A better future for people and nature: a social-ecological systems approach to ecosystem restoration

Doctoral dissertation
submitted to the School of Sustainability
Leuphana University Lüneburg, Germany
for the award of the degree
Doctor of Philosophy (Dr. phil.)

Marina Frietsch
06.05.1994, Freiburg im Breisgau

Committee

Supervisor and first reviewer:
Prof. Dr. Berta Martín-López, Leuphana University, Lüneburg, Germany

Second reviewer:
Prof. Dr. Claudia Bieling, University of Hohenheim, Stuttgart, Germany

Third reviewer:
Prof. Dr. Anja Linstädter, University of Potsdam, Potsdam, Germany

Date of submission: October 4, 2024
Date of defence: December 16, 2024

Copyright notice

Paper I: Frietsch, M., J. Loos, K. Löhr, S. Sieber, and J. Fischer. 2023. Future-proofing ecosystem restoration through enhancing adaptive capacity. Communications Biology **6**:377.

Paper II: Frietsch, M., M. Pacheco-Romero, V. M. Temperton, B. A. Kaplin, and J. Fischer. 2024. The social–ecological ladder of restoration ambition. Ambio **53**:1251–1261.

Paper III: Frietsch, M., J. Fischer, B. A. Kaplin, and B. Martín-López. 2024. The relevance of international restoration principles for ecosystem restoration practice in Rwanda. Restoration Ecology **32**:e14085.

Paper IV: Frietsch, M., et al. Visions for the future of ecosystem restoration. Manuscript submitted to Conservation Letters.

"The best way to take care of the future
is to take care of the present moment."

- Thích Nhât Hanh

Table of contents

Acknowledgements V

Abstract VI

Zusammenfassung VII

List of publications VIII

List of abbreviations IX

List of figures IX

List of tables IX

List of boxes IX

Chapter I 1

1. Introduction 2
   1.1 Ecosystem restoration: definition, history, and developments 2
   1.2 Ecosystem restoration in tropical and subtropical landscapes 4
   1.3 Current challenges for ecosystem restoration science and practice 5
   1.4 Research questions 7
2. Research approach 8
   2.1 Positionality 8
   2.2 Study area 9
   2.3 Research design 12
3. Key findings and contributions 15
4. Lessons for ecosystem restoration 21
   4.1 Lesson I: Ecosystem restoration needs time 21
   4.2 Lesson II: Ecosystem restoration needs people 22
   4.3 Lesson III: Ecosystem restoration needs ecology 24
   4.4 Lesson IV: Ecosystem restoration needs to be embedded in its social-ecological context 25
5. Outlook 26
6. Bibliography 27

Chapter II 35

Chapter III 45

Chapter IV 57

Chapter V 69

Appendix 83

Appendix 1: Author contribution statements 84

Appendix 2: Approval to conduct research in Rwanda 86

Appendix 3: Supplementary material for Paper I 87

Appendix 4: Supplementary material for Paper III 88

Appendix 5: Supplementary material for Paper IV 92

Acknowledgements

This dissertation is the product of many people and places, of many hours spent in conversation with others and many hours spent contemplating by myself. Thank you to every person and every place that made this journey possible.

First of all, I want to thank Berta for supervising my PhD. You not only offered valuable scientific guidance but also words of encouragement when I was in doubt and good ideas when I was stuck. Thank you for making a difference in this world by sharing your presence, energy, and motivation.

Thank you to all the people who make SESI such a wonderful place to work at. I am beyond grateful to be part of a team of brilliant, creative, motivated, and kind people. A special thank you to Manu for always brightening my day. Thank you also to all the people who left SESI and continue to make an impact elsewhere.

Thank you to all members of the DFG Research Unit. I have learned so much from the many different approaches you take on ecosystem restoration and I am looking forward to continue working with you for the next three years – and perhaps beyond.

Thank you to all the people who made field work in Rwanda possible. Prof. Dr. Beth Kaplin for guiding my first steps in Rwanda and always doing everything possible to help out. Gloria Kamwezi for supporting data collection and showing me new sides of Rwanda. All stakeholders who shared their thoughts and experiences. Thank you for your trust, your time, and your openness.

Thank you to Anja Linstädter and Claudia Bieling for investing their time and energy into reviewing my PhD. I am looking forward to meeting you in person in December!

Thank you to my family and friends who enrich my live and shape who I am. Thank you to my parents for all the opportunities you gifted me. Thank you, Jakob, for continuously showing me new ways of perceiving and interacting with the world that surrounds us. A special thank you to the people who shared some of the most important periods of life with me and allowed me to grow as a person: my grandparents, Sabine, Aspen, Alison, Thea, Jule, Annabelle, Olivia, Malin, and Maria.

Finally, I am thankful beyond words for Amalia, who joined me mid-way on my PhD journey, and for Joern. Thank you for gifting me so much joy, meaning, and love every single day.

Abstract

The restoration of degraded ecosystems is increasingly recognized as a key strategy to respond to interconnected social-ecological challenges such as climate change and biodiversity loss. To this end, ecosystem restoration practice encompasses a wide range of activities which seek to halt and reverse the degradation of ecosystems and thereby contribute to ecosystem integrity and human well-being. Notwithstanding continuous scientific and practical advances in ecosystem restoration, many restoration projects do not deliver desired ecological and social outcomes. Specifically, many restoration projects lack long-term orientation and there exists limited guidance for restoration practitioners and policy-makers for how to prioritize diverse approaches and goals. In addition, restoration projects are often not embedded in their social-ecological context. Although the potential of integrating social-ecological systems thinking into ecosystem restoration is increasingly being recognized, the operationalization of this perspective for restoration remains little explored.

By combining conceptual considerations with empirical work in western and central Rwanda, this dissertation applies a social-ecological systems perspective to ecosystem restoration. Paper I integrates key restoration and social-ecological systems literature to inform the enhancement of adaptive capacity of restoration sites. Paper II proposes a framework for navigating dynamically shifting social and ecological restoration goals. Paper III examines the relevance and application of international restoration principles in local-scale restoration in the study area. Paper IV explores visions for the future of restoration in Rwanda. Together, the four papers advance the operationalization of a social-ecological systems perspective on ecosystem restoration.

Across the four papers, four lessons for ecosystem restoration emerge. The lessons are related to (i) the importance of time in ecological and social restoration processes, (ii) the role of people who shape and are affected by ecosystem restoration, (iii) the value of a strong ecological science foundation for ecosystem restoration, and (iv) the benefits of applying social-ecological systems thinking to ecosystem restoration. These four general lessons as well as the specific findings of each paper entail diverse implications for ecosystem restoration science, policy, and practice. First, ecosystem restoration science can contribute to shifting discourses on restoration approaches, scales, and goals by providing context-specific, accessible knowledge. Second, ecosystem restoration policy can promote supportive governance systems, sustainable financing schemes, and coordination across scales. Finally, ecosystem restoration practice can open up spaces for people to interact and exchange diverse types of knowledge at all stages of a restoration project drawing on different inter-and transdisciplinary formats. Together, ecosystem restoration science, policy, and practice can realize the potential of ecosystem restoration to enhance ecological integrity and human well-being.

Zusammenfassung

Die Wiederherstellung degradierter Ökosysteme gilt zunehmend als Schlüsselstrategie zur Bewältigung miteinander verknüpfter sozial-ökologischer Herausforderungen wie Klimawandel und Biodiversitätsverlust. Hierzu gibt es ein breites Spektrum an Interventionen, die darauf abzielen, zur Integrität von Ökosystemen und zum menschlichen Wohlergehen beizutragen. Trotz kontinuierlicher Fortschritte in Forschung und Praxis, führen viele Wiederherstellungsprojekte nicht zu den gewünschten ökologischen und sozialen Ergebnissen. Insbesondere mangelt es vielen Wiederherstellungsprojekten an einer langfristigen Ausrichtung, und es gibt nur begrenzte Anhaltspunkte, wie verschiedene Wiederherstellungsansätze und -ziele priorisiert werden können. Außerdem sind Wiederherstellungsprojekte oft nicht in ihren sozial-ökologischen Kontext eingebettet. Obwohl das Potenzial der Integration von sozial-ökologischem Systemdenken in die Wiederherstellung degradierter Ökosysteme zunehmend erkannt wird, ist die Operationalisierung dieser Perspektive noch wenig erforscht.

Basierend auf konzeptionellen Überlegungen und empirischen Daten aus Ruanda wendet diese Dissertation eine sozial-ökologische Systemperspektive auf die Wiederherstellung von Ökosystemen an. Artikel I integriert Literatur zur Wiederherstellung von degradierten Ökosystemen mit Literatur zu sozial-ökologischen Systemen, um die Anpassungsfähigkeit von Wiederherstellungsprojekten zu verbessern. Artikel II schlägt einen Rahmen für die Steuerung sich dynamisch verändernder sozialer und ökologischer Ziele in Wiederherstellungsprojekten vor. Artikel III untersucht die Relevanz und Anwendung internationaler Wiederherstellungsprinzipien bei der Wiederherstellung auf lokaler Ebene in Ruanda. Artikel IV erforscht Visionen für die Zukunft der Wiederherstellung von degradierten Ökosystemen in Ruanda. Zusammen bringen die vier Artikel die Operationalisierung einer sozial-ökologischen Systemperspektive in der Forschung und Praxis der Ökosystemwiederherstellung voran.

Aus den vier Artikeln lassen sich vier Lektionen für die Wiederherstellung von Ökosystemen ableiten. Die Lektionen beziehen sich auf (i) die Bedeutung von zeitlichen Dimensionen in ökologischen und sozialen Prozessen, (ii) die Rolle von Menschen, (iii) den Wert einer starken wissenschaftlichen Grundlage und (iv) die Vorteile der Anwendung des sozial-ökologischen Systemdenkens bei der Wiederherstellung von Ökosystemen. Daraus ergeben sich Implikationen für die Wissenschaft, Politik und Praxis der Wiederherstellung von Ökosystemen. Wissenschaft kann den Diskurs über Wiederherstellungsansätze, -skalen, und -ziele mitgestalten, indem sie kontextspezifisches, zugängliches Wissen bereitstellt. Politik kann durch nachhaltige Governance-Systeme und Finanzierungsregelungen die Koordination von Wiederherstellung von Ökosystemen auf verschiedenen Ebenen optimieren. In der Praxis können Räume für Interaktion und Wissensaustausch von Mitgliedern verschiedener Interessengruppen mit Hilfe von inter- und transdisziplinären Formaten geöffnet werden.

List of publications

Paper I

Frietsch, M., J. Loos, K. Löhr, S. Sieber, and J. Fischer. 2023. Future-proofing ecosystem restoration through enhancing adaptive capacity. Communications Biology **6**:377.
DOI: 10.1038/s42003-023-04736-y

Paper II

Frietsch*, M., M. Pacheco-Romero*, V. M. Temperton, B. A. Kaplin, and J. Fischer. 2024. The social–ecological ladder of restoration ambition. Ambio **53**:1251–1261.
DOI: 10.1007/s13280-024-02021-8
*Marina Frietsch and Manuel Pacheco-Romero have contributed equally to the manuscript.

Paper III

Frietsch, M., J. Fischer, B. A. Kaplin, and B. Martín-López. 2024. The relevance of international restoration principles for ecosystem restoration practice in Rwanda. Restoration Ecology **32**:e14085.
DOI: 10.1111/rec.14085

Paper IV

Frietsch, M., B. Martín-López, D. Akirimari, W. Apollinaire, B. Arakwiye, M. Baumann, S. Bohn, D. W. Duguma, E. Imanirareba, B. A. Kaplin, L. Kmoch, T. Kuemmerle, K. Löhr, J. Loos, M. Mujawamariya, A. Mukuralinda, V. Ndagijimana, G. Ndayizeye, V. Nsengimana, P. Ntaganda, V. Nyiramvuyekure, T. Plieninger, S. Sieber, M. Sindikubwabo, P. Sun, V. M. Temperton, E. Turikunkiko, S. Vögele, M. Wollni, and J. Fischer. Visions for the future of ecosystem restoration. Manuscript submitted to Conservation Letters.

List of abbreviations

CBD	Convention on Biological Diversity
DFG	Deutsche Forschungsgemeinschaft/German Research Foundation
H1	Horizon one
H2	Horizon two
H3	Horizon three
RQ	Research question
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change

List of figures

FIGURE 1 Overview of key restoration approaches 4

FIGURE 2 Study area and restoration practices in Rwanda 10

FIGURE 3 Structure of the dissertation 13

List of tables

TABLE 1 Overview of challenges for ecosystem restoration science and practice, research gaps, research questions, and contributing papers 8

TABLE 2 Summary of the four papers by their methods and concepts, key findings and insights, and conceptual, empirical, and/or methodological contributions 20

List of boxes

BOX 1 A short history of Rwanda 11

Chapter I

A better future for people and nature: introduction, synthesis, and outlook

Marina Frietsch

1. Introduction

The world is facing complex interrelated challenges that affect both nature and people (Steffen et al. 2015). Examples range from ongoing biodiversity loss (Díaz et al. 2019) and accelerating climate change (IPCC 2023) to widespread social inequality and livelihood insecurity (Barbier & Hochard 2018). All over the world, scientists, governments, NGOs, and citizens are looking for ways to address these and other social-ecological issues. The restoration of degraded ecosystems is increasingly recognized as a key response to such interconnected sustainability challenges (Tedesco et al. 2023).

The potential of ecosystem restoration to tackle social-ecological challenges has resulted in a rapid increase of restoration efforts from local to international scales (IUCN 2022). However, the complex context in which ecosystem restoration is embedded is not accounted for in many cases, resulting in inadequate or even detrimental outcomes of restoration interventions (Coleman et al. 2021; Banin et al. 2023). Hence, new and improved approaches are needed that address the inherent ecological, social, and economic complexity of human-modified landscapes (Tedesco et al. 2023). Here, social-ecological systems thinking provides an approach to analyse and interact with the interconnected ecological and social elements and dynamics which shape restoration sites (Fischer et al. 2021).

In recent years, the need to adopt a social-ecological systems perspective to ecosystem restoration has been increasingly recognized (Krievins et al. 2018; Maes et al. 2024). Despite many advances in the theory and application of a social-ecological systems approach to restoration (Fischer et al. 2021; Dudney et al. 2022), this is still a young field, and many important questions remain poorly understood. This dissertation combines conceptual contributions with place-based empirical research in Rwanda to contribute to the advancement of a social-ecological systems perspective on ecosystem restoration.

1.1 Ecosystem restoration: definition, history, and developments

Ecosystem restoration has been defined as the "process of halting and reversing the degradation of ecosystems" (UNEP 2021) and can be applied to assist the recovery of all types of terrestrial and aquatic ecosystems. In practice, restoration encompasses a continuum of activities that aim to generate healthy and biodiverse ecosystems that benefit people and nature (Di Sacco et al. 2021; Chazdon et al. 2021a). These activities range from reducing harmful societal impacts to fully recovering native ecosystems (Gann et al. 2019) and bringing back values, goods, and services of ecosystems that people appreciate and depend on (Martin 2017). As a result, ecosystem restoration can refer to actions at various scales and in various spheres, and can use a vast array of methods and approaches. Examples include small-scale agroforestry practices that seek to improve food security (Shennan-Farpón et al. 2022) just as much as large-scale projects that aim to restore entire regions (Goffner et al. 2019).

To make sense of current practices, debates, and challenges in ecosystem restoration, it is helpful to understand its history. While indigenous people have engaged in diverse land management practices for thousands of years, including some practices that might be considered 'restoration' in current terms (Fox et al. 2017; Santini & Miquelajauregui 2022), modern restoration is commonly traced back to revegetation projects that aimed to rebuild land health in the USA (Leopold 1966; Piccolo 2020) and Australia (McDonald & Williams 2009). These early restoration efforts emerged in the 1920s from the fields of landscape architecture and ecology and focused on re-establishing native plant species on degraded lands (Martin 2022). Increasingly, restoration also became established in the scientific community with the launch of two scientific journals (Ecological Restoration in 1981 and Restoration Ecology in 1993) and the foundation of the Society for Ecological Restoration in 1988. Since then, interest in restoration has been increasing. This is reflected by an ever-growing number of restoration projects (IUCN 2022) and the continuous advancement of scientific literature (Ballari et al. 2020).

Over the last three decades, ecosystem restoration has also entered the global policy stage. This has anchored restoration goals in national and international law and policy (Vezzoni et al. 2023), making financial resources available (Zu Ermgassen & Löfqvist 2024), and connecting stakeholders across scales and jurisdictions (Scarlett & McKinney 2016). The first major international calls for restoration include the Rio Conventions in the 1990s (encompassing the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), and the United Nations Convention to Combat Desertification (UNCCD)) and the Bonn Challenge in 2012 (IUCN 2020a). These global-level restoration ambitions inspired diverse collaborations to coordinate restoration action at the regional level. In Africa, the most notable ones are the 2007 UNCCD flagship initiative Great Green Wall, which aims to create a 100 million ha mosaic of restored landscapes across more than 20 African countries (Goffner et al. 2019), and the 2015 African Forest Landscape Restoration Initiative, which was launched to contribute to the Bonn Challenge by restoring 100 million ha of degraded land by 2030 (Messinger & Winterbottom 2016). The importance of restoration is also recognized by other important policy agendas, such as the 2015 Sustainable Development Goals (UN General Assembly 2015), the 2015 Paris Agreement on climate change (UN 2015), and the 2022 Kunming-Montreal Global Biodiversity Framework on biodiversity loss (CBD 2022). Finally, a further symbolic stepping stone to catalyse global restoration efforts was the declaration of 2021-2030 as the "Decade on Ecosystem Restoration" by the United Nations (UN Environment Agency 2019).

The continuous evolution of restoration practice, policy, and science has also entailed numerous shifts in terminologies, target scales, and goals of restoration. **Revegetation** is a rather simple restoration approach that focuses on returning plants to locations where vegetation has been lost without much regard for nativeness of species or structural diversity (Stanturf et al. 2014). In contrast, **ecological restoration** is "an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability" (Society for Ecological Restoration 2004), which has traditionally implied the recovery of degraded ecosystems oriented towards a historic reference state (although the concept of reference states is increasingly debated in ecological restoration literature (Harris et al. 2006; Balaguer et al. 2014)). **Functional restoration** focuses on ecological processes and dynamics rather than particular species compositions (Naeem 2006) and aims to "recover ecosystem services of the original ecosystem based on functional traits" (Carlucci et al. 2020). **Forest landscape restoration** strives to create multifunctional landscapes, seeking to enhance ecological integrity and human well-being, especially in degraded forest landscapes (Dudley et al. 2005). The term was coined in 2000 and emphasizes the importance of a landscape-scale vision and the involvement of local stakeholders (Mansourian & Parrotta 2018). Most recently, **social-ecological restoration** has been promoted to integrate the social, economic, and ecological complexity of human-modified landscapes (Fischer et al. 2021; Tedesco et al. 2023). Importantly, these different terms and approaches are not exclusive and can co-occur in a landscape. The term **ecosystem restoration** is used in this dissertation as an umbrella term that spans the range of restoration approaches outlined above (Fig. 1).

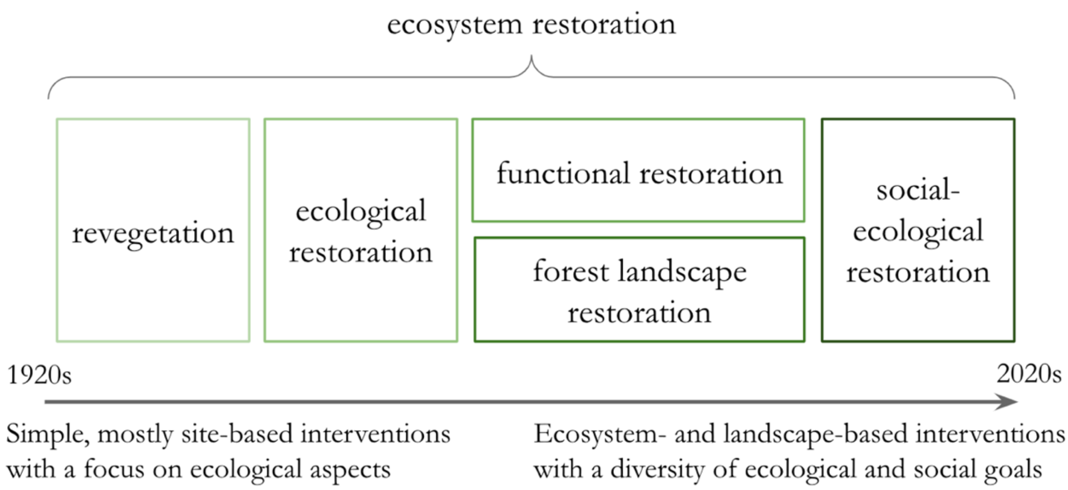

FIGURE 1 Overview of key restoration approaches. New approaches to restoration developed over the years without fully replacing preceding approaches. In a specific landscape or restoration project, these approaches can co-occur. Ecosystem restoration can be used as an umbrella term for diverse approaches to restoration.

1.2 Ecosystem restoration in tropical and subtropical landscapes

While ecosystem restoration is applied all around the world, there is a particular focus on tropical and subtropical countries (Strassburg et al. 2020; Nsikani et al. 2023). Specific conditions that can be found in diverse settings across the tropics and subtropics shape the social-ecological context in which ecosystems restoration takes place in this region. First, many of the world's most biodiverse locations under intense human pressure are located in the tropics and subtropics (Mittermeier et al. 2004). Second, ecological and social outcomes of ecosystem restoration are deeply interwoven in this region due to a widespread direct dependence on nature of local livelihoods and basic human needs (Adams et al. 2016; Fedele et al. 2021) as well as strong cultural links of many indigenous communities to the natural environment (Wehi & Lord 2017; Reyes-García et al. 2019). Third, many restoration efforts in the tropics and subtropics are characterized by top-down governance, which can entail problematic outcomes for social inclusion and justice (Sigman & Elias 2021; Chazdon et al. 2021b). Fourth, unequal power relations at different scales caused by colonial histories (Osborne et al. 2021) and present-day ecologically unequal exchange (Dorninger et al. 2021) mean that restoration priorities and narratives in the tropics and subtropics are often shaped by Western values instead of local needs and preferences (Elias et al. 2021; Löfqvist et al. 2022). In combination, these factors illustrate the importance of better understanding ecosystem restoration in the tropics and subtropics and at the same time highlight the vulnerability of people and landscapes in these regions to environmental change. Parts of this dissertation are informed by place-based research in central and western Rwanda, which shares many of the typical conditions that are common for ecosystem restoration in tropical and subtropical landscapes more broadly.

1.3 Current challenges for ecosystem restoration science and practice

Ecosystem restoration science is inherently intertwined with practical restoration interventions happening on the ground. In the following, I outline current debates in restoration science and practice and, based on this, derive three research gaps that will be addressed in this dissertation.

Challenge I: Designing ecosystem restoration projects that benefit people and nature in the long run

Today as well as in the future, people directly and indirectly depend on ecosystems (M.E.A. 2005; Fedele et al. 2021). Yet, despite major potential of restoration interventions to improve the state of natural resources and contribute to human well-being, the future of many restoration sites is uncertain (Dudney et al. 2022). In general, outcomes of restoration interventions are difficult to predict, especially for the mid- and long-term future (Brudvig & Catano 2021). In addition, sites that are restored today might face considerably different conditions in a few decades due to rapid environmental and societal changes such as an increase in extreme climatic events (Zabin et al. 2022) or shifting motivations, values, and power dynamics among stakeholders (Mansourian 2021).

To date, most restoration projects do not account for these challenges related to long-term restoration outcomes but instead focus on short-term benefits. This is reflected by the prevalence of short project periods (Hodge & Adams 2016), a focus on the number of seedlings planted rather than their survival (Holl & Brancalion 2020), the choice of tree species based on immediate utility or political incentives rather than biodiversity (Martin et al. 2021) or livelihood value (Fleischman 2014), and a widespread lack of monitoring (Schubert et al. 2024) and project follow-up (Kodikara et al. 2017). Importantly, obtaining immediate benefits from restoration is indispensable under some circumstances such as natural catastrophes (Fernández-Manjarrés et al. 2018). Yet, given the ongoing dependence of people on nature (Fedele et al. 2021) and the large time frames of ecosystem recovery (Moreno-Mateos et al. 2020), restoration must not neglect the long-term viability of interventions.

To ensure intact ecosystems that contribute to human well-being not only in the next years but also in the coming decades and centuries, new frameworks, methods, and tangible activities to support the design and implementation of restoration projects that generate sustained, long-term benefits for people and nature are needed (Research Gap I). This applies to restoration in general and is especially relevant in the context of central and western Rwanda, where the majority of people directly rely on the land they live on (National Institute of Statistics of Rwanda 2023), and where rapid population growth is expected in the coming years (UN DESA 2019).

Challenge II: Navigating differing priorities related to ecosystem restoration approaches and outcomes

Since the very beginnings of modern restoration, practitioners, policy-makers, and scientists have been debating the "how" and "why" of restoration (Hobbs & Harris 2001). Restoration takes place within a dynamic social-ecological context in which biophysical conditions and societal priorities keep shifting, often in new and surprising ways (Fischer et al. 2021). The questions of what a restoration site should provide and which methods to apply thus remain just as relevant today as they have always been.

Priorities related to restoration approaches, costs, and benefits differ among stakeholders (Mansourian 2018). Here, power imbalances play a central role: in many cases, restoration decision-makers design restoration projects that do not reflect the needs and values of the people living in or close to restoration sites (Duguma et al. 2020; Elias et al. 2021). In the worst case, restoration projects can fail when the diverse needs and expectations related to restoration are not acknowledged and coordinated, for example due to a lack of community support (Höhl et al. 2020) or mismatches between national restoration objectives and local land-use planning realities (Wiegant et al. 2020).

It is thus highly important to support restoration practitioners and policy-makers in navigating competing interests and changing perceptions of how and what ecosystem restoration should achieve. While a multitude of principles exists to support restoration interventions (e.g., Gann et al. 2019; FAO et al. 2021), there is limited tangible guidance for how to navigate trade-offs and competing needs. Hence, practitioners and policy-makers require approaches that help them navigate diverse approaches and goals, especially when confronted with differing priorities (Research Gap II). Like the first challenge outlined above, this second challenge, too, is relevant in restoration projects all over the world. It, too, is especially relevant in Rwanda, where goals pursued by different stakeholders can be conflicting at times (e.g., long-term biodiversity restoration versus immediate support of livelihoods).

Challenge III: Embedding ecosystem restoration interventions in their social-ecological context

The two challenges outlined above illustrate how a diverse set of interacting ecological and social system components shape ecosystem restoration. In practice, this means that restoration practitioners need to navigate complex ecological, social, and interconnected social-ecological processes to ensure that restoration projects meet their respective goals. To date, restoration projects often fail to integrate ecological and social considerations. This can cause unintended negative ecological and social effects such as habitat homogenization (Holl et al. 2022), spread of invasive species (Naia et al. 2021), or increased social inequalities (Holl & Brancalion 2020).

Applying a social-ecological systems perspective to restoration can support restoration practitioners in harmonizing diverse system components that impact restoration sites at different temporal and spatial scales. In short, a social-ecological systems perspective recognizes that links between humans and their environment shape contexts and outcomes of restoration interventions (Fischer et al. 2021), and emphasizes the importance of considering interactions across spatial and temporal scales (Fischer et al. 2015). In terms of space, entities that play a role in ecosystem restoration range from single seedlings and individual restoration practitioners to ecological interactions across biomes and international policies. In terms of time, restoration interventions inherently connect different temporal horizons by linking past ecosystem states, present-day interventions, and future-oriented goals.

While the need to integrate a social-ecological systems perspective into restoration is increasingly being recognized in restoration science (Krievins et al. 2018; Yang et al. 2018; Fischer et al. 2021; Tedesco et al. 2023; Maes et al. 2024), it is not always clear how to operationalize this perspective (Research Gap III). By definition, this research gap applies to ecosystem restoration worldwide and at all scales. The Rwandan case study can help to demonstrate how the – sometimes abstract – concept of social-ecological systems can be embedded in ecosystem restoration practice on the ground.

1.4 Research questions

In this dissertation, I applied a social-ecological systems perspective to ecosystem restoration. With this, I contributed to the discourse describing the ongoing shift in restoration science and practice towards a social-ecological systems approach. Based on the three research gaps outlined above, I combined conceptual considerations on ecosystem restoration with place-based empirical research in central and western Rwanda to address the following research questions (RQ). Research Question I and Research Question II address Research Gap I. Research Question III addresses Research Gap II. Research Question IV addresses Research Gap III (Table 1).

RQ I: Which frameworks and methods can support the design of ecosystem restoration projects that benefit people and nature in the long run?

RQ II: Which tangible activities can increase the long-term viability of ecosystem restoration projects?

RQ III: Which frameworks and methods can support ecosystem restoration practitioners and policy-makers to navigate dynamically shifting restoration priorities?

RQ IV: How can social-ecological systems thinking be integrated into ecosystem restoration?

TABLE 1 Overview of challenges for ecosystem restoration science and practice, research gaps, research questions, and contributing papers. The "✓" indicates the research questions addressed by each of the four papers. RQ = research question.

Restoration challenge	Research gap	Research question	Paper I	Paper II	Paper III	Paper IV
Challenge I: Designing ecosystem restoration projects that benefit people and nature in the long run	Gap I: Frameworks, methods, and tangible activities to support the design and implementation of restoration projects that generate long-term benefits for people and nature are lacking.	RQ I: Which frameworks and methods can support the design of ecosystem restoration projects that benefit people and nature in the long run?	✓		✓	✓
		RQ II: Which tangible activities can increase the long-term viability of ecosystem restoration projects?			✓	✓
Challenge II: Navigating differing priorities related to ecosystem restoration approaches and outcomes	Gap II: Guidance for ecosystem restoration practitioners and policy-makers for how to prioritize diverse approaches and goals and navigate trade-offs is limited.	RQ III: Which frameworks and methods can support ecosystem restoration practitioners and policy-makers to navigate dynamically shifting restoration priorities?		✓		✓
Challenge III: Embedding ecosystem restoration interventions in their social-ecological context	Gap III: The operationalization of a social-ecological systems approach to ecosystem restoration is underexplored.	RQ IV: How can social-ecological systems thinking be integrated into ecosystem restoration?	✓	✓	✓	✓

2. Research approach

In this section, I provide background on my dissertation. This encompasses a reflection of the position I adopted in relation to my research (2.1), a description of the study area (2.2), and the research design including an overview of the methods, frameworks, and concepts I applied in the four papers (2.3).

2.1 Positionality

Research is not objective and value-free. Assumptions about ontology and epistemology shape what is researched, how research is conducted, and which results are obtained (Darwin Holmes 2020). Below, I reflect on the position I adopted in relation to (i) my field of study, (ii) the study area and research participants, and (iii) the research process (Savin-Baden & Howell Major 2023) to acknowledge the viewpoints and circumstances which influenced the questions I asked and how people perceived me.

First, in terms of assumptions about what exists and hence can be studied (i.e., ontology) and how knowledge can be created (i.e., epistemology), my approach is strongly shaped by my educational background which includes a B.Sc. in Landscape Ecology and a M.Sc. in Sustainability Science. Both study programmes highlighted the importance of interactions between natural and social entities, making these interactions a central interest for my own research. The diverse perspectives from which social-ecological systems can be approached influence interpretations and outcomes of social-ecological systems research. Hence, I view knowledge generation on social-ecological restoration systems as mostly normative and context-dependent (although generalizable insights that apply beyond the concrete study object can often be derived). This is also reflected by the repeated use of inductive approaches throughout my research.

Second, my personal set of values, experiences, and skills undoubtedly shaped interactions with stakeholders in Rwanda. First, I entered the study area as an outsider without previous experience with working in sub-Saharan Africa. Second, I talked to stakeholders who mostly were involved in restoration for much longer than I have been. Third, because I do not speak Kinyarwanda and did not hire a translator, stakeholders had to communicate complex thoughts in a foreign language. Finally, I experienced time and mobility constraints due to a pregnancy during data collection for Paper III and a baby that accompanied me during data collection for Paper IV.

Third, this dissertation is closely intertwined with the DFG Research Unit "A social-ecological systems approach to inform ecosystem restoration in rural Africa" which focuses on western Rwanda. I worked as a research associate to contribute to the conceptualization and coordination of the Research Unit proposal which inspired me to think about the bigger picture of restoration and, as a result, write Paper I and pursue a PhD. The inspiration for Paper II came during the first field trip to Rwanda that aimed at verifying the proposed research design for the Research Unit. Data collection for Paper III took place while we awaited the decision on our proposal to the DFG and wanted to keep in contact with stakeholders. Paper IV presents the outputs of a two-day kick-off event that marked the start of the Research Unit. While I mapped out the general structure of this dissertation at the beginning, many details of my work organically developed in response to the Research Unit.

2.2 Study area

This dissertation primarily focuses on the central and western parts of Rwanda (Fig. 2). Originally, central and western Rwanda were mostly covered by Afromontane rainforest (Kanyamibwa 1998). Over the past decades, high natural resource demand and armed conflicts heavily degraded the local natural ecosystems (Kanyamibwa 1998; Arakwiye et al. 2021). This adversely affected biodiversity (Arakwiye et al. 2021), ecosystem functioning (Rwibasira et al. 2021), and human well-being (Nash et al. 2020). As a response to widespread degradation, Rwanda was the first African country to commit to the Bonn Challenge in 2011, pledging to bring more than 80% of its terrestrial area into restoration by 2030 (IUCN 2020b). Today, almost all districts in the country have implemented restoration interventions to some extent (Nash et al. 2020) and over 700,000 ha of degraded systems have been brought into restoration across the nation (IUCN 2020b). While restoration efforts have considerably increased since 2011, tree plantings that date back to the 1980s (Clay 2019) as well as plantings that predate Rwanda's independence in 1962 (pers. observation, June 2022) can be found in central and western Rwanda (for additional information on Rwanda's history see Box 1).

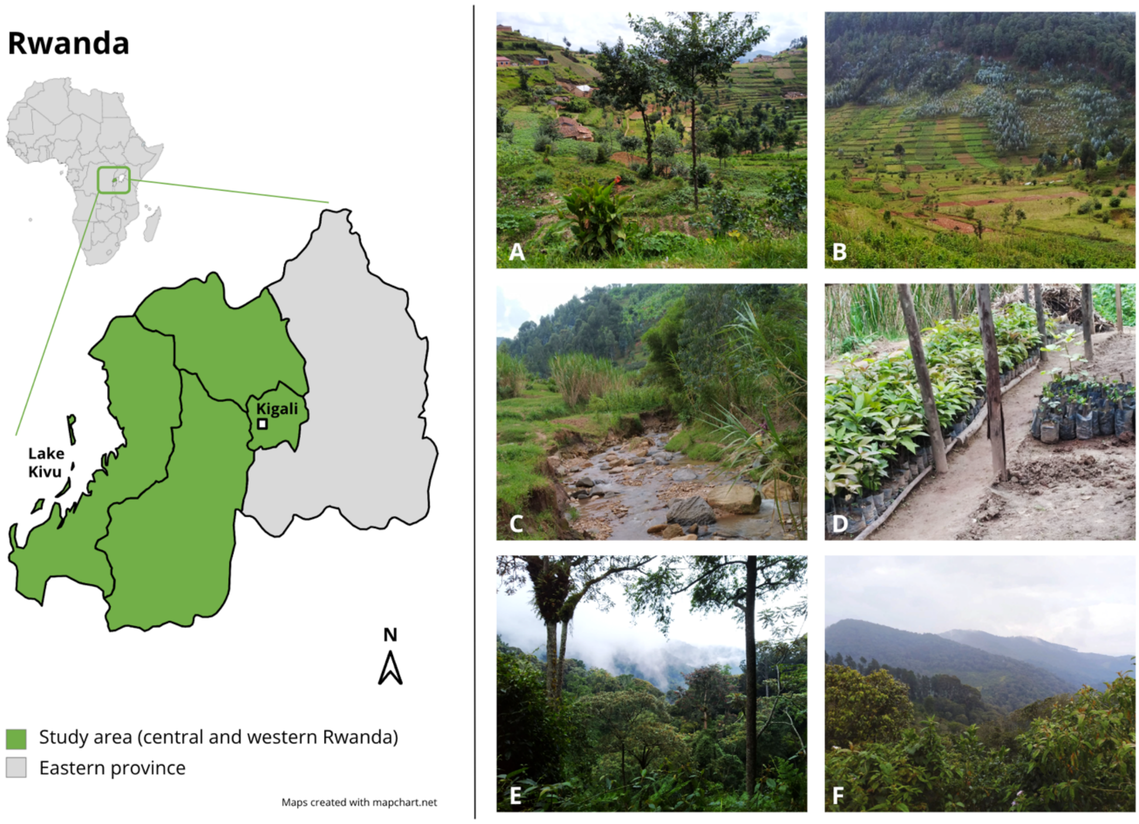

FIGURE 2 Study area and restoration practices in Rwanda. Left panel: This dissertation focuses on central and western Rwanda, i.e., the Western, Northern, and Southern Province, and Kigali Province. Right panel: The pictures taken in May 2022 in Rwanda's Western Province show different restoration practices (A: agroforestry; B: young and old Eucalyptus woodlots in an agricultural landscape; C: protective planting along a watercourse), a tree nursery (D), and protected natural forest in Nyungwe National Park (E) and Mukura National Park (F). Photo credit: Joern Fischer.

Rwanda has one of the highest human population densities in Africa (UN DESA 2019), and 69% of Rwandan households engage in agricultural activities, often in the form of subsistence agriculture (National Institute of Statistics of Rwanda 2023). In addition to widespread agricultural practices, the high-altitude landscape of central and western Rwanda is characterized by hills and steep slopes. In this context, four types of ecosystem restoration practices that meet different needs are common throughout the landscape. First, agroforestry practices integrate agricultural activities and tree-related livelihoods. Second, woodlots support local needs for fuelwood and timber. Third, protective plantings prevent erosion and support watercourses. In addition to these active ecosystem restoration practices, creating the conditions for natural forest regeneration is also part of Rwanda's restoration portfolio (Nash et al. 2020) (Fig. 2).

BOX 1 A short history of Rwanda.

Rwanda's recent history fundamentally shaped the social-ecological context of today's restoration interventions. In 1897, Germany colonized the kingdoms of Rwanda and Burundi, and after World War I, Belgium took control of the region. To strengthen their power, the colonisers reinforced the categorization of the local population into three groups (Hutu, Tutsi, Twa). Tensions between Hutu and Tutsi amplified over the decades and resulted in a Hutu-led revolution in 1959 and independence from Belgium in 1962. The Hutu government vilified the Tutsi minority, leading to a civil war in 1990 and a systematic genocide in 1994 which claimed an estimated 800,000 lives (Prunier 1995; Kanyamibwa 1998). In recent years, the Rwandan government started to pursue economic and agricultural transformation via nation-wide programs (Government of Rwanda 2017).

These political changes also impacted Rwanda's ecosystems. During Belgian colonial rule, *Eucalyptus* spp. trees were introduced for timber and erosion control (Dr. William Appollinaire, pers. communication, May 2022). Post-independence, unstable political conditions (Plumptre et al. 2001), ineffective protected area management, failed development projects (Clay 2019), and armed conflicts caused habitat fragmentation, deforestation, and biodiversity loss (Kanyamibwa 1998; Hanson et al. 2009). After the genocide, settlements of refugees (Ordway 2015) and paramilitary militias (Plumptre et al. 2001) within or close to protected areas resulted in forest loss, with some protected areas losing up to two-thirds of their historical extent (Kanyamibwa 1998; Plumptre et al. 2001). Since 2011, the Rwandan government is promoting restoration throughout the country (Nash et al. 2020).

Despite the extensive restoration efforts in central and western Rwanda so far, numerous challenges remain unaddressed. First, while restoration is successful on paper, restored sites are dominated by non-native species (Nash et al. 2020) and monoculture plantings are often declared as restoration (Ministry of Natural Resources Rwanda 2014). The most commonly used non-native species are *Eucalyptus spp., Pinus spp.*, *Acacia spp.*, *Alnus spp.*, and *Grevillea spp.* (pers. observation, June 2022). While these species provide important short-term benefits such as fuelwood, they cause long-term ecological problems including low biodiversity (Arakwiye et al. 2021) and degraded soils (Rwibasira et al. 2021). In addition, it remains unclear how restoration sites will perform in the face of looming social-ecological changes that are likely to affect the study area in the coming decades, such as a projected warmer and wetter climate (Seimon & Picton Phillipps 2010) and an expected doubling of the country's population by 2060 (UN DESA 2019). This highlights the importance of shifting the current focus from quick fixes to sustainable and versatile restoration interventions that can deliver beneficial ecological and social outcomes in the short-, medium-, and long-term. This directly corresponds to Research Gap I.

Second, ecosystem restoration in the study area is confronted with a multitude of differing expectations and needs. On the one hand, government stakeholders pursue international restoration targets (Ministry of Environment 2020) as well as national goals related to economic and agricultural development (Buckingham et al. 2020). On the other hand, rural communities directly depend on the state of ecosystems for their well-being (Pritchard 2013; Nishimwe et al. 2020) and are primarily interested in livelihood opportunities and climate mitigation resulting from ecosystem restoration (Buckingham et al. 2020). Moreover, the remaining patches of Afromontane rainforest are highly valuable in terms of biodiversity conservation (Uwizelimana et al. 2022) and are thus considered priority areas for mitigating biodiversity loss (Kehoe et al. 2017). These diverse priorities can create conflicts among stakeholders (Buckingham et al. 2020). Yet, when synergies between these priorities are identified and harnessed, ecosystem restoration could benefit from the widespread interest in ecosystem restoration interventions. This requires exchanges between stakeholders and coordination of restoration interventions and is thus directly linked to Research Gap II.

Finally, the social-ecological context of ecosystem restoration in Rwanda shares key characteristics with many ecosystem restoration settings around the world. For example, issues related to inadequate biodiversity outcomes (Arakwiye et al. 2021), inequitable governance structures (Clay 2019), and negative effects on tenure security and livelihoods (Dawson et al. 2016) resulting from ecosystem restoration are not only evident in Rwanda but also in many other locations (see section 1.2 for a more details). The potential for transferring and upscaling insights gained from research on central and western Rwanda in combination with an expressed wish for more scientific input on ecosystem restoration in Rwanda (Nash et al. 2020) make the region a specifically interesting case study for exploring the application of a social-ecological systems approach to ecosystem restoration. This directly relates to Research Gap III.

2.3 Research design

Ecosystem restoration encompasses a wide array of different actors, components, and interactions (Ostrom 2007; Fischer et al. 2021). Hence, to fully understand causes of degradation and develop effective solutions, an integrated perspective is needed that accounts for the complexity and diversity of the sites, ecosystems, and landscapes which restoration interventions seek to recover (Higgs 1994; Tedesco et al. 2023). This includes in-depth knowledge on biophysical parameters, socio-economic characteristics, external influencing factors, as well as the interactions between them across temporal and spatial scales. Here, systems thinking provides a framework for identifying, understanding, and engaging with the elements and underlying structures that shape overall dynamics. A system consists of diverse, interconnected, coherently organized elements which have a purpose or function (Meadows 2008). In social-ecological systems, people and nature are linked and influence each other (Berkes et al. 2000; Ostrom 2009). In this dissertation, I applied social-ecological systems thinking to ecosystem restoration along a spatial gradient from local to global and a temporal gradient from present to future based on conceptual considerations and empirical data from central and western Rwanda (Fig. 3).

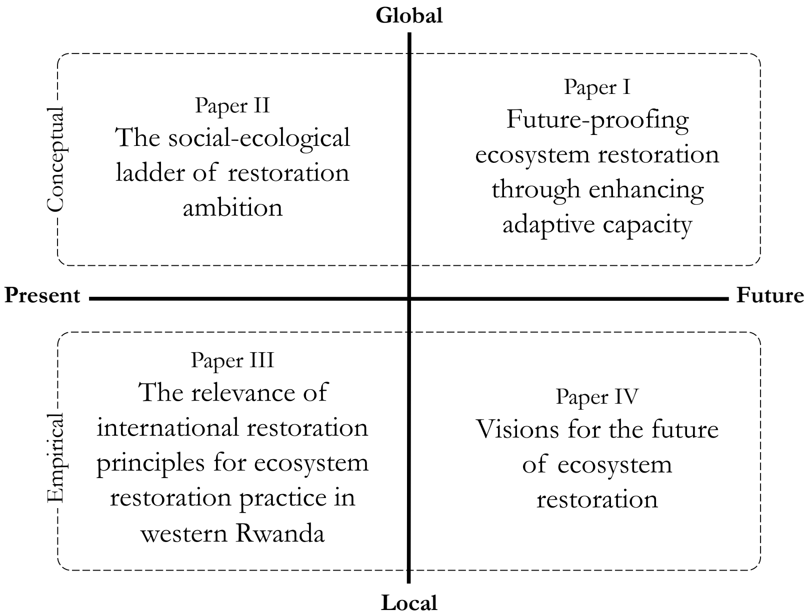

FIGURE 3 Structure of the dissertation. The dissertation consists of four papers that address questions on ecosystem restoration along a spatial gradient from local to global and a temporal gradient from present to future. Paper I and Paper II are mainly based on conceptual considerations. Paper III and Paper IV are mainly based on empirical data.

Social-ecological systems science offers a range of methods and concepts for understanding and shaping complex social-ecological systems (Biggs et al. 2021). Methodologically, social-ecological system science provides methods for data generation and system scoping (e.g., Q-methodology), methods for analyzing systems components and their interactions (e.g., causal loop diagrams), and methods for co-producing knowledge, informing decision-making, and effecting system change (e.g., three horizons framework). Conceptually, social-ecological systems science offers concepts that help to understand the dynamics of social-ecological systems (e.g., resilience). These methods and concepts can also be applied to ecosystem restoration research. Below, I present the methods and concepts applied in this dissertation.

Methodologically, Paper I is based on the **iterative coding** of restoration and resilience principles. Iterative coding is a systematic yet dynamic process that uses repeated cycles of text analysis to reveal patterns in qualitative data (Locke et al. 2020). In practice, this entails several rounds of reviewing data line-by-line, grouping it into themes that emerge from the data, and developing overarching codes from these themes (Neale 2016). This very commonly applied method is especially useful for exploratory research that aims to develop new ideas and theories. As such, iterative coding was ideally suited to bring together principles for restoration and resilience which were not systematically integrated to this point.

Conceptually, Paper I connects ecosystem restoration with two central concepts of social-ecological systems science, namely **resilience** and **adaptive capacity**. Notably, these two concepts are defined differently across disciplines (Gallopín 2006). In the context of this dissertation, I adopted a system thinking approach to resilience informed by the work of Folke et al. (2003), Walker and Salt (2006), Biggs et al. (2012), and Carpenter et al. (2012). Historically, the term resilience was first introduced to describe the capacity of an ecosystem to respond to, and recover from disturbance (Holling 1973). The concept was later also applied to social-ecological systems to describe the capacity of a system to cope with changing conditions while maintaining its essential function, identity, and structure, as well as retaining its capacity for self-organization, adaptation, and transformation (Berkes et al. 2000; Walker et al. 2004; Folke 2006). Adaptive capacity is closely related to resilience and describes a systems‘ ability to adjust to disturbances, take advantage of opportunities that arise when conditions change, or respond to potential consequences of change (Smit & Wandel 2006; IPCC 2022). There is no clear-cut definition of the relationship between resilience and adaptive capacity and the two terms are sometimes used interchangeably (Gallopín 2006). In this dissertation, I adopted the perspective that adaptive capacity is a component that is needed to build resilience (Carpenter et al. 2001; Folke et al. 2003).

For Paper II, we used **causal loop diagrams** to visualize relationships and feedbacks between key system elements that shape ecosystem restoration in two study areas in Rwanda and Germany. Causal loop diagrams facilitate the analysis of complex systems (Haraldsson 2004) and are a central tool for **systems thinking** (Hanspach et al. 2014; Groundstroem & Juhola 2021). A causal loop diagram is composed of variables that represent the most important elements of a given system. These variables are connected by arrows. Closed cycles between system variables indicate either self-regulating or reinforcing feedback loops that shape system structures (Haraldsson 2004). Paper III aimed at revealing generally applicable dynamics that occur in restoration sites over time. Here, causal loop diagrams were an ideally suited tool from systems thinking to break down two complex case study systems by identifying and visualizing key system elements and their relationships with each other.

Paper III is based on the **Q-methodology** and a specially developed **relative weighting exercise**. The Q-methodology combines quantitative and qualitative methods to explore diverse perspectives on a specific topic (Stenner 2012; Zabala et al. 2018). First, each participant is asked to rank printed proxy statements that reflect different aspects of a given topic on a scoreboard. After finalizing this so-called Q-sort, respondents are asked qualitative follow-up questions about the reasoning behind their sorting pattern in **semi-structured interviews**. The Q-sort data are analysed using multivariate analysis to find groups of similarly performed sorts (Zabala 2014). These groups of similar Q-sorts are combined with the interview data to formulate narratives that describe the different perspectives distilled from the exercise (Zabala et al. 2018). In addition to the Q-methodology, we gave each participant 60 LEGO bricks to build towers on the Q-methodology proxy statement cards to indicate the extent to which each statement had been applied in ecosystem restoration projects in the study area. Again, we asked semi-structured, qualitative follow-up questions. While the Q-methodology offered participants a structured approach to contemplate and visualize their perspectives, the LEGO exercise allowed participants to engage with research in a new and playful way. As such, this combination was ideally suited to assess the broad range of attitudes towards ecosystem restoration and related success factors, and to facilitate a structured and at the same time creative setting for data collection that encouraged in-depth reflection.

Paper IV was based on a **three horizons visioning process** conducted with Rwandan ecosystem restoration stakeholders. The three horizons framework is a participatory tool to assess current system dynamics, explore desirable future system states, and develop pathways that connect the present and the future (Curry & Hodgson 2008; Sharpe et al. 2016). To this end, the framework identifies three horizons: horizon one (H1) represents the current dominant system, horizon three (H3) describes the long-term successor of H1 and embodies desired future system characteristics, and horizon two (H2) outlines strategic pathways to transition from H1 to H3 (Sharpe et al. 2016). Participants form groups, discuss questions related to each horizon, and share their thoughts and ideas via post-it notes on a large illustration of the three horizons. Notably, the framework does not imply that there is a single preferable future that can be achieved by following a single strategy but encourages the exploration of diverse futures and pathways (Schaal et al. 2023). This iterative and collaborative process enables **knowledge co-production** by opening up space to integrate multiple ways of knowing and doing to develop context-specific, actionable outcomes (Norström et al. 2020). Similarly to the methods used for Paper III, the three horizons framework is a structured yet creative and interactive approach that encourages participants to think outside the box. The three horizons visioning process was ideal to make diverse stakeholders' assumptions and preferences explicit, foster in-depth reflection and exchange on ecosystem restoration in the study area, and co-produce tangible, action-oriented strategies for how to move forward.

3. Key findings and contributions

This section provides an overview of the content of the four papers that constitute this dissertation. To this end, I summarize the key results of each paper and elaborate on their conceptual, empirical, and methodological contributions (Table 2). Because questions related to ecosystem restoration are so multifaceted (Fischer et al. 2021), these contributions have the biggest potential when they are applied in inter- and transdisciplinary settings which bring together diverse restoration stakeholders.

Paper I: Future-proofing ecosystem restoration through enhancing adaptive capacity

Paper I is a conceptual contribution that links key restoration principles with social-ecological systems literature against the background of complex interacting challenges that might considerably impact ecosystem restoration interventions in the next decades. Designing restoration sites that are able to adapt to changing conditions is especially important because social-ecological threats such as climate change, resource overexploitation, and political instability are predicted to disproportionately affect areas earmarked for ambitious restoration efforts.

To support the development of responses to complex social-ecological challenges, we synthesized 52 key restoration and resilience principles and derived three guiding themes that can help to enhance the adaptive capacity of restoration sites: (i) work with the existing system, (ii) create self-sustaining, adaptive systems, and (iii) foster diversity and participation. These three guiding themes need to be applied at all levels of restoration action, and should consider ecological as well as social components of restoration sites. To operationalize the three guiding themes, we proposed a two-step approach that encompasses (i) an initial assessment of the impacts a given threat would likely have on a specific site at different points in time followed by (ii) the development of specific activities that can strengthen skills, mechanisms, strategies, and institutional structures that support the social-ecological restoration system in adjusting to each threat based on the three guiding themes. Using the case of climate change in western Rwanda, we exemplarily illustrated the application of this two-step approach. Importantly, a collaborative process that involves practitioners, scientists, and policymakers is needed to develop responses that are rooted in the social-ecological context and account for the perspectives and needs of those living and working around restoration sites.

Paper I addresses Research Gap I by clearly elucidating the importance of adopting a long-term perspective on restoration projects and providing an overview of key threats that could harm the future viability of restoration sites. In addition, Paper I addresses Research Gap I by offering concrete tools (the three guiding themes and the two-step approach for their application) to increase the adaptive capacity of restoration sites. These two contributions to Research Gap I directly support restoration policy and practice with designing restoration projects that benefit people and nature in the long run (RQ I). Further, Paper I addresses Research Gap III and advances the research field conceptually by linking restoration and resilience literature. Finally, Paper I further contributes to Research Gap III by linking present-day restoration interventions with future threats and making spatial patterns of restoration threats visible, thereby illustrating how social-ecological restoration systems interplay across temporal and spatial scales. These two conceptual contributions to Research Gap III foster the operationalization of a social-ecological systems approach to ecosystem restoration.

Paper II: The social-ecological ladder of restoration ambition

Paper II is a conceptual contribution that explores dynamically shifting ecological and social restoration goals and proposes a framework to help scientists and decision-makers to think about, communicate, and navigate these shifts. Because ecosystem restoration takes place in dynamic social-ecological systems, both biophysical conditions and societal priorities keep evolving. As a result, ecological and social ambitions related to restoration change over time. This indicates that restoration goals need to be considered in a dynamic way and require regular reassessment and adjustment.

In Paper II, we outlined three interconnected processes that shape social-ecological restoration ambitions. First, degrading processes underpin the need for restoration and are typically reinforcing through time. Second, restoration goals are the ecological and social objectives set for a specific restoration intervention. Third, remedial actions are the activities implemented to reach a given restoration goal. To halt and counteract the ongoing degradation of a system, remedial actions need to break the reinforcing feedback cycles that characterize degrading processes. In a specific restoration site, these three processes change through time generating new feedback mechanisms that reflect current social-ecological conditions and related restoration ambitions. To apply this conceptual framework in practice, restoration projects need to be assessed at different points in time with respect to their goals, degrading process, and remedial actions. We illustrated this process using two case studies that show how restoration ambitions changed through time in forest landscape restoration in Rwanda and grassland restoration in Germany. Here, we used stylized causal loop diagrams to capture key social-ecological dynamics that shaped each case study system.

Paper II addresses Research Gap II by offering a framework to think about, communicate, and navigate shifting restoration ambitions. As such, the proposed framework can benefit policy-makers, practitioners, and researchers at different stages of a restoration project: first, the ladder can act as a post-hoc analytical tool to identify and understand processes in established restoration system. Second, the ladder can support communication and decision-making by facilitating an integrated view of restoration in new or ongoing restoration projects. In both cases, the ladder can help to navigate common challenges faced in restoration projects related to contradictory social and ecological ambitions, the representation of diverse ambitions in restoration projects, and the prioritization of short-term benefits over long-term visions. In addition, Paper II addresses Research Gap III by showing how diverse ambitions can be integrated, and by demonstrating how causal loop diagrams can be used to illustrate social-ecological interactions in ecosystem restoration systems. In addition, Paper II contributes to Research Gap III by highlighting how restoration ambitions change through time, and by offering a structured framework to discuss these changes across different temporal scales.

Paper III: The relevance of international restoration principles for ecosystem restoration practice in Rwanda

Paper III used empirical data to assess the relevance of international-level restoration principles for local-level stakeholders. We sought to understand if stakeholders who plan, manage, and implement restoration interventions in central and western Rwanda perceive the ten international restoration principles put forward for the UN Decade on Ecosystem Restoration as useful for restoration practice in their local context. In addition, we elicited the extent to which these principles are being applied in practice in the study area. Finally, we explored additional features of successful restoration for Rwanda that emerged throughout the research but were not explicitly emphasized by the UN Decade principles.

We applied the Q-methodology to explore how 32 Rwandan restoration stakeholders perceive the ten UN Decade principles in terms of their relevance for successful restoration, and carried out a relative weighting exercise to assess the extent of application of the UN Decade principles in practice. In general, participants agreed that the UN Decade principles are relevant in the context of the Rwandan study area. However, there were no significant patterns in terms of the perceived relevance of a statement and its application in practice for the vast majority of participants. A multivariate analysis of the 32 Q-sorts revealed three distinct groups of stakeholders who hold different opinions related to restoration goals, stakeholder involvement, and relevant spatial scales: the first group adopted a process-oriented, linear management approach to restoration; the second group was outcome-oriented and acknowledged the interconnectivity of social-ecological restoration system; the third group focused on ecological integrity at the local scale. Participants repeatedly mentioned four features of successful restoration that did not directly correspond to the summary we provided of the UN Decade principles: restoring historical conditions; systematically collecting baseline data; increasing local communities' sense of ownership; and following a long-term vision for restoration actions.

Paper III addresses Research Gap I by revealing priorities for ecosystem restoration in central and western Rwanda that are needed to design successful, long-lasting restoration projects (RQ II). In addition, Paper III contributes to closing Research Gap I by exemplifying how the UN Decade principles, the Q-methodology, and the relative weighting exercise can guide reflections and conversations on what is needed for successful restoration. This provides methodological support for practitioners, policy-makers, and researchers who seek to design restoration projects that account for different perspectives and incorporate ecological as well as social considerations for long-term restoration success (RQ I). Finally, Paper III addresses Research Gap III by revealing the different spatial scales on which the three groups identified via the Q-methodology focused, and by highlighting how ecological, social, and integrated social-ecological features of restoration are needed for success.

Paper IV: Visions for the future of ecosystem restoration

Paper IV presents the empirical results of a collaborative exercise based on the three horizons framework. We brought together key ecosystem restoration stakeholders in central and western Rwanda to reflect on current dynamics and desirable futures for ecosystem restoration, and to develop concrete strategies to advance ecosystem restoration in the region. Shared visions for ecosystem restoration are urgently needed given the prevalence of simplistic, short-sighted restoration interventions that disregard the social-ecological complexity of restoration systems and can even result in unintended negative outcomes for nature and people. This problem is not only widespread in the Rwandan study area but also in other restoration sites around the world.

Guided by the three horizons framework, a diverse group of 21 Rwanda-based restoration experts discussed approaches and social-ecological dynamics that currently dominate ecosystem in central and western Rwanda, and exchanged visions for desirable futures of restoration the study area. Based on the restoration experts' input, we identified five interconnected priorities for restoration in the study area: (i) biodiverse and multifunctional landscapes; (ii) livelihoods, value chains and nutrition; (iii) participation and community engagement; (iv) financing of sustainable restoration; and (v) coordination, integration and partnerships. For each of these priorities, restoration experts developed tangible strategies. In the context of livelihoods, these included for example the promotion of fruit trees to enhance nutrition diversification and income opportunities. To improve participation and community engagement, restoration experts proposed inclusive approaches such as participatory land-use planning and demonstration plots. The three horizons visioning process highlighted the potential of inter- and transdisciplinary approaches to create shared visions for ecosystem restoration. In addition, inter- and transdisciplinary approaches can help implement these visions on the ground by overcoming lock-in mechanisms that currently restrict transformative restoration practices and trialling innovative restoration strategies such as the ones developed by the restoration experts. Finally, the exercise emphasized the importance of prioritizing ecological integrity to ensure the long-term viability of restored ecosystems and thereby also ensure the well-being of people depending on them.

Paper IV addresses all three research gaps. Methodologically, the application of the three horizons framework demonstrated its use for designing long-term oriented restoration projects (Research Gap I, RQ I) and navigating diverse priorities and expectations related to restoration (Research Gap II) through inclusive knowledge co-production. In addition, restoration policy and practice in Rwanda benefit from the tangible activities developed by the restoration experts which contribute to closing Research Gap I (RQ II). Finally, Paper IV contributes to Research Gap III by showcasing a method that inherently integrates social-ecological considerations into restoration at different temporal scales and by highlighting the interdependence of the five priorities for restoration in the study area.

TABLE 2 Summary of the four papers by their methods and concepts, key findings and insights, and conceptual, empirical, and/or methodological contributions.

Methods and concepts	Key findings and insights	Contributions
Paper I: Future-proofing ecosystem restoration through enhancing adaptive capacity		
Iterative coding to integrate **restoration** and **resilience** literature to propose ways to enhance **adaptive capacity**	• Presents impacts of three social-ecological threats (climate change, resource overexploitation, political instability) on restoration • Proposes three guiding themes to enhance adaptive capacity of restoration sites: (i) work with the existing system; (ii) create self-sustaining, adaptive systems; (iii) foster diversity and participation • Highlights importance of collaborative, context-based processes to develop responses to social-ecological threats	**Conceptual**: highlights importance of adopting long-term perspective on restoration; links restoration across temporal and spatial scales; links resilience and restoration literature; synthesizes three guiding themes to enhance adaptive capacity **Methodological**: proposes two-step approach to operationalize the three guiding themes
Paper II: The social-ecological ladder of restoration ambition		
Systems thinking and **causal loop diagrams** to analyse and visualize two complex case study systems and derive generally applicable insights on restoration processes	• Presents three interconnected processes that shape social-ecological restoration ambitions • Summarizes and visualizes key restoration system elements and their interactions in two study areas in Rwanda and Germany • Proposes a framework to think about, communicate, and navigate shifting restoration ambitions	**Conceptual**: uses lens of causal loop diagrams to apply systems thinking to restoration **Empirical**: synthesizes dynamics in two restoration case studies in Rwanda and Germany **Methodological**: offers new approach to deal with shifting restoration ambitions
Paper III: The relevance of international restoration principles for ecosystem restoration practice in Rwanda		
Q-methodology, **relative weighting exercise**, and **semi-structured interviews** to elicit stakeholders' perspectives on and implementation of success factors for restoration	• Reveals three groups of stakeholders that hold different opinions related to restoration goals, stakeholder involvement, and relevant spatial scales for restoration in Rwanda • Reveals four features of successful restoration that are particularly relevant in Rwanda but did not correspond to the summary we provided of the UN Decade principles • Shows that there is no significant correlation between perceived importance of a success factor and extent of current application in practice	**Methodological**: applies Q-methodology in the context of restoration in Rwanda; develops and trials relative weighting exercise using LEGO bricks in combination with Q-methodology **Empirical**: identifies and describes three distinct groups of restoration stakeholders in Rwanda; highlights four features of successful restoration that need to be considered when designing and implementing restoration projects
Paper IV: Visions for the future of ecosystem restoration		
Three horizons visioning process to guide **knowledge co-production** on current restoration practice, desirable futures, and tangible strategies to move forward	• Provides comprehensive overview of (i) the current dominant restoration system, and (ii) diverse visions for a desirable future for restoration central and western Rwanda • Identifies five interconnected priorities for restoration in Rwanda (biodiversity, livelihoods, participation, financing, coordination) and presents tangible strategies to address these priorities based on stakeholders' input • Highlights importance of inter- and transdisciplinary approaches to develop and implement visions of desirable futures • Highlights importance of prioritizing ecological integrity for long-term viability of restoration	**Methodological**: applies three horizons framework and thereby enables knowledge co-production in the context of restoration in Rwanda **Empirical**: elicits stakeholders' perspectives on current practices and desirable future states of restoration in Rwanda; outlines concrete actions to move towards a more desirable future for restoration in Rwanda

4. Lessons for ecosystem restoration

The four papers which constitute this dissertation approach ecosystem restoration from different angles. Across the four papers, four lessons emerge that can enhance the viability of ecosystem restoration interventions. While some aspects of these lessons confirm recent advances in restoration literature, other aspects provide new insights for restoration in Rwanda and in general. In the following, I discuss the four lessons and their implications for restoration science, policy, and practice.

4.1 Lesson I: Ecosystem restoration needs time

Ecosystem restoration interventions are often characterized by short project periods that mainly result from a lack of continuous, long-term funding (Iftekhar et al. 2017) and a widespread preference for compact, project-based restoration interventions (Borgström et al. 2016; Hodge & Adams 2016). However, ecosystem restoration is much more complex than what many short-term projects allow for: both the ecological processes that are part of restoration as well as the people that plan, implement, or are affected by restoration need time.

In terms of ecological processes, the recovery of ecological complexity and adaptive potential of degraded ecosystems can take centuries (Cole et al. 2014; Moreno-Mateos et al. 2020). Similarly, the ecological benefits that can be obtained from restoration such as levels of soil carbon content or plant biodiversity need time and can take many decades to recover (Martin et al. 2013). Given their long-term nature, such ecological processes are especially vulnerable to possible forthcoming social-ecological threats such as the ones explored in Paper I – ecological integrity might never be restored when a restoration site is subjected to degrading dynamics such as climate change, resource exploitation, or political instability.

In terms of the people involved in restoration, social processes related to community participation, capacity building, decision-making, and the navigation of power dynamics and diverging values require considerable time (Hodge & Adams 2016). Yet it is these processes that foster effective and equitable restoration governance which is, in turn, more likely to result in improved social and ecological outcomes (Chazdon et al. 2021b; Löfqvist et al. 2022). During field visits in Rwanda and data collection for Paper III and Paper IV, we directly experienced what this means in practice: stakeholders needed time to build trust to be able to open up and share their thoughts. In addition, we witnessed the delicate social processes at play in the context of ecosystem restoration in Rwanda, such as power differences between actors or examples of long-standing, intimate relationships between communities and restoration NGOs.

As illustrated by Paper II, ecological and social processes such as the ones outlined above interact over time and thereby shape restoration trajectories. The resulting need for time in ecosystem restoration entails several implications for restoration science, policy, and practice. First, restoration science can play an important role in shifting the focus from short-term restoration outcomes, to the actual timescales that are needed for ecological processes to unfold. Here, data on how different ecological parameters develop in relation to time after restoration can help to create a realistic understanding about the timescales at which restoration operates (Moreno-Mateos et al. 2020; Massi et al. 2022).

Second, restoration policy can contribute to move past financing that favours short-term, compartmentalized restoration interventions which force restoration managers to settle for outputs that are deliverable within relatively short project periods and prioritize project size and number over success (Hodge & Adams 2016; Palmer & Stewart 2020). Instead, continuous financial resources that increase planning security, leave room for surprises and uncertainty, and encourage synergies between restoration projects are needed to let social and ecological processes fully unfold (Neeson et al. 2015; Iftekhar et al. 2017). Importantly, to prevent restoration from being subordinated to public and private finance objectives which not always match long-term social-ecological restoration goals, restoration financing needs to be aligned with the site-specific social-ecological context of restoration interventions (Zu Ermgassen & Löfqvist 2024). Specific suggestions for how to sustainably finance ecosystem restoration in Rwanda and similar settings can be found in Paper IV.

Third, restoration practice can help to open up spaces for people to interact, develop ideas, and build a community to engage in restoration together. This can be supported by approaches such as the Q-methodology (see Paper III) and the three horizons framework (see Paper IV) as well as other inter- and transdisciplinary formats that are already being applied in ecosystem restoration (Sinclair et al. 2021; Hemmerling et al. 2023) and other realms of environmental management (Margules et al. 2020; Biggs et al. 2021). In addition, monitoring needs to be extended from just a few years to several decades (Schubert et al. 2024) to be able to detect and respond to potential unintended developments. Finally, restoration practice needs to view restoration as a dynamic process that is subjected to uncertainty and changing conditions and thus requires adjustments over time (see Paper I and Paper II).

4.2 Lesson II: Ecosystem restoration needs people

Historically, restoration was predominantly approached from a natural science perspective with a strong focus on biophysical system elements (Higgs 1994; Martin 2017). However, ecosystem restoration is intimately intertwined with people in diverse ways. First, people are the causes of degradation. Here, it is important to highlight that complex webs of global inequity, marginalization, and poverty (Dorninger et al. 2021; DeFries et al. 2022) often force people to use natural resources in unsustainable ways and thereby cause degradation. Second, to reach international restoration targets, ecosystem restoration interventions cannot solely focus on sparsely inhabited landscapes but also need to be implemented in areas where people live (Choksi et al. 2023). Globally, more than an estimated 1.4 billion people live in areas considered to be of high restoration priority (Löfqvist et al. 2022), and an estimated 300 million people live on land suitable for tropical forest restoration (Erbaugh et al. 2020). Third, complex interplays between power, values, and needs shape what is being restored how, when, and why (Elias et al. 2021; Mansourian 2021). As a result, ecosystem restoration depends on the people that work and live around restoration systems. This has been increasingly acknowledged in recent years (Gann et al. 2019; Elias et al. 2022).

The four papers that constitute this dissertation reflect different roles that people play in ecosystem restoration. Paper I highlights degrading human activities that cause the need for restoration and jeopardize the long-term success of restoration interventions. Paper III exemplifies the role of individual perceptions in restoration practice. Paper II and Paper IV demonstrate how people can be a force for good in the context of restoration by navigating restoration processes based on resilience and equity. The case study in Rwanda typifies the special interaction between people and ecosystem restoration in subtropical and tropical landscapes where many people depend on nature to meet basic human needs (Fedele et al. 2021), which makes them especially vulnerable to environmental change and at the same time bears high potential for improving well-being through restoration interventions (DeFries et al. 2022; Löfqvist et al. 2022).

The central role of people in ecosystem restoration directly results in implications for restoration science, policy, and practice. First, restoration science needs to account for people, also when examining biophysical aspects of restoration. Of course, research on the ecological realms of restoration is vital – when it blanks out people, however, the full reality of restoration sites is not represented. This can lead to unintended negative social and ecological restoration outcomes (Höhl et al. 2020), most likely at the expense of already marginalized groups (Löfqvist et al. 2022).

Second, restoration policy needs to foster governance systems that integrate people in restoration and carefully navigate trade-offs. This can be supported by frameworks and methods that actively encourage reflection on the role of people in restoration (see Paper II, Paper III, and Paper IV). Ideally, such processes should amplify diverse voices to represent the variety of people affected by restoration (Elias et al. 2021). In addition, financing again plays an important role: projects that promote simple measures such as tree planting without concern for people's needs will most likely do more harm than good and should not be supported (Fleischman et al. 2020). Finally, tenure arrangements need to be explicitly integrated in restoration policy (see Paper III) (de Jong et al. 2018; Erbaugh et al. 2020).

Third, restoration practice needs to involve all stakeholders who are affected by restoration in the different steps of restoration processes. In practice, this can for example include the integration of traditional ecological knowledge in restoration planning (Reyes-García et al. 2019) or the participation of local communities in the selection of species (Méndez-Toribio et al. 2021). These processes need to consider power relations, scales, and historical contexts (Elias et al. 2021) and hence require formats that match the context and capacities of the people involved (see all four papers).

Finally, this lesson touches complex questions surrounding the prevailing dichotomy of nature and people which is rooted in millennia of social and cultural processes in Western societies which made humans categorize themselves as separate from nature (Loreau 2023). I argue that to fundamentally advance restoration, a radical philosophical shift is needed that rethinks human-nature relationships across and beyond the science-policy-practice nexus that shapes ecosystem restoration. This, however, is beyond the scope of this dissertation and will thus not be discussed in more depth here.

4.3 Lesson III: Ecosystem restoration needs ecology

The world is facing a multitude of pressing social issues that can benefit from ecosystem restoration. As a result, many recent restoration projects focus on delivering positive outcomes for livelihoods, poverty alleviation, and human well-being (Erbaugh & Oldekop 2018; Goffner et al. 2019). While the attempt to generate social benefits from restoration is highly valuable, an exclusive focus on social and political objectives can cause the neglect of ecological aspects of restoration. This, in turn, comes at the expense of biodiversity and long-term ecological integrity (Edwards & Cerullo 2024) and is also likely to backfire on social objectives (Hua et al. 2018; Coleman et al. 2021). To generate ecosystems that are multifunctional, biodiverse, and viable for the long-term future, it is important to base ecosystem restoration on a strong ecological science foundation.

There are many examples of how social, economic, and political motivations upstage ecological considerations. First, many restoration projects select species not based on their ecological suitability but on seedling availability, costs, and short-sighted project objectives (Lesage et al. 2018; Palmer & Stewart 2020). However, species selection has long-lasting consequences for ecosystem function and resilience (Di Sacco et al. 2021; Fremout et al. 2022), and habitat heterogeneity (Holl et al. 2022). Second, when ecosystem restoration is mainly informed by political agendas and global-level restoration programmes are indiscriminately applied to local ecosystems, there is a high risk of planting unsuitable species that might even destroy intact ecosystems. This is especially the case for tree planting in non-forest ecosystems (Bond et al. 2019; Parr et al. 2024). In both cases, the lack of well-informed restoration decisions entails not only ecological but also negative social and economic consequences (Holl & Brancalion 2020; Fremout et al. 2022).

This trend is also visible in the Rwandan study area where ecosystem restoration has mainly focused on fast-growing, non-native species to reach urgent social objectives (see Paper II). This, however, resulted in low biodiversity (Arakwiye et al. 2021) and most likely limited resilience to potential social and ecological disturbances (see Paper I). Further, Paper III and Paper IV show how ecological considerations informed by scientific evidence are often side-lined in discussions on ecosystem restoration in Rwanda, mostly due to a lack of time, financial resources, and awareness.

The examples provided above show how ecosystem restoration needs to better incorporate ecology. First, restoration science can support this by increasing the accessibility of existing knowledge and thereby simplifying the connection of theory and practice which can be difficult for non-academic restoration stakeholders (Heger et al. 2022). Where needed, restoration science can also provide evidence-based assessments of species suitability for specific locations (Temperton et al. 2019; Di Sacco et al. 2021), ideally also considering possible future conditions (see Paper I).

Second, restoration policy needs to acknowledge the importance of scientifically rooted ecological objectives and not get side-tracked by simplistic campaigns that do not provide social or ecological benefits in the long run. In addition, supportive regulations and financing schemes can facilitate the coordination of restoration across scales and thus avoid negative ecological outcomes at the landscape scale which might be overseen when restoration only focuses on small projects (Holl et al. 2022).

Third, when designing restoration interventions, restoration practitioners need to bring stakeholders with contextual ecological expertise to the table to foster the selection of species which maximize biodiversity and foster mutualistic interactions between planted species (Di Sacco et al. 2021). Here, all four papers present approaches to facilitate exchange and Paper IV presents tangible strategies to enhance biodiversity and multifunctionality in restoration sites in Rwanda and beyond.

4.4 Lesson IV: Ecosystem restoration needs to be embedded in its social-ecological context

The three lessons outlined above all have something in common: they can best be implemented when restoration is approached from a social-ecological systems perspective. While social-ecological systems thinking for restoration has gained momentum in recent years (Fischer et al. 2021; Tedesco et al. 2023; Maes et al. 2024), many restoration projects do not yet account for the social-ecological complexity of restoration interventions (Li et al. 2021b; Tedesco et al. 2023). Hence, it is important to continuously highlight the benefits of approaching restoration from a social-ecological systems perspective.

The four papers cover a range of social-ecological systems elements and dynamics which play a role in ecosystem restoration. Paper I and Paper II both highlight the importance of understanding the particular social-ecological system that is to be restored. Paper I connects the present system with the future by encouraging the analysis of possible future impacts on restored sites and emphasizes the role of underlying drivers. By contrast, Paper II focuses on the present system and demonstrates how the application of causal loop diagrams can help to identify and understand system elements and their interactions. In addition, Paper II offers a framework to reflect on changing ambitions for restoration and highlights the synergy between social and ecological restoration objectives. Paper III and Paper IV emphasize the role of stakeholders' perceptions and priorities for ecosystem restoration. Both papers offer ways to reflect on system elements and to prioritize diverse approaches and outcomes.

The Rwandan case study illustrates how stakeholders who plan, manage, implement, and monitor restoration need to find approaches that work in their respective social-ecological systems. First, Paper I shows how restoration in Rwanda needs to find locally appropriate ways to deal with looming social-ecological threats, such as climate change in tropical mountain landscapes. Second, Paper II presents the key elements and interactions which shape restoration in the study area and illustrates how ecological and social restoration ambitions changed over the years. Third, Paper III demonstrates how current debates related to restoration success are also relevant in Rwanda and reveals Rwandan stakeholders' priorities in terms of restoration approaches, rationales, and outcomes. Fourth, Paper IV shows how the specific context of restoration in Rwanda creates path-dependencies that need to be considered when planning for the future. The four papers demonstrate how all realms of ecosystem restoration need to be based on social-ecological systems thinking – in Rwanda and beyond.

5. Outlook

In the coming years and decades, ecosystem restoration can play a critical role in responding to local to global level social-ecological sustainability challenges. These include for example large-scale threats such as climate change and biodiversity loss, ethical questions related to the just distribution of benefits and disbenefits people obtain from nature, and the continuous reliance of people on ecosystems in the face of ongoing degradation. To harness the potential of ecosystem restoration to tackle these and other challenges, restoration science, policy, and practice need to work together to facilitate context-specific interventions. In addition, ecosystem restoration needs to pay special attention to timescales, the role of people, and ecological evidence. Here, developments in terminologies, target scales, and goals of restoration during the past century show how ecosystem restoration is capable of adapting to new circumstance, values, expectations, and aims. Based on the integration of social-ecological systems thinking and ecosystem restoration, this dissertation offers methodological and conceptual approaches to support researchers, policy-makers, and practitioners with implementing the next wave of ecosystem restoration by understanding and working with complex interactions between ecological and social system elements that shape ecosystem restoration sites.

6. Bibliography

Adams, C., S. T. Rodrigues, M. Calmon, and C. Kumar. 2016. Impacts of large-scale forest restoration on socioeconomic status and local livelihoods: what we know and do not know. Biotropica **48**:731–744.

Alexander, S., J. Aronson, O. Whaley, and D. Lamb. 2016. The relationship between ecological restoration and the ecosystem services concept. Ecology and Society **21**:34.

Arakwiye, B., J. Rogan, and J. R. Eastman. 2021. Thirty years of forest-cover change in Western Rwanda during periods of wars and environmental policy shifts. Regional Environmental Change **21**:27.

Balaguer, L., A. Escudero, J. F. Martín-Duque, I. Mola, and J. Aronson. 2014. The historical reference in restoration ecology: Re-defining a cornerstone concept. Biological Conservation **176**:12–20.

Ballari, S., C. Roulier, E. Nielsen, J. Pizarro, and C. Anderson. 2020. A Review of Ecological Restoration Research in the Global South and North to Promote Knowledge Dialogue. **18**:298.

Banin, L. F. et al. 2023. The road to recovery: a synthesis of outcomes from ecosystem restoration in tropical and sub-tropical Asian forests. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences **378**:20210090.

Barbier, E. B., and J. P. Hochard. 2018. Land degradation and poverty. Nature Sustainability **1**:623–631.

Bastin, J.-F., Y. Finegold, C. Garcia, D. Mollicone, M. Rezende, D. Routh, C. M. Zohner, and T. W. Crowther. 2019. The global tree restoration potential. Science **365**:76–79.

Bergstrom, D. M. et al. 2021. Combating ecosystem collapse from the tropics to the Antarctic. Global Change Biology **27**:1692–1703.

Berkes, F., C. Folke, and J. Colding. 2000. Linking social and ecological systems: management practices and social mechanisms for building resilience. Cambridge University Press.

Biggs, R. et al. 2012. Toward Principles for Enhancing the Resilience of Ecosystem Services. Annual review of environment and resources **37**:421–448.

Biggs, R., A. de Vos, R. Preise, H. Clements, K. Maciejewski, and M. Schlüter. 2021. The Routledge Handbook of Research Methods for Social-Ecological Systems, 1st edition. Routledge, London.

Bond, W. J., N. Stevens, G. F. Midgley, and C. E. R. Lehmann. 2019. The Trouble with Trees: Afforestation Plans for Africa. Trends in Ecology & Evolution **34**:963–965.

Borgström, S., A. Zachrisson, and K. Eckerberg. 2016. Funding ecological restoration policy in practice—patterns of short-termism and regional biases. Land Use Policy **52**:439–453.

Brudvig, L. A., and C. P. Catano. 2021. Prediction and uncertainty in restoration science. Restoration Ecology:e13380.

Buckingham, K., B. Arakwiye, S. Ray, O. Maneerattana, and W. Anderson. 2020. Cultivating networks and mapping social landscapes: How to understand restoration governance in Rwanda. Land Use Policy **104**:104546.

Carlucci, M. B., P. H. S. Brancalion, R. R. Rodrigues, R. Loyola, and M. V. Cianciaruso. 2020. Functional traits and ecosystem services in ecological restoration. Restoration Ecology **28**:1372–1383.

Carpenter, S. et al. 2012. General Resilience to Cope with Extreme Events. Sustainability **4**:3248–3259.

Carpenter, S., B. Walker, J. M. Anderies, and N. Abel. 2001. From Metaphor to Measurement: Resilience of What to What? Ecosystems **4**:765–781.

CBD. 2022. The Kunming-Montreal Global Biodiversity Framework. United Nations Environment Programme. Available from https://www.un.org/depts/german/umwelt/COP-15-DEC-4.pdf (accessed August 20, 2024).

Chazdon, R. L., D. A. Falk, L. F. Banin, M. Wagner, S. Wilson, R. C. Grabowski, and K. N. Suding. 2021a. The intervention continuum in restoration ecology: rethinking the active–passive dichotomy. Restoration Ecology:e13535.

Chazdon, R. L., S. J. Wilson, E. Brondizio, M. R. Guariguata, and J. Herbohn. 2021b. Key challenges for governing forest and landscape restoration across different contexts. Land Use Policy **104**:104854.

Choksi, P. et al. 2023. Combining socioeconomic and biophysical data to identify people-centric restoration opportunities. npj Biodiversity **2**:7.

Clay, N. 2019. Fixing the ecosystem: Conservation, crisis and capital in Rwanda's Gishwati Forest. Environment and planning E: Nature and Space **2**:23–46.

Cole, L. E. S., S. A. Bhagwat, and K. J. Willis. 2014. Recovery and resilience of tropical forests after disturbance. Nature Communications **5**:3906.

Coleman, E. A. et al. 2021. Limited effects of tree planting on forest canopy cover and rural livelihoods in Northern India. Nature Sustainability **4**: 997–1004.

Curry, A., and A. Hodgson. 2008. Seeing in multiple horizons: connecting futures to strategy. Journal of Futures Studies **13**:1–20.

Darwin Holmes, A. G. 2020. Researcher Positionality - A Consideration of Its Influence and Place in Qualitative Research - A New Researcher Guide. American Journal of Educational Research **8**:1–10.

Dawson, N., A. Martin, and T. Sikor. 2016. Green Revolution in Sub-Saharan Africa: Implications of Imposed Innovation for the Wellbeing of Rural Smallholders. World Development **78**:204–218.

de Jong, W., M. van der Zon, A. F. Urushima, Y.-C. Youn, J. Liu, and N. Li. 2018. Tenure, property rights and forest landscape restoration. Pages 158–175 in S. Mansourian and J. Parrotta, editors. Forest Landscape Restoration: integrated approaches to support effective implementation. Routledge, London.

DeFries, R., M. Agarwala, S. Baquie, P. Choksi, S. Khanwilkar, P. Mondal, H. Nagendra, and J. Uperlainen. 2022. Improved household living standards can restore dry tropical forests. Biotropica **54**:1480–1490.

Di Sacco, A. et al. 2021. Ten golden rules for reforestation to optimize carbon sequestration, biodiversity recovery and livelihood benefits. Global Change Biology **27**:1328–1348.

Díaz, S. et al. 2019. Pervasive human-driven decline of life on Earth points to the need for transformative change. Science **366**:eaax3100.

Dorninger, C., A. Hornborg, D. J. Abson, H. von Wehrden, A. Schaffartzik, S. Giljum, J.-O. Engler, R. L. Feller, K. Hubacek, and H. Wieland. 2021. Global patterns of ecologically unequal exchange: Implications for sustainability in the 21st century. Ecological Economics **179**:106824.

Dudley, N., S. Mansourian, and D. Vallauri. 2005. Forest landscape restoration in context. Pages 3–7 Forest restoration in landscapes. Springer-Verlag, New York.

Dudney, J., C. D'Antonio, R. J. Hobbs, N. Shackelford, R. J. Standish, and K. N. Suding. 2022. Capacity for change: three core attributes of adaptive capacity that bolster restoration efficacy. Restoration Ecology:e13647.

Duguma, L., P. Minang, E. Aynekulu, S. Carsan, J. Nzyoka, A. Bah, and R. Jamnadass. 2020. From tree planting to tree growing: rethinking ecosystem restoration through trees. World Agroforestry Centre, Nairobi.

Edwards, D. P., and G. R. Cerullo. 2024. Biodiversity is central for restoration. Current Biology **34**:371–379.

Elias, M. et al. 2022. Ten people-centered rules for socially sustainable ecosystem restoration. Restoration Ecology **30**:e13574.

Elias, M., D. Joshi, and R. Meinzen-Dick. 2021. Restoration for whom, by whom? A feminist political ecology of restoration. Ecological Restoration **39**:3–15.

Erbaugh, J. T., and J. A. Oldekop. 2018. Forest landscape restoration for livelihoods and well-being. Current Opinion in Environmental Sustainability **32**:76–83.

Erbaugh, J. T., N. Pradhan, J. Adams, J. A. Oldekop, A. Agrawal, D. Brockington, R. Pritchard, and A. Chhatre. 2020. Global forest restoration and the importance of prioritizing local

communities. Nature Ecology & Evolution **4**:1472–1476.
FAO, IUCN, CEM, and SER. 2021. Principles for Ecosystem Restoration to Guide the United Nations Decade 2021–2030. Food and Agricultural Organization of the United Nations, Rome.
Fedele, G., C. I. Donatti, I. Bornacelly, and D. G. Hole. 2021. Nature-dependent people: Mapping human direct use of nature for basic needs across the tropics. Global Environmental Change **71**:102368.
Fernández-Manjarrés, J. F., S. Roturier, and A.-G. Bilhaut. 2018. The emergence of the social-ecological restoration concept. Restoration Ecology **26**:404–410.
Fischer, J. et al. 2015. Advancing sustainability through mainstreaming a social–ecological systems perspective. Current Opinion in Environmental Sustainability **14**:144–149.
Fischer, J., M. Riechers, J. Loos, B. Martin-Lopez, and V. M. Temperton. 2021. Making the UN Decade on Ecosystem Restoration a Social-Ecological Endeavour. Trends in Ecology & Evolution **36**:20–28.
Fleischman, F. et al. 2020. Pitfalls of Tree Planting Show Why We Need People-Centered Natural Climate Solutions. Bioscience **70**:947–950.
Fleischman, F. D. 2014. Why do Foresters Plant Trees? Testing Theories of Bureaucratic Decision-Making in Central India. World Development **62**:62–74.
Folke, C. 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. Global Environmental Change **16**:253–267.
Folke, C., J. Colding, and F. Berkes. 2003. Synthesis: Building resilience and adaptive capacity in social-ecological systems. Page in F. Berkes, J. Colding, and C. Folke, editors. Navigating social-ecological systems. Cambridge University Press, Cambridge.
Fox, C. A. et al. 2017. "The river is us; the river is in our veins": re-defining river restoration in three Indigenous communities. Sustainability Science **12**:521–533.
Fremout, T. et al. 2022. Diversity for Restoration (D4R): Guiding the selection of tree species and seed sources for climate-resilient restoration of tropical forest landscapes. Journal of Applied Ecology **59**:664–679.
Gallopín, G. C. 2006. Linkages between vulnerability, resilience, and adaptive capacity. Global Environmental Change **16**:293–303.
Gann, G. D. et al. 2019. International principles and standards for the practice of ecological restoration. Second edition. Restoration Ecology **27**:1–46.
Goffner, D., H. Sinare, and L. J. Gordon. 2019. The Great Green Wall for the Sahara and the Sahel Initiative as an opportunity to enhance resilience in Sahelian landscapes and livelihoods. Regional Environmental Change **19**:1417–1428.
Government of Rwanda. 2017. 7 Years Government Programme: National Strategy for Transformation (NST1) 2017-2024. Ministry of Finance and Economic Planning.
Groundstroem, F., and S. Juhola. 2021. Using systems thinking and causal loop diagrams to identify cascading climate change impacts on bioenergy supply systems. Mitigation and Adaptation Strategies for Global Change **26**:29.
Hanson, T., T. M. Brooks, G. A. B. Da Fonseca, M. Hoffmann, J. F. Lamoreux, G. Machlis, C. G. Mittermeier, R. A. Mittermeier, and J. D. Pilgrim. 2009. Warfare in biodiversity hotspots. Conservation Biology **23**:578–587.
Hanspach, J. et al. 2014. A holistic approach to studying social-ecological systems and its application to southern Transylvania. Ecology and Society **19**:27.
Haraldsson, H. V. 2004. Introduction to system thinking and causal loop diagrams. Department of Chemical Engineering, Lund University, Lund, Sweden.
Harris, J. A., R. J. Hobbs, E. Higgs, and J. Aronson. 2006. Ecological Restoration and Global Climate Change. Restoration Ecology **14**:170–176.
Heger, T., J. M. Jeschke, C. Febria, J. Kollmann, S. Murphy, L. Rochefort, N. Shackelford, V. M. Temperton, and E. Higgs. 2022. Mapping and assessing the knowledge base of ecological restoration. Restoration Ecology:e13676.
Hemmerling, S. A. et al. 2023. A community-informed transdisciplinary approach to coastal

restoration planning: Maximizing the social and ecological co-benefits of wetland creation in Port Fourchon, Louisiana, USA. Frontiers in Environmental Science **11**:1105671.
Higgs, E. 1994. Expanding the Scope of Restoration Ecology. Restoration Ecology **2**:137–146.
Higgs, E. 2003. Nature by Design: People, Natural Process, and Ecological Restoration. MIT Press.
Hobbs, R. J., and J. A. Harris. 2001. Restoration ecology: repairing the earth's ecosystems in the new millennium. Restoration Ecology **9**:239–246.
Hodge, I., and W. Adams. 2016. Short-Term Projects versus Adaptive Governance: Conflicting Demands in the Management of Ecological Restoration. Land **5**:39.
Höhl, M., V. Ahimbisibwe, J. A. Stanturf, P. Elsasser, M. Kleine, and A. Bolte. 2020. Forest landscape restoration—what generates failure and success? Forests **11**:938.
Holl, K. D., and P. H. S. Brancalion. 2020. Tree planting is not a simple solution. Science **368**:580–581.
Holl, K. D., J. C. Luong, and P. H. S. Brancalion. 2022. Overcoming biotic homogenization in ecological restoration. Trends in Ecology & Evolution **37**:777–788.
Holling, C. S. 1973. Resilience and Stability of Ecological Systems. Annual Review of Ecology and Systematics **4**:1–23.
Hua, F., L. Wang, B. Fisher, X. Zheng, X. Wang, D. W. Yu, Y. Tang, J. Zhu, and D. S. Wilcove. 2018. Tree plantations displacing native forests: The nature and drivers of apparent forest recovery on former croplands in Southwestern China from 2000 to 2015. Biological Conservation **222**:113–124.
Iftekhar, M. S., M. Polyakov, D. Ansell, F. Gibson, and G. M. Kay. 2017. How economics can further the success of ecological restoration. Conservation Biology **31**:261–268.
IPCC. 2022. Annex II: Glossary. Pages 2897–2930 (V. Möller, R. van Diemen, J. B. R. Matthews, C. Méndez, S. Semenov, J. S. Fuglestvedt, and A. Reisinger, editors). Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.
IPCC. 2023. Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Pages 35–115 (H. Lee and J. Romero, editors). IPCC, Geneva, Switzerland.
IUCN. 2020a. Taking the Bonn Challenge to Rio. Available from https://www.bonnchallenge.org/sites/default/files/resources/files/%5Bnode%3Anid%5D/Taking%20the%20Bonn%20Challenge%20to%20Rio.pdf (accessed August 20, 2024).
IUCN. 2020b. Restore Our Future: Bonn Challenge. Impact and Potential of Forest Landscape Restoration. IUCN.
IUCN. 2022. IUCN Restoration Barometer 2022 Report. IUCN Center for Conservation Action, Washington DC.
Jiang, C., H. Zhang, L. Zhao, Z. Yang, X. Wang, L. Yang, M. Wen, S. Geng, Q. Zeng, and J. Wang. 2020. Unfolding the effectiveness of ecological restoration programs in combating land degradation: Achievements, causes, and implications. The Science of the Total Environment **748**:141552.
Kanyamibwa, S. 1998. Impact of war on conservation: Rwandan environment and wildlife in agony. Biodiversity and Conservation **7**:1399–1406.
Kehoe, L., A. Romero-Muñoz, E. Polaina, L. Estes, H. Kreft, and T. Kuemmerle. 2017. Biodiversity at risk under future cropland expansion and intensification. Nature Ecology & Evolution **1**:1129–1135.
Kodikara, K. A. S., N. Mukherjee, L. P. Jayatissa, F. Dahdouh-Guebas, and N. Koedam. 2017. Have mangrove restoration projects worked? An in-depth study in Sri Lanka. Restoration Ecology **25**:705–716.
Krievins, K., R. Plummer, and J. Baird. 2018. Building Resilience in Ecological Restoration Processes: A Social-Ecological Perspective. Ecological Restoration **36**:195–207.
Leopold, A. 1966. A Sand County Almanac. Oxford University Press, New York.
Lesage, J. C., E. A. Howard, and K. D. Holl. 2018. Homogenizing biodiversity in restoration: the

"perennialization" of California prairies. Restoration Ecology **26**:1061–1065.
Li, C., M. Yang, Z. Li, and B. Wang. 2021a. How Will Rwandan Land Use/Land Cover Change under High Population Pressure and Changing Climate? Applied Sciences **11**:5376.
Li, R., H. Zheng, P. O'Connor, H. Xu, Y. Li, F. Lu, B. E. Robinson, Z. Ouyang, Y. Hai, and G. C. Daily. 2021b. Time and space catch up with restoration programs that ignore ecosystem service trade-offs. Science Advances **7**:eabf8650.
Locke, K., M. Feldman, and K. Golden-Biddle. 2020. Coding practices and iterativity: beyond templates for analyzing qualitative data. Organizational Research Methods **25**:262–284.
Löfqvist, S. et al. 2022. How social considerations improve the equity and effectiveness of ecosystem restoration. Bioscience **73**:134–148.
Loos, J. et al. 2023. An environmental justice perspective on ecosystem services. Ambio **52**:477–488.
Loreau, M. 2023. Nature that makes us human: why we keep destroying nature and how we can stop doing so. Oxford University Press, New York.
Maes, S. L. et al. 2024. Explore before you restore: Incorporating complex systems thinking in ecosystem restoration. Journal of Applied Ecology **61**:922–939.
Malkamäki, A., D. D'Amato, N. J. Hogarth, M. Kanninen, R. Pirard, A. Toppinen, and W. Zhou. 2018. A systematic review of the socio-economic impacts of large-scale tree plantations, worldwide. Global Environmental Change **53**:90–103.
Mansourian, S. 2018. Stakeholders and forest landscape restoration: who decides what to restore, why and where? Pages 139–157 in S. Mansourian and J. Parrotta, editors. Forest Landscape Restoration: integrated approaches to support effective implementation. Routledge, London.
Mansourian, S. 2021. Disciplines, sectors, motivations and power relations in forest landscape restoration. Ecological Restoration **39**:16–26.
Mansourian, S., and J. Parrotta, editors. 2018. Forest Landscape Restoration: Integrated approaches to support effective implementation, 1st edition. Routledge, London.
Margules, C., A. K. Boedhihartono, J. D. Langston, R. A. Riggs, D. A. Sari, S. Sarkar, J. A. Sayer, J. Supriatna, and N. L. Winarni. 2020. Transdisciplinary science for improved conservation outcomes. Environmental Conservation **47**:224–233.
Martin, D. M. 2017. Ecological restoration should be redefined for the twenty-first century. Restoration Ecology **25**:668–673.
Martin, L. J. 2022. Wild by Design: The Rise of Ecological Restoration. Harvard University Press.
Martin, M. P., D. J. Woodbury, D. A. Doroski, E. Nagele, M. Storace, S. C. Cook-Patton, R. Pasternack, and M. S. Ashton. 2021. People plant trees for utility more often than for biodiversity or carbon. Biological Conservation **261**:109224.
Martin, P. A., A. C. Newton, and J. M. Bullock. 2013. Carbon pools recover more quickly than plant biodiversity in tropical secondary forests. Proceedings. Biological Sciences / the Royal Society **280**:20132236.
Massi, K. G., R. B. Chaves, and L. R. Tambosi. 2022. Simple indicators are good proxies for ecological complexity when assessing Atlantic Forest restoration success. Restoration Ecology **30**:e13520.
McDonald, T., and J. Williams. 2009. A perspective on the evolving science and practice of ecological restoration in Australia. Ecological Management & Restoration **10**:113–125.
M.E.A. 2005. A Report of the Millennium Ecosystem Assessment. Ecosystems and Human Well-Being. Island Press, Washington DC.
Meadows, D. 2008. Thinking in Systems: A Primer. Chelsea Green Publishing, Vermont.
Méndez-Toribio, M., C. Martínez-Garza, and E. Ceccon. 2021. Challenges during the execution, results, and monitoring phases of ecological restoration: Learning from a country-wide assessment. Plos One **16**:e0249573.
Messinger, J., and B. Winterbottom. 2016. African forest landscape restoration initiative (AFR100): restoring 100 million hectares of degraded and deforested land in Africa. Nature & Faune **30**:14–17.
Ministry of Environment. 2020. National Land-Use & Development Master Plan 2020-2050. Republic of Rwanda.

Ministry of Natural Resources Rwanda. 2014. Forest landscape restoration opportunity assessment for Rwanda. MINIRENA (Rwanda), IUCN, WRI.
Mittermeier, R. A., P. R. Gill, M. Hoffman, J. Pilgrim, T. Brooks, C. G. Mittermeier, J. Lamoreux, and G. A. B. da Fonseca. 2004. Hotspots revisited: earths biologically richest and most endangered terrestrial ecoregions. Cemex.
Moreno-Mateos, D., A. Alberdi, E. Morriën, W. H. van der Putten, A. Rodríguez-Uña, and D. Montoya. 2020. The long-term restoration of ecosystem complexity. Nature Ecology & Evolution **4**:676–685.
Mugabowindekwe, M. et al. 2022. Nation-wide mapping of tree-level aboveground carbon stocks in Rwanda. Nature Climate Change **13**:91–97.
Naeem, S. 2006. Biodiversity and Ecosystem Functioning in Restored Ecosystems: Extracting Principles for a Synthetic Perspective. Page in D. Falk, M. A. Palmer, and J. B. Zedler, editors. Foundations of Restoration Ecology. Island Press, Washington DC.
Naia, M. et al. 2021. Potential negative effects of the Green Wall on Sahel's biodiversity. Conservation Biology **35**:1966–1968.
Nash, C., S. Carvalho, L. Raes, A. Ndoli, C. Karangwa, E. Imanirareba, J. Njue, and D. Toovey. 2020. A Thousand Hills Turn Green: How Rwanda became a leader in forest landscape restoration. Available from https://iucn.maps.arcgis.com/apps/MapJournal/index.html?appid=0c40be7f83c64bb9b7c8f3372358c6f9 (accessed August 2, 2024).
National Institute of Statistics of Rwanda. 2023. The Fifth Rwanda Population and Housing Census - Main Indicators Report. NISR, Kigali.
National Institute of Statistics Rwanda. 2021. Labour Force Survey Annual Report 2020.
Neale, J. 2016. Iterative categorization (IC): a systematic technique for analysing qualitative data. Addiction **111**:1096–1106.
Neeson, T. M., M. C. Ferris, M. W. Diebel, P. J. Doran, J. R. O'Hanley, and P. B. McIntyre. 2015. Enhancing ecosystem restoration efficiency through spatial and temporal coordination. Proceedings of the National Academy of Sciences of the United States of America **112**:6236–6241.
Nishimwe, G., D. M. Rugema, C. Uwera, C. Graveland, J. Stage, S. Munyawera, and G. Ngabirame. 2020. Natural capital accounting for land in rwanda. Sustainability **12**:5070.
Norström, A. V. et al. 2020. Principles for knowledge co-production in sustainability research. Nature Sustainability **3**:182–190.
Nsikani, M. M. et al. 2023. UN Decade on Ecosystem Restoration: key considerations for Africa. Restoration Ecology **31**:e13699.
Ordway, E. M. 2015. Political shifts and changing forests: Effects of armed conflict on forest conservation in Rwanda. Global Ecology and Conservation **3**:448–460.
Osborne, T., S. Brock, R. Chazdon, S. Chomba, E. Garen, V. Gutierrez, R. Lave, M. Lefevre, and J. Sundberg. 2021. The political ecology playbook for ecosystem restoration: Principles for effective, equitable, and transformative landscapes. Global Environmental Change **70**:102320.
Ostrom, E. 2007. Sustainable Social-Ecological Systems: An Impossibility? SSRN Electronic Journal.
Ostrom, E. 2009. A general framework for analyzing sustainability of social-ecological systems. Science **325**:419–422.
Palmer, M. A., and G. A. Stewart. 2020. Ecosystem restoration is risky … but we can change that. One Earth **3**:661–664.
Parr, C. L., M. Te Beest, and N. Stevens. 2024. Conflation of reforestation with restoration is widespread. Science **383**:698–701.
Perring, M. P., R. J. Standish, J. N. Price, M. D. Craig, T. E. Erickson, K. X. Ruthrof, A. S. Whiteley, L. E. Valentine, and R. J. Hobbs. 2015. Advances in restoration ecology: rising to the challenges of the coming decades. Ecosphere **6**:131.
Piccolo, J. J. 2020. Celebrating Aldo Leopold's land ethic at 70. Conservation Biology **34**:1586–1588.
Plumptre, A., M. Masozera, and A. Vedder. 2001. The Impact of Civil War on the Conservation of Protected Areas in Rwanda.

Pritchard, M. F. 2013. Land, power and peace: Tenure formalization, agricultural reform, and livelihood insecurity in rural Rwanda. Land Use Policy **30**:186–196.

Prunier, G., editor. 1995. The Rwanda crisis: history of a genocide. Columbia University Press, New York.

Radeloff, V. C., F. Beaudry, T. M. Brooks, V. Butsic, M. Dubinin, T. Kuemmerle, and A. M. Pidgeon. 2012. Hot moments for biodiversity conservation. Conservation Letters **6**:58–65.

Reyes-García, V., Á. Fernández-Llamazares, P. McElwee, Z. Molnár, K. Öllerer, S. J. Wilson, and E. S. Brondizio. 2019. The contributions of Indigenous Peoples and local communities to ecological restoration. Restoration Ecology **27**:3–8.

Rutebuka, J., D. M. Kagabo, and A. Verdoodt. 2019. Farmers' diagnosis of current soil erosion status and control within two contrasting agro-ecological zones of Rwanda. Agriculture, Ecosystems & Environment **278**:81–95.

Rwibasira, P., F. X. Naramabuye, D. Nsabimana, and M. Carnol. 2021. Long-Term Effects of Forest Plantation Species on Chemical Soil Properties in Southern Rwanda. Soil Systems **5**:59.

Santini, N. S., and Y. Miquelajauregui. 2022. The restoration of degraded lands by local communities and indigenous peoples. Frontiers in Conservation Science **3**:873659.

Savin-Baden, M., and C. Howell Major. 2023. Qualitative research: the essential guide to theory and practice. Routledge, London.

Scarlett, L., and M. McKinney. 2016. Connecting people and places: the emerging role of network governance in large landscape conservation. Frontiers in Ecology and the Environment **14**:116–125.

Schaal, T., M. Mitchell, B. C. Scheele, P. Ryan, and J. Hanspach. 2023. Using the three horizons approach to explore pathways towards positive futures for agricultural landscapes with rich biodiversity. Sustainability Science **18**:1271–1289.

Schubert, S. C., K. E. Battaglia, C. N. Blebea, C. J. P. Seither, H. L. Wehr, and K. D. Holl. 2024. Advances and shortfalls in applying best practices to global tree-growing efforts. Conservation Letters **17**:e13002.

Seimon, A., and G. Picton Phillipps. 2010. Climatological Assessment of the Albertine Rift for Conservation Applications. Wildlife Conservation Society.

Sewell, A., S. van der Esch, and H. Löwenhardt. 2020. Global Restoration Commitments database. Available from https://www.pbl.nl/sites/default/files/downloads/pbl-2021-global-restoration-commitments-database-4680.ods (accessed August 11, 2024).

Sharpe, B., A. Hodgson, G. Leicester, A. Lyon, and I. Fazey. 2016. Three horizons a pathways practice for transformation. Ecology and Society **21**.

Shennan-Farpón, Y., M. Mills, A. Souza, and K. Homewood. 2022. The role of agroforestry in restoring Brazil's Atlantic Forest: Opportunities and challenges for smallholder farmers. People and Nature **4**:462–480.

Sigman, E., and M. Elias. 2021. Three approaches to restoration and their implications for social inclusion. Ecological Restoration **39**:27–35.

Sinclair, M., M. K. Vishnu Sagar, C. Knudsen, J. Sabu, and A. Ghermandi. 2021. Economic appraisal of ecosystem services and restoration scenarios in a tropical coastal Ramsar wetland in India. Ecosystem Services **47**:101236.

Smit, B., and J. Wandel. 2006. Adaptation, adaptive capacity and vulnerability. Global Environmental Change **16**:282–292.

Smith, P. et al. 2019. Interlinkages between desertification, land degradation, food security and greenhouse gas fluxes: Synergies,trade-offs and integrated response options. Pages 551–672 in J. Skea et al., editors. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.

Society for Ecological Restoration. 2004. The SER International Primer on Ecological Restoration. Society for Ecological Restoration International, Tucson, Arizona.

Steffen, W., W. Broadgate, L. Deutsch, O. Gaffney, and C. Ludwig. 2015. The trajectory of the Anthropocene: The Great Acceleration. The Anthropocene Review **2**:81–98.

Stenner, P., Watts, Simon. 2012. Doing Q Methodological Research: Theory, Method & Interpretation. Sage Publications Ltd, Thousand Oaks.
Strassburg, B. B. N. et al. 2020. Global priority areas for ecosystem restoration. Nature **586**:724–729.
Tedesco, A. M., et al. 2023. Beyond ecology: ecosystem restoration as a process for social-ecological transformation. Trends in Ecology & Evolution **38**:643–653.
Temperton, V. M., N. Buchmann, E. Buisson, G. Durigan, L. Kazmierczak, M. P. Perring, M. de Sá Dechoum, J. W. Veldman, and G. E. Overbeck. 2019. Step back from the forest and step up to the Bonn Challenge: How a broad ecological perspective can promote successful landscape restoration. Restoration Ecology **27**:705–719.
UN. 2015. Paris Agreement to the United Nations Framework Convention on Climate Change. United Nations.
UN DESA. 2019. World Population Prospects 2019. United Nations Department of Economic and Social Affairs.
UN Environment Agency. 2019. Resolution 73/284: United Nations Decade on Ecosystem Restoration. United Nations Environment Agency.
UN General Assembly. 2015. Resolution 70/1: Transforming our world: the 2030 Agenda for Sustainable Development. United Nations General Assembly.
UNEP. 2021. Becoming #GenerationRestoration: Ecosystem restoration for people, nature and climate. United Nations Environment Programme.
Uwizelimana, J. de D., D. Nsabimana, and T. Wagner. 2022. Diversity and distribution of Fruit-feeding butterflies (Lepidoptera: Nymphalidae) in Nyungwe National Park, Rwanda. African Journal of Ecology **60**:621–632.
Veldman, J. W. et al. 2019. Comment on "The global tree restoration potential". Science **366**:eaay7976.
Vezzoni, R., F. Sijtsma, and H. Vihinen. 2023. Designing effective environmental policy mixes in the UN Decade on ecosystem restoration. Ecosystem Services **62**:101541.
Walker, B., C. S. Holling, S. R. Carpenter, and A. P. Kinzig. 2004. Resilience, Adaptability and Transformability in Social-ecological Systems. Ecology and Society **9**.
Walker, B., and D. Salt. 2006. Resilience thinking: sustaining ecosystems and people in a changing world. Island Press, Washington DC.
Wehi, P. M., and J. M. Lord. 2017. Importance of including cultural practices in ecological restoration. Conservation Biology **31**:1109–1118.
Wiegant, D., M. Peralvo, P. van Oel, and A. Dewulf. 2020. Five scale challenges in Ecuadorian forest and landscape restoration governance. Land Use Policy **96**:104686.
Yang, A., I. Bellwood-Howard, and M. Lippe. 2018. Social-ecological systems and forest landscape restoration. Pages 65–82 in S. Mansourian and J. Parrotta, editors. Forest Landscape Restoration: integrated approaches to support effective implementation. Routledge, London.
Zabala, A. 2014. Qmethod: A package to explore human perspectives using Q methodology. The R Journal **6**:163–173.
Zabala, A., C. Sandbrook, and N. Mukherjee. 2018. When and how to use Q methodology to understand perspectives in conservation research. Conservation Biology **32**:1185–1194.
Zabin, C. J., L. J. Jurgens, J. M. Bible, M. V. Patten, A. L. Chang, E. D. Grosholz, and K. E. Boyer. 2022. Increasing the resilience of ecological restoration to extreme climatic events. Frontiers in Ecology and the Environment **20**:310–318.
Zu Ermgassen, S. O. S. E., and S. Löfqvist. 2024. Financing ecosystem restoration. Current Biology **34**:412–417.

Chapter II

Future-proofing ecosystem restoration through enhancing adaptive capacity

Paper I

Marina Frietsch, Jacqueline Loos, Katharina Löhr,
Stefan Sieber, Joern Fischer

Communications Biology, 2023

communications biology

PERSPECTIVE

https://doi.org/10.1038/s42003-023-04736-y OPEN

Future-proofing ecosystem restoration through enhancing adaptive capacity

Marina Frietsch[1,2✉], Jacqueline Loos[1,3], Katharina Löhr[4,5], Stefan Sieber[4,6] & Joern Fischer[1]

Social-ecological ecosystem restoration involves interacting challenges, including climate change, resource overexploitation and political instability. To prepare for these and other emerging threats, we synthesized key restoration and social-ecological systems literature and derived three guiding themes that can help to enhance the adaptive capacity of restoration sites: (i) work with the existing system, (ii) create self-sustaining, adaptive systems, and (iii) foster diversity and participation. We propose a two-step approach and provide an example from Rwanda detailing the application of these principles. While site-specific activities have to be designed and implemented by local practitioners, our synthesis can guide forward-thinking restoration practice.

The restoration of degraded ecosystems is increasingly recognized as a key strategy to respond to climate change, biodiversity decline, and associated ecological and social challenges[1,2]. Worldwide, many initiatives from local to global scales contribute to ecosystem restoration[3,4], and the United Nations declared 2021–2030 the "Decade on Ecosystem Restoration"[5]. Ecosystem restoration can be defined as the "process of halting and reversing the degradation of ecosystems"[6]. In practice, restoration encompasses diverse activities that range from revegetation[7] through interventions to restore species composition, ecosystem structure or function[8], to approaches that aim for multifunctional landscapes such as forest landscape restoration[9]. Increasingly, restoration is no longer seen as a purely ecological task but rather as a social-ecological endeavour[10,11] that seeks to restore inherent ecosystem values as well as provide goods and services to humanity[12,13]. Defined this way, ecosystem restoration needs to consider species composition, ecosystem functions and services, as well as human well-being.

Restoration activities inherently need to grapple not only with connections across space, but also with connections through time: restoration is informed by the past but created for the future, while drawing on the knowledge of today. Because the world is rapidly changing, past reference states might significantly differ from biophysical and also social conditions that shape a specific site now, let alone in 50 or 100 years[14,15]. In some cases, novel or hybrid ecosystems might emerge that are characterized by significantly altered abiotic conditions and new, unprecedented species assemblages[16]. Rapid and partly unpredictable social-ecological change thus makes ecosystem restoration particularly complex, and also influences the context in which restoration activities take place[17].

Despite their importance, three well-known challenges are commonly neglected in the design of restoration projects: (1) climate change, (2) overexploitation of resources, and (3) political instability. While some aspects of all three challenges have been discussed in recent restoration

[1] Leuphana University, Social-Ecological Systems Institute, Faculty of Sustainability, Universitätsallee 1, 21335 Lüneburg, Germany. [2] University of Rwanda, Center of Excellence in Biodiversity and Natural Resource Management, KN 7 Ave, Kigali, Rwanda. [3] Leuphana University, Institute of Ecology, Faculty of Sustainability, Universitätsallee 1, 21335 Lüneburg, Germany. [4] Leibniz Centre for Agricultural Landscape Research (ZALF), Eberswalder Straße 85, 15374 Müncheberg, Germany. [5] Humboldt Universität zu Berlin, Thaer-Institute of Agricultural and Horticultural Sciences, Urban Plant Ecophysiology, Lentzeallee 55/57, 14195 Berlin, Germany. [6] Humboldt Universität zu Berlin, Thaer-Institute of Agricultural and Horticultural Sciences, Resource Economics, Unter den Linden 6, 10099 Berlin, Germany. ✉email: marina.frietsch@leuphana.de

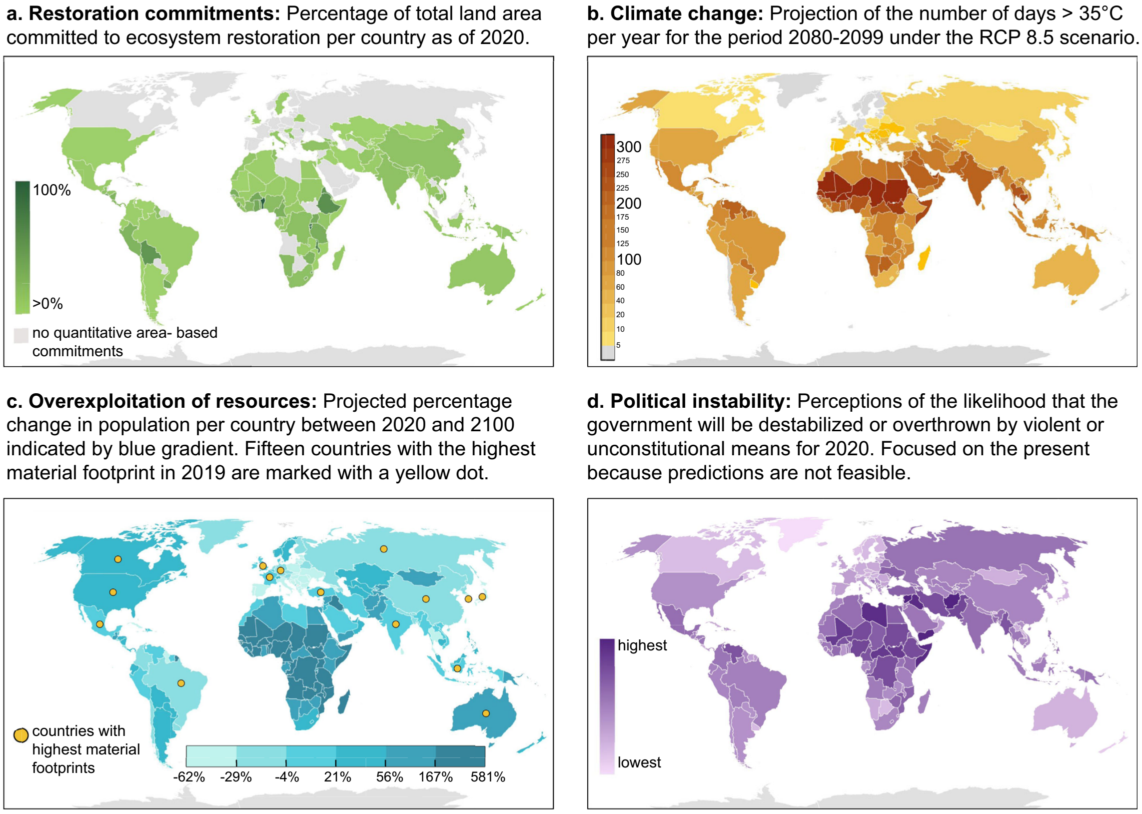

Fig. 1 Global patterns of restoration commitments, projected effects of climate change, overexploitation of resources, and political instability. The areas where many restoration activities are being implemented or planned (**a**) are also disproportionately affected by climate change (**b**), overexploitation of resources (**c**), and political instability (**d**). Data sources: **a** Restoration commitments from the Global Restoration Commitments Database by the PBL Netherlands Environmental Assessment Agency[90]. **b** Climate change represented by the number of days above 35 °C in the period 2080–2099 from the Climate Impact Lab.[85, 91]. **c** Human population growth from the United Nations World Population Prospects 2019[49] and national material footprint from the United Nations Environment Programme International Resource Panel Global Material Flows Database[92] (a list of the 15 countries is provided in Supplementary Table 1); **d** Political instability from the Worldwide Governance Indicators project by the World Bank[93].

literature[18–21], restoration practice still lags behind in consistently taking measures to safeguard restoration sites against future threats[15,20,22]. As a result, how climate change, overexploitation of resources, and political instability affect restoration sites in the short and medium term remains underexplored. In addition, interactions among these challenges—and perhaps other contemporary or emerging social-ecological changes—might result in new types of compounding threats for the viability of current and planned restoration efforts.

In this perspective article, we discuss how these three challenges and their interactions could disrupt, impede, or undermine ecosystem restoration. Based on this, we provide tangible suggestions for ways forward. Specifically, we (1) generate a concise synthesis of key principles from restoration and social-ecological systems literature, (2) introduce a two-step approach detailing how the resulting three guiding themes can be applied to restoration sites, and (3) illustrate via a case study on western Rwanda how the application of this approach can help restoration sites prepare for emerging challenges that might increasingly influence restoration in the future. In combination, our discussion of potential future threats, integration of different bodies of literature and operationalization of the resulting guiding principles provide a novel approach that can guide forward-thinking restoration practice.

Three key challenges for long-term successful restoration

Globally, locations predicted to experience severe climate change, overexploitation of resources, and political instability broadly coincide with locations earmarked for ambitious restoration activities (Fig. 1). Drawing on examples from around the world, we illustrate some of the many impacts that these challenges can have on social-ecological systems in general, and that they may have on restoration sites in particular.

Climate change. Climate change challenges ecosystem restoration by shaping future biophysical conditions in ways that are difficult to predict and, in some cases, may result in entirely unknown system constellations[16]. Climate models project that temperatures will rise, precipitation patterns will change, sea levels will rise, and the occurrence of extreme weather events will increase over the coming decades[23,24]. Notably, climate change is projected to have above-average impacts on regions with many restored and pledged restoration sites—as indicated for example by the number of extremely hot days predicted for the future (Fig. 1b).

Climate, directly and indirectly, influences ecosystem structure and processes, as well as the distribution of species and ecosystems[25]. Changes in climate might cause biome and habitat shifts[26,27]. At a coarse resolution, biome boundaries might shift[28] either gradually or abruptly, depending on the scale and type of climate change-induced pressure[29]. For example, the boundaries of the Sahel, where the Great Green Wall (one of the world's most ambitious restoration projects) is currently being implemented[3], are anticipated to shift southwards as a response to increasing temperatures, changes in precipitation patterns, and general drying in the region[28,29]. Such biome shifts could have major effects on restoration outcomes because ecological conditions will change over vast areas of land. At a finer resolution, climatic changes will cause the ranges of individual species to shift, generally to higher latitudes and higher altitudes[30]. Such changes in habitat suitability have major implications for species selection in restoration, and require the consideration of different timescales in restoration practice. Besides shifts in the location of biomes and habitats, the spatial extent of these will also change in response to climate change, and completely new systems with unknown ecological outcomes might emerge in the process[31]. Unless restoration is planned with climate change in mind, species newly planted for ecosystem restoration could fail to keep pace with associated shifts in geographical range[32].

Another aspect of how climate change might influence restoration sites is the effect of more frequent and intense extreme weather events[15,23]. Extreme temperatures, precipitation, floods, droughts, winds, or wildfires have the potential to destroy vast areas of biomass at once. For example, the 2021 wildfires in California, United States of America, burned almost 1 million ha[33]. Yet, California is considered a priority area for ecosystem restoration with a high potential to safeguard biodiversity and mitigate climate change[34]. Extreme weather events can irreversibly alter the structure of ecosystems and cause the decline or even local extirpation of species[35]. Notably, changes in patterns of extreme weather events are acknowledged to impact ecosystem functioning more strongly than shifts in average conditions[36]. Combinations of gradual changes in temperature and precipitation as well as more frequent extreme weather events thus could significantly undermine restoration efforts locally because planted species may not grow as expected, or because extreme weather events could destroy restoration areas.

Overexploitation of resources. Overconsumption as well as human population growth challenge ecosystem restoration by increasing global and local demand for natural resources, potentially triggering their overexploitation. Intensifying pressure on ecosystems therefore is both the reason why ecosystem restoration is so urgently needed, as well as a potential threat to restored ecosystems[37,38]. In addition, overexploitation aggravates competition for space between long-term restoration projects and resource extraction that benefits people in the short term[39,40]. In most high-income countries, the human population is projected to only grow moderately or may even decline in the coming decades (Fig. 1c). However, excessive per capita consumption in these countries results in a disproportionate demand for resources[41]. Consumption-related environmental impacts caused by high-income countries are estimated to be three to six times larger than those of low-income countries[42]. Often, these impacts are outsourced to middle- and low-income regions[43,44]. South American countries, for example, are the largest producers of soybeans which are used as livestock feed in the European Union. Large-scale soy production for the international market in countries such as Brazil and Argentina has resulted in the loss of primary forests, the expansion of monocultures[45], and grassland conversion, while providing no economic benefits to society at large[46]. Such telecouplings (i.e., interactions among social and ecological phenomena across large distances[11,47] and ecologically unequal exchange (i.e., asymmetric exchange of biophysical resources from poorer to richer countries[43] increasingly shift environmental burdens to poorer countries, and thus to many of the nations that have committed themselves to ecosystem restoration (Fig. 1a).

In addition to excessive consumption in the Global North, human population growth (especially in the Global South) can also fuel the overexploitation and degradation of ecosystems[38] and can be an important driver of deforestation[48]. The world population is projected to grow from nearly 8 billion today to 10.9 billion in 2100[49]. As with climate change, rapid population growth is projected to occur in many countries where ambitious restoration projects are being implemented or planned, such as Pakistan, Bolivia, and Nigeria (Fig. 1c). In Madagascar, the co-occurrence of human population growth and forest loss is clearly evident: a rising demand for food and energy has caused the ongoing clearance of formerly forested land for agricultural production and biomass extraction. Between 1950 and 2000, Madagascar's population grew from 4.1 million to 15.7 million[49]. In the same time period, 40% of forest cover was lost, leading to losses of biodiversity and ecosystem services, as well as causing soil degradation and increased carbon dioxide emissions[50,51]. Similarly, population growth played a central role in deforestation in Malawi[52], where a 1% increase in the human population was related to a deforestation rate of 2.7%[38]. Today, Madagascar and Malawi are among the countries with the highest projected population growth in the coming decades[49]; but they have also pledged to restore close to 7% and 50%, respectively, of their land by 2030[4].

Notably, increasing resource demands caused by high per capita consumption and human population growth are met not only by land-use change, but also by intensifying production on existing agricultural land[38]. In the Brazilian Amazon, for example, intensification was induced by local population growth and associated growing demand for food[53]. However, in many cases, agricultural intensification fails to achieve its goal of delivering higher levels of ecosystem services or human well-being, especially when it is driven by human population growth[54]. In the Brazilian example, agricultural intensification in fact caused a reduction in cassava yield while simultaneously increasing labour and decreasing household incomes[53].

In combination, high per capita resource demand in high-income countries combined with growing demand for essential ecosystem services by a growing population in low-income countries could jeopardize restoration activities: growing demand, necessity, and resource scarcity might drive people to prioritize the short-term gains of extracting resources—and potentially degrading restoration sites in the process—over the long-term benefits of restoration. Moreover, mosaic restoration that integrates trees into mixed-use landscapes, especially agricultural lands, is a key restoration strategy that seeks to generate diverse benefits for both ecosystems and humans[55]. The ongoing simplification of agricultural landscapes driven by a desire to increase agricultural yields, however, runs counter to mosaic restoration[56].

Political instability. Political instability challenges ecosystem restoration by destabilizing structures that are vital for the implementation and ongoing management of restoration projects (Rai et al.[57]). We define political instability as the absence of orderly transfers of government power and failure to maintain the rule of law, leading to social unrest, tensions, and conflicts at an international, national, or regional level. Because political instability is inherently uncertain, future developments in political stability are difficult to predict[58,59]. However, many of the priority areas for restoration have experienced political instability in the past[58] or are unstable today (Fig. 1d). It thus seems reasonable to expect that these areas also could be vulnerable to ongoing political instability in the coming years and decades[60,61].

Box 1 | Ecosystem degradation and restoration in the case of Rwanda

The case of Rwanda illustrates the interactions between political instability, redistribution of human pressures due to migration, causing the overexploitation of resources, and climate change in a restoration context across time. Over the past decades, a complex interplay of societal and political factors has resulted in the large-scale degradation of ecosystems in all parts of the country. Unstable political conditions[94], short-sighted protected area governance[95], armed conflicts in the 1960s, and a civil war culminating in the genocide against the Tutsi in 1994 caused habitat fragmentation, unregulated resource extraction, biodiversity loss, the killing of endangered animals, and ecosystem pollution[96]. Protected areas experienced disproportionate forest loss following the settlement of refugees[96, 97] and paramilitary militias[94, 95] within or close to their borders, with some protected areas losing up to two-thirds of their historical extent[96]. The breakdown in law and order that accompanied the armed conflicts interrupted research and conservation activities, resulted in higher poaching rates, loss of lives of conservationists[94, 96], and declining conservation funding[94].

In the aftermath of the civil war, fast-growing non-native plantation forests were established throughout Rwanda[96, 98, 99]. These early restoration efforts focused on establishing woodlots or adopting agroforestry practices due to land scarcity[98]. While these activities provide short-term benefits for local communities such as fuelwood, they have resulted in patchy forests with relatively low biodiversity[98] and degrading soils[99]. It also remains unclear how the many non-native monocultures will perform under a changing climate.

Despite these limitations of early restoration efforts in particular, today Rwanda is considered one of the world's ecosystem restoration leaders[9], and has pledged to restore more than 80% of its terrestrial area. However, in order to respond to ongoing climate change, human population growth, increasing resource demands, and the risk of renewed political instability in the coming decades, Rwanda will need to increase the adaptive capacity of its restoration sites. In the case of Rwanda, this might involve planting a mix of species that respond well to changing climatic conditions, further refining agroforestry approaches that benefit both biodiversity and a growing human population, as well as decentralizing restoration responsibility to safeguard restoration sites even in the event of political turmoil.

To reach its full potential, ecosystem restoration hinges on a minimum level of stable political and societal conditions. This includes the protection of restoration sites through legal tenure arrangements[62,63], as well as long-term political and economic commitments by major public and private stakeholders[13,64]. In areas where such conditions are missing, the degradation of restoration sites is probable. When political instability undermines the rule of law, high levels of corruption and impunity can result in illegal destruction of ecosystems and even threaten the lives of environmental activists. For example, many murders of environmental defenders became public in recent years, especially in countries across Latin America[65]. Case studies in Nepal, Sri Lanka, Peru, and Côte d'Ivoire further show that deforestation rates had increased in the aftermath of armed conflicts when resource demands were high, and when political instability resulted in weak enforcement of environmental regulations[66].

In the worst case, political instability can result in armed conflict. This can trigger human displacement, forced reliance on natural resources, uncontrolled resource exploitation, and subsequently biodiversity loss[67]. For example, an analysis of the effect of armed conflicts in forests in Colombia between 1992 and 2015 revealed that conflict areas were eight times more likely to undergo deforestation relative to average deforestation rates. The main drivers included efforts to finance the conflict through illegal agricultural production, mining, and logging, as well as insecure land tenure and unstable political institutions that paved the way for land grabbing[68]. Similarly, in Myanmar, the world's longest civil war and recent political transitions have caused the degradation of ecosystems due to weak land tenure, economic pressures, internal displacement, and other associated factors[69]. Based on these examples, armed conflicts can be expected to degrade or even destroy restoration sites, and the effects are difficult to anticipate and control. For example, the civil war in Ethiopia's Tigray region which erupted in 2020 substantially overlaps with many of Ethiopia's key restoration sites in the Great Green Wall[3] – but at present, consequences of the conflict for these sites remain unknown.

Additional challenges, interactions, and unforeseen surprises. While climate change, overexploitation of resources, and political instability are central challenges ecosystem restoration will need to face, they are far from being the only social-ecological pressures. Other potential ecological risks are related to (1) the spread of invasive species that can significantly change the composition of ecological communities, result in biotic homogenization[70], or cause the local extinction of species[71]; (2) habitat fragmentation that only allows for small, isolated restoration sites where biodiversity levels are low and key ecosystem functions are impaired (Haddad et al.[72]); and (3) the pollution of air, water, and soil that can harm organisms and reduce biodiversity[71]. Other social risks include poverty, structural inequities, and a lack of environmental justice[19], which can limit community commitment to ecosystem restoration and thereby indirectly cause the overexploitation of restoration sites. Finally, conflicting expectations regarding restoration sites can slow down or inhibit the implementation of restoration activities[22,55] or reinforce social inequalities[19,64] if stakeholders cannot agree on common goals. Thus, while climate change, overexploitation of resources, and political instability are some of the largest and most visible challenges to the future of restoration sites, they underpin and interact with many other additional challenges. Interactions among possible future challenges to restoration sites are inherently difficult to anticipate and might lead to numerous unforeseen surprises such as the crossing of social-ecological system tipping points. An example of how climate change, overexploitation of resources, and political instability are interconnected in Rwanda, and how this affects ecosystem restoration activities, is provided in Box 1.

The way forward

When planning ecosystem restoration, it is important to consider the challenges laid out above. Already, there are numerous suggestions for how to design sustainable, adaptive systems that can be applied to restoration. Globally applicable restoration guidelines date back to 2012, when Keenleyside et al. argued for restoration of Protected Areas to be effective, efficient, and engaging. Partly overlapping principles have since been put forward by Suding et al.[73]; while the most recent, comprehensive lists of principles were published by Gann et al.[13], Gichuki et al.[74], and FAO et al.[75]. Similarly, numerous principles have been proposed to maintain the adaptive capacity of production landscapes[76] or social-ecological systems in general[77–79].

To distil a tangible set of usable suggestions from the burgeoning lists of existing principles, we focus on two key bodies of literature that provide guidance on how to design and manage restoration sites and navigate complex human-environment relations, respectively. Specifically, (i) restoration literature and

Table 1 Principles put forward by different sources to support successful ecosystem restoration and enhance resilience.

Restoration Principles	Resilience Principles
Suding et al. 2015[73]	Walker & Salt 2006[77]
Increase ecological integrity □	Promote and sustain diversity ☆
Establish long-term sustainable systems □ ○	Embrace and work with ecological variability □ ☆
Learn from the past and plan for the future □	Maintain and create modularity ○
Benefit and engage society □ ☆	Acknowledge slow variables □
Gann et al. 2019[13]	Tighten the strength of feedbacks □ ○
Engage stakeholders □ ☆	Strengthen social capital □ ☆
Draw on many types of knowledge ☆	Emphasize innovation ☆
Relate to native reference ecosystems while considering environmental change □	Create redundancy in governance ☆
Support ecosystem recovery processes □ ○	Include unpriced ecosystem services □ ☆
Assess against clear goals using measurable indicators ○	Biggs et al. 2012[78]
Seek the highest level of recovery possible □	Maintain diversity and redundancy ☆
Gain cumulative value when applied at large scales □ ○	Manage connectivity ○
Design activities as part of a restorative continuum □ ☆	Manage slow variables and feedback □
Gichuki et al. 2019[74]	Foster an understanding of social-ecological systems as complex adaptive systems ○
Focus on landscapes □	Encourage learning and experimentation ☆
Maintain and enhance natural ecosystems □	Broaden participation ☆
Engage stakeholders, support participatory governance ☆	Promote polycentric governance systems ☆
Tailor to local conditions □	Carpenter et al. 2012[79]
Restore multiple functions for multiple benefits ☆	Promote diversity ☆
Manage adaptively for long-term resilience ○	Create modularity ○
FAO, IUCN & CEM 2021[75]	Manage openness ○
Contribute to the SDGs and the Rio Conventions ☆	Maintain reserves ○ ☆
Promote inclusive and participatory governance ○ ☆	Manage feedbacks □
Include a continuum of restorative activities ☆	Enable polycentric governance by nesting systems ☆
Benefit nature and people ○	Conduct monitoring ○
Address causes of degradation □	Promote leadership and trust ☆
Integrate different types of knowledge ☆	
Establish well-defined and measurable goals ○	
Tailor to local contexts while considering the larger landscape □	
Include management and monitoring ○	
Ensure an enabling policy environment ○	

We iteratively assigned these principles to three core themes: work with the existing system = □; create self-sustaining systems = ○; foster diversity and participation = ☆.

(ii) social-ecological systems literature both put forward diverse sets of principles that are useful, but that have not been integrated to date. Restoration principles often focus on ecological and design aspects of restoration, and often emphasize the connection between local actions and the larger landscape[13,73–75]. By contrast, in social-ecological systems science, there is a rich literature on resilience—i.e., the degree to which a system can cope with changing conditions while retaining key elements of structure, function, and identity[80,81]—which highlights social capital and the need for a deep understanding of system complexity[77–79].

Despite their possible utility, the proliferation of theory-driven principles can be difficult to operationalize for restoration practitioners, and as such does not automatically translate into practical implementation on the ground. As a consequence, adequate responses to future uncertainties (such as the three threats outlined above) are still not sufficiently well anchored in restoration practice[15,20,22]. We argue that while theoretical considerations on restoration, system complexity and resilience abound, there is a lack of practical skills, mechanisms, strategies, and institutional structures that support system components in restoration sites (e.g., actors, species, ecological communities) in adjusting to changing environmental and socio-economic conditions. As such, there is a need to further enhance the adaptive capacity of restoration projects[81–84].

To help navigate the myriad of existing principles and provide tangible guidance on how the adaptive capacity of restoration sites can be increased by integrating insights from restoration and resilience literature, we offer a two-fold contribution. First, we draw on 52 recognized restoration and resilience principles, and distil these into three core guiding themes for how to respond to the specific threats outlined above. Second, we demonstrate how these three themes can be operationalized in practice, and illustrate our approach by applying it to restoration in western Rwanda.

For the synthesis of restoration and resilience principles, we selected seven influential publications by scientists and organisations that together encompass a very broad range of principles that are relevant for social-ecological restoration contexts (for restoration principles, see ref. [13,73–75]; for resilience principles, see ref. [77–79].). For restoration, we focused on the most recent, comprehensive lists of principles. We then iteratively coded these principles into three themes (Table 1). In highly simplified (but usable) terms, the 52 principles can be boiled down to three main themes: (1) work with the existing system, (2) create self-sustaining, adaptive systems, and (3) foster diversity and participation.

First, *working with the existing system* means considering restoration sites as social-ecological systems and tailoring restoration activities to local contexts, including site-specific ecological variability and drivers of degradation. Second, *creating self-sustaining, adaptive systems* entails promoting polycentric governance systems, managing feedbacks, and monitoring and responding to developments in restoration sites over time. Third, *fostering diversity and participation* in a given social-ecological restoration system implies strengthening social capital, encouraging exchange and innovation, and promoting functional and response diversity as well as maintaining suitable levels of modularity. All three guiding themes need to be applied at all levels of restoration action, and should consider both the ecological and social components of a given social-ecological restoration system. Ideally, the guiding principles will inform the scoping and design of restoration projects as well as their ongoing management.

To integrate restoration and resilience principles in practice and create restoration sites that are well-equipped to face climate change, overexploitation of resources, political instability, and other unexpected threats, we propose a two-step approach (Fig. 2). The first step is an initial assessment of the impacts each threat would likely have on a specific site at different points in time. Meaningful timeframes will differ across restoration sites; for example, it could mean to consider the present, 30 years and 100 years in the future. As a second step, each of the three guiding themes can be applied to formulate specific activities that can strengthen skills, mechanisms, strategies, and institutional structures that support different system components in adjusting to

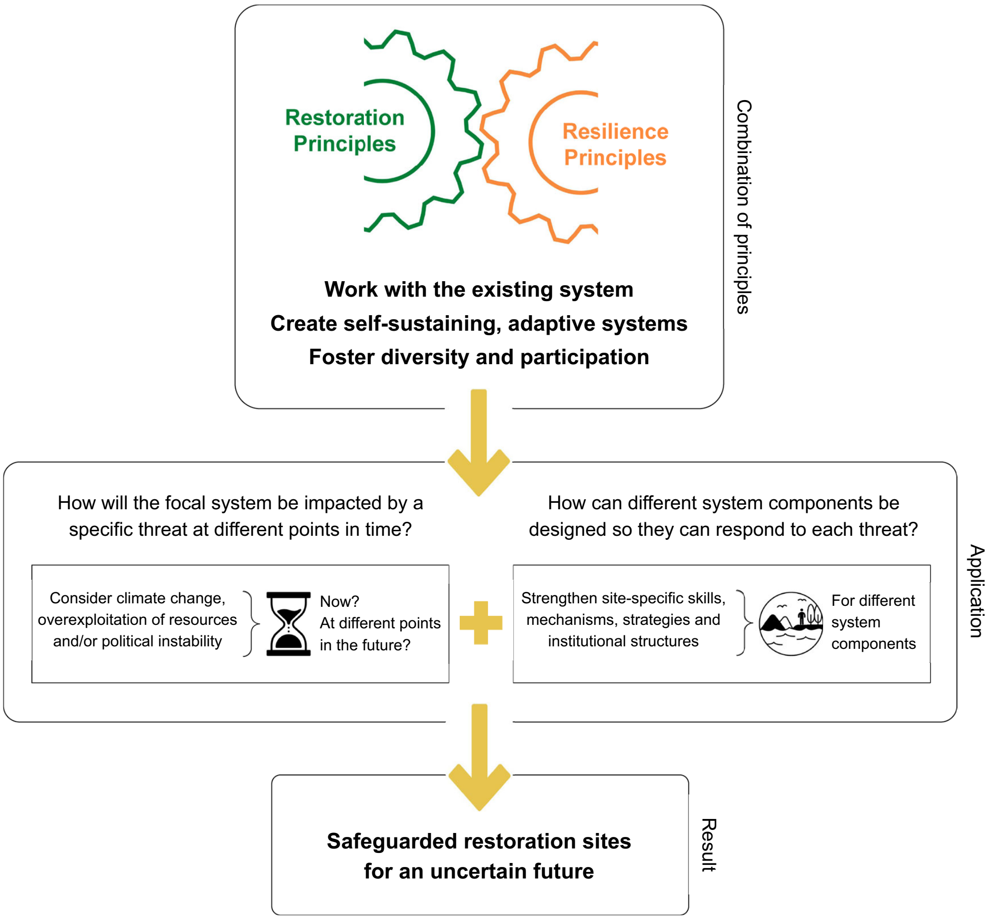

Fig. 2 Safeguarding restoration sites by integrating restoration and resilience principles. Three high-level guiding themes for future-proof restoration practice were derived from the synthesis of 52 existing restoration and resilience principles (see Table 1). These guiding principles can be applied to restoration projects to facilitate the development of site-specific skills, mechanisms, strategies, and institutional structures that enhance the restoration system's adaptive capacity.

each threat. Relevant system components might include people living in the restoration landscape, landowners, restoration practitioners, governance bodies and formal institutions, currently occurring ecological communities, and species planted within the scope of restoration activities.

We suggest these two steps because they help to break down the myriad of existing high-level principles into concrete actions to be carried out within a given social-ecological restoration project. The site-specific skills, mechanisms, strategies, and institutional structures that are strengthened in the process will, in turn, enhance the adaptive capacity of the social-ecological restoration site. Restoration projects designed and managed in this way thus can be expected to have an enhanced capacity to respond to climate change, overexploitation of resources, and political instability.

Practical application. To illustrate what this approach may look like in practice, we use the example of the Albertine Rift in western Rwanda. We specifically consider climate change in this instance, noting that a similar rationale could also be applied to political instability or resource exploitation. Major climatic changes expected for the Albertine Rift relate to a substantially warmer climate[85], the redistribution and increase of precipitation, altitudinal habitat shifts[86], a changing distribution of vegetation types and homogenization of habitats, and an increasing likelihood of floods and landslides[87]. Combining these potential changes with the three themes suggested above results in 12 concrete activities that can be embedded in restoration projects to increase their adaptive capacity (Fig. 3). Notably, these activities are examples only. Ideally, a combined group of scientists, local practitioners and policy makers should design suitable activities in a collaborative process.

While the suggested strategies in Fig. 3 are by no means complete, they illustrate how professionals and communities involved in restoration in western Rwanda could potentially increase the adaptive capacity of restoration sites to climate change by drawing on recognized restoration and resilience principles. Similarly, in the case of overexploitation of resources, viable strategies might include, for example, creating a mosaic of land uses that allow for diverse livelihood opportunities, designing incentives for the long-term commitment to restoration on different organisational levels, safeguarding restoration sites via contextually appropriate land tenure arrangements, and making telecouplings visible that connect restoration sites with actors elsewhere. To safeguard restoration sites against possible incidents of political

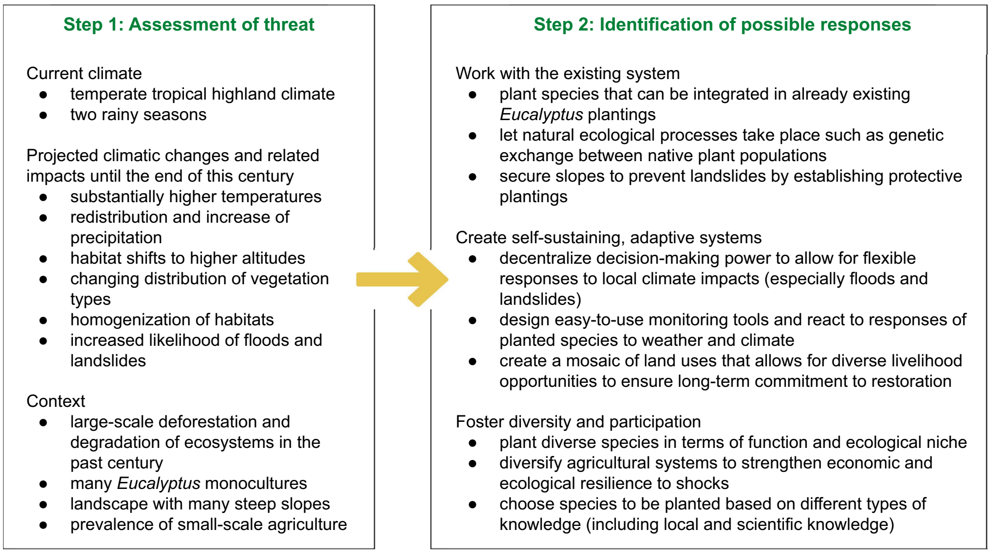

Fig. 3 Exemplary application of the three guiding themes to the threat of climate change in western Rwanda. In practice, the three guiding principles can be applied to any possible threat. Here, we apply it to effects of climate change on the Albertine Rift in western Rwanda. In a first step, the current context and the effects of the focal threat need to be understood. In a second step, possible context-specific responses based on the three guiding principles can be formulated.

instability, possible strategies might be decentralizing power and decision-making authority to local and regional levels, being sensitive to existing power imbalances and inequalities in communities where restoration takes place, organizing restoration as independent as possible from temporary political power structures—especially when the political system is prone to quick, fundamental changes. As noted above, these are general suggestions only; collaborative processes would be required to generate an authoritative list of context-specific adaptive responses that also take into account possible interactions among potential threats.

Conclusion

In conclusion, climate change, resource overexploitation and political instability individually and in combination generate major uncertainty for restoration projects in many parts of the world. Restoration and social-ecological systems literature can guide forward-thinking restoration practice to address these threats by strengthening site-specific skills, mechanisms, strategies, and institutional structures that enhance a system's adaptive capacity. Drawing on a combination of resilience and restoration principles is valuable not only when applied to the three threats identified in this paper, but can also support the development of measures aiming to enhance the resilience of restoration sites to other site-specific, interconnected threats. Across both ecological and social realms, the particular ways to enhance the capability of a restoration site to adjust to change will vary. Hence, it is central to bring together researchers, practitioners, policy-makers and the people living at restoration sites to exchange knowledge and align restoration practice with local realities[22,88,89]. This way, restoration sites will stand the best chance of benefitting both nature and people into the long-term future.

Reporting summary. Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Received: 6 May 2022; Accepted: 21 March 2023;
Published online: 07 April 2023

References

1. IPBES. Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. *Zenodo* https://doi.org/10.5281/zenodo.6417333 (2019).
2. IPCC. *Climate Change and Land: an IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems* (IPCC, 2019).
3. Goffner, D., Sinare, H. & Gordon, L. J. The Great Green Wall for the Sahara and the Sahel Initiative as an opportunity to enhance resilience in Sahelian landscapes and livelihoods. *Reg. Environ. Change* **19**, 1417–1428 (2019).
4. IUCN. *Restore Our Future: Bonn Challenge. Impact and Potential of Forest Landscape Restoration* (IUCN, 2020).
5. United Nations Environment Agency. *Resolution 73/284: United Nations Decade on Ecosystem Restoration* (United Nations Environment Agency, 2019).
6. United Nations Environment Programme. *Becoming #GenerationRestoration: Ecosystem Restoration for People, Nature and Climate* (United Nations Environment Programme, 2021).
7. Munshower, F. F. *Practical Handbook of Disturbed Land Revegetation* (CRC Press, 2018). https://doi.org/10.1201/9781351075923.
8. Stanturf, J. A., Palik, B. J., Williams, M. I., Dumroese, R. K. & Madsen, P. Forest restoration paradigms. *J. Sustain. Forestry* **33**, 161–194 (2014). **Overview of the context and goals of four of the most important restoration paradigms, namely revegetation, ecological restoration, functional restoration, and forest landscape restoration.**
9. Mansourian, S. et al. Reflecting on twenty years of forest landscape restoration. *Restor. Ecol.* **29**, e13441 (2021).
10. Yang, A., Bellwood-Howard, I. & Lippe, M. in *Forest Landscape Restoration: Integrated Approaches to Support Effective Implementation* (eds. Mansourian, S. & Parrotta, J.) 65–82 (Routledge, 2018). https://doi.org/10.4324/9781315111872-5. **Application of a social-ecological systems lens to forest landscape restoration to explore resilience and interactions within linked ecological and social systems.**
11. Fischer, J., Riechers, M., Loos, J., Martin-Lopez, B. & Temperton, V. M. Making the UN decade on ecosystem restoration a social-ecological endeavour. *Trends Ecol. Evol.* **36**, 20–28 (2021).
12. Martin, D. M. Ecological restoration should be redefined for the twenty-first century. *Restor. Ecol.* **25**, 668–673 (2017).
13. Gann, G. D. et al. International principles and standards for the practice of ecological restoration. Second edition. *Restor. Ecol.* **27**, 1–46 (2019). **Introduction of eight principles to support ecological restoration practice in achieving interconnected social, community, productivity, and sustainability goals.**
14. Harris, J. A., Hobbs, R. J., Higgs, E. & Aronson, J. Ecological restoration and global climate change. *Restor. Ecol.* **14**, 170–176 (2006).

15. Zabin, C. J. et al. Increasing the resilience of ecological restoration to extreme climatic events. *Front. Ecol. Environ.* **20**, 310–318 (2022).
16. Hobbs, R. J., Higgs, E. S. & Hall, C. M. in *Novel Ecosystems: Intervening in the New Ecological World Order* (eds. Hobbs, R. J., Higgs, E. S. & Hall, C. M.) 58–60 (John Wiley & Sons, Ltd, 2013). https://doi.org/10.1002/9781118354186.ch6.
17. Homayounfar, M., Muneepeerakul, R. & Anderies, J. M. Resilience-performance trade-offs in managing social-ecological systems. *E&S* **27**, (2022).
18. Chazdon, R. L., Wilson, S. J., Brondizio, E., Guariguata, M. R. & Herbohn, J. Key challenges for governing forest and landscape restoration across different contexts. *Land Use Policy* **104**, 104854 (2021).
19. Osborne, T. et al. The political ecology playbook for ecosystem restoration: principles for effective, equitable, and transformative landscapes. *Glob. Environ. Change* **70**, 102320 (2021).
20. Simonson, W. D. et al. Enhancing climate change resilience of ecological restoration—a framework for action. *Perspect. Ecol. Conserv.* **19**, 300–310 (2021).
21. Fremout, T. et al. Diversity for Restoration (D4R): Guiding the selection of tree species and seed sources for climate-resilient restoration of tropical forest landscapes. *J. Appl. Ecol.* **59**, 664–679 (2022).
22. Stanturf, J. A. Forest landscape restoration: building on the past for future success. *Restor. Ecol.* **29**, e13349 (2021).
23. IPCC. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC, 2014).
24. IPCC. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC, 2021).
25. Leemans, R. & Eickhout, B. Another reason for concern: regional and global impacts on ecosystems for different levels of climate change. *Glob. Environ. Change* **14**, 219–228 (2004).
26. IPCC. *Global Warming of 1.5 °C. An IPCC Special Report on the Impacts of Global Warming of 1.5 °C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty* (IPCC, 2018).
27. IPCC. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC, 2008).
28. Higgins, P. A. T. & Harte, J. Biophysical and biogeochemical responses to climate change depend on dispersal and migration. *Bioscience* **56**, 407 (2006).
29. Keys, P. W. et al. Anthropocene risk. *Nat. Sustain.* **2**, 667–673 (2019).
30. Sintayehu, D. W. Impact of climate change on biodiversity and associated key ecosystem services in Africa: a systematic review. *Ecosyst. Health Sustain.* **4**, 225–239 (2018).
31. Pecl, G. T. et al. Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *Science* **355**, eaai9214 (2017).
32. Corlett, R. T. & Westcott, D. A. Will plant movements keep up with climate change? *Trends Ecol. Evol.* **28**, 482–488 (2013).
33. Department of Forestry and Fire Protection. 2021 Incident Archive. https://www.fire.ca.gov/incidents/2021/ (2021).
34. Strassburg, B. B. N. et al. Global priority areas for ecosystem restoration. *Nature* **586**, 724–729 (2020).
35. Maxwell, S. L. et al. Conservation implications of ecological responses to extreme weather and climate events. *Divers. Distrib.* **25**, 613–625 (2019).
36. Jentsch, A. & Beierkuhnlein, C. Research frontiers in climate change: effects of extreme meteorological events on ecosystems. *Comptes Rendus Geosci.* **340**, 621–628 (2008).
37. Bradshaw, C. J. A. & Brook, B. W. Human population reduction is not a quick fix for environmental problems. *Proc. Natl Acad. Sci. USA* **111**, 16610–16615 (2014).
38. Maja, M. M. & Ayano, S. F. The impact of population growth on natural resources and farmers' capacity to adapt to climate change in low-income countries. *Earth Syst. Environ.* **5**, 271–283 (2021).
39. Latawiec, A. E., Strassburg, B. B., Brancalion, P. H., Rodrigues, R. R. & Gardner, T. Creating space for large-scale restoration in tropical agricultural landscapes. *Front. Ecol. Environ.* **13**, 211–218 (2015).
40. Delzeit, R. et al. Forest restoration: expanding agriculture. *Science* **366**, 316–317 (2019).
41. Marín-Beltrán, I. et al. Scientists' warning against the society of waste. *Sci. Total Environ.* **811**, 151359 (2022).
42. International Resource Panel. *Global Resources Outlook 2019: Natural Resources for the Future We Want* (International Resource Panel, 2019).
43. Dorninger, C. et al. Global patterns of ecologically unequal exchange: Implications for sustainability in the 21st century. *Ecol. Econ.* **179**, 106824 (2021).
44. Meyfroidt, P. et al. Ten facts about land systems for sustainability. *Proc. Natl Acad. Sci. USA* **119**, e2109217118 (2022). **Synthesis of core knowledge on terrestrial social-ecological systems to explain sustainability challenges in land use and guide the development of solutions**.
45. Martínez-Valderrama, J. et al. Mediterranean landscape re-greening at the expense of South American agricultural expansion. *Land (Basel)* **10**, 204 (2021).
46. Boerema, A. et al. Soybean trade: balancing environmental and socio-economic impacts of an intercontinental market. *PLoS ONE* **11**, e0155222 (2016).
47. Liu, J. et al. Framing sustainability in a telecoupled world. *Ecol. Soc.* **18**, (2013).
48. Bologna, M. & Aquino, G. Deforestation and world population sustainability: a quantitative analysis. *Sci. Rep.* **10**, 7631 (2020).
49. United Nations, Department of Economic and Social Affairs, Population Division. *World Population Prospects* (United Nations, 2019).
50. Harper, G. J., Steininger, M. K., Tucker, C. J., Juhn, D. & Hawkins, F. Fifty years of deforestation and forest fragmentation in Madagascar. *Environ. Conserv.* **34**, 325–333 (2007).
51. Clark, M. Deforestation in Madagascar: consequences of population growth and unsustainable agricultural processes. *Global Majority E J.* (2012).
52. Ngwira, S. & Watanabe, T. An analysis of the causes of deforestation in Malawi: a case of mwazisi. *Land (Basel)* **8**, 48 (2019).
53. Jakovac, C. C., Peña-Claros, M., Mesquita, R. C. G., Bongers, F. & Kuyper, T. W. Swiddens under transition: consequences of agricultural intensification in the Amazon. *Agric. Ecosyst. Environ.* **218**, 116–125 (2016).
54. Rasmussen, L. V. et al. Social-ecological outcomes of agricultural intensification. *Nat. Sustain.* **1**, 275–282 (2018).
55. Stanturf, J. A. et al. Implementing forest landscape restoration under the Bonn Challenge: a systematic approach. *Ann. Sci.* **76**, 50 (2019).
56. Chaplin-Kramer, R., Chappell, M. J. & Bennett, E. M. Un-yielding: evidence for the agriculture transformation we need. *Ann. N. Y. Acad. Sci.* **1520**, 89–104 (2023).
57. Rai, N. D., Bhasme, S., & Balaji, P. Power, inequality and rights: A political ecology of forest restoration. in *Forest landscape restoration: integrated approaches to support effective implementation* (eds. Mansourian, S. & Parrotta, J.) 47-62 (Routledge, 2018).
58. Goldstone, J. A. et al. A global model for forecasting political instability. *Am. J. Pol. Sci.* **54**, 190–208 (2010).
59. Bowlsby, D., Chenoweth, E., Hendrix, C. & Moyer, J. D. The future is a moving target: predicting political instability. *Br. J. Polit. Sci.* **50**, 1405–1417 (2020).
60. Bello-Schürmann, J. & Moyer, J. D. *Structural Pressures and Political Instability: Trajectories for Sub-Saharan Africa* (2018).
61. Fund for Peace. *Fragile State Index Annual Report* (2021).
62. de Jong, W. et al. in *Forest Landscape Restoration: Integrated Approaches to Support Effective Implementation* (eds. Mansourian, S. & Parrotta, J.) 158–175 (Routledge, 2018). https://doi.org/10.4324/9781315111872-10.
63. Elias, M., Joshi, D. & Meinzen-Dick, R. Restoration for whom, by whom? A feminist political ecology of restoration. *Ecol. Restor.* **39**, 3–15 (2021). **Critical analysis of the social inclusivity of restoration agendas and practices to illustrate the need for more inclusive and context-specific restoration initiatives**.
64. Mansourian, S. in *Forest Landscape Restoration: Integrated Approaches to Support Effective Implementation* (eds. Mansourian, S. & Parrotta, J.) 139–157 (Routledge, 2018).
65. Bille Larsen, P. et al. Understanding and responding to the environmental human rights defenders crisis: The case for conservation action. *Conserv. Lett.* **14**, e12777 (2021).
66. Grima, N. & Singh, S. J. How the end of armed conflicts influence forest cover and subsequently ecosystem services provision? An analysis of four case studies in biodiversity hotspots. *Land Use Policy* **81**, 267–275 (2019).
67. Dudley, J. P., Ginsberg, J. R., Plumptre, A. J., Hart, J. A. & Campos, L. C. Effects of war and civil strife on wildlife and wildlife habitats. *Conserv. Biol.* **16**, 319–329 (2002).
68. Landholm, D. M., Pradhan, P. & Kropp, J. P. Diverging forest land use dynamics induced by armed conflict across the tropics. *Glob. Environ. Change* **56**, 86–94 (2019).
69. Lim, C. L., Prescott, G. W., De Alban, J. D. T., Ziegler, A. D. & Webb, E. L. Untangling the proximate causes and underlying drivers of deforestation and forest degradation in Myanmar. *Conserv. Biol.* **31**, 1362–1372 (2017).
70. Filgueiras, B. K. C., Peres, C. A., Melo, F. P. L., Leal, I. R. & Tabarelli, M. Winner-loser species replacements in human-modified landscapes. *Trends Ecol. Evol.* **36**, 545–555 (2021).
71. Díaz, S. et al. Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science* **366**, eaax3100 (2019).
72. Haddad, N. M. et al. Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science advances* **1**, e1500052 (2015).
73. Suding, K. et al. Committing to ecological restoration. *Science* **348**, 638–640 (2015).
74. Gichuki, L. et al. *Reviving Land and Restoring Landscapes: Policy Convergence between Forest Landscape Restoration and Land Degradation Neutrality*

(International Union for Conservation of Nature, 2019). https://doi.org/10.2305/IUCN.CH.2019.11.en.
75. FAO, IUCN CEM & SER. *Principles for Ecosystem Restoration to Guide the United Nations Decade 2021–2030* (2021).
76. Fischer, J., Lindenmayer, D. B. & Manning, A. D. Biodiversity, ecosystem function, and resilience: ten guiding principles for commodity production landscapes. *Front. Ecol. Environ.* **4**, 80–86 (2006).
77. Walker, B. & Salt, D. *Resilience Thinking: Sustaining Ecosystems and People in a Changing World* (Island Press, 2006).
78. Biggs, R. et al. Toward principles for enhancing the resilience of ecosystem services. *Annu. Rev. Environ. Resour.* **37**, 421–448 (2012).
79. Carpenter, S. et al. General resilience to cope with extreme events. *Sustainability* **4**, 3248–3259 (2012).
80. Folke, C. Resilience: the emergence of a perspective for social–ecological systems analyses. *Glob. Environ. Change* **16**, 253–267 (2006). **Overview of the development of the resilience perspective and its role in understanding linked social-ecological systems**.
81. Cinner, J. E. & Barnes, M. L. Social dimensions of resilience in social-ecological systems. *One Earth* **1**, 51–56 (2019).
82. Folke, C., Colding, J. & Berkes, F. in *Navigating Social-ecological Systems* (eds. Berkes, F., Colding, J. & Folke, C.) (Cambridge University Press, 2003).
83. Mortreux, C. & Barnett, J. Adaptive capacity: exploring the research frontier. *WIREs Clim. Change* **8**, e467 (2017).
84. Dudney, J. et al. Capacity for change: three core attributes of adaptive capacity that bolster restoration efficacy. *Restor. Ecol.* https://doi.org/10.1111/rec.13647 (2022).
85. Climate Impact Lab. Climate Impact Map—End of Century 2080-2099. https://impactlab.org/map/#usmeas=absolute&usyear=1981-2010&gmeas=absolute&gyear=2080-2099&tab=global&gvar=tasmax-over-95F.
86. Seimon, A. & Picton Phillipps, G. in *Longterm Changes in Africa's Rift Valley: Impacts on Biodiversity and Ecosystems Impacts on Biodiversity and Ecosystem* (ed. Plumptre, A.) 9–30 (Nova Science Publishers, 2011).
87. Ayebare, S., Plumptre, A. J., Kujirakwinja, D. & Segan, D. Conservation of the endemic species of the Albertine Rift under future climate change. *Biol. Conserv.* **220**, 67–75 (2018).
88. Carmenta, R. & Vira, B. Integration for restoration. in *Forest Landscape Restoration: Integrated Approaches to Support Effective Implementation* (eds. Mansourian, S. & Parrotta, J.) 16–36 (Routledge, 2018). https://doi.org/10.4324/9781315111872-2.
89. Holl, K. D. & Brancalion, P. H. S. Tree planting is not a simple solution. *Science* **368**, 580–581 (2020).
90. Sewell, A., van der Esch, S. & Löwenhardt, H. Global Restoration Commitments database. https://www.pbl.nl/sites/default/files/downloads/pbl-2021-global-restoration-commitments-database-4680.ods (2020).
91. Rasmussen, D. J., Meinshausen, M. & Kopp, R. E. Probability-weighted ensembles of U.S. County-Level Climate Projections for Climate Risk Analysis. *J. Appl. Meteorol. Climatol.* **55**, 2301–2322 (2016).
92. United Nations Environment Programme & International Resource Panel. Global Material Flows Database. https://www.resourcepanel.org/global-material-flows-database (2019).
93. The World Bank. Worldwide Governance Indicators. https://databank.worldbank.org/source/worldwide-governance-indicators (2021).
94. Plumptre, A., Masozera, M. & Vedder, A. *The Impact of Civil War on the Conservation of Protected Areas in Rwanda* (2001).
95. Clay, N. Fixing the ecosystem: conservation, crisis and capital in Rwanda's Gishwati Forest. *Environ. Plan. E Nat. Space* **2**, 23–46 (2019).
96. Kanyamibwa, S. Impact of war on conservation: Rwandan environment and wildlife in agony. *Biodivers. Conserv.* **7**, 1399–1406 (1998).
97. Ordway, E. M. Political shifts and changing forests: effects of armed conflict on forest conservation in Rwanda. *Glob. Ecol. Conserv.* **3**, 448–460 (2015).
98. Arakwiye, B., Rogan, J. & Eastman, J. R. Thirty years of forest-cover change in Western Rwanda during periods of wars and environmental policy shifts. *Reg. Environ. Change* **21**, 27 (2021).
99. Rwibasira, P., Naramabuye, F. X., Nsabimana, D. & Carnol, M. Long-term effects of forest plantation species on chemical soil properties in Southern Rwanda. *Soil Syst.* **5**, 59 (2021).

Acknowledgements
The authors thank Tobias Plieninger and Tobias Kuemmerle for providing valuable feedback on drafts of this manuscript.

Author contributions
M.F. devised the main conceptual ideas and wrote the manuscript in consultation with J.F. J.L., K.L., S.S. and J.F. critically revised the work and contributed to the synthesis of restoration and social-ecological systems principles led by M.F. J.L. supported M.F. with the acquisition of data for the maps. J.F. was involved in planning and supervising the work. All authors discussed the results and edited the manuscript. All authors approved this version to be published.

Funding
Open Access funding enabled and organized by Projekt DEAL.

Competing interests
The authors declare no competing interests.

Additional information
Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s42003-023-04736-y.

Correspondence and requests for materials should be addressed to Marina Frietsch.

Peer review information *Communications Biology* thanks Eric Higgs, William Simonson and the other, anonymous, reviewer(s) for their contribution to the peer review of this work. Primary Handling Editors: Shouli Li and Luke R. Grinham.

Reprints and permission information is available at http://www.nature.com/reprints

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Chapter III

The social-ecological ladder of restoration ambition

Paper II

Marina Frietsch*, Manuel Pacheco-Romero*, Vicky M.,
Beth A. Kaplin, Joern Fischer

Ambio, 2024

* Marina Frietsch and Manuel Pacheco-Romero have contributed equally to the manuscript.

Ambio
https://doi.org/10.1007/s13280-024-02021-8

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

Check for updates

PERSPECTIVE

The social–ecological ladder of restoration ambition

Marina Frietsch, Manuel Pacheco-Romero, Vicky M. Temperton, Beth A. Kaplin, Joern Fischer

Received: 12 May 2023 / Revised: 5 February 2024 / Accepted: 31 March 2024

Abstract Expanding in both scope and scale, ecosystem restoration needs to embrace complex social–ecological dynamics. To help scientists and practitioners navigate ever new demands on restoration, we propose the "social–ecological ladder of restoration ambition" as a conceptual model to approach dynamically shifting social and ecological restoration goals. The model focuses on three dynamic aspects of restoration, namely degrading processes, restoration goals and remedial actions. As these three change through time, new reinforcing and balancing feedback mechanisms characterize the restoration process. We illustrate our model through case studies in which restoration has become increasingly ambitious through time, namely forest landscape restoration in Rwanda and grassland restoration in Germany. The ladder of restoration ambition offers a new way of applying social–ecological systems thinking to ecosystem restoration. Additionally, it raises awareness of social–ecological trade-offs, power imbalances and conflicting goals in restoration projects, thereby laying an important foundation for finding more practicable and fairer solutions.

Keywords Ecosystem restoration · Forest landscape restoration · Grassland restoration · Social–ecological systems

INTRODUCTION

With ongoing land degradation, human population growth and anthropogenic climate change, restoration ambitions are rising globally, in both scale and scope. For example, in terms of scale, under the Bonn Challenge, 61 countries have pledged to restore 350 million hectares by 2030 (Dave et al. 2018); the Great Green Wall initiative seeks to restore a 7000-km-long band across the Sahel (Goffner et al. 2019); and the United Nations have declared 2021–2030 the Decade on Ecosystem Restoration (UNEA 2019). In terms of scope, ecosystem restoration evolved from a focus on simply replanting disturbed areas (McDonald 2008), to attention to reference states (Society for Ecological Restoration 2004), the "rewilding" of ecosystems (Perino et al. 2019), and reinstating ecosystem functions and processes (Manning et al. 2018). Today, restoration often pursues diverse social goals such as enhancing intrinsic ecological values, advancing human well-being, supporting livelihoods or empowering local people (Martin 2017). Satisfying the growing ambitions of restoration is challenging, not least because restoration inevitably takes place within a dynamic and contested social–ecological context, in which both biophysical conditions as well as societal priorities and hence expectations of restoration keep shifting (Fischer et al. 2021).

The Society for Ecological Restoration recently proposed restoration standards (Gann et al. 2019) that include a restoration continuum from remediation to ecological restoration, as well as "restoration wheels" to trace restoration progress against various ecological and social goals. Here, we argue that these standards could be complemented by considering how drivers of degradation as well as remedial actions dynamically change in response to evolving needs, values, environmental context, knowledge, policies and resources (see also Keenleyside et al. 2012, p. 53). Integrating such dynamism could help, for instance, to address questions related to restoration in human-created and

Marina Frietsch and Manuel Pacheco-Romero have contributed equally to the manuscript.

maintained "novel ecosystems", such as whether restoring a historical reference state is feasible and desirable. Ecological and ethical challenges posed by ecological novelty are widely acknowledged, but solutions remain controversial (Aronson et al. 2018; Higgs et al. 2018). In addition, legacy effects of past conditions operate both in the ecological (Weidlich et al. 2020) and social spheres (Clay 2019), which further constrains and shapes restoration possibilities and outcomes over time. Perhaps most notably, shifting societal expectations of restoration are rarely considered, although the history of restoration shows that such expectations have changed and hence are likely to continue to change.

In practice, although many restoration projects focus primarily on re-establishing species-rich communities, there is growing interest in multifunctional outcomes of restoration (Manning et al. 2018) such as climate change mitigation or human livelihoods. For example, a project in Brazil's Atlantic Forest that initially focused on the conservation of a highly endangered monkey species transformed into a landscape-scale restoration project seeking to simultaneously enhance the ecological integrity of the area as well as improving the food security of local communities (Chazdon et al. 2020). Sometimes, these new expectations can be controversial, because they can lead to simplistic restoration measures (e.g. indiscriminate planting of exotic trees). An analysis of restoration projects in 74 tropical countries revealed that a focus on social objectives translated into the use of the same few commercial and utilitarian species in many restoration initiatives, intensifying the homogenization of tropical ecosystems around the world (Martin et al. 2021). Both examples further underline the need for an integrative social–ecological framework to conceptualize restoration in a way that accounts for both ecological and social ambitions in restoration practice.

Restoration goals thus differ between restoration sites or projects, but can also change through time for a given site or project. While transparent goal-setting and monitoring should be a vital part of good restoration practice (Gann et al. 2019), we argue that restoration goals themselves also need to be considered in a dynamic way. For example, in some ecosystems, drying climatic conditions may require shifts towards different species assemblages than initially intended, or in parts of the Global South, societal demands might be intensifying such that restoration needs to more rapidly generate livelihood opportunities than initially recognized, while still safeguarding ecological sustainability in the long run.

In this paper, we propose a conceptual framework that can help scientists and decision-makers think about, communicate, and navigate changing restoration goals. The framework is based on observations by the author team of the dynamics of restoration projects with regard to ecological and social ambitions in already existing restoration projects. We term this framework the "social–ecological ladder of restoration ambition", signalling that moving along this ladder can also help make restoration more integrative through time. Our framework is grounded in social–ecological systems thinking—that is, the application of systems thinking to interlinked social and ecological phenomena that involve dynamic feedbacks (Hobbs et al. 2011). With vast areas around the world being earmarked for restoration—but at the same time, with critique that some current restoration efforts are ecologically (Bond et al. 2019; Temperton et al. 2019) or socially (Löfqvist et al. 2022) short-sighted—it is important to offer pathways for restoration science and practice that encourage restoration to remain explicitly ambitious, open, and future-oriented (Higgs et al. 2018). Even if existing critiques of some large-scale restoration initiatives are warranted, perhaps these initiatives can still be seen as a valuable starting point. What is needed then is a way to think about how to further improve restoration outcomes, both ecologically and socially, in the longer term. Our paper seeks to provide a framework for this. We first outline our suggested framework and then illustrate it via two case studies representing a forest-dominated ecosystem in the Global South, and a grassland-dominated ecosystem in the Global North. In a final step, we discuss the general utility of applying the proposed framework.

THE SOCIAL–ECOLOGICAL LADDER OF RESTORATION AMBITION

Both ecological and social goals of restoration can be more or less ambitious. Ecological ambition is captured well by the "restorative continuum" (Gann et al. 2019), which depicts a gradient from reducing impacts, through remediation and rehabilitation of degraded systems, to fully recovering native ecosystems. Social ambition is more difficult to define because it is extremely multi-faceted. It might relate to the degree of stakeholder participation in the restoration process (see, for example, Arnstein's (1969) classic "ladder of participation"), or more generally, to the material and non-material benefits that people obtain from restoration, including livelihoods (Erbaugh and Oldekop 2018), human-nature connectedness (Furness 2021), social cohesion (Alba-Patiño et al. 2021), or other dimensions of environmental justice (Löfqvist et al. 2022). In practice, the ecological and the social level of ambition are likely interrelated and as such can be captured by the notion of "social–ecological ambition".

The level and type of ambition of any restoration project depend on the setting and actors involved (Carmenta and Vira 2018; Elias et al. 2022). Ambitions can change through time due to advancements in scientific knowledge (Perring et al. 2015), shifting stakeholder needs and values (Fox and Cundill 2018), alternating political orientation (Brunckhorst 2011), changing environments (Dudney et al. 2022), or the resources available to carry out restoration. In addition, past restoration outcomes can shape attitudes and expectations connected to future restoration projects (McGuire and Ehlinger 2022). These and other factors may lead to different modes of stakeholder participation, choices of focal species, or prioritized ecosystem functions and services. Pursuing fixed restoration goals therefore is too rigid in many instances—instead, goals need to be regularly re-assessed across both ecological and social realms. Arguably the best (though not always feasible) way to carry out restoration projects is to design interventions as active adaptive experiments (Keenleyside et al. 2012).

Three key concepts then are part of the social–ecological ladder of restoration ambition (Fig. 1). First, *degrading processes* relate to the drivers underpinning the need for restoration. In systems terms, degrading processes are typically reinforcing through time; that is, they are characterized by one or multiple reinforcing feedback loops. Reinforcing feedback loops, in fact, underpin the vast majority of contemporary sustainability problems and usually go hand-in-hand with exponentially increasing resource degradation (e.g. Steffen et al. 2011). Second,

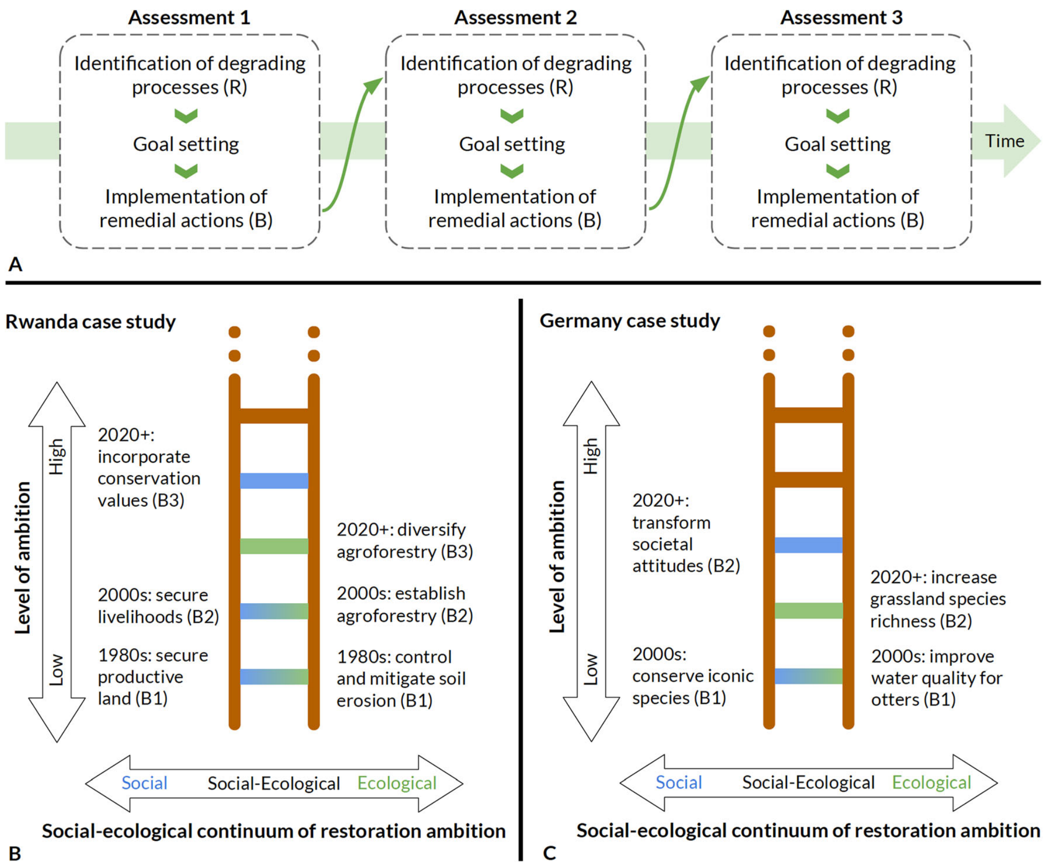

Fig. 1 The social–ecological ladder of restoration ambition. Panel A: Restoration can follow three steps to replace degrading processes with restorative actions in an ecosystem or landscape: (1) assessment of the current social–ecological system state and identification of reinforcing feedback loops that drive degrading processes (R); (2) restoration goal setting; (3) implementation of remedial actions that disrupt or counteract the detrimental reinforcing feedback loop, or establish a balancing feedback loop instead (B). Steps 1–3 can be part of an active adaptive management approach and can be repeated as needs, values, environmental context and resources change over time. Panels B and C: Restoration actions take place within a social–ecological continuum, such that ambitious actions bridge social and ecological goals (purple rungs), signifying truly integrated social–ecological restoration. The text on the left and right of each ladder shows examples of the social and ecological ambitions that underpin the remedial actions that were undertaken in the study areas in Rwanda (Panel B) and Germany (Panel C). B1, B2 and B3 in brackets refer to the balancing feedback loops established through the remedial actions in each case study (please see the causal-loop diagrams of Figs. 3 and 4)

Fig. 2 Photographs of the two case studies considered in this paper. Left: Forest landscape restoration in western Rwanda. Right: Grassland restoration in northern Germany. Photograph left: Joern Fischer. Photograph right: Konrad Gray

restoration goals are the ecological and social objectives to be achieved through restoration, as captured—for example—by quantifiable social and ecological indicators such as those in the restoration monitoring wheels proposed by the Society for Ecological Restoration (Gann et al. 2019) or the United Nations' Food and Agriculture Organization (Buckingham et al. 2019). Third, *remedial actions* are the restoration interventions undertaken to reach a given restoration goal. In systems terms, remedial actions need to break the reinforcing feedback cycle characterizing degrading processes in order to "bend back" the curve of exponential resource degradation.

At any given point in time, then, a restoration project can be assessed—ideally using a formal adaptive management approach—with respect to its current restoration goal, the degrading processes that need to be stopped and reversed, and the remedial actions taken to move towards the desired goal. At a later point in time, the assessment can be repeated—ideally with a more ambitious goal than the first time around (Keenleyside et al. 2012), encouraging more multifunctional outcomes. Even if unintentional, such iterative goal-setting towards more and more ambitious levels of social–ecological restoration in fact characterizes many restoration projects, as illustrated by two case studies below.

CASE STUDIES

To illustrate our framework, we applied the social–ecological ladder of restoration ambition to two case studies. The case studies cover two very different social–ecological systems—one concerns forest landscape restoration in the Global South, the other grassland restoration in the Global North (Fig. 2). Despite major differences, both share conceptual commonalities in terms of changes in social–ecological restoration ambition through time. We present these case studies not as detailed empirical studies, but rather through stylized causal loop diagrams that capture, in qualitative and conceptual terms, the essence of key dynamics of social–ecological systems. We conceived both causal loop diagrams based on research experience on ecosystem restoration in Rwanda (BK, JF, MF) and Germany (MPR, VT, JF). Here, we focused on the most important system components that substantially shape dynamics in the respective restoration system (Haraldsson 2004).

Case study I: Forest landscape restoration, Western Province, Rwanda

Rwanda has committed to restoring more than 80% of its terrestrial area by 2030 (IUCN 2020), and many restoration projects are underway throughout the country. Originally, modern restoration in Rwanda was motivated by large-scale degradation of ecosystems throughout the country caused by population pressure and excessive land use intensity in the 1970s (Nduwamungu 2011). In the Western Province, resource degradation was additionally exacerbated by commercialized tea production starting in the 1960s as well as an intensive dairy farming project in the 1980s (Clay 2019). Land was left depleted of native vegetation, resulting in soil erosion and landslides, which, in turn, increased land and food scarcity (Augenstein 2017) (initial degrading process characterized by reinforcing feedback loop R1 in Fig. 3).

As a response, fast-growing non-native plantation forests dominated by readily available and low-maintenance *Eucalyptus spp.* were established as of 1975 (first remedial action characterized by balancing feedback loop B1 in Fig. 3) (Arakwiye et al. 2021; Rwibasira et al. 2021). Through time, restoration more explicitly sought to address ongoing challenges of land and food scarcity and climate

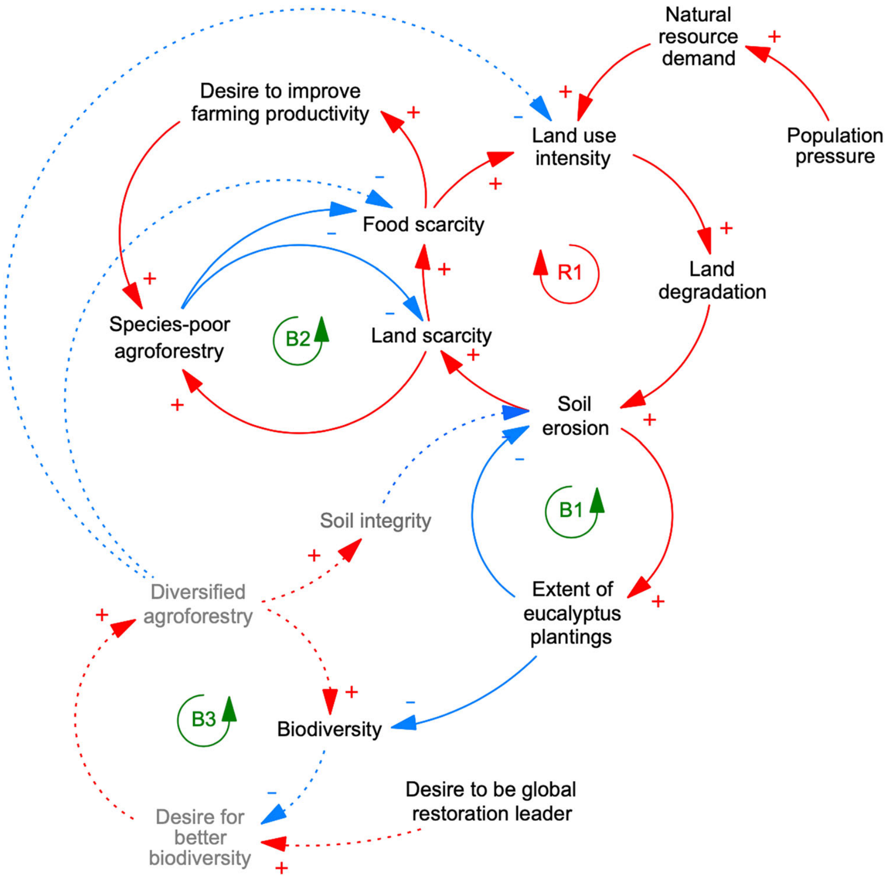

Fig. 3 Causal-loop diagram of restoration dynamics in the Western Province of Rwanda. Restoration initially sought to reduce erosion (B1) and later specifically targeted land and food scarcity (B2), all of which were fuelled by high natural resource demand resulting in unsustainable land use (R1). In the future, the diversification of agroforestry (B3) could further contribute towards these restoration goals while also contributing to a more biodiverse landscape and healthier soils, moving towards the more ambitious end of the restorative continuum (sensu Gann et al. 2019). Variables printed in grey are possible future developments that are still in their early stages; dashed lines indicate possible future dynamics. Blue arrows with a "−" represent relationships between variables with a reducing effect (i.e. an increase in variable "a" leads to a decrease in variable "b"). Red arrows with a " + " indicate relationships with an enhancing effect (i.e. an increase in variable "a" leads to an increase in variable "b"). Closed cycles in the diagram indicate either balancing, self-regulating (B) or reinforcing, growing (R) feedback loops. Please note that causal loop diagrams only show the direction of an effect one system component has on another (i.e. reducing or enhancing effect) and not the extent of this effect

adaptation. Over the last two decades, the Rwandan government launched nation-wide programs aimed at economic and agricultural transformation (Government of Rwanda 2017; Weatherspoon et al. 2021; Kim et al. 2022). Associated measures to increase farming productivity such as crop intensification highlighted the need to counteract degrading processes such as soil erosion and led to both negative and positive environmental and societal impacts (Nyandwi et al. 2015; Isaacs et al. 2016; Clay 2018). Especially agroforestry was and continues to be highly promoted as part of Rwanda's Vision 2020, with the goal of expanding to over 80% of agricultural land (second remedial action characterized by feedback loop B2 in Fig. 3).

Both remedial actions—monoculture woodlots and species-poor agroforestry—have provided short-term benefits for local communities such as fuelwood and more secure livelihoods. Yet, they have also resulted in a landscape with a patchy cover of mostly exotic trees, and agricultural plots with relatively low biodiversity (Arakwiye et al. 2021) and poor-quality soils (Rwibasira et al. 2021), whose resilience to climate change remains unclear. In terms of the restorative continuum (Gann et al. 2019), the interventions so far have mainly resulted in rehabilitation and reclamation, with little focus on more sophisticated semi-natural or native communities.

Today, rapid population growth and the legacy of past land-use decisions are fuelling ever-increasing pressure on natural resources throughout Rwanda. Hence, Rwanda is currently at a crossroads, and decisions on land-use and restoration practices will substantially influence the country's future landscape. One possible trajectory is connected to the nation's growing recognition of the importance of biodiversity and climate adaptation: complementing—and over time perhaps replacing—species-poor agroforestry with more diversified agroforestry could increase biodiversity and soil fertility, reduce soil erosion, and contribute to food security (possible future remedial action characterized by balancing feedback B3 in Fig. 3).

Case study II: Grassland restoration, Lower Saxony, Germany

Species-rich grasslands are among the most threatened ecosystems worldwide (Newbold et al. 2015), and their restoration is increasingly seen as important (Conrad and Tischew 2011). In Europe, the most prominent threats to grasslands are conversion to arable land, agricultural intensification (including agrochemical use) and land abandonment (Jacquemyn et al. 2011; Wesche et al. 2012). Since the 1950s, different regions in Germany have lost between 15 and 85% of species-rich grasslands (Wesche et al. 2012). Grassland restoration now constitutes one of the main compensation measures to counteract negative ecological impacts of infrastructure development (e.g. roads and railways) (Conrad and Tischew 2011). Most grassland restoration has taken place on former arable land (Conrad and Tischew 2011), where excessive fertilizer use typically causes declines in soil and water quality (i.e. degrading process characterized by a reinforcing feedback loop; R1 in Fig. 4).

In our case study (Fig. 4) near Gifhorn, Lower Saxony, the decrease of otter (*Lutra lutra*) populations in polluted waterways sparked calls to reduce land-use intensity. Some 20 years ago, one NGO began to convert arable lands into lower-intensity grasslands (first remedial action characterized by balancing feedback loop B1 in Fig. 4). This remedial action led to the recovery of otter populations, yet the biodiversity of the grasslands themselves remained low because of the use of low-diversity commercial seed

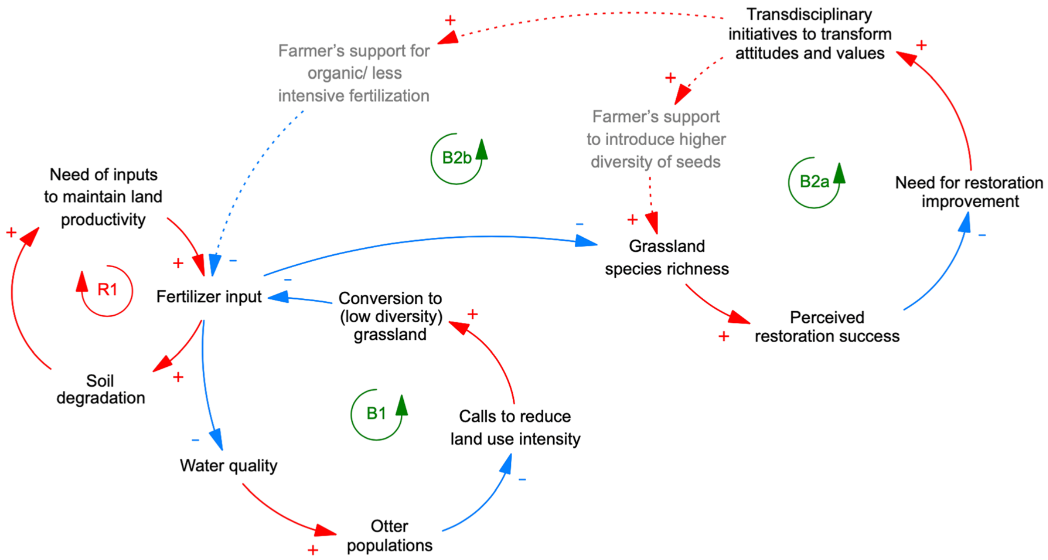

Fig. 4 Causal-loop diagram of grassland restoration dynamics in Lower Saxony, Germany. Following degradation from intensive agriculture (R1), grassland restoration in the Ise floodplain in Lower Saxony was initially motivated by the desire to improve water quality and bring otters back to the river, with little focus on other aspects of biodiversity (B1). More recently, perceptions of low restoration success with respect to grassland diversity have sparked more ambitious restoration initiatives, including transdisciplinary collaborations that promote less intensive farmland management (B2a, b). Variables printed in grey are possible future developments that are still in their early stages; dashed lines indicate possible future dynamics. Blue arrows with a "-" represent relationships between variables with a reducing effect (i.e. an increase in variable "a" leads to a decrease in variable "b"). Red arrows with a " + " indicate relationships with an enhancing effect (i.e. an increase in variable "a" leads to an increase in variable "b"). Closed cycles in the diagram indicate either balancing, self-regulating (B) or reinforcing, growing (R) feedback loops. Please note that causal loop diagrams only show the direction of an effect one system component has on another (i.e. reducing or enhancing effect) and not the extent of this effect

mixtures. Many farmers also continued to apply relatively high levels of fertilizers (around 50 kg N per year per hectare) to the grasslands, which prevented their transition to more species-rich communities.

More recently, a value shift in what society perceives as successful grassland restoration has led to more ambitious restoration goals. New initiatives based on transdisciplinary approaches are now emerging that connect academia, NGOs, government institutions and farmers, and are beginning to foster a change in attitudes. These initiatives are testing and promoting less intensive management practices (e.g. lower fertilizer input) and more diverse seed mixtures to improve grassland species diversity (second remedial action characterized by balancing feedback loops B2a, b in Fig. 4).

TWO WAYS OF USING THE LADDER

These two case studies illustrate how the ladder of ambition can act as an analytical tool to identify and make sense of how degrading processes and remedial actions change within a restoration landscape as social and ecological ambitions shift. Ongoing social–ecological changes create a dynamic playing field in which restoration faces the challenge of responding to imminent threats such as erosion or decreases in a species' population size, while also meeting social needs and values that change over time. The proposed framework acknowledges the co-occurrence and co-evolution of both social and ecological ambitions and offers a dynamic way of thinking about restoration planning. In practice, such a post hoc assessment of restoration processes informed by the "ladder way of thinking" would follow the three steps outlined above: (i) the assessment of the state of a social–ecological system at a given point in time and the identification of associated degrading processes, (ii) the identification of restoration goals at that point, and (iii) the identification of which remedial actions were implemented to counteract these degrading processes. In our case, we conducted expert interviews (as part of broader empirical projects), evaluated scientific publications and reports and designed causal loop diagrams for our two case studies, but additional methods such as original field data collection, participatory workshops or surveys may be required in other contexts. Figure 1 illustrates what the result of such an assessment looks like for the two case studies in Rwanda and Germany.

In addition to acting as an analytical tool, the ladder of ambition can also be applied to support decision-making in new or ongoing restoration projects. Drawing on adaptive management, the ladder of ambition can be used to design restoration interventions as active adaptive experiments from the start (Keenleyside et al. 2012), in order to test hypotheses on restoration outcomes in settings characterized by uncertainty (Allen and Gunderson 2011). In practice, this would entail the systematic assessment of the social–ecological context shaping a planned restoration project. Here, causal loop diagrams such as presented in Fig. 3 and Fig. 4 can provide a valuable overview of key variables and interactions that need to be considered (Meadows 2008). To design such causal loop diagrams, elements which have a significant influence on the system need to be identified, the relationships between these elements need to be understood, and the feedbacks between elements need to be analysed. This is best done in cooperation with diverse stakeholders with in-depth knowledge of the system in question (Haraldsson 2004). Next, based on such a detailed contextual understanding, future-oriented methods such as scenario planning or the three-horizons method (Sharpe et al. 2016) can help to define future restoration activities that account for both ecological and social ambitions of diverse groups of interest in a transdisciplinary way. Subsequent monitoring and evaluation of these activities, in turn, can generate valuable knowledge to inform iterative learning and guide the adjustment of actions and goals. This last step makes sure that restoration projects account for ongoing change in ambitions and is ideally guided by active adaptive management principles (Williams 2011)).

This combination of methods for (i) understanding the social–ecological context of restoration efforts (causal loop diagram), (ii) deciding on next steps for restoration activities in a transdisciplinary way (scenario panning, three horizons method), and (iii) iterative evaluation (active adaptive management) on the basis of integrated social–ecological thinking inspired by the ladder can help design long-term oriented restoration projects that consider both social and ecological ambitions and account for change. In other words, the ladder of ambition can act as a framework to support policymakers and practitioners to view restoration in an integrated way, while specific established methods help to translate this perspective into practice.

In summary, the two modes of application—analytical tool and decision-support tool—mean the ladder of ambition can benefit policymakers, practitioners and researchers at different stages of restoration projects. When using the ladder of ambition as an analytical tool, processes and ambitions in completed or ongoing restoration projects can be systematically assessed. This retrospective application generates a comprehensive understanding of the restored system that can provide insights for restoration in other contexts or inform the adaptation of ongoing activities. Used as a decision-making tool, the ladder of ambition can be applied before starting new restoration projects or as part of ongoing iterative processes. This proactive mode of application can inform future-oriented decisions by acknowledging the changing nature of ambitions instead of designing restoration interventions based on short-lived preferences.

Finally, the ladder of ambition could also be applied beyond restoration: diverse contexts in which social and ecological objectives coexist would also benefit from a more integrated way of approaching multiple ambitions that change over time. Examples range from biodiversity conservation to food security and the use of renewable resources. In all such instances, both ways of using the ladder could be valuable—as either an analytical tool for post hoc assessments or as decision-support tool.

IMPLICATIONS FOR POLICY AND PRACTICE

The ladder of ambition can help to navigate common challenges faced by restoration projects. Perhaps most importantly, contradictory social and ecological ambitions can imply trade-offs. When several desirable goals impair each other, actors are confronted with complex decisions regarding which ambitions to pursue to which degree. For example, a large-scale restoration project in Vietnam, while reaching its ecological goal of reforesting bare hills, led to unequal distribution of access to and benefits from forest resources (McElwee 2009). If and which trade-offs arise depends on the individual social–ecological context of a given system. By illustrating that (i) both social and ecological goals are important and (ii) goals change over time, the ladder of ambition can increase awareness of such trade-offs, as well as indicating ways to foster synergies through time.

Another common challenge in restoration relates to the question of whose ambitions are taken into account. Individual actors have different needs and values, leading to different visions for a given social–ecological system. In many cases, the people living in restored landscapes are not the ones who set restoration priorities due to power imbalances and lack of participation (Mansourian 2018). This can result in one-sided decisions that do not account for the diversity of ambitions actually present in a given system. For example, in Ghana, hierarchies in authority, control, and access over land-shaped decision-making, and excluded certain groups from participating in the design of a farmer-managed natural regeneration project (Kandel et al. 2021). Although power imbalances cannot be eradicated via a conceptual model, applying the ladder of ambition throughout a restoration process can help remind decision-makers that different ambitions likely coexist and may take precedence at different points in time of the restoration process.

Finally, stakeholders with a lot of decision-making power often prioritize short-term benefits over longer-term visions. In the context of restoration, such short-term thinking is problematic because restoration activities can take substantial time to yield beneficial results (Nerlekar and Veldman 2020), and some long-term pressures such as climate change require consideration now although their effects might not yet be visible. In the semi-arid and arid regions of China, for example, large-scale afforestation was motivated by the short-term goal to increase forest cover but did not adequately account for local environmental conditions, resulting in the planting of fast-growing yet ecologically inappropriate trees and shrubs which now impede restoration of native grasslands in the future (Cao et al. 2011). In such contexts, the ladder of ambition highlights the evolving nature of restoration goals and emphasizes the need for restoration to move beyond simple short-term fixes. This can sensitize decision-makers to consider ambitions for a given site for different points in time and to evaluate the feasibility and timing of diverse restoration options of different levels of ambition. In addition, instead of sticking to rigid, short-sighted goals that are set at the beginning of a restoration project, the ladder of ambition encourages iterative assessments of a given restoration project (see also Keenleyside et al. 2012).

Beyond addressing the specific challenges outlined above, the social–ecological ladder of restoration ambition contributes to improved restoration science and practice in three general ways. First, it suggests to view restoration sites as social–ecological systems, offering many of the benefits of thinking in systems (Meadows 2008). This includes the consideration of possible synergies and trade-offs between different ambitions, which increases the likelihood of identifying detrimental dynamics and fostering beneficial ones.

Second, establishing repeated re-assessments of restoration goals, processes, and remedial actions as part of restoration management makes restoration more adaptive and dynamic. This opens up room for making adjustments and prevents unsuitable trajectories to be continued just because they seemed appropriate in the past. Indeed, more routinely applying active adaptive management (and monitoring) provides important learning opportunities for restoration science and practice; starting with the rigorous assessment of social–ecological baseline conditions, the ladder of ambition is a way to think about successive layers of intertwined social and ecological restoration interventions.

Finally, restoration is inherently temporal: past land-use decisions cause a present need for restoration in social–ecological systems that will inevitably change in the future. The ladder of ambition integrates past, present and future through focusing on emerging possibilities rather than past deficiencies. It emphasizes that restoration is not a once-off effort but through time, can offer ever new opportunities to keep moving towards an increasingly more sustainable world.

Acknowledgements We gratefully acknowledge funding by the German Ministry of Education and Research (BMBF) for the Grassworks project. M.P-R thanks the Spanish Ministry of Universities and NextGenerationEU for the Margarita Salas fellowship to carry out a postdoctoral research stay at Leuphana University Lueneburg.

Funding Open Access funding enabled and organized by Projekt DEAL. The funding was provided by the German Ministry of Education and Research (BMBF) for the Grassworks project and the Spanish Ministry of Universities and NextGenerationEU for the Margarita Salas fellowship for M P-R to carry out a postdoctoral research stay at Leuphana University Lueneburg.

Declarations

Conflict of interest All authors declare that they have no conflicts of interest.

REFERENCES

Alba-Patiño, D., V. Carabassa, H. Castro, I. Gutiérrez-Briceño, M. García-Llorente, C. Giagnocavo, M. Gómez-Tenorio, J. Cabello, et al. 2021. Social indicators of ecosystem restoration for enhancing human wellbeing. *Resources, Conservation and Recycling* 174: 105782. https://doi.org/10.1016/j.resconrec.2021.105782.

Allen, C.R., and L.H. Gunderson. 2011. Pathology and failure in the design and implementation of adaptive management. *Journal of Environmental Management* 92: 1379–1384. https://doi.org/10.1016/j.jenvman.2010.10.063.

Arakwiye, B., J. Rogan, and J.R. Eastman. 2021. Thirty years of forest-cover change in Western Rwanda during periods of wars and environmental policy shifts. *Regional Environmental Change* 21: 27. https://doi.org/10.1007/s10113-020-01744-0.

Arnstein, S.R. 1969. A ladder of citizen participation. *Journal of the American Institute of Planners* 35: 216–224. https://doi.org/10.1080/01944366908977225.

Aronson, J.C., D. Simberloff, A. Ricciardi, and N. Goodwin. 2018. Restoration science does not need redefinition. *Nature Ecology & Evolution* 2: 916. https://doi.org/10.1038/s41559-018-0536-0.

Augenstein, P. 2017. *Reframing Restoration—Rwanda re-photographed 100 years later or the reconstruction of landscape memory Unpublished PhD thesis*. Bremen: University Library Bremen.

Bond, W.J., N. Stevens, G.F. Midgley, and C.E.R. Lehmann. 2019. The trouble with trees: Afforestation plans for Africa. *Trends in Ecology & Evolution* 34: 963–965. https://doi.org/10.1016/j.tree.2019.08.003.

Brunckhorst, D. 2011. Ecological restoration across landscapes of politics, policy, and property. In *Human dimensions of ecological restoration: Integrating science, nature, and culture*, ed. D. Egan, E.E. Hjerpe, and J. Abrams, 149–161. Washington: Island Press.

Buckingham, K., S. Ray, C. Gallo Granzio, L. Toh, F. Stolle, F. Zoveda, K. Reytar, R. Zamora-Cristales, et al. 2019. *The Road to Restoration—A Guide to Identifying Priorities and Indicators for Monitoring Forest and Landscape Restoration*. FAO & WRI.

Cao, S., L. Chen, D. Shankman, C. Wang, X. Wang, and H. Zhang. 2011. Excessive reliance on afforestation in China's arid and semi-arid regions: Lessons in ecological restoration. *Earth-Science Reviews* 104: 240–245. https://doi.org/10.1016/j.earscirev.2010.11.002.

Carmenta, R., and B. Vira. 2018. Integration for restoration. In *Forest landscape restoration: integrated approaches to support effective implementation*, ed. S. Mansourian and J. Parrotta, 16–36. Abingdon, Oxon; New York: Routledge, [2018] | Series: The Earthscan forest library: Routledge. https://doi.org/10.4324/9781315111872-2.

Chazdon, R.L., L. Cullen, S.M. Padua, and C.V. Padua. 2020. People, primates and predators in the Pontal: From endangered species conservation to forest and landscape restoration in Brazil's Atlantic Forest. *Royal Society Open Science* 7: 200939. https://doi.org/10.1098/rsos.200939.

Clay, N. 2018. Seeking justice in Green Revolutions: Synergies and trade-offs between large-scale and smallholder agricultural intensification in Rwanda. *Geoforum* 97: 352–362. https://doi.org/10.1016/j.geoforum.2018.09.021.

Clay, N. 2019. Fixing the ecosystem: Conservation, crisis and capital in Rwanda's Gishwati Forest. *Environment and Planning E, Nature and Space* 2: 23–46. https://doi.org/10.1177/2514848619826576.

Conrad, M.K., and S. Tischew. 2011. Grassland restoration in practice: Do we achieve the targets? A case study from Saxony-Anhalt/Germany. *Ecological Engineering* 37: 1149–1157. https://doi.org/10.1016/j.ecoleng.2011.02.010.

Dave, R., C. Saint-Laurent, L. Murray, G. Daldegan, R. Brouwer, C. de Scaramuzza, R. Er, S. Simonit, et al. 2018. *Second Bonn Challenge progress report: Application of the Barometer in 2018*. Gland: IUCN.

Dudney, J., C. D'Antonio, R.J. Hobbs, N. Shackelford, R.J. Standish, and K.N. Suding. 2022. Capacity for change: Three core attributes of adaptive capacity that bolster restoration efficacy. *Restoration Ecology*. https://doi.org/10.1111/rec.13647.

Elias, M., M. Kandel, S. Mansourian, R. Meinzen-Dick, M. Crossland, D. Joshi, J. Kariuki, L.C. Lee, et al. 2022. Ten people-centered rules for socially sustainable ecosystem restoration. *Restoration Ecology* 30: e13574. https://doi.org/10.1111/rec.13574.

Erbaugh, J.T., and J.A. Oldekop. 2018. Forest landscape restoration for livelihoods and well-being. *Current Opinion in Environmental Sustainability* 32: 76–83. https://doi.org/10.1016/j.cosust.2018.05.007.

Fischer, J., M. Riechers, J. Loos, B. Martin-Lopez, and V.M. Temperton. 2021. Making the UN decade on ecosystem restoration a social–ecological endeavour. *Trends in Ecology & Evolution* 36: 20–28. https://doi.org/10.1016/j.tree.2020.08.018.

Fox, H., and G. Cundill. 2018. Towards increased community-engaged ecological restoration: A review of current practice and future directions. *Ecological Restoration* 36: 208–218. https://doi.org/10.3368/er.36.3.208.

Furness, E. 2021. How participation in ecological restoration can foster a connection to nature. *Restoration Ecology* 29: e13430. https://doi.org/10.1111/rec.13430.

Gann, G.D., T. McDonald, B. Walder, J. Aronson, C.R. Nelson, J. Jonson, J.G. Hallett, C. Eisenberg, et al. 2019. International

principles and standards for the practice of ecological restoration. *Restoration Ecology* 27: 1–46.
Goffner, D., H. Sinare, and L.J. Gordon. 2019. The Great Green Wall for the Sahara and the Sahel Initiative as an opportunity to enhance resilience in Sahelian landscapes and livelihoods. *Regional Environmental Change* 19: 1417–1428. https://doi.org/10.1007/s10113-019-01481-z.
Government of Rwanda. 2017. *7 years government programme: National strategy for transformation (NST1) 2017–2024*. Kigali: Ministry of Finance and Economic Planning.
Haraldsson, H.V. 2004. *Introduction to system thinking and causal loop diagrams*. Lund: Department of chemical engineering, Lund University.
Higgs, E.S., J.A. Harris, T. Heger, R.J. Hobbs, S.D. Murphy, and K.N. Suding. 2018. Keep ecological restoration open and flexible. *Nature Ecology & Evolution* 2: 580. https://doi.org/10.1038/s41559-018-0483-9.
Hobbs, R.J., L.M. Hallett, P.R. Ehrlich, and H.A. Mooney. 2011. Intervention ecology: Applying ecological science in the twenty-first century. *BioScience* 61: 442–450. https://doi.org/10.1525/bio.2011.61.6.6.
Isaacs, K.B., S.S. Snapp, K. Chung, and K.B. Waldman. 2016. Assessing the value of diverse cropping systems under a new agricultural policy environment in Rwanda. *Food Security* 8: 491–506. https://doi.org/10.1007/s12571-016-0582-x.
IUCN. 2020. *Restore Our Future: Bonn Challenge. Impact and Potential of Forest Landscape Restoration*.
Jacquemyn, H., C.V. Mechelen, R. Brys, and O. Honnay. 2011. Management effects on the vegetation and soil seed bank of calcareous grasslands: An 11-year experiment. *Biological Conservation* 144: 416–422. https://doi.org/10.1016/j.biocon.2010.09.020.
Kandel, M., G. Agaba, R.S. Alare, T. Addoah, and K. Schreckenberg. 2021. Assessing social equity in farmer-managed natural regeneration (FMNR) interventions: Findings from Ghana. *Ecological Restoration* 39: 64–76. https://doi.org/10.3368/er.39.1-2.64.
Keenleyside, K., N. Dudley, S. Cairns, C. Hall, and S. Stolton. 2012. *Ecological restoration for protected areas*. Gland: IUCN.
Kim, S.K., F. Marshall, and N.M. Dawson. 2022. Revisiting Rwanda's agricultural intensification policy: Benefits of embracing farmer heterogeneity and crop-livestock integration strategies. *Food Security*. https://doi.org/10.1007/s12571-021-01241-0.
Löfqvist, S., F. Kleinschroth, A. Bey, A. de Bremond, R. DeFries, J. Dong, F. Fleischman, S. Lele, et al. 2022. How social considerations improve the equity and effectiveness of ecosystem restoration. *BioScience*. https://doi.org/10.1093/biosci/biac099.
Manning, P., F. van der Plas, S. Soliveres, E. Allan, F.T. Maestre, G. Mace, M.J. Whittingham, and M. Fischer. 2018. Redefining ecosystem multifunctionality. *Nature Ecology & Evolution* 2: 427–436. https://doi.org/10.1038/s41559-017-0461-7.
Mansourian, S. 2018. Stakeholders and forest landscape restoration: Who decides what to restore, why and where? In *Forest landscape restoration: Integrated approaches to support effective implementation*, ed. S. Mansourian and J. Parrotta, 139–157. London: Routledge.
Martin, D.M. 2017. Ecological restoration should be redefined for the twenty-first century. *Restoration Ecology* 25: 668–673. https://doi.org/10.1111/rec.12554.
Martin, M.P., D.J. Woodbury, D.A. Doroski, E. Nagele, M. Storace, S.C. Cook-Patton, R. Pasternack, and M.S. Ashton. 2021. People plant trees for utility more often than for biodiversity or carbon. *Biological Conservation* 261: 109224. https://doi.org/10.1016/j.biocon.2021.109224.
McDonald, T. 2008. Evolving restoration principles in a changing world. *Ecological Management & Restoration* 9: 165–167. https://doi.org/10.1111/j.1442-8903.2008.00413.x.
McElwee, P. 2009. Reforesting "bare hills" in Vietnam: Social and environmental consequences of the 5 million hectare reforestation program. *Ambio* 38: 325–333. https://doi.org/10.1579/08-r-520.1.
McGuire, A., and T. Ehlinger. 2022. Restoration as social–ecological transformation: Emergence in the Pike River Watershed. *Journal of Great Lakes Research* 48: 1505–1516. https://doi.org/10.1016/j.jglr.2022.05.017.
Meadows, D. 2008. *Thinking in systems: A primer*. Vermont: Chelsea Green Publishing.
Nduwamungu, J. 2011. Forest plantations and woodlots in Rwanda. *African Forest Forum* 1: 2–61.
Nerlekar, A.N., and J.W. Veldman. 2020. High plant diversity and slow assembly of old-growth grasslands. *Proceedings of the National Academy of Sciences of the United States of America* 117: 18550–18556. https://doi.org/10.1073/pnas.1922266117.
Newbold, T., L.N. Hudson, S.L.L. Hill, S. Contu, I. Lysenko, R.A. Senior, L. Börger, D.J. Bennett, et al. 2015. Global effects of land use on local terrestrial biodiversity. *Nature* 520: 45–50. https://doi.org/10.1038/nature14324.
Nyandwi, E., A. Veldkamp, and S. Amer. 2015. Delineating Rwandan wetland using topographic and climatic parameters.
Perino, A., H.M. Pereira, L.M. Navarro, N. Fernández, J.M. Bullock, S. Ceauşu, A. Cortés-Avizanda, R. van Klink, et al. 2019. Rewilding complex ecosystems. *Science*. https://doi.org/10.1126/science.aav5570.
Perring, M.P., R.J. Standish, J.N. Price, M.D. Craig, T.E. Erickson, K.X. Ruthrof, A.S. Whiteley, L.E. Valentine, et al. 2015. Advances in restoration ecology: Rising to the challenges of the coming decades. *Ecosphere* 6: art131. https://doi.org/10.1890/ES15-00121.1.
Rwibasira, P., F.X. Naramabuye, D. Nsabimana, and M. Carnol. 2021. Long-term effects of forest plantation species on chemical soil properties in Southern Rwanda. *Soil Systems* 5: 59. https://doi.org/10.3390/soilsystems5040059.
Sharpe, B., A. Hodgson, G. Leicester, A. Lyon, and I. Fazey. 2016. Three horizons a pathways practice for transformation. *Ecology and Society* 21: 1–15.
Society for Ecological Restoration. 2004. *The SER International Primer on Ecological Restoration*. www.ser.org & Tucson: Society for Ecological Restoration International.
Steffen, W., A. Persson, L. Deutsch, J. Zalasiewicz, M. Williams, K. Richardson, C. Crumley, P. Crutzen, et al. 2011. The anthropocene: From global change to planetary stewardship. *Ambio* 40: 739–761. https://doi.org/10.1007/s13280-011-0185-x.
Temperton, V.M., N. Buchmann, E. Buisson, G. Durigan, L. Kazmierczak, M.P. Perring, M. Sá Dechoum, J.W. Veldman, et al. 2019. Step back from the forest and step up to the Bonn Challenge: How a broad ecological perspective can promote successful landscape restoration. *Restoration Ecology* 27: 705–719. https://doi.org/10.1111/rec.12989.
UNEA. 2019. *Resolution 73/284: United Nations Decade on Ecosystem Restoration (2021–2030)*. United Nations Environment Agency, https://undocs.org/A/RES/73/284.
Weatherspoon, D.D., S.R. Miller, F. Niyitanga, L.J. Weatherspoon, and J.F. Oehmke. 2021. Rwanda's commercialization of smallholder agriculture: Implications for rural food production and household food choices. *Journal of Agricultural & Food Industrial Organization*. https://doi.org/10.1515/jafio-2021-0011.
Weidlich, E.W.A., C.R. Nelson, J.L. Maron, R.M. Callaway, B.M. Delory, and V.M. Temperton. 2020. Priority effects and ecological restoration. *Restoration Ecology*. https://doi.org/10.1111/rec.13317.
Wesche, K., B. Krause, H. Culmsee, and C. Leuschner. 2012. Fifty years of change in Central European grassland vegetation: Large losses in species richness and animal-pollinated plants.

Biological Conservation 150: 76–85. https://doi.org/10.1016/j.biocon.2012.02.015.
Williams, B.K. 2011. Adaptive management of natural resources–framework and issues. *Journal of Environmental Management* 92: 1346–1353. https://doi.org/10.1016/j.jenvman.2010.10.041.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

AUTHOR BIOGRAPHIES

Marina Frietsch (✉) is a PhD student at the Social-Ecological Systems Institute at Leuphana University Lueneburg, Germany. She is a sustainability scientist using a social–ecological systems approach to study interacting human–environment systems at different scales.
Address: Social-Ecological Systems Institute, School of Sustainability, Leuphana University, Lueneburg, 21335 Lüneburg, Germany.
Address: Center of Excellence in Biodiversity and Natural Resource Management, University of Rwanda, Kigali, Rwanda.
e-mail: marina.frietsch@leuphana.de

Manuel Pacheco-Romero is a postdoctoral researcher at the Social-Ecological Systems Institute at Leuphana University Lueneburg, Germany. He is a sustainability scientist using a social–ecological systems approach to study interacting human–environment systems at different scales. He also affiliated with the University of Almería, Spain.
Address: Social-Ecological Systems Institute, School of Sustainability, Leuphana University, Lueneburg, 21335 Lüneburg, Germany.
Address: Department of Biology and Geology, Andalusian Center for the Assessment and Monitoring of Global Change (CAESCG), University of Almería, Almería, Spain.
e-mail: manuel.pacheco_romero@leuphana.de

Vicky M. Temperton is a professor at the Institute of Ecology at Leuphana University Lueneburg, Germany. She is a specialist in restoration and functional plant ecology with extensive experience in experimental functional biodiversity research.
Address: Institute of Ecology, School of Sustainability, Leuphana University Lüneburg, 21335 Lüneburg, Germany.
e-mail: vicky.temperton@leuphana.de

Beth A. Kaplin is a professor at the University of Rwanda, Rwanda, and the University of Massachusetts, USA. Her research focuses on montane tropical forests and explores community ecology, ecosystem functioning, and conservation.
Address: Center of Excellence in Biodiversity and Natural Resource Management, University of Rwanda, Kigali, Rwanda.
Address: School for the Environment, University of Massachusetts, Boston, MA, USA.
e-mail: bkaplin@antioch.edu

Joern Fischer is a professor at the Social-Ecological Systems Institute at Leuphana University Lueneburg, Germany. He is a sustainability scientist using a social–ecological systems approach to study interacting human–environment systems at different scales.
Address: Social-Ecological Systems Institute, School of Sustainability, Leuphana University, Lueneburg, 21335 Lüneburg, Germany.
e-mail: joern.fischer@leuphana.de

Chapter IV

The relevance of international restoration principles for ecosystem restoration practice in Rwanda

Paper III

Marina Frietsch, Joern Fischer, Beth A. Kaplin, Berta Martín-López

Restoration Ecology, 2024

RESTORATION ECOLOGY
The Journal of the Society for Ecological Restoration

SER SOCIETY FOR ECOLOGICAL RESTORATION

RESEARCH ARTICLE

The relevance of international restoration principles for ecosystem restoration practice in Rwanda

Marina Frietsch[1,2,3], Joern Fischer[1], Beth A. Kaplin[2,4], Berta Martín-López[1]

The restoration of degraded ecosystems is considered a key strategy to contribute to ecological integrity and human well-being. To support restoration practice, 10 "Principles to guide the UN Decade on Ecosystem Restoration 2021–2030" were conceived through a consultative process and put forward by a group of leading international restoration actors. The extent to which these principles can inform successful restoration activities on the ground, however, remains largely unknown. Using a combination of qualitative and quantitative data collection methods, we probed 32 stakeholders who plan, manage, and implement restoration in Rwanda to elicit which factors they perceive as most important for successful restoration based on the UN Decade principles. Using the Q-methodology, we discovered that participants overall agreed that the UN Decade principles are relevant to inform successful ecosystem restoration in the study area. Further, the Q-study revealed three distinct groups of stakeholders with different priorities in terms of opinions on restoration aims, stakeholder involvement, and relevant spatial scales. Based on semi-structured interviews, we identified four considerations for successful restoration that require special attention in future restoration interventions in the study area: (1) restoring historical conditions, (2) collecting baseline data, (3) increasing local communities' sense of ownership, and (4) pursuing a long-term vision for restoration activities. To address these considerations and thereby harvest the potential of ecosystem restoration to benefit both people and nature in the long run, diverse stakeholders with different priorities for restoration need to come together to discuss possible differences in their perceived priorities, perspectives, and approaches.

Key words: ecosystem restoration, forest landscape restoration, Q-methodology, social-ecological systems

Implications for Practice

- The "Principles to guide the UN Decade on Ecosystem Restoration 2021–2030" can be a basis for reflection and exchange among stakeholders on restoration approaches and priorities.
- In Rwanda, approaches to restoration differ among key restoration stakeholders with respect to (1) the envisioned goal of restoration, (2) the motivation for involving stakeholders, and (3) the spatial scale at which restoration interventions are carried out.
- Sound knowledge on ecological conditions, communities' sense of ownership of restored sites, and a long-term vision for restoration activities are key for successful restoration in the study area and most likely beyond.

Introduction

Ecosystems that safeguard biodiversity contribute to human well-being and provide resilience against global threats such as climate change are key for securing a safe and sustainable foundation for life on Earth. Ecosystem restoration can significantly contribute to maintaining or reinstating such systems by "halting and reversing [their] degradation" (UNEP 2021). Around the world, restoration is gaining momentum: it is one of 23 global targets defined by the Kunming-Montreal Global Biodiversity Framework (CBD 2023) and central to achieving the Sustainable Development Goal (SDG) "Life on Land" (Sachs et al. 2022). In addition, the United Nations declared 2021–2030 the "Decade on Ecosystem Restoration" (hereafter "UN Decade"). To date, 115 countries have put forward quantitative, area-based commitments to restore various portions of their territory as part of the UN Decade (Sewell et al. 2020).

In practice, however, ecosystem restoration still faces many challenges. For example, on the ecological side, many restoration projects fail to restore complex ecological functions and processes (Jones et al. 2018; Holl et al. 2022). In many cases, unsuitable species are selected for planting

Author contributions: MF conceived and designed the research with support from BM-L and JF; MF collected and analyzed the data; JF supported the statistical analysis of the data; MF wrote the manuscript; BM-L, BAK supervised this research; all authors discussed the results and edited the manuscript.

[1]Social-Ecological Systems Institute, School of Sustainability, Leuphana University Lueneburg, 21335, Lueneburg, Germany
[2]Center of Excellence in Biodiversity and Natural Resource Management, University of Rwanda, Kigali 4285, Rwanda
[3]Address correspondence to M. Frietsch, email marina.frietsch@leuphana.de
[4]School for the Environment, University of Massachusetts, Boston, MA 02125, U.S.A.

doi: 10.1111/rec.14085
Supporting information at:
http://onlinelibrary.wiley.com/doi/10.1111/rec.14085/suppinfo

(Coleman et al. 2021; Naia et al. 2021), which can result in low biodiversity of restoration-dominated landscapes (Holl et al. 2022). On the social side, inflexible or short-sighted governance structures can slow restoration activities or promote misplaced restoration goals (Jepson 2022), and restoration projects face complex questions surrounding equity and inclusive participation (Elias et al. 2021; Osborne et al. 2021). Finally, a lack of adaptive capacity and resilience to complex social-ecological threats can jeopardize the long-term sustainability of restoration efforts (Dudney et al. 2022; Frietsch et al. 2023). These and other challenges related to restoration raise an important question: what do the people who plan, manage, and implement restoration interventions perceive as most important for successful restoration?

A myriad of principles exist that can guide restoration practice. Over the past decade, multiple partially overlapping restoration guidelines have been put forward focusing, for example, on the restoration of protected areas (Keenleyside et al. 2012), ecological restoration in general (McDonald et al. 2016; Gann et al. 2019), or forest landscape restoration in particular (Gichuki et al. 2019). For the UN Decade, through a consultative process and by synthesizing existing work, a group of key international restoration actors including the Food and Agricultural Organization of the United Nations, the International Union for Conservation of Nature, and the Society for Ecological Restoration formulated 10 guiding principles to "underpin all of the restorative activities that are part of the continuum of ecosystem restoration defined by the UN Decade, and which are applicable across all sectors, biomes and regions" (FAO et al. 2021). However, principles alone do not necessarily translate into more effective and successful restoration on the ground: a possible gap between science and policy on the one side versus practical application on the other side is well-known in the context of restoration (Cabin et al. 2010; Heger et al. 2022). Hence, the extent to which global level principles such as the UN Decade principles are actually relevant to practitioners in local restoration contexts remains largely unknown (Tedesco et al. 2023).

In this article, we assess the perceived relevance of restoration principles in practice in a case study in Rwanda. We focus on Rwanda because it has made one of the most ambitious restoration pledges worldwide (Nash et al. 2020). Over the past decades, hundreds of individual sites were restored across the country in the form of woodlots, agroforestry patches, wetlands, and protective plantings (Nash et al. 2020). However, most restored sites exhibit low levels of biodiversity (Arakwiye et al. 2021) and are dominated by exotic species (Nash et al. 2020), with monoculture plantings being widespread (Ministry of Natural Resources Rwanda 2014). In addition, access to resources needed for restoration such as financial support and seedlings is limited in Rwanda (Buckingham et al. 2020). Rwanda's ambitious restoration efforts, combined with the broad range of challenges that restoration is facing in the country, provide an ideal setting to explore the relevance of international restoration principles.

Against this background, our overarching goal was to assess to what extent the 10 international restoration principles put forward for the UN Decade on Ecosystem Restoration are relevant to restoration practice among stakeholders in Rwanda. We sought to (1) elicit the perspectives of diverse ecosystem restoration stakeholders on the importance of different facets of each of the 10 principles, (2) assess to what extent these principles are being applied in practice, and (3) explore future priority features of successful restoration for Rwanda that emerged throughout the research.

Methods

Study Area

The study targeted national, subnational and local stakeholders in Rwanda. All stakeholders were involved in restoration projects in the central and western parts of the country, which are characterized by a hilly, high-altitude landscape and inhabited by a mostly rural population (National Institute of Statistics Rwanda 2021). Over the past 30 years, western and central Rwanda experienced a rapid decline in natural ecosystems due to high natural resource demand and armed conflicts (Kanyamibwa 1998; Nduwamungu 2011; Arakwiye et al. 2021). As a result, the vast majority of local ecosystems are now degraded, with negative consequences for biodiversity (Arakwiye et al. 2021), ecosystem functioning (Rwibasira et al. 2021), and human well-being (Nash et al. 2020). As a response to widespread degradation, the Rwandan government and NGOs have actively pursued restoration in the past decades.

Data Collection: Q-Methodology, Relative Weighting Exercise, and Interviews

Our data collection was structured into three components. We (1) used a quantitative ranking exercise to elicit perspectives and opinions of stakeholders on what makes restoration successful, (2) subsequently carried out a relative weighting exercise to explore the reality of restoration practice in the study area, and (3) complemented these two quantitative approaches with semi-structured, qualitative interviews (Fig. 1). Components (1) and (3) together are widely known in sociological studies as the "Q-methodology" (Brown 1996; Watts & Stenner 2012). Component (2) was developed by us as a specific complement for this study. Participants were surveyed individually and, depending on their availability, participated in all three components or in components (1) and (3) only.

The Q-methodology is a structured approach to explore the reasoning behind diverse perspectives on a particular topic and combines quantitative and qualitative methods (Brown 1996; Watts & Stenner 2012; Zabala et al. 2018). Data collection for the Q-methodology follows three main steps. First, different discourses around a given topic are identified and proxy statements that represent various aspects of these discourses are developed (known as Q-set) (Watts & Stenner 2012; Zabala et al. 2018). In our case, we aimed to portray the discourse around features that contribute to successful ecosystem restoration. We based our Q-set on the 10 UN Decade principles for restoration that were designed by leading international restoration actors. Because the principles have the ambitious aim to provide guidance for all types of restoration in all parts of the world, it is particularly interesting to explore their real-world relevance in specific

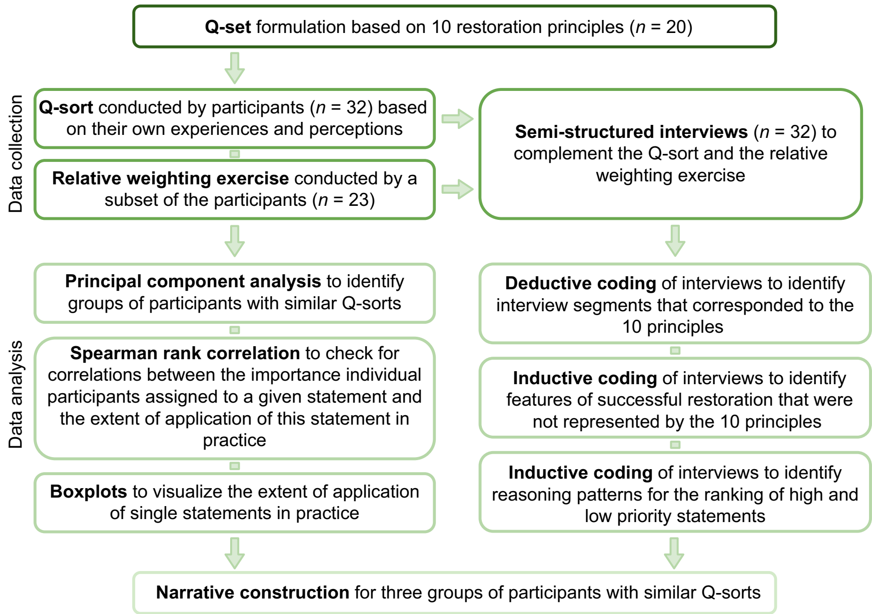

Figure 1. Study design. Data collection encompassed three steps: a Q-sort, a relative weighting exercise, and semi-structured interviews. The data obtained were subsequently analyzed using the "qmethod" package in R as well as deductive and inductive coding.

contexts such as western and central Rwanda. We developed two detailed proxy statements for each of the 10 principles and obtained a Q-set of 20 specific statements (Table 1). We carefully worded the statements based on the short explanations of each principle provided by the official document on the UN Decade principles (see FAO et al. 2021) and cross-checked these for intelligibility within the author team and via two pretests with other colleagues. Finally, the statements were numbered randomly to avoid biases in the sorting process while also enabling easy data collection, and subsequently printed on cards.

In the second step, we selected participants. Because the Q-methodology seeks to identify the diversity of perspectives on a given topic, the participants are usually a nonrandom, purposively sampled, diverse selection of individuals that are familiar with the topic of interest, who are likely to represent the range of viewpoints on the topic. Participant numbers typically range from 26 to 46 (Zabala et al. 2018). Notably, the Q-methodology is not primarily designed to reach general conclusions about how different demographic groups perceive a given topic, but rather seeks to illustrate more broadly the reasoning underpinning different types of perspectives—diversity in participants is therefore more important than balanced representation of particular demographic groups (Cairns 2012). In our case, we conducted the Q-methodology with 32 participants who were active in restoration projects as either researchers ($n = 8$), government officials ($n = 8$), or NGO staff ($n = 16$) in 12 districts in western and central Rwanda. For this study, we chose to speak to people with the agency to actively shape restoration interventions. Local people were not included in our study because at present, they are mostly the recipients of restoration interventions. Future research can (and should) pursue similar research questions to those presented in this paper but focus on local people instead. We interviewed five women and 27 men who had been involved in restoration between one and 18 years. In the following, interviewees will be referred to by their role as either researcher (R), government official (G), or NGO staff (N) and numbered consecutively within these categories.

In a third step—the so-called Q-sorting—participants were asked to rank the proxy statements according to their own experiences and perspectives (Zabala et al. 2018). We first asked participants to read all statements and initially presort them for their own convenience into three categories, namely "most important," "medium important," and "least important" for successful restoration. Next, we provided respondents with a scoreboard showing 20 empty fields along a gradient from most to least important for successful restoration with a few boxes at the extremes (i.e., very important or not very important) and the majority of boxes in the middle (i.e., medium important) (Fig. S1). We then asked participants to place the statement cards on the scoreboard according to their importance for successful restoration. Finally, after completing the Q-sort, participants were given time to re-arrange the statements until they were satisfied with their order.

The application of the Q-methodology generated data on the features that were deemed more or less important for successful restoration according to participants' perspectives. As a second part of our study, we explored the extent to which these features were actually applied in restoration practice within the study

Table 1. The 10 guiding principles and the derived Q-set. For each principle, two statements were developed resulting in a Q-set with $n = 20$. The z-scores are weighted averages of the values that Q-sorts of a given group assign a statement; high z-scores indicate that a statement was considered very important for successful ecosystem restoration. G1 = group 1; G2 = group 2; G3 = group 3.

Principle	*#*	*Statement*	*z-Score G1*	*z-Score G2*	*z-Score G3*
Principle 1: Global Contribution	1.1	Restoration projects should help to safeguard biodiversity and combat climate change.	0.12	0.88	0.17
Principle 1: Global Contribution	1.2	Successful restoration should contribute to the 17 Sustainable Development Goals.	0.00	1.62	−2.25
Principle 2: Broad Engagement	2.1	Stakeholders should be integrated throughout the whole process of a restoration project, from planning to monitoring.	1.28	0.13	0.43
Principle 2: Broad Engagement	2.2	Inclusive participation of stakeholders is necessary for achieving the desired outcomes of restoration over the long term.	1.22	0.01	0.05
Principle 3: Many types of activities	3.1	Restoration projects should encompass a wide range of activities.	−1.71	−2.24	−1.99
Principle 3: Many Types of Activities	3.2	Different approaches and measures should be part of restoration projects.	−0.91	−1.65	−1.21
Principle 4: Benefits to Nature and People	4.1	Restoration should aim to achieve the greatest gains possible for both nature and people.	0.52	1.43	0.17
Principle 4: Benefits to Nature and People	4.2	Restoration should support natural recovery processes and increase ecological integrity.	0.05	−0.72	0.44
Principle 5: Addresses Causes of Degradation	5.1	Restoration projects should help to eliminate causes of ecosystem degradation	−0.52	0.51	0.67
Principle 5: Addresses Causes of Degradation	5.2	During the planning phase of restoration projects, the causes of degradation should be identified.	1.94	0.11	0.12
Principle 6: Knowledge Integration	6.1	Restoration projects should facilitate learning and knowledge-sharing among stakeholders and practitioners.	−1.16	−0.40	0.57
Principle 6: Knowledge Integration	6.2	Restoration projects should integrate all types of knowledge such as traditional, local, and scientific knowledge.	0.33	−0.24	0.88
Principle 7: Measurable Goals	7.1	Goals of restoration projects should be based on a shared vision of desired outcomes.	−0.14	0.44	−0.85
Principle 7: Measurable Goals	7.2	Restoration planning should include the establishment of realistic and measurable goals.	0.92	−0.77	−0.65
Principle 8: Local and Landscape Contexts	8.1	The ecological, cultural, and social setting should be taken into account when planning a restoration project.	0.82	−0.23	1.96
Principle 8: Local and Landscape Contexts	8.2	The goals of restoration projects should be aligned with the local context and local needs.	0.83	1.52	1.19
Principle 9: Monitoring and Management	9.1	Restoration projects should be monitored to adapt activities as a response to changing conditions over time.	−1.03	−1.12	0.22
Principle 9: Monitoring and Management	9.2	Restoration projects should be monitored beyond their lifetime to capture longer-term impacts.	−0.99	−0.10	0.16
Principle 10: Policy Integration	10.1	Laws and regulations on restoration should support the planning and implementation of restoration projects.	−0.16	0.27	−0.12
Principle 10: Policy Integration	10.2	Successful restoration activities should influence the design of laws and policies to help prevent ecosystem degradation.	−1.43	0.54	0.04

area. To this end, we conducted a relative weighting exercise with some of the participants ($n = 23$). We asked these participants to build towers using 60 LEGO bricks and place them on the 20 statement cards to indicate to what extent each statement had been applied in one specific restoration project they had been involved in (Fig. S1). The higher the tower on a given card, the more the ideas represented in the statement had been applied in the restoration project. We asked participants to use all 60 LEGO bricks. Participants had the option of putting zero LEGO bricks on a card in case a statement was not at all reflected in the restoration project. Again, participants were given time to re-arrange the LEGO towers until they were satisfied.

To complement the quantitative data collection based on the Q-sorting and the LEGO exercise, we conducted semi-structured interviews (Supplement S1). Right at the beginning of these interviews, that is, before handing out the Q-set, we asked participants to define successful ecosystem restoration in their own words and name contributing features to obtain their initial, unbiased perspective on restoration success. Next, as part of the Q-methodology, we asked participants why they chose the three most and the three least important statements to understand the reasoning behind participants' Q-sorts. Finally, we asked follow-up questions on the LEGO exercise about the distribution of the towers, especially in the case of discrepancies between the statements a participant sorted as most or least important versus the height of the LEGO tower they built on these statements. We did not tell participants that the Q-set was based on the UN Decade principles until after the interviews were completed; most participants stated that they were not familiar with the principles.

Data Analysis: Statistics and Interview Coding

As a first step, to synthesize the Q-methodology data and identify groups of participants with similar perspectives on successful restoration, we performed a multivariate analysis of Q-sorts using principal component analyses with the "qmethod" package in R software. The "qmethod" package was specifically designed to analyze data obtained from Q-studies that typically have small sample sizes (Zabala 2014). The principal component analysis allowed us to compare the collected Q-sorts, group them by similarity, and summarize shared views in the form of idealized sorting patterns of the statements. These sorting patterns are called "factors" in the Q-methodology and reflect shared viewpoints of groups of participants (Zabala 2014; Zabala et al. 2018). To improve readability, we will use the term "groups" instead of "factors" in this article. Following the initial exploration of two- to six-group solutions, we decided to extract three groups that explained the variation in prioritizing features of successful restoration based on their high eigenvalues.

For the analysis of the LEGO exercise, we used Spearman rank correlation to check for correlations between the importance individual participants had assigned to a given statement (i.e., the statement's position on the scoreboard) and the extent of application of this statement in practice (i.e., the height of the LEGO tower for the statement). We also generated boxplots for the LEGO towers pertaining to each statement to check if certain statements were applied in practice to a particularly high or low extent.

Finally, to analyze the qualitative data obtained from the semi-structured interviews we transcribed all interviews and conducted three rounds of iterative content analysis. First, we deductively coded all responses following the 10 UN Decade principles to identify interview segments that corresponded to the principles. Second, we inductively coded all responses to identify features of successful restoration that were not represented by our statements summarizing the 10 principles. Third, we inductively coded all responses to identify different types of reasoning for the classification of high and low priority statements given by participants. In addition to these three rounds of coding, we also integrated the results of the principal component analysis of Q-sorts and the interview data by synthesizing general narratives for the three resulting groups.

Results

Overview of Q-Sorts and LEGO Exercise Results

Participants referred to all 10 principles throughout the interviews and the majority of participants expressed that all principles were important in the context of restoration. This was captured by one participant's comment stating that prioritizing the statements was "like choosing between your Mom and your Dad" (R5). There were no strong correlations between the position of a given statement on the scoreboard and the height of the respective LEGO tower for the vast majority of participants (i.e., only three rho values >0.6, for participants N5, N7, and N9). The average heights of LEGO towers on the 20 statements representing the degree of application in practice did not differ significantly across all statements, with a mean height of 2.95 LEGO bricks per statement.

Based on the 20 Q-statements, the principal component analysis identified three distinct perspectives on what stakeholders perceived as important for successful restoration (Fig. 2). Together, the three groups of participants explained 53% of the total variance in rankings. Correlations among the three groups were generally low (Pearson correlation values of 0.39, 0.34, and 0.21, respectively), such that they could be seen as genuinely different perspectives. The composite reliabilities of the three groups were high (0.98, 0.97, and 0.96, respectively). The three groups captured the priorities of 26 out of the 32 participants; the remaining six participants did not load significantly on any of the three groups.

There were five statements that clearly distinguished all three groups from one another (Fig. 2). Here, different perceptions on the importance of SDGs for restoration most strongly distinguished the three groups. Repeated reasons given for ranking statements at the bottom of the scoreboard were that the approach or idea represented in that statement was (1) not necessarily needed for successful restoration at particular scales or in particular contexts (18 participants) or (2) not as important as other steps that are part of the restoration process (14 participants). For particularly highly ranked statements, participants repeatedly stated that the reason for prioritization was that the approach or idea represented in that statement (1) was the foundation of good restoration (11 participants) or (2) constituted the main goal of restoration (10 participants).

Three Different Perspectives on Successful Restoration

Group 1: "You Can't Treat a Disease If You Don't Know the Cause" (G5). The first group had 12 significantly loading participants. Two of the loading participants were researchers, six worked for NGOs and four were government staff. This group explained 21% of the total variance and had an eigenvalue of 6.4.

Participants who loaded highly on the first group viewed *ecosystem restoration as a process*. The first step of this process was the identification of root causes of degradation to then develop "context-appropriate solutions" (G5) because you "can't plan without knowing cause and effect" (R3). This "combination of problem assessment and planning" (N13) included understanding the local context and setting realistic, measurable goals to guide the project. Participants who loaded highly on this group valued the involvement of local stakeholders because they "depend on and shape ecosystems" (N12). Local knowledge was thus indispensable to understand root causes and establish successful projects because "technicians tend to think they know all they need, but local knowledge gives context" (N4).

Group 1: restoration as a process

"You can't treat a disease if you don't know the cause"

-3	-2	-1	0	+1	+2	+3
3.1*	6.1'	3.2	1.1	4.1'	2.1	5.2
	10.2	5.1	1.2'	7.2	2.2	
		9.1	4.2	8.1'		
		9.2	6.2'	8.2		
			7.1'			
			10.1			

Group 2: interconnected outcomes

"Where trees grow, people grow"

-3	-2	-1	0	+1	+2	+3
3.1*	3.2	4.2	2.1	1.1	4.1'	1.2'
	9.1	6.1'	2.2	5.1	8.2	
		6.2'	5.2	7.1'		
		7.2	8.1'	10.2		
			9.2			
			10.1			

Group 3: local context and ecology

"Real-world knowledge should be the foundation of every restoration project"

-3	-2	-1	0	+1	+2	+3
1.2'	3.1*	7.1'	1.1	2.1	6.2	8.1'
	3.2	7.2	2.2	4.2	8.2	
		10.1	4.1'	5.1		
		10.2	5.2	6.1		
			9.1			
			9.2			

Figure 2. Idealized Q-sorts of the three groups. Each group brings together participants with a shared perspective on what is needed for successful restoration. The quotes summarize the essence of these groups' perspectives and were extracted from the semi-structured interviews. The 20 Q-set statements are represented by numbers indicated in Table 1. The gradient from −3 to +3 indicates the position of a statement on the scoreboard ranging from perceived low importance (red) over perceived medium importance (yellow) to perceived high importance (green) for successful ecosystem restoration. * = consensus statement that showed no significant difference in ranking between groups; ' = distinguishing statements that showed a statistically significant difference in ranking between groups ($p \leq 0.001$).

In addition, stakeholder involvement could "prevent conflicts" (N4), "increase ownership and make [stakeholders] part of the team" (N12), and "help overcome degrading processes" (G5) to ultimately "increase the strength of the project" (N12). Finally, participants who loaded highly on this group focused on restoration itself and did not prioritize possible flow-on effects such as knowledge-sharing or influencing laws because these were seen as the "last step" (N9) of the restorative process and were therefore considered "less important than other [steps]" (R3).

Group 2: "Where Trees Grow, People Grow" (G8). The second group had eight significantly loading participants. Four of the loading participants worked for NGOs and four were government staff. This group explained 17% of the total variance and had an eigenvalue of 5.2.

Participants who loaded highly on the second group were *outcome-oriented and adopted a social-ecological systems perspective* to restoration by acknowledging that natural and social "systems are interconnected" (G8). According to this group of participants, the overarching goal of restoration was to benefit nature and people at all scales. This included to "contribute to the well-being of people and ecosystems" (N1) and restore "nature and natural values of the landscape" (N7). To this end, it was considered necessary to "think and act long-term" (N16) and include "the biophysical setting, the policy setting [and] the socio-economic capacities of communities" (N16). Envisioned outcomes of this integrated form of restoration were to bring back "productive and functional ecosystems" (G8), "support livelihoods of dependent communities" (N16), and promote "transformation and inspire others" (N10). Participants who loaded highly on this group additionally sought to connect local restoration activities with the "worldwide vision" (G2) of the SDGs and highlighted that restoration would need to span multiple scales where local "actions contribute to global goals" (G2). Although outcomes were the main focus of this group of participants, applying a diversity of restorative activities was not considered a high priority because successful restoration "can just consist of some key activities" (N7).

Group 3: "Real-World Knowledge Should Be the Foundation of Every Restoration Project" (R5). The third group had six significantly loading participants. Four of the loading participants were researchers and two worked for NGOs. This group explained 15% of the total variance and had an eigenvalue of 4.8.

Participants who loaded highly on the third group *strived to restore ecological integrity and anchored restoration activities in their local context*. According to this group of participants, the "ultimate goal" (N3) of restoration was to restore "biodiverse and functional ecosystems" (R1). To achieve this, restoration projects needed to be embedded in the "local social and ecological context" (R1): "sound knowledge on the baseline of biodiversity, ecosystem integrity and ecosystem services" (N3) was needed to "see what existed before and get inspired by it" (R1). This is why participants who loaded highly on this group assigned high "importance [to] local knowledge and skills" (R2) and valued "conversations between all stakeholders to share knowledge and grow from there" (R5). To this end, it was considered important to "respect [local communities'] cultural connections to the landscape" (R5) and "engage stakeholders in all steps of the project in a bottom-up" (N3) and "participatory approach" (N15). In addition, the integration of local stakeholders was seen to contribute to the long-term sustainability of restoration efforts because "communities only maintain what they want" (R8). These local processes were only loosely connected to larger scales: "restoration should be focused on the local and regional scale" (R5) because "global level goals are too general" (N15) and are "for politicians but are not known to local communities" (R2).

Priorities for Ecosystem Restoration in Rwanda

Four features of successful restoration were repeatedly mentioned in the interviews but did not directly correspond to the statement cards developed for this paper. Seven participants expressed the importance of *restoring historical conditions*, including "functionality" (G8), "biodiversity" (G3), and "ecosystem services" (N12). Five participants highlighted the necessity of systematically *collecting baseline data* on "biodiversity, ecosystem integrity and ecosystem services" (N3) to "understand what is needed" in terms of restoration (N15). Five participants advocated *increasing local communities' sense of ownership* of restored sites by "giving them decision making power" (N14) and making sure that projects created "assets for communities" (N1). Finally, 10 participants emphasized the importance of a *long-term vision* for restoration actions which requires "patience" (R6) and "long-term thinking" (N3) to "focus on growing trees, not planting them" (N7).

Discussion

"Different Interests for Different Stakeholders" (R7)—Approaching Restoration from Diverse Perspectives

Although participants appreciated the general relevance of all statements, participants prioritized different aspects of what they felt was especially important for successful restoration. The resulting three groups were linked to different ways of approaching restoration interventions in relation to (1) the envisioned goal of restoration, (2) the motivation for involving stakeholders, and (3) the spatial scale at which restoration interventions were carried out. Participants who loaded highly on the first group ("restoration as a process") were mostly concerned with how to best go about restoration, with the precise definition of aims considered relatively less important, or perhaps assumed as obvious. In comparison, participants who loaded highly on the second group ("interconnected outcomes") and third group ("local context and ecology") focused more on the ends they wanted to achieve by using restoration as a means. With regard to stakeholder involvement, the second group expressed an intrinsic motivation for stakeholder participation because stakeholders were viewed as important in their own right, whereas groups 1 and 3 mainly viewed stakeholder engagement as a tool to secure better ecological outcomes. Finally, participants who loaded highly on the first group did not position themselves with regards to spatial scales, whereas group 2 sought to connect different scales from local to global, and group 3 explicitly focused on local and regional scales.

In addition to a lot of general agreement, our findings thus also illustrate subtle differences in the beliefs and approaches underpinning restoration in Rwanda. Group 1 ("restoration as a process") might best be described as a process-oriented, linear management approach to restoration. Tedesco et al. (2023) argue that approaching restoration as a process was useful to practitioners to think beyond single projects and could help to achieve multiple synergistic restoration objectives. However, this requires the consideration of diverse social-ecological dimensions across different scales (Tedesco et al. 2023), which were typically not accounted for by the first group. Although the restoration approach displayed by group 1 understands restoration as a process, it lacks the notion of learning while implementing restoration practices. In fact, the linear way of thinking displayed by this group runs contrary to the principles of active adaptive management (Murray & Marmorek 2003; Keenleyside et al. 2012) which is widely considered crucial for restoration (Fischer et al. 2021; Dudney et al. 2022).

Group 2 ("interconnected outcomes"), with its vision to benefit people and nature across multiple scales, is closely related to the rationale underpinning *Forest Landscape Restoration* (Dudley et al. 2005; Mansourian et al. 2021). As such, the logic put forward by this group faces the same challenges as the approach of Forest Landscape Restoration in general: balancing competing interests of stakeholders (Chazdon et al. 2021; Stanturf 2021), aligning local with national goals (Stanturf 2021), and dealing with a possible lack of enabling conditions and implementation capacity (Chazdon et al. 2021; Mansourian 2021). In the study area, competition for space between the livelihood needs of a growing population and biodiversity (National Institute of Statistics Rwanda 2021), as well as limited access to resources needed for restoration (Buckingham et al. 2020) can pose challenges to restoration implementation.

Group 3 ("local context and ecology") followed an ecologically motivated approach to restoration more consistent with an *ecological restoration* logic that focuses on ecosystem composition and structure and is often oriented toward a historical reference state (Stanturf et al. 2014). A local focus on clearly defined criteria for ecological success is useful from a biodiversity perspective (Gann et al. 2019), and arguably, a well-defined ecological focus is sometimes lost in large-scale efforts of Forest Landscape Restoration. Yet, focusing primarily on one dimension of an intertwined social-ecological system—be it the social or ecological dimension—is bound to result in suboptimal outcomes for the system as a whole (Walker & Salt 2006). In addition, a strong focus on the local scale can lead to unintended negative interactions with processes occurring at larger spatial scales, because restored sites are connected to a global web of resource use, funding, and policies (Fischer et al. 2021; Osborne et al. 2021).

Despite differences, the three perspectives on how to best design and implement restoration interventions are rather complementary and thus do not have to result in conflict between groups. Integrating these different views can be an asset in restoration practice, for example, in a context of transdisciplinary mechanisms for deliberation and collaboration (Lang et al. 2012; Fischer et al. 2021). With appropriate platforms for exchange, different viewpoints can enrich each other and thus lead to more integrated restoration activities.

"That's the Change I Want to See in the Future" (N7)—Features of Successful Restoration

Four features were repeatedly mentioned in the interviews that did not directly correspond to one of the 20 statements of the Q-set. Participants emphasized that these features need to be considered when designing and implementing restoration interventions in Rwanda. Two of these features—*collecting baseline data* and *restoring historical conditions*—represent classical ecological priorities for restoration (Stanturf et al. 2014). In comparison, the feature of *increasing local communities' sense of ownership* is not at all ecological but political in nature, and is closely related to recent discourses on equity and justice in restoration (Erbaugh et al. 2020; Löfqvist et al. 2022). Finally, the feature *long-term vision for restoration* brings the other three features together—it highlights that it can take many years for ecological and social goals to be fully realized. In the following, we discuss these four features in the context of the UN Decade principles and current debates surrounding ecosystem restoration.

Collecting Baseline Data and Restoring Historical Conditions. Access to baseline data and an awareness of historical reference conditions are central to the paradigm of ecological restoration (Society for Ecological Restoration 2004), which dominated restoration science and practice before approaches such as Forest Landscape Restoration (Dudley et al. 2005) or social-ecological restoration (Fischer et al. 2021) entered the discussion. Baseline data on the historical state of an ecosystem before degradation (CBD 2016) as well as data describing ecological conditions at the onset of restoration (Society for Ecological Restoration 2004) can guide restoration activities and provide important reference points for monitoring and evaluation of restoration projects (Gann et al. 2019).

The UN Decade principles highlight the importance of baseline data (principles 7 and 9) and the associated "Standards of Practice to Guide Ecosystem Restoration" (FAO et al. 2023) describe in more detail what to consider when conducting baseline assessments. In the context of the Rwanda, baseline data remain scarce in many instances: participants reported that for many restoration projects there is not enough time and funding to assess baseline conditions before starting an intervention (N3, N15, R1). This knowledge gap can lead to restoration interventions "based on assumptions rather than hard data or proof" (N3) and result in the implementation of unsuitable restoration measures (Bond et al. 2019). Hence, while there is ample theoretical knowledge and guidance on how to effectively assess baseline data (e.g., (Gann et al. 2019; FAO et al. 2023), practical and financial capacity is urgently needed in order to facilitate baseline assessments. Solving the problem of data availability and access is critical for effective restoration, and national conservation actors must have a sense of ownership in biodiversity information and how it can be applied (Buschke et al. 2023).

When it comes to historical conditions, the UN Decade principles do not explicitly advocate for the restoration of past ecosystem structure and function. This is in accordance with critics of historical reference points, who have argued that their relevance could be limited: critics believe that restoration should focus on fostering desired future system characteristics instead of past conditions (Hobbs & Harris 2001; Corlett 2016). The usefulness of historic states as guidance might be especially reduced given inevitable large-scale changes such as global warming (Harris et al. 2006), the emergence of new abiotic and biotic conditions (Hobbs et al. 2009), and changing social preferences (Higgs et al. 2014). In line with this, the UN Decade principles do recognize that restoration can entail the recovery of an ecosystem "to the trajectory it would be on if degradation had not occurred" as long as environmental change is accounted for (principle 3). As such, knowledge on historical conditions can provide useful contextual understanding of ecosystem conditions that helps to assess the trajectory of restored sites (Higgs et al. 2014). Arguably, this contextual way of using historical reference points is more feasible than simply trying to "bring back ecosystems to [their] initial state" (R4). It means using historical knowledge as a guide rather than a rigid template (Higgs et al. 2014) as it is outlined in the UN Decade principles. In addition, it might open doors to integrate traditional ecological knowledge on historical conditions (Tengö et al. 2014), and may imply an explicit re-orientation away from species composition as the prime restoration goal toward a stronger focus on ecosystem function (Perring et al. 2015).

Increasing Local Communities' Sense of Ownership. The third feature of successful restoration that was repeatedly mentioned to be underemphasized in our Q-set—*increasing local communities' sense of ownership*—is tightly connected to political ecology discourses on justice in restoration. Many restoration interventions are shaped by unequal power relations that determine which activities are prioritized, whose knowledge is included in decision-making, and how resources, benefits, and opportunity costs are distributed (Mansourian 2018; Elias et al. 2021). This can result in restoration interventions that are not aligned with social and ecological local realities (Osborne et al. 2021) and that perpetuate the marginalization of local communities (Löfqvist et al. 2022). Such lack of accounting for local communities is problematic not only from a justice perspective, but can also lead to a lack of identification of local communities with the restoration project, which in turn can cause the unsustainable exploitation of restored sites as soon as those managing the intervention leave or funding runs out (N15).

In this context, both the sense of mental ownership as well as legal ownership matter. Mental ownership is the feeling of connection with a restored site and can be fostered by strengthening emotional connections between people and restored sites (Gottschalk Druschke & Hychka 2015). Valuing and integrating diverse local knowledge and practices is key for building on already existing forms of ownership (Osborne et al. 2021). To create and sustain connections between stakeholders and restoration projects, all stakeholder groups—that is, those who are affected by or can affect restoration (Freeman 1984)—need to be able to participate (Osborne et al. 2021; Elias et al. 2022). Here, to foster participation beyond simple information or consultation (Arnstein 1969), stakeholders need to be given actual decision-making power (Ruano-Chamorro et al. 2021; Sigman & Elias 2021) which can be supported by inclusive governance models (Löfqvist et al. 2022), and effective mediation in stakeholder processes that accounts for power imbalances (Ruano-Chamorro et al. 2021). Legal ownership includes formal tenure rights as well as other regulated and reliable types of access to, management of, and control over resources (Schlager & Ostrom 1992). A degree of certainty that the efforts put into a restoration project will result in benefits is an important incentive for local communities' participation and investment (McLain et al. 2021). In practice, access rights and tenure are often messy, complex, and sometimes contested (Meyfroidt et al. 2022). This is why informal ways of legal ownership need to be considered (de Jong et al. 2018) to not exacerbate inequalities and strengthen marginalized groups (Elias et al. 2022).

The UN Decade principle 2 as well as the associated Standards of Practice refer to participation, different types of knowledge, tenure, and equity. As such, they go some way toward acknowledging the importance of generating a sense of ownership. However, because true ownership requires an interaction of these factors and is more than just participation, respondents in this study felt that ownership was not represented in the Q-set. Importantly, there is no one-size-fits-all solution to increase the sense of both mental and legal ownership because communities are embedded in different legal, political, and social contexts (de Jong et al. 2018) and encompass multiple actors with different interests, capabilities, and values that can change over time (Elias et al. 2022). Based on our interviews, to foster ownership in the study area (and most likely also in other restoration settings), ownership needs to be (1) more explicitly discussed, (2) move beyond superficial participation schemes, and (3) account for all types of legal ownership (sensu Schlager & Ostrom 1992).

Pursuing a Long-Term Vision for Restoration. The last feature highlighted by participants was the importance of *pursuing a long-term vision* for restoration projects. Although this might seem obvious, the long-term viability of restoration interventions is often neglected in practice (Frietsch et al. 2023). This is, among others, caused by limited funding (Höhl et al. 2020) and the project-bound design of many restoration interventions (Tedesco et al. 2023). Examples from around the world show how a lack of long-term thinking in restoration practice significantly limits the potential of restoration interventions and can even lead to more harm than good. In Rwanda, for example, *Eucalyptus* remains the dominant species in many restored woodlots (Arakwiye et al. 2021) even though experiments showed that this had long-lasting, undesirable impacts on soil properties (Rwibasira et al. 2021). Similarly, a case study from Northern India found no evidence that tree planting projects resulted in substantial benefits for carbon mitigation or livelihood support after decades of restoration efforts (Coleman et al. 2021). To avoid such unintended consequences and instead create restoration projects that are valuable now and in the future, restoration needs to better account for interacting social and ecological elements that together shape the restored system (Mansourian et al. 2020). The importance of the long-term vision for restoration efforts is also emphasized by the UN Decade principle 10, which provides a list of tangible activities to increase long-term benefits of restoration. These recommendations mostly focus on governance and socio-economic aspects of restoration projects and need to be complemented with context-specific approaches to maximize the ecological viability of restoration interventions.

"For Real Transformation, Restoration Should Be Inspiring" (R1)—Restoration Principles Sparking Exchange and Guiding Action

In conclusion, the 10 UN Decade principles encompass a wide variety of relevant tenets to guide successful ecosystem restoration. More specifically, we argue that their main value lies in their potential to inspire reflection and start conversations: During the interviews, many participants expressed how the Q-methodology exercise based on the 10 UN Decade principles as well as the LEGO exercise provided them with a structured way to reflect on what they feel is important for successful restoration, how their theoretical values differ from how projects they were involved in play out in practice, and what they want to pay special attention to in future restoration interventions. Moreover, following data collection, participants from different NGOs and government institutions reported that the Q-methodology and LEGO exercise sparked internal discussions about perspectives and values regarding restoration interventions in their institutions.

In the case of Rwanda, the Q-methodology exercise based on the 10 UN Decade principles revealed social and ecological features of restoration that require special attention in future restoration efforts. We acknowledge that ecologically sound knowledge on baselines and historical references is difficult to establish, questions surrounding ownership are complex and potentially politically problematic, and assuring the long-term viability of restored sites is resource intensive. Nevertheless, we argue that these features are central for successful restoration that not only fulfills short-term project goals but contributes to ecological integrity and human well-being in the long run. Here, both the UN Decade principles and the associated Standards of Practice provide tangible steps to better incorporate these features in practice. These recommendations need to be complemented with sound ecological knowledge. In addition, to integrate diverse needs, values, and knowledge, fostering an exchange of perspectives and approaches by bringing together diverse stakeholders with different priorities can support the long-term viability of restoration efforts. This holds true not only for our case study in western and central Rwanda but for restoration efforts worldwide.

Acknowledgments

The authors thank all interviewees for their collaboration and time. The authors thank G. Kamwezi for her support during fieldwork. This research was legally and ethically approved by the National Council for Science and Technology, Rwanda, and obtained ethical clearance from the University of Rwanda. The authors have no conflicts of interest to declare. Open Access funding enabled and organized by Projekt DEAL.

LITERATURE CITED

Arakwiye B, Rogan J, Eastman JR (2021) Thirty years of forest-cover change in Western Rwanda during periods of wars and environmental policy shifts. Regional Environmental Change 21:27. https://doi.org/10.1007/s10113-020-01744-0

Arnstein SR (1969) A ladder of citizen participation. Journal of the American Institute of Planners 35:216–224. https://doi.org/10.1080/01944366908977225

Bond WJ, Stevens N, Midgley GF, Lehmann CER (2019) The trouble with trees: afforestation plans for Africa. Trends in Ecology & Evolution 34:963–965. https://doi.org/10.1016/j.tree.2019.08.003

Brown SR (1996) Q methodology and qualitative research. Qualitative Health Research 6:561–567. https://doi.org/10.1177/104973239600600408

Buckingham K, Arakwiye B, Ray S, Maneerattana O, Anderson W (2020) Cultivating networks and mapping social landscapes: how to understand restoration governance in Rwanda. Land Use Policy 104:104546. https://doi.org/10.1016/j.landusepol.2020.104546

Buschke FT, Capitani C, Sow EH, Khaemba Y, Kaplin BA, Skowno A, et al. (2023) Make global biodiversity information useful to national decision-makers. Nature Ecology & Evolution 7:1953–1956. https://doi.org/10.1038/s41559-023-02226-2

Cabin RJ, Clewell A, Ingram M, McDonald T, Temperton V (2010) Bridging restoration science and practice: results and analysis of a survey from the 2009 Society for Ecological Restoration International Meeting. Restoration Ecology 18:783–788. https://doi.org/10.1111/j.1526-100X.2010.00743.x

Cairns R (2012) Understanding science in conservation: a Q method approach on the galápagos islands. Conservation and Society 10:217. https://doi.org/10.4103/0972-4923.101835

CBD (2016) Ecosystem restoration: short-term action plan. Conference of the Parties to the Convention on Biological Diversity, Cancun, Mexico

CBD (2023) Kunming-Montreal global biodiversity framework: 2030 targets. https://www.cbd.int/gbf/targets/

Chazdon RL, Wilson SJ, Brondizio E, Guariguata MR, Herbohn J (2021) Key challenges for governing forest and landscape restoration across different contexts. Land Use Policy 104:104854. https://doi.org/10.1016/j.landusepol.2020.104854

Coleman EA, Schultz B, Ramprasad V, Fischer H, Rana P, Filippi AM, et al. (2021) Limited effects of tree planting on forest canopy cover and rural livelihoods in northern India. Nature *Sustainability* 4:997–1004. https://doi.org/10.1038/s41893-021-00761-z

Corlett RT (2016) Restoration, reintroduction, and rewilding in a changing world. Trends in Ecology & Evolution 31:453–462. https://doi.org/10.1016/j.tree.2016.02.017

Dudley N, Mansourian S, Vallauri D (2005) Forest landscape restoration in context. Pages 3–7. In: Mansourian S, Vallauri D, Dudley N (eds) Forest restoration in landscapes. Springer-Verlag, New York

Dudney J, D'Antonio C, Hobbs RJ, Shackelford N, Standish RJ, Suding KN (2022) Capacity for change: three core attributes of adaptive capacity that bolster restoration efficacy. Restoration Ecology e13647. https://doi.org/10.1111/rec.13647

Elias M, Joshi D, Meinzen-Dick R (2021) Restoration for whom, by whom? A feminist political ecology of restoration. Ecological Restoration 39:3–15. https://doi.org/10.3368/er.39.1-2.3

Elias M, Kandel M, Mansourian S, Meinzen-Dick R, Crossland M, Joshi D, et al. (2022) Ten people-centered rules for socially sustainable ecosystem restoration. Restoration Ecology 30:e13574. https://doi.org/10.1111/rec.13574

Erbaugh JT, Pradhan N, Adams J, Oldekop JA, Agrawal A, Brockington D, Pritchard R, Chhatre A (2020) Global forest restoration and the importance of prioritizing local communities. Nature Ecology & Evolution 4:1472–1476. https://doi.org/10.1038/s41559-020-01282-2

FAO, IUCN, CEM, SER (2021) Principles for ecosystem restoration to guide the United Nations Decade 2021–2030. FAO, Rome, Italy

FAO, SER, IUCN, CEM (2023) Standards of practice to guide ecosystem restoration. A contribution to the United Nations Decade on Ecosystem Restoration. FAO, Rome, Italy

Fischer J, Riechers M, Loos J, Martin-Lopez B, Temperton VM (2021) Making the UN Decade on Ecosystem Restoration—a social-ecological endeavour. Trends in Ecology & Evolution 36:20–28. https://doi.org/10.1016/j.tree.2020.08.018

Freeman RE (1984) Strategic management: a stakeholder approach. Pitman, Boston, Massachusetts

Frietsch M, Loos J, Löhr K, Sieber S, Fischer J (2023) Future-proofing ecosystem restoration through enhancing adaptive capacity. Communications Biology 6:377. https://doi.org/10.1038/s42003-023-04736-y

Gann GD, McDonald T, Walder B, Aronson J, Nelson CR, Jonson J, et al. (2019) International principles and standards for the practice of ecological restoration. Second edition. Restoration Ecology 27:1–46. https://doi.org/10.1111/rec.13035

Gichuki L, Brouwer R, Davies J, Vidal A, Kuzee M, Magero C, Walter S, Lara P, Oragbade C, Gilbey B (2019) Reviving land and restoring landscapes: policy convergence between forest landscape restoration and land degradation neutrality. International Union for Conservation of Nature, Gland, Switzerland. https://doi.org/10.2305/IUCN.CH.2019.11.en

Gottschalk Druschke C, Hychka KC (2015) Manager perspectives on communication and public engagement in ecological restoration project success. Ecology and Society 20:58. https://doi.org/10.5751/ES-07451-200158

Harris JA, Hobbs RJ, Higgs E, Aronson J (2006) Ecological restoration and global climate change. Restoration Ecology 14:170–176. https://doi.org/10.1111/j.1526-100X.2006.00136.x

Heger T, Jeschke JM, Febria C, Kollmann J, Murphy S, Rochefort L, Shackelford N, Temperton VM, Higgs E (2022) Mapping and assessing the knowledge base of ecological restoration. Restoration Ecology e13676. https://doi.org/10.1111/rec.13676

Higgs E, Falk DA, Guerrini A, Hall M, Harris J, Hobbs RJ, Jackson ST, Rhemtulla JM, Throop W (2014) The changing role of history in restoration ecology. Frontiers in Ecology and the Environment 12:499–506. https://doi.org/10.1890/110267

Hobbs RJ, Harris JA (2001) Restoration ecology: repairing the earth's ecosystems in the new millennium. Restoration Ecology 9:239–246. https://doi.org/10.1046/j.1526-100x.2001.009002239.x

Hobbs RJ, Higgs E, Harris JA (2009) Novel ecosystems: implications for conservation and restoration. Trends in Ecology & Evolution 24:599–605. https://doi.org/10.1016/j.tree.2009.05.012

Höhl M, Ahimbisibwe V, Stanturf JA, Elsasser P, Kleine M, Bolte A (2020) Forest landscape restoration—what generates failure and success? Forests 11:938. https://doi.org/10.3390/f11090938

Holl KD, Luong JC, Brancalion PHS (2022) Overcoming biotic homogenization in ecological restoration. Trends in Ecology & Evolution 37:777–788. https://doi.org/10.1016/j.tree.2022.05.002

Jepson PR (2022) To capitalise on the Decade of Ecosystem Restoration, we need institutional redesign to empower advances in restoration ecology and rewilding. People and Nature 4:1404–1413. https://doi.org/10.1002/pan3.10320

Jones HP, Jones PC, Barbier EB, Blackburn RC, Rey Benayas JM, Holl KD, McCrackin M, Meli P, Montoya D, Mateos DM (2018) Restoration and repair of Earth's damaged ecosystems. Proceedings of the Royal Society B: Biological Sciences 285:20172577. https://doi.org/10.1098/rspb.2017.2577

de Jong W, van der Zon M, Urushima AF, Youn Y-C, Liu J, Li N (2018) Tenure, property rights and forest landscape restoration. Pages 158–175. In: Mansourian S, Parrotta J (eds) Forest landscape restoration: integrated approaches to support effective implementation. Routledge, Abingdon, Oxon and New York

Kanyamibwa S (1998) Impact of war on conservation: Rwandan environment and wildlife in agony. Biodiversity and Conservation 7:1399–1406. https://doi.org/10.1023/A:1008880113990

Keenleyside K, Dudley N, Cairns S, Hall C, Stolton S (2012) Ecological restoration for protected areas. IUCN, Gland, Switzerland

Lang DJ, Wiek A, Bergmann M, Stauffacher M, Martens P, Moll P, Swilling M, Thomas CJ (2012) Transdisciplinary research in sustainability science: practice, principles, and challenges. Sustainability Science 7:25–43. https://doi.org/10.1007/s11625-011-0149-x

Löfqvist S, Kleinschroth F, Bey A, de Bremond A, DeFries R, Dong J, et al. (2022) How social considerations improve the equity and effectiveness of ecosystem restoration. Bioscience 73:134–148. https://doi.org/10.1093/biosci/biac099

Mansourian S (2018) Stakeholders and forest landscape restoration: who decides what to restore, why and where? Pages 139–157. In: Mansourian S, Parrotta J (eds) Forest landscape restoration: integrated approaches to support effective implementation. Routledge, Oxfordshire, UK. https://doi.org/10.4324/9781315111872-9

Mansourian S (2021) Disciplines, sectors, motivations and power relations in forest landscape restoration. Ecological Restoration 39:16–26. https://doi.org/10.3368/er.39.1-2.16

Mansourian S, Berrahmouni N, Blaser J, Dudley N, Maginnis S, Mumba M, Vallauri D (2021) Reflecting on twenty years of forest landscape restoration. Restoration Ecology 29:e13441. https://doi.org/10.1111/rec.13441

Mansourian S, Parrotta J, Balaji P, Bellwood-Howard I, Bhasme S, Bixler RP, et al. (2020) Putting the pieces together: integration for forest landscape restoration implementation. Land Degradation & Development 31:419–429. https://doi.org/10.1002/ldr.3448

McDonald T, Gann GD, Jonson J, Dixon KW (2016) International standards for the practice of ecological restoration—including principlesand key concepts. 1st ed. Society for Ecological Restoration, Washington D.C.

McLain R, Lawry S, Guariguata MR, Reed J (2021) Toward a tenure-responsive approach to forest landscape restoration: a proposed tenure diagnostic for assessing restoration opportunities. Land Use Policy 104:103748. https://doi.org/10.1016/j.landusepol.2018.11.053

Meyfroidt P, de Bremond A, Ryan CM, Archer E, Aspinall R, Chhabra A, et al. (2022) Ten facts about land systems for sustainability. Proceedings of the National Academy of Sciences of the United States of America 119: e2109217118. https://doi.org/10.1073/pnas.2109217118

Ministry of Natural Resources Rwanda (2014) Forest landscape restoration opportunity assessment for Rwanda. International Union for Conservation of Nature, Eastern Africa Regional Office, Nairobi, Kenya

Murray C, Marmorek D (2003) Adaptive management and ecological restoration. Pages 417–428. In: P Freiderici (ed) Ecological restoration of southwestern ponderosa pine forests. Island Press, Washington, D.C.

Naia M, Tarroso P, Sow AS, Liz AV, Gonçalves DV, Martínez-Freiría F, et al. (2021) Potential negative effects of the Green Wall on Sahel's biodiversity. Conservation Biology 35:1966–1968. https://doi.org/10.1111/cobi.13755

Nash C, Carvalho S, Raes L, Ndoli A, Karangwa C, Imanirareba E, Njue J, Toovey D (2020) A thousand hills turn green: how Rwanda became a leader in forest landscape restoration. https://iucn.maps.arcgis.com/apps/MapJournal/index.html?appid=0c40be7f83c64bb9b7c8f3372358c6f9

National Institute of Statistics Rwanda (2021) Labour force survey annual report 2020. National Institute of Statistics of Rwanda (NISR), Kigali, Rwanda

Nduwamungu J (2011) Forest plantations and woodlots in Rwanda. African Forest Forum 1:2–61. https://doi.org/10.13140/RG.2.1.1360.4724

Osborne T, Brock S, Chazdon R, Chomba S, Garen E, Gutierrez V, Lave R, Lefevre M, Sundberg J (2021) The political ecology playbook for ecosystem restoration: principles for effective, equitable, and transformative landscapes. Global Environmental Change 70:102320. https://doi.org/10.1016/j.gloenvcha.2021.102320

Perring MP, Standish RJ, Price JN, Craig MD, Erickson TE, Ruthrof KX, Whiteley AS, Valentine LE, Hobbs RJ (2015) Advances in restoration ecology: rising to the challenges of the coming decades. Ecosphere 6: 131. https://doi.org/10.1890/ES15-00121.1

Ruano-Chamorro C, Gurney GG, Cinner JE (2021) Advancing procedural justice in conservation. Conservation Letters 19:e12861. https://doi.org/10.1111/conl.12861

Rwibasira P, Naramabuye FX, Nsabimana D, Carnol M (2021) Long-term effects of forest plantation species on chemical soil properties in southern Rwanda. Soil Systems 5:59. https://doi.org/10.3390/soilsystems5040059

Sachs JD, Lafortune G, Kroll C, Fuller G, Woelm F (2022) Sustainable development report 2022—sustainable development report. https://www.sustainabledevelopment.report/reports/sustainable-development-report-2022/

Schlager E, Ostrom E (1992) Property-rights regimes and natural resources: a conceptual analysis. Land Economics 68:249. https://doi.org/10.2307/3146375

Sewell A, van der Esch S, Löwenhardt H (2020) Global Restoration Commitments database. https://www.pbl.nl/sites/default/files/downloads/pbl-2021-global-restoration-commitments-database-4680.ods

Sigman E, Elias M (2021) Three approaches to restoration and their implications for social inclusion. Ecological Restoration 39:27–35. https://doi.org/10.3368/er.39.1-2.27

Society for Ecological Restoration (2004) The SER international primer on ecological restoration. Society for Ecological Restoration International, Tucson, Arizona

Stanturf JA (2021) Forest landscape restoration: building on the past for future success. Restoration Ecology 29:e13349. https://doi.org/10.1111/rec.13349

Stanturf JA, Palik BJ, Williams MI, Dumroese RK, Madsen P (2014) Forest restoration paradigms. Journal of Sustainable Forestry 33:161–194. https://doi.org/10.1080/10549811.2014.884004

Tedesco AM, López-Cubillos S, Chazdon R, Rhodes JR, Archibald CL, Pérez-Hämmerle K-V, et al. (2023) Beyond ecology: ecosystem restoration as a process for social-ecological transformation. Trends in Ecology & Evolution 38:643–653. https://doi.org/10.1016/j.tree.2023.02.007

Tengö M, Brondizio ES, Elmqvist T, Malmer P, Spierenburg M (2014) Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach. Ambio 43:579–591. https://doi.org/10.1007/s13280-014-0501-3

UNEP (2021) Becoming #GenerationRestoration: ecosystem restoration for people, nature and climate. United Nations Environment Programme. Nairobi, Kenya

Walker B, Salt D (2006) Resilience thinking: sustaining ecosystems and people in a changing world. Island Press, Washington, D.C.

Watts S, Stenner P (2012) Doing Q methodological research: theory, method & interpretation. Sage, Thousand Oaks, California. https://doi.org/10.4135/9781446251911

Zabala A (2014) Qmethod: a package to explore human perspectives using Q methodology. The R Journal 6:163–173. https://doi.org/10.32614/RJ-2014-032

Zabala A, Sandbrook C, Mukherjee N (2018) When and how to use Q methodology to understand perspectives in conservation research. Conservation Biology 32:1185–1194. https://doi.org/10.1111/cobi.13123

Supporting Information

The following information may be found in the online version of this article:

Supplement S1. The interview guideline directed the semi-structured interviews.
Figure S1. Participants were given a scoreboard with 20 empty fields along a gradient from least to most important for successful restoration to sort the Q-set according to their own priorities.

Coordinating Editor: Henny Van der Windt

Received: 15 June, 2023; First decision: 26 July, 2023; Revised: 13 December, 2023; Accepted: 13 December, 2023

Chapter V

Visions for the future of ecosystem restoration

Paper IV

Marina Frietsch, Berta Martín-López, Daniel Akirimari, William Apollinaire, Bernadette Arakwiye, Matthias Baumann, Sophia Bohn, Dula Wakassa Duguma, Ephrem Imanirareba, Beth A. Kaplin, Laura Kmoch, Tobias Kuemmerle, Katharina Löhr, Jacqueline Loos, Myriam Mujawamariya, Athanase Mukuralinda, Valery Ndagijimana, Gaelle Ndayizeye, Venuste Nsengimana, Peter Ntaganda, Verene Nyiramvuyekure, Tobias Plieninger, Stefan Sieber, Martin Sindikubwabo, Ping Sun, Vicky M. Temperton, Ezechiel Turikunkiko, Susanne Vögele, Meike Wollni, Joern Fischer

Submitted to Conservation Letters

Visions for the future of ecosystem restoration

Marina Frietsch[1], Berta Martín-López[1], Daniel Akirimari[2], William Apollinaire[3], Bernadette Arakwiye[4], Matthias Baumann[5], Sophia Bohn[6], Dula Wakassa Duguma[1], Ephrem Imanirareba[7], Beth A. Kaplin[8,9], Laura Kmoch[10], Tobias Kuemmerle[5,11], Katharina Löhr[3,12], Jacqueline Loos[13], Myriam Mujawamariya[8,14], Athanase Mukuralinda[15], Valery Ndagijimana[3], Gaelle Ndayizeye[10], Venuste Nsengimana[8,14], Peter Ntaganda[4], Verene Nyiramvuyekure[1], Tobias Plieninger[10,16], Stefan Sieber[3,17], Martin Sindikubwabo[18], Ping Sun[1], Vicky M. Temperton[19], Ezechiel Turikunkiko[20], Susanne Vögele[6], Meike Wollni[21], Joern Fischer[1].

[1]Leuphana University, Social-Ecological Systems Institute, Faculty of Sustainability, Universitätsallee 1, 21335 Lüneburg, Germany

[2]Nyabihu District Office, Nyabihu, Rwanda

[3]Leibniz Centre for Agricultural Landscape Research (ZALF), Eberswalder Str. 84, 15374 Müncheberg, Germany

[4]World Resources Institute, KG 622 St, Fairview Building, Kimihurura, Kigali, Rwanda

[5]Geography Department, Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany

[6]University of Göttingen, Department of Agricultural Economics and Rural Development, Chair of Environmental and Resource Economics, Platz der Göttinger Sieben 5, 37073 Göttingen, Germany.

[7]International Union for Conservation of Nature, Rwanda Country Office, House 25, KN 16 Ave, Kigali, Rwanda

[8]Center of Excellence in Biodiversity and Natural Resource Management, University of Rwanda, Kigali, Rwanda

[9]School for the Environment, University of Massachusetts, Boston, MA, USA

[10] University of Göttingen, Department of Agricultural Economics and Rural Development, Platz der Göttinger Sieben 5, 37073, Göttingen, Germany

[11]Integrative Research Institute for Transformations of Human-Environment Systems (IRI THESys), Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany

[12]Humboldt Universität zu Berlin, Thaer-Institute for Agricultural and Horticultural Sciences, Urban Plant Ecophysiology, Lentzeallee 55/57, 14195 Berlin, Germany

[13]University of Vienna, Department of Botany and Biodiversity Research, Biodiversity Dynamics and Conservation Group, Rennweg 14, 1030 Vienna, Austria

[14] University of Rwanda, Department of Biology, College of Science and Technology, Kigali, Rwanda

[15]CIFOR-ICRAF, Rwanda Country Office, P.O. Box 227, Huye, Rwanda

[16]University of Kassel, Faculty of Organic Agricultural Sciences, Steinstr. 19, 37213 Witzenhausen, Germany

[17]Humboldt Universität zu Berlin, Thaer-Institute for Agricultural and Horticultural Sciences, Agricultural Economics, Invalidenstr. 42, 10115 Berlin, Germany

[18]ARCOS, KN 14 Avenue, No. 47, Kigali, Rwanda

[19]Leuphana University, Institute of Ecology, Faculty of Sustainability, Universitätsallee 1, 21335 Lüneburg, Germany

[20]Rwanda Development Board, Gishwati-Mukura National Park, Rutsiro, Rwanda

[21]University of Göttingen, Department of Agricultural Economics and Rural Development and Campus Centre of Biodiversity and Sustainable Land Use, Platz der Göttinger Sieben 5, 37073 Göttingen, Germany

Abstract

Especially in the Global South, ecosystem restoration has come under heavy criticism for not adequately delivering on its ecological or social promises. To support context-appropriate and forward-looking restoration interventions, restoration practitioners and decision-makers need to (i) reflect on current restoration practice, (ii) envision desirable futures for restoration, and (iii) develop tangible strategies to move forward. We explored these priorities in Rwanda through an in-depth visioning process that involved diverse key restoration stakeholders. Five fundamental and intertwined challenges for future restoration efforts relate to biodiversity, livelihoods, participation, financing, and coordination. Inter- and transdisciplinary methods can help to address these challenges in Rwanda, and very likely also in other similar settings, especially in the Global South. Although restoration is often rightfully expected to address a multitude of social goals, we highlight the importance of adequately incorporating ecological considerations to create multifunctional restoration systems that can support ecological integrity in the long run.

Keywords: ecosystem restoration; ecological restoration; forest landscape restoration; social-ecological systems; three horizons framework

Introduction

Ecosystem degradation is threatening biodiversity and human well-being globally (Díaz et al. 2019; Bergstrom et al. 2021). In response, ecosystem restoration has gained momentum, and over 100 countries have committed to restore parts of their land (Sewell et al. 2020). Ecosystem restoration is the process of halting and reversing ecosystem degradation (UNEP 2021) and encompasses a continuum of activities ranging from reducing detrimental societal impacts to fully recovering native ecosystems (Gann et al. 2019). Embedded within a favourable social-ecological context (Tedesco et al. 2023), restoration interventions can (re-)generate biodiverse ecosystems that counteract land degradation (Jiang et al. 2020) and species extinction (Strassburg et al. 2020), provide diverse ecosystem services (Alexander et al. 2016), increase food security (Smith et al. 2019), and contribute to climate change mitigation and adaptation (Bastin et al. 2019).

However, restoration has come under heavy critique because of the prevalence of simplistic, short-sighted approaches. In many cases, restoration is equated to tree planting, which can cause the destruction of intact non-forest ecosystems (Temperton et al. 2019; Veldman et al. 2019; Parr et al. 2024). In tropical forest and woodland landscapes, common challenges include (i) the (over-)use of non-native, potentially invasive (Naia et al. 2021), fast-growing tree species in monocultures that can cause landscape homogenization (Holl et al. 2022), (ii) low levels of monitoring (Martin et al. 2021), and project follow-up shortfalls (Schubert et al. 2024), and (iii) ill-advised financial incentives that can result in high tree mortality (Fleischman et al. 2020). As a result, restoration often fails to rebuild complex networks of ecological interactions (Moreno-Mateos et al. 2020). Finally, complex equity and justice implications of restoration have recently gained attention. Here, major criticisms concern unequal power relations that result in the disregard of local communities' needs and knowledge (Loos et al. 2023), lack of ownership (Frietsch et al. 2024), and superficial community involvement in restoration decision-making (Elias et al. 2021; Löfqvist et al. 2022).

To improve outcomes, restoration practice needs to better account for social-ecological complexity (Fischer et al. 2021). In practice, this should include taking stock of dominant social-ecological dynamics and restoration approaches, as well as jointly developing visions for the future of restoration that capture diverse stakeholders' values and needs (Perring et al. 2015). Here, we explore these two priorities in Rwanda, a country that has embraced an ambitious restoration agenda (Nash et al. 2020) – but also a setting where many of the criticisms laid out above apply (Arakwiye et al. 2021; Rwibasira et al. 2021). Hence, insights for how to improve restoration in Rwanda are also likely to be relevant for many other locations, especially in tropical forest landscapes in the Global South.

Our paper makes a twofold contribution. We (i) provide an overview of favourable outcomes as well as shortfalls of restoration practice in Rwanda to date, and based on that, (ii) lay out tangible strategies to improve future restoration in Rwanda (and beyond). Our findings highlight five priorities for future restoration efforts in Rwanda related to biodiversity, livelihoods, participation, financing, and coordination.

Methods

Study area

We focused on western Rwanda, which represents conditions that are typical for many landscapes in the Global South targeted for restoration (Nsikani et al. 2023): it has undergone heavy deforestation (Arakwiye et al. 2021), has a high population density and competing land use priorities (Li et al. 2021a), and restoration is strongly shaped by government agendas (Clay 2019; Buckingham et al. 2020).

Our work focused on four districts (Ngororero, Nyabihu, Rubavu, Rutsiro). Their hilly, high-altitude landscape is inhabited by a mostly rural population (National Institute of Statistics Rwanda 2021) and contains Gishwati-Mukura National Park. Steep slopes and heavy rainfall make the landscape vulnerable to soil erosion, landslides, flooding, and the associated destruction of infrastructure (Rutebuka et al. 2019). The area experienced high deforestation due to high natural resource demand and armed conflicts (Clay 2019; Arakwiye et al. 2021). This has had negative consequences for biodiversity (Arakwiye et al. 2021), ecosystem functioning (Rwibasira et al. 2021), and human well-being (Nash et al. 2020). To counteract degradation, the Rwandan government and several NGOs have actively pursued ecosystem restoration, especially since the Bonn Challenge in 2012. To date, restoration has predominantly focused on planting tree patches, establishing terraces, and introducing agroforestry, often including non-native species, most notably *Eucalyptus spp.* and *Alnus acuminata* (Nash et al. 2020; Mugabowindekwe et al. 2022).

Three horizons framework: background and application

To assess the current state of, and explore desirable futures for ecosystem restoration, we applied the three horizons framework, which is a participatory approach that engages with normative futures and helps develop pathways that connect the present system with desirable future states based on diverse stakeholders' input (Curry & Hodgson 2008; Sharpe et al. 2016). The framework distinguishes between three horizons: horizon one (H1) describes the present dominant system, horizon three (H3) relates to the long-term successor of H1 and represents a desired future system state, and horizon two (H2) denotes strategic pathways to bridge H1 and H3. Importantly, the framework encourages the exploration of multiple futures and associated pathways (Schaal et al. 2023).

The workshop was designed and led by a subset of the author-group (MF, JF, BML) and then implemented by a transdisciplinary, multi-stakeholder group (the entire author team, plus individuals listed in Acknowledgements). In terms of roles, a group of researchers facilitated the process without providing input on content, whereas a diverse group of Rwanda-based restoration experts from science (n= 5), policy (n= 7), and practice (n= 9) shaped the actual content of the discussion. We conducted three rounds of discussion in small groups on (i) the present, and (ii) the future of restoration in the study area, and (iii) ways to link the two. The restoration experts were randomly assigned to six groups for rounds one and two.

In the first round (H1), experts discussed two questions about the present, noting key points on red cards *("Of the established ways of doing restoration in western Rwanda, what do you want to see less of in the future?"* and *"Of the established ways of doing restoration in western Rwanda, what do you want to keep in the future?"*; Fig. 1). For the second round (H2), two future-oriented questions were discussed, and key points noted on green cards *("What would ideal restoration in western Rwanda look like in the future?"* and *"What are innovative and inspirational practices in restoration today that could be scaled up to realize ideal restoration in the future?"*; Fig. 1). After each round (H1 and H3), each group presented their insights, and we collected the cards and displayed them on a large illustration of the three horizons (Fig. S1).

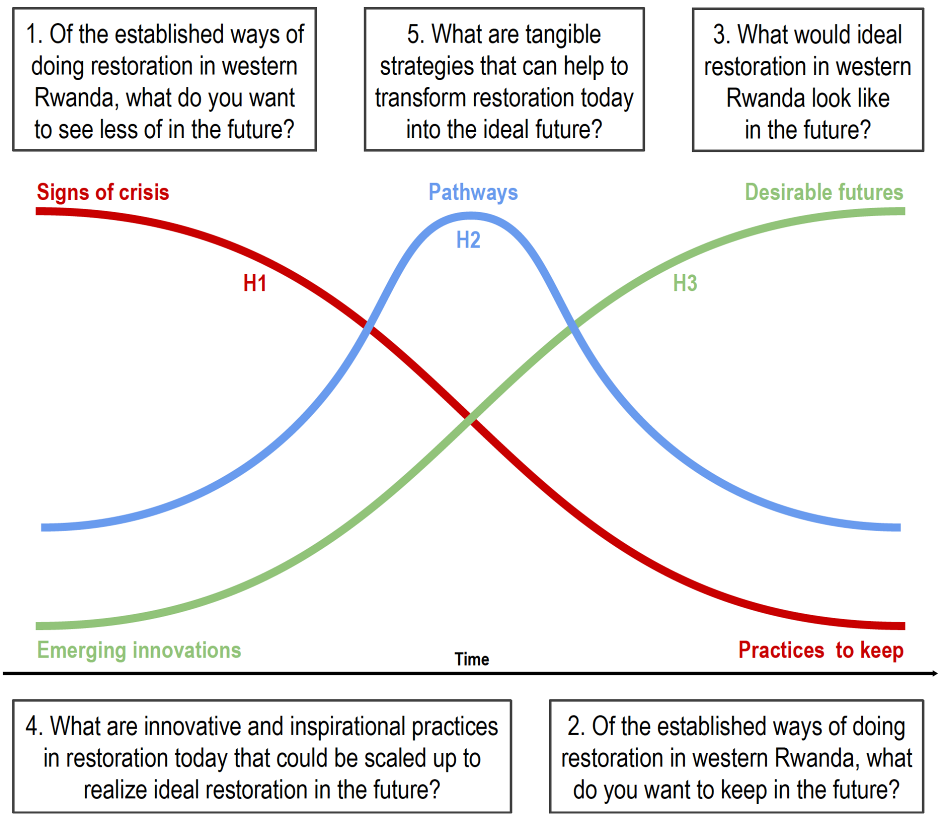

FIGURE 1 The three horizons related to the present system (H1), desirable future system elements (H3), and pathways to connect H1 and H3 (H2). The five questions guided the expert discussions for each of the horizons in the order of their numbering.

Drawing on the collected cards for H1 and H3, for the third round (H2), four scientists (MF, BML, JF, JL) identified five emerging themes during a workshop break. We then asked the restoration experts to get together in groups based on the theme they were most interested in to note tangible strategies – so-called "pathways" (Sharpe et al. 2016) – that might help to transform restoration into the desired future. Experts' findings from this round were shared in the plenum, and displayed on blue cards.

After the workshop, the red, green, and blue cards were iteratively coded to identify recurring ideas. Based on this, insights on present and future restoration (red and green cards, H1 and H3 respectively) were summarized. Similarly, the tangible strategies (blue cards, H2) for each emerging theme were synthesized into short narratives.

Results

The restoration experts noted 107 partially overlapping key points referring to ecological, social, and social-ecological aspects of the present system (H1: signs of crisis and practices to keep) and the ideal future for ecosystem restoration in the study area (H3: desirable future and emerging innovations) (Fig. S1, Supplementary text). From these, we identified five interconnected themes of particular interest to restoration in the study area: (i) biodiverse and multifunctional landscapes; (ii) livelihoods, value chains and nutrition; (iii) participation and community engagement; (iv) financing of sustainable restoration; and (v) coordination, integration and partnerships. In the following, we provide an overview of the current system, desirable future characteristics of restoration, and present strategies towards these desired future elements.

Assessing the present: Signs of crisis and practices to keep

In the first round, restoration experts described the dominant restoration system today (H1 in Fig. 2). Perceived current challenges and shortcomings were the lack of long-term, well-informed coordination of restoration activities, the high share of exotic species and monocultures, and limited inclusion of local people and their needs, values, and knowledge.

Valuable elements at present included widespread positive attitudes towards restoration at both community and national level, existing networks that link diverse actors, mechanisms for community-level capacity building, and some effective policies such as compensation payments for communities or village land use action plans. Further, first examples of multifunctional restoration sites that provide benefits for both people and the environment, for example in the form of erosion control, livelihood opportunities, and relational values, were mentioned.

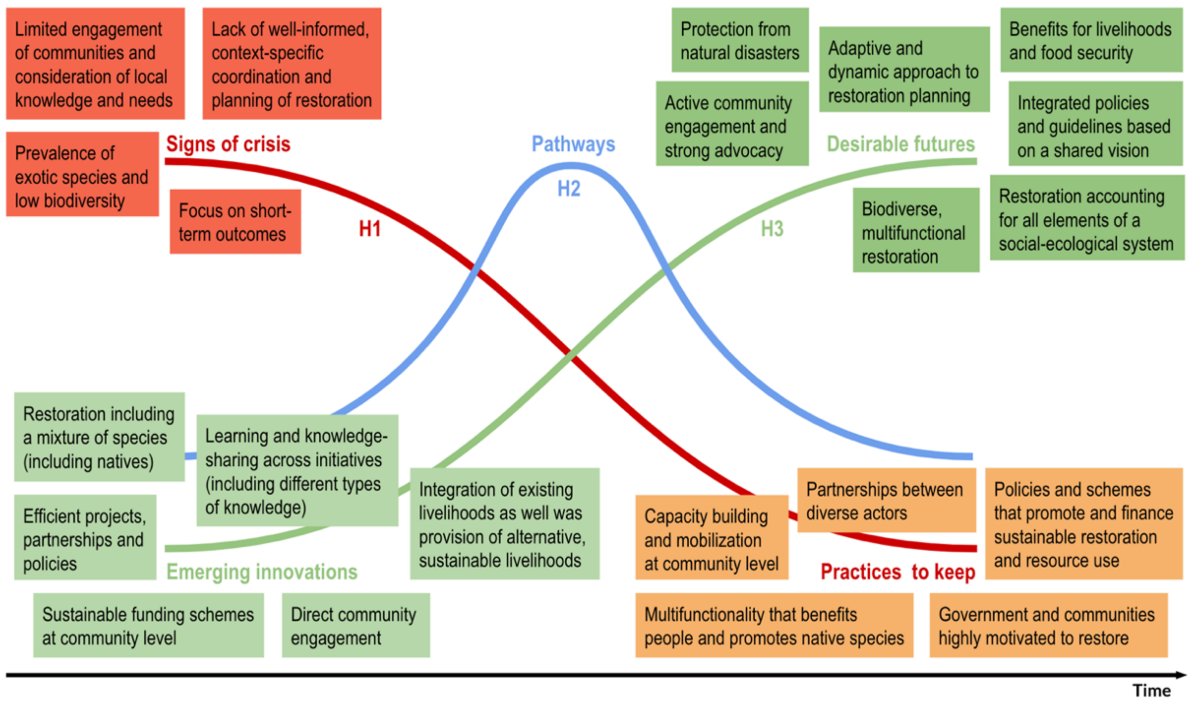

FIGURE 2 The three horizons (H1, H2, H3) and the key signs of crisis (H1), practices to keep (H1), desirable futures (H3), and emerging innovations (H3) for the study area in western Rwanda, as identified by local restoration experts. For the pathways identified (H2), see the narrative descriptions in the main text, as well as Fig. 3 for a generalization thereof.

Envisioning the future: Desirable futures and emerging innovations

In the second round, restoration experts discussed visions for a positive future for restoration (H3 in Fig. 2). They envisioned multifunctional and biodiverse restoration sites that account for the complexity of social-ecological systems and entail different benefits such as income opportunities, access to nutrition, protection from floods and landslides, and wildlife conservation. Further, restoration experts emphasized the importance of having a shared vision that is supported by integrated policies to reconcile agricultural and environmental goals. Here, the importance of adaptive restoration planning and implementation was deemed important. Finally, restoration experts specified ways to strengthen community engagement and advocacy such as facilitating open, non-hierarchical communication between stakeholders, supporting community-led landscape development based on local knowledge, and translating policies into the national language, Kinyarwanda, for increased accessibility.

Some relevant innovations were identified in the present. For example, experts noted instances of direct community engagement and sustainable funding schemes, such as revolving funds for tree planting, and benefit sharing by building schools from restoration revenues. Diverse policies and initiatives that link local restoration activities with national agendas (e.g., via village land-use action plans), and strengthen cooperations between actors (e.g., via forest co-management) were also mentioned. In addition, experts also highlighted research, learning and knowledge-sharing across initiatives to transfer and scale up successful restoration approaches, and discussed the importance of fostering sustainable livelihoods through restoration activities by focusing, for example, on edible and medicinal native plants, bee-keeping, or livestock rearing. Finally, experts shared examples of restoration sites with relatively high biodiversity, which could serve as demonstration plots.

Bridging the present and the future: Five tangible strategies for sustainable ecosystem restoration

Five themes emerged from discussions in rounds one (H1) and two (H3). For each theme, the restoration experts highlighted tangible strategies towards a desirable future.

Biodiverse and multifunctional landscapes. Restoration should create multifunctional landscapes that benefit ecological integrity and human well-being. In these landscapes, native species should be prioritized, and the focus should shift from merely planting as many trees as possible to monitoring and supporting their actual growth and survival. Local communities could benefit, for example, via capacity building and the monetization of carbon storage and other services. Restoration decisions should be informed by context-specific knowledge based on land suitability models and known best practices. To ensure their implementation, these elements need to be integrated into viable policies.

Livelihoods, value chains and nutrition. Nutrition, food security, and income generation should be put at the center of restoration activities. In practice, this requires a comprehensive understanding of the social and economic characteristics of a restoration site to conceive context-specific solutions. These solutions should be developed in participatory processes that pay special attention to integrating women. Specific approaches include improved cooking stoves that decrease pressure on forests, enhanced integration of fruit trees that provide both nutrition diversification and income opportunities, nutrition education, and the identification of sustainable and nutrition-sensitive value chains for restoration-based products, such as timber, fruit, and charcoal.

Participation and community engagement. Restoration projects should be based on inclusive and equitable participation of diverse stakeholders to increase community engagement and ownership. Inclusive approaches could include participatory land-use planning, demonstration plots, and farmer cooperatives. To strengthen recognition, advocacy and stewardship might be enhanced by honoring restoration practitioners. There is also a need to recognize those actor groups most affected by restoration interventions, with a particular focus on gender and economic status. To increase distributional justice, restoration activities should integrate diverse needs. To enhance procedural justice, community leaders require support to effectively connect local communities with higher level governance, and public-private partnerships need to be fostered to boost restoration across scales.

Financing of sustainable restoration. Restoration activities should create financial benefits for involved communities and pay for themselves over time. Diverse mechanisms to increase local communities' access to financial returns from restoration need to be established: finance training for farmers, links between farmers and carbon markets, compensations for tree planting, micro-credit systems, and revenue sharing from tourism and national parks. Funders should finance knowledge exchange and coordination between restoration initiatives, and local communities must be remunerated for partaking in resource allocation and other decision-making processes.

Coordination, integration and partnership. Restoration should be coordinated across multiple governance, spatial, and temporal scales to foster a shared vision and knowledge co-production. Locally and regionally, restoration activities and actors should be connected via gatherings, media, and diverse communication channels. Nationally, strategies that consider diverse sectors interacting with restoration, and that link Rwanda to the international restoration movement are needed. Mechanisms to link restoration across scales could include the integration of social-ecological restoration in education curricula, strengthening public-private partnerships, developing sustainable value chains, marketing restoration products, and supporting research on best practice examples.

Discussion

Restoration practice has been criticised for the prevalence of simplistic, short-sighted interventions that do not match ecological contexts, social realities, and technical capacities of the social-ecological systems within which restoration projects are embedded (Malkamäki et al. 2018; Fleischman et al. 2020; Schubert et al. 2024). Such mismatches can cause detrimental ecological (Holl et al. 2022; Parr et al. 2024) and social (Elias et al. 2021; Löfqvist et al. 2022) outcomes. Our findings highlight opportunities to shift discussions away from problems towards possible solutions that draw on local knowledge and experience. Many approaches and methods identified here can help improve restoration policy and practice not only in Rwanda but also more broadly. In the following, we (i) emphasize the importance of inter- and transdisciplinary approaches to restoration, (ii) reflect on the role of biodiversity in restoration, and (iii) summarize general priorities for restoration policy beyond western Rwanda.

Inter- and transdisciplinary approaches for social-ecological restoration

The five themes that emerged from discussions here are closely intertwined and relevant in diverse settings (Höhl et al. 2020; Nsikani et al. 2023; Schubert et al. 2024). Our collaborative exercise facilitated an exchange to synthesize visions that restoration actors already hold individually but had not yet brought into structured dialogues to identify ways forward. A critical next step will be to dissolve lock-in mechanisms that currently hinder restoration actors from realising their transformative visions on the ground, and to seize opportunities to trial and scale innovative restoration strategies. Inter- and transdisciplinary restoration research could support this process by addressing practical knowledge gaps that pertain to the identified strategies (H2), by appraising why signs of crisis (H1) that characterise the current restoration system persist, and how emerging innovations (H3) and windows of opportunities that arise from (inter-)national policy and finance fora could be strategically matched (see also Radeloff et al. 2012).

The role of biodiversity

Strikingly, only one of the five emerging themes was directly concerned with the original focus of ecological restoration: biodiversity and ecosystems. This reflects the reality of restoration in many parts of the world. Instead of seeking to recreate an ecological reference state (Higgs 2003), modern restoration faces the challenge of straddling conventional biodiversity objectives alongside goals related to human well-being (Balaguer et al. 2014). However, valid reasons for diverging from the narrower aim to focus solely on biodiversity do not automatically justify the widespread use of non-native species and monocultures. Indeed, as recent criticisms show (Holl et al. 2022; Parr et al. 2024), ecosystem restoration is at risk of losing its public and political credibility if it does not deal with ecological considerations appropriately. To that end, three priorities seem especially important. First, *ecological reference states* – whether they be historical or contemporary – are vital to judge whether restoration works from an ecological perspective; yet their importance seems much less recognised today than one or two decades ago. Second, efforts to work with *diverse native species* in restoration projects must be intensified urgently, which implies a need to invest into nurseries and propagation methods, as well as into research on how native species can benefit local communities. Third, restoration is more than planting trees, and *ecosystems with few or no trees* must be re-integrated into global restoration narratives. These ecological priorities do not negate the need to generate tangible benefits for local people, but are grounded in an understanding that ultimately, human well-being fundamentally depends on halting and reversing biodiversity loss.

General lessons for policy and practice

Our findings from western Rwanda offer three general lessons (Fig. 3). First, our work emphasizes the importance of developing context-specific visions for restoration that include diverse stakeholder perspectives and harmonize social goals with biodiversity and ecological integrity. Second, the shared experiences of the Rwanda-based experts highlight five interacting key priorities that need to be jointly considered: (i) biodiverse and multifunctional landscapes, (ii) livelihoods, value chains and nutrition, (iii) participation and community engagement, (iv) financing of sustainable restoration, and

(v) coordination, integration and partnership. Third, to put restoration visions into practice and account for the interconnected nature of restoration systems, we argue that ecosystem restoration should be grounded in social-ecological systems thinking, and carried out using inter-and transdisciplinary methods.

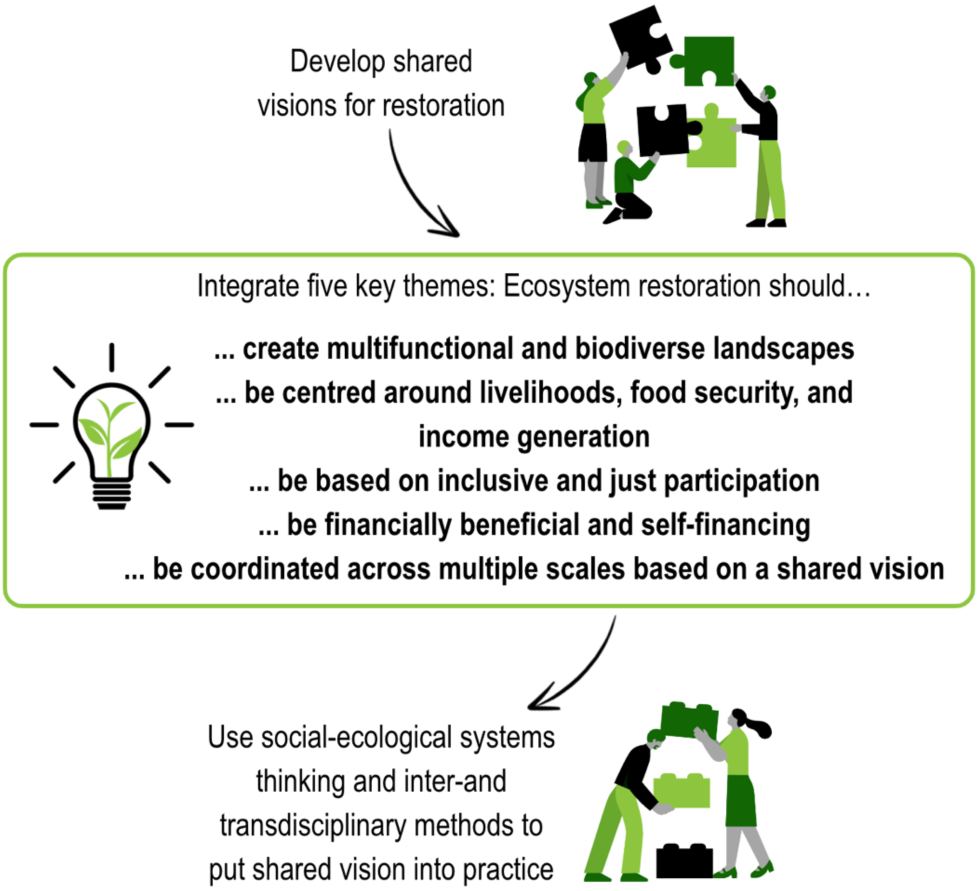

FIGURE 3 Tangible strategies to inform restoration policy and practice beyond the Rwandan case study.

Acknowledgements

This publication was funded by the German Research Foundation (DFG) through the Research Unit "A social-ecological systems approach to inform ecosystem restoration in rural Africa". The proposal to collaboratively publish the findings from the workshop was agreed on by all participants during the workshop. All workshop participants were given the opportunity to contribute to this article as co-authors by engaging with drafts of the paper (in addition to providing input at the workshop). The author team appreciates additional valuable input provided during the workshop by Marie-Laetitia Busokeye, Fidele Karamage, Jean Kayitsinga, Pascal Lopez, Eric Ruhanamirindi Mudakikwa, Ildephonse Munyampamira, Innocent Mutwarangabo, Abubakar Nshimuyumukiza, Jeffrey L. Ullman, and Emmanuel Uwizeyimana.

References

Alexander, S., J. Aronson, O. Whaley, and D. Lamb. 2016. The relationship between ecological restoration and the ecosystem services concept. Ecology and Society **21**:34.

Arakwiye, B., J. Rogan, and J. R. Eastman. 2021. Thirty years of forest-cover change in Western Rwanda during periods of wars and environmental policy shifts. Regional Environmental Change **21**:27.

Balaguer, L., A. Escudero, J. F. Martín-Duque, I. Mola, and J. Aronson. 2014. The historical reference in restoration ecology: Re-defining a cornerstone concept. Biological Conservation **176**:12–20.

Bastin, J.-F., Y. Finegold, C. Garcia, D. Mollicone, M. Rezende, D. Routh, C. M. Zohner, and T. W. Crowther. 2019. The global tree restoration potential. Science **365**:76–79.

Bergstrom, D. M. et al. 2021. Combating ecosystem collapse from the tropics to the Antarctic. Global Change Biology **27**:1692–1703.

Buckingham, K., B. Arakwiye, S. Ray, O. Maneerattana, and W. Anderson. 2020. Cultivating networks and mapping social landscapes: How to understand restoration governance in Rwanda. Land Use Policy:104546.

Clay, N. 2019. Fixing the ecosystem: Conservation, crisis and capital in Rwanda's Gishwati Forest. Environment and Planning E: Nature and Space **2**:23–46.

Curry, A., and A. Hodgson. 2008. Seeing in multiple horizons: connecting futures to strategy. Journal of Futures Studies **13**:1–20.

Díaz, S. et al. 2019. Pervasive human-driven decline of life on Earth points to the need for transformative change. Science **366**:eaax3100..

Elias, M., D. Joshi, and R. Meinzen-Dick. 2021. Restoration for whom, by whom? A feminist political ecology of restoration. Ecological Restoration **39**:3–15.

Fischer, J., M. Riechers, J. Loos, B. Martin-Lopez, and V. M. Temperton. 2021. Making the UN Decade on Ecosystem Restoration a Social-Ecological Endeavour. Trends in Ecology & Evolution **36**:20–28.

Fleischman, F. et al. 2020. Pitfalls of Tree Planting Show Why We Need People-Centered Natural Climate Solutions. Bioscience **70**:947–950.

Frietsch, M., J. Fischer, B. A. Kaplin, and B. Martín-López. 2024. The relevance of international restoration principles for ecosystem restoration practice in Rwanda. Restoration Ecology.

Gann, G. D. et al. 2019. International principles and standards for the practice of ecological restoration. Second edition. Restoration Ecology **27**:1–46.

Higgs, E. 2003. Nature by Design: People, Natural Process, and Ecological Restoration. MIT Press.

Höhl, M., V. Ahimbisibwe, J. A. Stanturf, P. Elsasser, M. Kleine, and A. Bolte. 2020. Forest landscape restoration—what generates failure and success? Forests **11**:938.

Holl, K. D., J. C. Luong, and P. H. S. Brancalion. 2022. Overcoming biotic homogenization in ecological restoration. Trends in Ecology & Evolution **37**:777–788.

Jiang, C., H. Zhang, L. Zhao, Z. Yang, X. Wang, L. Yang, M. Wen, S. Geng, Q. Zeng, and J. Wang. 2020. Unfolding the effectiveness of ecological restoration programs in combating land degradation: Achievements, causes, and implications. The Science of the Total Environment **748**:141552.

Li, C., M. Yang, Z. Li, and B. Wang. 2021. How Will Rwandan Land Use/Land Cover Change under High Population Pressure and Changing Climate? Applied Sciences **11**:5376.

Löfqvist, S. et al. 2022. How social considerations improve the equity and effectiveness of ecosystem restoration. Bioscience **73**:134–148.

Loos, J. et al. 2023. An environmental justice perspective on ecosystem services. Ambio **52**:477–488.

Malkamäki, A., D. D'Amato, N. J. Hogarth, M. Kanninen, R. Pirard, A. Toppinen, and W. Zhou. 2018. A systematic review of the socio-economic impacts of large-scale tree plantations, worldwide. Global Environmental Change **53**:90–103.

Martin, M. P., D. J. Woodbury, D. A. Doroski, E. Nagele, M. Storace, S. C. Cook-Patton, R. Pasternack, and M. S. Ashton. 2021. People plant trees for utility more often than for

biodiversity or carbon. Biological Conservation **261**:109224.
Moreno-Mateos, D., A. Alberdi, E. Morriën, W. H. van der Putten, A. Rodríguez-Uña, and D. Montoya. 2020. The long-term restoration of ecosystem complexity. Nature Ecology & Evolution **4**:676–685.
Mugabowindekwe, M. et al. 2022. Nation-wide mapping of tree-level aboveground carbon stocks in Rwanda. Nature Climate Change **13**:91–97.
Naia, M. et al. 2021. Potential negative effects of the Green Wall on Sahel's biodiversity. Conservation Biology **35**:1966–1968.
Nash, C., S. Carvalho, L. Raes, A. Ndoli, C. Karangwa, E. Imanirareba, J. Njue, and D. Toovey. 2020. A Thousand Hills Turn Green: How Rwanda became a leader in forest landscape restoration. Available from https://iucn.maps.arcgis.com/apps/MapJournal/index.html?appid=0c40be7f83c64bb9b7c8f3372358c6f9 (accessed March 26, 2024).
National Institute of Statistics of Rwanda. 2023. The Fifth Rwanda Population and Housing Census - Main Indicators Report. NISR, Kigali.
Nsikani, M. M. et al. 2023. UN Decade on Ecosystem Restoration: key considerations for Africa. Restoration Ecology **31**:e13699.
Parr, C. L., M. Te Beest, and N. Stevens. 2024. Conflation of reforestation with restoration is widespread. Science **383**:698–701.
Perring, M. P., R. J. Standish, J. N. Price, M. D. Craig, T. E. Erickson, K. X. Ruthrof, A. S. Whiteley, L. E. Valentine, and R. J. Hobbs. 2015. Advances in restoration ecology: rising to the challenges of the coming decades. Ecosphere **6**:131.
Radeloff, V. C., F. Beaudry, T. M. Brooks, V. Butsic, M. Dubinin, T. Kuemmerle, and A. M. Pidgeon. 2012. Hot moments for biodiversity conservation. Conservation Letters **6**:58–65.
Rutebuka, J., D. M. Kagabo, and A. Verdoodt. 2019. Farmers' diagnosis of current soil erosion status and control within two contrasting agro-ecological zones of Rwanda. Agriculture, Ecosystems & Environment **278**:81–95.
Rwibasira, P., F. X. Naramabuye, D. Nsabimana, and M. Carnol. 2021. Long-Term Effects of Forest Plantation Species on Chemical Soil Properties in Southern Rwanda. Soil Systems **5**:59.
Schaal, T., M. Mitchell, B. C. Scheele, P. Ryan, and J. Hanspach. 2023. Using the three horizons approach to explore pathways towards positive futures for agricultural landscapes with rich biodiversity. Sustainability Science **18**:1271–1289.
Schubert, S. C., K. E. Battaglia, C. N. Blebea, C. J. P. Seither, H. L. Wehr, and K. D. Holl. 2024. Advances and shortfalls in applying best practices to global tree-growing efforts. Conservation Letters **17**:e13002.
Sewell, A., S. van der Esch, and H. Löwenhardt. 2020. Global Restoration Commitments database. Available from https://www.pbl.nl/sites/default/files/downloads/pbl-2021-global-restoration-commitments-database-4680.ods (accessed March 30, 2022).
Sharpe, B., A. Hodgson, G. Leicester, A. Lyon, and I. Fazey. 2016. Three horizons a pathways practice for transformation. Ecology and Society **21**.
Smith, P. et al. 2019. Interlinkages between desertification, land degradation, food security and greenhouse gas fluxes: Synergies,trade-offs and integrated response options. Pages 551–672 in J. Skea et al., editors. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.
Strassburg, B. B. N. et al. 2020. Global priority areas for ecosystem restoration. Nature **586**:724–729.
Tedesco, A. M. et al. 2023. Beyond ecology: ecosystem restoration as a process for social-ecological transformation. Trends in Ecology & Evolution **38**:643–653.
Temperton, V. M., N. Buchmann, E. Buisson, G. Durigan, L. Kazmierczak, M. P. Perring, M. de Sá Dechoum, J. W. Veldman, and G. E. Overbeck. 2019. Step back from the forest and step up to the Bonn Challenge: How a broad ecological perspective can promote successful landscape restoration. Restoration Ecology **27**:705–719.
UNEP. 2021. Becoming #GenerationRestoration: Ecosystem restoration for people, nature and climate. United Nations Environment Programme.
Veldman, J. W. et al. 2019. Comment on "The global tree restoration potential". Science **366**:eaay7976.

Appendix

Appendix 1: Author contribution statements

Author contribution statements based on the Contributor Roles Taxonomy (CRediT) system. This overview of articles included in the dissertation is in accordance with the Doctoral Regulations of 20 July 2023 § 8 Section 3 and the Guideline for Cumulative Dissertations enacted at the Faculty of Sustainability at Leuphana University in January 2012.

Paper	Bibliography, publication status	Specific contributions by authors	Weight
I	Frietsch, M., et al. (2023). Future-proofing ecosystem restoration through enhancing adaptive capacity. Communications Biology **6**:377. DOI: 10.1038/s42003-023-04736-y Publication status: published in 2023	**Marina Frietsch** (conceptualization, formal analysis, data curation, writing – original draft, visualization), **Jacqueline Loos** (writing – review and editing), **Katharina Löhr** (writing – review and editing), **Stefan Sieber** (writing – review and editing), **Joern Fischer** (writing – review and editing)	Predominant contribution (1.0)
II	Frietsch, M., et al. (2024). The social–ecological ladder of restoration ambition. Ambio **53**:1251–1261. DOI: 10.1007/s13280-024-02021-8 Publication status: published in 2024	**Marina Frietsch*** (conceptualization, formal analysis, writing – original draft, visualization), **Manuel Pacheco-Romero*** (conceptualization, formal analysis, writing - original draft, visualization), **Vicky M. Temperton** (writing – review and editing), **Beth A. Kaplin** (writing - review and editing), **Joern Fischer** (conceptualization, writing – original draft, supervision) MF and MPR have contributed equally to this publication	Equal contribution (1.0)
III	Frietsch, M., et al. (2024). The relevance of international restoration principles for ecosystem restoration practice in Rwanda. Restoration Ecology **32**:e14085. DOI: 10.1111/rec.14085 Publication status: published in 2024	**Marina Frietsch** (conceptualization, methodology, formal analysis, investigation, writing – original draft, visualization, project administration), **Joern Fischer** (conceptualization, formal analysis, writing – review and editing, funding acquisition), **Beth A. Kaplin** (writing – review and editing), **Berta Martín-López** (conceptualization, writing – review and editing, supervision)	Predominant contribution (1.0)
IV	Frietsch, M., et al. Visions for the future of ecosystem restoration. Publication status: not published	**Marina Frietsch** (conceptualization, methodology, formal analysis, investigation, writing – original draft, visualization, project administration), **Berta Martín-López** (conceptualization, investigation, writing – review and editing, supervision), **Daniel Akirimari** (writing – review and editing, investigation), **William Apollinaire** (writing – review and editing, investigation), **Bernadette Arakwiye** (writing – review and editing, investigation), **Matthias Baumann** (writing – review and editing, investigation), **Sophia Bohn** (writing – review and editing, investigation), **Dula Wakassa Duguma** (resources, project administration), **Ephrem Imanirareba** (writing – review and editing, investigation), **Beth A. Kaplin** (writing – review and editing, investigation), **Laura Kmoch** (writing – review and editing, investigation), **Tobias Kuemmerle** (writing – review and editing, investigation), **Katharina Löhr** (writing – review and editing, investigation), **Jacqueline Loos** (writing – review and editing, investigation), **Myriam Mujawamariya** (writing – review and editing, investigation), **Athanase Mukuralinda** (writing – review and editing, investigation), **Valery Ndagijimana** (writing – review and editing, investigation), **Gaelle Ndayizeye** (writing – review and editing, investigation), **Venuste Nsengimana** (writing – review and editing, investigation), **Peter Ntaganda** (writing – review and editing, investigation), **Verene Nyiramvuyekure** (writing – review and editing, investigation), **Tobias Plieninger** (writing – review and editing, investigation), **Stefan Sieber** (writing – review and editing, investigation), **Martin Sindikubwabo** (writing – review and editing, investigation), **Ping Sun** (writing – review and editing, investigation), **Vicky M. Temperton** (writing – review and editing, investigation), **Ezechiel Turikunkiko** (writing – review and editing, investigation), **Susanne Vögele** (writing – review and editing, investigation), **Meike Wollni** (writing – review and editing, investigation), **Joern Fischer** (conceptualization, methodology, writing – review and editing, investigation, funding acquisition)	Predominant contribution (1.0)

Declaration (according to § 16 of the guideline for cumulative dissertations)
I avouch that all information given in this appendix (Appendix 1) is true in each instance and overall.

Lüneburg
September 25, 2024

Marina Frietsch

Appendix 2: Approval to conduct research in Rwanda

[redacted]

Appendix 3: Supplementary material for Paper I

Supplementary Table 1

The 15 countries with the highest material footprint in 2019 according to the United Nations Environment Programme International Resource Panel Global Material Flows Database [90]. The material footprint attributes global material extraction to domestic final demand of a country.

Rank	**Country**
1	China
2	United States of America
3	India
4	Brazil
5	Japan
6	Indonesia
7	Germany
8	Turkey
9	Mexico
10	Russia
11	Canada
12	United Kingdom
13	Australia
14	South Korea
15	France

Appendix 4: Supplementary material for Paper III

Supplement S1. The interview guideline directed the semi-structured interviews. Participants were surveyed individually and, depending on their availability, participated in all parts of the interview or in the first part of the guideline only (i.e., introductory questions, questions on principals and Q-sorting).

Interview on the relevance and practical application of restoration principles in Rwanda

Marina Frietsch, PhD project, January/February 2023

Informed consent

I am a PhD student from Leuphana University in Germany. Together with colleagues from Germany and from the University of Rwanda, I want to better understand how ecosystem restoration can benefit both people and nature. To this end, I am currently conducting interviews with people involved in ecosystem restoration in western Rwanda.

I would like to ask you to be part of this interview. I will ask you questions about ecosystem restoration projects that you are involved in or that you know of. The interview will take about 1 hour. There are no right or wrong answers to any of my questions.

Me and my colleagues are university-based and are not working for any other organizations. Your name will not be used in any publications and all data will be stored safely. Your participation is voluntary, you are free to skip any questions if you do not want to answer them. You can also stop your participation at any time. Do you have any questions?

Do you agree to participate? □ Yes □ No

Do you agree to be recorded during the interview? □ Yes □ No

Do you agree that I can store and analyze the information you provide? □ Yes □ No

Signature of participant:

Socio-demographic information

Age: □ 20-35 □ 35-50 □ 50-65 Gender: □ m □ f

Occupation:

Participant identification number:

Intro

What is your relationship with restoration projects?

What is your role in restoration practice?

For how long have you been involved in restoration?

Principles - overall

How would you define successful restoration?

Which factors do you think are most important for successful restoration?

Principles - Q-sorting for importance

Please read all 20 statements and prioritize them into the three categories ‘most important’, ‘medium important’ and ‘least important’ for successful restoration. Please try to think about restoration in general and not about a particular project.

Now, please place the cards on the scoreboard according to their importance. Please start with the five most important statements that you want to put in the boxes at the top, followed by the five least important statements you want to put in the boxes at the bottom, and lastly place the medium important statements.

Please re-read and perhaps re-order the statements if you want to change their sorting.

Can you tell me why you chose the three most and the three least important statements?

Transition

In which part of the study area are you involved in restoration? Please indicate on this map.

> In case participant is involved in many different restoration projects: please select one project that you have been involved in most deeply or that you know the most about to focus on when answering the following questions.

Participant identification number:

Principles - Towers indicating extent of application

Thank you for your participation so far. The last part of this interview is not about how important you think these statements are, but to what extent the approaches and ideas represented in the statements have been applied in the restoration project you have been involved in or that you know a lot about.

Please use these 60 Lego bricks to build little towers on the statement cards to indicate to what extent they have been applied in the restoration project you are thinking about. The higher the tower, the more the approaches and ideas represented in the statement that you build that tower on have been applied in the restoration project. In case a statement is not at all reflected, please don't put any Lego bricks on that card. Please use all Lego bricks.

Please have a look at your towers again and perhaps rearrange them if you want to.

Can you please tell me about the distribution of the towers?

Follow-up question depending on the outcome of the exercise:

> What are your thoughts about the discrepancy between the statements you find most important and the height of the Lego tower you built on these statements? Which steps do you think should be taken to close this gap?
>
> The height of the towers and the importance you assigned to the statements align. What actions were taken in this restoration project to achieve this?

Thank you

Thank you very much for your time and for sharing your thoughts with me. I will conduct more interviews and start to evaluate the data when I'm back in Germany. You can always contact me in case you have any questions or if you want to withdraw from this project. Is there anyone else you can think of that would also be a suitable participant for this project?

Participant identification number:

Appendix 5: Supplementary material for Paper IV

Supplementary Material 1

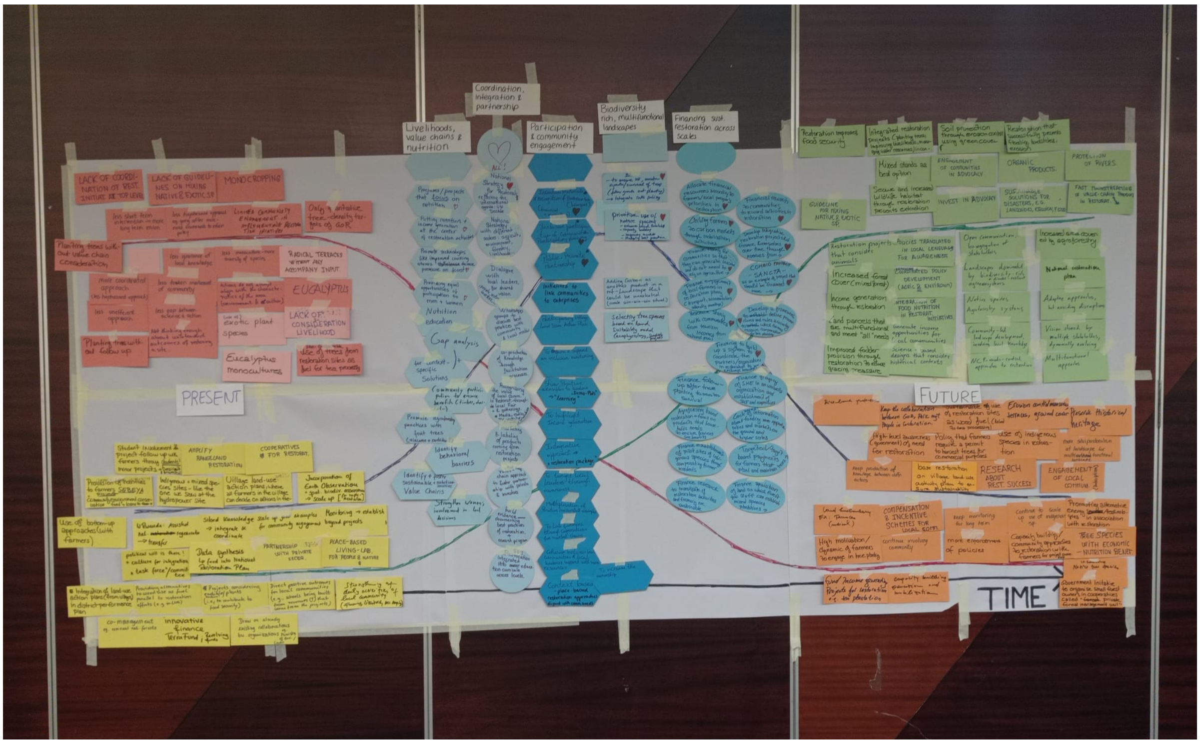

FIGURE S1. Photograph of the three horizons board.

Supplementary Material 2

Supplementary text. Transcript of all cards generated in the three-horizons workshop.

Signs of crisis (horizon 1)

- Lack of coordination of restoration initiatives at top level
- Planting trees without value chain consideration
- More coordianted approach (less haphazard approach)
- Less short-term intervention - more long-term intervention
- Less unefficient approach
- Planting trees without follow up
- Lack of guidelines in mixing native and exotic species
- Less hapahzard approach, e.g., going after more need framework to inform policy
- Less igonrance of local knowledge
- Less token involvement of community
- Less gap between science and action
- Not thinking enough about unintended outcomes of restoring a site
- Monocropping
- Limited community engagament in implementing restoration initatives
- Less monoculture - more diversity of species
- Actions do not always align with the characteristics of the area (environment & culture)
- Use of exotic plant species
- Eucalyptus monocultures
- Eucalyptus
- Only quantitative tree-density targets of GoR
- Radical terraces without any accompany input
- Lack of consideration livelihood
- Non-sustainable use of trees from restoration sites as fuel for tea processing

Practices to keep (horizon 1)

- Keep the collaboration between GoR, park management and people in restoration
- Sustainable use of restoration sites as wood fuel (linked to tea processing)
- Erosion control measures, terraces, ground cover
- Preserve historical heritage
- Protection
- High-level awareness (government) of need for restoration
- Policy that farmers require a permit to harvest trees for commercial purposes
- Use of indigenous species in restoration
- More silvo-pastoralism at landscape for multifunctional landscape
- Keep production of knowledge between different actors
- Base restoration on village land use activity plan to ensure sustainability
- Research about restoration success

- Engagement of local communities (adoption)
- Land husbandry, example: radical terraces
- Compensation and incentive schemes for local communities
- Keep monitoring for long term
- Continue to scale up use of indigenous species
- Promoting alternative energy/ technologies in association with restoration
- High motivation/dynamic of farmers to engage in tree planting
- Continue involving community
- More enforcement of policies
- Capacity building/community approaches to restoration with farmers for project ownership
- Tree species with economic / nutrition benefit
- Increasing native tree species
- Government initiative to organise small forest owners' cooperatives called "private forest management unit"
- Fund income generating projects for restoration, e.g., tea plantation
- Capacity building, education and mobilization

Desirable futures (horizon 3)

- Restoration improves food security
- Integrated restoration projects (planting trees, improving livelihoods, managing water resources)
- Soil protection through erosion control using green cover
- Restoration that successfully prevents flooding, landslides, erosion
- Mixed stands as best options
- Engagement of communities in advocacy
- Organic products
- Protection of rivers
- Guideline for mixing native and exotic species
- Secure and increased wildlife habitat through restoration prevents extinction
- Invest in advocacy
- Sustainable solutions for disasters, e.g., landslides, erosion, flood
- Fast mainstreaming of value chain products in restoration
- Restoration projects that consider animals
- Policies translated in local language for awareness
- Open communication, less segregation of stakeholders
- Increased area covered by agroforestry
- Increased forest cover (mixed forest)
- Harmonize coordinated policy development (agriculture & environment)
- Landscapes dominated by biodiversity rich and disaster resilient agroecosystems
- National restoration plan
- Income generation through restoration
- Integration of food nutrition in restoration initiatives

- Native species agroforestry systems
- Adaptive approaches but avoiding disruptions
- Land parcels that are multifunctional and meet "all" needs
- Generate income opportunities for local communities
- Community-led landscape development involving local knowledge
- Vision shared by multiple stakeholders, dynamically evolving
- Improved fodder provision through restoration to reduce grazing pressure
- Science-based designs that consider historical contexts
- NCP-needs-centred approaches to restoration
- Multifunctional approaches

Emerging innovations (horizon 3)

- Student involvement in project follow-up with farmers through students' minor projects → Desira project
- Amplify rangeland restoration
- Cooperatives for restoration
- Provision of incentives to farmers - Sebeya project "community environment conservation fund" loans
- Indigenous + mixed species sites - like the one we saw at the hydropower site
- Village land-use action plans, where all farmers in the village can decide on actions
- Incorporation of Earth Observation + spatial biodiversity assessment → scale up (for implementation)
- Use of bottom-up approaches (with farmers)
- W Rwanda: assisted natural regeneration → transfer
- Siloed knowledge → integrate and coordinate
- Scale up good examples for community engagement
- Monitoring → establish beyond projects
- Political will is there! + culture for integration - "task force"/committee
- Data synthesis → feed into national restoration plan
- Partnership with private sector
- Place-based living lab for people and nature
- Integration of land-use action plan (from villages) in district performance plan
- Providing alternatives to wood use as fuel parallel to restoration efforts (e.g., LNG)
- Projects considering edible/medical plants (i.e., to contribute to food security)
- Direct positive outcomes for local communities (e.g., schools being built from revenues that come from projects)
- Strengthening of daily activities of local community (family, livestock, bee keeping)
- Co-management e.g., remnant natural forests
- Innovative finance TerraFund; Revolving funds
- Draw on already existing collaborations between organizations, e.g., Ministry of Environment/ Centre

Pathways (horizon 2)

Livelihoods, value chains and nutrition

- Programs/projects that focus on nutrition
- Putting nutrition and income generation at the centre of restoration activities
- Promote technologies like improved cooking stoves that decrease pressure on forests
- Providing equal opportunities of participation to men and women
- Nutrition education
- Gap analysis for context specific solutions
- Community participation to ensure benefits (timber, charcoal)
- Promote agroforestry practices with fruit tress (→ income and nutrition)
- Identify behavioural barriers
- Identify and foster sustainable and nutrition-sensitive value chains
- Strengthen women's involvement in land decisions

Biodiverse and multifunctional landscapes

- To ensure multifunctionality, monitor growth/survival of trees (follow growth, not planting) → integrate into policy
- Prioritize use of native species (enhance local knowledge, capacity building, studying best practice)
- Adding carbon as a product in a multifunctional landscape that could be marketed (create win-win-win situation)
- Selecting tree species based on land suitability model (ecophysiology, Swedish project)

Participation and community engagement

- Incentives materials and recognition (Restoration champions) (financial)
- Inclusive participation of communities: Participatory planning
- Public-private partnership
- Initiatives to link communities to enterprises
- Participatory Village Land Use Action Plan
- To ensure and support an inclusive monitoring
- Show positive examples to leaders → "learning", "demo plots"
- To highlight income generation
- Integrative approach → "restoration package"
- To target local leaders through awareness
- Multiplication of positive/ successful examples
- To link farmers through cooperatives for market chains
- Cohesion between local communities and local leaders
- Context-based: place-based restoration approaches aligned with community needs
- To increase the ownership

Financing sustainable restoration across scales

- Allocate financial resources according to farmers/local people's priorities in restoration
- Linking farmers to carbon markets through mobilization activities

- Finance training for communities so that they can generate income and do not need to rely on agriculture
- Finance engagement of local farmers in restoration (transport, accommodation, attending meetings)
- Revenue sharing with communities from tourism incomes from national level
- Financial rewards to communities to reward activities in restoration
- Develop integrative restoration projects that finance themselves over time through revenues
- COMBIO project - SANCTA - as an example project that should be financed more
- Develop a framework to define procedures and rules according to which farmers receive compensations for tree planting
- Financing to build up a system to coordinate the partners/organisations in restoration to exchange knowledge
- Finance follow-up after tree planting to monitor survival
- Agroforestry based restoration → focus on products that households need to ensure farmers see benefits
- Finance establishment of pilot sites of indigenous species through compensating former residents
- Finance research to investigate if restoration activities and financing are sustainable
- Finance acquisition of land on which forest gov. staff can establish mixed species plantations
- Targeted/ target-based payments for farmers that plant and maintain trees
- Address lack of information about funding opportunities and markets on the ground and higher scales
- Finance grouping of SME in an umbrella organisation and establishment of SME and cooperatives

<u>Coordination, integration and partnership</u>

- National strategy for restoration reflecting the international agenda: UN Decade
- National strategy with different sectors: agriculture, environment, forestry, livelihoods, ...
- Dialogue with local leaders, private sector, investors, ... for shared vision
- WhatsApp groups to discuss best practices with community and locals
- Co-production of knowledge through facilitation processes
- Recognizing the value of local communities in restoration through: local fair and gatherings; media, radio, TV, WhatsApp
- Marketing and labelling of products coming from restoration projects
- Value chain approach to foster partnership with private and investors
- Build evidence - documenting best practices of restoration + research program
- SES restoration integrated into education curricula across levels