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Leveraging the power of forests and trees for transformational adaptation

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Abstract

It is well established that forest conservation, restoration, and sustainable management of forests and trees outside forests can help to reduce the vulnerability of both humans and ecosystems to climate change. Yet the role of forests and trees in providing multiple goods and services that contribute to the adaptive capacity and resilience of social-ecological systems is only beginning to gain traction in climate policy and action. Climate change research and policy has overwhelmingly focused on the role of forests and trees in mitigation, neglecting the adaptation of societies that own and maintain the forests. We combined two different transformational adaptation frameworks, the Values, Rules and Knowledge framework (VRK) and the spheres of transformation framework to classify and analyse key principles and way they relate to transformational adaptation. We propose a conceptual typology of five

overarching concepts and derive 10 organizing principles to address the shortcomings of current adaptation framing. The overarching concepts and key principles emphasize adaptive management, stakeholder involvement, and the need for multiple objectives, synergies and co-benefits. Various constraints are recognized, with institutional and governance barriers identified as the most severe obstacles to implementation. These key principles serve to define operational actions and guidelines specific to forests and trees for transformational adaptation. We discuss how these principles differ from more conventional sectoral and project-based approaches.

1. Introduction - *Why forests and trees for transformational adaptation?*

It is well established that forest conservation, restoration, and sustainable management of forests and trees outside forests can help to reduce the vulnerability of both humans and ecosystems to climate change (IPCC 2022). Forests and trees play a crucial role in climate change adaptation and resilience in many different ways. They can provide income and safety nets through accessible forest products for food, fibre and fuel in case of hardship (Pramova et al. 2012, Angelsen et al. 2014, López-Feldman et al. 2014, Etongo et al. 2016). They can also help regulate local and regional climates by contributing to rainfall or cooling temperatures through evapotranspiration and other biophysical processes (Ellison et al. 2017, Lawrence et al. 2022). They limit infectious diseases and reduce healthcare costs, while in specific contexts reducing the risk of floods, extreme weather, and air pollution (Poratelli et al. 2020, Tembata et al. 2020, Pataki et al. 2021). Hence the sustainable management of forests, and of trees outside of forests, is vital to the implementation of the 2030 Agenda for Sustainable Development.

Yet the role of forests and trees in providing multiple goods and services that contribute to the adaptive capacity and resilience of social-ecological systems is only beginning to gain traction in climate policy and action. Climate change research and policy has overwhelmingly focused on the role of forests and trees in mitigation, leaving aside the adaptation of the societies that own and maintain the forests. A number of studies claim an extraordinarily high mitigation potential for forests (Griscom et al. 2017; Bastin et al. 2019; Roe et al. 2021). These claims have been contested (Friedlingstein et al. 2019), while recent papers point to the limited contribution 'nature restoration' can make to reducing warming over the century (Dooley et al. 2022).

The majority of NDCs include forest-related actions, such as afforestation, reforestation, and sustainable forest management for mitigation (Crumpler et al. 2021). The real potential of forests to facilitate both mitigation and adaptation, however, is still largely untapped. This is even less tangible when it comes to trees outside forest and agroforestry systems (Mbow et al. 2014, Skole et al. 2021; Somarriba et al. 2021; van Noordwijk et al. 2021, Park et al. 2022). This paper aims to summarise a set of clear and tangible key principles, which are backed by science, to fully tap into the potential of forests and trees for adaptation.

The linkage between forests and adaptation is two-fold: forests provide ecosystem services (adaptation services) that contribute to human well-being and reduce social vulnerability (van Noordwijk et al. 2021). This is referred to as 'forests for adaptation'. Forests, however, are also impacted by climate change and need to adapt. In this second instance, which is referred to as

'adaptation of forests', there is a need to implement measures for reducing the negative impacts of climate change on forests, including through increased incidence of wildfires, pests and disease, droughts and floods (Locatelli et al. 2010). The question of scale is crucial to adaptation (Vincent 2007). The manner in which society responds to climate change, and the degree to which adaptation options are constrained, can happen at the local level, or across landscapes in which stakeholder's objectives interact and often compete, ecosystem processes and decisions unfold and where different interests and power dynamics materialise (van Oosten et al. 2018).

2. Framing transformational adaptation

Considering the increasingly intense and frequent impacts of climate change, the vulnerability of resource-dependent communities, and the existing evidence that incremental adaptation is not enough, the need for transformational adaptation is clear. Natural resource dependent populations face increasing vulnerabilities as severe climate change overwhelms ecosystems in many places (IPCC 2022, Fedele et al. 2021). A relational framing of adaptation and transformation comes under critical adaptation perspectives with calls for transformational adaptation whereby interventions should entail deep systemic changes that question and confront business-as-usual approaches (O'Brien and Sygna 2013, Fedele et al. 2019). The dominant definition and practice of adaptation remains reactive, incremental, and focused primarily on biophysical and techno-managerial changes (Doerr et al. 2019). It is necessary to work on forest and tree management options outside the forest that allow transformational adaptation instead of mere short-term options (Fedele et al. 2019).

A transition from incremental to transformational adaptation, which changes the fundamental attributes of social-ecological systems in anticipation of climate change impacts, can help overcome soft adaptation limits (IPCC 2022). Implementing transformational adaptation requires effort to overcome institutional and behavioral barriers that tend to maintain existing resource systems and policies (Kates et al. 2012, Berrang-Ford et al. 2021). For instance, scholars illustrate that transformational adaptation encompasses those actions that operate changes in the nature, the composition, and location of menaced systems (Pelling 2010; IPCC 2022; Smit and Wandel 2006). We understand transformation as fundamental alterations to political, economic and socio-natural relations, practices, values and meaning-making (O'Brien 2018; Pelling 2011). Transformational change acknowledges moving forward in the process of sustainably adapting to climate change and adopting triple-blended actions of mitigating, adapting, and sustainable development (Denton et al. 2014). Simply put, we refer to transformational adaptation as desired processes and relations (not state) through which change can be enabled, and that is effective in producing just and equitable processes.

Transformational adaptation demands a political, cross-scalar, affective, and socio-political analysis. Socio-political processes are those that meditate "how individuals and collectives deal with multiple and concurrent environmental and social changes" (Eriksen et al. 2015, p. 523). These processes conceptualize the world in a constant state of becoming, capturing how trajectories of change are shaped by inherently stochastic human and more-than-human relations. Transformational outcomes entail fundamental shifts in these repetitive relations.

The Transformative Adaptation Research Alliance (TARA) framework proposes to understand how ecosystems and people interact along adaptation pathways by weaving together Nature's

Contributions to Adaptation (or adaptation services), a values-rules-knowledge (VRK) perspective (Gorddard et al. 2016), and co-production of adaptation pathways (Colloff et al. 2017; 2020; 2021). Trade-offs are identified and where possible addressed along nature-based adaptation pathways, acknowledging that some are “hard” trade-offs that cannot be resolved but need to be considered. Applying the framework enables changes in institutions and governance needed to support nature-based transformative adaptation (Colloff et al. 2021). The VRK framework is based on the premise that changing the decision context for adaptation is a fundamental part of a transformative approach. This means understanding the role of societal values, rules and knowledge to identify options to reframe decision contexts. The intention here is to transform socio-ecological systems through a mix of incremental and transformative co-production processes, based on five ‘propositions’ for moving from current approaches to intentional transformative adaptation (Colloff et al. 2021). These are: change can be accepted and anticipated; uncertainty is the norm; agency involves navigating the top-down and bottom-up; adaptation is a governance issue; participative learning and co-production are needed (Colloff et al. 2021). The IPCC recognizes that transitioning from incremental to transformational adaptation can help overcome “soft” adaptation limits, that is, when adaptation options may exist but are currently not available to avoid intolerable risks through adaptive action (IPCC 2022).

Transformational change can be generally represented through three interacting spheres of transformation, referred to as the practical, political, and personal spheres (O’Brien and Sygna 2013). These spheres capture the ways that beliefs, values and worldviews interact with political decision-making and governance, as well as with on-the-ground practices that contribute to sustainable systems. According to O’Brien and Sygna (2013), transformation in practice is contingent on a political sphere, which includes the systems and structures that create the rules, norms and incentives for different types of behaviours and practices. These in turn are influenced by subjective views of systems and relationships that are represented in a personal sphere. Indeed, individual and shared beliefs, values and worldviews often drive political priorities and goals and influence framings of problems and solutions, which can lead to conflicts and tensions in decision-making processes that often impede transformative change.

A growing body of literature has been dealing with adaptation principles, synthesizing existing knowledge on adaptation into guiding principles. This includes principles to increase the effectiveness of adaptation interventions (Singh et al. 2021); address manifestations of power in adaptation (Vij et al. 2021, Barnett 2021); identify maladaptation and promote sustainable climate actions (Eriksen 2011, Tabara 2016); and ecosystem restoration and nature-based solutions (Seddon 2022, Osborne et al. 2021, Cohem-Shacham et al. 2019). This paper aims to build upon this existing work and takes a transformational adaptation perspective that outlines principles specifically applied to the role of forests and trees for adaptation.

3. Approach and Methods

3.1. Formulation of concepts and principles

To develop a new set of principles specific to the role of trees and forests for transformational adaptation, we started in a first step with identifying a set of more broadly applicable overarching “concepts”, distilled from the literature on transformational adaptation. We define overarching “concepts” as existing theories and well-understood perspectives on transformational adaptation, or as general ideas that frame transformation in ways that address shortcomings of current framings. In a second step, we then developed a set of guiding

principles for action on forests and trees that were further informed and validated by a series of stakeholder workshops. Our definition of guiding principles captures ideas that influence decision-making on adaptation to climate change to better leverage the power and value of forest and trees and to transition to transformational adaptation. In other words, principles to guide transformative action (Figure 1).

The literature analysis resulted in five overarching concepts as they are agreed upon in several bodies of literature, beyond climate change adaptation (forest governance, sustainability science, climate change, biodiversity studies). From this we derived 10 guiding principles to promote the role of forests and trees in transformational adaptation, through a series of expert workshops.

3.2. First expert's validation

Two expert consultation workshops were organized with adaptation experts from Latin America, Africa, Asia, Europe and Australia in December 2021 to evaluate the draft concepts and principles and to build consensus on the validity of the principles to better leverage the power of forests and trees for adaptation.

Discussions during the workshop focused on thematic areas, specifically:

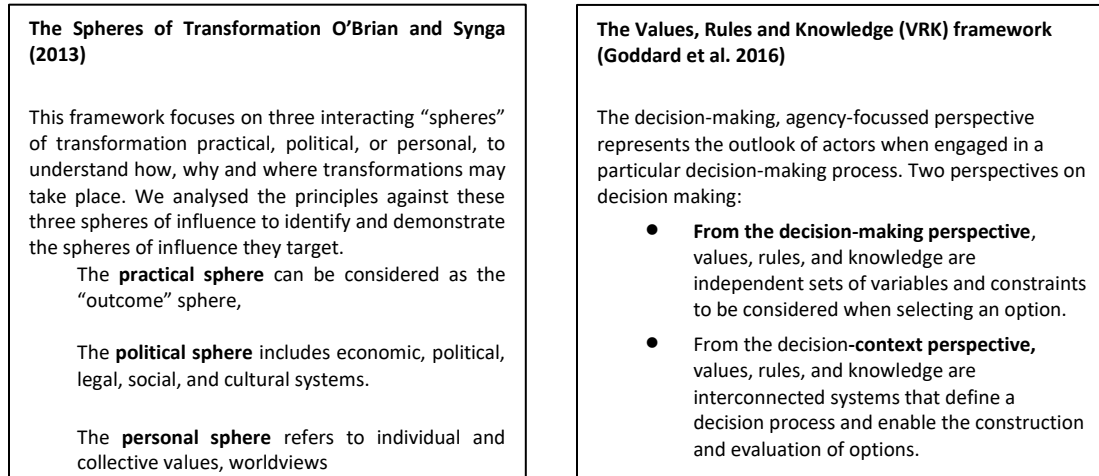
1. Context and scale: Adaptation is context-specific, cross-scale and cross-sectoral interactions are key
 2. Diversity: Biological and social diversity are central to adaptation, shifting focus on capacities and strengths of the vulnerable are key
 3. Transformations: Promoting transformative adaptation and addressing structural inequities
- Workshop discussions were transcribed and processed in order to synthesize current knowledge and build consensus on evidence-based principles to guide a better integration of forests and trees in adaptation.

3.3. Consolidation: literature review and classification using two theoretical frameworks

A systematic literature on adaptation principles was conducted to identify: 1) relation to the main objectives and the specific focus on tree and forest ecosystems, and: 2) reference to transformational adaptation. A Google Scholar database search was conducted which included the following key title words: "adaptation" "climate change" "Nature Based Solutions" and "principles". Results were screened for potential relevance, retaining 38 papers out of 46 initial results.

Two different transformational adaptation frameworks were combined, the Values, Rules and Knowledge framework (VRK) (Goddard et al. 2016) and the spheres of transformation framework (O'Brien and Sygna, 2013) to classify the principles and to analyse the way they relate to transformational adaptation (Figure 1). The VRK concept was used to situate the principles in the decision context and understand how they can enhance changes related to values, rules and knowledge to enable transformative windows of agency (Colloff et al. 2017) and enhance societal decision-making contexts that enable transformation.

Figure 1. Theoretical transformational adaptation frameworks used to consolidate the principles: VRK framework (Goddard et al. 2016) (right) and the Sphere of Transformations (left) (O'Brien and Sygna 2013)



3.4. Second experts' validation. In a third step, the results and the documents describing the overarching concepts and the principles were assessed by the expert group for final validation. The principles were also presented in two international venues and conferences: a CIFOR-ICRAF side event at the 56th session of the Subsidiary Bodies to the UNFCCC in Bonn in June 2022 [Leveraging the power of Forests and Trees for Climate Change Adaptation of the most vulnerable - YouTube](#) and at the Forests and Livelihoods Assessment, Research and Engagement (FLARE) conference in Rome in October 2022 (<https://www.forestlivelihoods.org/annual-meeting-2022/>). Remarks and comments from those processes were integrated into the concepts and principles.

4. Results

The analysis of the existing literature on climate change adaptation principles shows that trees-based systems and forests are not the focus of this body of literature. From the 38 papers on adaptation principles very few papers used a transformational adaptation approach (Nagoda et al. 2017 and Sing et al. 2022). The adaptation principles developed in most of the papers were cross-sectoral (Prutsch et al. 2010, Eriksen et al., 2011, Ingold and Balsiger 2015, Vij et al. 2021 and Singh et al. 2022) with very few providing examples or references to forests and trees (Prutsch et al. 2010, Eriksen et al., 2011 and Singh et al. 2022). The remaining papers developed adaptation principles for specific sectors including agriculture (Karing et al. 1999, Cohen-Shacham et al. 2019), coastal ecosystems and fisheries (Knapp, 2008, Ausden 2014, Sheaves et al. 2016, Watson 2016, Caponigro 2017), urban adaptation (Pucare te al. 2018, Hasani and Mofidi Shemirani 2020 and Hughes 2020), strategies for linking development and adaptation (Skrimizea et al. 2022), law and legal systems (Cook 2010, Ruhl 2010, Craig 2011, Hecht 2013 and Lavrik 2022), and other issues like infrastructure (Kim et al. 2019). While this analysis shows the relevance of our paper to close those gaps and contribute to this body of literature, we build upon existing papers to consolidate our set of concepts and principles.

4.1 Proposed set of concepts and guiding principles

The adaptation concepts (Table 1) emphasize breaking from business-as-usual pathways for transformational adaptation.

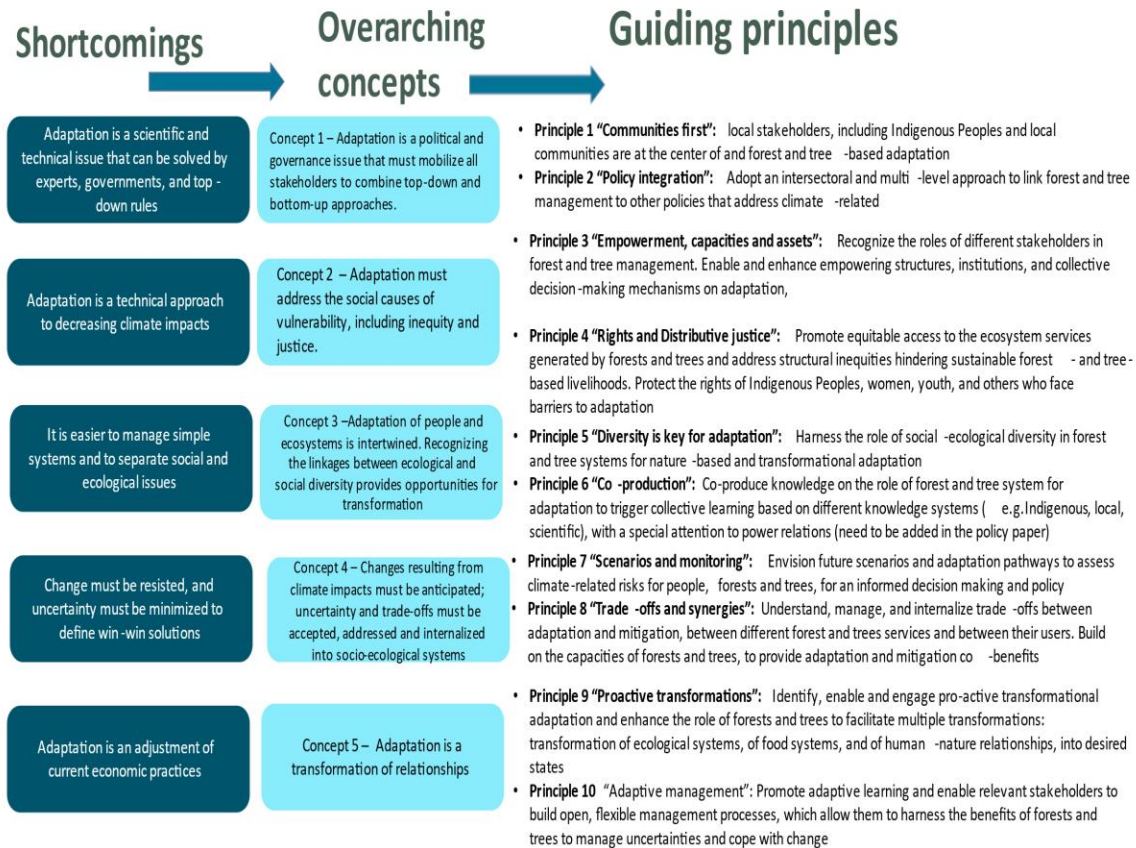


Table 1: Shortcomings of current framing of adaptation and overarching concepts and principles for forest- and tree-based adaptation (adapted from Coloff et al. 2017).

We propose a conceptual typology of five overarching concepts and the derived 10 organizing principles to address the shortcomings of current adaptation framing (as identified in Coloff et al. 2020). The concepts and the principles emphasize adaptive management, stakeholder involvement, and the need for multiple objectives, synergies and co-benefits. Various constraints are recognized, with institutional and governance barriers identified as the most severe obstacles to implementation. These general principles serve to define operational principles specific to forests and trees. We discuss how these principles differ from more conventional sectoral and project-based approaches. Although no panacea, we see the potential of those principles to

address the shortcoming of current adaptation approaches (Figure 1) more effectively circumscribed by the five concepts and 10 principles outlined here:

Concept 1 – Adaptation is a political and governance issue that must mobilize all stakeholders to combine top-down and bottom-up approaches.

Adaptation is too often imagined and practiced as a non-political process (Ribot, 2011, Adger et al. 2013, Brockhaus et al. 2020). This framing maintains and perpetuates exclusion patterns, with a lack of attention to agency and to the participation of marginalized stakeholders in designing and implementing adaptation actions (Eriksen et al. 2021). A re-politicization and decolonization of adaptation discourses, policy and practices is needed to counteract narratives of marginalisation and overcome the bottlenecks related to the political and intersectoral nature of adaptation.

Concept 2 – Adaptation must address the social causes of vulnerability, including inequity and injustice.

The underlying sources of human vulnerability to environmental hazards include a wide range of social and biophysical stressors resulting from the interaction of social, economic, historical, and political factors, operating at multiple scales (Ribot, 2011, Bassett and Fogelman, 2013, Erikson et al. 2021). Social scientists and political ecologists have been emphasizing that adaptation is a social process highlighting the importance to deepen the understanding of the vulnerability context (Pascual et al. 2022). A shallow understanding of the underlying causes of vulnerability can result in maladaptive outcomes, which inadvertently reinforce, redistribute, or create new sources of vulnerability (Eriksen et al. 2021). A dynamic social approach, which accounts for the multidimensional dynamic nature of vulnerability, is most likely to improve outcomes for adaptation and mitigation (Thomas et al. 2019).

Concept 3 – Adaptation of people and ecosystems is intertwined. Recognizing the linkages between ecological and social diversity provides opportunities for transformation.

There continues to be too much separation of the socio-political from the biophysical sphere in climate adaptation (Thonicke et al. 2020). Social and environmental systems and their diversity need to be considered together, as they are interdependent, co-evolutionary and linked by mutual feedback (Colloff et al. 2020). Divides and dichotomies persist which must be addressed to reach an optimal integration of human and environmental diversity in adaptation. These include artificial disciplinary divides in science; unequal value given to different ways of knowing and being, such as traditional knowledge and scientific knowledge; and power imbalances among political scales and between those governing and those being governed (Lavorel et al., 2020, Locatelli et al., 2022; Wyborn et al., 2019).

Concept 4 – Changes resulting from climate impacts must be anticipated; uncertainty and trade-offs must be accepted, addressed, and internalized into socio-ecological systems.

Recent climate science highlights significant uncertainty in current climate change risk assessment economic models, which are likely to lead to a greater warming damage than predicted (Rising et al. 2022). Those uncertainties are associated with the spatial and temporal

variations of climate impacts, the lack of knowledge co-production across disciplines, the lack of understanding of interactions and feedbacks between risks as well as the risk of the “unknown unknowns”, referring to currently unidentified risks (Simpson et al. 2021). Furthermore, the interaction of factors like climate change, population growth and mobility, dislocation, relocation, instability, and conflict increase the degree of uncertainty and might result in a great bandwidth of future divergent pathways (Rising et al. 2022). Against this background, resource management and conservation have been predominantly focused on resisting changes and maintaining historical or current conditions of ecosystems (Peterson et al. 2021). There is an urgent need for a paradigm shift in the way uncertainties are addressed in policy and science. This can happen through stronger interdisciplinary as well as across-scale collaboration to better account for uncertainties in climate risk assessment and to build a better way of communicating to policy makers and to the public (Rising et al. 2022).

Concept 5 – Adaptation is a transformation of relationships

There is growing evidence that incremental adaptation is not sufficient to address the ever-increasing and uncertain climate change impacts (Kates et al. 2012). Unless adaptation is rethought in a transformational perspective, it might result in maladaptive pathways for ecosystems and people that reproduce and exacerbate patterns of exclusion and inequities. We need to engage in fundamental changes in political, personal, and practical spheres (O’Brian, 2017) and foster desirable changes in values, knowledge, and rules (Colloff et al. 2017). Approaches that are built on the existing potential and capacity for learning and human agency recombine sources of experience and knowledge to deal with crises, handling it as windows of opportunity for novelty and innovation (O’Brian and Synga, 2013). Cultural, economic and governance institutions are key in this process as they can hinder or enable transformation (Westley et al., 2011). However, transformation is not a one-size-fits-all concept; in fact, different “transformations”, such as transformational change at smaller scales, is likely to enable resilience at larger scales (Folke et al. 2016). Societies need to transform the way they relate to and value nature and restore the relationships between humans and between humans and non-humans.

4.2. Ten Principles to harness the power of trees and forests for transformational adaptation.

The 10 principles were derived from the combined approach of literature analysis and expert consultations described above. They are a result of a consensus building among experts in climate change adaptation, natural resource management and forestry on how trees and forest can be best integrated into adaptation to trigger transformational processes at different levels of governance from the local to the global. While the overarching concept addresses adaptation in general, the principles aim to translate the general concepts for forest- and tree-based adaptation.

Principle 1 “Communities first”: *Enable local stakeholders, including Indigenous Peoples and local communities, to be at the centre of adaptation and forest and tree management. Adaptation is context specific and needs to emerge from bottom-up processes that articulate with other levels. Top-down planning can lead to maladaptation.* The way society responds to climate change, and the degree to which adaptation is constrained, can occur at the local level or across landscapes in which stakeholders’ objectives interact and often compete, ecosystem processes and decisions unfold, and where different interests are materialised (Sayer et al. 2015). Hence, this first principle

calls for a shift away from the centre of gravity of adaptation processes to local people and Indigenous Peoples to use and benefit from the forests and trees they manage and own. Tree- and forest-based landscapes are subject to multiple interests of various stakeholders for different and diverging objectives (Brockhaus et al. 2021). Some of those interests don't necessarily prioritise the adaptive capacity of local actors who are at the forefront of climate change (Coger et al. 2022). Similarly, the adaptation process is characterised by competing interests and values, which can lead to inequitable outcomes through the enclosure of resources, the exclusion of certain stakeholders from adaptation decision-making processes, and/or the encroachment upon local and indigenous people's rights (Turnhout et al. 2020). In a transformational forest- and trees-based adaptation approach, the needs of local people for adaptation services generated by forests and trees and their entitlement to those services should be prioritized (Nightingale, 2016, Djoudi et al. 2013). When managed in an adequate and context-specific manner, forest- and tree-based systems offer a significant potential for locally led adaptation (Meybeck et al. 2021). Hence, the first principle aims to harness the potential of forests and trees for transformational *local* adaptation. This means a paradigm shift in adaptation governance, from the business-as-usual conceptualisation of local communities and Indigenous Peoples, disempowered and reduced to vulnerable recipients of top-down adaptation projects. Forest and tree based transformational adaptation calls for a radical rethinking of a common future, which prioritises the interests of the marginalized, future generations and non-human entities (Pelling 2010, Tschakert et al. 2021).

Principle 2 “Policy integration”: *Adopt an intersectoral and multilevel approach to link forest and tree management to other policies that address climate-related risks (e.g. climate policies, watershed management, carbon projects).* While the literature has built a multidimensional understanding of vulnerability, sectoral approaches dominate in empirical studies (Ajibade, 2017; Kmoch et al., 2018). Multi-scalar socio-political relations that underpin vulnerability are underdiscussed, in part because they are difficult to assess with linear or sectoral approaches. Transformational forest- and tree-based adaptation needs to build mechanisms to overcome sectoral fragmentation, and trigger and allow intersectoral collaboration. Identifying multi-sector climate change vulnerabilities and addressing those holistically has proven to be a more efficient approach to adaptation (Lemieux et al 2014). Trees and forests are key for achieving many objectives, including climate change mitigation and adaptation, economic development, and sustainable development. Integration across sectoral policies (e.g., climate, watershed management, biodiversity conservation, landscape restoration, food security and economic planning) requires horizontal overarching governance structures for cross-sectoral coordination (Di Gregorio et al. et 2017). Furthermore, Intersectoral Action (ISA) is a well-advanced approach in other domains, such as in the health sector, and can benefit adaptation. This body of knowledge highlights that technical concerns for strengthening capacities and providing support instruments and mechanisms are key for intersectoral collaboration. However, power and inter-organizational dynamics need a great deal of attention to ensure the sustainability of intersectoral initiatives (Mondal et al. 2021).

The closest example for integration is in the domain of mitigation and adaptation actions. Forest and trees are relevant to both, but to derive benefits for multiple actors (local, regional, global) it is crucial to promote synergies in planning and implementation of forest-based mitigation and adaptation strategies. Activities to address mitigation and adaptation in the forestry sector are planned and implemented locally. Integration can be reached by promoting and enhancing adaptive forest management, aligning climate finance to avoid competitive use of funds, and

creating transparent and clear finance access mechanisms for local communities and Indigenous Peoples.

Principle 3 “Empowerment, capacities and assets”: *Recognize the roles of different stakeholders in forest and tree management. Enable and enhance empowering structures, institutions, and collective decision-making mechanisms on adaptation, which include the voices of the most vulnerable or marginalized.*

Forests and trees represent natural assets of great importance for adaptation. When facing hardship, the poorest and most vulnerable households increase their use of forest- and tree-based resources (Angelsen and Dokken, 2018, Koffi et al. 2011). Even when they don't generate considerable wealth for local people, they are increasingly important for the poorest, because the adaptation goods and services they provide are often the only safety net to protect the most vulnerable from slipping into increased poverty and food insecurity during times of crisis (Djouidi et al. 2015, Shackleton et al. 2007, Osbahr et al. 2008, Fisher et al. 2010, Fisher et al. 2010, Pramova et al. 2012, Brockhaus et al. 2013, Koffi et al. 2017). Around 1.6 billion Indigenous Peoples and local communities live in and around forests and depend on them (Newton et al., 2020; RRI, 2020). Protecting these natural assets and building the necessary financial, social, human, and physical assets people need to manage forests is key. There is increased concern that the degradation and loss of resources provided by forests and trees will exacerbate already existing vulnerabilities (Griffiths, et al. 2019). Managing forests and tree ecosystems sustainably for adaptation should be a key priority in adaptation policies (Fedele et al. 2020).

Principle 4 “Rights and Distributive justice”: *Promote equitable access to the ecosystem services generated by forests and trees and address structural inequities hindering sustainable forest- and tree-based livelihoods. Protect the rights of Indigenous Peoples, women, youth, and others who face barriers to adaptation.*

Climate change will affect people differently according to their cultural, economic, environmental, and social context. Several studies highlight the need to recognize the importance of inequity as determinant of vulnerability (Thomas et al. 2019, Gaynor and Wilson, 2020). Rights-based approaches to adaptation have emerged in the climate change literature (Jodoin et al. 2021) arguing that adaptive capacity requires an engagement that goes beyond technical responses to climate change to include the question of equity associated with the disproportionate impacts of climate change, access and control over resources needed for adaptation, and the distribution of costs and benefits of adaptation (Tschakert et al 2012, Ensor et al. 2015, Djouidi et al. 2017).

Even if emissions slow and the climate stabilises, some societies and ecosystems might not be able to adapt to 2°C of warming above preindustrial levels (Adger and Barnett, 2009). This raises important questions of global climate justice in the context of adaptation (Adger and Barnett, 2009). Rural communities, for their part, do not escape challenges of power and differentiation (e.g. gender, class, ethnicity) in their own internal governance systems, which might increase marginalisation and vulnerability as climate change unfolds (Stocks, 2005). Transformational forest- and tree-based adaptation needs to focus on enabling and enhancing empowering structures, institutions, and collective decision-making mechanisms. Scholars illustrate that forests and trees are the only available resources for the poorest to cope with hardship (Principle 3), this means inevitably that protecting the rights and access to forest- and tree-based adaptation services is an effective mechanism to enhance the adaptive capacity of people, particularly of

Indigenous Peoples, women, youth, and others who face greater barriers to access other assets needed for adaptation (Dooley et al. 2022; Dawson et al. 2021; Doss and Meinzen-Dick 2020)

Principle 5 “Diversity is key for adaptation”: *Harness the role of social-ecological diversity in forest and tree systems for nature-based and transformational adaptation*

Diversity contributes to adaptation and resilience in different ways with two types of diversity being important for social-ecological systems: functional diversity, or the number of functional groups influencing system performance, and; the diversity of responses to disturbances, which influences resilience. In the social domain, performance is related to the diversity of actors or groups, and the more different types of actors there are in a system, the more functions are performed (Walker et al.2006).

Natural forests, mixed species plantations and high diversity grassland have more stable carbon stocks during climate extremes (Hutchison et al.,2018; Osuri et al., 2020, Isbell et al., 2017). Similarly, biodiverse natural forests and naturally regenerated forests have higher resilience to fires, pests, and diseases (Barlow et al., 2007; Jactel et al., 2017, Seddon et al. 2021). Along the same lines, global assessments demonstrate that sustainable forest management is likely to help reduce environmental, social and economic vulnerabilities under a wide range of potential future climatic conditions (Seddon et al. 2021).

Local actions to protect or restore ecosystem complexity and structure can increase the adaptive capacity of ecosystems to extreme events (França et al. 2020). Biological diversity and social diversity (diversity of social actors) are interlinked. The positive relationship between biodiversity, the diversity of social actors and the resilience of social-ecological systems has been demonstrated in recent studies (Grêt-Regamey, 2019). Forest and tree management for transformational adaptation needs to maintain the abilities of both the ecological and the social systems to co-evolve over time.

Principle 6 “Co-production”: *Co-produce knowledge on multiple forest and tree systems with diverse stakeholders and diverse knowledge systems (e.g. Indigenous, local, scientific).*

In the context of ecosystems, co-production refers to the process in which benefits arise through people’s interactions with ecosystems, as a result of multiple, long-term and dynamic interactions, with the interplay of a mixture of natural capital and various forms of social, human, financial and technological capitals (Lavorel et al. 2020, Palomo et al. 2016). Co-production promises to address the complex nature of sustainability challenges (Norström et al. 2020) and rejects top-down, science-driven knowledge creation and dissemination, in favour of interactive arrangements between academic and non-academic actors. Adaptation, being a multi-sided, multidisciplinary, and multilevel process requires integrative and holistic knowledge creation and exchange (Hegger et al. 2012a, b; Klenk and Meehan 2015; Runhaar et al. 2016, Boon et al. 2019). Adaptation scholars highlight that knowledge, personal and societal values and institutional rules determine how different actors prioritize their adaptation options (Gorddard al. 2016) making coproduction a promising concept to advance the understanding of trade-offs in forest- and tree-based adaptation. Furthermore, knowledge co-production has the potential to create institutional processes which trigger and enable collective learning to adapt to change (Armitage et al. 2011). However, coproduction requires long-term commitments to build institutions and create favourable conditions for complex social processes, social interactions and collective action (Armitage et al. 2011, Lavorel et al. 2020). We argue that knowledge co-production needs to go beyond simplistic dichotomies and aggregation of

academic and non-academic knowledge, by engaging with the political and power asymmetries of knowledge. Forests bear the historical legacies of past periods (Walters et al. 2019) and this inevitably means knowledge co-production for forest- and tree-based adaptation will require more attention to historical processes, power asymmetries in forest governance, as well as the gaps between global concepts and locally situated practices (van der Hel 2018, Hill et al, 2020, Norström et al. 2020). Depending on context and place, coproduction that ignores the complex and contested histories of colonisation, which are still limiting adaptation, can result in maladaptation and increase vulnerabilities (Hill et al. 2020). Knowledge co-production researchers and practitioners working in the global south context and/or in Indigenous People's territories need to deeply engage with decolonial theories and practice, moving away from naïve integration narratives, toward a transformative framing with Indigenous leadership in research and practice (Latulippe and Klenk, 2020, Hill et al. 2020).

Principle 7 “Scenarios and monitoring”: Envision future scenarios and adaptation pathways to assess climate-related risks for people, forests and trees, and use them in decision making. Integrate local knowledge in participatory monitoring.

Recent studies highlight that the risks from climate change are likely to be greater than current economic models suggest, because these models routinely exclude potentially devastating but hard-to-quantify threats. Common Monitoring and Evaluation (M&E) frameworks are often focused on quantified outputs and value for money rather than the longer-term qualitative dimensions of building resilience (Kaika, 2017, Donatti et al. 2019). Flexible, no regret strategies can make future uncertainty manageable in a cost-effective manner, but common M&E timescales are too short to assess longer-term outcomes and impacts. Furthermore, context specific dynamics and complex characteristics of vulnerability challenge adaptation M&E frameworks, which are often ill equipped to assess whether vulnerability is reinforced or redistributed by adaptation interventions. In the forestry domain similar approaches have been previously used (Miller et al., 2017), but monitoring transformational impact of forest- and tree-based adaptation needs the right mix of quantitative and qualitative approaches to capture the nuanced context-sensitive, cross-case and multidisciplinary processes (Cohen-Shacham et al. 2019). Investments in tree-based systems and forest involve measures with a life span up to 50-100 years, which will strongly determine future land use. To envision resilient pathways for people, forests and trees, transformational adaptation monitoring needs flexible, non-linear and iterative approaches with long timelines, which enable effective stakeholder engagement (Lemieux et al. 2014). Furthermore, the ever-increasing impacts of climate change have demonstrated that approaches that aim to control or prevent perturbations and disturbances, which are natural components of ecosystems that allows diversity and renewal, show their limits (Kasperson et al 2022) Stronger collaboration within and between the natural and social science communities for M&E is crucial to address those challenges.

Principle 8 “Trade-offs and synergies”: Understand, manage, and internalize trade-offs between adaptation and mitigation, and between different ecosystem services and users of forests and trees. Build on the capacities of forests, trees and people to enhance adaptation and mitigation synergies. The adaptation process requires navigating trade-offs at different levels and scales among actions, ecosystem services (ES) and different stakeholders along adaptation pathways. Understanding trade-offs and co-benefits is therefore essential to support social adaptation (Lavorel et al. 2020).

Forest- and tree-based systems provide services at different scales, including local, regional and global. Needs and priorities for ES are different among users and are scale dependant. Power imbalances in decision making over ES can lead to policies and prioritizations, which entail losses of vital adaptation services for local people. Governance processes and structures are needed that enhance dialogue among stakeholders to better anticipate and navigate current or future trade-offs to come (Larson et al. 2020). By 'building with nature', that is, using natural processes for adaptation, and adopting flexible, no regrets adaptation and forest management measures, and prioritizing mitigation activities that enhance local adaptive capacity can help balance future trade-offs (Guariguata et al. 2008, Duguma et al, 2019, van Noordwijk et al.2021).

The importance of forests and trees for local adaptation needs to be adequately captured to overcome carbon-centric metrics (Lawrence et al. 2022, Windisch et al. 2022). This is well illustrated in recent studies showing that trees in silvopastoral systems offer substantial cooling benefits through evapotranspiration, hinting that even at the local scale smallholders can reap important cooling services to counteract local temperature increases from global climate change (Zeppetello et al. 2022). A shift in thinking is urgently needed to resolve trade-offs and facilitate synergies between adaptation and mitigation, by accounting for the non-carbon benefits of forest.

It is worth mentioning that scholars highlight the fact that some trade-offs arise because of the ways adaptation is assessed, often through incompatible and ill designed measures and criteria (Adger et al. 2005; Doria et al. 2009; Moser and Boykoff 2013), stressing again the importance of adequate M&E frameworks (principle 7).

Principle 9 “Proactive transformations”: *Identify, enable and engage pro-active transformational adaptation and enhance the role of forests and trees to facilitate multiple transformations: transformation of ecological systems, of food systems, and of human-nature relationships, into desired states.*

As climate change unfolds and particularly if we move beyond 2° C of warming, social ecological systems may progressively transform into new states that can no longer support human populations (IPCC, 2022), underscoring the need for transformational actions. Against this background, and according to a systematic review on forest management adaptive strategies, most forest management recommendations (86%) focused primarily on maintaining existing ecological patterns and processes, while only 14% focused on transforming to new system configurations through proactive interventions (Hagerman and Pelai, 2018). This is also the general trend in conservation, where long term strategies, for instance the role of climate change refugia, are not given the attention they deserve in adaptation planning (Munera-Roldan et al, 2022).

Pro-active management for ecosystem transformation is lacking, maintaining business as usual structures and ways of working that are hindering transformations. Powerful actors (e.g., politicians, representatives from donor agencies and non-governmental organizations) use their discursive capacities and financial support to prioritise agendas that focus on tangible, short-term development activities associated with immediate political gains, rather than investing in long-term transformative adaptation (Vij et al, 2021 Morrison et al., 2017; Nawab and Nyborg 2017). The result is the common trend of retrofitting adaptation into existing development agendas, driving maladaptive outcomes at various levels (Eriksen et al. 2021).

Pro-active management for transformation includes understanding and investing in levers for transformational change, which include restructuring institutions, reconnecting people to nature, and rethinking how knowledge is created and used in pursuit of sustainable and just outcomes (Norström et al. 2020).

Principle 10 “Adaptive management and learning”: *Promote adaptive learning and enable relevant stakeholders to build open, flexible management processes, which allow them to harness the benefits of forests and trees to manage uncertainties and cope with change.*

Adaptive management is an approach for simultaneously managing and learning about natural resources. Given the importance of forests to climate mitigation and for people, it is important that forests are able to adapt to climate change. However, scholars highlight that unmitigated climate change would exceed the adaptive capacity of many forests over the current century even if adaptation measures are fully implemented (Keenan, 2015.). Recent studies show that a loss of resilience usually paves the way for ecosystems to switch to an alternative state. Adaptive strategies should focus primarily on maintaining ecosystem resilience (Scheffer et al. 2001). Collaborative learning to improve adaptive management is much needed in the conventional environmental governance systems, which seem to lack learning capacity (Birkes 2017).

4.3. Operationalising the principles: Unlocking barriers for trees and forest-based transformational adaptation

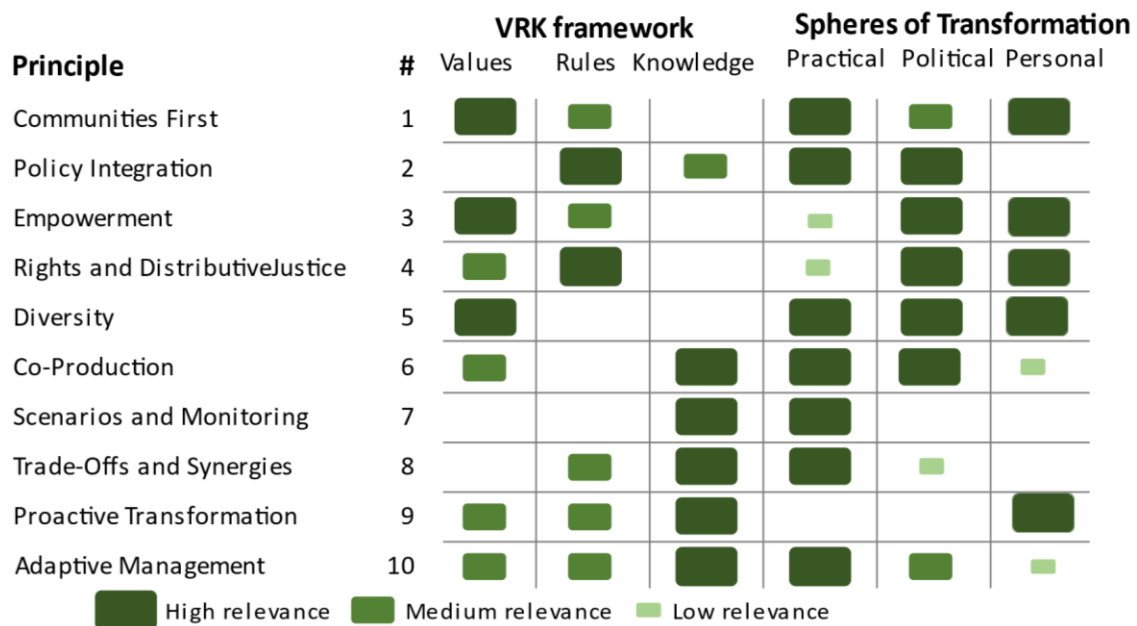
We used two transformational frameworks (VRK) and the Sphere of Transformation to classify the principles to deepen our understanding of their potential to unlock barriers for tree- and forest-based transformational adaptation. The results are shown in Figure 2.

The VRK framework was used to situate the principles (P) in the decision context and understand how they can enhance changes related to values, rules and knowledge to enable transformative windows of agency (Colloff et al. 2017) and enhance societal decision-making contexts that enable transformation. The results highlight that individual principles can often be located with a centre of gravity in one or more of the three components of VRK. Seven principles involve values, six involve knowledge, and seven involve rules. However, P6 (co production) to P10 (adaptive management) are highly relevant to knowledge (K), while P2 (integration) and P4 (distributive justice) are highly relevant to rules (R). Furthermore, P1 (community first) , P3 (empowerment, capacity and asset) and P5 (diversity) are highly relevant toward values (V). This classification shows that principles that address future pathways are relevant to deblock bottlenecks situated at the nexus of transformative adaptation, uncertainties and trade-offs, while principles related to inclusion, distributive justice and diversity need to unblock issues related to values and rules.

This said, it is important to highlight that the VRK is about interactions among V, R and K, and individual principles for trees and forest-based adaptation unlock barriers situated in their interactions. Our analysis shows that all principles related to proactive transformations and adaptive management are related to all three components of VRK, while three principles relate to values and rules, four to rules and knowledge and only one to knowledge and values. In general, most constraints that need to be addressed are situated at the knowledge and value nexus.

The classification of our principles along the sphere of transformation framework shows that seven of the 10 principles are highly relevant to deblock bottlenecks at the interface of political and practical spheres, whereas politics and power influence the rules and create the conditions to enable or hinder transformations in the practical sphere. This is not surprising as we deliberately took a political approach to adaptation, and our results call for a better integration of political, technical, and social dimensions of forest and tree-based adaptation. The personal sphere, which refers to individual and collective values, is where the transformation of individual and collective beliefs, values and worldviews occurs.

Figure 2: Classification of the principles according to the VRK framework (Goddard et al. 2016) and the Spheres of Transformation framework (O'Brien and Sygna 2013) frameworks



5. Conclusions

This paper aims to advance scientific knowledge on how to harness the role of forests and trees for adaptation. It aims to address some of the adaptation research frontiers associated with the incremental versus the transformational nature of adaptation, the divergent pathways of adaptation and mal-adaptation, the dichotomy versus coproduction of knowledge, rights and justice, and the importance of context-specific adaptation pathways.

The paper identifies concepts and principles to better integrate forest and trees into transformational adaptation strategies. These principles are derived from the position that business-as-usual approaches to adaptation will continue to generate social and environmental outcomes that are unsustainable and inequitable.

The 10 principles presented here were developed from a combined approach of literature analysis and expert consultations. They are a result of a consensus among experts in climate change adaptation, natural resource management and forestry on how trees and forests can be best integrated into adaptation to trigger transformational processes at different levels from the local to the global.

The principles emphasize adaptive management, stakeholder involvement, and the need for achieving multiple objectives, synergies, and co-benefits. Various constraints are recognized, with institutional and governance barriers identified as the most severe obstacles to implementation. These principles serve to define operational actions and guidelines specific to forests and trees. These principles differ from more conventional sectoral and project-based approaches and can guide action to unlock barriers situated in the interactions of values, rules and knowledge acting in practical, political and personal spheres of transformation.

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