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ORIGINAL ARTICLE

Reversing degradation of social–ecological systems: explaining the outcomes of interventions in Africa

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Abstract

Social–ecological systems need to become more sustainable, especially in places undergoing rapid land degradation. The challenge is to reverse the depletion of natural resources while improving human well-being. This is especially critical in Africa where rural populations are often highly dependent on natural resources. Since the 1980s, several territories in Africa have initiated changes to reverse land degradation. This study aims at drawing lessons from these experiences. We identified seventeen cases of African territories that have engaged in sustainability interventions, either restoration or rehabilitation initiatives, with varying degrees of success. The key factors—grouped as information of key actors, their motivation to change practices, and their capacity to do so—that are recognized as potential success factors or obstacles for interventions towards sustainable resource use were analysed. Results highlighted the importance of maintaining a balance of factors over the long term. Managing sustainability transitions in low-income contexts requires integrating poverty-related concerns, mitigating the risks inherent to any change in practices, creating incentives for participation by all actors, and strengthening coalitions over the long term between actors around a sustainability agenda.

Keywords Sustainability · Transition · Transformation · Governance · Land system · Africa

Introduction

Bending the curve of ecosystem degradation while ensuring human well-being is a major priority for the next decades (Mace et al. 2018). Social–ecological approaches consider humans as both part of the ecological systems they depend on and major contributors to their dynamics (Folke 2006). Social–ecological systems are complex systems intertwining both ecological systems—defined as "self-regulating communities of organisms interacting with one another and with their environment"—and social systems—that include governance systems, systems of knowledge, norms, values, technologies, distribution of power, authority, and resources (Berkes 2008). These systems react to external or internal disturbances, whether natural or anthropogenic, triggering feedback mechanisms that lead to changes of the interlinked subsystems (Berkes et al. 2000). For instance, a new technology can trigger a change in the use of resources by a community that may lead to a change in the resource state. A mismatch between natural resource use and ecosystem conditions can lead to social–ecological traps (Baker et al. 2018; Cinner 2011). This can cause several issues of environment degradation such as land degradation, defined as "a negative trend in land condition, caused by direct or indirect human-induced processes including anthropogenic climate change, expressed as long-term reduction or loss of at least one of the following: biological productivity, ecological integrity or value to humans" (Olsson et al. 2022). Such issues are even more critical in low-income areas, where populations rely more heavily on local natural resources.

There is a growing emphasis on ways to reverse land degradation, e.g. by the United Nations Convention to Combat Desertification and its goal to achieve land degradation

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neutrality (Kust et al. 2017), and the Convention on Biological Diversity goal of reducing pressures on biodiversity. Addressing sustainability issues requires analyzing their root causes in interrelated social and ecological systems to fundamentally modify human–environment interactions. Several theoretical frameworks support a comprehensive analysis of processes and factors influencing sustainability pathways of social–ecological systems. They describe multiphase and multiscale processes (Folke 2006; Moore et al. 2014; Olsson et al. 2004), interactions between variables that influence outcomes (Ostrom 2009), institutional arrangements (Koontz et al. 2015), or management strategies (Berkes et al. 2000). They also highlight non-linear dynamics of social–ecological systems, when thresholds are associated with rapid changes (Walker and Meyers 2004).

These different frameworks have recently been operationalized to conduct comparative analyses of empirical case studies (Leslie et al. 2015; Partelow 2018). A large part of this literature focuses on cases of community-based management systems (Binot 2009; Ruiz-Mallén and Corbera 2013) or co-management systems involving communities (d'Armengol et al. 2018). Comparative analyses also often cover a same resource-use sector, mostly small-scale fisheries (d'Armengol et al. 2018; Gutiérrez et al. 2011), irrigation systems (Meinzen-Dick 2007), forestry (Fleischman et al. 2010; Gebreegziabher et al. 2021), freshwater or seafood (Herrfahrdt-Pähle et al. 2020), and marine ecosystem management (Ban et al. 2017; Cinner et al. 2012). Comparative studies covering a variety of resource-use sectors and diverse management systems are likely to generate even more generalizable insights.

This study focuses on rural areas of the African continent, where more than 62% of the population depends directly on natural resources (IPBES 2018) and therefore where social–ecological dynamics have direct implications on well-being. Africa is characterized by a great diversity in social–ecological systems that is associated with diverse climatic and biophysical conditions and cultures. Recently, several interventions were implemented in low-income areas where natural resources were perceived to be under threat. These interventions pursued the double objective of restoring natural resources and improving livelihoods, with various degrees of success. An intervention consists in changing one or several elements of the social system (e.g. norms, rules, powers, and practices). These interventions include actions carried out by public, private or civil society actors to change the management of a natural resource to achieve greater sustainability. They need to be evaluated in terms of both social and ecological outcomes (Agrawal and Benson 2011; Ferraro and Hanauer 2015).

The objective of this study is to identify conditions and factors associated with the outcomes of these interventions. The social–ecological systems framework stresses the importance of considering interactions between factors that define the resource system, resource unit, users and governance system to understand outcomes at the social–ecological system level (Ostrom 2009). Accordingly, our analysis is focused on the following themes: (1) the social, economic and ecological outcomes following an intervention, (2) the system of governance of the resources, and (3) the factors influencing outcomes of interventions on social–ecological systems. In addition, a recent literature highlights the importance of the sequencing of policies to achieve their intended outcome (Furumo and Lambin 2021). Our fourth theme, therefore, concerns the timing of interventions. Below, we first review key analytical frameworks pertinent to these themes. We then present the case studies and the methodology for our comparative analysis. The results section reveals the key factors at play in sustainability interventions in Africa. We then identify a few general lessons while recognizing the importance of local contexts.

Background on the four themes of the study

Theme 1: social, economic and ecological outcomes of interventions

Social–ecological sustainability is defined as the maintenance of human and nonhuman components of the social–ecological system to meet the needs of people and nature now and in the future (Leslie et al. 2015). Sustainability can be assessed by measuring social, economic and ecological outcomes (Purvis et al. 2019). Addressing the dual challenge of improving people's well-being while protecting natural resources requires finding trade-offs or synergies between social, economic and ecological improvements. In a context of food insecurity, population growth, climate change, and a complex historical heritage, "win–win" situations are elusive (IPBES 2018). Such situations would occur, for example, if the restoration of degraded forests would generate new income sources from timber and non-timber forest products, leading to investments in health and education and triggering more gender equity in forest management institutions. Pursuing goals of ending poverty and reducing inequalities is often associated with higher environmental impacts (Scherer et al. 2018), especially in low-income countries (Kroll et al. 2019). Conversely, improving environmental outcomes may lead in some cases to more economic inequality (Piñeiro et al. 2020).

Theme 2: involvement of communities in the governance of natural resources

In Africa, the management of natural resources often involves a layering of governance structures, formal and

informal, often with overlapping jurisdictions (Habtezion et al. 2015). It encompasses a large diversity of actors, including local communities, public agencies, civil society organizations, donors, and private sector actors. An important aspect of governance systems concerns the degree of involvement of communities in decision-making and natural resource management, which can be positioned along a continuum of approaches (Wood et al. 2019). In an exclusionary approach, the state takes ownership of natural resources and local communities have limited decision-making power (Wood et al. 2019). Advocates of participatory interventions argue that local agents possess greater knowledge about their resources and preferences than central governments. They are thus better able to manage their ecosystems in the pursuit of the public good, with greater legitimacy (Casey 2018). In a co-management approach, local communities and the state share power and responsibility for the management of natural resources (Berkes et al. 1991). It can lead to various degrees of power and responsibility sharing. In a community-based management, communities make decisions and are responsible for natural resource management (Ferraro and Agrawal 2021; Ostrom 1990). This often implies an emphasis on collective decision-making. Another approach is based on individual resource ownership, where individuals make management decisions about their natural resource (Wood et al. 2019).

Theme 3: factors influencing the outcomes of interventions

Interventions to reverse natural resource degradation can be analysed by identifying the factors that influence whether interventions actually lead to greater sustainability. Analyzing social–ecological system dynamics requires insights from multiple disciplines (Rahimi et al. 2016). Several frameworks have been proposed (Folke et al. 2005; Herrfahrdt-Pähle et al. 2020; Ostrom 2009). Lambin (2005) grouped these factors into three components of human–environment interactions: information on the state of the resource, motivation to manage this resource sustainably, and capacity to implement the intervention to adopt more sustainable practices. The factors can be contextual (e.g. climate, national policy, and economy) or internal (e.g. leadership, state of the resource). It is assumed that all factors need to be present to reach the desired outcome of an intervention for greater sustainability.

Theme 4: sequencing of factors influencing the outcome of interventions

The literature on changes towards sustainability for a range of sectors converges in recognizing the importance of the time sequencing of policies, e.g. for energy transitions (Meckling et al. 2017), land use transitions (Furumo and Lambin 2021) or large-scale adoption of agricultural innovations (Kohl 2023). Scholars highlight the dynamic and non-linear dimension of social–ecological systems, with several feedbacks between the systems. Conceptual frameworks on transformation of social–ecological systems identify key stages in longer term system changes, each phase corresponding to a series of changes and feedbacks in subsystems (Moore et al. 2014; Olsson et al. 2004). The framework proposed by Moore et al. (2014) and Olsson et al. (2004) identifies four phases: (1) the pre-transformation phase, when the triggering element occurs and creates a window of opportunity; (2) the preparation phase, when actors assess their interpretation of the "problem", self-organize and search for alternative solutions; (3) the navigation phase, when actions for change are implemented; and (4) the stabilization phase of up-scaling and building resilience of the new development trajectory. Empirical research on the role of key enabling or hindering factors within these stages is elusive (Tuckey et al. 2023).

Comparative method

Selection of case studies

The case studies were identified through a search for articles or documents focusing on interventions to reverse a degradation of natural resources in Africa. A successful completion of the intervention was not a requirement for case selection, as both improvements and failures were part of the study. We selected case studies: (1) with an initial narrative on natural resource degradation, (2) where some actors initiated actions to reverse this degradation. Moreover, case studies were considered eligible when the literature review resulted in documents: (3) providing insights on the ecological, economic and social outcomes of the intervention (theme 1), and (4) containing information on the factors and phases (themes 2–3 and 4). We conducted a scoping review, with multiple searches on the *Web of Science* and *Google Scholar*, two of the major databases for scientific information, with the keywords "*natural resource/ecosystems regeneration/restoration/rehabilitation*" and "*Africa*" and iteratively identifying the case studies. Given our stringent selection criteria, the selected case studies are not exhaustive as cases less thoroughly documented were ignored.

Coding and analyzing outcomes

From the literature, we derived information on ecological, economic and social outcomes for each case. These were trends in indicators of: (1) the ecosystem health, such as changes in tree cover or in wildlife population, (2) the

economic conditions of the population, such as incomes, crop yields or rate of employment, and (3) the social conditions of the populations, such as conflicts, level of equity in governance, or access to education. These trends were assessed by the difference between the values of the indicators prior to the intervention and at the end of the intervention or at the time of the last published study on the case if the intervention was still ongoing. The specific indicators for each type of outcome varied between the case studies. For example, the indicators for ecological outcomes for a situation of forest degradation could be wildlife populations and tree cover, while for soil degradation, it could be soil fertility, soil erosion and groundwater levels. The economic indicators could be income from forest products or employment in one case, and crop yield for another case. The social indicators could be education, health, conflicts, equity or empowerment, depending on the case. The list of referenced indicators for each case study is provided in SM 25.

For each case study, we attributed a score for each type of outcome—ecological, economic, and social—according to the indicators measured for each study. Scores were attributed based on the values of indicators and/or the degree of convergence between all indicators for a given outcome. This categorical scoring allowed us to compare across cases despite differences in specific indicators per type of outcome.

Our scores are:

- 1 if all indicators showed a worsening of the situation,
- 2 if indicators showed a moderate worsening or the majority of indicators showed different degrees of worsening,
- 3 if the intervention did neither worsen, nor improve the situation, or if we found contradictory conclusions in the articles,
- 4 if the intervention moderately improved the situation or if the majority of indicators showed improvement,
- 5 if all indicators showed a great improvement at the end of the intervention.

If some cases obtained a score equal or superior to 4 on the ecological, economic and social outcomes, the case was coded as "sustainability improvement". If at least one outcome was lower than 4, we considered the case as "incomplete intervention" as the case did not achieve simultaneous improvements in the three outcomes.

For cases involving multiple communities and showing positive outcomes in some locations and negative outcomes in others, we coded the different outcomes as 3. For analyses on the first theme of this study, we considered interventions as a whole to evaluate whether an intervention achieved improvements across social, ecological and economic outcomes. For the subsequent analyses, we separated these cases into two sub-cases, one including the locations with positive outcomes and the other one including the locations with mixed or negative outcomes. For example, an intervention implemented at the national scale that led to sustainability improvements in some districts but showed limited results in the rest of the country led to the creation of a sub-case for the districts with improvements and another sub-case for the rest of the country.

Categorizing and analyzing the governance systems

We focused on the level and form of community involvement in the intervention, as one of the key aspects of the governance system. For each case, we derived from the literature information on the actors involved in the conceptualization, management, implementation, and monitoring of the intervention. We then categorized the cases according to the degree of community involvement in the interventions. We measured the association between the outcomes of cases and their types of governance system based on this degree of engagement using descriptive statistics.

Coding and analyzing factors and phases

We listed all the factors identified in the case studies as having played a role in the intervention for each case study. We compared this list with the list of factors proposed by Lambin (2005), grouped into information, motivation and capacity factors. It led to an updating of the list of key factors influencing the adoption of more sustainable practices, either by updating the definition of a factor or by adding a new factor. For example, the original definition of the factor concerning the incentive or disincentive to engage in the sustainable intervention was "balance of risk-adjusted benefits and costs, taking into account the time horizon of managers and the fraction of real costs of resource management practices that appear as nonmarketed externalities and are, therefore, ignored by private decision-makers". In several of our cases, we found mentions of incentives that were not economic, but rather concerned land tenure or social benefits. We thus extended the definition to: "incentives and disincentives (not only economic)".

We then combined this list of factors with the analytical framework of Moore et al. (2014) on multiphase processes of transformation applied to the interventions in the case studies. Table S2 in Supplementary Material (SM) presents the phases identified for each case study. We created a table of the factors grouped per phase for each case study (SM Tables S3 to S23). Each entry was extracted from the articles and coded as either "success factor" if the factor was identified as having contributed to reach the goal of the intervention for this phase, "obstacle" if the factor was identified as having impeded the intervention, or "non-significant" if the

factor was identified as having no impact on the intervention or if articles revealed contradictory insights on the role of this factor. When articles did not discuss a factor for a phase, we coded it as "not mentioned". For example, in the case of the BMUs in Kenya, the factor "leadership" was coded as "obstacle" as studies reported that the absence of leaders caused difficulties (Murunga et al. 2021). In the case of Kafue Flat in Zambia, the same factor was also coded as "obstacle" because the leaders were not recognized as legitimate by the population and their leadership lacked transparency (Chabwela and Haller 2010). In cases like soil and water conservation (SWC) in Burkina Faso or farmer managed natural regeneration (FMNR) in Niger, charismatic leaders such as Sawadogo (Kabore and Reij 2004) or Rinaudo (WRI 2008) were explicitly identified as having played a notable role in motivating people to adopt new practices, so this factor was coded as "success factor".

To ensure coding reliability, the lead author conducted the coding of all the case studies and the second author independently evaluated the coding for 10 case studies. SM Tables S3 to S23 give the exact quotations extracted from the literature supporting the coding of each factor per phase.

We also aggregated the phases to obtain one code per variable for the whole intervention based on the following rule: the code of a factor in the aggregated table is equal to its code in the stabilization phase; if this code was "not mentioned", we took the code of the navigation phase or, if also "not mentioned", of the preparation phase.

We analysed descriptive statistics per factor for the whole initiative. A factor was considered as important for interventions if it was identified either as success factor or obstacle in most cases. We complemented the analysis by training a Random Forest (RF) classification (Breiman 2001) to predict outcome (as a binary variable) from the combination of factors, and to estimate their relative weight in influencing the outcome of an intervention. RF identifies which factors were most frequently associated with whether the intervention reached or failed to reach its goal. This analysis improves the identification of patterns of associations by estimating the relative weights of factors in explaining outcomes. We performed multiple sensitivity analyses to test the robustness of results (SM Fig. 24). We then analysed descriptive statistics per phase and per factor.

Results

Presentation of the case studies

We selected 17 case studies (Fig. 1) described by a total of 212 peer review articles, reports and book chapters (Table 1). The cases included 13 African countries and covered areas ranging between 80 and 1,000,000 km^2. They addressed a variety of natural resource degradation issues: soil degradation, fish stock decline, deforestation, wildlife decline, and rangeland degradation. The interventions were based on a diverse set of solutions such as technologies for soil and water conservation, farmer managed natural regeneration, rotative exclosures, trees sowing, agroforestry, and by-laws (Fig. 1). Most of the case studies have a colonial history—or a history of a highly centralized and authoritarian power—during which the authorities denied many of the pre-existing rights of the populations over natural resources (IPBES 2018). A dominant narrative emerged, often from the colonial or central powers, on the gradual degradation of the environment attributed to an over-exploitation of resources (Akamani et al. 2015; Benjaminsen 2021; Homewood 2004). Many scholars question the reality underlying this narrative, which sometimes reflected the vision and old fears of the colonial powers rather than an actual trend towards degradation (Benjaminsen 2021; Leach and Fairhead 1994; Schuetze 2015). In most cases, top-down and authoritarian projects attempting to restore natural resources were implemented, with often limited impacts and low adoption by populations (Audouin and Gonin 2014; Cinner and McClanahan 2015; Kumasi 2011; Mutisya et al. 2010; Nyamekye et al. 2018; Ros-Tonen et al. 2013; Siraj et al. 2018). During the 1970s and 1980s, famines affected several countries of the African continent and were widely covered by media, reinforcing the narrative about the threat of an ecological crisis in many parts of Africa (Lanckriet et al. 2015; Sorenson 1991; West 2015). In this context, a variety of new interventions emerged. Our seventeen case studies illustrate this diversity, associated with different geographical, climate, cultural and historical contexts, different resource degradation issues, and a diversity of stakeholders and social dynamics (Table 1). For a more detailed description of the cases, refer to the Supplementary Material.

Theme 1: outcomes of the interventions

Seven cases among the 17 received a score larger or equal to 4 for their ecological, economic and social outcomes and were thus considered as having achieved sustainability improvement (cases 2–3–4–8–9–13–14) (Table 2). For example, the Shinyanga region in Tanzania, a deforested territory with soil erosion issues and high rates of hunger, have seen 300,000–500,000 ha of its area being restored (Barrow 2016). The intervention actively involved 90% of the population, which were empowered by the creation of new institutions to manage the reforestation. It also led to improvements in livelihoods (Barrow 2016) and in ecosystem services such as the provision of fodder, fuel wood, tree products, and erosion control (Fisher 2008; Wainaina et al. 2021).

Four cases obtained positive outcomes in some locations and negative outcomes in others (cases 10–11–12–15). For

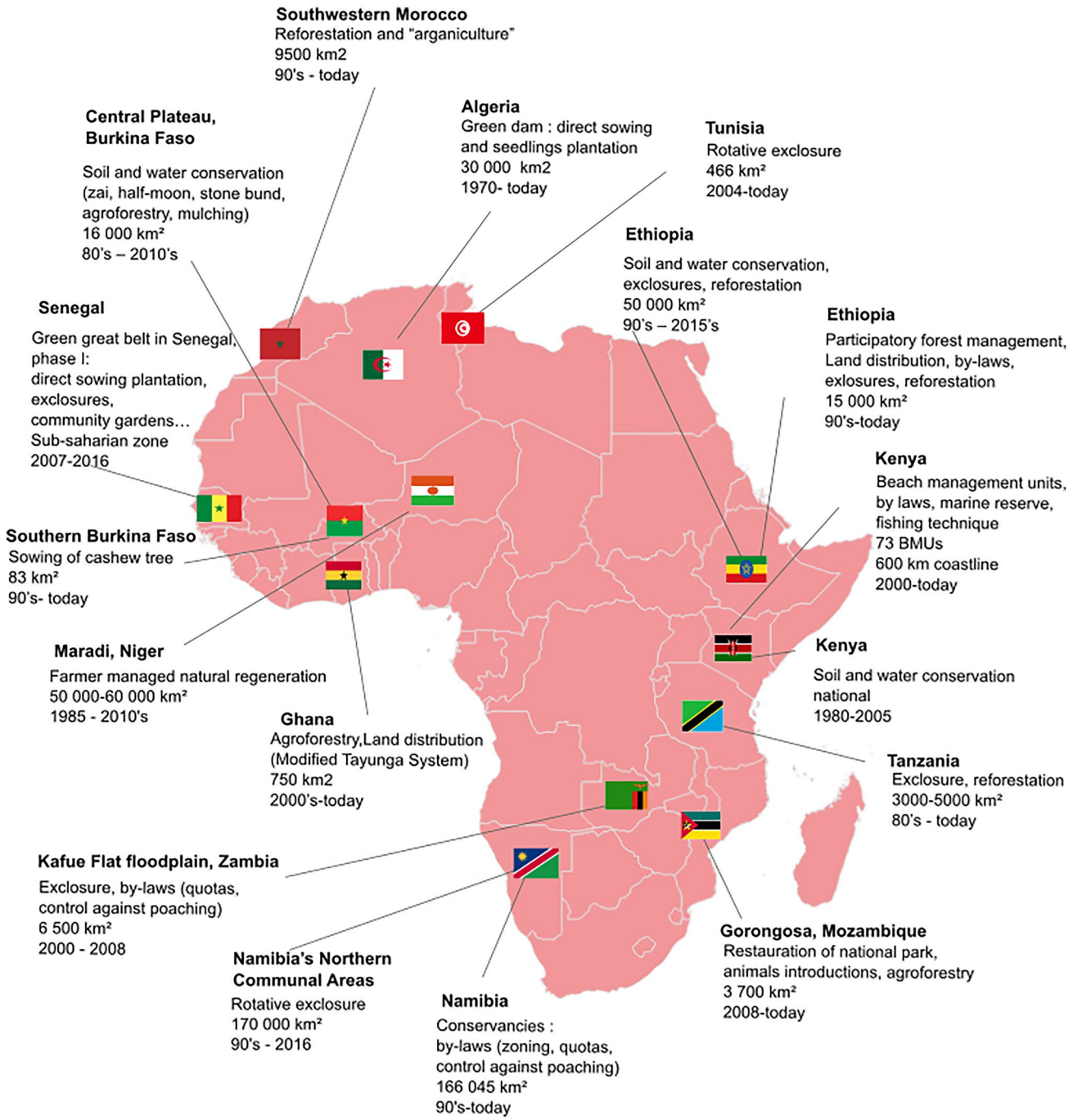

Fig. 1 Location of the selected case studies with their key characteristics

the case in Zambia, all indicators had worsened at the end of the intervention, with a decline in wildlife, low incomes and an increase in conflicts (Chabwela and Haller 2010). For the Great Green Wall initiative in Senegal, clear trade-offs were observed between the environmental, economic and social outcomes. This intervention led to small ecological and economic improvements combined with negative social outcomes (e.g. conflicts with herders, pasture conversion and difficulties in water access) (Diop et al. 2018; Sacande et al. 2021; Turner et al. 2023). For the interventions in Ghana and Mozambique (cases 1 and 14), trade-offs were milder, with land restoration and income increase, but no clear improvement in social outcomes for Ghana, or improvement of the majority of social indicators for Mozambique, despite some resistance against the project from part of the population (Acheampong et al. 2016; Akamani and Hall 2019; Appiah

Table 1 Case studies and their references

Case	Location	Degradation issue	Intervention	Spatial extent (km^2)	References
1	Ghana	Deforestation	In humid tropical forests of Ghana, the government introduced a collaborative planting scheme in 2002, giving farmers access to plots of degraded forest in exchange for planting trees. For the first 3 years, food crops could be intercropped until canopy closure, after which farmers were responsible for maintaining the growing trees. The timber revenues were shared between farmers and the government.	750	Acheampong et al. (2016), Adams et al. (2016), Adjei et al. (2020), Agyeman et al. (2003), Akamani et al. (2015), Akamani and Hall (2019), Appiah et al. (2020), Foli et al. (2018), Forestry Commission (2021), Kalame et al. (2011), Ros-Tonen et al. (2013, 2014), Yeboah-Assiamah et al. (2023)
2	Maradi, Niger	Desertification	In the 1990s, farmers and a local NGO conducted experiments with the "Farmer Managed Regeneration" technique, which consists in supporting the regeneration of native species in plots, rather than planting new trees. Large-scale dissemination began slowly, supported by NGOs, with waves of excitement followed by abandonment, to finally reach large-scale adoption. It was made possible by a temporary withdrawal of government agents accompanied by the intervention of village-level institutions.	50,000/60000	Abasse et al. (2023), Adams et al. (2016), Agúndez et al. (2020), Baggnian et al. (2019), Binam et al. (2015, 2017), Carey (2020), Chomba et al. (2020), Danjuma et al. (2016), Dramé Yayé and Berti (2008), Haglund et al. (2011), Kuyah et al. (2020), Larwanou et al. (2006), Larwanou and Saadou (2011), Lohbeck et al. (2020), Magrath (2020), Mamadou Boureima et al. (2020), Reij et al. (2009), Reij and Garrity (2016), Sendzimir et al. (2011), Tougiani et al. (2009), van Haren et al. (2019), Weston et al. (2015) and WRI (2008)
3	Central Plateau, Burkina Faso	Desertification	Farmers and NGOs began experimenting in the 1980s with different soil and water conservation (SWC) techniques derived from indigenous practices. These innovations were then disseminated on a large scale through the creation of farmers' schools, by local institutions and later with financial support from the government and the international community.	16,000	Bunclark et al. (2018), Kabore and Reij (2004), Magrath (2020), Maizi (1993), Mazzucato et al. (2001), Millogo et al. (2018), Morris and Barron (2014), Nyamekye et al. (2021), (2018), Reij et al. (2005, 2009, 2020), Reij and Smaling (2008), Sawadogo (2011), Smale and Ruttan (1994), Spaan (2003), Thor West et al. (2020), West (2015), West et al. (2021, 2017), Zida et al. (2019)

Table 1 (continued)

Case	Location	Degradation issue	Intervention	Spatial extent (km^2)	References
4	Southern Burkina Faso	Desertification	The government introduced cashew plantations in the 1980s to combat desertification. This initiative failed and the project came to an end in 1991. The arrival of Indian buyers in the 1990s triggered a cashew boom, which led to the large-scale adoption of these plantations by farmers, which covered about 100,000 ha in 2008. This boom was accompanied by a networking of farmers through the organization of the value chain, supported by a number of international organizations and later by the government.	83	Audouin (2014), Audouin et al. (2018), Audouin and Gazull (2014), Audouin and Gonin (2014), Augusseau et al. (2006), Gausset (2003), Knauer et al. (2017)
5	Senegal	Desertification	The idea of combating desertification by erecting a wall of trees led to The Great Green Wall Initiative in 2007 by the African Union. The initial objective was a vegetation barrier over at least 7,000 km along the Sahel and a width of about 15 km. In Senegal, tree planting projects were launched in 2008, accompanied by capacity-building, firebreaks, agroforestry and shared gardens. The initiative was significantly reoriented from 2012 onwards, giving way to a series of regional development initiatives. This study focuses on the implementation of the first phase of the Great Green Wall in Senegal, between 2007 and 2016.	National	Delay et al. (2022), European Commission. Joint Research Centre., (2016), Goffner et al. (2019), Magrin and Mugelé, (2020), Mechiche-Alami et al. (2022), Mirzabaev et al. (2022), Mugelé, (2018), Ndiaye (2016), O'Byrne et al. (2022), Sacande et al. (2021), Sarr et al. (2021), Turner et al. (2023, 2021), UNCCD (2020), Wade et al. (2018)
6	Southwestern Morocco	Deforestation	A restoration intervention concerned the argan forest, which extends over 950,000 ha. In the 1980s, the discovery of the cosmetic virtues of argan oil attracted the interest of international agencies and companies, triggering a boom in the market value of the oil. This new economic interest gave rise to forest restoration projects, with the idea that the economic value of forests would foster its protection and lead to its sustainable exploitation.	9500	Idrassen et al. (2024), Le Polain de Waroux and Lambin (2012, 2013), Lybbert et al. (2011, 2002), Montanari et al. (2023), Perry (2020), Santoro et al. (2023), Sinsin et al. (2020)

Table 1 (continued)

Case	Location	Degradation issue	Intervention	Spatial extent (km^2)	References
7	Algeria	Desertification	In the 1970s, the Algerian government initiated a "green dam" project consisting of afforesting 3 million hectares of Aleppo pine monoculture over a strip 1,500 km long and 20 km wide between the 200 mm and 300 mm isohyets. The project was reoriented 10 years later, attempting to integrate a rural development approach and introducing other tree species into plantations.	30,000	Ballais (1994), Benalia (2009), Benhizia et al. (2021), Bensaid (1995), Bensouiah (2004), Dia and Duponnois (2010), Goffner et al. (2019), OSS (Observ. Sahara Sahel), (2008), Tahar and Boureboune (2009)
8	Governorate of Tataouine, Tunisia	Rangeland degradation	In the 1990s, following a proposal of the Ministry of Agriculture, groups of livestock farmers were set up to implement the old "*gdel*" technique used to let pastures rest while their herbaceous cover is reconstituted. New local institutions were created to coordinate with neighboring communities, government and other external support to collectively manage pastures.	466	Belgacem et al. (2008), Fetoui (2021), Ouled Belgacem et al. (2023, 2019), Robinson et al. (2021), Sghaier et al. (2020)
9	Tigray, Ethiopia	Soil degradation, deforestation	In the Tigray region in Ethiopia, by the 1990s, the government and several associations launched a series of SWC interventions involving strong participation by populations. This occurred after decades of civil war in Tigray, in a context of strong mobilization of the population. These programs led to the development of new local institutions to manage the collective implementation of check dams, stone bunds, water harvesting, exclosures or reforestation.	50,000	Alemu and Kidane (2014), Belay et al. (2015), Deressa et al. (2009), Gebregziabher et al. (2009), Gebremedhin et al. (2002, 2003, 2004), Gebremeskel et al. (2018), Hagos et al. (1999), Haregeweyn et al. (2012), Kidane-Mariam, (2003), Kumasi (2011), Lanckriet et al. (2015), Meaza et al. (2016), Nyssen et al. (2015, 2014, 2004), Segers et al. (2008)
10	Ethiopia	Deforestation	In Ethiopia in the late 1990s, the government, supported by international NGOs, launched a participatory forest management (PFM) programme, based on an arrangement negotiated between the government and local communities to jointly manage areas of forest land. Several forest user groups were set up. They developed and implemented management plans. Since the mid-90s, PFM have covered an estimated 1.5 million ha.	15,000	Ameha et al. (2014a, 2014b), Ayana et al. (2017), Cronkleton et al. (2017), Dessie and Christiansson (2008), Gashu and Aminu (2019), Gatiso (2019), Gebreegziabher et al. (2021), Girma et al. (2023), Kahsay and Bulte (2021), Kassa et al. (2017), Lowell et al. (2014), Muluneh and Sime (2024), Siraj et al. (2018), Tadesse et al. (2017), Takahashi and Todo (2012), Tesfaye et al. (2015), Walle and Nayak (2020), Wood et al. (2019)

Table 1 (continued)

Case	Location	Degradation issue	Intervention	Spatial extent (km^2)	References
11	Kenya	Soil degradation	The government launched the "National Soil and Water Conservation Programme" in 1974 to promote and support farmers in implementing various SWC techniques. In one of the pilot sites, the Machakos region, these techniques were largely adopted, accompanied by an expansion in the number of institutions and supports from other programs. In other regions of Kenya, the adoption of SWC techniques has had limited success.	National	Murton (1999), Mutisya et al. (2010), Mutoko et al. (2014a, 2014b, 2014c); Nyangena (2008), Okoba et al. (2007), Tiffen et al. (1994), Zaal and Oostendorp (2002)
12	Kenya	Fish stocks decline	After a first failed attempt to create a national marine reserve on the southern coast to halt fish stock decline, the government developed legal frameworks to share management responsibility of fishery resources. It enabled the establishment of formal organizations of fish resource users, known as Beach Management Units (BMUs). Each BMU establishes its own rules for the sustainable management of fish stocks, such as regulating access or banning certain types of gear. In 2016, legislation was strengthened to define mandates for fisheries co-management in Kenya.	73 BMUs 600 km coastline	Cinner et al. (2009), Cinner and McClanahan (2015), Etiegni et al. (2020), Gichuru et al. (2019), Kawaka et al. (2017), McClanahan et al. (2016), Murunga et al. (2021), Obiero et al. (2015), Ogoma et al. (2020), Tubman et al. (2021), Wilson et al. (2010)
13	Region of Shinyanga, Tanzania	Desertification	The government launched a project in 1986 to promote the re-establishment of traditional institutions to foster reforestation. Village by-laws were implemented by village institutions in agreement with other village committees. The main practice established was the Ngitils, consisting in restoration perimeters set aside for natural regeneration. It resulted in the restoration of 300,000 to 500,000 ha 20 years later.	3–5000	Barrow (2014, 2016), Fisher (2008), Duguma and Minang (2015), Malunguja et al. (2021), Nzyoka et al. (2021), Pye-Smith (2010), Safari et al. (2019; Wainaina et al. (2021), Walters et al. (2021)

Table 1 (continued)

Case	Location	Degradation issue	Intervention	Spatial extent (km^2)	References
14	Gorongosa, Mozambique	Wildlife decline, deforestation	Government's efforts to restore Gorongosa National Park in the 1990s have failed to prevent the gradual decline of wildlife. In 2008, an American philanthropic foundation signed with the government a 20-year park co-management agreement. A programme to restore the park was launched, based on wildlife reintroduction and reforestation. The local development in the park's buffer zone was based on a sharing of park revenues, job creation, new education and health infrastructure, and agroforestry projects.	3700	Diallo (2015, 2020, 2011), Herrero et al. (2020), Huntley (2023a), Jacobs (2010), Lindsey et al. (2021), Matos et al. (2021), Pringle (2017), Schuetze (2015), Walker (2015), Yeats (2010)
15	Namibia	Wildlife decline	First successful community initiatives of wildlife management in the 1980s led to legal changes in 1996 to enable the establishment of communal conservancies. They consist in local organizations with a governing constitution made of members from a community, with user rights over the wildlife of a given land area. Conservancies generate revenue from wildlife-based activities such as tourism and leisure hunting, often with an arrangement between a conservancy and a private partner. By 2007, approximately 50 conservancies covered 166,045 km^2 of land.	166,045	Bandyopadhyay et al. (2004), Gargallo (2021), Hewitson and Sullivan (2021), Hoole (2010), Humavindu and Stage (2015), Huntley (2023b), Kalvelage et al. (2021), Khumalo and Yung (2015), Koot et al. (2020), Lapeyre (2010), Mosimane and Silva (2015), Nattrass (2021), Riehl et al. (2015), Scanlon and Kull (2009), Schnegg and Kiaka (2018), Silva and Mosimane (2014), Snyman (2012), Suich (2013, 2010), Wenborn et al. (2022), Meyer et al. (2021)
16	Namibia's Northern Communal Areas	Rangeland degradation	In northern Namibia, in 2004, the government and an international NGO launched a programme to develop community-based rangeland management. Several committees were established to coordinate and monitor the collective rangeland grazing management, mainly planned rotations. In parallel, the program provided support to communities, including infrastructure, training, livestock loans and technical assistance.	170,000	Coppock et al. (2022), GOPA (2014)

Table 1 (continued)

Case	Location	Degradation issue	Intervention	Spatial extent (km^2)	References
17	Kafue Flat floodplain, Zambia	Wildlife decline	In Zambia, wildlife policies and legislation were changed in the 1980s to better involve local communities in wildlife management. The government and an international NGO implemented successively two projects in the Kafue Flat wetland of southern Zambia, aiming at developing a sustainable co-management of the wetland area jointly by the government and the communities. Both projects proposed a new management organization and different schemes of revenues sharing.	6500	Chabwela and Haller (2010), Chomba et al. (2021), Haller and Chabwela (2009), Haller and Merten (2018), Nkhata and Breen (2010)

et al. 2020; Diallo 2015; Foli et al. 2018; Jacobs 2010; Pringle 2017; Ros-Tonen et al. 2013; Schuetze 2015). See the Supplementary Material for more details on outcomes (Table SM 25).

Concerning the seven cases leading to improvements in sustainability outcomes, notable ecological restorations were reported, such as recovery rates ranging from 30 and more than 100% for elephant, waterbuck, sable antelope and lion populations in Gorongosa (Huntley 2023a), or a regreening of some 5 million hectares in Niger (Abasse et al. 2023). Average income increased relative to their pre-intervention levels—by 10–50% depending on the cases (Appiah et al. 2020; Gausset 2003; Haglund et al. 2011; Reij and Smaling 2008; Ros-Tonen et al. 2013; Sacande et al. 2021). However, their absolute values remained low (Table 3). When yield improvements took place, yields remained far lower than their potential values (Table 3). Social outcomes were also moderate. Overall, governance and access to natural resources improved and, in some cases like in Niger, women, young and marginal people were better integrated into decision-making bodies. In four interventions having led to improvements in sustainability outcomes, populations did not equally benefit from the ecological, economic and social improvements.

For the following analyses, we separated into two sub-cases each case study involving multiple communities and showing positive outcomes in some locations and negative outcomes in others (cases 10–11–12–15). For example, the intervention based on soil and water conservation techniques in Kenya was implemented at the national scale. It led to sustainability improvements in Machakos district but showed limited results in the rest of the country. We, therefore, created a sub-case for Machakos and another one for the rest of the country. As a result, the next steps of the analysis included 21 case studies.

Theme 2: involvement of communities in the governance of natural resources

The case studies represented four types of governance systems for natural resource management, derived from the different degrees of involvement of the communities in the interventions.

Weak involvement of communities (cases 5–7–14)

For these cases, one or several actors outside the local communities conceptualized, planned, implemented, and monitored an intervention. The local population was sometimes consulted and involved in the implementation of the intervention but it had no real decision power and accountability. For example, the Great Green Wall in the Sahel was conceptualized and planned by a coalition of

Table 2 Outcomes for each case study

Case	Ecological outcomes	Economic outcomes	Social outcomes
3—Central Plateau, Burkina Faso	5	4	4
2—Maradi, Niger	5	4	4
9—Tigray, Ethiopia	5	4	4
16—Namibia's Northern Communal Areas (rangeland)	1	3	4
11—Kenya, Soil and Water Conservation	3	3	3
8—Governorate of Tataouine, Tunisia	4	4	4
5—Senegal Great green wall	4	4	2
7—Algeria, green belt	1	3	1
14—Gorongosa, Mozambique	5	4	4
15—Namibia, Conservancies	3	3	3
17—Kafue Flat floodplain, Zambia	1	1	1
1—Ghana	4	4	3
13—Shinyanga, Tanzania	5	4	4
12—Kenya Fisheries	3	3	3
10—Ethiopia Participatory Forest Management	3	3	3
4—Southern Burkina Faso	4	5	4
6—Southwestern Morocco	1	3	2

Table 3 Examples of absolute values of yield and income improvements

	Yield before the intervention	Yield after the intervention	Water-limited yield potential (Yw)[a]	Additional income
Machakos	0.2–0.45 t ha^{-1}	0.55 t ha^{-1}	3.1–14.2 t ha^{-1}	–
Burkina Faso	0.4–0.45 t ha^{-1}	0.62–0.67 t ha^{-1}	5.7 t ha^{-1}	–
Tigray	0.5 t ha^{-1}	0.8 t ha^{-1}	8.4 t ha^{-1}	–
Niger	–	–	–	US$ 46–56 $person^{-1}$ $year^{-1}$
Shinyanga	–	–	–	US$ 14 $month^{-1}$ $person^{-1}$ + 16 natural resource products valued at US$ 1200 $household^{-1}$ $year^{-1}$
Source	(Gebremeskel et al. 2018; Reij and Smaling 2008; Tiffen et al. 1994a)		www.yieldgap.org (van Bussel et al. 2015)	(Barrow 2016; Binam et al. 2015; Haglund et al. 2011)

[a]referring to the potential yield for rainfed crops attainable considering the soil type, water limitation and field topography, and supposing no nutrient limitation

West African governments. The local implementation was delegated to national agencies (UNCCD 2020). In Senegal, local populations were consulted to choose the plots and tree species for some reforestation projects or for programs of women-run communal vegetable gardens (Goffner et al. 2019). In the Gorongosa National Park in Mozambique, a private foundation and the state decided and implemented the management strategy for the conservation area without involving local communities. They also managed development programs that benefited these communities (Diallo 2015).

Co-management (cases 1–10–12–15–17)

In these cases, the local communities and one or several external actors agreed on an arrangement for a co-management of the resource. A formal distribution of roles, commitments and benefit sharing between stakeholders was decided through the establishment of a contract. The cases of Participatory Forest Management (PFM) in Ethiopia and Beach Management Units (BMU) in Kenya are examples of co-management partnerships between the government and local communities. The communities formed legally recognized

groups, the BMU in Kenya and the PFM in Ethiopia, who decided and implemented rules for resource use. These rules were subject to approval by the State, which provided financial resources (Ameha et al. 2014a; Cinner and McClanahan 2015; Kassa et al. 2017).

Community-based management (CBM) with external support (cases 2–3–8–9–11–13–16)

For most of the cases, an external actor (the government, a local NGO or an international institution) initiated the intervention. This external actor first proposed a project to the local communities, which then took ownership of it. The communities then created or reactivated institutions to govern and manage the project. For example, in Tunisia, the Ministry of Agriculture proposed to reintroduce the rotative exclosure technique known as *gdel*, and the communities were responsible for the design and implementation of the project (Robinson et al. 2021). A fully bottom-up implementation took place when the new intervention was initiated, planned and managed by the communities. In Burkina Faso and Niger, new practices—respectively, soil and water conservation inspired by indigenous knowledge and farmer-managed natural regeneration—were developed by farmers and local NGOs. The communities developed rules and agreements that facilitated the adoption and dissemination of these new practices. The government only intervened at a later stage and supported large-scale projects to facilitate the adoption and dissemination of the new practices in other areas (Nyamekye et al. 2018; Sendzimir et al. 2011; Thor West et al. 2020).

Conservation through commercialization (4–6)

In other cases, change was mainly driven by market dynamics. The cases of cashew nuts in Burkina and argan oil in Morocco both began by the opening of international niche markets triggering a change in the use of these resources by individuals—respectively, the plantation of cashew trees on farm plots and the intensification of argan exploitation—and the creation of new social organizations (cooperatives or farmer groups). The initial objective was not the preservation of the natural resource but rather to obtain benefits from the commercialization of biological resource-based niche commodities (Le Polain de Waroux and Lambin 2013). The preservation of the resource came as a consequence of the exploitation of its products. In Burkina Faso, for example, farmers started planting cashew trees over extended regions, contributing at the same time to reduce desertification. In both cases, the State accompanied the intervention by adjusting the legal framework and providing technical and financial support (Audouin et al. 2018; Le Polain de Waroux and Lambin 2013).

No important difference in the classification of interventions between "sustainable improvement" and "incomplete intervention" was observed in relation to the type of governance system for natural resource management, except for slightly better performances for cases of community-based management with almost no outcome showing a worsening (Fig. 2). Given the small sample size per group, comparing mean scores is not relevant. For each type of governance system, cases of both improvements of sustainability outcomes and incomplete interventions were observed. Two CBM cases out of seven did not achieve expected improvements, but all of them had positive or neutral social and economic outcomes. One of the three cases of projects with low community involvement achieved improvements in sustainability outcomes; and one of the two cases of conservation through commercialization led to clear improvements.

Theme 3: factors influencing the outcomes of interventions

a. Key factors for sustainability interventions

The analysis of the case studies led us to update the factors likely to influence the outcome of an intervention. We broadened the definition of several factors and we added two factors: the horizontal communication between local stakeholders and the project managerial capacity (Table 4).

b. Factors associated with the overall outcome of an intervention

Almost all factors played a role either as success factor or as obstacle for at least 70% of the cases (Fig. 3). Two factors were mentioned as important (as success or obstacle) in only about half of the cases: rejuvenated local environmental attitudes and values, and project managerial capacity. For the cases with an intervention leading to improvements in sustainability outcomes, almost all factors were identified as success factor, suggesting the need to align all the factors.

The role of these factors as obstacle or success factor differs depending on the outcome of the intervention (Table 5). Some factors were identified as success factors for all cases whatever the outcome of the intervention, whereas others were success factors in the majority of the interventions leading to improvements in sustainability outcomes and an obstacle or a success factor for incomplete interventions. Other factors—mainly motivation and capacity factors—were identified as obstacles for incomplete interventions but success factors for interventions leading to improvements in sustainability outcomes.

The Random Forest (RF) analysis confirms an association between factors and outcomes (Fig. 4). The presence of incentives, such as economic benefits or security of land access, was the factor most strongly associated with the outcome of interventions. Social capital and community-level institutions was also strongly associated with outcomes, and

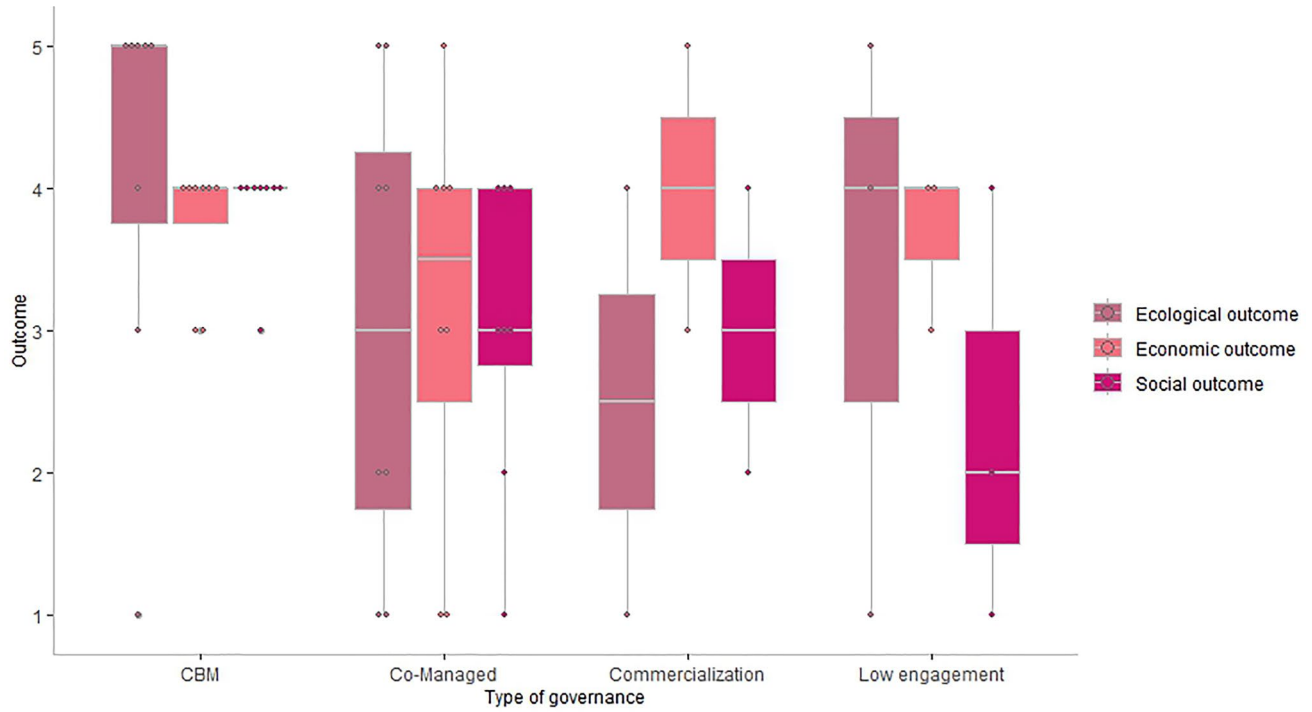

Fig. 2 Outcomes according to the type of governance system for natural resource management (median, standard deviation, and min–max values)

the reconciliation of divergent interests and resource availability more weakly so.

The most cited incentives and disincentives were of an economic nature, associated with the commercialization of biological resource-based commodities or new employment opportunities (Fig. 5). A better provision of ecosystem services following the restoration of natural resources, e.g. crop yields and tree production, was also mentioned in several cases. Less frequently cited were increase in security of land access, food, tools and other input distribution, compensatory subsidies for populations involved in interventions—e.g. in return for giving up the use of rested areas in Tunisia (Sghaier et al. 2020), or the construction of infrastructure such as boreholes, schools, roads or health centers. In most cases, multiple incentives jointly increased motivation and involvement of project participants. Disincentives such as fines or social pressure were only mentioned in four case studies. For example, social pressure acted as a disincentive to abstain from participating in the case of Tigray because leaders from Tigray People's Liberation Front exerted a strong influence on farmers' decisions (Segers et al. 2008).

Theme 4: sequencing of factors influencing the outcome of interventions

No clear distribution of factors according to phases was observed (Fig. 6). Almost all factors were present during the navigation and stabilization phases of the cases with an intervention leading to improvements in sustainability outcomes. For these cases, the only pattern was the presence of obstacles related to a low motivation and low capacity during the preparation phase, which disappeared in the following phases (Fig. 6). The ability of these interventions to reach their objective rested precisely on the ability to overcome these obstacles.

For the cases of incomplete intervention, the failure of the intervention was rarely due to a single factor during the intervention but rather to a combination of obstacles, which mainly appeared in the navigation phase and persisted in the stabilization phase (Fig. 6).

Four information factors—i.e., ecosystem service assessment, early perception of the environmental change, recognition of the relevance of the change, and attribution of the change to human activities rather than to natural processes—were prevalent for most cases in the preparation phase, independently from the outcome of the intervention.

Table 4 Factors applied in this study

Refined definition	Abbreviation
Information	
Anticipation and early perception of the current state of the environment via reliable environmental indicators and monitoring systems	Perception, monitoring
Detecting the signal of (human) perturbation from the background noise of natural variability in environmental conditions, which requires a deep knowledge of ecosystem functioning	Attribution
Recognition of the importance and relevance of the change in environmental attributes	Importance, relevance
Proper assessment of ecosystem services provided by natural ecosystems	ES assessment
Horizontal communication between local stakeholders on environmental changes and interventions	Horizontal communication
Two-way communication between higher level decision-makers and resource managers	Vertical communication
Motivation	
Rejuvenated (expression of) local environmental attitudes and values	Attitudes, values
Incentives and disincentives (not only economic)	Incentives, disincentives
National and international policies and programs	Motivating policies
Conflicts of interest between various stakeholders which affects the willingness of decision-makers to intervene, given private interests, short-term or long-term stakes in resources by different agents, divergence of objectives between social groups, and governance issues	Reconciling interests
Fit between ecosystems and institutional systems—the closer the congruence or compatibility between, on one hand, the rules, decision-making procedures and social practices that assign roles to agents in the management of ecosystems and, on the other hand, the specific configuration of that ecosystem, the better the relevant institutions will perform in terms of sustainability	Fit ecosystem institutions
Capacity	
Project managerial capacity	Managerial capacity
Leader(s) that are able to create the readiness to change	Leadership
A high level of social capital between resource users to deal with conflicts between stakeholders and reconcile varying perspectives, interests and attitudes, and an institutional system that induces compliance with rules, based on a good balance between incentives and sanctions	Social capital
Availability of a diverse portfolio of skills and new technologies to manage natural resources	Technology
Availability of resources (external and internal) to experiment with, adapt and maintain new practices	Resources availability
Effective policy implementation	Policy implementation

Discussion

Main findings concerning the four themes

Theme 1: simultaneous but moderate improvements in ecological, economic and social outcomes

Our results provide evidence that it is possible to reverse natural resources degradation trends while improving human well-being in Africa. Thus, it is possible to avoid major trade-offs between the ecological, economic and social dimensions of sustainability. There are several caveats, however, to these interventions having led to improvements in sustainability outcomes. Our results show that the seven cases with a notable recovery of natural resources also experienced moderate social and economic progress in absolute value.

A common criticism of development interventions aimed at natural resource restoration and poverty reduction is that they are sometimes used to increase control over populations (Andersson et al. 2011; Jones 1996). For instance, in Gorongosa, Diallo (2020) denounced the use by the government of the Park restoration project to strengthen its authority in a historically rebellious region. In Tigray, Kidane-Mariam (2003) denounced state strategies 'based on population control, poverty reduction, sustainable development, and capacity-building' (Kidane-Mariam 2003). The green wall or dam projects are also seen as a way to increase state control on ethnic minorities and politically marginalized people (Turner et al. 2023). This does not diminish the improvements observed in the case studies, but calls for careful consideration of power relationships when evaluating interventions to reverse natural resource degradation.

The positive outcomes of interventions may also be difficult to sustain over the longer term. In four of the seven interventions having led to improvements in sustainability outcomes, external upheavals related to security have jeopardized the post-intervention's social–ecological systems. From late 2020 to late 2022, the Tigray region experienced a deadly civil war, involving the same actors who led the intervention 20 years earlier (Negash et al. 2023). Burkina Faso is facing great insecurity since 2015 due to jihadist

Fig. 3 Distribution of codes for factors according to the outcome of the intervention

Table 5 Categorization of factors according to their influence on the outcome of interventions

	Factors identified as success factors for all cases whatever the outcome of the intervention	Success factors in the majority of the interventions leading to improvements and a mixture of obstacles or success factors for incomplete intervention	Obstacle in the majority of incomplete interventions, and success factors for interventions leading to improvements
Information	Importance, relevance Attribution Perception monitoring	ES assessment Horizontal communication Vertical communication	
Motivation	Motivating policies	Attitude, values	Reconciling interests Fit ecosystem institutions Incentives, disincentives
Capacity		Policy implementation Technology	Resources availability Leadership Social capital Managerial capacity

attacks. These tragic events show how interventions that took decades to bear fruits can rapidly collapse due to political turmoil.

Theme 2: building coalitions of committed actors for an effective governance system

We did not find a clear association between the level of involvement of communities in the resource management and the outcome of interventions, even though there is some indication that community-based management is associated with more positive social outcomes. However, our results do show that social arrangements and organizations between actors played a central role in interventions having led to improvements in sustainability outcomes. This was captured by the factors describing social capital, community-level institutions, and the ability to reconcile divergent interests, which were both highly associated with the outcome of interventions.

In cases for which social institutions were identified as a factor of success, interventions often drew on traditional institutions and on newly created social structures such as environmental committees, user groups, or cooperatives. This approach built on existing, well-functioning institutions that were already established, legitimate and respected within communities, while defusing some

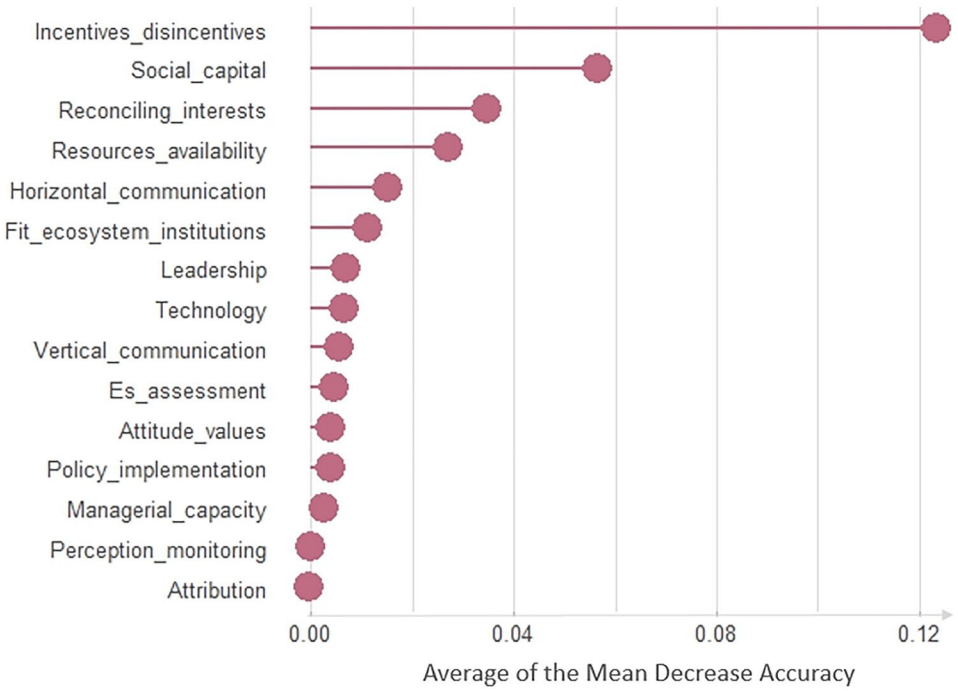

Fig. 4 Association of each factor with the outcome of interventions in terms of the average of the mean decrease accuracy of 10,000 simulations of Random Forest. The factors "policy implementation" and "importance, relevance" were not included as they have the same value for all cases

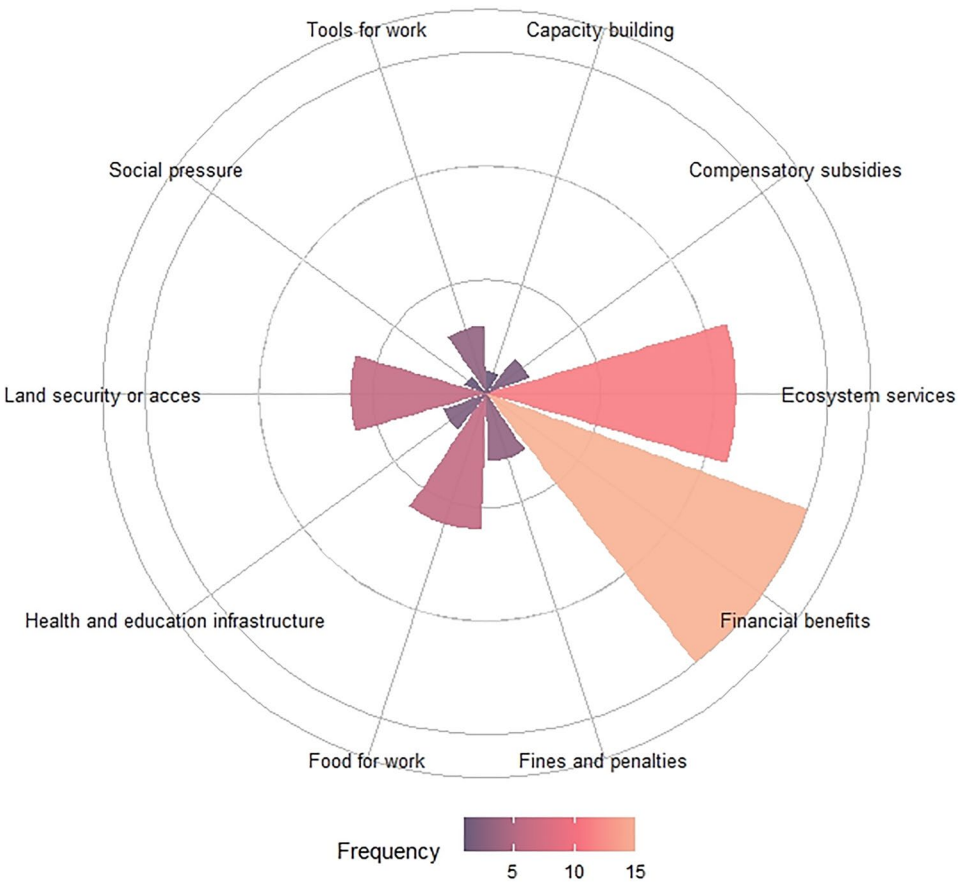

Fig. 5 Incentives and disincentives explicitly identified in the cases as present or missing

Fig. 6 Code of key factors (success factor, obstacle, not significant, or not mentioned) by phase and outcome

dysfunctional aspects such as a lack of transparency or excessive power concentration. For example, new institutions in Niger succeeded in integrating the elders while reinventing other rules and integrating new stakeholders such as women and herders who were previously excluded from such decision structures (Sendzimir et al. 2011). Conversely, the case of Kafue Flat showed how the eviction of traditional leaders of the communities from the new institutions led to a lack of legitimacy and low acceptance of the new organization (Nkhata and Breen 2010). This underlines the importance of drawing on local, traditional knowledge, particularly in the domain of conflict resolution and community creation (Sarr 2019).

The factor "reconciling divergent interests" captured the importance of the willingness of stakeholders to align their interests, move in the same direction and identify fair and equitable arrangements. This suggests that identifying mutual interests of stakeholders and finding common ground are essential for success. For example, in cases of market-driven interventions, there was an alignment between the commercial sector, the state, civil society, and local communities, each having vested interests. Conversely, the Namibia rangeland CBM partly failed due to a lack of agreement between herders to jointly adopt the same new land use practices (Coppock et al. 2022).

Functioning coalitions of actors from different levels of governance are thus essential and should be central in initiatives to promote more sustainable resource use. This is in line with the concept of polycentric governance, in the sense that independent players with different perspectives and positions build compromises in the same political arena while maintaining their autonomy (Biggs et al. 2015). This also places justice and fairness concerns at the center of natural resource governance. Consensus is difficult to find in a social context of great inequality and without a dialogue to identify a fair and equitable path to allocate resources and define accountability (Gupta et al. 2023).

Theme 3: low-income contexts require low-risk interventions

In situations where poverty is prevalent, populations are constantly adopting risk reduction strategies. Yet, risk is inherent to changes in practices as it involves unknowns and experimentation. Risk-averse behaviors may thus be an obstacle to the adoption of more sustainable resource management practices. The achievements of interventions in such contexts depends on the ability to change while maintaining an acceptable level of risk. This requires strong incentives to motivate stakeholders to engage in

the intervention. Our comparative study showed that a lack of incentives most frequently contributed to the failure of interventions, particularly a lack of clear economic benefits or improved provision of ecosystem services.

External financial, material or time resources also play a key role in sustaining interventions and buffering against major risks of failure. A successful intervention requires having accumulated a surplus of resources to experiment, diffuse information on the innovation, organize collective action, implement solutions at scale, and monitor and evaluate impacts. Our results showed that the factor "availability of resources" was among the most frequently associated with the outcome of interventions. For cases where this variable was a factor of success, these resources were generally provided by external agents such as local NGOs, governments and donors. For example, experimental plots and material resources provided by local NGOs were essential for experimentation in Burkina Faso when farmers had no such resources (Kabore and Reij 2004). In many cases of unsuccessful intervention, the cost of the intervention was passed to local communities who were unable to cover them, thus hindering the continuation of the new practices. For example, the PFM groups in Ethiopia had to pay registration fees that were superior to what members could afford (Ameha et al. 2014a), and the Kenyan farmers had to buy the tools to implement soil and water conservation practices (Mutisya et al. 2010).

A challenge for interventions is to reconcile the different time scales of ecological regeneration, social processes (e.g. building trust, overcoming old conflicts, learning, changing social norms and values), short-term basic needs, and political agendas. The strategy adopted in several cases was to remove short-term constraints that created hurdles to long-term action, mainly by bringing external resources and creating short-term incentives. The case of Ghana exemplifies the consequences of neglecting the need to reconcile temporal scales in decision-making. The government gave farmers access to degraded plots on which they had to plant and grow trees in exchange for the right to cultivate crops in the short-term, before canopy closure, and earn a share of the timber revenues. However, the time interval between canopy closure and timber harvesting was too long, causing several farmers to abandon these plots (Acheampong et al. 2016).

These conclusions are consistent with those of Piñeiro et al. (2020), whose study on the factors of adoption of sustainable practices highlighted the need for short-term economic incentives with benefits offsetting the costs of adoption, for strong external support from technical assistance and extension services, and for an articulation between long-term environmental outcomes and short-term priorities.

Theme 4: reversing natural resource degradation requires maintaining factors of success over the long term

Interventions to reverse natural resource degradation are long-distance races, made up of interruptions, setbacks and accelerations. Their success depends on the capacity of actors to steer them over the long term. Our results showed that, while the preparation phase required mainly factors related to information on the resource, most other factors of success were present during the phases of navigation and stabilization. This highlights the need to maintain multiple types of levers that will last over time. Many projects have fallen into the trap of neglecting support for local actors and follow-up activities once the first positive results were obtained. This negated the efforts and progress achieved during the navigation phase. In some interventions, donors disengaged and funding ended after the navigation phase, which prevented proper monitoring and sustaining interventions. It was the case for several BMU in Kenya (Obiero et al. 2015) or PFM in Ethiopia (Ameha et al. 2014a; Kassa et al. 2017).

Maintaining factors of success over time does not mean keeping them unchanged as they often need to be adapted according to the stage of system change. For example, in the case of SWC in Burkina Faso, the factor "horizontal communication" required evolving strategies during the stages of the intervention. It first consisted in communicating on experimentation and state of the resource between some farmers and local NGOs during the preparation stage. During the navigation stage, the communication consisted in convincing neighboring farmers to adopt the same practices, with the organization of "zaï markets" where farmers could share their experiences. During the stabilization stage, the horizontal communication was handled by NGOs who diffused the practices more broadly and funded study visits or demonstrations in more remote villages (Kabore and Reij 2004). This highlights the need for long-term planning by decision-makers to ensure that all factors of success remain present while maintaining sufficient flexibility to adapt strategies to both incremental change and unforeseen circumstances.

Generic lessons versus the influence of local context

Our results unveiled similar sets of factors associated with the outcomes of interventions in very different cases. This suggests that it is possible to generalize to a certain degree across a diversity of situations. However, identifying commonalities across diverse cases runs the risk of erasing the importance of local contexts.

Our comparative analysis was based on broad and generic categories of factors, which encompass a diversity of modalities specific to the context of each case study. For instance,

in Macchako, Kenya, proximity to markets led to high returns to commercialization of agricultural products by farmers who adopted soil and water conservation practices, which facilitated adoption of these practices (Nyangena 2008). This market accessibility was, therefore, coded as an incentive. In Ethiopia, in a context of land tenure insecurity, the opportunity for securing land access offered by the PFM was also coded as an incentive for farmers to participate (Ameha et al. 2014a). For these two cases, the factor "incentive" was coded in the same way, while covering different modalities due to contextual differences.

The importance of contexts is highlighted by cases with mixed outcomes, where the same technology implemented at a national scale was successful in some places but a failure in others with different socio-economic characteristics. In Namibia, some conservancies far from a main road failed to attract tourists and, therefore, did not generate a profit. Low population density and aridity also explained the sustainable outcomes of some conservancies as these variables favored wildlife over agricultural crops (Binot 2009). In Kenya, factors explaining different outcomes between BMUs were linked to the social context, such as leadership, market dynamics and past experiences such as historical conflicts and governance failures (Murunga et al. 2021).

Many scholars have identified the role of local context in influencing the success of interventions (Edwards and Steins 1999; Gharesifard et al. 2019; Marks 1999). Their results highlight the risk of replicating elsewhere a successful initiative by underestimating the importance of the complexity and specificity of each context (Lejano et al. 2007; Olivier de Sardan 2021). In our analyses, the effects of these contextual factors were integrated within the key factors of success, making them invisible in our results. It is, therefore, important to combine case studies and generalizations across cases to extract both the specific and the general.

Limitations of the study: selection and disciplinary biases

Our study may have underestimated the importance of several factors related to the information on the initial degradation of the natural resource due to a bias in case selection. All our cases had initiated an intervention, which suggests that some stakeholders had already identified a resource degradation and the need to intervene. Thus, information factors such as early perception of the environmental change and attribution of the change to human activities were almost never coded as 'obstacles' and were not associated with the outcomes of interventions. However, many studies show that the absence of these factors can contribute to inaction and a lack of interventions, for example, when stakeholders do not perceive the natural resource degradation or do not identify its root causes (Dietz 2003).

Another possible bias may arise from the discipline of authors of the articles. We attempted to reduce this bias by selecting articles with authors from different disciplines and by including articles that are critical of the interventions (e.g. Diallo 2015; Kidane-Mariam 2003; Perry 2020; Segers et al. 2008; Turner et al. 2023), thus avoiding idealized "success stories". More specific factors such as landscape heterogeneity (Wu 2013), natural resource characteristics (Ostrom 2009) or severity of degradation (Kelly et al. 2015) were not mentioned in most case studies. These factors are not easily measurable.

Most factors of our framework were mentioned in all cases. Two factors were not mentioned in more than half of the case studies: the project managerial capacity and local environmental attitudes and values. These factors have only recently been integrated in human–environment studies, beyond a few pioneer studies (Kallio and Nordberg 2006; Pascual et al. 2021). This may explain their absence in our results. One could hypothesize that, in rural contexts, people are more connected with nature than in urban areas. Their environmental values and attitudes were, therefore, not identified as hindering or leveraging factors as it did not differ strongly from case to case. Our sensitivity analysis showed that a high number of codes "not mentioned" did not influence our overall results but could have led to a small bias in the estimation of the role of these factors.

This study was seeking generalizations based on published case studies. It has to be complemented by field-based research with interviews of stakeholders to better capture the complexity of interventions in specific contexts. In particular, field studies could better identify whether performances in the social, economic and environmental dimensions of sustainability occurred with synergistic, neutral or antagonistic effects.

Conclusion

Decisions about restoring natural resources and striking a balance between nature conservation and human development have a major importance in rural areas of Africa. Our comparative analysis of interventions to reverse resource degradation shows that sound decision-making at different governance levels can lead to sustainability improvements on several dimensions simultaneously. Our results also suggest that creating multi-stakeholder coalitions is essential for the long-term success of interventions for sustainable resource management. It requires integrating poverty-related concerns, mitigating the risks inherent to a change in practices, creating incentives for participation by all actors, and maintaining the commitments to change over the long term.

Our analysis shows that interventions having achieved improvements in sustainability outcomes were linked to the

endurance of a mix of all the success factors previously identified and categorized as being related to information, motivation and capacity. This requires incorporating long-term thinking to achieve a system transformation when short-term shocks and crises constantly threaten to derail interventions for sustainability.

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Data availability The dataset generated and analyzed in this study is in the Supplementary Material.

Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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