition to known methods for restoration[32] helped identify the type of restoration required at each site (for example, threat abatement, partial versus full restoration).

The Red List of Ecosystems framework provided a logical and replicable process that assisted The Nature Conservancy in designing national restoration targets and a restoration programme supported by science. The clear framework and logical rationale for site selection and goal setting was easy to convey to policy makers and the public. Having a numerical target was critical in developing estimates of the social and economic benefits for restoration (for example, number of jobs and volunteer positions created, tonnes of fish produced, litres of water filtered) and cost for each site to restore 5 ha of reef. This information was used to help secure a AUS$ 20 million investment from the Australian Commonwealth Government in 2020 towards 13 new sites, in addition to further investment from State Governments and the Australian Philanthropic community. To date, 20 sites are in the process of being restored, or have been restored (Figure 19), with the Reef Builder initiative now considered Australia's largest underwater restoration programme.

Box 11 (continued)

Figure 19: Conceptual drawing of the restoration process for a shellfish reef. *Source: Drawing by Katie Shriner, courtesy of The Nature Conservancy.*

Oyster reef, a Red Listed ecosystem with Critically Endangered (CR) status. Southern and Eastern Australia. *Photo: Chris Gilles.*

Further reading:

Assessing restoration priorities for high-risk ecosystems: An application of the IUCN Red List of Ecosystems. https://doi.org/10.1016/j.landusepol.2020.104874

Guidelines and tools on ROAM are available at: www.iucn.org/ROAM

Information on STAR methodology is available at: https://www.iucnredlist.org/assessment/star

Multi-species plantation (shade coffee), Chikmagalur, India. *Photo: Prashantby.*

Chapter 4: **Applying ecosystem risk assessment to site-level restoration**

James G. Hallett, University of Montana and Society for Ecological Restoration
Cara Nelson, University of Montana and IUCN Commission on Ecosystem Management
Josie Carwardine, CSIRO Australia

This chapter explores how to progress from identifying the ecosystem types and locations that are priorities for restoration, to operationalising a programme of restoration work at the local scale. Spatial prioritisation can be used to identify opportunities for restoration at watershed, regional or national levels. Once these are completed, analyses focused on the local context are necessary to determine the appropriate type of restorative intervention to deploy at a particular site. Ecosystem restoration includes a broad range of approaches from reducing human pressures causing degradation, to fully recovering native ecosystems (see Figure 3). At the local level, restoration activities should be designed to reduce threats and improve ecological integrity, either in areas where ecosystems have been extirpated or in degraded remnants.

From landscapes and seascapes to local-scale restoration planning

Undertaking a landscape- or seascape-scale assessment of restoration priorities, as described in Chapter 3, is critical prior to planning restoration at the local scale because ecosystems are affected by and have effects on the larger context in which they are embedded.[25] Therefore, their management cannot occur in isolation, but rather requires explicit consideration of the types and proportions of ecosystems within the landscape or seascape, the spatial organisation of the units, and linkages among composition, structure and function (see Figure 2). For example, because threats from the larger landscape or seascape cause degradation at the local level, local restoration activities may fail if they have not been identified and mitigated. Furthermore, vital ecosystem services, such as water regulation and climate mitigation, often accrue at the landscape or seascape scale. Thus, for on-the-ground restoration activities to provide benefits to ecosystem integrity or human well-being, they must be strategically deployed across the larger landscape or seascape (Figure 20). In fact, managing functions, flows of energy, nutrients and other subsidies through the landscape or seascape may be as, or more, important than managing composition and structure within individual ecosystems, especially for the delivery of ecosystem services. Therefore, activities intended to impact ecosystem services that benefit society require landscape-or seascape-scale approaches integrated with site-specific activities.

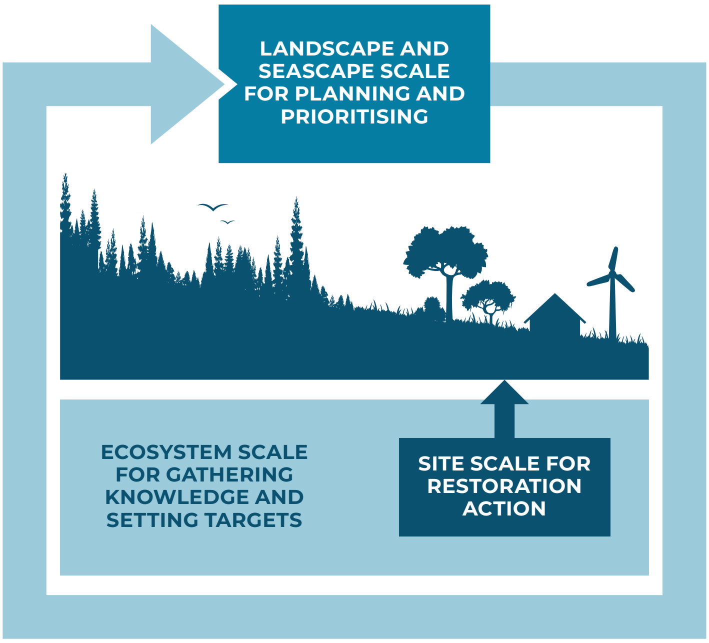


Figure 20: Restoration activity is conducted at sites, but must be set within the broader context of ecosystems and landscapes or seascapes. *Source: Compiled by the report authors.*

Local-scale restoration activities to reduce ecosystem risks

The previous chapter explored the two types of areas to conduct ecosystem restoration (that is, areas where an ecosystem has been lost, and degraded areas of remnant ecosystems). Once these areas have been identified, there are two complementary ways that restoration activities may reduce risks to ecosystem types:

1. **Reducing existing or potential future threats,** including those that cause ecosystem loss (a threat to ecosystem extent) and threats that degrade the ecosystem, such as invasive weeds, pests and inappropriate fire or grazing regimes.
2. **Improving the integrity of the ecosystem**, by carrying out restorative activities such as reintroducing extirpated native species and restoring ecosystem processes.

Eliminating the root causes of degradation is essential before recovery can be initiated. Improving the integrity and extent of the ecosystem through restoration is key to increasing the resilience of the ecosystem to future threats.

Actions to abate threats for site-level restoration

The Red List of Ecosystems framework includes an assessment of the threats affecting the ecosystem's risk category based on the IUCN threat classification scheme.[42] Actions can then be targeted to overcome these threats and restore degraded processes to reduce the risk to the ecosystem. For example, criterion D indicators of biotic disruptions might be affected by invasive weeds. Understanding the link between the threatening process and the overall risk of collapse of the ecosystem is a key step in determining the type of restoration activity needed.

Additional information will need to be combined with the Red List of Ecosystems data, such as information on costs and benefits, and the social and technical feasibility of abating each threat, including considering the drivers of each threat and the stakeholders involved.[14] The steps and considerations for deciding how to address threats to improve ecological integrity and to prevent ecosystems from escalating towards collapse are shown in Figure 21.

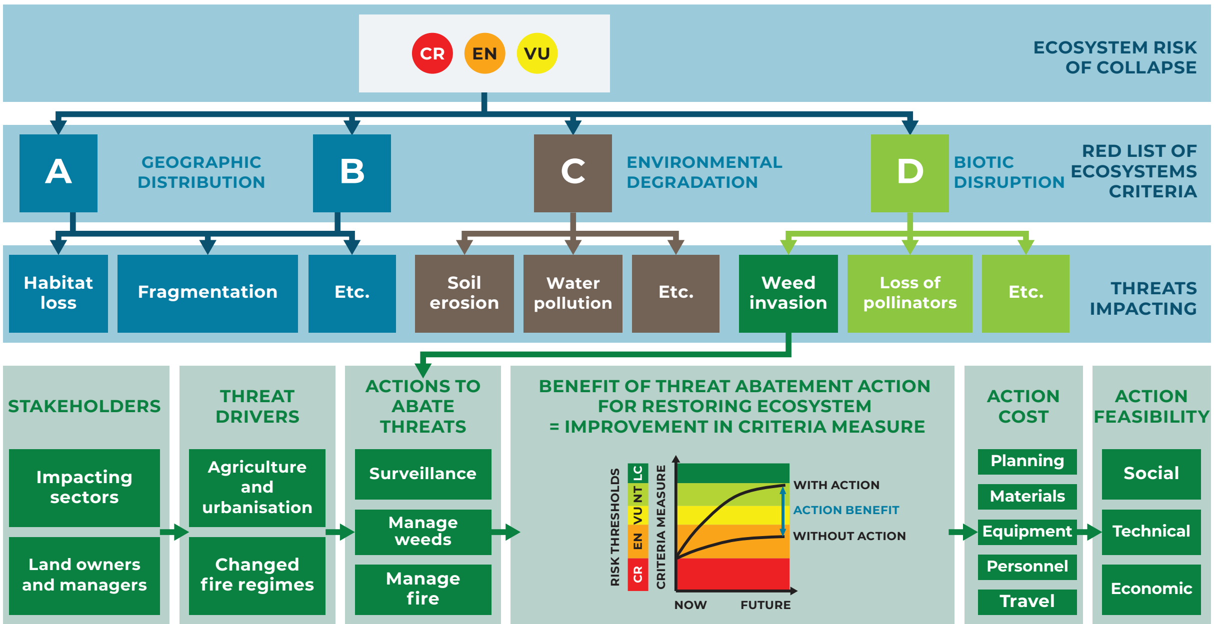


Figure 21: The process for identifying priority threat abatement activities for reducing risks to ecosystems. An example showing how weed invasion affects criterion D, and how reducing weeds through threat abatement activities could improve the ecosystem's score for this criterion. *Source: Compiled by the report authors.*

Threat abatement activities should be designed by experts with knowledge about both the ecological and social dimensions of managing threats. This will allow for social preferences, costs, funding and the availability of reliable management practices to be considered in the implementation of threat abatement actions. When defining threat abatement actions, it is useful to break these down into specific activities needed to implement a given action, allowing each one to be planned for, including identifying key steps, information collection

Bushfires below Stacks Bluff. Tasmania, Australia. *Photo: Matt Palmer.*

and planning, stakeholder engagement, policy change, on-the-ground management of the threat, and monitoring efforts. Costs for each step should be estimated.

It is critical to consider the driving factors behind each threatening process when determining the best activities to overcome threats, which often involves looking more broadly than the restoration site. In Australia, for example, the introduction and spread of weeds can occur as a result of some agricultural and urbanisation activities, or changed fire regimes.[31] In some cases, enabling an on-the-ground action such as weed management, will require cooperation and agreement amongst key stakeholders, such as land owners or high-level managers of particular sectors, implicated in the threatening processes or its management. Without overcoming these barriers, on-the-ground activities can be ineffective or even infeasible.

The information can be brought together in a prioritisation framework to help choose the activities to be undertaken to restore the integrity of an ecosystem at a site. The Priority Threat Management (PTM) process was originally designed to prioritise the management of threats to biodiversity but can equally be applied to managing risks of ecosystem collapse.[14] When applying PTM, an objective is set for each problem. For example, the aim could be to identify the most cost-effective management strategies to reduce the risk of collapse of an ecosystem at a site, helping the ecosystem achieve a down-listing from Critically Endangered to Endangered. To do this, it would be necessary to identify all the activities that could assist in improving the ecosystem's risk at the site level. In some cases, more than one action is possible to abate a threat or restore an ecological process. A simple measure of the relative priority of activities for achieving this target would be estimated by the likely benefit of the activity (such as improvement in the measure of risk, or reduction in the threat), divided by its cost. The approach can also be used to identify the set of threat abatement strategies that most efficiently meets the prespecified target for site level risk reduction.

Thorny Desert. Cataviña, Mexico. *Photo: David Keith.*

Restoration actions to improve ecosystem integrity

In addition to removing threats, restoration aims to improve ecosystem integrity. There is a continuum of approaches to restoration, ranging from entirely passive (where after threat abatement, natural processes are responsible for recovery) at one end of the continuum, to entirely active (where recovery is initiated through reintroducing organisms or modifying the abiotic environment) at the other. The selection of approach largely depends on the degree of degradation (Figure 22). For example, allowing spontaneous natural regeneration is a cost-effective approach to restoring ecosystems, where degradation has not been severe and propagule sources are available on site or via dispersal from the larger landscape or seascape. More active intervention (such as water harvesting, returning appropriate disturbances, installing fauna attractants and managing competition) is also widely used across the world to assist natural regeneration where it has been stalled. A hybrid approach that combines regeneration treatments with some reintroduction of plants and animals is applied when natural regeneration is insufficient, and extensive reintroduction is used to rebuild ecosystems when regeneration potential is fully depleted.

Information from the Red List of Ecosystems assessment, and specifically indicators of criteria C and D, can help determine whether biotic or abiotic thresholds have been crossed (see Figure 22). The spatial analyses described in Chapter 3 can also provide information on the extent to which natural regeneration is possible relative to other features in the landscape or seascape. Where ecosystem integrity is the goal, restoration should promote natural processes of recovery and actively assist when necessary. Assistance can take many forms depending on the ecosystem and can include soil amendments, hydrological changes, invasive plant and animal control, and reintroductions of species. Different types of restoration activity will also have different related costs and benefits.

Rangeland and grassland health assessments (see Box 12 for more details). Northern Kenya. *Photo: Pauline Kiamba.*

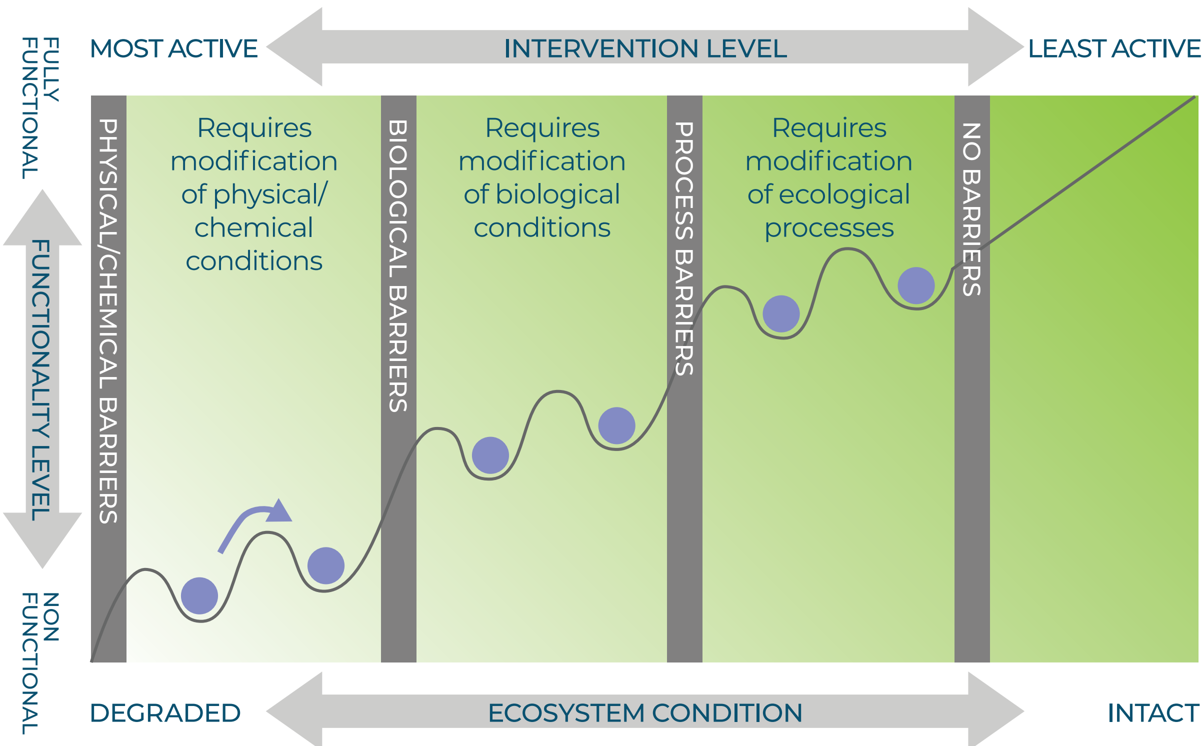


Figure 22: Approaches to restoration based on ecosystem condition and with respect to biotic and abiotic barriers. This representation does not imply a linear pathway, but illustrates one of several possible dimensions of restoration, depending on the ecosystem, landscape or seascape, and the socio-ecological context. Note: The requirement of abiotic modifications, biotic reintroductions or improved management may not be in this sequence nor will they necessarily apply to all species at a site. *Source: Reference Group SERA (2021) modified after Whisenant (1999).*[71,94]

Box 12: Case study: Assessing rangeland and grassland health to inform restoration in Kenya

Contributed by Bora Masumbuko and Jonathan Davies (IUCN)

Rangelands are land on which the indigenous vegetation is predominantly grasses, grass-like plants, forbs or shrubs that have the potential to be grazed. They are natural ecosystems used for the production of grazing livestock and wildlife.[2] Rangelands cover more than half of Earth's free land surface,[41] and provide vital ecosystem services that support local communities, including climate regulation, livestock production and biodiversity conservation. Rangelands contribute to achieving the Sustainable Development Goals and Land Degradation Neutrality. Despite their importance, rangelands receive few investments and attention. As a result, rangelands continue to experience degradation, with negative environmental, social and economic impacts.

The Food and Agriculture Organisation of the United Nations (FAO) and IUCN have developed a methodology, known as the Participatory Rangeland and Grassland Assessment (PRAGA) methodology, to assess rangeland and grassland health based on a combination of scientific and local knowledge. The methodology aims to fill existing gaps in rangeland assessment by increasing awareness of degradation processes, using large-scale ecosystem assessment, and strengthening the capacity of stakeholders to assess land degradation and make evidence-based decisions. A core component of the methodology is participation by relevant stakeholders.

In Kenya, more than 75% of total land area is classified as arid and semi-arid. Land degradation is more pronounced in arid and semi-arid areas. The direct cost of land degradation in the country was approximately US$ 1.3 billion per year between 2001 and 2009.[62] The methodology was piloted in northern Kenya, most of which is arid or semi-arid, where the large pastoral populations depend on rangeland resources for their livelihoods. A participatory community mapping exercise identified an assessment area of 7,253 km^2. Landscapes were selected based on pressure to the rangelands, presence of rangeland governance challenges and the heterogeneity of the landscape. Communities classified their landscapes at macro and micro levels. At the macro level, the landscape is divided into ecosystems – generally forest or lowlands. Remote sensing data provided evidence of degradation. Local pastoralists then complemented these data by describing the degradation status of the landscape.

Results of the rangeland assessment revealed that the health of the assessment landscape is relatively good. The assessment helped to better understand the pressures on rangelands and drivers of degradation. It also highlighted the importance of monitoring rangeland health to detect land degradation and inform restoration activities. A Red List of Ecosystems assessment was not carried out. However, a Red List of Ecosystems assessment would complement this methodology by further identifying the main risks and impacts on rangeland ecosystems. Furthermore, a Red List of Ecosystems in the future could help to inform the prioritisation of restoration activities based on scientific evidence, rangeland management and landscape planning.

For more information see:

- Policy brief for Kenya.
- PRAGA project.

Kenyan rangeland and grassland assessments (sex Box 12 for more details). Kenya. *Photo: Bora Masumbuko.*

Standards of practice for implementing restoration

Once restoration activities have been selected, best practice must be followed to increase the likelihood of successful restoration implementation. Detailed standards of practice are available for ecological restoration,[34] and an inventory of standards for specific sectors and biomes is forthcoming. Standards of practice should be followed with respect to the following steps for all restorative activities:

Achieving the highest level of recovery possible: An underlying principle of ecosystem restoration is that it aims to achieve the highest level of recovery possible. This means that in analysing which type of restorative activity to deploy, practitioners should consider the extent to which ecological restoration (partial or full recovery of native ecosystems) is possible. Ecosystem restoration should result in net improvement in both ecological condition and human well-being. As a practical matter, however, there are often trade-offs between the magnitude of ecological benefits and delivery of ecosystem goods and services that support people. To manage these trade-offs, stakeholders must undertake a deliberate decision-making process (see Multi-criteria approaches to assess restoration opportunities). Such trade-offs are often an inevitable feature of restoration interventions, and therefore require that their likely consequences are properly assessed, fully disclosed and agreed upon by the most affected stakeholders.

Site assessment: Evaluation of the restoration site focuses first on determining the factors responsible for degradation currently or in the past (for example, high cover of invasive weeds, overgrazing, soil disturbance). Second, the presumed likelihood of natural regeneration must be assessed by examining the composition and structure of the ecosystem. The presence of native ecosystems that exhibit diversity in both species and structure or evidence of natural regeneration both suggest a good likelihood of recovery. Prior land-use or soil disturbance, on the other hand, can reduce the availability of propagules for natural regeneration. Both factors inform restoration planning and prioritisation. When funds are limited, for example, emphasis might be placed initially on sites that are most likely to recover naturally if threats are removed.

Box 13: Adaptive management for restoration

Adaptive management is the process of incorporating new information into the implementation of a project or plan to ensure that the goals of the activity are being reached efficiently. It promotes flexible decision making to modify existing actions or create new actions if new circumstances arise (for example, new scientific information) or if projects are not meeting their goals.

Adaptive management is a systematic approach for improving restoration that includes learning from management outcomes and other available information.[96] Application of adaptive management acknowledges the uncertainty in our understanding of ecosystem behaviour in response to restoration activities and to changes in environmental conditions (for example, variability in precipitation, adjacent land-use changes).

Intrinsic to the entire decision-making process for restoration (Principle 9, Box 2), adaptive management begins during the initial processes of stakeholder engagement and planning, and continues throughout project implementation (Figure 23). As our understanding of ecosystem dynamics improves from monitoring, scientific research, and other information that may become available, changes in restoration activities or in management goals and objectives can be made.

Adaptive management is not unique to ecosystem restoration and has been useful in achieving conservation and international development objectives. The Open Standards for the Practice of Conservation provides standardised terminology and description of the steps in an adaptive management project cycle.[16]

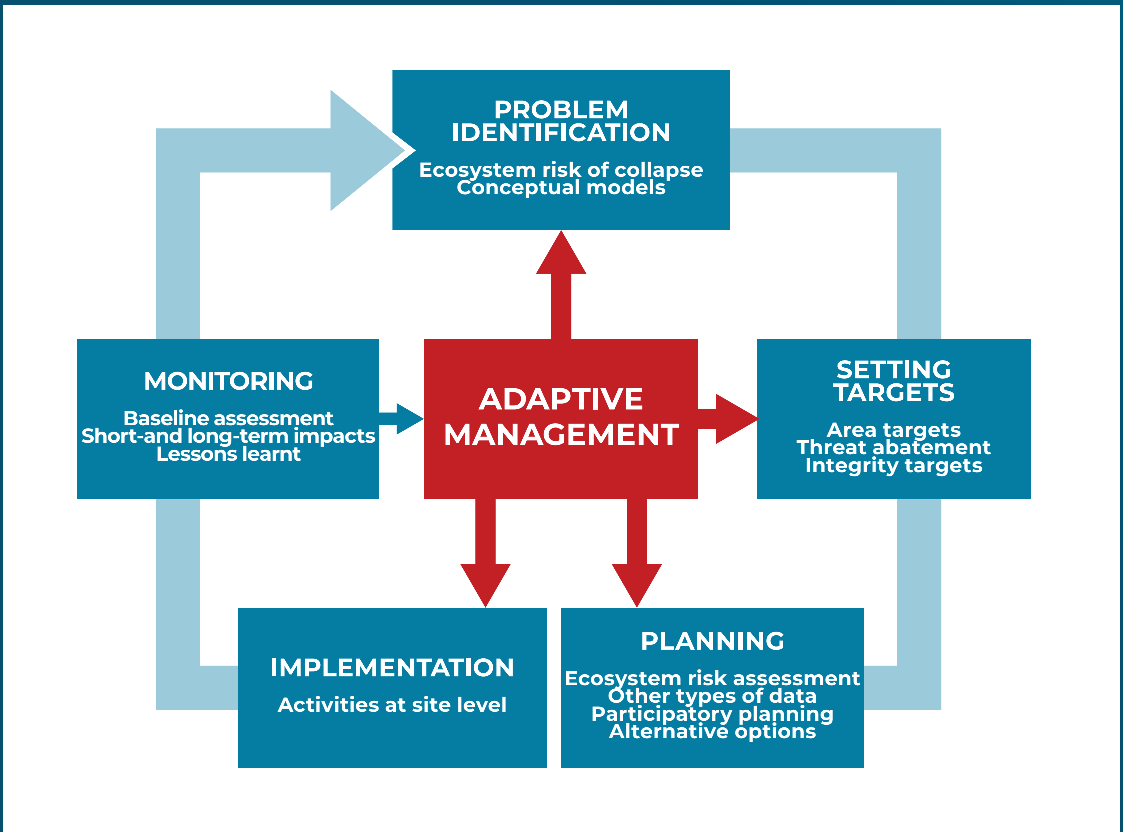


Figure 23: Adaptive management should occur throughout the decision-making process for restoration. *Source: Compiled by the report authors.*

Implementation: Restoration activities are initiated according to the plan of work devised after research into ecologically appropriate management options, stakeholder consultation, determination of the availability of required resources (for example, financial and material) and workforce available. As appropriate, local stakeholders should be encouraged to participate in the restoration. Adequate training should be provided to ensure that all practitioners conduct the work competently and without lasting harm to areas within and outside the project site. Although not all activities will be designed to improve ecosystem composition, structure and function (for example, agroforestry), they should avoid degradation of any of these (for example, by spreading invasive organisms and chemical contaminants).

Monitoring, evaluation and reporting: The implementation, effectiveness and effects of restoration activities need to be monitored using reliable approaches (see Chapter 5). Regular assessment of the change resulting from restoration will indicate the extent to which ecosystem changes are or are not desired or anticipated. Stakeholder participation in monitoring, including developing monitoring questions, collecting and analysing data, may improve understanding and engagement in the restoration process. Because restoration proceeds over long timeframes, all information about the planning and decision making, details of implementation, monitoring and reporting should be maintained. This archive will inform both adaptive management (Box 13) and other restoration programmes in similar ecosystems (see Box 14).

Post-implementation: Project life cycles are rarely more than a few years, which is generally inadequate to realise the objectives of large restoration initiatives. Many projects that appear successful in the near-term have ultimately failed because the areas under restoration have been converted to other uses.[38] Consequently, continued investment in monitoring and evaluation, as well as stakeholder engagement, is as essential as any subsequent maintenance that may be required to prevent renewed degradation.

Further reading:

International principles and standards for the practice of ecological restoration.[34] https://onlinelibrary.wiley.com/doi/10.1111/rec.13035

Priority Threat Management for biodiversity conservation: A handbook.[14] https://doi.org/10.1111/1365-2664.13268

The open standards for the practice of conservation.[16] https://conservationstandards.org/

Underground water project in Jomblang Cave. Java, Indonesia. *Photo: Muhammad Sidik/CIFOR-Kanoppi Project.*

Chapter 5: **Monitoring the effects of restoration activities on ecosystem area, integrity and risk of collapse**

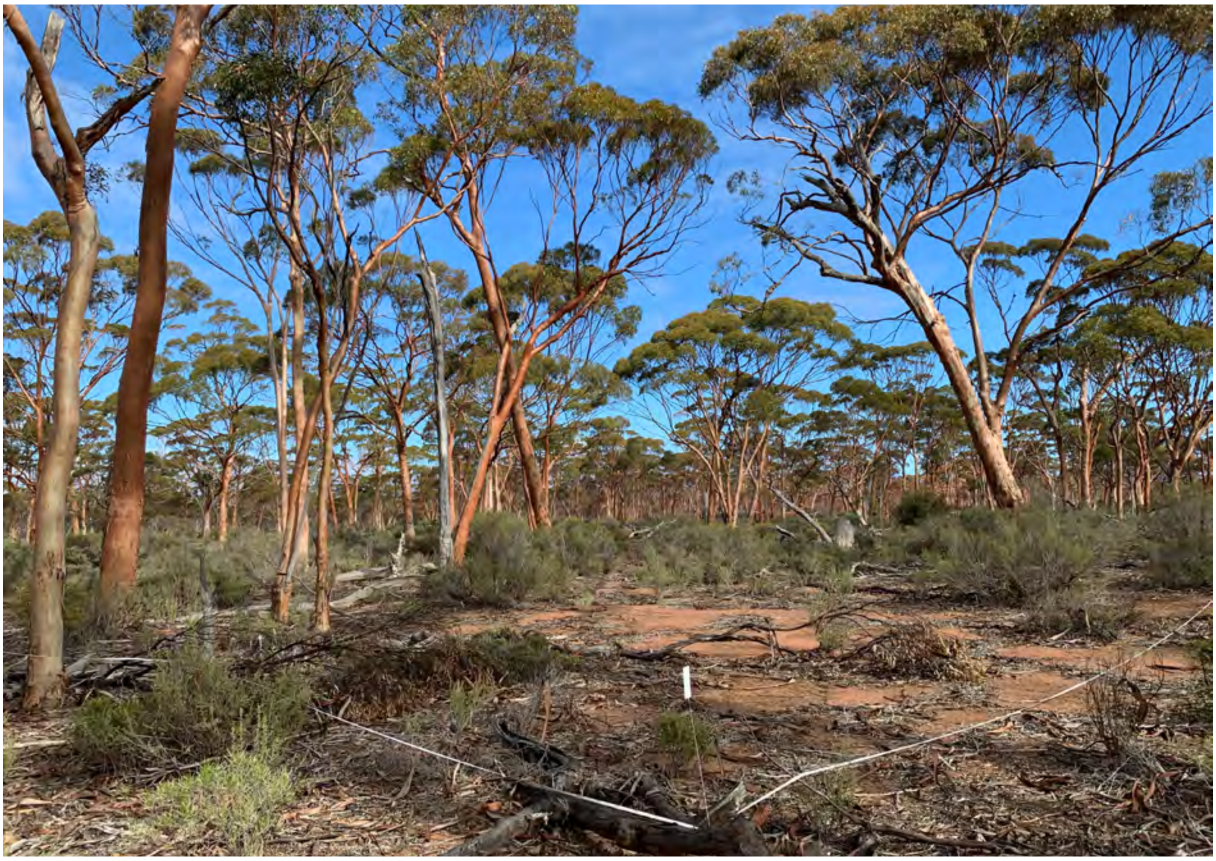
Cara Nelson, University of Montana and IUCN Commission for Ecosystem Management

This chapter explores methods for assessing the success of ecosystem restoration from the lens of ecosystem types and their risk of collapse. Despite widespread understanding of the importance of monitoring, many restoration projects and programmes do not include adequate assessment of progress.[9] This chapter aims to improve monitoring and evaluating the impacts of restoration on ecosystem area, integrity and, ultimately, risk of collapse, by clearly describing key approaches to monitoring. These range from assessing the implementation of the spatial prioritisation process, to evaluating the efficacy and effects of restoration activities at local, ecosystem and landscape or seascape scales. The chapter also explores how the Red List of Ecosystems can be useful in monitoring the state and trends of ecosystem integrity, and the effectiveness of restoration activities. The chapter ends with a call to report monitoring results to global initiatives, so that lessons can be shared and the contribution of restoration to global initiatives, such as the Global Biodiversity Framework and Sustainable Development Goals, can be demonstrated.

Note that this chapter focuses on monitoring ecosystem area, integrity and risk of collapse. Given that specific focus, it does not cover monitoring the effects of restoration on human health or well-being, nor the effects on any measures of socio-economic or cultural variables, despite the fact that by definition ecosystem restoration activities should result in net gain for people.

Elements of an effective monitoring programme

For monitoring to be effective at generating knowledge about the impacts of ecosystem restoration on ecosystem area, integrity and risk of ecosystem collapse, it must be done in the context of a comprehensive monitoring programme (Figure 24).[53] The monitoring programme needs to have a detailed plan that articulates the questions to be addressed, as well as instructions for collecting, managing, archiving and analysing data, interpreting results, sharing findings and applying lessons learned to ongoing and future restoration efforts, and evaluating the efficacy of the monitoring programme itself. It is critical to plan the monitoring programme at the same time that the restoration project or programme is designed, rather than after implementation. This enables managers to develop adequate



Monitoring plot in a Salmon Gum Eucalyptus salmonophloia (wurak or weerluk) ecosystem. Great Western Woodlands, Western Australia. *Photo: Suzanne Prober/CSIRO.*

project budgets to complete all phases of the monitoring programme. Equally as important, it allows monitoring questions to be directly linked with restoration objectives. Restoration objectives can only be monitored for success if they are clearly described in planning documents, with specific measurable indicators that include the amount of change desired and a specified timeframe (see Chapter 3, Setting ecosystem targets for strategic restoration). For example, a measurable indicator could be to 'increase by 40% compared to 2020 levels the number of breeding pairs of a key species within 10 years', or to 'reduce by 20% compared to pre-treatment conditions the nitrogen load into a wetland system within five years'.

An effective monitoring programme includes more than just a plan for collecting data. Successful monitoring programmes must also include: data management (cleaning, meta-data documentation and archiving); conducting statistical analyses and using the data to tell a story about treatment impacts; sharing lessons learned with relevant stakeholders; applying lessons learned to adaptive management within and across programmes; and assessing the efficacy of the monitoring programme itself. If any of these elements are missing, resources invested in monitoring and evaluation will be wasted. For instance, if the questions are not detailed before data is collected, there is a high probability of collecting information that is not needed and not collecting data that is critical for analysis. If data are not appropriately archived with meta-data documentation, it may be impossible to access data collected in previous years to assess trends observed in future ones. For this reason, archiving data in a public database is recommended. Best practice for ensuring that each required element of the monitoring programme is implemented is to include specific details about each component of monitoring in the project plan, including the amount of funding needed for each.

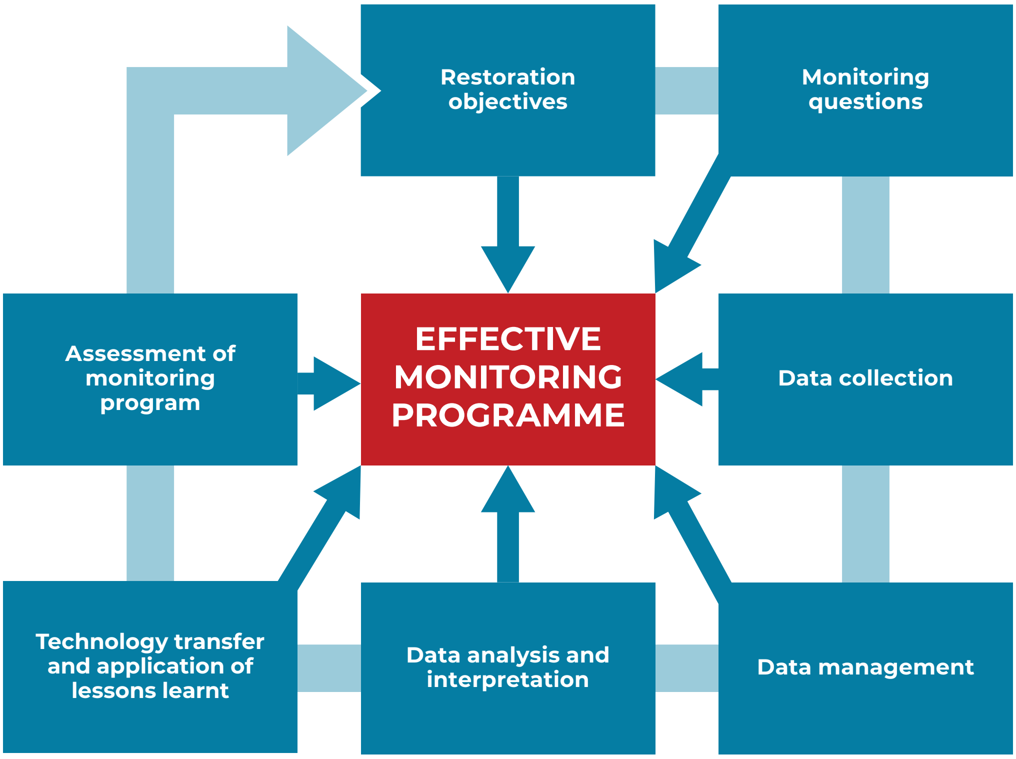


Figure 24: Elements of an effective ecological monitoring programme. *Source: Compiled by the report authors.*

Types of monitoring questions and designs

There are three general types of monitoring.[34,51] Each addresses a different type of monitoring question and requires a specific sampling design.

Implementation monitoring addresses the question of whether restoration activities were implemented as planned. It requires having detailed treatment information in project plans and involves comparing planning documents with data collected during and immediately after treatments are deployed. Implementation monitoring can also be done to assess whether treatments were located in areas that are the highest priorities for restoration (see Chapter 3),[77] the extent to which treatments were implemented according to the prescription (for example, number of seedlings planted per hectare), as well as to assess variables related to the treatment itself (for example, flame length achieved for prescribed fire) or environmental conditions when the treatment was conducted (for example, temperature and moisture conditions). Information on the treatment is often necessary to interpret monitoring data. For instance, to understand the effects of a prescribed fire treatment, it is critical to know the number of monitoring plots that experienced fire and, for those that did, the intensity or severity of the fire. This information may be easy to collect immediately after the treatment is implemented, but increasingly difficult with time since treatment.

To conduct implementation monitoring, managers must appropriately document information on the treatments that were employed. The specific types of information that should be documented varies by type of treatment and project, but generally the following details should be included in treatment reports:

Sand erosion fencing in the Outer Banks. North Carolina, United States. *Photo: Cvandyke/Shutterstock.*

- The specific types of management activities implemented, including the materials used and intensity of treatment (for example, basal area removed, density of planted seedlings, flame lengths of prescribed fire or measures of fire severity, active ingredients and strength of application of herbicides).
- Provenance of any biota used on the project.
- The geographic area where the treatment was employed, including the treatment boundary and, within the boundary, areas where the treatment was and was not implemented.
- The dates when the treatments were implemented.
- Environmental variables associated with the treatment application, if relevant (for example, temperature, wind speed).

Efficacy monitoring is done to assess whether restoration objectives have been achieved. There are two primary approaches to efficacy monitoring, and the approach selected should be dependent on the specific questions that practitioners have about project success:

1. If the question is whether a particular project objective has been met (for example, specific number of breeding pairs of a target species), it is generally only necessary to collect data from treated sites after treatment. Here, the comparison is between the condition after treatment with the stated project objective.

2. If the question refers to the extent to which ecological integrity has been restored, best practice is to sample and compare indicators of integrity (see Selecting indicator variables) in treated areas after treatment with a reference model (see Box 5).[34,60]

Efficacy monitoring is important for tracking progress toward objectives, but does *not* allow determination of whether – or the extent to which – the restoration activities were directly responsible for achieving the objective. In other words, this type of monitoring cannot be used to determine if the treatment caused the outcome observed.[68] This is because indicators being assessed may have changed over the assessment period due to factors other than the restoration treatment (for example, annual variation in precipitation that could affect plant cover, or spatial variation among sites irrespective of the treatment having an effect). If stakeholders are interested in knowing the extent to which treatments were responsible for the observed changes, it is necessary to use an approach that specifically allows detection of causal relationships (effects monitoring).

Effects monitoring assesses the direct effects of the restoration activities on indicators of ecological integrity. To do so, it is necessary to compare the magnitude of changes pre-to-post treatment in treated areas with the magnitude in untreated control areas (areas that are similar to those scheduled for treatment in terms of abiotic environment, biotic condition and degradation, but that will not be treated).[68] This type of monitoring involves sampling both before and after treatment in areas scheduled for treatment as well as control areas. Although effects monitoring is the most intensive in terms of sampling time and effort, it avoids confounding treatment effects with temporal variation (for example, annual variation in temperature and precipitation that could influence survival or growth) or spatial variation (for example, site-to-site variation in species composition or population growth rates). Effects monitoring can be used to assess both intended and unintended consequences of treatments (positive and negative effects) and, therefore, can be used even if projects did not include measurable objectives.

Citizen scientists monitoring abundance of noxious weeds in a grassland. Western Montana, USA. *Photo: Cara Nelson.*

Assessing efficacy and effects of restoration on ecosystem area and integrity

Given the potential contribution of restoration to increasing the integrity and area of ecosystem types, it is critical to know whether restoration activities are having their intended effects – specifically the effect of restoration on improving the ecosystem risk category. The Red List of Ecosystems framework assists with this type of monitoring by providing a framework for selection of monitoring variables and benchmarks from which to measure progress, and allows managers to understand the extent to which restoration activities lead to down-listing threatened ecosystems.

A former fisherman plants corals. Indonesia. *Photo: Martin Colognoli/Ocean Image Bank.*

Selecting indicator variables

The contribution of site-based restoration to ecosystem risk status can be assessed by monitoring the efficacy and effects of restoration interventions on ecosystem integrity and ecosystem area. To do this, it is critical to select indicators from the Red List of Ecosystems assessment, where two categories of indicators of ecological integrity are specified (see Table 1):

- Physical (abiotic) conditions of the ecosystem (criterion C).
- Biotic elements and interactions, including composition, structure and ecological functions of the biota (criterion D).

Within these broad attributes, selecting an appropriate set of ecosystem-specific indicators of ecological integrity is key to performance evaluation. The specific indicators will vary by ecosystem type. To be able to monitor the impact of restoration on risk of ecosystem collapse for a given ecosystem type, the same indicators used to determine ecosystem risk category (those used in the Red List of Ecosystems assessment) should be considered for use. However, it may not be feasible to collect data for all indicators used in the original assessment. Best practice is to include at least several metrics each of physical condition, composition, structure and function at both the ecosystem and landscape or seascape scales.[34,35,48]

For each indicator of ecosystem integrity that is monitored, restoration success (or degree of recovery) can be measured as degree of similarity to the reference state (Figure 25), also commonly referred to as 'response ratios'.[7,60] This is a univariate approach, in which each indicator variable is assessed independently and overall recovery is determined through evaluation of the full suite of indicators. For each variable, there is a threshold value for ecosystem collapse included in the Red List of Ecosystems assessment. Monitoring recovery of each variable with respect to this threshold allows determination of when restoration has achieved a sufficient level of ecological integrity that the ecosystem could be considered partially or fully restored (and thus contribute to an increase in area of that ecosystem type).

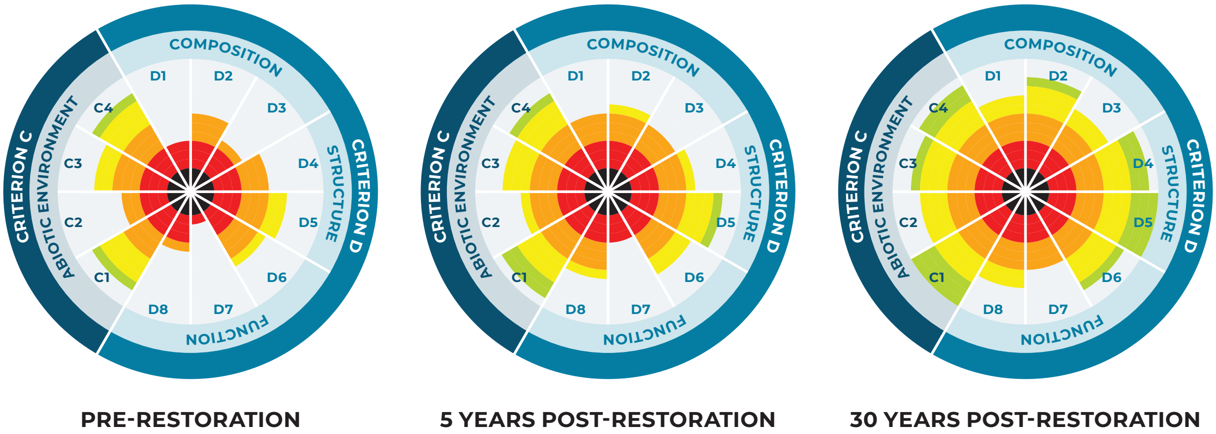


Figure 25: Hypothetical results of change in ecological integrity from pre-restoration (first panel) to 5 years (middle panel) and 30 years (right panel) after restoration, for physical (criterion C), and compositional, structural and functional (criterion D) attributes. Specific indicator variables (separate wedges labelled with letters and numbers) would vary by ecosystem type and project or programme. Shading indicates degree of degradation (pre-restoration) and recovery (post-restoration) for each indicator variable. The colours correspond to the Red List of Ecosystems risk categories: Black = Collapsed; Red = Critically Endangered; orange = Endangered; Yellow = Vulnerable; Green = Near Threatened. In this example, the ecosystem is degraded to such an extent that even five years post restoration, it is categorised as Critically Endangered. After 30 years, attributes of integrity have recovered above the threshold for Endangered. *Source: Modified after the 'recovery wheel' for ecological restoration, Gann et al. (2019).*[34]

In addition to univariate approaches, multivariate procedures can be powerful tools for assessing overall similarity to the reference state or effects of restoration activities. For instance, if data are collected on multiple species, it is possible to measure overall 'percent dissimilarity' with respect to all species measured (for example, Sorenson's community coefficient[61]). Similarly, multiple measures of ecosystem structural attributes can be combined using multivariate ordination.[95] Multivariate approaches, like ordination, are not just useful for determining changes in multiple indicators of an attribute (for example, composition, structure or function), but can also be used to assess changes in overall ecosystem integrity (considering all indicator variables of all attributes). If a multi-dimensional approach is desired, it is critical to use statistically valid multivariate techniques rather than creating indexes from univariate measurements.

Generally, monitoring and evaluation focus on site-level indicators. It is equally important, however, to monitor variables at the landscape or seascape scale, outside of the project or programme border. If threats from the larger landscape are not addressed, investments in site-level restoration may not be warranted.

Furthermore, some variables related to ecosystem integrity can only be evaluated at the landscape or seascape scale, because effects are cumulative across the landscape or seascape and not limited to impacts at any one site. For instance, if restoration activities are being implemented to reduce sedimentation into stream ecosystems, monitoring sediment inputs must occur at the watershed not site-scale.

Estimating sample size

Regardless of the type of monitoring, it is critical to determine the required sample sizes for estimating each treatment or monitoring variable prior to initiating any monitoring activity. Given that the goal of monitoring is to determine trends over time, it is crucial that estimates for each variable are made with enough precision that changes over time and in response to treatment can be detected. For instance, if cover of native vegetation changes by 20% in response to treatment over two sampling periods, then the margin of error around the mean needs to be less than 20%. One way to reduce the margin of error is to increase the number of replicates. Under-sampling is often a fatal flaw in monitoring programmes as it will prevent meaningful inference from monitoring data. Over-sampling of some variables is also a common problem. While it does not affect ability to make inferences, it will waste time and money.

Although it may seem daunting to estimate sample sizes, with just a small amount of pilot data (or data from past projects at similar sites), determining sample sizes can be done using simple mathematical calculations.[26] The same calculations used to determine sample sizes can be used to determine precision of estimation (error around the mean), which will allow managers to detect whether additional data is needed for some variables as well as whether sample sizes could be reduced. Because the success of a monitoring programme hinges on adequate sample sizes, sample size analysis should be built into the monitoring plan at the time of project design.

Determining frequency and duration of monitoring

The frequency and duration of monitoring for changes in ecosystem integrity and area, and its impact on risk of collapse, is also important to consider. Most restoration activities create disturbances that may initially lead to short-term declines in ecological integrity. In contrast, other adverse effects of treatments may not be apparent until years or decades after implementation. Similarly, there are complex temporal dynamics involved in ecosystem recovery. Some components of ecological integrity require long time periods to recover (for example, abundance and fitness of native fish populations), while others respond quickly to changes in the environment (for example, macroinvertebrate density).[81] For these reasons, monitoring should be done over time scales relevant to understanding the full impacts (intended and unintended) on the ecosystem. This means that, given limited budgets, more weight might be placed on long-term monitoring than on monitoring in year 2–3 post treatment. Short-term monitoring immediately after treatment, however, may be necessary for adaptive management or to determine if maintenance or additional treatment is needed (see Chapter 4).

The timeframe required to observe changes in risk of ecosystem collapse may be considerable. For this reason, despite recovery of multiple indicators of ecosystem integrity, the ecosystem condition may not pass thresholds for collapse risk (see Figure 25) for decades, resulting in no observable improvement in risk category. Stakeholders should be appropriately informed about the expected timeframe of recovery of ecosystem risk so that expectations are realistic and success can be measured over the appropriate time frame.

Given that it may take decades to observe changes in risk of ecosystem collapse and ecosystem area, there may be a benefit of

Landscapes of Dauria. Mongolia and Russia. *Photo: IUCN/Maja Vasilijević.*

using predictive models to assess the extent to which observed changes in ecological integrity over the monitoring timeframe might result in changes in ecosystem area and risk category over longer time frames. Predictive models are commonly used in conservation planning, for instance in understanding potential changes in species ranges due to anticipated changes in climate.[52]

Reporting lessons learnt to national and global restoration initiatives

Reporting efficacy and effects of restoration activities

Recent national and global restoration initiatives (see Box 1) provide an unprecedented opportunity to improve ecosystem area and integrity, and reduce risk of collapse, through investments in ecosystem restoration. Ecosystem restoration, however, is an experimental endeavour, and the extent to which it will be successful will likely be directly tied to the extent to which evidence from past projects is applied to ongoing and future ones.

Unless there is a plan for sharing lessons learnt and feeding evidence into future restoration efforts, all the hard work and investment in the monitoring and evaluation will not impact restoration success. If restoration activities are not effective at repairing degraded ecosystems – or worse, if they increase degradation – the promise of the UN Decade on Ecosystem Restoration will be lost.

Developing the evidence needed to improve restoration implementation depends on synthesising lessons learnt from as many

Perito Moreno Glacier. Los Glaciares National Park, Argentina. *Photo: NOAA.*

Laojunshan watershed. Hubei Shennongjia, China. *Photo: IUCN/Bruce Jefferies.*

projects or programmes as possible. Of course, results of monitoring and evaluation are needed for adaptive management within individual projects and programmes (see Box 13). However, sharing across projects within a region can lead to stronger inference about the efficacy and effects of treatment and can expand the knowledge base. Equally as important, reporting to global initiatives will allow up-scaling of best practices across ecosystems and biomes. To date, much of the reporting for global initiatives has been based entirely on implementation monitoring, such as the area in which restoration treatments have been implemented. Although statistics on implementation are important to understand total investment in restoration, these data do not provide information about the effect of ecosystem restoration, such as whether restorative goals were met or whether there were net positive benefits to ecosystem integrity.

The recent development of internet platforms to share lessons learnt and best practices presents a powerful opportunity to advance understanding of restoration methods (Box 14). However, these databases will only be useful if the global restoration community actively engages in reporting data from their projects and programmes. Getting data into the appropriate format and uploading it will require extra effort. If there is critical mass of participation, however, the extra effort will make the difference between a future where ecosystem risk of collapse has been avoided, versus one in which investments in restoration have not yielded the maximum benefits to ecosystem repair.

Reporting to global goals and agreements

Finally, multilateral global goals and agreements are increasingly focused on ecosystem-level biodiversity, in addition to species and genetic diversity, and recognise the importance of ecosystems for sustaining human well-being.[93] For example, the post-2020 Global Biodiversity Framework and the Sustainable Development Goals both refer to the need to increase ecosystem area and integrity. Restoration will be key to achieving this.[67] The United Nations System for Environmental Economic Accounting (SEEA) – Ecosystem Accounting (EA) framework provides an opportunity to integrate ecosystems into Natural Capital Accounting at a national level (Box 15). Red List of Ecosystems data provides a means of monitoring changes in ecosystems, through indicators that aggregate and summarise changes in area, integrity and collapse risk through time.[74] This allows the contributions of local-level restoration to be quantified in terms of meeting national and global goals, and ultimately demonstrating whether the world is achieving its aspirations to reverse biodiversity loss.[67]

Box 14: Knowledge platforms for restoration

Practitioners and stakeholders interested in sharing results of their restoration projects, programmes and initiatives can choose from a wide array of platforms and databases designed for reporting the efficacy and effects of ecosystem restoration and identifying good practices. The Best Practices Task Force of the UN Decade on Ecosystem Restoration is compiling an extensive list of these platforms and databases, which will be available through the UN Decade on Ecosystem Restoration website. A few examples of global databases are presented here.

The **Restoration Resource Centre** (RRC) is hosted by the Society for Ecological Restoration (SER). It is a searchable database of ecological restoration projects and programmes from across the globe. The database includes a consistent set of information for all submissions, covering aspects of location, type of ecosystem, project design and outcomes, as well as a contact for each entry. Information is self-submitted and not subject to peer review. The RRC focuses specifically on ecological restoration, although it may also include other types of restorative activities.

The **Global Database on Sustainable Land Management** is hosted by the World Overview of Conservation Approaches and Technologies (WOCAT). It defines Sustainable Land Management as "the use of land resources – including soil, water, vegetation and animals – to produce goods and provide services to meet human needs, while ensuring the long-term productive potential of these resources and sustaining their environmental functions." The database includes a wide array of Sustainable Land Management technologies and approaches and is not limited to restoration. Database entries include a range of information from general descriptions, to knowledge management, impact analysis and more. Submissions are edited and reviewed to assure the quality of the data before publication.

PANORAMA – Solutions for a Healthy Planet is a collaborative initiative that focuses on sharing successful practices from around the globe. It covers a wide range of conservation and sustainable development topics, from Ecosystem-based Adaptation to Forest and Landscape Restoration. Each topic has its own web-portal, within which information on successful practices is published. Each entry on a project or programme is referred to as a "solution" and includes "replicable building blocks'' which are defined as key success factors. Solutions are self-submitted, and then subject to peer review and revision prior to publication. After publication, PANORAMA collaborators integrate information on the solutions into capacity development activities and workshops.

Restor is a platform operated by the Restor Foundation. The goal of the platform is to make information from a variety of sources, from satellite imagery to field data, available to practitioners working in conservation and ecosystem restoration. It combines machine learning with other data sources to create maps that describe global ecosystems, in order to help practitioners plan, manage and monitor restoration projects. Restor focuses on data and methods that have been published in peer-reviewed scientific journals, or validated by experts, and content on the platform is approved by a scientific advisory board. To access the beta version, you must become a subscriber.

Group of pelagic sharks. Hawaii, USA. *Photo: Kimberly Jeffries/Ocean Image Bank.*

Box 15: The United Nations System for Environmental Economic Accounting – Ecosystem Accounting

The United Nations System for Environmental Economic Accounting (SEEA) is the global standard for Natural Capital Accounting, developed by the United Nations Statistical Division. It aims to include the environment's contributions to the economy in a comparable way to the System of National Accounts used globally to record important economic information (such as Gross Domestic Product – GDP). SEEA's Ecosystem Accounting framework (SEEA EA) was revised in 2021, and specifically focuses on ecosystems, including trends in their extent and condition, and the benefits they provide. For more detail, see the guidelines[87] and the SEEA website.

Although they serve different purposes (accounting versus ecosystem risk assessment), there are several linkages between the Red List of Ecosystems and SEEA EA. In particular, information and data may be shared between these frameworks. The SEEA EA has also adopted the IUCN Global Ecosystem Typology as the reference classification for ecosystems (see Box 6). The frameworks have similar conceptualisations and definitions of ecosystems, although SEEA EA tends to have a greater focus on intensive anthropogenic ecosystems (such as urban areas and agricultural lands) than the Red List of Ecosystems. The SEEA EA extent accounts measure change in ecosystem area in a very similar way to Red List of Ecosystems criterion A, though not necessarily over the same timeframes, allowing data to readily be shared. The SEEA EA condition accounts have many common features to Red List of Ecosystems criteria C and D (measuring degradation of abiotic and biotic processes), in particular the types of indicators used, the criteria for selecting them and ideas of reference states or baselines.

Differences stem largely from the differing objectives of the Red List of Ecosystems and SEEA EA. The Red List of Ecosystems aims to assess risk of ecosystem collapse, whereas SEEA EA focuses on tracking changes of the contributions of nature to the economy and people, and recording the impacts of economic and human activities on the environment. Therefore, for assessing ecosystem degradation (criteria C and D), collapse thresholds must be specified for Red List of Ecosystems indicators, focusing on the most important indicators of degradation; in contrast, condition accounts for SEEA EA often use a larger number of indicators because they aim to measure multiple elements of ecosystems that may be relevant for the capacity to supply services.

Further reading:

Making monitoring count: Project design for active adaptive management.[51] https://doi.org/10.5849/jof.13-021

Effective ecological monitoring.[53] https://www.publish.csiro.au/book/7812/

Statistical issues and study design in ecological restorations: Lessons learned from marine reserves.[68] https://islandpress.org/books/foundations-restoration-ecology

Lake Burullus, a Red Listed ecosystem with Critically Endangered (CR) status. Lake Burullus, Egypt. *Photo: Myousry6666/Wikimedia Commons.*

Conclusions

The continued decline of the world's ecosystems has previously been considered a problem for biodiversity loss. However, as understanding of the human-nature relationship improves, and the scale of degradation escalates, it is increasing recognised as a societal problem. The degradation and collapse of ecosystems results not only in the loss of irreplaceable biodiversity, but also the loss of the contributions that nature provides to people.

Increasing recognition of the vital need for ecosystem restoration has coalesced into ambitious global initiatives, notably the UN Decade on Ecosystem Restoration. The importance of including restoration in plans to shape a sustainable future will likely guide priorities for years to come. These ambitious global initiatives are not intended to address site-specific degradation, but to restore entire ecosystems, landscapes or seascapes.

Setting targets at the ecosystem level, that reflect the changes intended through restoration, are essential to meet this level of ambition. Ecosystem targets support both initial planning of restoration interventions, and later the monitoring and evaluation of the impacts of restoration.

Considerable advances have been made in recent years in building the science of ecosystem risk assessment to quantify the risk of ecosystem collapse. The IUCN Red List of Ecosystems is now the global standard for ecosystem risk assessment. It provides a wealth of information that is useful for restoration, providing information on ecosystem dynamics, management and effective restoration interventions.

Espiguette Beach. Southern France. *Photo: PRILL/Shutterstock.*

The Red List of Ecosystems can be useful across the entire cycle of a restoration project or programme, from building knowledge, through planning and decision making, to implementation on the ground, monitoring and learning, and finally, in global, national and regional policies. The answer to ecosystem restoration success may require incorporating ecosystem risk assessment science at multiple stages:

A. At the knowledge gathering stage:

1. Defining ecosystems is key for ecosystem restoration success. The Red List of Ecosystems provides a detailed ecosystem description, a conceptual model of biotic and abiotic features and threatening processes, as well as spatial information on its location.
2. The Red List of Ecosystems can provide information on how ecosystem area, integrity and threats have changed over time, as well as anticipated future changes.
3. Climate change may create the need for dynamic ecosystem restoration goals in areas where current or anticipated future climate may alter ecosystems in response to changed environmental conditions.

B. At the planning stage:

1. The Red List of Ecosystems can be used to guide decisions around where to implement restoration to improve ecosystem area or ecosystem integrity.
2. Even if restoration activities occur at the local level, targets should be defined for ecosystem types and spatial planning should consider the broader landscape or seascape context.
3. Prioritising restoration may involve multiple stakeholders with conflicting interests. Participation by all relevant stakeholders, as well as equitable governance, is key to success.
4. Priorities and targets for ecosystem restoration should consider key factors in the decision process, such as the benefits, costs and feasibility of restoration activities, including threat management, to help identify the likely return on investment of managing a particular ecosystem, threat or process.
5. The Restoration Opportunities Assessment Methodology (ROAM) can provide a framework for stakeholders to identify areas that are priorities for restoration.
6. The information provided by the Red List of Ecosystems can help to set targets for ecosystem restoration at the level of ecosystem types.

C. At the implementation stage:

1. Understanding the local context is necessary to determine appropriate restoration activities, including abatement of threats.
2. Restoration activities should follow best practice standards to improve the likelihood of success.
3. A comprehensive adaptive management framework can guide management decisions in complex systems, and ecosystem risk assessment science provides knowledge-based information to adapt options and modify targets.

D. At the monitoring and learning stage:

1. Monitoring results, reflecting on successes, setbacks and surprises, and adaptively managing projects and programmes, is a critical part of the restoration process.
2. It is important to monitor changes of ecosystem integrity at site, ecosystem and landscape or seascape levels.
3. Criteria in the Red List of Ecosystems framework reflect different pathways of ecosystem collapse, so while improvements in several indicators may improve ecological integrity, they may not result in a change in overall risk category.
4. There are time lags between restoration activities and impacts, so achieving improvements in risk category may only happen over long timeframes.
5. Sharing the results for individual projects and programmes to global learning databases can improve understanding and help maximise investments in restorative activities.

6. The IUCN Global Ecosystem Typology provides a mechanism for sharing information on similar ecosystems around the world, building capacity and increasing a shared global understanding.
7. The Red List of Ecosystems provides suitable indicators for measuring restoration impact, and allows local restoration successes to contribute to national and global goals for ecosystems.

E: At the policy level:

1. At global level, ecosystem risk assessment using the Red List of Ecosystems can support ecosystem restoration efforts by providing science-based knowledge to set targets, and support planning and monitoring.
2. Investing in ecosystem risk assessment is beneficial to large-scale ecosystem restoration initiatives, when this information is integrated into planning processes, project funding and decision making.
3. At national and regional levels, the information from the Red List of Ecosystems can be used to support planning and monitoring of restoration, especially when integrated with data from species and sites.

Coral Restoration Foundation™ conducts training for the public during their Coralpalooza™ event. Key Largo, Florida, USA. *Photo: Coral Restoration Foundation™.*

An Adelie penguin searches for food from the sea. Fish Islands, Antarctica. *Photo: Hui Shuk Kwan.*

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