

# Applying social-ecological system resilience principles to the context of woody vegetation management in smallholder farming landscapes of the Global South

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## ABSTRACT

Woody vegetation diversity is declining due to human-induced land-use changes, mainly agricultural expansion and intensification, deforestation, forest degradation and urbanisation. This loss challenges the resilience and sustainability of smallholder farming landscapes, in which woody vegetation plays an important role for the provision of multiple material and non-material benefits to people and nature. In this review, we examine the relevance and application of established social-ecological resilience principles to woody vegetation management and explore how the resilience of smallholder farming landscapes can be enhanced in the Global South. To this end, we conducted a qualitative review and purposefully selected scientific literature relevant to each resilience principle. Exemplified by different cases from across the Global South, we collate evidence for the significance of all principles for woody vegetation management. Our review also sheds light on widespread obstacles to sustainable woody vegetation management and landscape resilience, such as the pursuit of top-down and sectoral policies for agriculture and woody vegetation management, deep-rooted power dynamics and asymmetries, and the marginalisation of local people and their traditional knowledge systems. Applying resilience principles to woody vegetation management in smallholder farming landscapes therefore requires transformative changes that enable paradigm shifts, for example, through more genuine recognition of local people and their livelihoods, knowledge and experiences.

## HIGHLIGHTS

- Ongoing ecosystem destruction and unsustainable development pathways are posing a challenge in smallholder farming landscapes of the Global South.
- More specifically, they are triggering rapid loss of ecological and social diversity.
- These mainly affect the diversity of woody vegetation and ecosystem services, which are essential for nature and human life.
- To manage such landscapes, it is therefore useful to think of them as interconnected social-ecological systems and use resilience principles.

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## 1. Introduction

Safeguarding biodiversity, ecosystem functions and services (ES) for a rapidly growing human population is a global challenge (Steffen et al. 2015; Díaz et al. 2019; WWF 2020). Human-induced land cover changes, including agricultural expansion and intensification, have significantly affected almost all terrestrial ecosystems today (Foley et al. 2011; Steffen et al. 2015; Jaureguiberry et al. 2022). The resulting impacts include climate change, environmental pollution, land degradation and biodiversity loss (Foley et al. 2005; IPBES 2019; WWF 2020). These, in turn, have affected the functioning of the entire Earth system, triggering non-linear and irreversible changes on a variety of ES, from local to global scales (Steffen et al. 2015; Díaz et al. 2019).

These effects are particularly alarming in smallholder farming landscapes of the Global South (Box 1), where local people still greatly depend on natural resources from their immediate surrounding

and often have close ties to nature (Grass et al. 2020; Hickel et al. 2022; Santiago et al. 2022). Those changes devastate not only nature, but also drive local people to abandon their traditional ecological knowledge that might be essential for sustainable land management (Arora 2019; Lyver et al. 2019; Fernández-Llamazares et al. 2021; Hartel et al. 2023; Rahman et al. 2023). As a consequence, many landscapes are being homogenized, losing both their ecological and social diversity (Curtis et al. 2018; Rasmussen et al. 2018; Appelt et al. 2022; Kastner et al. 2022). This, in turn, threatens their resilience – that is, their ability to buffer shocks and to continue functioning (Altieri 2008; Folke et al. 2010; Lyver et al. 2019; Nyström et al. 2019). In smallholder farming landscapes, especially the diversity of woody vegetation and their associated ES can be critically affected by ongoing changes (Rasmussen et al. 2018; Shumi et al. 2018; Rivers et al. 2022).

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**Box 1.** Definition of key terms.

**Global South:** The Global South refers to low and middle-income countries situated mainly in Africa, Asia, and Latin America. Here, many landscapes have maintained diverse cultural practices and traditional ecological knowledge to this day.

**Local people:** We mainly refer to local people as those who were born, grew up, work, and live, and have local ecological knowledge and practical experiences in a particular landscape.

**Local benefits:** These are benefits that are co-produced by social and ecological systems and actually flow to local people in a specific landscape.

**Resilience** is the ability of a complex adaptive system to withstand shocks and to continue functioning in much the same way as before disturbance in the long run at landscape level.

**Smallholder farming** is a family farming system often performed on less than or equal to two hectares of land, and harbour crop diversity at local and landscape levels.

**Social-ecological system:** A complex adaptive system involving interlinked human and non-human living and non-living components.

**Woody vegetation management:** These are actions to deliberately enhance different woody plant species (i.e. their traits, composition and configuration) across the landscapes (in agriculture-forest mosaic heterogeneous land-uses) to secure an ongoing flow of both material and non-material benefits.

Woody vegetation diversity – including diversity in species identity, traits, composition and configuration across the landscape – provides multiple material and non-material benefits to people and nature (e.g. see [Figure 1](#); [Fischer et al. 2010](#); [Wu 2013](#); [Rivers et al. 2022](#); [Pironon et al. 2024](#)). For example, trees and shrubs in farming landscapes (i.e. in arable land, pastures, wetlands, gardens and forest patches) can provide food, construction materials, fuelwood, medicine, as well as cultural services such as ritual or spiritual meanings to local people ([Maarif 2015](#); [Shumi et al. 2019a](#); [Pehou et al. 2020](#)). Globally, several billion people rely on woody plants for their livelihoods ([Kaimowitz and Sheil 2007](#); [Reed et al. 2017](#)), with between 1.3 and 2.4 billion people using wood for house construction and cooking, respectively ([FAO 2014](#)). Trees also play a role in soil fertilization and contribute to the regulation of soil and water erosion, and provide climate regulation services ([Bayala et al. 2014](#); [Gitz et al. 2021](#); [Shumi et al. 2021](#)). Furthermore, trees serve as habitat and a food source for many vertebrate and invertebrate species ([Rodrigues et al. 2018](#); [FAO and UNEP 2020](#); [Rivers et al. 2022](#); [Zemp et al. 2023](#)). Woody vegetation diversity thus underpins ecosystem integrity and vital functions such as crop pollination, pest and disease regulation, which are crucial for agricultural production ([Barrios et al. 2018](#)). It is therefore an important component of ES multifunctionality, including ensuring food security and nutrition in smallholder farming landscapes ([Gitz et al. 2021](#)). Indeed, it is a critical element of sustainability of farming landscapes ([Loreau et al. 2003](#); [Pramova et al. 2012](#); [Shumi et al. 2021](#)) and thus, its active and sustainable management can significantly contribute to the achievement of several of the United Nations Sustainable Development Goals (SDGs; [UN 2015](#)).

Addressing the complex challenges associated with woody vegetation management in smallholder farming landscapes is therefore essential. Conceptualising such landscapes as social-ecological systems (SES) (e.g. see [Fischer et al. 2015](#)) helps to study and manage the emergent behaviour of complex and interlinked elements through systems thinking ([Ostrom 2007](#); [Meadows 2009](#); [Donohue et al. 2016](#)). Seven generic resilience principles identified and developed by [Biggs et al. \(2012; Table 1\)](#) can be helpful to guide the analysis

of the resilience of these SES. Three of these principles target SES properties and processes management, while the other four principles aim to foster adaptive and integrative governance aspects of SES ([Biggs et al. 2012; Table 1](#)). Applying these principles to the context of woody vegetation management can reveal insights on sustainable SES management – that is, a way to adapt system change and to avoid undesirable shifts into degraded system states–, i.e. they can enhance both ecological and social diversity simultaneously for long-term SES resilience. However, it is crucial to acknowledge that their effectiveness may be contingent upon broader factors. The full realization of change requires effective implementation, outreach, funding, and substantial institutional and systemic changes. Thus, the resilience principles may serve as an initial step to leverage further necessary actions. Since their original publication, there have been efforts to apply them to diverse contexts such as ecological restoration ([Krievins et al. 2018](#); [Fischer et al. 2021](#)), agricultural system and watershed management ([Baird et al. 2021](#); [Bennett et al. 2021](#)) and water management ([Reilly et al. 2021](#)).

In this review, we apply the resilience principles to the context of woody vegetation management and explore how their consideration may enhance the resilience of smallholder farming landscapes in the Global South. In doing so, our review brings together two currently disparate bodies of work – namely insights on resilience principles and insights on woody vegetation management. Although there is a growing body of scientific work and literature on resilience insights and sustainable woody vegetation management (e.g. [Bayala et al. 2014](#); [Quandt et al. 2017](#); [Nyong et al. 2020](#)), their practical application in smallholder farming landscapes of the Global South remains largely unexplored. Thus, the aim of our paper is to generate useful insights for how the resilience principles can be applied to woody vegetation management to enhance the resilience of smallholder farming landscapes and their ES in the Global South.

By linking resilience thinking and sustainable woody vegetation management aspects, our review seeks to provide useful information for researchers, academics, policy



**Figure 1.** Overview of multiple and basic material and non-material benefits of trees in smallholder farming landscapes. (a) trees in the landscape regulating wetland and small streams drainage; (b) trees serving for social learning or experience sharing; (c) trees for honey production (food and medicine); (d) a tree for coffee shade-production; (e) trees regulating water flow and evapotranspiration of a river; (f) homegarden trees serving as habitat for a chameleon (*Chamaeleo calyptratus*); (g) various material benefits of trees to local people; and (h) trees as construction materials for a local house. (Photo: Girma Shumi).

makers, managers and other stakeholders interested in sustainable landscape management (see Reed et al. 2020).

## 2. Materials and methods

We focused on smallholder farming landscapes in the Global South (see Box 1). The Global South, particularly the tropics, harbours most of the planet's biodiversity (Samberg et al. 2016; Ocampo-Ariza et al. 2023;

Pironon et al. 2024). It also comprises most of the world's smallholder farming landscapes that are characterized by subsistence agriculture (Samberg et al. 2016; Brück et al. 2023). These landscapes have many common features irrespective of their geographic diversity (Kates et al. 2001; IPBES 2018; Nagendra 2018). The features are primarily persisting colonial legacy (Jayaprakash and Hickey 2019; Loos 2021); lack of good governance, power relations, conflicts,

**Table 1.** Principles for building SES resilience adapted from Biggs et al. (2012).

|                                  |                                      |  |
|----------------------------------|--------------------------------------|--|
| Key SES properties and processes | Maintain diversity and redundancy    | Diversity refers to diversity of social actors (can be expressed by a variety of social and age classes, lifestyles, cultures, language, ethical and spiritual values, knowledge systems and experiences); and diversity of species (i.e. species identity, traits, composition, their configuration), their habitats and ecosystems in the landscape. Redundancy is the functional replication of social actors (e.g. their roles in securing livelihood or tree management for different purposes) and species that provide options for responding to change and confronting uncertainty, thereby building SES resilience. |
|                                  | Manage connectivity                  | It pertains to the way in which various social actors can interact with each other and collaborate across units and levels. It also refers to the way in which species or resources, e.g. seeds disperse, species migrate, mate or interact with each other across habitats. It is useful to maintain diversity and redundancy and thus, a key for SES resilience.   |
|                                  | Manage slow variables and feedbacks  | It refers to slowly changing ecological and social variables (e.g. gradual loss of trees, human population growth or gradual change in norms, cultures and values) in the landscape, as well as positive and negative feedbacks that influence the configuration and dynamics of a system. Monitoring and managing them in the landscape is important to avoid crossing a threshold.   |
| Key SES governance aspects       | Foster systems understanding         | It refers to viewing and understanding landscapes as complex adaptive systems. Promoting systems thinking and its understanding helps to make sense of SES dynamics and manage SES for multiple benefits in an integrated way, across multiple temporal and spatial scales.  |
|                                  | Learning and experimentation         | It is a continuous renewal of SES knowledge via adaptive management, co-monitoring and governance. It is useful to adapt to unavoidable uncertainty, change and shocks.  |
|                                  | Broaden participation                | It refers to active and genuine involvement of all relevant stakeholders in SES management and governance processes. It fosters collective action for SES resilience building.   |
|                                  | Foster polycentric governance system | This refers to a system in which power is distributed to various interacting bodies and hence, have autonomy to make and enforce rules across units and levels to enhance resilience by increasing diversity and redundancy, connectivity, participation and adaptive learning.  |

inequalities and injustices (IPBES 2018; Di Gregorio et al. 2019); property and tenure insecurity (André et al. 2009); and pressure from globalization (Zoomers 2010; Tu et al. 2019; Hickel et al. 2022).

Our review employs resilience principles as its analytical framework (Biggs et al. 2012: Table 1). These principles were developed with their synergies in mind, in order to enhance transformation to sustainability (Biggs et al. 2012; Olsson et al. 2014; Baird et al. 2021). For our review, we purposefully selected scientific literature that we considered relevant to each resilience principle (following Lindenmayer and Fischer (2006)). This approach enabled a comprehensive analysis of diverse social and ecological studies without rigid constraints on specific keywords or study types (Lindenmayer and Fischer 2006; Paré et al. 2014).

This long-established, flexible method was deemed useful for our purpose, but we acknowledge that it is not without limitations – for example, we cannot claim that our literature equally covers all of the Global South. A certain level of subjectivity is in fact inherent to all qualitative reviews, and our is no exception. With these limitations in mind, the following sections present an assessment of how resilience principles can be applied to the context of woody vegetation management by exploring existing perspectives, challenges, opportunities and insights for future SES resilience building in the Global South.

### 3. Applying resilience principles to a woody vegetation management context

#### 3.1. Managing SES properties and processes

Driven by ‘green revolution’ or ‘economic growth’ policies and its one-size-fits-all approaches,

homogenization of landscapes poses challenges in the Global South (Cioffo et al. 2016; Schultner et al. 2021; Winkler et al. 2021; Appelt et al. 2022). Many cultural landscapes are losing diversity, redundancy, connectivity, and the ability or agency to identify and manage slow variables and feedbacks closely (Lyver et al. 2019; Kim et al. 2022). Below, we assess how such SES properties and processes can be managed – that is, how the first three resilience principles can be applied – in the context of woody vegetation management to improve the resilience and sustainability of SES in the Global South.

*Systems can be resilient if their diversity and functional redundancies (i.e. elements overlapping in their function) are managed* (Biggs et al. 2012; Table 1). Ecologically, diversity is best approximated via biodiversity – the diversity of genes, species, and ecosystems, and interactions across those levels (MA 2005). Redundancy occurs when multiple species fulfil the same ecosystem function (Walker 1992; Naeem 1998). Socially, diversity is captured by variety in social actors (e.g. different ethnic groups, language groups, genders or age groups) as well as variety of rules, norms, beliefs and knowledge systems or livelihood strategies in a specific SES (Maffi 2005; Biggs et al. 2012; Grêt-Regamey et al. 2019). Social redundancy exists when multiple actors have similar roles or when there is actors’ functional diversity (e.g. managing the landscape for agrobiodiversity) (Folke et al. 2005; Brondizio et al. 2009; Grêt-Regamey et al. 2019). These ideas directly related to woody vegetation diversity management (Ehrlich and Walker 1998; Loreau et al. 2003; Pramova et al. 2012). Woody vegetation management can be enhanced via purposefully selecting, maintaining and managing diverse tree and shrub species across the landscapes. Tree and shrub species

in the landscapes (i.e. in a mix of arable land, pastures, gardens, forest patches or protected areas) can provide particular or multiple functions directly or through their interactions (Naeem 1998; Wu 2013; Shumi et al. 2021). For example, different tree species may fulfil specific ES such as attracting bees for honey production (Ango et al. 2014) or many other ES such as the provision of food, medicine and fuelwood (Rodrigues et al. 2018; Shumi et al. 2019a; Pehou et al. 2020). Social diversity and redundancy can also be enhanced via authorizing various social actors to fulfil woody vegetation management functions (e.g. tree planting or monitoring) in the landscape (Pretty and Smith 2004; Maffi 2005; Reed et al. 2019). Instead of existing top-down approach, enabling particularly local people to manage woody vegetation for various purposes, e.g. for uses by genders – men and women (Pehou et al. 2020), by age groups – young and old people (Seyoum et al. 2015) can enhance social diversity and wellbeing (Loreau et al. 2003; Folke et al. 2005; Grêt-Regamey et al. 2019). For example, in Ethiopia, Kenya, Cameroon and Indonesia, various local groups customarily prefer to maintain and manage diverse tree and shrub species across the landscapes, paying attention to their ongoing flow of diverse ES such as food, construction wood and soil fertilization (Kehlenbeck et al. 2013; Ango et al. 2014; Sheil et al. 2015; Jiren et al. 2017; Shumi et al. 2019a).

However, sectoral thinking and top-down approaches pose numerous challenges for ‘diversity and redundancy’ in the Global South (Holling and Meffe 1996; Cioffo et al. 2016; Jiren et al. 2018; Reed et al. 2020). Specifically, the ongoing expansion and intensification of crop and livestock farming in many farming landscapes is the underlying cause for loss of diversity and ES (Foley et al. 2005; Jew et al. 2017; Curtis et al. 2018; Rasmussen et al. 2018; Appelt et al. 2022; Kastner et al. 2022). Conservation approaches, which often neglect the conservation value of farmland (e.g. Shumi et al. 2018), as well as local actors and their roles, prove ineffective in addressing deforestation and the loss of on-farm tree species. This oversight extends to the management of protected areas within farming landscapes, neglecting the essential ecological and social diversity and redundancy (Ban et al. 2013; Shumi et al. 2018; Ayivor et al. 2020). Notably, attempts such as expert-driven forest management for REDD+ in Zanzibar (Benjaminsen and Kaarhus 2018) and conservation strategies in other systems (e.g. Appelt et al. 2022; Bocci 2023) have faltered in addressing these complexities. Additionally, tenure insecurity and unclear property rights in many Global South countries cause conflicts, hindering the effective management of diversity and redundancy in farming landscapes (e.g. André et al. 2009; Lemenih and Kassa 2014; Etongo et al. 2015; Shumi et al. 2019a).

*Resilience of SES can also build up via managing connectivity – that is, if different elements of SES are connected and interact with each other* (Biggs et al. 2012; Table 1). Ecologically, connectivity between habitats or species can occur via corridors between large patches or via species interactions, enabling species to migrate, disperse, mate and feed. It also underpins ecosystem integrity and functions such as pollination, predator-prey interactions and nutrient cycling (Gilbert-Norton et al. 2010; Saura et al. 2014; UNEP 2019). Socially, connectivity among actors across administrative levels occurs via social networks or communication channels, and ideally facilitates collaborative management (Brondizio et al. 2009; IPBES 2018). Woody vegetation diversity management can be reinforced if strips of vegetation (corridors) or scattered trees (i.e. stepping stones) are managed and exist in between large patches of forests (Beier and Noss 1998; Dawson et al. 2013; Saura et al. 2014), and help seed dispersal, for example by wild animals and dispersal agents like birds in the landscape (Gilbert et al. 1998). This is particularly crucial for native species, whose existence largely depends on seed dispersal agents (Beier and Noss 1998; Brudvig et al. 2009) that enable them to persist despite the ongoing land-use and climate changes (Gilbert et al. 1998; Krosby et al. 2010). For example, in Southwestern Ethiopia, native species diversity increase at sites closer to forests and with high tree cover (Koelemeijer et al. 2021). Woody vegetation management can also be enhanced if social networks are enacted among multiple actors and bridged across various governance levels (Friedman et al. 2020). This is particularly important for enhancing collaboration among smallholder farmers, who can share their perspectives and experiences in farming landscapes (Crona and Bodin 2006; Sheil et al. 2015). Social networks can also facilitate mutual benefit, information sharing, trust, common rules, norms and sanctions, all of which are important for the collaborative management (Brondizio et al. 2009; IPBES 2018; Visseren-Hamakers et al. 2021). For example, in Indonesian Borneo, social networks among diverse actors spanning multiple administrative levels increased collaborative forest management (Friedman et al. 2020).

Yet, as stated above, rapid change in the landscape due to deforestation, forest degradation and agricultural intensification (e.g. Shumi et al. 2018) impair tree seed dispersal (Haddad et al. 2015; UNEP 2019). Increasing isolation reduce the adaptability of native tree species to new land use and environmental conditions, thereby exacerbating the risk of local extinction (Kuussaari et al. 2009; Haddad et al. 2015; Shumi et al. 2019b). Expert-driven approaches frequently undermine local people and their social networks, and hence, collaborative management (Akinnifesi 2016; Irakiza et al. 2016; Lyver et al. 2019; van Noordwijk 2020; Zinngrebe et al. 2020). For example, a study by Zinngrebe et al. (2020) showed the widespread existence of disconnected agroforestry

governance among government actors and farmers (i.e. their social networks) in Honduras, Peru, Indonesia and Uganda. Such disconnection and lack of effective collaboration among actors in woody vegetation governance and management, might exacerbate biodiversity loss and poverty in many smallholder farming landscapes (Dietz et al. 2003; Cioffo et al. 2016; Di Gregorio et al. 2019; Lyver et al. 2019). Too much connectivity in a system can also cause rigidity when the connections and interactions within the system are structured in a way that limits adaptability to changing conditions. In practice, however, this problem is usually less prominent than the problem of having too little or no connectivity at all in the Global South nowadays.

*The resilience of SES can increase if key slow variables and feedbacks can be identified and managed to proactively maintain the systems' functions in the face of disturbance and change* (Biggs et al. 2012; Table 1). Slow ecological variables are often associated with regulating ES, such as gradual loss of trees, land degradation, or climate change. Slow social variables are linked to human population growth, rising poverty, or gradual changes in values and customs. Fast variables, in contrast, typically relate to provisioning services, such as food or fuelwood (Biggs et al. 2012). Slow variables determine the underlying structure of a given SES, while system dynamics result from interactions and feedbacks among fast variables that respond to the conditions created by the slow variables. Reinforcing (positive) or dampening (negative) feedbacks occur when there is a change in particular variables that loop back to impact the SES element producing other variables (Biggs et al. 2012). Woody vegetation management for social-ecological resilience can be facilitated by identifying and managing slow ecological variables or lags (e.g. time-delayed response of trees to landscape changes; Shumi et al. 2018) and reinforcing stabilizing feedbacks (Thrush et al. 2009). For example, farming landscapes that harbour diverse tree species often also provide diverse ES (Pramova et al. 2012; Wu 2013; Shumi et al. 2021; Leary et al. 2021). However, deforestation and agricultural intensification can lead to gradual loss of trees from the landscape and eventually, can shift such system to a regime devoid of trees (e.g. Jew et al. 2017; Curtis et al. 2018; Rasmussen et al. 2018). In this case, stabilizing ecological feedbacks can be strengthened by controlling loss of trees and disturbance regimes (slow variables) (van Noordwijk et al. 2019; Leary et al. 2021; Pramova et al. 2012) and further by enhancing connectivity (P2) (Gilbert et al. 1998; UNEP 2019). Key feedbacks also require attention in controlling slow social variables, such as human population growth (e.g. by ensuring equitable access to family planning services) or unsustainable changes in cultural practices (e.g. by building tree

management approaches on local cultures, values and institutions that facilitate the customary ties between people and ecosystems) in many smallholder landscapes (e.g. Ostrom 2009; Irakiza et al. 2016; Lyver et al. 2019). In other cases, it is also important to disrupt those feedbacks that hold a given system in a resilient but undesirable regime. This could be, for example, an ecosystem taken over by invasive species, or a social system controlled by development policies that pursue the interests of few elites (Anderson et al. 2000; Schlüter and Herrfahrdt-Pähle 2011; Rembold et al. 2017). In such cases, regime shifts towards more favoured states can be triggered by the deliberate removal of invasive species or assisted regeneration of native species, or by proactive changes to the existing policy (Anderson et al. 2000; Suding et al. 2004; Young 2010).

Nevertheless, identifying and managing slow variables and feedbacks that underpin a given farming landscape in woody vegetation management can be difficult in practice in sectoral and expert-driven approaches (Scheba and Mustalahti 2015; Chazdon and Guariguata 2018; Sigman 2022) – that is, without true participation of local actors (Ishizawa 2006; Bocci 2023). It can be especially challenging when human-nature connectedness is deteriorated (Biggs et al. 2015; Irakiza et al. 2016; Takeuchi et al. 2016) or disrupted (Lyver et al. 2019; Hartel et al. 2023). Equally, linking slow ecological and social variables is also difficult under such approaches (Biggs et al. 2015; Goffner et al. 2019; Lyver et al. 2019). For example, recent efforts in forest landscape restoration in Ethiopia (e.g. Pistorius et al. 2017; Kassa et al. 2022; Sigman 2022) and elsewhere (e.g. Chazdon and Guariguata 2018; Fischer et al. 2021) exemplify insufficient consideration of slow social-ecological variables and their connections.

In general, our review shows the absence of SES properties and processes management in many landscapes of the Global South. This agrees with findings, for example, by Bocci (2023), Shumi et al. (2023) and Pironon et al. (2024). Consequently, loss of biodiversity and ES, and local people's diverse roles, knowledge systems and experiences in such systems can cause irrecoverable and adverse impact at global scale beyond the Global South (MA 2005; Irakiza et al. 2016; Fischer et al. 2017; Lyver et al. 2019; UN 2022; Hartel et al. 2023). This, in turn, signals urgent need to change the ways we are managing our systems.

### **3.2. Fostering systems thinking, and adaptive, inclusive and integrative governance**

Although transformative change towards sustainability is widely recognized as important (2019; IPBES 2021; UN 2023), it remains a challenge owing to its political and normative character, and the inherent complexities and uncertainties of SES (Donohue et al.

2016; Blythe et al. 2018; Brand et al. 2021). Transformation from reductionist thinking to systems thinking; and from sectoral or expert-driven approaches and power asymmetry to adaptive, inclusive and integrative SES governance is vital (IPBES 2018; Massarella et al. 2021; Visseren-Hamakers et al. 2021). Below we assess how such transformations – that is, the four remaining resilience principles – can be applied to SES in the Global South.

*The resilience of a given SES can be enhanced if scientists, managers and society at large view and understand landscapes as complex adaptive systems (CAS), and use this understanding to manage landscapes in ways that appreciate high levels of interconnectedness, non-linear change, and inherent uncertainty* (Biggs et al. 2012; Table 1). CAS are shaped from diverse networking elements that can discretely or collectively adapt to change, self-organise and evolve, and often produce new behaviour at different spatial and temporal scales. CAS can also shift from one regime to another, often suddenly, producing a system that behaves differently than before. Such CAS characteristics make SES highly uncertain (Biggs et al. 2012). CAS thinking is a cognitive framework that requires shifting away from reductionist and sectoral thinking (Jones et al. 2011) towards holistic and integrated approaches that recognise multiple goals and actors, including local people, their needs and experiences (Cilliers et al. 2013; Foli et al. 2018; Reed et al. 2020). Fostering CAS thinking by itself may not directly enhance resilience, but it can change the cognitive models that reinforce unsustainable management decisions and methods (Folke et al. 2010). CAS thinking can help to manage woody vegetation diversity in a sustainable way (Folke et al. 2005; Jones et al. 2011; Cilliers et al. 2013; Shumi et al. 2021), if diverse actors, particularly managers, policy makers and society collectively use CAS thinking to guide their decision-making and actions (Biggs et al. 2012; Grêt-Regamey et al. 2019). CAS thinking can help to identify and manage slow variables, lags, and feedbacks (P3) for improved woody vegetation management (e.g. Sheil et al. 2015; Irakiza et al. 2016). It also facilitates to prepare for uncertainty and change, and thereby supports continuous learning and experimentation (P5) in order to better adapt to unforeseen disturbances in systems (Brugnach et al. 2008; Cilliers et al. 2013; Visseren-Hamakers and Kok 2022). For example, many traditional smallholders, including those in the Global South, recognise links between people and nature, i.e. use CAS thinking, and manage systems to provide safety against natural shocks (e.g. in climate) rather than to produce maximum quantities of few commodities (Ishizawa 2006; Altieri 2009).

Yet, reductionist and sectoral thinking that focuses on linearity, determinism and supremacy of humans over nature and other people remains profoundly rooted in the mental model of many scientists, policy makers and managers, which are dominant actors in the Global South today (Ludwig 2001; Akinnifesi 2016; Brand 2016). Such views cause single-sector development, as well as ‘command and control resource management’ approach that fails to anticipate important links between policy changes, equity and diversity (Holling and Meffe 1996; Akinnifesi 2016; Neimark et al. 2019). Furthermore, this Western approach has been used to eliminate (rather than navigate) uncertainty and accurately predict the most suitable actions for optimal agricultural and socioeconomic growth (Holling et al. 2002; Arora 2019), thereby significantly destroying biocultural diversity (Cioffo et al. 2016; Irakiza et al. 2016; Curtis et al. 2018; Lyver et al. 2019). This impede resilience thinking and transformation to sustainability (Fazey et al. 2020; Visseren-Hamakers et al. 2021; Shumi et al. 2023).

*Building resilience of SES requires continuous learning.* Continuous learning is desirable, because SES are CAS and hence, knowledge about them is always incomplete, and also needs repeated renewal to adapt to unavoidable uncertainty, change and surprise (Biggs et al. 2012; Table 1). In CAS, learning can be facilitated through adaptive management, co-management, and governance processes. These processes facilitate loop learning or social learning (Cundill et al. 2015). Loop learning includes single-loop learning that focuses on the question ‘are we doing things right?’, double-loop learning ‘are we doing the right things?’, and triple-loop learning ‘how do we know what the right thing to do is?’ (Pahl-Wostl 2009). Social learning refers to knowledge acquired across wider social units via deliberate or unintended interactions within social networks (P2) (Reed et al. 2010). By influencing decision-making and governance processes, continuous learning and experimentation can enhance adaptive woody vegetation and ES management (Schreiber et al. 2004; Folke et al. 2005; Biggs et al. 2012; van Noordwijk et al. 2019). Particularly, specific characteristics of trees (e.g. their lifespan and species specific benefits or uses) and associated farmers’ long-standing ecological experiences can provide valuable opportunities to amplify such learning processes (Berkes et al. 2000; Kendrick and Manseau 2008). Manipulating woody vegetation and comparing or co-monitoring the impacts of different management practices can enable learning about the responses of species and ES to different management practices and changes (Danielsen et al. 2005). Specifically, co-monitoring by diverse actors facilitates knowledge co-

production among actors involved (Danielsen et al. 2005; Sheil et al. 2015). It can help to anticipate how a given system may perform in the future (e.g. scenario planning; Fischer et al. 2018). Involving a wide range of actors (P6) in co-monitoring processes can also facilitate knowledge sharing across scales, thereby connecting actors across landscapes and governance levels (P2) (Armitage et al. 2009). Moreover, social learning processes can help different actors to understand and empathize with each other's thinking (P4), thereby building trust, norms and values that may facilitate conflict resolution (Biggs et al. 2011). For example, learning via adaptive and collaborative management in the three Colombian Andes' community-based agroecology fostered community resilience, social cohesion and social learning (Chavez-Miguel et al. 2022).

Nevertheless, ensuring effective and ongoing learning is especially challenging in the Global South (e.g. see Scheba and Mustalahti 2015; Brand 2016; Foli et al. 2018). This is because learning is often inhibited by normative politics that fails to recognize local people and their culturally rooted experiences (Akinnifesi 2016; Lyver et al. 2019; Burgos-Ayala et al. 2020). Historically grounded power dynamics and asymmetries, and reductionist approaches are the key factors that negatively affect learning processes in many landscapes of the Global South (Armitage et al. 2009; Foli et al. 2018; Arora 2019). Particularly, powerful actors often dominate learning processes and assert their own positions and knowledge, thereby marginalizing smallholder farmers who often hold deep ecological knowledge about their systems (Béné et al. 2009; Scheba and Mustalahti 2015). In the worst case, poorly designed social learning and experimentation activities can lead to misinformation and conflicts around woody vegetation management (Olsson et al. 2004; Faye 2017; Mustalahti et al. 2020), and thus, hindering transformation to sustainability (Visseren-Hamakers et al. 2021).

*SES resilience can be enhanced by the active participation of multiple actors in SES management and governance* (Biggs et al. 2012; Table 1). Conceptually, participation can range from informing people about decisions already made to complete devolution of decision-making power to them (Arnstein 1969). Participation can occur in all or some stages of SES management, from the identification of problems and objectives to policy implementation, monitoring of results and evaluation of outcomes (Biggs et al. 2012). Active participation is important for sustainable woody vegetation management (Pretty and Smith 2004; Turnhout et al. 2012; Reed et al. 2019). In contrast to top-down centralized approaches (Holling and Meffe 1996), inclusive and true

participation can have various advantages (Schreiber et al. 2004; Van Rijsoort and Jinfeng 2005; Lebel et al. 2006). First, engaging relevant stakeholders, particularly farmers, in woody vegetation management and governance can help to increase trust and build a common understanding (Schreiber et al. 2004; Folke et al. 2005; Lebel et al. 2006) based on existing knowledge and experiences (Pretty and Smith 2004). Second, it can improve legitimacy, co-monitoring and decision-making (Folke et al. 2005; Lebel et al. 2006; Sheil et al. 2015; Reed et al. 2019). Third, active participation can also increase the level of collaboration among actors and transparency of information sharing (Danielsen et al. 2005; Uychiaoco et al. 2005; Van Rijsoort and Jinfeng 2005). This, in turn, facilitates improved understanding of ecological, social, and political perspectives of SES dynamics that may not be discovered by conventional scientific approaches (e.g. Brand 2016; Fazey et al. 2020). Fourth, it can reinforce the link between research and decision-making, and foster learning and the creation of new rules, norms and institutions for effective landscape governance (Uychiaoco et al. 2005; Caniglia et al. 2020). By transforming actors' perceptions and attitudes, participation can therefore promote a shift to more sustainable woody vegetation management for SES resilience in general (Folke et al. 2005; Pahl-Wostl 2009; Sheil et al. 2015).

Yet, despite widespread recognition of its importance, well-functioning participation in integrated woody vegetation management still remains a challenge in many landscapes of the Global South (Reed et al. 2019; Burgos-Ayala et al. 2020; Bocci 2023; Rahman et al. 2023). This is because in practice, it is often influenced by deep-rooted political power struggles, and reductionist views or loss of sense for 'the whole' by most of scientists, managers and local elite practitioners (Holling et al. 2002; Béné et al. 2009; Scheba and Mustalahti 2015). In many cases, local people are simply informed and reported as having participated to satisfy donors (Mutune and Lund 2016). Such pseudo-participatory approaches, in turn, can exacerbate elite capture and marginalization of smallholder farmers (Viana et al. 2016; Lyver et al. 2019). Essentially, participation that fails to develop and use local social capital (e.g. Pretty and Smith 2004) can lead to competition among actors and thereby trigger biodiversity loss and ES degradation (Büscher and Schoon 2009). Moreover, lack of incentives or inadequate recognition of land and forest tenure security and use rights can hinder participation (André et al. 2009; Fischer et al. 2012; Chomba et al. 2015). Persisting highly sectoral institutions can also hinder actors across and governance levels to engage with one another in participatory processes. Similarly, rigid legislative power and control over

resource management and use in farming landscapes might negatively influence participation (van Noordwijk 2020; Bocci 2023).

*Polycentric governance systems, in which decision-making power is dispersed among institutions and levels, are also widely recognised as beneficial for SES resilience* (Biggs et al. 2012; Table 1). Governance refers to the structures and processes in which people share power, and shape individual and collective actions. In polycentric networks, each unit has some autonomy, and can connect to other units horizontally and to broader governmental levels vertically (Biggs et al. 2012; Reed et al. 2020). In this way, polycentric systems can build SES resilience via enabling governance to fit to the problem being addressed (Piattoni 2009). This is relevant to woody vegetation management and governance in farming landscapes (Olsson et al. 2004; Salomon et al. 2018; Reed et al. 2019). Here, the arrangement of multiple and nested woody vegetation management institutions can imitate or follow smaller scales or groups embedded in smallholder farming landscape, and can also benefit from context-specific local knowledge and social networks (e.g. see Figure 2; Brondizio et al. 2009; Kozar et al. 2014; Foli et al. 2018). Such highly networked institutions can tackle complex woody vegetation management problems rapidly at the right time via a set of rules that interact across multiple units and levels (Olsson et al. 2004; Lebel et al. 2006; Nagendra and Ostrom 2012). They can facilitate the fit between experience, action and social-ecological contexts, and enable actors to manage woody vegetation adaptively (Carlisle and Gruby

2019). Moreover, nested institutions can also stabilize power imbalance between top-down and bottom-up governance (Kozar et al. 2014; Megerssa and Kassam 2020). In doing so, polycentric governance can enhance sustainable woody vegetation management and SES resilience via creating institutional modularity (i.e. independently emerging and functioning units; Beilin et al. 2013; IPBES 2018), increasing diversity and functional redundancy (P1), improving ecological and social connectivity (P2), and enhancing continued learning and experimentation, and active participation (P5 and P6) (Biggs et al. 2012).

Nevertheless, polycentric governance remains challenging in many low-income countries (Brockhaus et al. 2012; Foli et al. 2018). Transformation to polycentric systems is hampered by power structures, institutions, and social-political reluctance as well as conflicting interests and values of multiple actors at multiple levels (e.g. Brockhaus and Angelsen 2012; Foli et al. 2018; Reed et al. 2019; Hickel et al. 2022). Power structures that lack political willingness to vitally consider biodiversity and people hinder not only the development of polycentric systems, but also constrain devising appropriate policies, and affect the way policy outcomes are evaluated (Salomon et al. 2018; Foli et al. 2018; Morrison et al. 2019). Similarly, institutions in repressive regimes are likely to resist institutional changes and thereby prevent new institutions for more integrated decision-making (Brockhaus et al. 2012; Chomba et al. 2015). Attempts to enhance polycentric governance are further hindered by conflicting interests, values and norms of actors (e.g. Tu et al. 2019; Hickel et al. 2022). In such cases, negotiation for change may be easily



**Figure 2.** Illustrating context specific smaller scale units embedded in smallholder farming landscapes, which can be used for the arrangement of multiple and nested units for polycentric governance systems. Blue coloured circles show each small-scale unit, and red arrows highlight horizontal connections among units across the landscape. (Photo: Girma Shumi).

dominated or unduly influenced by a small number of powerful actors (Brockhaus and Angelsen 2012; Di Gregorio et al. 2019; Hickel et al. 2022).

Overall, our review shows the difficulty of applying these four resilience principles – that is, of transformative change, in the context of woody vegetation management in the Global South (see also Brand 2016; Shumi et al. 2023; UN 2023). This clearly calls for a paradigm shift to enhance the resilience and sustainability of SES in the Global South.

#### 4. Conclusion

A major challenge of this century is to ensure the conservation of biodiversity and associated ES, in order to sustainably meet the needs of present and future generations (Curtis et al. 2018; Díaz et al. 2019; WWF 2020). To the best of our knowledge, although research on SES has made great advances, the practical application of the well-known social-ecological resilience principles outlined above to enhance social and ecological diversity for sustainable biodiversity maintenance and human wellbeing lags well behind their conceptual development. A likely reason is that resource management and development intervention in many smallholder landscapes are still conducted without consideration of the benefits of diversity and redundancy, social-ecological complexity, their political and normative character, and without adequate recognition of local people legitimacy and their livelihoods (Salomon et al. 2018; Brand et al. 2021; Chaigneau et al. 2022). Our comprehensive, however, non-exhaustive review suggests that established resilience principles can provide meaningful and tangible guidance for sustainable woody vegetation management in smallholder farming landscapes – with likely positive repercussions for social-ecological resilience and adaptability, if relevant stakeholders, particularly dominant and powerful actors, change their mental models and strive to apply them properly.

We collated evidence from wide range of literature to highlight the relevance of applying all seven resilience principles in the Global South. As all principles are meant to enhance both social and ecological diversity, they also partly overlap, and many synergies may arise from applying all principles at once. Because of this, the application of one principle can also improve the application of the other principles. Some principles are well understood and appear easier to apply in the context of woody vegetation management in smallholder farming landscapes of the Global South. This is particularly the case for managing diversity and redundancy (P1), connectivity (P2), and slow variables and feedbacks (P3). In contrast, applying other principles – such as enhancing participation (P6), continuous learning (P5) and polycentric governance systems (P7) – seems more challenging. Applying these principles requires a paradigm

shift and political willingness to care for nature and more genuinely recognise local people, their livelihoods and experiences. In the case of understanding landscapes as CAS (P4), its consideration remains limited or purposefully obscured, and seems depend on context specific situation, but its application, too, requires moving away from deep-rooted mental models such as sectoral and reductionist views of environmental and green economy management approach.

Given the high bicultural diversity and varied livelihood activities in smallholder farming landscapes, juxtaposed to the prevalence of informal and unplanned land cover changes due to the absence of coherent landscape planning and entrenched power asymmetries in many nondemocratic regimes in the Global South, a more effective approach might be to initiate the application of principles with P7, P4 and P6, progressing to others. This can help to avoid a repetition of the same mistakes that happened in countries of the Global North, where industrial agriculture caused major ecological and social losses that so far has not been restored despite strong democratic institutions, scientific know-how and capital.

To conclude, our review highlights an urgent need for more adaptive, holistic and integrative approaches that appreciate diverse goals and actors to make use of these resilience principles to a woody vegetation management context in smallholder landscapes of the Global South. Operationalizing of the resilience principles thus requires and benefits from the full recognition of local people, most importantly farmers, who have lifelong ecological knowledge and close ties to nature in the Global South.

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