Restoration Reckoning

Assessment of available options (geospatial / local measurement and modelling) and their strengths and weaknesses for measuring forest landscape restoration (FLR) by Forest and Farm Producer Organisations (FFPOs)

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1. Introduction

1.1. Forest Landscape Restoration (FLR)

Forest Landscape Restoration (FLR) is a planned process to regain ecological functionality and enhance human well-being across deforested or degraded forest landscapes[1]. It does not aim to recreate past ecosystems, but to re-establish a self-sustaining forest ecosystem that provides benefits to people and biodiversity while balancing ecological, social and economic priorities. FLR encompasses a broad range of interventions to restore ecological function such as tree planting, promoting natural regeneration and agroforestry, in a participatory manner that also enhances human wellbeing. There are multiple potential benefits associated with FLR: increasing crop yields, improving water availability and quality, economic and social development, promoting and maintaining biodiversity, and mitigating the impacts of climate change. FLR is recognised to be complex and context-specific, but can be defined by six widely adopted principles (Box 1).

Box 1 Six principles of Forest Landscape Restoration, from Global Partnership on Forest and Landscape Restoration[2].

(1) *Focus on landscapes*. FLR takes place within and across entire landscapes, not individual sites, representing mosaics of interacting land uses and management practices under various tenure and governance systems. It is at this scale that ecological, social, and economic priorities can be balanced.

(2) *Engage stakeholders and support participatory governance*. FLR actively engages stakeholders at different scales, including vulnerable groups, in planning and decision-making regarding land-use, restoration goals and strategies, implementation methods, benefit sharing, monitoring and review processes.

(3) *Restore multiple functions for multiple benefits*. FLR interventions aim to restore multiple ecological, social and economic functions across a landscape and generate a range of ecosystem goods and services that benefit multiple stakeholder groups.

(4) *Maintain and enhance natural ecosystems within landscapes*. FLR does not lead to the conversion or destruction of natural forests or other ecosystems. It enhances the conservation, recovery, and sustainable management of forests and other ecosystems.

(5) *Tailor to the local context using a variety of approaches*. FLR uses a variety of approaches that are adapted to the local social, cultural, economic and ecological values, needs, and landscape history. It draws on latest science and best practice, and traditional and indigenous knowledge, and applies that information in the context of local capacities and existing or new governance structures.

(6) *Manage adaptively for long-term resilience*. FLR seeks to enhance the resilience of the landscape and its stakeholders over the medium and long-term. Restoration approaches should enhance species and genetic diversity and be adjusted over time to reflect changes in climate and other environmental conditions, knowledge, capacities, stakeholder needs, and societal values. As restoration progresses, information from monitoring activities, research, and stakeholder guidance should be integrated into management plans.

The concept of FLR has grown in importance on the global stage and is central to the achievement of ambitious targets for stabilisation of global forest cover. The Bonn Challenge

[1] Stanturf, John, Stephanie Mansourian, and Michael Kleine. "Implementing forest landscape restoration, a practitioner's guide." International Union of Forest Research Organizations (2017) 1-128.

[2] Besseau P, Graham S, Christophersen T (2018) Restoring forests and landscapes: The key to a sustainable future. Global Partnership on Forest Landscape Restoration, Vienna, Austria

called for restoration of 150 million ha by 2020, the New York Declaration called for an additional 200 million ha by 2030, and the Glasgow Leader's Declaration on Forests and Land Use committed to working to halt and reverse forest loss and land degradation by 2030. Regionally, the African Forest Landscape Restoration Initiative (AFR100) commits to bringing 100 million ha under restoration by 2030 and Initiative 20x20 to protect and restore 50 million ha in Latin America and the Caribbean by 2030.

The ambition of FLR targets calls for large scale action on the ground. However, restoration opportunities typically occur at small scales, such as on or adjacent to agricultural land, in small forest management areas, or under sustainable agroforestry practices. Smallholder farmers and Indigenous Peoples and Local Communities (IPLCs) are the main actors in management of forest and farm landscapes. Without their support and involvement, FLR at scale is unlikely to be successful.

1.2. Forest and Farm Producer Organisations (FFPOs)

Forest and farm producer organisations (FFPOs) are associations formed by smallholders, indigenous peoples, women, youth and local communities. FFPOs provide the organisational structures that allow for FLR to be implemented at large scales. They assist their members by facilitating knowledge sharing, engaging in policy advocacy, securing tenure and access rights to land and other natural resources, improving management of forests and farms, expanding markets, and increasing income, social protection and well-being. FFPOs are a unique opportunity to engage the world's 1.2 billion smallholder forest farmers to achieve FLR, providing the required support to achieve long-term goals while remaining focussed on the locally important actions of FLR.

1.3. The Forest and Farm Facility (FFF)

The Forest and Farm Facility (FFF) is a partnership of FAO (management and direct in-country support to national FFPOs), IIED (knowledge generation and monitoring and learning), IUCN (direct support to regional and global FFPOs) and Agricord (FFPO organisational support), built around a multi-donor trust fund. FFF offers technical assistance and financing through direct grants to strengthen FFPOs. FFF works with FFPOs across Africa, Asia, and Latin America, covering a range of FLR activities.

Support from FFF is focused on the delivery of four outcomes:

1. More inclusive governance and cross-sectorial processes, leading to enabling policies
2. Increased entrepreneurship, access to markets and finance through an equitable value chain and business development services within FFPOs
3. Improved delivery of landscape-scale mitigation, adaptation, and resilience for climate change through improved environmental technical knowledge, direct engagement of FFPOs and integration with inclusive livelihood approaches.
4. Improved and equitable access to social and cultural services. A comprehensive participatory monitoring and learning system will provide continuous feedback and generate adaptive responses.

Outcome 3 covers the environmental and ecological impacts of FFF support, and is the topic of this report. Since 2013 FFF has been working with FFPOs towards FLR objectives. This year FFF plans to measure and quantify FFPOs contributions to climate action and identify where FLR practices are expanding as a result of FFF support. This report anticipates that work by considering how successful FLR efforts might be measured – a 'restoration reckoning' so to speak.

1.4. FFF and FLR

Measuring the impact of forest restoration efforts will require FFF to support the collection of new data in collaboration with FFPOs. Monitoring of restoration for FFF is a challenging proposition, with a very wide range of activities, differing locally important restoration outcomes, and hundreds of FFPOs each with their own objectives, and each with a membership with differing spatial patterns that occupies some or all of forest landscapes. Important questions to be answered include how can FFPO's impacts be quantified, recognised, and incentivised? How can a diverse set of interventions be consistently monitored at scale? How can FFPOs be fully involved in the monitoring process? How can it be ensured that this process can be sustained into the future?

To be sustained, restoration monitoring must have benefits for both FFF and FFPOs. The primary motivation for FFF is the need for reliable data to report impact statistics to donor organisations. It is also an opportunity to assess the evidence for which interventions have a positive restoration impact and facilitate sharing of best practice between FFPOs. For FFPOs the motives are more variable. In some instances FFPOs have an explicit aim of FLR, with better data needed to gain recognition for their work and better advocate for policy changes. Other FFPOs are focussed on supporting sustainable agricultural production and require robust inventories to improve market access. New statistics on carbon stocks and change also opens the possibility of access to results-based finance, such as payments for climate change mitigation. In all cases there are opportunities to improve data held by FFPOs on membership and management activities, with a range of potential uses in marketing and promotion of FFPO efforts.

The subject of this report is a preliminary assessment of FLR monitoring approaches that can be used in different FFF contexts. This objective is to identify realistic monitoring options for FFF that consider the unique operations of FFF and its complex collaboration with FFPOs. Work was guided by interviews with FFF country facilitators (Ecuador, Ghana, Kenya, Tanzania, Vietnam), a desk-based review of existing methods and tools for restoration monitoring, and an assessment of applicability to the situation of FFF. Detailed discussions were also held with FFPOs in Nepal and Tanzania, for which practical monitoring options are presented. The report ends with a series of recommendations for FFF to generate maximum value from the roll-out of restoration monitoring across supported FFPOs.

2. Measuring restoration

2.1. The challenge of restoration

Although there is widespread recognition of the importance of monitoring restoration, few standardised methods exist to measure success. Measuring restoration is challenging for a number of reasons:

Restoration is context dependent

Actions to deliver FLR and their impact vary between ecosystems and management systems. Even just within FFF restoration might refer to forest conservation, climate-smart agriculture, improved soil and erosion management, agroforestry, enrichment planting for food forests, or farmer managed natural regeneration. The climate change adaptation and mitigation potential of these actions is widely variable, as are the forms of monitoring required to capture their impacts. Some impacts of restoration can be readily estimated at scale (e.g. tree cover, biomass), and other outcomes are more challenging (e.g. biodiversity, soil condition). Success in monitoring is dependent on the form of management intervention, the desired restoration outcome, and its amenability to measurement.

Restoration is a slow process

Unlike efforts to reduce environmental degradation (e.g. reducing deforestation), the impacts of restoration interventions are gradual and progressive. Trees grow slowly, agricultural practices change incrementally, and ecological function and biodiversity recover over the long-term. The outcomes of FLR play out over the course of decades, with impacts that may only be visible long after the investments that promoted them.

Estimating restoration impact requires a reference state

The assessment of whether FLR has been achieved requires some reference state against which to compare. This might be a measure of whether an area has achieved some threshold indicative of restoration (e.g. sufficient tree cover, low deforestation), or whether an area has improved relative to the past or relative to other comparable locations (e.g. increased tree cover, reduced deforestation). In either of these cases, it's necessary to have an idea of what the target for restored land is (e.g. How many trees? Which species? What degree of vegetation stability?). Given the variety of landscapes across FFF, their diverse uses, and divergent definitions of restoration, a credible benchmark against which to assess restoration impact presents a real barrier to estimating restoration impact.

Monitoring requires new technical capacity

The complexity of FLR requires specialised approaches to measure and monitor. Methods variously require skills in environmental measurement, statistics and modelling, geospatial data processing, data management and storage, as well as a good understanding of local ecological dynamics. While these skills can be built in organisations, it's a long-term process that requires ongoing support and development of new capacity.

2.2. Indicators of restoration

An indicator of restoration is a measurement used to gauge progress towards restoration goals. Commonly used indicators of restoration span socioeconomic outcomes (e.g. cultural practices and rights, economic benefits, land use and tenure), agricultural production (e.g. crop yields, market access), energy availability (e.g. woodfuel), water (e.g. water availability and quality), climate change adaptation and mitigation (e.g. carbon stocks, climate-smart agricultural practices), and biophysical properties of the landscape (e.g. soil health and management, biodiversity, forest cover and quality)[3]. The concept of restoration is complex and site dependent, and it is likely that multiple indicators will need to be considered to judge restoration success at a given location.

The selection of appropriate indicators will be important for effectively estimating the impacts of FFF support. Foremost, indicators must relate to the objectives and activities of FFPOs. For

[3] FAO and WRI. 2019. The Road to Restoration: A Guide to Identifying Priorities and Indicators for Monitoring Forest and Landscape Restoration. Rome, Washington, DC

example, measuring tree cover and associated carbon stocks may be indicative of restoration in some contexts, but is unlikely to be useful where the objective of restoration was to improve soil quality. Where there is also an aim to support biodiversity, replacement of natural forests by lower biodiversity plantation forests will also not be captured by simple indicators of tree cover or carbon stockc. Selection of appropriate indicators of restoration will require consultation with FFPOs who understand the restoration context and availability of relevant data.

This review is concerned with FFF's outcome 3 which aims for 'delivery of landscape-scale mitigation, adaptation and resilience for climate change'. Indicators relating to the themes of the biophysical environment and climate change are therefore prioritised, taking a broad view including vegetation properties, ecological processes, climate change mitigation, and biodiversity. With the differing local restoration contexts of FFF there will be a trade-off between consistency of indicators across sites and measuring the most locally relevant indicators. The need to aggregate together total impacts for the purposes of FFF reporting will require a degree of standardisation in indicators.

2.3. Examples of restoration monitoring at scale

While measuring restoration presents known technical challenges which are the subject of ongoing research, the ambition of existing targets for FLR require immediate monitoring. At present progress towards FLR targets is not well quantified, and there exist few mechanisms for the consistent monitoring of restoration globally. However, individual projects and regional targets are documenting their efforts towards FLR, providing a point of comparison for FFF.

The Bonn Challenge, launched in 2011, monitors pledges from countries to achieve FLR. Currently, 60 countries have committed a total area of 210 million ha of restoration in degraded and deforested land. The 'Bonn Challenge Barometer' is a systematic framework used to track progress in terms of area under restoration, climate change mitigation, biodiversity and socio-economic impacts, as well as enabling policies and financial flows[4]. The approach relies on self-reporting of impacts, and has not yet been applied across all countries.

AFR100 tracks the number of hectares of land committed to FLR (currently at 127.8% of the 100 million ha goal), the area under restoration (estimated at 917,014 ha from a partial stocktaking exercise from 2016 to 2021), and estimates CO_2 sequestration are produced using default removal estimates by a set of standardised activities (5,637,869 million tonnes CO_2 in total)[5]. Ongoing efforts aim to integrate remote sensing estimates and surveys to estimate FLR impact, but this has not yet been universally applied.

Initiative 20x20 has surveyed the area of degraded land under restoration (8.2 million ha) and new conservation areas (14.6 million ha) since 2014. Monitoring of restoration impact is limited to experimental work and case studies, such as the 'Sustainability Index for Landscape Restoration' which provides a score between 0 and 1 based on compliance with goals established in restoration plans[6].

In common across these initiatives is the relative ease of recording areas of land either committed to FLR or located within landscapes targeted for FLR, but tracking implementation is considerably more challenging. While exploratory new approaches using remote sensing to

[4] https://infoflr.org/bonn-challenge-barometer

[5] African Union Development Agency - NEPAD. 2022. The State of AFR100: The progress of forest landscape restoration by implementing partners. AUDA-NEPAD, Midrand, South Africa.

[6] World Resources Institute 2020. Sustainability Index for Landscape Restoration. WRI, Washington DC, USA.

directly monitor impact do exist, they are typically employed at project scale, with existing impact estimates largely based on stock-taking exercises and modelled climate change mitigation estimates.

2.4. Selection of methods for FFF

Free of practical constraint, methods for restoration monitoring would be selected based only on accuracy. In practice, methods also vary in their requirements for resourcing, new capacity, and desirability for FFPOs. To specify monitoring methods for FFF, a series of discussions were conducted with FFF and FFPO staff, who identified the following technical considerations for a restoration monitoring system.

Validity

Monitoring methods should be capable of measuring the indicators that are the most relevant to the activities of an FFPO. For example, an FFPO promoting forest conservation might measure forest cover using satellite data, but these same methods will have little relevance for an FFPO supporting improved market access for smallholders. The broad variety of interventions under FFF means that there will be no universal set of indicators, and no universal method that can be applied across FFF.

Data quality

Methods vary in their suitability for producing accurate and consistent estimates of restoration impact that are relevant to FFPOs. Outputs will need to be of sufficient quality to produce credible estimates of chosen indicators.

Ease of data collection

Restoration monitoring can be resource intensive, requiring development of new capacity, management of field monitoring, maintenance of statistical databases, and specialised staff for data collection. An ideal case will use datasets that exist already (e.g. membership numbers, areas under management), are tightly allied to existing statistics (e.g. areas of new management interventions), or produce data that have good alternate uses (e.g. for advocacy or commercial purposes). In many cases new data will be required, in which case low impact, simple, and sustainable methods should be preferred.

Flexibility

The broad range of FFF activities will require customisation of monitoring methods to produce useful data for each FFPO. A method that is applicable to multiple common situations is preferable to a specialised method that addresses only rare monitoring cases.

Capacity requirements

New data collection methods will require the development of new technical capacity at FFPOs. Methods that utilise existing capacity, or help to develop new useful skills, are preferable to approaches that are technically complex or are highly specialised.

Participatory

Methods that include FFPOs and their members are preferred to those that are reliant on outside technical experts. Ensuring monitoring is participatory helps with engagement with FFPOs and can also improve data quality by making use of the expertise of local farmers and land managers.

Good alternate data uses

While the motivation of FFF might be to produce data to demonstrate performance against FLR targets, FFPOs have a range of other objectives including securing market access for their members, estimating aggregated stock for sale, advocating for improved policy, and securing funding to further their work. Where possible, data with multiple uses should be gathered as part of restoration monitoring. For example, an FFPO supporting sustainable timber production may use new data to support sales, and an FFPO arguing for improved policy for smallholder farmers will be more effective with rigorous supporting data.

2.5. Scales of monitoring

There are multiple options available for measuring restoration and estimating restoration impact. At the smallest scale, estimates of restoration impact can be produced for individual farms or management areas. Typically this will involve data collection by individual farmers and provision of individual impact estimates. Monitoring can also be conducted as an aggregate estimate for an FFPO. This can be more efficient and produce impact statistics with greater consistency, but loses the connection to the efforts of individuals. At the largest scales monitoring can take place across a landscape, monitoring restoration over a spatially defined area. This method will only be valid in the case that FFPOs are large or impactful enough to have a meaningful effect on FLR at the scale of a landscape.

The various scales of monitoring and their advantages and disadvantages are summarised in Table 1.

Table 1 Scales of restoration monitoring for FFF.

Unit of measurement	**Measurement approach**	**Pre-requisites**	**Advantages and limitations**
Farm / Individual	• Field measurement	• Knowledge of management interventions • FFPO membership list with locations	**Advantages** • Participatory • Results can be provided to individuals • Thematically detailed **Limitations** • Greater training requirement • Challenges to ensure data consistency
Producer organisation	• Field measurement • Remote sensing • Modelling	• Knowledge of management interventions • Total area under management	**Advantages** • Makes use of existing data from FFPOs • Reduced training requirement **Limitations** • May require new data collection (e.g. field boundaries)
Landscape	• Remote sensing • Modelling	• Knowledge of management interventions • Spatial boundary of area under management • A consistently measurable indicator (e.g. tree cover)	**Advantages** • Provides spatial information and maps • Operation at scale and repeatable **Limitations** • Only effective where FFPOs have a meaningful impact at landscape scale

2.6. Impact evaluation

Impact evaluation is the field that assesses how interventions such as projects, programs or policies, can be related with observed changes. Monitoring indicators can be useful, but alone cannot provide an unequivocal estimate of impact. For example, an observation of increasing tree cover across a landscape following FFF support could be interpreted as a success, but in the case that tree cover was increasing across the region due to widespread natural regeneration the impact of an FFPO would be open to challenge. Conversely a reduction in tree cover in FFPO managed lands could be interpreted as a failure, but where this loss is less severe than in the absence of an intervention this should alternately be considered a success.

To know whether an intervention is working or not, outcomes need to be compared against a counterfactual that represents what would have happened in the absence of the intervention. In a variable environment where indicators of restoration are expected to fluctuate even in the absence of action, this comparison ensures that reported impacts meet the criterion of being additional to existing trends. While what would have happened without an intervention is unknowable, there exist several methods to estimate this counterfactual scenario. Impact evaluation designs can be identified by the methods used to generate a counterfactual.

2.6.1. Experimental approaches

The gold standard for impact evaluable is to conduct a randomised controlled trial (RCT). RCTs are performed by randomly selecting a subset of farmers, organisations or landscapes to carry out an intervention (the ‘treatment’ group) and a second group to not carry out an intervention (the ‘control’ group). Performance of the intervention is estimated by comparing the outcomes over these two groups. The process of randomisation is important, as it ensures an unbiased estimate of the counterfactual scenario.

These methods are not currently mainstream in restoration monitoring, and for the case of FFF present serious practical and logistical challenges. An ideal case for an RCT has well-defined interventions, randomly assigned treatment and control groups, and would be set up in advance of support by FFF. In practice interventions by FFPOs are ongoing, and it is unlikely that the FFPOs that FFF work with represent an unbiased sample of the potential producer organisations with which FFF could work with (selection bias).

2.6.2. Quasi-experimental designs

A more practical alternative aims to mimic the properties of an experimental design using observational study data. These methods aim to remove or correct for the selection bias arising from the non-random determination of the treatment group and aid in the selection of a valid control group. A commonly-used approach is to use statistical methods to construct an artificial control group by ‘matching’ each treatment observation (e.g. an FFPO, a farm, a pixel) with a non-treatment observation with similar characteristics. A challenge with this approach is that while in some cases a confounding variable can be readily estimated and corrected for (e.g. accessibility), in others it can be far more challenging (e.g. cultural differences). The result is that the matched observations can retain some bias and conclusions are less robust.

2.6.3. Non-experimental approaches

Non-experimental designs do not involve comparison against a control group. This may be because relevant data don’t exist or are impractical to produce. In place they may compare efficacy against performance before the intervention, or against neighbouring locations in which the intervention was not performed, or simply report indicators without reference to a counterfactual. This is the weakest design for impact evaluation, as there are often many plausible mechanisms to explain an observed effect than just the intervention. Although limited, these methods are the most commonly used for impact evaluation in restoration efforts, largely due the impracticality of alternatives.

3. Monitoring options for FFF

Three classes of restoration monitoring are considered in this review: field-based measurements (*in situ* monitoring), geospatial monitoring (using maps and satellite data), and modelling (using simple computational simulations) of restoration outcomes. For each approach, prerequisites, the form of outputs, examples of tools, experimental design considerations, and advantages and limitations are presented.

3.1. Field measurement

The most common approach to monitoring restoration is to measure restoration impact *in situ*. Field methods are distinguished by requiring a physical presence at restoration sites, with measurements taken by specialised field staff or FFPO members contributing their own data. Field measurements provide unrivalled detail on management interventions and impact, but they are more resource intensive and may not scale as well as other options. They are therefore best suited to detailed studies of smaller management interventions, or where restoration impact is not amenable to remote measurement or prediction with models.

3.1.1. Pre-requisites

Whether measurements are driven by field staff or FFPO members, field measurement requires observations to be made on the ground. Accessibility is a requirement for either a specialised field team or to provide training to FFPO members. Areas that are inaccessible, have poor communications infrastructure or limited power will all add to the challenge of field-based methods. Field measurements are more intrusive than remote approaches, and necessitate the cooperation and assistance of FFPO members to access restoration sites.

Field measurement also require sufficient prior understanding of the management interventions that have been supported by FFPOs, and in which locations they have been deployed. Field work is most commonly conducted by individual farmers who best understand local restoration effort, supported by mobile apps.

3.1.2. Scale of monitoring

Field based measurements will be typically conducted at the scale of a landholding (e.g. a farm, a forest reserve), but can also be applied to landscape scales subject to a suitable sampling strategy. Estimates can be aggregated to generate the net impact of an FFPO, either by measuring every restoration site, or by taking measurements at a sample of locations.

3.1.3. Indicators

Measuring indicators of restoration in the field has some of the lowest technical barriers and the greatest flexibility in what to measure. Indicators of restoration can range from complex scientific measurements to a survey of ecosystem and management properties using smartphones. Common ecological measurements related to restoration are listed in Table 2.

Table 2 Example indicators of restoration commonly measured in the field.

Theme	Indicators	Units	Methods
Restored land	Area of land under restoration, Area of farmer managed natural regeneration	ha	GPS unit, mobile apps
Species composition	Indicator species, Invasive species, Diversity indices	-	Forest inventory plots, species counts, camera traps
Tree planting	Number of samplings grown/planted, Sapling survival rate	/ha	Survey, mobile apps
Climate change mitigation	Biomass	tonnes/ ha	Forest inventory plots, mobile apps
Soil quality	Soil organic carbon	tonnes/ ha	Laboratory measurement
Soil management	Farmers using soil conservation practices	%	Survey, mobile apps

In order to provide sufficient scale it is important that indicators can be measured by local partners, such as staff associated with FFPOs or their members. Measurements that can be facilitated by mobile apps (e.g. restoration boundaries, tree planting) stand to be particularly effective at meeting the scales required for FFF.

3.1.4. Examples of tools

Mobile apps

Groups or individuals involved in restoration can manage their own data through mobile apps. Existing apps are usually centred around tree management (e.g. tree survival, growth, tree planting areas), including IPTIM Mobile, i-Tree, and Regreening Africa (Figure 1). IPTIM Mobile is a user-friendly app for forestry data collection, allowing individual farmers to collect data and manage their information for decision making and carbon stock estimation. IPTIM Mobile is designed around management of timber plantations, and has particular relevance for FFPOs supporting timber production. Regreening Africa is a project aiming to reverse land degradation on 1 million hectares of land, who as part of their monitoring efforts have designed an app for managing and protecting trees on farms. The app can record data on tree planting areas, farmer-managed natural regeneration and seedling production through nurseries.

Apps allowing customised data collection can also be used, including the open-source Open Foris Collect and ODK (formerly Open Data Kit). These tools support survey design and data collection through customisable forms. ODK, for example, supports the design of complex surveys including use of GPS for locating points or areas and inclusion of photographs, uploaded to the cloud where internet is available. While offering far greater flexibility, forms will not be as user friendly as dedicated apps, and there is a limited ability for automated data analysis.

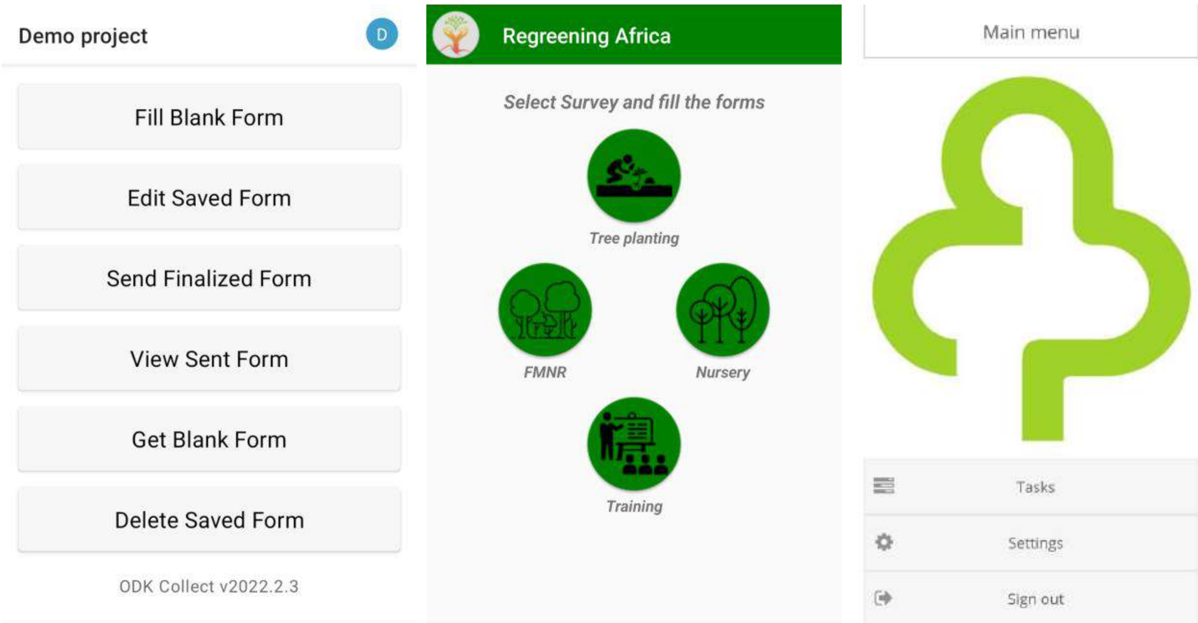

Figure 1 Interfaces for ODK Collect (left), Regreening Africa (centre), and IPTIM Mobile (right), each examples of mobile apps that can be used for collection of data for restoration monitoring.

Field protocols

There are standardised methods for systematic collection of data relevant to restoration taking the form of field measurement protocols. Protocols are often designed with a scientific application in mind but can be adapted for restoration monitoring. Forest inventory plots are a common example, such as protocols from forestplots.net.

Improved soil management is of relevance to many FFPOs, with restoration measured from improvements to soil health, soil carbon stocks, and agricultural yield. 'Recarbonisation of global soils' (RECSOIL) is a programme combining field measurements of soil organic carbon with promotion of improved soil management to encourage large-scale action. Financial incentives are delivered as part of the RECSOIL programme in return for implementation. RECSOIL is an ongoing process and is not designed for the backward-looking restoration analysis currently required by FFF.

Unmanned Aerial Vehicles
Field measurements can be taken at scale using unmanned aerial vehicles (UAVs, drones), now available at relatively low cost. Drone-based monitoring is discussed further in section 3.2.

3.1.5. Experimental design

Field data collection protocols will need to be carefully designed to ensure that estimates of restoration outcomes meet the requirement of additionality. A survey might specify only measurement of new actions or actions that can be demonstrably linked to membership of an FFPO. More complex restoration situations will also need to consider a counterfactual scenario of no management intervention, which must rest on defensible assumptions (e.g. no agroforestry planting) or a comparison against similar locations without FFPO support.

Farmer-led measurements are the most common approach to restoration monitoring in the field. Even supported by apps, it's unlikely that a field measurement effort can conduct a complete inventory of all FFPO restoration activities at all locations. Monitoring effort can be reduced by measuring restoration impact at a representative sample of locations, and the total area supported by the FFPO used to estimate the total restoration impact. Reasonable efforts should be made to ensure this sample isn't biased (e.g. measurements arising mainly from best performing locations, or the most engaged farmers).

3.1.6. Advantages and limitations

Advantages

- Unrivalled detail – stands a chance of measuring everything FFF does
- Suitable for providing data at the scale of individual farms
- Mobile apps reduce barriers and promote consistency in measurements
- Use local knowledge and engage directly with FFPO members

Limitations

- Difficult to perform at scale
- Data quality/consistency issues
- High training burden for FFPOs and their members
- Some restoration impacts are readily measured in the field (e.g. plantation forestry), others harder (e.g. erosion control, agroforestry)
- Fieldwork can be costly

3.2. Geospatial monitoring

Geospatial methods are distinguished by the inclusion of spatial information that describes properties of the Earth's surface. Two key technologies are important for geospatial monitoring of restoration:

- *Geographic Information Systems (GIS)* Software used to generate, manage, and analyse spatial data and maps.

- *Remote sensing* The acquisition of information of the Earth's surface without making physical contact, usually using airborne or satellite sensors.

The unique ability of geospatial methods to perform at scale at low cost means geospatial methods are one of the dominant approaches to natural resource monitoring, and are increasingly being applied for monitoring restoration.

3.2.1. Pre-requisites

Although measurements are often performed remotely, this does not eliminate the need to have a clear understanding of what is changing on the ground. Two key pieces of information are required for geospatial monitoring.

First, the area under management by the FFPO or group of FFPOs must be understood. This could be boundaries of individual farms (e.g. from GPS measurements), forest reserves or management areas (e.g. from government or maps held by FFPOs), or the boundaries of landscapes under management (e.g. administrative areas or watersheds). In the case of defining a landscape under management, it's required that an FFPO has a meaningful impact on that landscape. For example, measuring restoration in a landscape where the FFPO directly manages <1% of land cannot be expected to yield reliable information on the impact of that FFPO.

Second, a prior understanding will be required on the management changes introduced by the FFPO and what restoration impacts are expected. FFPO operations are widely divergent across FFF, so monitoring must focus on relevant indicators that are measurable using geospatial technology. Any geospatial monitoring strategy will therefore require detailed contextual knowledge from FFPOs to attribute restoration impacts, gathered from existing data (e.g. membership, information on activities), interviews, and on-the-ground observations (e.g. surveys, validation fieldwork, drone measurements).

3.2.2. Scale of monitoring

Geospatial monitoring typically involves large-scale monitoring at landscape to global scales. Estimates of impact can be produced at smaller scales based on suitably defined areas of interest such as individual farms or protected areas, but these can be expected to be associated with greater uncertainty than larger-scale estimates where errors get averaged out.

3.2.3. Indicators

Remote sensing methods can be used to measure a very wide range of properties of the Earth surface. In some cases remote sensing can match the quality of field data (particularly for drone-based measurements), but in most cases estimates will be less precise than *in situ* measurements. From a restoration perspective, the most commonly used geospatial indicators relate to tree cover and tree cover change. Some commonly used geospatial indicators are summarised in Table 3.

Table 3 Examples of biophysical restoration indicators using geospatial methods.

Theme	Indicators	Units	Methods
Land use	Land cover, Land cover change	ha	Satellite mapping, Unmanned Aerial Vehicles (UAVs).
Forest properties	Tree cover, Forest type, Aboveground biomass, Canopy height, Canopy cover	ha tonnes/ ha m %	Satellite mapping, UAVs
Forest change	Deforestation, Afforestation	ha	Satellite mapping, UAVs
Biodiversity	Fragmentation	-	Post-processing of forest maps
Restored land	Area of land under restoration, Area of farmer managed natural regeneration	ha	Participatory mapping, GIS

A key challenge to remote sensing estimation of restoration is identification of indicators that are suitable for detecting restoration that can be reliably monitored from space. There are two related, but methodologically very different classes of satellite-based indicators of restoration.

Measuring a state: The simplest characteristic to measure is a property of the land surface, for example land cover, aboveground biomass, or tree canopy cover. Methods for estimating the land surface properties with remote sensing are well developed, and many existing tools and guidance materials are available to support mapping and quality assessment. Knowledge of the state of the land surface has some relevance to monitoring restoration. For example, it could be used to assess whether tree cover in a landscape is above some threshold, the area of forest plantations or agroforestry, or extent of soil erosion. For some cases this level of information could be sufficient (e.g. introduction of new tree planting in defined areas), but for others it will be insufficiently rich to quantify impact where changes to a process are more relevant (e.g. efforts to encourage natural regeneration).

Measuring a change: A more complex application of remote sensing data is change detection. This aims to map changes to the land surface, such as the extent of deforestation or tree cover increase. These methods are inherently more challenging than measuring the state of the land surface, but open up the possibility of deeper analyses of the impact of FFPOs. For example, change information could answer whether an FFPO has successfully increased tree cover over time, that deforestation has been held below some threshold of concern, or that previously unmanaged land was brought under management. Some changes are easier to detect than others, with methods being well-developed for deforestation but currently less effective for the more subtle changes associated with forest regrowth.

3.2.4. Examples of tools

Cloud processing environments

The recent proliferation of open access Earth Observation data has made processing of satellite imagery on desktop computers impractical, particularly where internet connections are unreliable. Analysis of remote sensing data in the cloud is now commonplace, allowing access to large data archives with only basic equipment (Figure 2). Google Earth Engine provides access to a multi-petabyte catalogue of geospatial datasets and data processing capacity for analysing remote sensing imagery. Building on this capability, the FAO's SEPAL platform aggregates tools and methods for forestry data analysis, including methods for restoration monitoring. Other platforms are specifically focussed on restoration, such as the FAOs' Framework for Ecosystem Monitoring (FERM), which provides access to satellite imagery and derived indicators relevant to restoration through a map interface. From a user perspective there will commonly be a trade-off between simplicity and flexibility - a platform that is highly automated and easy to use will likely be less easily tailored for local circumstances.

Figure 2 Examples of cloud processing environments for geospatial data analysis: SEPAL (left),FERM (centre), and Google Earth Engine (right).

Survey-based methods

A second form of remote-sensing approach uses visual interpretation of high-resolution satellite images to quantify the impacts of restoration. These methods have far lower technical barriers than computational approaches, and data collection can feasibly be conducted in collaboration with trained FFPO members. Collect Earth is a tool that enables data collection through Google Earth, Bing Maps and Google Earth Engine with customisable survey forms (Figure 3). Users can assess satellite data for any property that can be consistently visualised in available imagery, with common examples being tree cover, land use, properties of agricultural land, and land use change. Surveys with high-resolution images can offer a degree of consistency in data collection that is difficult to match with other remote methods, but the lack of automation makes monitoring more resource intensive.

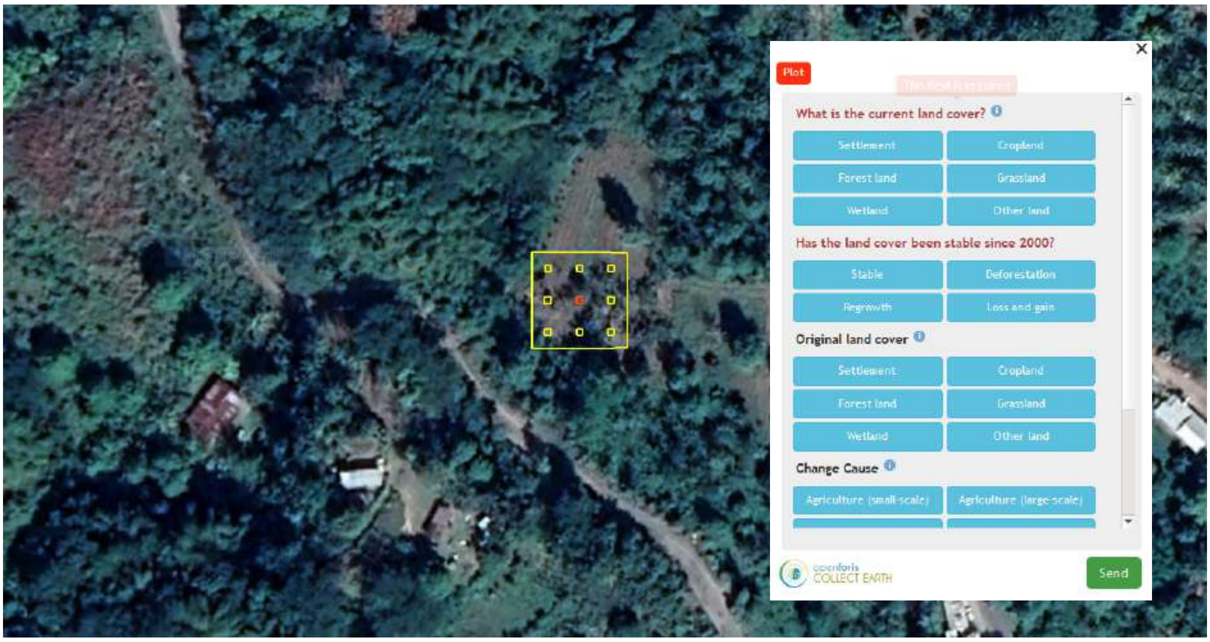

Figure 3 A Collect Earth sample plot overlaid on high-resolution imagery from Google Earth. Data collection requires users to visually interpret the imagery (e.g. to identify restoration indicators) at 100s - 1000s of sample locations.

Custom analysis

Given the complexity and variety of interventions by FFPOs, highly customised geospatial methods might be required to capture restoration outcomes of interest. For these cases a broad suite of open source software is available, including programming environments (R, Python), data processing tools (GDAL, OGR, PostGIS, Google Earth Engine), cloud platforms (Google Earth Engine, SEPAL) and GIS software (QGIS). Many of these methods require specialised skills to use but will be the only practical means of monitoring for some cases, such as advanced experimental designs such as pixel-matching described below.

Unmanned Aerial Vehicles

An increasingly common means of remote sensing monitoring involves the use of UAVs (drones), available at comparatively low cost. Relative to satellite remote sensing, data from UAVs tends to be higher resolution and capable of delivering greater detail, but typically delivered over a smaller area given range limitations of drones. As well as direct measurements of structural properties at a site of interest (e.g. tree canopy cover from optical imagery, vegetation structure using lidar or ‘structure from motion’), a common application of UAV data is as a means of calibrating satellite imagery. This process, known as upscaling, combines the strength of detailed local datasets with the scale offered by satellite imagery. Although UAV data offer great promise, operational monitoring with UAVs is a comparatively new field and these methods aren’t yet widely applied for restoration monitoring.

3.2.5. Experimental design

Estimating impact requires observations of a counterfactual scenario of what might have happened in the case of no intervention. In the simplest case this would involve estimates from before FFF’s involvement, or comparison against nearby landscapes in which FFF is not operating. A promising quasi-experimental design approach well-suited to geospatial data analysis is known as ‘pixel matching’. This approach compares observations of a property within an area of intervention (e.g. tree cover, probability of deforestation) to equivalent matched locations without the management change. For the case of FFF this might ensure that the control sites have similar ecosystems, accessibility, climate, population density and land use as the treatment sites. While these methods are not currently mainstream, they are increasingly being used for impact evaluation in conservation where randomised controlled trials typically aren't feasible.

3.2.6. Advantages and limitations

Advantages:

- Spatial representation
- Low cost at large-scales
- Repeatable and automated measurements

Disadvantages:

- Methods for restoration monitoring are still experimental
- Necessary to define an area of interest, which might be a lot of work for some FFPOs.
- Analyses are technical, requiring a specialist in GIS/remote sensing.

3.3. Modelling restoration outcomes

The final set of methods rely on predicting the impact of restoration using computational or statistical models. Models are a theoretical representation of a system that are based on knowledge of important processes used to simulate outcomes of interest. In place of direct measurements of restoration impact, the result of restoration efforts is predicted based on inputs that are simpler to measure (e.g. area under management, management types) using existing knowledge from other locations to predict the overall impact of restoration impacts. While all the methods presented in this report rely to some degree on models of some form, the distinction here is in relying heavily on simulated impact estimates in place of measurements.

The most commonly used form of model for restoration monitoring is a greenhouse gas (GHG) calculator. These are simple models that use an inventory of activities to predict restoration impact in terms of emissions and removals. Other more complex methods aim to capture the processes and mechanisms of restoration ('process-based models'), but these are mostly research tools with a limited scope that do not directly address restoration impacts so are not further considered here.

Modelling restoration outcomes is a particularly useful approach in the case that observational data are difficult or impractical to produce, allowing an estimate of restoration impact even where observational data on impacts are limited. Where data production is unworkable (e.g. very remote areas, no information on locations) or outcomes of interest are difficult to measure over short time-scales (e.g. soil interventions), using model predictions can provide a practical means of estimating restoration impact.

3.3.1. Pre-requisites

In the simplest cases, model estimates of restoration impact require less data than other methods, and can potentially be conducted using existing management information and default model parameters. However, it remains necessary to maintain at least basic data on restoration efforts to provide inputs to the model. Two forms of data are essential:

1) Knowledge of the management changes and when they were implemented

2) An estimate of the total area under each type of management

The more detailed the information that can be provided, the more relevant and accurate model estimates are likely to be. For example, geospatial data on areas of interventions ensure that the area under a management type is accurate, and records of land management in each land parcel (e.g. planting dates, years of regeneration) can be used as model inputs. The axiom 'garbage-in garbage-out' is worth remembering - flawed model input data will produce a nonsense output.

3.3.2. Scale of monitoring

Model estimates can be produced at any relevant scale, but while input data are generally easier to generate at the level of individual farms, it's generally larger scales (e.g. an FFPO or a landscape) where emissions and removals are of interest. Where centralised information on management interventions exists this process will be more straightforward, otherwise a survey of FFPO members activities will be required (e.g. with mobile apps, field surveys). Large-scale assessments commonly require the use of expert knowledge to identify model inputs, which can increase uncertainty.

3.3.3. Indicators

Models have a great deal of flexibility, with examples existing of model outputs predicting all kinds of indicators of interest. The most common indicators relate to carbon stocks and fluxes, associated with the availability of well-developed greenhouse gas (GHG) calculators. However, models can also be used to predict other biophysical indicators such as biodiversity and soil erosion, and socioeconomic indicators such as value chain analysis. The main limitations are what suitable models are available, for what management types calibration data exist, and whether their input data are readily generated in the context of FFF.

3.3.4. Examples of tools

GHG calculators

GHG calculators combine activity data (e.g. areas of forest protection, agroforestry, soil management) with generic or site-specific emission factors (e.g. emissions from deforestation, removals associated with improved soil management) to estimate the total restoration impact of an intervention. GHG calculators are often used as a decision support tool to predict the impact of a proposed management intervention before implementation (*ex-ante*), but can also be used to estimate the impact of a management change after implementation (*ex-post*).

A commonly used GHG calculator is the Ex-Ante Carbon-balance Tool (EX-ACT) (Figure 4). EX-ACT is an Excel-based tool that provides a consistent means of estimating and tracking the outcomes of agricultural interventions on GHG emissions and removals. EX-ACT includes default parameters derived from IPCC[7] which cover many of the activities of FFF including

[7] https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

Agriculture, Forestry and Other Land Use (AFOLU) inland and coastal wetlands, fisheries and aquaculture, agricultural inputs and infrastructure.

3.3.5. Experimental design

GHG calculators are well-suited to analysis of different scenarios, including modelling the impact of no intervention. However, these predictions will only be reliable where a determination can be made about the counterfactual scenario of no intervention. In some cases this will be straightforward, such as the introduction of new soil management methods with a known rate of uptake that replace previous practices that are well-understood. In many others this counterfactual will be more speculative, such as an estimate of what deforestation rate might be expected in the absence of an intervention, or where the uptake of tree planting on farms is not well quantified. In all cases, model inputs should be specified carefully, and assumptions for models must be clearly stated.

Model predictions alone may be useful, but the most credible analyses will also make efforts to validate model predictions. This can involve field measurements to test predictions, or efforts to better quantify important model parameters. Useful methods exist for this process, including model sensitivity analysis to identify parameters to which model predictions are particularly responsive, and uncertainty analysis to estimate a confidence range for results.

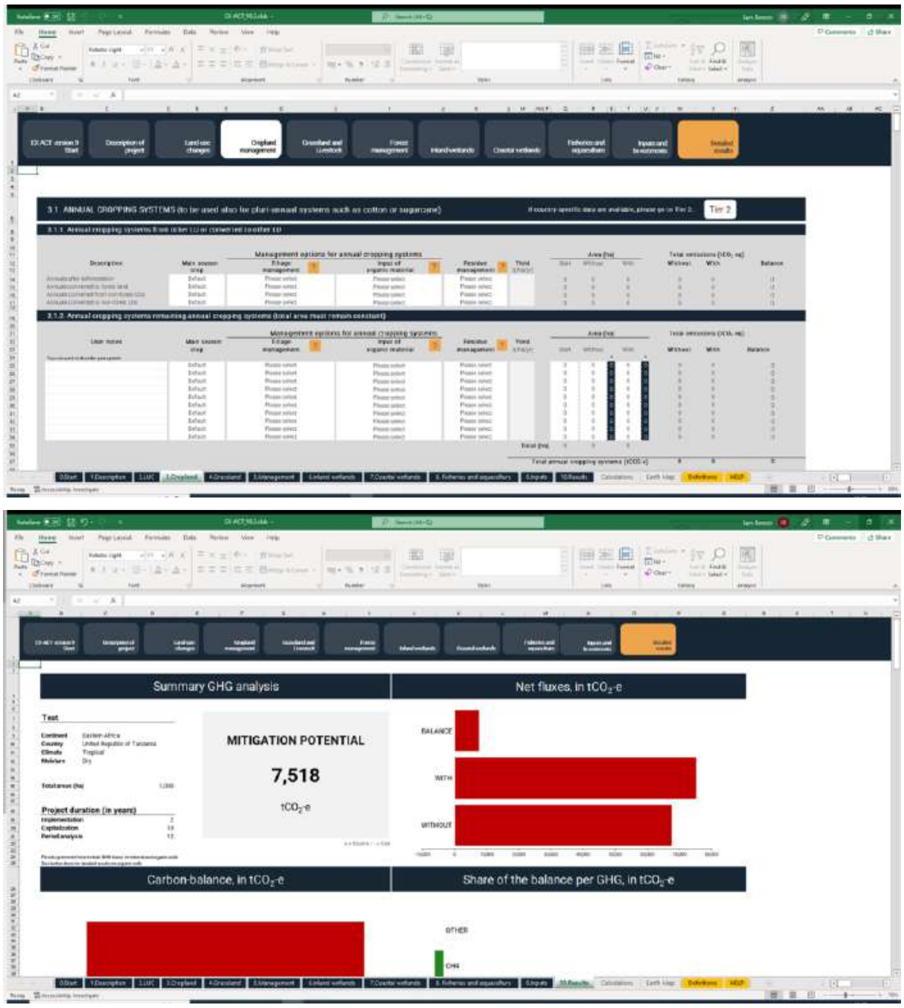

Figure 4 Interface of EX-ACT, a greenhouse gas accounting tool.

3.3.6. Advantages and limitations

Advantages

- Minimal data requirement
- Ability to make predictions of impact to guide restoration activities, and to quantify restoration impacts that take place over long time scales (e.g. tree growth).
- Flexible and scalable
- As well as predicted outputs, model inputs can have good alternative uses, such as data on areas under particular management types.
- Suitable for both *ex-ante* and *ex-post* emissions and removal estimates
- Models provide the only set of methods flexible enough for consistently producing an impact estimate for all of FFF.

Disadvantages

- Model predictions can be difficult to verify
- Suitable model calibration data must exist to predict the impact of an activity, and in some cases collecting this data will be demanding.
- Model estimates produce data that are abstract, and may not be well-suited to the objectives of some FFPOs.
- Garbage in, Garbage out

4. Example applications

This section describes potential practical applications of restoration monitoring based on discussions with FFPOs based in Nepal and Tanzania, and using the situation of Ecuador as case studies. For each case the restoration situation is described, candidate indicators identified, and suitable technologies for monitoring restoration in each situation described. The objective is to anticipate the challenges and opportunities in the roll-out of restoration monitoring for FFF.

4.1. Case study 1: Community forestry in Nepal

Situation

Formed in 1995, The Federation of Community Forest Users, Nepal (FECOFUN) aims to link ~8.5 million forest users from across the country to strengthen their role in policy making. FECOFUN works with community forest user groups to improve management of community forests. A core activity of FECOFUN is advocacy for forest policies that serve the needs of community forest users across Nepal. FFF is providing ongoing support to FECOFUN for scaling up income generation activities and promoting climate resilient enterprises. FECOFUN was recently selected as a case study to pilot-test restoration monitoring for FFF work using geospatial technologies in the 'Churia' landscape of central Nepal (Figure 5).

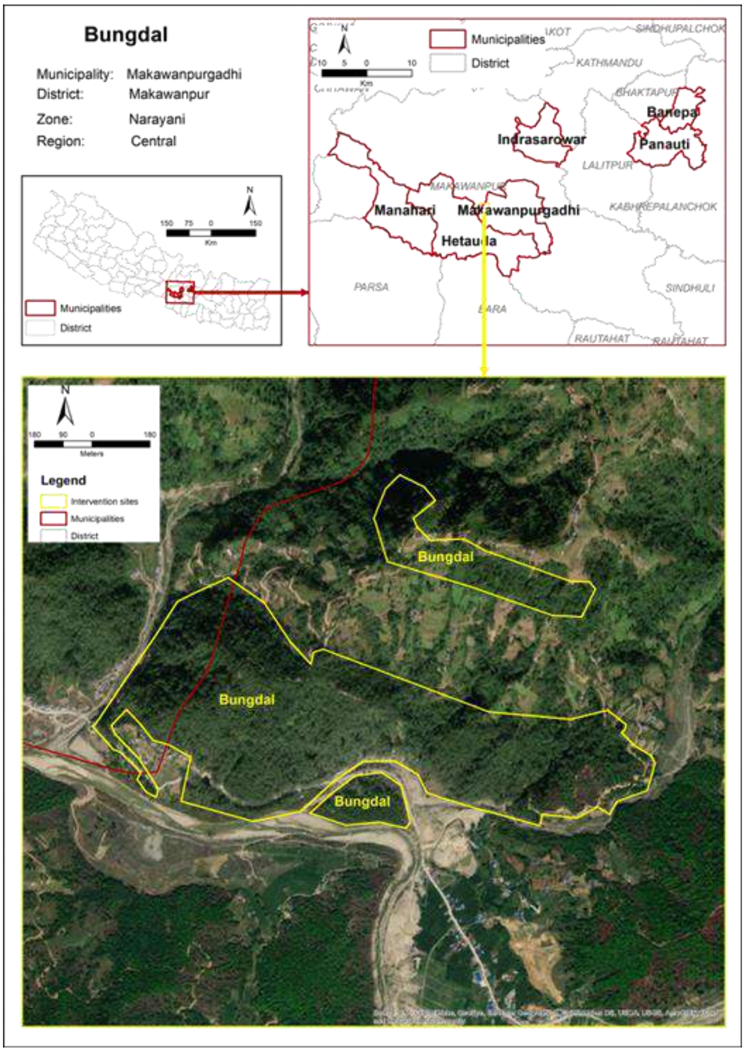

Figure 5 Example of a community forest in Nepal, where yellow polygons show the extent of forest management areas and form the basis of monitoring. *Map by Rashed Jalal and FECOFUN.*

A monitoring solution

The national scale of FECOFUN's operations and the existence of well-defined community forest areas targeted for restoration point towards a geospatial monitoring approach. Monitoring will be supported by the FAO SEPAL and FERM platforms, providing satellite data products and computational power to assist in data processing and summarisation. A series of geospatial indicators of restoration were proposed to FECOFUN staff with the potential to describe the condition and change of community forest areas (Table 4). These indicators aim to quantify the total area of forest managed under community forest reserves and estimate the quantity of carbon stored in their trees. An ongoing series of consultations will reduce these potential indicators down to a final selection.

Table 4 Proposed geospatial indicators under consideration for monitoring community forest areas in Nepal.

Indicator	Time period	Unit
Net change in forest area	2000 – 2019	ha, %
Net change in cropland area	2000 – 2019	ha, %
Conversion of forest to cropland	2000 – 2019	ha, %
Conversion of forest to bare soil	2000 – 2019	ha, %
Tree cover loss	2001 - 2021	ha, %
Above ground biomass	2015	tonnes/ha
Tree height	2015	m
Forest type		
Presence of water		ha, %
Elevation	2011	m
Temperature	2021	C
Precipitation	2021	mm
Accessibility (road, market)		
Socioeconomic (pop density, etc.)		person/ha
Fragmentation		
Land degradation	2000-2015	ha, %

Initially, indicators will be monitored through time to characterise changes in the condition of forest. This information has value for the management of community forests by FECOFUN and community forest user groups by flagging community forests that have been particularly effective and identification of locations of concern. Geospatial data can also contribute to forest management plans, currently produced at site scale but difficult to scale given the volume of fieldwork required. While GIS won't be able to entirely replace fieldwork, it may be able to reduce the resource requirement through standardisation and provide an ongoing monitoring function that would be otherwise difficult to support.

Quantification of restoration impact will be a more challenging task than monitoring indicators, requiring comparison against other similar locations or prior to management changes. Without clear reference sites or changes of management resulting from FFF engagement, one promising option is to adopt a 'pixel matching' technique, where locations under community forest management are compared to a counterfactual reference pixel which shares the same properties (e.g. population density, accessibility, forest type) as the managed location except for the management type.

From the perspective of FECOFUN, the main application of restoration impact estimation is to support advocacy efforts. Much of FECOFUN's work involves engaging with the government to support effective forest management policy in Nepal. Being able to back up their advocacy work with evidence is a key aim of FECOFUN, and one that is well-supported by geospatial data analysis.

A particular challenge noted by FECOFUN was obtaining suitable geospatial information on the location and extent of community forest reserves. Over the past decade there have been efforts to standardise these data, but where maps exist they are variously held by government, development partners and local groups, and in some cases maps may exist only on paper. Consolidation, digitisation and quality assessment of these data will be central to any operational geospatial assessment of FECOFUN's restoration impact. Outside of community forest reserves, FECOFUN noted that not all restoration impacts will be readily measurable using geospatial technology. For example, members of community forest user groups are also encouraged to adopt sustainable agricultural management practices. Without data on the geographic locations of these farms and associated management metadata, the geospatial approach will not be suitable for quantification of these restoration impacts. The importance of existing geospatial information is a key lesson for the roll-out of geospatial restoration monitoring for FFF.

4.2. Case study 2: Smallholder farming in Tanzania

Situation

The Network of Farmers and Pastoralist Groups in Arusha Region (Mtandao wa Vikundi vya Wakulima na Wafugaji Mkoa wa Arusha - MVIWAARUSHA) is an FFPO based in northern Tanzania. The organisation aims to strengthen farmer's groups and improve their coordination to achieve social and economic development goals. MVIWAARUSHA facilitates the exchange of knowledge, skills, and experience on farming and livestock keeping activities. Their activities are spread across Arusha region with ~12,000 members including crop growers, livestock keepers, gatherers, beekeepers and fishermen. Management interventions relevant to restoration include tree planting on farmland (Figure 6) and the promotion of agroforestry.

Figure 6 Examples of tree planting supported by MVIWAARUSHA. Images from MVIWAARUSHA.

A monitoring solution

From a monitoring perspective the example of MVIWAARUSHA is more challenging than the example of Nepal. The landscape of northern Tanzania is heterogeneous and vegetation is highly seasonal, properties that make satellite monitoring of vegetation more difficult. There is currently only limited geospatial data associated with individual farms or management areas, requiring a large data collection effort before a geospatial approach could be made to work. Restoration efforts by MVIWAARUSHA also typically occur at small scale, involving planting of trees within a broader agricultural landscape. While some data do exist on restoration efforts, it is not currently collected on a systematic basis, adding a challenge to modelling of impacts.

Restoration monitoring for the case of MVIWAARUSHA is therefore likely to require new field measurements. Given the large membership and farms that are typically small (<2 ha), measurements by individual farmers is the most natural scale of measurement. This is consistent with past work by MVIWAARUSHA, who have monitored the impact of projects in collaboration with farmers supported by mobile apps. The indicators of restoration favoured by MVIWAARUSHA relate to tree planting and maintenance on farms, with relevant metrics being records of new saplings and growth and survival of trees. These data can be used to estimate carbon stocks, a further key indicator for MVIWAARUSHA. Existing mobile apps are well suited to this task, including methods for tagging individual trees and inputting their size/age to estimate carbon stocks. An alternative approach at farm scale would be to use UAVs to quantify vegetation structure on a subset of farms, with the possibility of re-measurement in future years. This approach would increase consistency between measurements relative to surveys, but is unlikely to be as scalable as famer-led monitoring.

The proposed monitoring approach only offers a partial analysis of MVIWAARUSHA’s impact, who in practice support more than just tree planting. This is a necessary simplification to keep monitoring manageable, band this is likely to be a common scenario for FFPOs across FFF. Even within just tree planting there has in the past been difficulties in measuring the impact of agroforestry supported by MVIWAARUSHA, which is harder to measure consistently. Technical assistance and additional testing would be required to effectively capture this restoration impact in future.

The main proposed application of data by MVIWAARUSHA is for promotional purposes. Like in Nepal, MVIWAARUSHA have an interest in demonstrating their impact using best practice methods, providing data for reporting to funders and securing new funding for future work. These outputs are well aligned with the reporting needs of FFF. There is also the potential to use field data to guide the future operations of MVIWAARUSHA, such as identification of the conditions that make for successful and sustainable tree cover increases.

4.3. Case study 3: Agroforestry systems in Ecuador

Situation

In Ecuador, FFF works across three areas defined by the Amazon, the coast, and the Andes. The three landscapes have widely divergent ecological and social contexts, making Ecuador an exemplar of the challenge represented by restoration monitoring for FFF.

The Amazon region of Ecuador presents a particular challenge for restoration monitoring. Landscapes are complex, including widespread use of the traditional ‘chakra’ agroforestry system. The region is perennially cloudy, adding challenge to remote sensing observations. There is also limited data on the locations of FFPO operations, such as georeferenced farm boundaries. The region is remote with limited power and internet connectivity, limiting the opportunities for fieldwork to gather this data, or for farmer-led reporting of restoration impact using mobile apps. It is also reported that there is also a strong commercial focus of FFPO operations, adding a challenge to engagement with FLR monitoring objectives where the outcomes aren’t well-related to existing goals of FFPOs or individuals.

A monitoring solution

These limitations present a particular challenge for FFF in Ecuador, and is a situation that is likely to be encountered in other locations. Where collection of new data presents a challenge, it is proposed to use a light-touch model-based estimate of restoration impact. This could use simple measures such as an aggregated area under management for an FFPO or membership numbers and average farm sizes, and information on the forms of management such as agroforestry through maintenance of the chakra system. While there may be advantages to more intensive monitoring options such as field monitoring or remote sensing (e.g. traceability and meeting certification requirements), where these are not feasible simpler approaches must suffice.

Estimates from a stock-taking exercise of activities and areas can alone be monitored as indicators of restoration, but a more useful option is to use a GHG calculator (e.g. Ex-ACT) to also provide an approximation of climate change mitigation impact. Following an inventory of activities (e.g. areas of agroforestry, areas of tree planting, areas of farmer-managed natural regeneration), estimates of carbon stocks and changes would be simulated based on expected returns from default model parameters or relevant scientific studies. While relatively easily performed by FFPOs with the assistance of FFF, it would be important to ensure consistency and quality of data to ensure credibility of model-based estimates. Estimates might be improved over time as data management skills are built by FFPOs, and with potential local calibrations of C sequestration (e.g. from fieldwork to estimate the biomass of chakra).

While simple approximations, these approaches have much in common with the methods used for larger FLR-focussed targets (see section 2.3). For FFF this presents the opportunity to produce estimates at large-scales at low-cost, subject to a method for consistently surveying FFPO's and effectively classifying their activities into standardised forms.

5. Recommendations

Estimation of the restoration impact of FFF is a challenging proposition: interventions are numerous, diverse in scope, geographically scattered, and there is limited existing data. While challenging, there are also opportunities in the roll-out of restoration monitoring. This section details some recommendations for the development of a restoration monitoring framework for FFF. It aims to identify a realistic monitoring scenario that serves the needs of FFF while furthering the objectives of FFPOs by strengthening capacity to promote enabling policy and legal frameworks, improving market access, and delivering landscape-scale mitigation, adaptation and climate resilience.

5.1. Focus on representative case studies

There is likely no single method available that will be sufficient for monitoring all of FFF's restoration impacts. FFPO's promote a wide range of activities, in differing political and socio-economic contexts, with variation capacity and data availability, with different expected ecological outcomes. The unique situation of each FFPO will require a large degree of customisation to monitoring methods to produce useful outputs. **Although technically possible, rolling out tailored monitoring methods across the entirety of FFF is unlikely to be a good use of FFF's resources**. Monitoring efficiency can be gained either by grouping FFPOs into landscapes or similar archetypes, or concentrating resources on a smaller number of representative case studies.

Focusing monitoring on landscapes where multiple FFPOs operate has the potential to achieve greater efficiency, but this will only be applicable where there is a clear landscape focus for FFF support and where a single set of indicators is sufficient for capturing the restoration impact of multiple FFPOs. This requirement is not likely to be met for all of FFF's work. A second form of aggregation is to group FFPOs by similar activities (e.g. timber production, improved soil management, agroforestry), and produce a measure of impact for these activities using a standardised set of indicators and methods. This form of aggregation of FFPOs presents the only realistic method of producing an estimate of the restoration impact of the entirety of FFF, and is most closely related to the methods used for large-scale restoration targets (see section 2.3). However, it has the cost of breaking the link of impact to individual FFPOs and their varied objectives and reduces the ability to fully customise monitoring methods to meet the needs of individual FFPOs.

An alternative approach given that monitoring is highly context-dependent is to **concentrate on a smaller number of representative case studies**. This is a pragmatic approach, with a smaller resourcing requirement and the possibility of engaging more deeply with each of the selected FFPOs to meet their requirements. It also comes with the advantage of being able to start small and scale up monitoring operations later once the most effective methods are identified. The main limitation to case studies is an inability to meaningfully scale-up estimates to quantify the restoration impact of the entire FFF programme given the variety of methods and indicators that will be used by FFPOs. This will require careful reporting on the part of FFF to ensure the robustness of derived statistics.

5.2. Maintain the existing focus on FFPOs

FFF facilitates the actions of FFPOs, who are considered as central to service delivery in forested landscapes. This model of delivery aims to sustainably deliver climate change mitigation outcomes such as FLR. A similar argument can be made for monitoring of restoration outcomes. For estimates to be produced on a sustainable basis, monitoring should also be performed by FFPOs.

As with case studies, supporting FFPOs to perform monitoring on their own terms is likely to reduce the comparability between estimates. The benefit of an FFPO-centric approach is production of data that directly benefits FFPOs and their members, motivating sustainable data production in future. In discussions with FFF and FFPO staff there was a clear focus on how restoration data would benefit FFPOs, with multiple direct and co-benefits identified. For example:

- Production of high-quality data to support advocacy work by FFPOs
- Combining inventory of carbon stocks with a timber inventory to improve market access
- Improving information on FFPO membership and activities to support their operations
- Developing access to results-based finance, such as payments for climate change mitigation

An FFPO-centric restoration monitoring approach is consistent with other FFF work, and stands the greatest chance of supporting local restoration objectives. One-off measurement campaigns supported by technical experts may be required initially, but sustainability will require FFPOs to monitor their own impacts.

5.3. Allow FFPOs to own their impact

FFF provides support to hundreds of different FFPOs, each with their own modes of operation and funding arrangements. FFPO's draw on multiple sources of funding and expertise, and also work independently towards their objectives. In this complex environment, disaggregating the impact of financial and technical support by FFF from other sources of support and the autonomous efforts of FFPOs would be necessary to determine the overall impact of FFF.

Apportioning the impact of FFF might be possible in some simple cases. For instance, if FFF is the sole significant supporter of an FFPO or the progenitor of an FFPO's work towards FLR. The more common scenario would require apportioning impact between groups, but this will be difficult to perform consistently and is potentially contentious. **FFF will find it difficult to fully quantify its FLR impact in isolation**.

A simpler alternative is to estimate the restoration impact of FFPOs without consideration of who is responsible for it. This approach will need to be carefully addressed when reporting outcomes - a statement of *"FFF resulted in X ha of FLR and Y tonnes of carbon sequestered"* would need to become *"FFPOs supported by FFF resulted in X ha of FLR and Y tonnes of carbon sequestered"*. For FFPO's this approach has clear advantages, providing outputs they have full ownership of and can use independently of FFF. For FFF this will again reduce the ability to report total impact statistics, but be more consistent with the existing mission to empower FFPOs.

5.4. Select the right method for each FFPO

The various approaches to measuring restoration each have strengths and limitations in their ability to capture processes of interest, and present different opportunities for FFPOs. Suitable methods for restoration monitoring will need to be selected to match the requirements, capacity and activities of an FFPO. Given restoration is context dependent, **selection of the most appropriate indicators of restoration will need to be conducted jointly with FFPOs**. This can take the form of stakeholder engagement, which considers both which indicators are relevant, which are practical to measure, and how to also meet the reporting needs of FFF.

In this report three broad approaches to restoration monitoring were considered. Field measurements offer low technical barriers, a high degree of flexibility, and can be readily made participatory through use of mobile apps, but to perform at scale will come at substantial cost and must be mutually beneficial to fully engage farmers and land managers. Geospatial monitoring provides repeatable monitoring at scale at substantially lower cost, but in most cases requires specialised technical skills and cannot usually match the detail of field measurements. Modelling approaches can be performed at the lowest cost and are best aligned with existing data commonly held by FFPOs, but will only function where suitable calibration data exist, and will produce outputs that can be difficult to verify. The various strengths and limitations of each of these options is summarised in Table 5.

Identification of the most effective monitoring approaches in each case of FFF support will require pilot testing across a range of FFPOs. This should consider not just the simplest cases or the most effective interventions, but also examples where impact is more challenging to quantify as a result of a complex set of interventions or a data limitation. The outcome of these tests should be a set of options suitable for restoration monitoring for common situations within FFF which can be applied by FFPOs to quantify their impact. This testing might also identify whether it is possible to perform a consistent stock-taking exercise of activities across FFF, and to simulate climate change mitigation impacts using a GHG calculator.

Table 5 Summary of monitoring approaches for FFF, and their strengths and limitations for FFPOs.

	Option 1: Field measurements	Option 2: Geospatial monitoring	Option 3: Modelling restoration outcomes
Readily scalable	✕	✓	✓
Low cost	✕	✓	✓
Thematic detail	✓	✕	✓
Engaging for FFPOs	✓	✓	?
Low technical barriers	✓	✕	✓
Verifiable	✓	✓	✕
Flexibility	✓	✕	✕
Able to measure biodiversity	✓	?	?
Able to estimate carbon	✓	✓	✓
Offers co-benefits to FFPOs	✓	✓	✓

5.5. Careful experimental design will produce credible results

Indicators of restoration impact can be produced to measure a range of biophysical properties of the landscape and their rates of change. While valuable, the results will be open to challenge on the basis of additionality, where changes that occur cannot be demonstrably related to FFPO activities. A robust experimental design can address this concern and ensure that reported restoration outcomes are credible.

Land systems science is complex, and practical limitations to robust experimental design mean that monitoring protocols will have to be pragmatic. One of the most practical approaches is a quasi-experimental design, where locations under FFPO management are matched with equivalent unmanaged areas. A particular strength of this approach is in the ability to apply the method retrospectively, without having to have defined a control group prior to FFF support, and with suitable data on management areas can be practically performed using geospatial data methods.

A well-designed impact evaluation is less likely to produce an unequivocally strong positive result than simpler experimental designs, exposing FFPOs to a greater risk of a negative or a null result. However, efforts to improve robustness of monitoring will ensure that the correct management lessons are learned for future interventions across FFF, and that reported impacts are more likely to be trusted.