Evidence-informed co-design of forest landscape restoration for biodiversity and people - the Kilombero Valley, Tanzania

POLICY BRIEF 2025

KEY ISSUES

- Larger forest patches enhance habitat for threatened mammals and forest-dependent birds.
- Heterogeneous forest-agroforestry-agriculture landscapes promote functional bird diversity.
- Tree canopies reduce heat stress and alleviate flood and erosion risks but can attract elephants, increasing the risk of crop damage.
- There are trade-offs in benefits and costs perceived from trees at farm and landscape scales.
- Ineffective restoration stems from limited data and data sharing, weak governance around project co-design, knowledge exchange and evaluation, and lack of coordination among stakeholders.

By integrating scientific evidence with stakeholder input, policymakers can design restoration strategies that maximize ecological and socio-economic benefits while addressing environmental and climate change challenges.

Context for the policy challenges

Rural tropical landscapes provide essential food resources and livelihood opportunities to communities across Tanzania. These landscapes are also rich in biodiversity, often located in biodiversity hotspots. They support a wide range of wildlife—such as birds, mammals, amphibians, and reptiles—as well as native tree species and diverse ecosystems, including semi-humid mountain forests, dry lowland forests, savannahs, natural grasslands, and wetlands.

However, these vital landscapes are under increasing pressure. Land degradation affects over 40% of agricultural land in Sub-Saharan Africa (Nkonya et al., 2016). Combined with climate change, limited capacity to adapt, and unsustainable land use, this creates serious challenges. Farming remains the main livelihood in rural areas, but rising population has driven higher food demand. In trying to meet this demand, harmful land practices have become common, worsening land degradation.

Degradation along riverbanks, in particular, increases the risk of drought, floods, and heatwaves. These threats harm crops and food security (Davies-Reddy et al., 2017), reduce biodiversity, and damage ecosystem health. Human health is also at risk—especially for mothers—due to heat stress linked to miscarriage and low birth weight (Bonell et al., 2022). Most farmers are smallholders, but climate risks also affect larger farms and agribusinesses. As a result, many rural communities remain vulnerable to extreme poverty and poor health, slowing progress toward the Sustainable Development Goals (SDGs).

The Kilombero Valley highlights the interconnected challenges facing rural tropical landscapes in Tanzania. Various actors have worked to address climate change, land degradation, biodiversity loss, and food insecurity. Their efforts have included restoring forests and wildlife corridors, which align with national goals to: (1) restore 5.2 million hectares of degraded and deforested land as part of the African Forest Landscape Restoration Initiative to restore 100 million hectares by 2030 (URT, 2023), and (2) restore key wildlife corridors (MNRT, 2022). There is now growing attention on restoring riparian buffers, which can help protect biodiversity and support local communities by reducing flood risks, soil erosion, and sediment buildup in freshwater streams.

However, efforts in the Kilombero Valley and similar landscapes are often fragmented, with different actors working in silos. This siloed approach limits collaboration and integration, resulting in insufficient evidence on which tree species to use, which restoration methods are most effective, and what socio-economic impacts interventions have. As a result, decision-making remains poorly informed. To address these gaps, land systems science offers frameworks that help understand how human activities shape rural tropical landscapes and how more holistic, integrated solutions can be developed. Based on evidence from applying a land systems approach to the forest landscape restoration, we suggest ten policy actions to address the challenges identified above. These actions are presented below, followed by a technical report that provides the supporting evidence.

POLICY RECOMMENDATIONS

1. **Close research and knowledge gaps in restoration actions to make them evidence-based.** Focus on six research challenges:

- **What to plant**:

Develop a handbook that matches tree species to the biophysical attributes of the site (soil, topography, climate), the socio-economic needs of communities at the site (nutrition, income, other values).

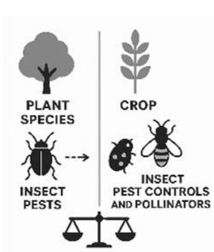
Identify cost and benefits of tree species (e.g. ecological: growth rate, microclimate buffering, native versus non-native trees; socioeconomic: competition between crops and trees, wildlife conflicts). Account for context: e.g. planting trees along riparian areas versus agroforestry farming. This will allow evaluation of trade-offs (e.g. planting fruiting trees for value addition or closing nutrient yield gaps might increase conflict with wildlife such as elephants attracted by fruits) for informed decision-making.

- **Where to plant**:

Develop a protocol for riparian buffer restoration: inform decisions on buffer extent and width accounting for wildlife needs and climate risk mitigation and identify where rules can be flexible depending on landscape context.

Quantify tree cover thresholds for climate hazard mitigation and biodiversity conservation, comparing taxa with differing habitat and movement ecologies.

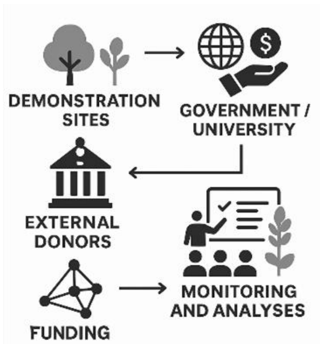
Adaptively develop and manage wildlife corridors, in partnership with communities from project start to monitoring its impact on biodiversity and human livelihood outcomes. Research effectiveness of mitigation options for human wildlife conflict associated with corridors.



Identify the effects of tree or plant species on insect pests, natural pest control, and pollinators. This requires more detailed, small-scale experiments focusing on specific crops or tree–crop combinations. Moreover, it is important to quantify whether the overall benefits outweigh the costs imposed by insects on crop health and yields.

2. **Build local and national technical capacity** in restoration on farms (agroforestry) and in the wider landscape to increase stakeholder buy-in and restoration effectiveness and to meet biodiversity, crop production and climate change mitigation commitments

- **Establish a network of demonstration sites:** agroforestry farms and forest restoration

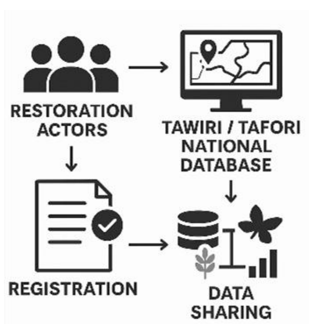


Establish as government led / university run sites distributed across different agroclimatic contexts, co-funded by levies on restoration/carbon sector/ conservation NGOs and agribusiness. Use for research and farmer/school/community visits.

Link network to training workshops (monitoring, analyses, reporting) with university accreditation (i.e. agroforestry advisor, carbon credit advisor). Secure funding from donors (Worldbank, IUCN).

- **Develop national scale capabilities**

Require all actors to register any restoration project in a national database regulated by TAFORI, including the following details: (i) spatial location; (ii) tools used to collect data for monitoring the effectiveness of interventions over at least five years; and (iii) stakeholders involved and strategies used to engage them. Consider the need for cross-checking by designated advisors (see above).



Require actors to deposit annual data on tree/plant species used in restoration, number of individuals planted per species, indicators for tree survival, biodiversity at site and landscape scales, and relevant household socio-economics.

Establish a data management centre. Analyse the data annually at national scale for restoration success and failure to learn which activities produce best outcomes in different agro-climatic contexts and identify variables contributing to success or failure.

Develop training in insect identification and classification into pest control and pollinator species ('good species') versus pest species to support agroforestry approaches to tree cover restoration.

3. **Ensure effective governance in the restoration sector**

Monitor compliance with site based permits and enforce stricter rules and criteria for the process of data management, sharing and reporting on all projects/NGOs working in the sector.

Identify local governance and management constraints and opportunities. This could include incentives —opportunities from carbon markets and biodiversity offsetting markets — and disincentives — fines for environmental pollution.

Require restoration actors to outline funded pathways for up skilling local students and staff for professional development within the organisation.

TECHNICAL REPORT

1 Research and knowledge gaps in restoration actions: the need to establish robust evidence linking trees to ecosystem services

The current evidence base for decision-making on forest landscape restoration in the Kilombero Valley is primarily limited to biodiversity, socio-economic and aboveground carbon stock objectives. The evidence has for example emerged from projects co-led by UK (Newcastle University, Stirling University, University of Leeds, etc) and Tanzanian universities (Sokoine University of Agriculture: National Carbon Monitoring Centre), partnering with local actors including Non-Governmental Organizations (NGOs) (Reforest Africa, Mazingira, Southern Tanzania Elephant Program (STEP), international entities (e.g. International Union for Conservation of Nature (IUCN) Sustain, World Wide Fund (WWF)), and industry (Illovo Sugar) but also government (Tanzania Forest Conservation Group (TFCG), Tanzania National Park (TANAPA), and Tanzania Agriculture Research Institute (TARI)).

As part of the United Kingdom Research and Innovation (UKRI)— Global Challenges Research Fund project 'Agrisys Tanzania', we developed a land systems method framework (Fig. 1) that can be used to understand and quantify the interconnectedness of climate and land use changes, and to measure and monitor how they shape biodiversity, food security and subsequently human wellbeing (Pfeifer et al. 2022). The model integrates across indicators for landscape configuration, and changes thereof due to land management and governance, and outlines measurable direct and indirect pathways from landscape configuration to biodiversity, microclimate and ecosystem services and disservices (Milheiras et al. 2022 a). We applied the framework to the northern part of the Kilombero Valley, where we collected data and predictively modeled, and mapped the relationships between tree cover and its spatial arrangement with other land uses (e.g. cropland, villages, roads, grassland) and biodiversity, microclimate, soil and yield health and carbon stocks.

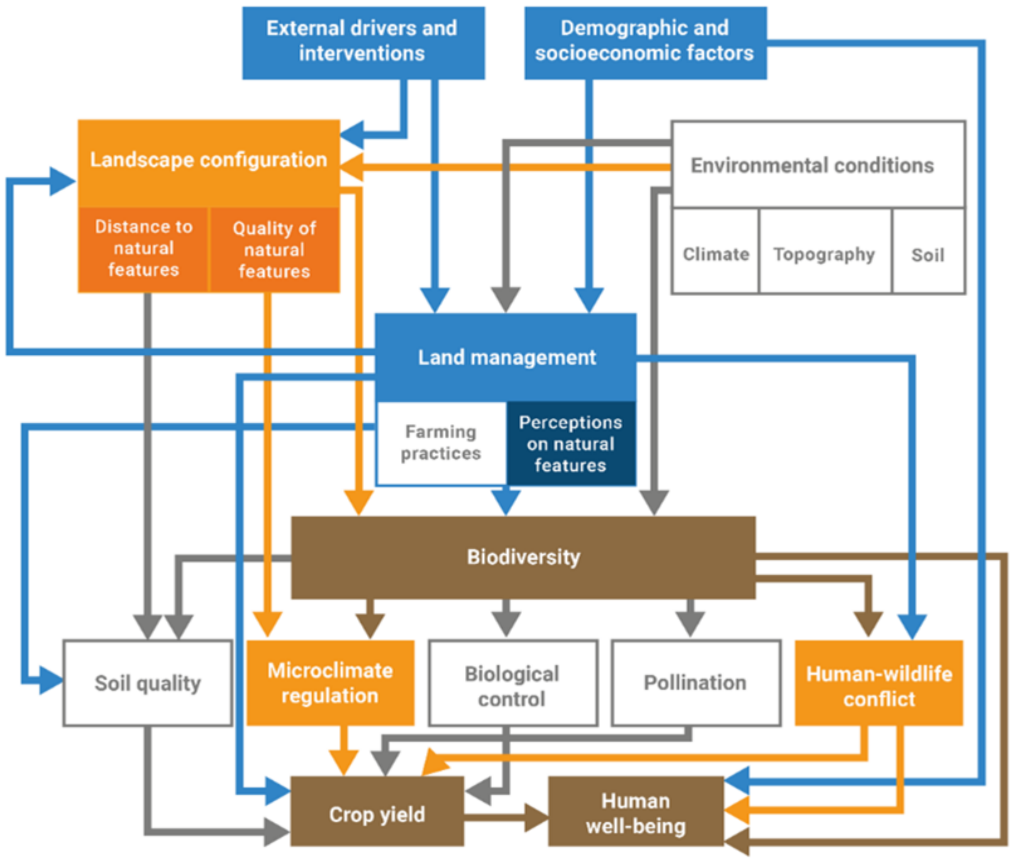


Fig. 1 Systems model describing direct and indirect pathways, with which social variables (including governance, households) affect land management and landscape configuration, which in turn can affect microclimate, soil quality, biodiversity and associated ecosystem services (pollination, pest control) and disservices (i.e. human wildlife conflicts including through pests/herbivores/predators). These in turn can affect crop yield and human – wellbeing, e.g. material wellbeing, health, and perceptions of safety (see Guerreiro-Milheiras et al. 2022 a).

Biodiversity benefits from increasing tree cover – case study Kilombero Valley

Mammal species richness, measured using camera traps, was highest in the forest habitats increasing with: forest amount (percentage of forest cover in a 250 m window around sample points), distance to roads and rivers and tree canopy heterogeneity (variation of canopy closure in 500 m window around sample point). In our case study landscape, six threatened mammals remain—leopard, elephant, hippo, and three monkey species—which tend to inhabit forested areas and are more likely to be observed farther from roads. The 10 mammal species were only recorded in the forests (*Colobus angolensis, Equus quagga, Petrodromus tetradactylus, Alcelaphus buselaphus, Hystrix cristata, Paraxerus palliatus, Hippotragus niger, Crocuta crocuta, Nesotragus moschatus, and Piliocolobus gordonorum*). Jackal and Greater cane rat were found on cropland, the cane rate specifically was found in two locations only: on the sugarcane plantation estate. ***Future data needs:*** Camera trap data need to be collected in forest canopies to capture the habitat requirements of arboreal and semi-arboreal mammal species. Additionally, camera trap data from within forests such as Udzungwa Mountains National Park and

Magombera Nature Reserve should be collected along linear transects extending from the forest edge and made available for sharing.

Bird species richness, measuring using point based surveys, was highest in the cropland, driven by heterogenous tree – farm mosaics on small-holder farmed land. We found at total of 178 bird species: 17 species were shared between forest and small-holder farms, and 10 species were shared between plantation/small-holder farm and forests. Thirty-eight species were only observed in forests, 3 only on the sugarcane estate, and 44 only on the smallholder farms. Bird species richness declined with increasing (within a 250 m window around sampling points) and dense tree canopy closure at the sampling point. However, birds tended to be more abundant near forests and rivers. For bird species that are invertebrate feeding, potential natural pest controllers, , declined with increasing distance from forest patches. Similarly, seed- feeding bird species, which also could be potential crop pests, also decreased with distance from forests. Three threatened bird species remain in landscape: *Ploceus burnieri* (found across small-holder farms, with abundance declining with both canopy closure and increasing distance to forests), *Polemaetus bellicosus* (found in one small-holder site), *Cinnyris rufipennis* (found in a forest plot). ***Future data needs***: analyse how forest bird species use riparian buffers and analyse bird diets to better understand food resources.

Insect species, measured using observations and netting in field plots, are difficult to identify and categorize according to their function and this role was done by National Museums Kenya, which also provided some training at SUA. The insects showed no simple relationship with land use types or tree cover density/configuration. ***Future data needs***: on farm experiments looking for crop – field margin vegetation and tree-crop interaction effects on insect distribution and abundance.

Wildlife corridor effects and trade-offs – case study Kilombero Valley

Wildlife corridors: Data have not been collected specifically to inform the wildlife corridors design. We can analyse the few existing data with assumptions: (i) wildlife corridors are created to promote the movements of mammals and birds that are only found in forests, (ii) their presence/absence is only determined by canopy closure and by distance to the forest edge. Pilot analyses suggest that for the 10 forest-only mammals, the minimum width of the corridor may need to be 120 m to support the movement of the most tolerant species, with a median required width of 544 m across species. The minimum canopy closure may need to be 51%. For the 38 forest-only birds, the median width should 414 m across species, with 55% canopy closure. Data from forest plots (native trees only) suggest a nonlinear relationship between the number of trees and the canopy closure in a 20 m x 20 m plot. To achieve over 50% canopy closure, at least 10 trees may need to be planted within such a plot. ***Future data needs***: capture more accurate distribution data for arboreal species (see Mammal Biodiversity) and have a larger sampling network of camera traps to monitor species movement across the crop – forest landscapes.

Trade-offs in vertebrate regulated biodiversity services and disservices: (i) Crop – elephant conflict is driven by elephant movements, with elephant abundance increasing with forest cover around sampling points and declining with increasing human density. The likelihood of crop damage is higher in low population density areas, closer to rivers and further away from the protected area and forest. (ii) Potential pest control species (vertebrate feeding mammals, invertebrate feeding birds) frequent small holder farmed land and the sugarcane estate but require forests and/or grassland. (iii) For insect pests, okra, maize and sugarcane - if farmed as monocrops – have perhaps higher pest levels compared to mixed crops but data are too sparse for meaningful conclusions. Natural areas (fallows, tree patches) also have higher pest levels and some crop mixes. Insect pollinators are found on monocrops and mixed crops, and in tree patches, fallow grassland plots. Predatory insects are more abundant in the forests and tree patches but also occur elsewhere, including sugarcane and maize systems. Parasitoids are overall rare and occur mainly in forests, fallow and tree patches, maize systems, and sugarcane. ***Future data needs:*** Key questions on where pests and pollinators originate? Do good species outweigh bad species?, and which tree - crop combinations and tree cover thresholds best support positive biodiversity outcomes? need to addressed.

Scenario modelling predicts positive effects of tree restoration along rivers/creeks - traversing the landscapes east to west - for mammal biodiversity, likely small losses for bird diversity, and an increase and spatial shift in the risk of crop raiding. ***Future data needs***: These models need to be solidified with more extensive biodiversity datasets to increase confidence. Research needs to identify tree species attracting elephants into the corridor but resilient to elephant damage.

Microclimate benefits versus yield costs – case study Kilombero Valley

Trees buffer crops or other plants grown underneath from heat stress. Tree canopies act as radiation shields, and this protective effect is stronger on sunny days compared to cloudy days. Crops such as maize and rice have specific temperature requirements for growth. Without the shade provided by trees, crops can experience significant heat stress — particularly on sunny days in the Kilombero Valley — where actual leaf surface temperatures can exceed 50°C. The higher the canopy closure (i.e., the more trees), the higher the shading effect. A canopy closure of at least 25% can have profound benefits. For exposed soil, the temperature buffering effect is even stronger, which is relevant for soil moisture and organism within soil. However, data from a few farms that grow crops with trees on the farm suggests that yields is lower on farms with denser canopy covers. ***Future data needs***: Quantify negative effects of shading on crop growth due to reduced radiation availability. Tree roots may also compete with crops for soil water and nutrients, although they can contribute positively by accessing water in deeper soils and enriching the soil with nutrients through leaf litter. Future research should increase the sample size and use experimental approach to better understand these dynamics.

Soil quality indicator benefits – case study Kilombero Valley

Higher soil organic carbon seems to correlate with higher maize yield (except for one outlier farm) and higher cane yield. Maize and sugarcane yields also increase with soil phosphate levels, but for sugarcane, yield declines when phosphate levels exceed 12 mg / kg. Additionally, sugarcane yield increases with higher soil nitrogen percentage. But, these important soil attributes do not show relationships with tree cover density or its configuration in the landscape. It is worth noting that, we only tested the effects of larger tree patches/forests, not single trees, due to limited data. Overall, in the 0-40 cm soil layer, cropland soils had 0.29% higher soil organic carbon and 0.02% higher total nitrogen than forest soils. Grassland soils had 0.61% higher organic carbon than forest soils. Both forest and grassland soils were slightly more acidic than cropland soils. Soil phosphorus level was ~7 ppm lower in sugarcane farms compared to maize farms. Future data needs: An experimental approach should be used to test the effects of tree presence on soil metrics, incorporating a gradient of maize and sugarcane production systems ranging from no trees to high tree density.

Flood risk modelling – case study Kilombero Valley

Soil loss models run using Revised Universal Soil Loss Equation (RUSLE) for annual soil loss estimations in the Kilombero Basin, at 1 ha resolution in 20-year intervals from 2020 to 2100 under different climate change scenarios, suggest that tree restoration can profoundly mitigate soil loss. Results estimate a 68% reduction in soil loss rates (0.22 t ha-1 a-1) compared to cropland expansion and forest disturbance, relative to the 2020 baseline. Landscape Evolution Models (LEM), calibrated for the Mangula Catchment within the basin and run at 30 m resolution for one year, suggest that agroforestry expansion can mitigate risk of peak flood discharges and inundation, benefiting small-holder farmers. The effectiveness of agroforestry depends on its spatial distribution and extent across the catchment. For instance, agroforestry expansion along riparian buffers is more effective at attenuating/mitigating flood impacts than random agroforestry expansion across the catchment. ***Future data needs***: Experimentally assess the effects of tree cover density and spatial configuration using the model framework. For exaple, increase tree cover density and configuration across different catchments to test the robustness of findings and determine tree cover thresholds at the basin scale.

2 **Build local and national technical capacity** in restoration of tree cover on farms (agroforestry) and across the wider landscape to increase stakeholder buy-in, improve restoration effectiveness, and support biodiversity, crop production, and climate change mitigation commitments.

Local capability needs – case study Kilombero Valley

Household survey data with small-holder farmers (November to December 2019, Milheiras et al. 2022) indicate high loss of crop production to both invertebrate and vertebrate species. Farmers experiencing elephant crop damage have more negative perception of the nature's impact on their livelihood, regardless of the level of damage due to invertebrates. The perceived number of ecosystem services provided by nature increased with the number of trees in-farm, and the number of in-farm trees was positively correlated with agroecological intensity. Surveys results indicate that, for most farmers, current levels of crop damage are expected, localized, and/or not intense enough to directly affect their well-being. However, elephant-related damage seems to sharply change farmer perceptions of nature from beneficial to harmful, potentially reducing local support for conservation interventions. Participatory scenario workshops with smallholder farmers (July and August 2022) showed that farmers weigh off benefits versus costs when thinking about aspirations for their farms in the context of tree restoration, whether on farm (agroforestry) or within the landscape (Durrant et al. 2025). Farmers were more positive about agroforestry, which relates to resources (e.g. beneficial trees), climate (e.g. shade for rests) and farm border management. In contrast, perceptions of forests were more negative, often associated with restricted access to resources and increased human-wildlife conflict. Furthermore, men were more positive towards agroforestry than women, often linking tree planting with income opportunities, while women favoured scattered trees to meet subsistence needs. ***Future needs***: Small-holder farmers lack technical capacity to make informed decisions about which tree species are best suited to their soil, climate, and socio-economic contexts. They specifically request support with identification of pests and diseases and advice for management, development of feasible mitigation strategies for elephant related challenges, and advice on tree maintenance. They also ask for demonstration farms to understand how agroforestry could work for them. There might also be a need for local flexibility with regards to forest access and use.

<u>National scale capabilities and governance – case study Kilombero Valley</u>

Focus group workshops held in 2022 and 2023) involved key stakeholders in the landscape, including conservation and restoration Non-Governmental Organizations (NGOS), universities, government affiliated institutions (Tanzania National Parks (TANAPA), Udzungwa Ecological Monitoring Centre (UEMC), Tanzania Agriculture Research Institute (TARI), Regional Commissioners, and Rufiji Water Basin), industry and a farmer representative. The discussions substantiated above outlined needs for research and data collections. Additionally, participants emphasized a lack of knowledge and transparency regarding tree restoration actions implemented by NGOs leading restoration projects in the landscape.

<u>There is limited data or knowledge exchange between NGOs</u> hampering coordinated efforts and causing maximum spread of activities. NGOs occasionally work in the same locations, distributing trees; their tree choice is not always clear mixing native and non-native tree species or providing fruit trees known to attract elephants.

Additionally, limited communication between NGOs and local communities raises concerns about informed consent, particularly for activities such as restoring wildlife corridors near settlements. This lack of engagement risks increasing mistrust, which must be addressed urgently—especially before introducing interventions like farmer training or the planned use of fences. There is also limited information on the effectiveness of fences in mitigating human–wildlife conflict in the landscape. Their success likely depends on the fence type and management. Moreover, concerns persist about the unknown socio-economic impacts of fences on farming households, including their potential to obstruct movement and access. These uncertainties make it challenging to build consensus on the suitability of fences as a long-term solution.

<u>There is limited knowledge exchange and coordination between NGOs and government actors in Tanzania</u>: Restoration projects are not registered with the government, hindering national efforts to develop standards for effective restoration interventions and to monitor forest landscape restoration across Tanzania.

<u>Future needs</u>: We urgently recommend a structured process for engagement and knowledge sharing related to data collection, sharing, and analysis to strengthen national capability . Given existing research gaps, capacity building efforts should be aligned with data collection needs. There is a need to integrate data collection routines implemented already by government institutions with improved data analyses and reporting capacities. We also call for the enforcement of stricter rules and criteria governing data management, sharing and reporting on all projects/NGOs working in the landscape. This may include a requirement for restoration projects to become spatially registered with a national designated institution such as TAFORI. Data management plans associated with restoration interventions should be scrutinized as part of the registration process and followed up on. This will help prevent NGOs from acting on ideas not covered under their permits or ethics clearance. Additionally, monitoring changes in local perceptions of the costs and benefits of biodiversity and restoration projects is important for evaluating their effectiveness in delivering meaning outcomes for communities.

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