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Resilience in Agro-ecological Landscapes:

Process Principles and Outcome Indicators

Christo Fabricius, Peter Novellie, Claudia Ringler, Stefan Uhlenbrook and Dale Wright

IN PARTNERSHIP WITH:

CGIAR Research Program on Water, Land and Ecosystems (WLE)

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Contents

Acronyms

CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
CIAT	International Center for Tropical Agriculture
CV	Coefficient of variation
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
ICARDA	International Center for Agricultural Research in the Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IWMI	International Water Management Institute
LIFT	Livelihoods and Food Security Fund
OICR	Outcome Impact Case Report
PIM	CGIAR Research Program on Policies, Institutions, and Markets
SADMS	South Asia Drought Monitoring System
SDG	Sustainable Development Goal
WLE	CGIAR Research Program on Water, Land and Ecosystems
WUA	Water users' association

Abstract

The CGIAR Research Program on Water, Land and Ecosystems (WLE) acknowledges the link between ecosystem services and the resilience of landscapes, food systems and livelihoods. WLE defined system resilience as a "system's capacity to withstand shocks and stresses, transform in response to changing conditions, and adapt in crisis situations." The assumption is that when agricultural landscapes are managed in sustainable ways, i.e., to sustain biodiversity and soil productivity and safeguard freshwater resources, they will be more resilient to shocks and changing conditions and be more productive in the long term.

Here, we aim to identify and validate core principles and outcome indicators for agro-ecological landscape resilience. We address four related questions: (1) which outcome indicators and process principles feature most prominently in the seminal literature on resilient agro-ecological landscapes? (2) to what extent are these principles represented in CGIAR Outcome Impact Case Reports (OICRs) and selected peer-reviewed studies, aimed at improving the sustainability of agro-ecological landscapes? (3) how does the use of process principles in the case studies compare to their occurrence in the theoretical literature? and (4) which process principles co-occur with related outcome indicators in the OICRs?

We conducted a rapid literature review using six published meta-syntheses to identify theoretical first order outcome indicators and process principles for resilient agro-ecological landscapes. These included five outcome indicators: (1) ecosystem integrity; (2) adaptive capacity; (3) human well-being; (4) sustained production; and (5) effective governance. Six action-oriented process principles were identified: (1) maintaining and enhancing diversity; (2) adopting a systems approach to landscape management; (3) promoting rights and equitable access to land and resources; (4) fostering inclusivity; (5) matching local and regional social needs and biophysical contexts; and (6) developing and supporting robust institutions.

We then evaluated the frequency of occurrence of the outcome indicators and process principles in 18 CGIAR OICRs and two peer-reviewed cases. The most common outcome indicators in the 20 case studies were sustained production, adaptive capacity and human well-being. Effective governance and ecosystem integrity were poorly represented.

The most common process principles (in order of prominence) were: (1) matching local and regional social needs and biophysical contexts; (2) adopting a systems approach to landscape management; (3) maintaining and enhancing diversity; (4) fostering inclusivity; and (5) developing and supporting robust institutions. Promoting rights and equitable access to land and resources was poorly represented. Two process principles – matching local and regional social needs and biophysical contexts, and adopting a systems approach to landscape management – seem to be consistently linked to positive outcomes for effective governance, adaptive capacity, human well-being and sustained production. The process principles co-occurred with outcome indicators in equal proportions to their presence in the case studies, i.e., none of the process principles appeared to be redundant in driving outcomes.

Implications for CGIAR's work

CGIAR may want to be more specific about the outcomes and processes that drive resilience in agro-ecosystems by adopting a clear theory of change for resilience building with well-defined outcome indicators and process principles. This will inform adaptive program management through continuous monitoring, evaluation and learning. A stylized theory of change for resilient agro-ecosystems, based on the outcome indicators and process principles reported here, is presented in this report. The theory of change needs to be underpinned by targeted monitoring and reporting systems. Furthermore,

CGIAR may want to consider strengthening the focus on ecosystem integrity and effective governance as outcomes, but without neglecting its current focus on sustained production, human well-being and adaptive capacity. We conclude the report by suggesting seven novel research themes.

Introduction

The CGIAR Research Program on Water, Land and Ecosystems (WLE) has been conducting research for development in agro-ecosystems in Africa, Asia and Latin America since 2012. The program focused on relieving water scarcity, reducing land degradation and enhancing ecosystem services, with an overarching focus on sustainable management of natural resources. WLE's Theory of Change aimed at achieving four outcomes: (1) awareness, including knowledge and attitudes; (2) implementable policies; (3) appropriate investments; and (4) uptake of solutions (Humphrey and Fabricius 2020). An evaluative recommendation of WLE (Humphrey and Fabricius 2020) noted that the program should "synthesize and analyze WLE results and learning ... to serve as a documented program legacy." This paper was conceived in response to that recommendation.

WLE acknowledges the link between ecosystem services and resilience of landscapes, food systems and livelihoods, defining resilience as a "system's capacity to withstand shocks and stresses, transform in response to changing conditions, and adapt in crisis situations" (WLE 2014). The assumption is that when agricultural landscapes are managed in sustainable ways, i.e., to sustain biodiversity and soil productivity and safeguard freshwater resources, they will be more resilient to shocks and changing conditions and be more productive in the long term (WLE 2016).

Integrated landscape management and its parallels, such as landscape agronomy, have evolved substantially since the 1980s. The definition of integrated landscape initiatives has gradually broadened to encompass almost any initiative beyond the field level that strives to minimize unnecessary external inputs in agro-ecological systems, with varying degrees of integration (Carmenta et al. 2020). While studies on agricultural resilience constitute only about 30% of the literature on resilience (Peterson et al. 2018), the literature on agro-ecological resilience is nevertheless replete with references to resilience. A search of WLE publications in the CGSpace database using the terms 'resilience' and 'landscape' produced 81 reports and 104 peer-reviewed papers (including book chapters) published since 2010.[1]

Early studies on landscape resilience tended to focus mainly on biodiversity and ecosystem conservation as desired outcomes. Among the earliest syntheses of resilience principles for production landscapes, Fischer et al. (2006) suggested 10 strategies to enhance biodiversity and ecosystem resilience. Their focus, however, was on the contribution of production landscapes to biodiversity and not vice versa. Sayer et al. (2013) identified principles for an integrated landscape approach to reconcile competing land uses. Many of these principles were adopted in formulating guidelines for sustainable landscape management (e.g., Denier et al. 2015), and five sustainable landscape elements proposed by WWF (2016). In unmanaged systems, resilience is likened to "the maximum pressure a system can undergo before losing its ability to recover" or "the degree to which a system withstands pressure", as well as interactions between system components at different spatial and temporal scales (Walker et al. 2004). In agro-ecosystems, however, resilience must also include production and mechanisms relevant to farmers (Peterson et al. 2018).

In agro-ecosystems, one of the key resilience challenges is to maintain multifunctionality, i.e., the capacity of the landscape to produce multiple ecosystem services and contribute to several United Nations Sustainable Development Goals (SDGs). This includes maintaining agricultural biodiversity – within and among species, fields, farms and landscapes. This diversity then allows landscapes to provide simultaneous benefits, including food, but also regulating services such as pest control and reliable clean water (Attwood et al. 2017). Multifunctional landscapes should also have increased

[1] Accessed on November 1, 2021.

adaptive capacity in an unstable world with many stressors, shocks and surprises; here, self-regulating feedbacks enhance long-term sustainable productivity. It is this capacity of a landscape to simultaneously support multiple benefits to society from its interacting ecosystems (Mastrangelo et al. 2014) that needs to be maintained or enhanced, using evidence-based criteria and design principles. This contrasts with monofunctional landscapes where the quest is purely for productivity gains, often leading to ecosystem degradation and greater vulnerability to unpredictable events (Frei et al. 2020). However, multifunctionality alone does not fully define resilience in agro-ecological systems: there should be additional considerations related to production, governance, justice, equity and benefit sharing, for example.

With some notable exceptions (e.g., Saito et al. 2020; Ashkenazy et al. 2018), most published landscape resilience principles and indicators are conceptually and theoretically formulated without validating them on the ground. Here, we aim to distill core principles and outcome indicators for agro-ecological resilience from the literature. We then systematically validate these principles and indicators using real-world WLE case studies in the form of Outcome Impact Case Reports (OICRs). The purpose of the paper is to identify and validate 'first order control' principles that are most crucial for successful interventions aimed at promoting landscape resilience. We address the following four related questions:

1) Which outcome indicators and process principles feature most prominently in the seminal literature on resilient agro-ecological landscapes?
2) To what extent are these principles represented in CGIAR outcome-indicator case studies, aimed at improving the sustainability of agro-ecological landscapes?
3) How does the frequency of occurrence of process principles in the case studies compare to their occurrence in the theoretical literature?
4) Which process principles co-occur with each of the outcome indicators in the case studies?

Furthermore, the implications for CGIAR's future work are discussed. We wish to derive learning and insights about landscape resilience from WLE case studies to be relevant to the new One CGIAR Research and Innovation Strategy and overarching Theory of Change. We focus on identifying outcome indicators and process principles that aim to promote agro-ecological resilience.

Methods

Rapid literature review

Rapid literature review methods included (1) formulating a relevant and replicable search string; (2) conducting a search; (3) screening the literature for inclusion; (4) assess quality of publications; (5) extracting relevant data; (6) coding the data; (7) analyzing and synthesizing results; (8) identifying most frequent principles and criteria, and outcomes; and (9) ranking principles and criteria, and identifying provisional first order design principles. We focused on the seminal literature related to the resilience of agro-ecological landscapes. The initial step included a systematic, though not exhaustive, search of the literature in the Google Scholar, Web of Science and Scopus databases. The keywords applied in search strings included 'agroecology', 'agroecosystem', 'agroecological landscapes', 'resilience' and 'principles'. A total of 145 eligible manuscripts were examined at the title and abstract level for inclusion in the final subset of articles, based on their associations with the core research focus. Papers were excluded if they focused on only agricultural or biodiversity components and did not explicitly indicate an agro-ecological focus.

This resulted in the retention of a near-final set of 27 manuscripts for analysis. These articles were reviewed to identify only those which documented principles around the resilience and sustainability of agro-ecological systems, leaving a core set of 17 publications. An inductive, thematic coding approach was then applied to extract the common principles emerging from these cases. Those principles which clearly aligned with one another were coded to group similar principles together. Once the coding was complete, similar principles were condensed into a single statement which encapsulated them to create a list of common outcome indicators and process principles. The frequency of occurrence of each principle in the list of core references was counted. Furthermore, each principle was coded according to one of the two components of a theory of change (processes and outcomes).

Case study selection

Case studies, described in Annex 1, were harvested from WLE's OICRs and supplemented by two published case studies from the searchable CGIAR and WLE literature collections, e.g., https://wle.cgiar.org/publications, CGSpace, Web of Science and Google Scholar. Selection criteria included: (1) case studies should focus on applying research results in practice; (2) the scale should be at the landscape or watershed level, i.e., coarser than individual fields, but below the national level; and (3) the outcomes and/or impacts should be aligned with resilience of agro-ecological systems.

Analysis and synthesis

Coding of case studies – Case studies were coded according to their congruence with the provisional design principles emerging from the rapid literature review, as described above.

Mapping case studies to criteria – Congruence of criteria and outcomes in case studies were semi-quantitatively assessed, using frequency histograms to assess frequency of occurrence of process principles and outcome indicators in case studies. The collection of 20 published case studies, mostly but not exclusively WLE's OICRs (see Annex 1 for provisional descriptions of case studies screened) were mapped onto the resilience criteria and principles and outcomes, to ascertain the extent of application of the principles. Case studies were scrutinized for evidence of any of the outcome indicators and process principles. This information was coded in a spreadsheet as either 1 (presence) or 0 (absence). The frequencies of occurrence of indicators and principles in the collection of case studies were summed to produce a total for each outcome indicator and process principle, respectively.

Data were analyzed using an outcomes-by-indicators matrix to produce heatmaps, indicating which associations of outcomes and principles were most and least common in the case studies. Results were also presented in the form of comparative tables and a radial diagram to depict the relative occurrence of outcome indicators and process principles.

Methodological shortcomings

The study was inhibited by two unavoidable shortcomings. First, case studies that demonstrate resilience outcomes on the basis of consistent criteria and indicators are scarce. The case studies used in this study were not pre-designed around a consistent suite of resilience outcomes or process principles and had to be retrospectively evaluated. Many of the parameters were inconsistently documented and had to be inferred from the case study reports. Second, the small number of case studies (20) prevented rigorous empirical analysis. This report should, therefore, be regarded as a qualitative and provisional response to the key questions raised earlier.

Results

Identifying provisional theoretical first order control principles

Here, we address the question: "Which outcome indicators and process principles feature most prominently in the seminal literature on resilient agro-ecological landscapes?"

Six meta-syntheses

The six most prominent meta-syntheses are (1) Mijatović et al. (2013) - analytical framework for strengthening resilience to climate change; (2) WLE (2014) - ecosystem services and resilience framework; (3) UNU-IAS, Bioversity International, IGES and UNDP (2014) - the collaborative toolkit for the indicators of resilience in socio-ecological production landscapes and seascapes; (4) Fischer et al. (2017) - archetypes for resilient social-ecological system states in agro-ecological landscapes; (5) Sayer et al. (2017) - metrics for effectively achieving resilient landscapes; and (6) Peterson et al. (2018) - four dimensions of agro-ecological resilience. The indicators and principles reflected in these publications are presented in more detail below.

1. *Mijatović et al. (2013)*. Based on a review of 172 case studies and project reports from around the world, Mijatović et al. (2013) developed a set of social-ecological indicators to determine the resilience baseline of a landscape: recovery from major shocks and stresses; ecosystem protection; agrobiodiversity; traditional knowledge and innovation; and social equity and infrastructure. They also identified three groups of practices at landscape, farming system and species variety scales that strengthen agro-ecological resilience:

    i. *At landscape level:* ecosystem protection and restoration through, for example, watershed restoration, reforestation and habitat protection.
    ii. *At the farming system level:* adaptation through innovation and diversification, e.g., reducing yield losses through the cultivation of a larger number of species (diversification), crop–livestock integration, crop rotation, irrigation and sustainable soil management.
    iii. *At the level of species/variety:* maintenance and access to biological diversity, e.g., cultivation of fast- growing and stress-tolerant crop species and varieties, and individual and collective efforts to protect diversity.

    The United Nations Development Programme (UNDP) Community Development and Knowledge Management for the Satoyama Initiative used the indicators in 10 countries to help develop project work plans and interventions.

2. *WLE (2014)* developed an ecosystem services and resilience framework grounded in five core principles:

    i. *People.* Meeting the needs of poor people is fundamental – specifically by improving food and livelihood security. This includes equitable access to a sustainable supply of provisioning services; reduced risk from shocks on livelihoods; and new opportunities to generate income.
    ii. *People and nature.* People use, modify and care for nature which provides material and immaterial benefits to their livelihoods. Both societal and ecological components of a system, and the interactions between them are understood and incorporated into governance decisions.
    iii. *Scale.* Cross-scale and cross-level interactions of ecosystem services in agricultural landscapes can be managed to positively impact development outcomes. Correctly identifying the ecological and spatial scales through which these ecosystem services are provided, and matching these to appropriate jurisdictional extents are critical for sound,

integrated management. This facilitates assessment of synergies and trade-offs within and across scales.

iv. *Governance.* Governance mechanisms are vital tools for achieving equitable access to, and provision of, ecosystem services. Managing ecosystem services as common pool resources through polycentric governance systems requires an understanding of stakeholder (i.e., local and national government, community organizations, nongovernmental organizations, private actors, research institutes) interests and agency at each governance level, and interactions between these stakeholders.

v. *Resilience.* Building resilience is about enhancing the capacity of communities to sustainably develop in an uncertain world. It is also about seeking to identify threats and thresholds affecting ecosystem service provision, and aiming to reduce these while increasing the ecological capacity to recover and avoid crossing critical thresholds.

3. *UNU-IAS, Bioversity International, IGES and UNDP (2014)* produced a toolkit for the indicators of resilience in socio-ecological production landscapes and seascapes, with indicators grouped into five areas:

i. *Landscape/seascape diversity and ecosystem protection.* The assumption is that heterogeneous landscapes and seascapes that resemble natural patterns provide greater biodiversity benefits than intensively-managed monocultures. The landscape or seascape is composed of a diversity/mosaic of natural ecosystems (terrestrial and aquatic) and land uses. Areas within the landscape or seascape are protected for their ecological and/or cultural importance. Ecological interactions between different components of landscape or seascape are taken into consideration in natural resource management. The landscape or seascape has the ability to recover and regenerate from environmental shocks and stresses.

ii. *Biodiversity* (including agricultural biodiversity). The assumption is that biodiversity contributes to community and landscape/seascape resilience by providing ecosystem services, which are sustained or degraded by the practices and institutions that regulate the use of natural resources. Agricultural biodiversity provides material for experimentation, innovation and adaptation. Loss in diversity of these traits decreases options for risk management and adaptation. Foods consumed in the landscape or seascape include food that is locally grown, gathered from local forests and/or fished from local waters. Households and/or community groups maintain a diversity of local crop varieties and animal breeds. Common pool resources are managed sustainably in order to avoid overexploitation and depletion.

iii. *Knowledge and innovation.* Communities strengthen their own resilience by experimenting, innovating and learning within and between different knowledge systems, cultures and age groups. New practices in agriculture, fisheries and forestry are developed, adopted and improved and/or traditional practices are revitalized. Local knowledge and cultural traditions related to biodiversity are transmitted from elders and parents to young people in the community. The biodiversity in the landscape or seascape, including agricultural biodiversity, and knowledge associated with it are documented, stored and made available to community members. Women's knowledge, experiences and skills are recognized and respected in the community.

iv. *Governance and social equity.* Gender equality and social inclusion can support women, indigenous groups and others to strengthen the resilience of their landscapes or seascapes. Rights over land/water and other natural resources are clearly defined and recognized by relevant groups and institutions, for example governments and development agencies. Recognition can be formalized by policy, law and/or through customary practices. The landscape or seascape has capable, accountable and transparent local institutions in place for the effective governance of its resources and the local biodiversity. Individuals within and between communities are connected and coordinated through networks that manage resources and exchange materials, skills and knowledge. Rights and access to resources and opportunities for education, information and decision making are fair and equitable for all community members, including women, at household, community and landscape levels.

v. *Livelihoods and well-being.* Livelihood improvement can be directly linked to the options and opportunities of community members to engage in a variety of sustainable income-generating activities. Socioeconomic infrastructure is adequate for community needs. The overall state of human health in the community is satisfactory, also considering the prevailing environmental conditions. People in the landscape or seascape are involved in a variety of sustainable income-generating activities. Livelihood improvements are concerned with innovative use of local biodiversity. Households and communities are able to move around to take advantage of shifts in production opportunities and avoid land degradation and overexploitation.

4. *Fischer et al. (2017)* developed scenarios for win-win solutions between food security and biodiversity conservation, with the assumption that agro-ecological landscapes provide benefits for both and are more resilient. Changes in two outcome metrics, food security and biodiversity, can result in win-lose, lose-win, lose-lose and win-win outcomes – with agro-ecology belonging to the win-win category. Key process elements for win-win solutions are: crop diversity; traditional practices; local governance arrangements supported by traditional institutions; strong reliance on social capital; strong reliance on natural capital; and close human-environment connections.

5. *Sayer et al. (2017)* identified four broad outcome metrics and six process metrics for effective landscape management to deliver multiple societal benefits, including conservation, production and livelihood benefits.

   The outcome metrics:

   i. *Conservation.* The landscape conserves, maintains and restores biodiversity and ecosystem services.
   ii. *Production.* The landscape provides for the sustainable production of crops, livestock, fish, trees and wild edible resources.
   iii. *Livelihoods.* The landscape sustains or enhances the livelihoods and well-being of all social groups who reside there.
   iv. *Institutions.* The landscape-scale institutions support the integration of conservation, production and livelihood functions.

   The process metrics:

   i. *Negotiation and communication of clear goals.* The definition of clear goals should be a stakeholder-driven process and will require skilled facilitation.
   ii. *A clear and agreed theory of change.* The complexity and inherent unpredictability of change in the multiple dimensions of a landscape pose special problems for formulating theories of change.
   iii. *A rigorous and equitable process for continuing stakeholder engagement.* The landscape approach requires a high level of rigor in equitable engagement of all stakeholders in data collection and decision-making processes.
   iv. *Connection to policy processes and key actors.* Explicit connections to policy processes at local, national and global levels are essential in landscape approaches.

v. *Effectiveness of governance.* Governance metrics can measure the effectiveness of institutions, their connectivity, and the extent to which they reflect the views of, and are trusted by, the full range of actors in the landscape.
vi. *Transparency.* Transparency is necessary for achieving landscape-level outcomes and is required for building trust in the management process and leadership.

6. *Peterson et al. (2018)* identified four outcome indicators for agro-ecological resilience:

i. *Productivity*, or total agricultural production or service provision.
ii. *Stability*, or the magnitude of variation around mean production levels.
iii. *Resistance* to declines in yield components or growth parameters and their supporting mechanisms in the face of disturbance (ecological resilience).
iv. *Rapid recovery* to baseline functionality when conditions improve. Maintaining agro-ecological resilience thus means avoiding irreversible change while promoting sustainable food production and allowing other ecosystem services, besides food, to persist.

Most common outcome indicators and process principles in the literature

Outcome indicators and process principles that were dominant in the six meta-syntheses and 17 systematically selected papers (see section *Methods*) are presented below.

Five outcome indicators

Five outcome indicators are common to the six meta-syntheses assessed.

1. *Ecosystem integrity.* The landscape conserves a diverse range of species and produces multiple ecosystem services with minimal environmental degradation.
2. *Adaptive capacity.* The social and ecological elements of the landscape have the capacity to adapt to and rapidly recover after change, shocks and surprises.
3. *Human well-being.* The landscape sustains livelihoods and improves well-being, including food security, and provides equitable access to a reliable supply of resources.
4. *Sustained production.* The landscape provides for sustainable and reliable production of food (crops, livestock, fish, wild resources).
5. *Effective governance.* The institutions governing the landscape are effective in achieving equitable access to and sustainable management of common pool resources.

Six process principles

The 17 systematically selected papers concurred on six primary process principles (Table 1).

1. *Maintaining and enhancing diversity.* A diversity of crop varieties and animal breeds are maintained. There is a strong reliance on diverse forms of natural capital. Areas within the landscape are protected for their ecological or cultural importance.
2. *Adopting a systems approach to landscape management.* The social and ecological components of landscapes, and the feedbacks between them, are managed in an integrated manner. Both components are incorporated into governance and management decisions, with close connections between humans and nature.
3. *Promoting rights and equitable access to land and resources.* Rights to land and resources are clearly identified and recognized, and resources are equitably shared.
4. *Fostering inclusivity.* Multiple stakeholders and knowledge systems, including traditional knowledge holders, contribute to decision making, learning and innovation.
5. *Matching local and regional social needs and biophysical contexts*. Strategies and interventions are appropriate to the circumstances of local resource users, with context-specific knowledge that fits the social, technological, economic, environmental, political and cultural contexts.

6. *Developing and supporting robust institutions.* Common pool resources are governed through functioning institutions, aligned with the scale of resources being managed, with a strong emphasis on participation, trust and transparency.

In the remainder of this paper, the 20 case studies are compared to these outcome indicators and process principles.

Table 1. Frequency of process principles for resilient production landscapes occurring in the selected literature on agro-ecology.

Process principle	Frequency	References
Maintaining and enhancing diversity	14	Bailey and Buck 2016; Cabell and Oelofse 2012; Fischer et al. 2006, 2017; Howard et al. 2006; Jeanneret et al. 2021; Koohafkan et al. 2012; Mijatović et al. 2013; Nicholls and Altieri 2018; Peterson et al. 2018; Sayer et al. 2013, 2017; Tittonell 2020; UNU-IAS, Bioversity International, IGES and UNDP 2014; WLE 2014
Developing and supporting robust institutions	14	Bailey and Buck 2016; Cabell and Oelofse 2012; Fischer et al. 2017; Howard et al. 2006; Jeanneret et al. 2021; Koohafkan et al. 2012; Kremen et al. 2012; Mijatović et al. 2013; Nicholls and Altieri 2018; Sayer et al. 2013, 2017; Scherr and McNeely 2008; Tittonell 2020; UNU-IAS, Bioversity International, IGES and UNDP 2014; WLE 2014
Promoting rights and equitable access to land and resources	12	Bailey and Buck 2016; Cabell and Oelofse 2012; Fischer et al. 2017; Howard et al. 2006; Jeanneret et al. 2021; Kremen et al. 2012; Mijatović et al. 2013; Sayer et al. 2013; Scherr and McNeely 2008; Tittonell 2020; UNU-IAS, Bioversity International, IGES and UNDP 2014; WLE 2014
Fostering inclusivity	12	Altieri and Toledo 2011; Cabell and Oelofse 2012; Fischer et al. 2006, 2017; Howard et al. 2006; Jeanneret et al. 2021; Koohafkan et al. 2012; Kremen et al. 2012; Mijatović et al. 2013; Nicholls and Altieri 2018; Tittonell 2020; UNU-IAS, Bioversity International, IGES and UNDP 2014
Adopting a systems approach to landscape management	11	Bailey and Buck 2016; Cabell and Oelofse 2012; Fischer et al. 2006; Jeanneret et al. 2021; Kremen et al. 2012; Peterson et al. 2018; Sayer et al. 2013; Scherr and McNeely 2008; Tittonell 2020; UNU-IAS, Bioversity International, IGES and UNDP 2014; WLE 2014
Matching local and regional social needs and biophysical contexts	9	Altieri and Toledo 2011; Cabell and Oelofse 2012; Fischer et al. 2006, 2017; Howard et al. 2006; Jeanneret et al. 2021; Kremen et al. 2012; Nicholls and Altieri 2018; Tittonell 2020

Use of the principles in case studies

Here, we address the question: *To what extent are these principles represented in CGIAR outcome-indicator case studies, aimed at improving the sustainability of agro-ecological landscapes?* The occurrence of outcome indicators and process principles discovered in the 20 case studies are presented.

Outcome indicators

The outcome indicators for resilient landscapes that occurred most frequently in the 20 case studies (described in Annex 1) were:

1) Sustained production
2) Adaptive capacity
3) Human well-being

The indicators for effective governance and ecosystem integrity were poorly represented in the 20 case studies (Table 2 and Figure 1). This ranking is consistent with CGIAR's strategic priorities, Theory of Change and prioritized investments in research funding (Holderness et al. 2021).[2]

Process principles

The most frequently occurring process principles (see Table 2 and Figure 1) were: (1) matching local and regional social needs and biophysical contexts; (2) adopting a social-ecological systems approach[3] to landscape management; (3) maintaining and enhancing diversity; (4) fostering inclusivity; and (5) developing and supporting robust institutions. Promoting rights and equitable access to land and resources featured infrequently.

Table 2. Outcome indicators and process principles in the 20 case studies.

Outcome indicator	Number of case studies	Process principle	Number of case studies
1. Sustained production	14	1. Matching local and regional social needs and biophysical contexts	19
2. Adaptive capacity	13	2. Adopting a systems approach to landscape management	11
3. Human well-being	12	3. Maintaining and enhancing diversity	7
4. Effective governance	5	4. Fostering inclusivity	7
5. Ecosystem integrity	4	5. Developing and supporting robust institutions	6
		6. Promoting rights and equitable access to land and resources	2

[2] While WLE frequently acknowledged the importance of governance and institutions, these outcomes were not reflected in the allocation of WLE research funding (Humphrey and Fabricius 2020).

[3] We define social-ecological systems as "interdependent and linked systems of people and nature that are nested across scales" (Bouamrane et al. 2016).

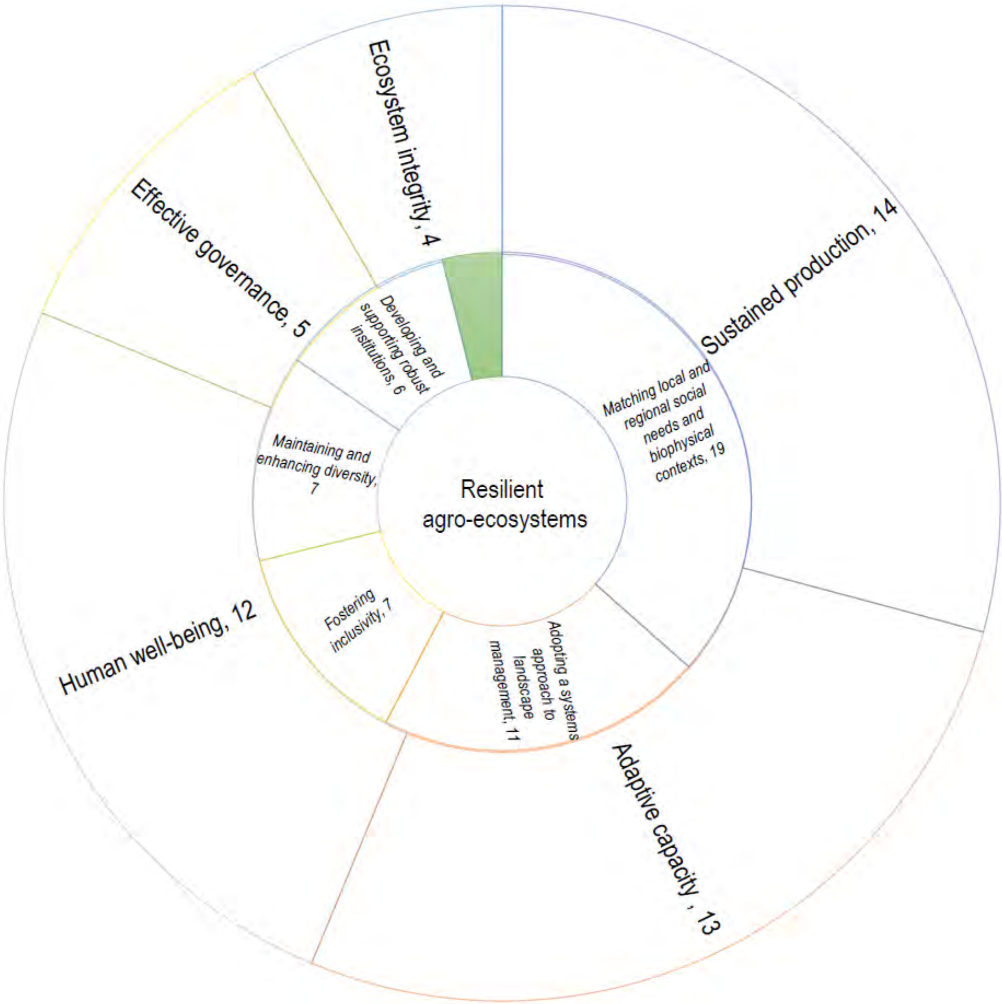

Figure 1. Relative frequencies of outcome indicators (outer circle) and process principles (inner circle) in the 20 case studies evaluated. The green shaded area shows the frequency of the process principle promoting rights and equitable access to land and resources, with 2 case studies.

Comparison of principles in theory and in case studies

Here, we address the question: “How does the frequency of occurrence of process principles in the case studies compare to their occurrence in the theoretical literature?” We found major incongruences. With a coefficient of variation (CV) of 14%, the occurrence of the six process principles in the literature we reviewed is far less varied than their uneven representation in the case studies, with a CV of 61%.

Figure 2 illustrates these incongruences. Adopting a systems approach is the only process principle that is somewhat equally represented in the theoretical literature and in the CGIAR case studies. Matching local and regional social needs and biophysical contexts is more common in the case studies than in the theoretical literature (95% in case studies versus 52% in theoretical literature). All the other principles are far less common in the case studies than in the theoretical literature (Figure 2), with the greatest difference in the principle of promoting rights and equitable access to land and resources, which occurred in 70% of the theoretical literature but in only 10% (two) of the case studies.

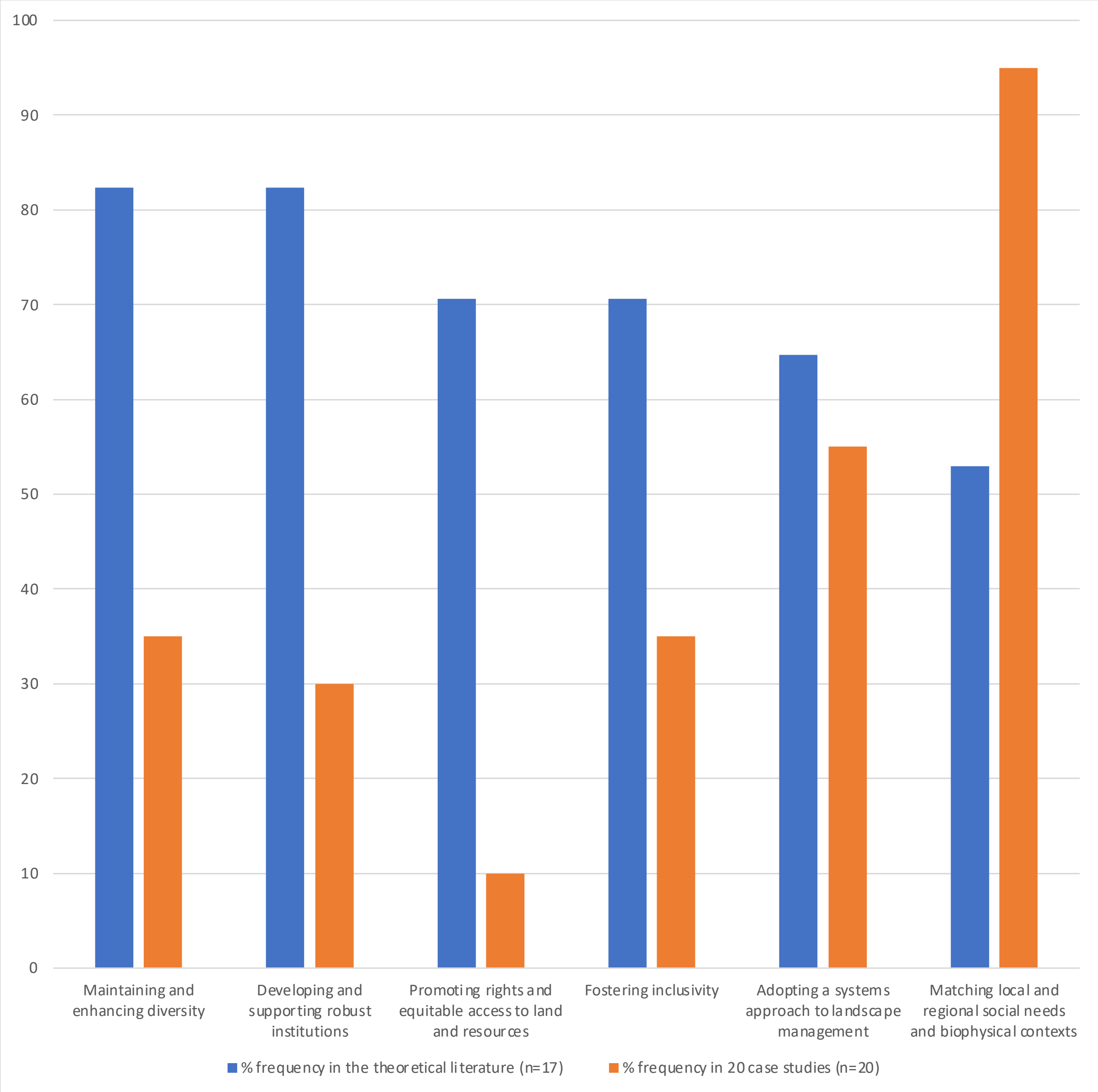

Figure 2. Frequency of occurrence (percentage) of process principles in the theoretical literature and in case studies.

Co-occurrence of process principles and outcome indicators in case studies

In this section, the association between process principles and outcome indicators is assessed, asking: "Which process principles co-occur with the outcome indicators in the case studies?"

A co-occurrence matrix, presented in the form of a heatmap, is shown in Figure 3. The process principle with the highest coincidence – also the most frequently occurring principle overall – was matching local and regional social needs and biophysical contexts, i.e., tailoring the approach to local and regional circumstances. In the theoretical literature and case studies reviewed, this principle co-occurred with the outcomes of adaptive capacity, human well-being and sustained production. The second most co-occurring process principle was adopting a systems approach to landscape management, i.e., simultaneously addressing the social and ecological components of the system. This principle co-occurred with adaptive capacity, human well-being and sustained production in the theoretical literature and case studies.

These results must, however, be interpreted with caution. It should be borne in mind that the frequently co-occurring outcome indicators and process principles are also most ubiquitous in the case studies (see Table 2). When Figure 3, the co-occurrence matrix, is more critically compared to Table 2, it becomes apparent that (with the possible exception of the process principle adopting a systems approach to landscape management) none of the co-occurrences are disproportionate to their representation in the case studies.

The implication is that, while unevenly represented in the case studies, all the process principles are to some extent relevant in influencing resilience outcomes. The relatively few case studies are, however, a significant constraint in interpreting the co-occurrence data.

Ecosystem integrity	*Adaptive capacity*	*Human well-being*	*Sustained production*	*Effective governance*	
3	5	4	5	3	*Maintaining and enhancing diversity*
3	8	10	9	3	*Adopting a systems approach to landscape management*
1	0	1	1	2	*Promoting rights and equitable access to land and resources*
2	6	5	6	3	*Fostering inclusivity*
3	13	12	14	5	*Matching local and regional social needs and biophysical contexts*
1	3	5	5	3	*Developing and supporting robust institutions*

Figure 3. Co-occurrence matrix of outcome indicators (top row) and process principles (right hand column). Numbers in the cells represent the number of times a process principle co-occurred with an outcome indicator in the same case study. The darker the color, the more frequent the co-occurrence.

Discussion and conclusions

Main findings

- There is reasonable agreement in the literature on a limited set of outcome indicators and process principles for agro-ecosystem resilience. However, differences in phraseology and language may give the impression of divergence.
- While authors seldom differentiate between outcome indicators and process principles, and often conflate these, their differentiation is important.
- Outcomes are unevenly represented in WLE case studies, with apparent biases toward sustained production, adaptive capacity and human well-being, with less emphasis on ecosystem integrity and effective governance. Two process principles – matching local and regional social needs and biophysical contexts, and adopting a systems approach to landscape management – seem to be consistently linked to positive outcomes for effective governance, adaptive capacity, human well-being and sustained production.
- Process principles are dominated by the principle of matching local and regional social needs and biophysical contexts – a key feature of WLE's work.
- All the process principles seem to be relevant to achieving the respective outcomes, with little evidence of redundancy.

Which outcome indicators and process principles feature most prominently in the seminal literature?

This study brought together and synthesized recent and historical indicators and principles for resilient agro-ecological landscape management. Synthesized resilience principles in agro-ecosystems display a remarkable level of convergence, despite the diverse ways they are phrased. There is, however, a fair amount of cross-referencing involved, i.e., several authors citing the same source. For the purpose of this study, we distinguished between outcome indicators and process principles. These two categories are often confused or conflated in the literature on resilience. We were thus able to construct a robust high-level theory of change for resilience in agro-ecological landscapes, presented in Figure 4.

Some previous studies on resilience have incorporated a large and unmanageable suite of principles and indicators; for example, Panpakdee and Limnirankul (2018) measured no fewer than 47 indicators in their case study of organic rice production in Thailand. Reducing the number of indicators and principles to a handful of first order principles has the advantage of practicability as well as comparability across case studies – provided the appropriate data are consistently and systematically collected.

To what extent are these principles represented in CGIAR outcome-indicator case studies?

We found that while all the theoretical outcomes and indicators were evident in the full complement of 20 case studies, they were highly unevenly represented. The most common case study outcomes were adaptive capacity, sustained production and human well-being, with ecosystem integrity and effective governance seldom incorporated. This imbalance is consistent with CGIAR's system level outcomes of reduced poverty and improved food and nutrition security, but less so with the system level outcome of improved natural resource systems and ecosystem services.

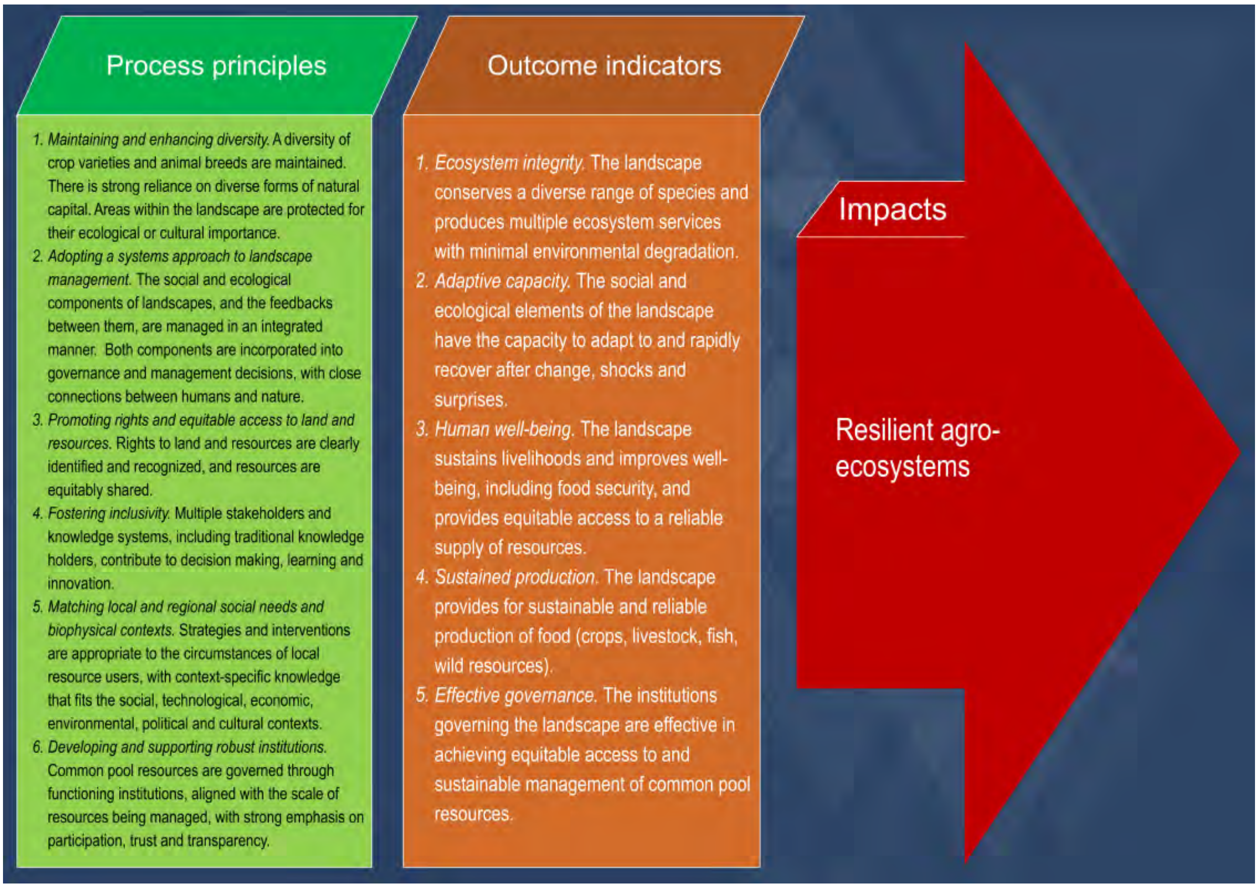

Figure 4. A stylized theory of change for resilient agro-ecological landscapes.

Among the reasons for this discrepancy are: (a) the difficulty of providing evidence of changes in governance and ecosystem integrity, beyond improvements in individual provisioning services such as crops, water and soil; and (b) the lower priority of ecosystem integrity, and governance, in resource allocation models for agro-ecology research in WLE and CGIAR, whose mandate focused more on people, food security and poverty and not all principles/outcomes (Humphrey and Fabricius 2020). This discrepancy was, however, to some extent compensated for by the strong representation of governance in other CGIAR Research Programs, e.g., Policies, Institutions, and Markets (PIM) (McLain 2021).

Which process principles co-occur with related outcome indicators in the case studies?

We found that, with the possible exception of adopting a systems approach to landscape management, all process principles and outcome indicators co-occur in the same proportions as their presence in the case studies – i.e., the observed and expected frequencies of co-occurrences did not differ.

While there are too few case studies to make any empirical conclusions, all of the principles are to some extent relevant, with little evidence of redundancy. The evidence does support the logic that the process principle adopting a systems approach to landscape management is important for adaptive capacity, human well-being and sustained production. The sample sizes were, however, too small to arrive at any definitive conclusions about co-occurrence.

Implications for One CGIAR's work

General recommendations

- *Being specific about the outcomes and principles of landscape resilience.* Systems transformation and resilient agrifood systems are two important action areas that are strongly represented in One CGIAR's "ways of working" (CGIAR 2020). CGIAR aims to strengthen their implementation through targeted risk management and resilience assessment (WLE 2014). An analysis of WLE OICRs suggests that resilience, as an outcome, has been vaguely defined with no explicitly defined process principles by which to assess progress toward outcomes. Sharpening this is important to inform adaptive management of resilient agro-ecosystems, as is clarifying whether the aim is to enhance general resilience or specified resilience (i.e., resilience of what, to what?) (Peterson et al. 2018; Meuwissen et al. 2019). Ciftcioglu (2017), for example, distinguished between ecological resilience, agricultural resilience, social resilience and overall resilience in her assessment of social-ecological production landscapes in Cyprus.
- *The need for a theory of change to build resilience.* To support this, One CGIAR should use the theory of change approach containing clear outcome indicators and measurable process principles for resilience in production landscapes. The stylized theory of change presented in Figure 4 provides an initial framework to guide monitoring and evaluation of resilience in agro-ecosystems (cf. Forsyth 2018), offering a basis for a more comprehensive theory of change coupled with empirical evaluation and incremental refinement.
- *Targeted monitoring and reporting systems.* To measure progress, it is imperative that One CGIAR adopts monitoring and reporting systems that explicitly and systematically incorporate the outcomes and principles of resilience along the lines of those defined in this paper. Achieving this would not only inform adaptive research program management, but also enable One CGIAR to demonstrate to its stakeholders that its work has had the desired resilience outcomes (cf. Lin 2011).
- *Stronger focus on ecosystem integrity and governance.* Our analysis suggests that CGIAR may want to strengthen its focus on two resilience outcomes – ecosystem integrity and effective governance – without neglecting sustained production, adaptive capacity and human well-being. It may be argued that ecosystem integrity has indeed received adequate attention: many of the case studies have demonstrated improvements in provisioning ecosystem services, particularly water and soil. However, improvements in individual ecosystem services are not necessarily equivalent to ecosystem integrity, which hinges on biodiversity, landscape multifunctionality, restoration and minimal ecological degradation. These factors have hardly been assessed in the case studies. WLE (2013), for example, found that in Nepal, reforestation and sustainable management of forest resources can strengthen ecosystem services such as soil erosion control, food and energy. Strong collective action and knowledge exchange in the communities have led to more sustainable farming practices.[4]

These four recommendations are well aligned with the recommendations by Holderness et al. (2021) for resilient agri-food systems, where they advise researchers to "put priority on expanding longer-term, place-based systems research" and "improve measures of risk and resilience."

[4] Of note, other CGIAR Research Programs, including Policies, Institutions, and Markets (PIM) and Forests, Trees and Agroforestry (FTA), contributed OICRs with a focus on governance that were not considered for this analysis.

Suggested novel research themes

One CGIAR may want to consider investing in well-defined projects and programs aimed at operationalizing social-ecological resilience in the context of agro-ecological landscapes. Examples of novel research themes could include the following:

- Understanding the drivers of social-ecological resilience in agro-ecosystems, asking: "Which institutions, processes and actions provide optimal outcomes for social-ecological resilience at landscape level?"
- Investigating the multiscale linkages between resilience outcomes and drivers at the scales of a nation, river basin, sub-catchment and local community, asking: "What are the cross-scale feedbacks between the drivers and outcomes of social-ecological resilience at multiple spatial scales, and can intervention strengthen resilience across sectors and scales and how?"
- Investigating the long-term costs, risks and benefits of initiatives geared toward enhancing local social-ecological resilience in agro-ecological landscapes, asking: "Which interventions provide the most favorable benefit-to-cost ratio in reducing risk and enhancing resilience in agro-ecological landscapes?"
- Investigating the overall, long-term system outcomes and trade-offs of enhancing social, economic and ecological resilience, asking: "What are the interactions and trade-offs among different kinds of system resilience?"
- Investigating how the feedbacks, trade-offs and synergies between social, ecological and economic resilience vary at multiple scales.
- Selecting appropriate surrogates or proxies to cost-effectively monitor economic, social and ecological as well as overall system resilience in agro-ecological landscapes.
- Conducting a comparative analysis of agro-ecological system response and recovery times after disturbance, using big data such as remote sensing and long-term data series.
- Investigating the relationship between indicators of institutional robustness (in the sense of Ostrom and Cox 2010) and resilience outcomes.

While these recommended research themes are aligned with those in Peterson et al. (2018) and Holderness et al. (2021), they add value through understanding the trade-offs and feedbacks between production systems, ecosystems and institutions in agro-ecological landscapes in minimizing risk and enhancing resilience.

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Annex 1. Case study descriptions.[5]

Case study name	Description
1. Making the leap from drought monitoring to managing agricultural drought risks in India	The South Asia Drought Monitoring System (SADMS), created by WLE and partners, provided real-time drought severity data at the micro level to three Indian districts. The crop yields and incomes in these areas were significantly higher than in the control areas. As a result, the Indian government and the World Bank plan to scale out the model.
2. Soil–plant spectral technology guiding soil fertility investments in Africa	Seventeen African countries are now using soil–plant spectral technology developed by WLE and partners to restore soils and boost agricultural production. The Africa Soil Information Service is now being deployed for targeting soil fertility restoration strategies. Ethiopia, Ghana, Nigeria and Tanzania have established state-of-the-art soil information systems based on the technology. Nongovernmental organizations and the private sector are delivering soil testing services to smallholder farmers and monitoring intervention impacts on soil health. Sophisticated technology improves soil fertility, a widespread problem in agro-ecosystems in Africa.
3. Smart water technology tools in Zimbabwe improved water and land productivity	The combined use of Agricultural Innovation Platforms and smart water management tools in two small-scale communal irrigation schemes in Zimbabwe resulted in major improvements in water and land productivity, household incomes, and reductions in conflict levels. As a result, the Director of Irrigation with support from the Australian Centre for International Agricultural Research agreed to fund a second project that is extending the model to 30 more irrigation schemes, covering 757 hectares and 1,698 farmers. The project is looked at in terms of complex outcomes, improved household incomes and a decline in conflicts.
4. Increasing irrigation water productivity in Mozambique, Tanzania and Zimbabwe through on farm monitoring, adaptive management and Agricultural Innovation Platforms	The project was developed to test a specific combination of technical and institutional change methods to increase irrigation water productivity and profitability in African smallholder irrigation schemes. This combination of tools and Agricultural Innovation Platforms has positive synergies that were found capable of reinvigorating failing irrigation schemes. To achieve better yields with reduced losses of water and nutrients, smallholder farmers have been helped to monitor and understand the water and nutrient levels in their soils by using two inexpensive, simple-to-use tools. Farmers used these to learn the best combination of fertilizer application and irrigation for their crops on their soils, and so increased their yields. This is another case of the successful use of technological innovation to make improvements, but there is also emphasis on learning and adaptation. The project also encouraged dialogue and problem solving to solve problems such as the lack of access to markets. It recognizes water productivity as a complex problem with no silver bullets, and emphasizes solving complex problems with multiple interventions, noting that single, ill-considered interventions can have negative outcomes. Complex irrigation systems require different and complementary measures at various scales to be more profitable and

[5] Sources: WLE unpublished OICRs provided by Keith Child (personal communication); WLE OICRs 2017-2019 (Humphrey and Fabricius 2020); Ashkenazy et al. (2018); Knickel et al. (2018).

	sustainable. Investing in people is as necessary as investing in hardware to overcome multiple barriers.
5. Building community prosperity through scaling out agricultural water management interventions for sustainable crop intensification in central India	Water harvesting and productivity interventions implemented by WLE, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the Central Agroforestry Research Institute on a pilot watershed in central India had significant impacts on water resources, incomes and farmers' livelihoods. As a result, the Government of Uttar Pradesh has asked ICRISAT and a consortium of national partners to scale the model out to over 35,000 hectares. Various interventions made more irrigation water available, and increased crop and livestock yields. Agricultural incomes nearly tripled. It reduced the need for farmers to seek work elsewhere. The interventions were largely technological, but were diverse, mostly in the realm of water use efficiency. Interventions supported farmers to diversify and intensify crop production through agroforestry. Ecosystem services were revitalized, and tree biomass and carbon sequestration increased, while soil erosion declined.
6. Enlisting the dairy industry to end Colombia's deforestation crisis	The Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT) (hereafter referred to as 'Alliance') was asked to lead the multistakeholder platform technical Secretariat for Colombia's zero-deforestation dairy value chain agreement. Alliance staff and partners went on an outreach blitz to encourage the sector's big players to sign the agreement. With active engagement and support provided by the Secretariat, Alpina, a large corporation, and Asoleche, the national association of milk processors, signed the agreement within a year. Exactly how the interventions helped to make appropriate trade-offs is not clear.
7. Data sharing on soil and agronomy leads to new possibilities for supporting farmers in Ethiopia	A collaborative effort by WLE/Alliance, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)-Ethiopia and partners to institutionalize data sharing in Ethiopia has resulted in further funding of the exercise and scaling of the framework to other countries. The partners undertook many activities: data collation, creation of a digital web portal, data standardization guidelines and big data analysis. This has led to better-targeted recommendations and a paradigm shift in the research and development discourse regarding contextualized agro-advisory services. The collaboration facilitated data storage, sharing, interpretation and use. It led to the development of a site-specific fertilizer recommendation tool and improved analytics for targeted applications.
8. Wheat varietal diversification increases smallholders' food security in Ethiopia	The WLE/Alliance-led Seeds for Needs program developed a new way to evaluate and promote improved seed varieties and advanced breeding lines. A survey of 1,008 households across three Ethiopian states shows how the program significantly enhanced wheat productivity and smallholders' food security by increasing varietal diversification. The study provides empirical evidence for the effective role varietal diversity can play in improving food security in marginal environments. The Seeds for Needs program provided farmers with diverse seeds that could survive in a changing climate. More than just distributing seeds, the farmers were invited to participate in on-farm experimental trials of selected seed varieties. The program significantly enhanced wheat crop productivity and food security through a single, technological intervention.
9. Agua de Honduras	Initially developed by WLE/CIAT and partners, the Agua de Honduras platform is being scaled out from western Honduras to additional regions. Further, its award-winning tool, AGRI (AGua para RIego), has attracted the

	attention of other international agencies: they are supporting its implementation in Central America, Ethiopia, Grenada, Kenya and Rwanda. Decision makers in these regions can now use these novel tools to better manage their water resources and investments. Good planning is data dependent, and the program links to world knowledge. The key in this case has been knowledge sharing and technological innovation.
10. ICARDA dryland watershed, Jordan	Mechanized micro water harvesting packages developed by WLE, the International Center for Agricultural Research in the Dry Areas (ICARDA) and the Jordanian National Agricultural Research Center are being scaled out in collaboration with local communities, targeting at least 1,000 hectares per year. The community-based approach effectively rehabilitates degraded, dry agro-pastoral watersheds through water harvesting, plantation of native vegetation and enhanced downstream floodwater agriculture. Community empowerment ensures long-term sustainability of the interventions. It achieves community-based rehabilitation of dry agro-pastures through mechanized micro water harvesting and flood irrigation agriculture. The approach includes plantation of native vegetation, and also includes rehabilitation of watersheds. Geographic information system (GIS) data is combined with a simulation of surface runoff to determine which areas are more suitable for rehabilitation activities. Engagement with local communities is critical for success.
11. Myanmar: New approach to water users' associations in pump-based irrigation schemes results in equitable water allocation and boosts production	Funded through the Livelihoods and Food Security Fund (LIFT) from December 2016 to mid-2019, WLE and the International Water Management Institute (IWMI) developed a novel approach to establishing water users' associations (WUAs) in pump-based irrigation schemes in Myanmar. This was accompanied by the introduction of new crop varieties and high-quality pulse and rice seeds by Welthungerhilfe and ICRISAT. Despite a drought, farmers reported 1.5 years after LIFT ended that their WUA had enabled them to double the irrigated area and increase crop production. The approach also involved new crop varieties, high-quality pulse and rice seeds. Farmers elected association leaders and drew up rules for distributing water. This case combined a technological and community intervention.
12. Water policy, Ethiopia	The Ethiopian government has initiated a process of water policy reform. WLE/IWMI was approached by the Ministry of Agriculture, and the Ministry of Water, Irrigation and Energy to contribute to the review. Drawing from its research, WLE/IWMI brought new ideas to the policy reform table. These ideas include the concept of multiple water values, payment for ecosystem services, irrigation cost recovery, and irrigation performance benchmarking. These options have been incorporated in the draft policy document, and influenced Ethiopian water sector policy reform to recognize multiple water values and other up-to-date options. They are informed by research and encompass stakeholder training as well. The process is a recognition of the complex, interlinked nature of the water resources of Ethiopia.
13. Mapping solar suitability to expand solar pump supply chains across sub-Saharan Africa	A set of online interactive maps have been developed by WLE/IWMI to show the highest-potential locations for targeting small solar-powered irrigation pumps to smallholder farmers. Millions of farmers can substantially increase their incomes using these pumps. The tool is used to inform planning and management of sustainable solar pump irrigation dissemination in sub-Saharan Africa. Several project partners, i.e., solar manufacturing and distribution companies, are using the maps to expand their distribution and

	supply chains. They have minimized negative environmental effects such as water resource depletion.
14. Water accounting tools to improve water distribution in Uzbekistan	An innovative water measurement and accounting tool developed and tested by WLE/IWMI and partners, Smartsticks, has proven to be successful in improving water accounting in Uzbek irrigation associations. They enable associations to automatically record water deliveries to farmers. This accurate, transparent and easy-to-use tool resolves conflicts over water distribution and incentivizes farmers to pay irrigation fees. As a result, the technology was included among priority investments in the Agricultural Development Strategy of Uzbekistan for 2020-2030. It discourages overuse of water.
15. Research findings on water and energy use have impacted water policies in Uzbekistan	WLE/IWMI research findings demonstrated that substantial water and energy savings could be achieved by adopting more efficient irrigation technologies in the lift irrigated areas of Uzbekistan. Researchers engaged with decision makers and recommended that the government shift subsidies from energy to water saving technologies. This recommendation has been adopted in a state program on water saving technologies covering 450,000 hectares in 2021. More efficient irrigation technologies resulted in substantial water and energy savings. The government shifted subsidies toward water saving technologies. The move to drip irrigation proved more efficient in terms of energy and improved yields.
16. SADMS (South Asia Drought Monitoring System)	The South Asia Drought Monitoring System (SADMS) was created by WLE/IWMI with support from Japan's Ministry of Agriculture, Forestry and Fisheries, the Indian Council of Agricultural Research, and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Since 2018, SADMS has provided real-time drought severity data to southern Indian states to inform drought contingency plans. Crop yields and incomes have been significantly higher than in areas that did not receive data. Following its success in India, the system has been scaled out in other Asian and African countries. It makes the leap from drought monitoring to managing agricultural drought risks. Information to guide drought contingency plans increases crop yields and incomes. Information/data improves resilience to drought.
17. Joint village land-use planning in Tanzania	Through the Sustainable Rangeland Management Project supported by PIM and the CGIAR Research Program on Livestock, joint village land use planning has been implemented in three areas in the Kiketo district in rural Tanzania, securing 150,000 hectares of grazing land to protect shared resources across village boundaries, and solve conflicts between farmers and pastoralists. Plans are underway to scale up this methodology through inclusion into national policy documents. Planning helps to protect shared resources across village boundaries and resolve conflicts between farmers and pastoralists. The methodology will be included in national policy documents. Overgrazing and insecure land rights lead to conflicts. A livestock keepers association was established and provided with group certificates of customary rights of occupancy. A draft manual on conflict resolution in village land use planning was produced and given to the government to produce a national manual.
18. Harnessing Ethiopian floodwaters helps dryland pastoralists	The government of Afar state, Ethiopia, has adopted a landscape-level water spreading approach demonstrated by WLE and partners in dry lowland areas. The approach reduces destruction from flooding and spreads water across pastures and cultivated fields, increasing their productivity.

	This approach has been integrated into a proposed project supported by the World Bank and International Fund for Agricultural Development. In a land of alternating droughts and floods, it uses interconnected weirs and small dams to capture and distribute water, reviving grazing lands and boosting crop productivity. Maps of water and nutrient deposits were created to guide recommendations on cultivation schedules, and what crops and forages to grow where. It also reduced the amount of sedimentation entering local water sources. Minimal fertilizer inputs were required.
19. Operationalizing resilience in farms and rural regions – Findings from fourteen case studies	Using case studies from 14 different countries across Europe and beyond, the researchers addressed two main questions. First, how the notion of resilience is being operationalized at a farm or regional level. That is to say, what are the different strategies that farmers, rural residents and other decision makers in rural areas are using to enhance resilience? Second, they looked at how the outcomes of implementing these strategies vary according to spatial and temporal factors. The research illustrated how resilience is operationalized on a farm and regional level, suggesting five categories of strategies that are being used to enhance resilience: recognizing the economic as well as social value of local traditions and capacities; finding new ways to diversify rural residents' economic activities and sources of income; utilizing new technologies and the scales of a globalized market economy while keeping in mind the vulnerabilities associated with it; bringing together different communities, residents and actors in rural regions and in cities to build greater social cohesion; and utilizing government assistance to farmers and rural regions to maintain public goods that may otherwise fade away.
20. Between aspirations and reality: Making farming, food systems and rural areas more resilient, sustainable and equitable	Evidence from case studies in 14 countries was used to explore the possibilities for, and drivers and limitations of, systemic change in four thematic areas: the resilience of farms and rural areas; prosperity and well-being; knowledge and innovation; and the governance of agriculture and rural areas.

RESEARCH PROGRAM ON Water, Land and Ecosystems

LED BY: IWMI International Water Management Institute

Photo: David Brazier/IWMI

CGIAR Research Program on Water, Land and Ecosystems (WLE)

The **CGIAR Research Program on Water, Land and Ecosystems (WLE)** is a global research-for-development program connecting partners to deliver sustainable agriculture solutions that enhance our natural resources – and the lives of people that rely on them. WLE brings together 11 CGIAR centers, the Food and Agriculture Organization of the United Nations (FAO), the RUAF Global Partnership and national, regional and international partners to deliver solutions that change agriculture from a driver of environmental degradation to part of the solution. WLE is led by the International Water Management Institute (IWMI) and partners as part of CGIAR, a global research partnership for a food-secure future.

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