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REVIEW

Exploring Challenges and Lessons for Monitoring Forest Landscape Restoration

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Abstract

Purpose of Review Forest landscape restoration (FLR) is an approach to restoring forest ecosystems first defined in 2000 that has gained prominence since the launch of the Bonn Challenge in 2011. FLR aims to enhance ecological integrity and improve human well-being within (forested) landscapes. The monitoring of FLR is essential to ensure effective implementation and to learn from practice. Yet to this day, monitoring remains a major challenge for FLR. Monitoring FLR requires measures at a landscape scale and across social and natural sciences. We explore some of the monitoring challenges raised by these dimensions of FLR. We assess the current theory and practice behind FLR monitoring and how it relates to practices in related environmental disciplines.

Recent Findings We highlight the challenges raised by the recent attempts at monitoring FLR and explore lessons from other related fields and conclude by proposing a framework of the basic issues to consider when monitoring FLR.

Summary Keywords Biodiversity and people · Conservation · Data · Indicators · UN Decade on ecosystem restoration

Introduction: Forest Landscape Restoration and Associated Monitoring Challenges

Forest landscape restoration (FLR) was first defined in 2000 as "a planned process that aims to regain ecological integrity and enhance human well-being in deforested or degraded landscapes" [1, 2]. This approach to restoration was purposefully intended to be different from previous approaches that focused on sites (e.g., ecological restoration), economic aspects (e.g., large-scale monoculture plantations), or ecological dimensions (of forests). More than 20 years since it was first defined, FLR has increased in popularity, notably with the Bonn Challenge on FLR being launched in 2011 and several associated initiatives [3] including the UN Decade on Ecosystem Restoration (2021–2030). Forest restoration more generally is seen as a vital component of strategies to mitigate climate change [4] and to reverse land degradation and address the biodiversity crisis [5].

Restoring forests is not a new concept, and many forest restoration initiatives were initiated before FLR was defined [6, 7]. However, two major innovations stemming from FLR have an impact on its planning, implementation, and monitoring: (1) the scale of interventions—the landscape—and (2) the need to reconcile both ecological and human objectives. The landscape is larger than an individual forest stand and smaller than a country or region yet has ill-defined boundaries [8]. The advantage of the landscape scale lies in that it can accommodate different objectives and benefits [9]. FLR necessarily aims to reconcile the needs and desires of several stakeholder groups present in the landscape or with a stake in it. Furthermore, it allows for both social and ecological benefits to be valued and restored. FLR also requires long timeframes as the benefits provided by restored forests take time to emerge. In practice, there are many different interpretations of FLR emphasizing different aspects such as carbon sequestration, biodiversity conservation, or food security that complicate planning, implementation, comparison, aggregation, and monitoring [10].

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In spite of the issues around definitions and practice, governments around the globe have set major targets to restore millions of hectares of forest [3]. The recently agreed Kunming-Montreal Global Biodiversity Framework commits Parties to the Convention on Biological Diversity (CBD), under target 2, to ensure that by 2030 at least 30% of areas of degraded terrestrial ecosystems are under effective restoration "in order to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity" [11]. Article 5 of the legally binding Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) refers to the need to enhance forests [12]. Large multinational companies have also launched several targets, generally concerning the number of trees to plant [13], although some are considering forest restoration too (e.g., [14, 15]).

Monitoring is standard best practice for project cycle management, and its importance is increasingly being recognized in environmental projects more generally [16•] and FLR more specifically [17, 18•, 19, 20]. However, there are several challenges inherent to FLR monitoring [19, 21•]. Efforts to date to improve the monitoring of FLR have been constrained by their focus on restoration expertise, without reference to the much larger body of knowledge on environmental and social monitoring more broadly.

Through this review, we aim to assess the challenges with FLR monitoring and to explore lessons learned from other conservation monitoring initiatives and practices that could be applicable to FLR. The review is based on recent literature (last 5–10 years) on FLR and monitoring (to identify challenges) and brings insights from the much larger body of knowledge on conservation monitoring (to identify lessons). To carry out the review, documents and websites of relevance were identified through online search engines and databases, such as Scopus and Google Scholar. A snowballing technique was used to source other literature from that uncovered. Between them, the authors have 50 years of expertise in forest landscape restoration and monitoring. Using their expert judgment, they merge two rich sets of literature, identify the benefits of this cross-fertilization and propose a simple framework to guide FLR monitoring.

Challenges Associated with Monitoring FLR

There have been a number of efforts to develop guidance on FLR monitoring, including frameworks and indicators to measure progress. Several sources underscore the need to set FLR indicators against program goals (e.g., [22, 23•, 24]). Monitoring requires a clear understanding of both the ambitions (objectives) and the starting points (baselines). Below we identify some of the major challenges impacting FLR monitoring.

Lack of Globally Agreed Definitions

There is no global consensus on key terms (e.g., forest, degradation) associated with FLR. Without clear and consistent terms concerning the object of measurement, monitoring results can be highly questionable (particularly when it comes to aggregating data from different sources). In the context of FLR, for example, if country X defines forests according to the UNFCCC definition (10–30% canopy cover, over at least 0.05–1 ha, and trees of 2–5 m at maturity), it will report a different rate of deforestation or restoration than country Y that defines its forests according to the FAO definition (i.e., at least 10% tree cover, over at least 0.5 ha, and tree height of 5 m), even if they both use the same source of data (e.g., satellite imagery). Equally, the definitions of FLR have evolved and changed over time, with slightly different interpretations or emphases. The original definition emphasized "ecological integrity" a term that is difficult to define and raises questions of judgment. The current definition used by the Global Partnership on FLR focuses on "ecological functionality," an equally difficult term to define, with divergent interpretations [25, 26]. Similarly, the "human well-being" dimension is defined by the Restoration Barometer as a change in income through jobs [27], whereas well-being is increasingly understood as a complex, multidimensional state [28]. The lack of consistent terminology directly hampers the identification of suitable indicators, data comparison, and aggregation.

Arbitrary Approaches for Setting Ambitious Objectives and Defining Baselines

There are no common approaches to setting ambitions for FLR. Developing realistic and effective FLR objectives requires several sources of information—some historical and some anticipatory [29]. Restoration goals, and progress to achieve them, can be gauged against natural reference sites that the restoration work is striving to replicate [30–32]. They may also be set in the context of a desired future state (which may be in part, but not exclusively, based on reference systems). On the one hand, a reference site (based on the past) helps to determine what sort of forest and ecosystem existed in the target area. At the same time, and given pressures and changes in the landscape, a realistic set of objectives may need to consider what are the current and future needs from the forest [33]. For example, local villagers may have a preference for specific medicinal tree species, and at the same time, changing ecological and climatic conditions may favor a different species mix to what was there before [29]. While a reference model may serve to inform these future needs, other sources of information (including societal needs) may also shape the objectives for FLR, with a more forward-looking perspective [34]. Such a perspective necessarily anticipates climate change and its impacts on specific tree species in the landscape to be restored [35]. Forward-looking planning should not however be seen as an excuse for setting unambitious objectives. Setting clear objectives—be they forward- or backward-looking or a mix of both—and having a clear baseline are both fundamental to monitoring progress.

Proliferation of Indicators

Existing papers, frameworks, and guidelines share a large suite of indicators. They include biotic indicators, such as habitat area and quality, species abundance, and diversity (e.g., [19]), abiotic indicators such as soil properties and hydrology (e.g., [19]), and social indicators, such as income generation (e.g., [18•]). Mansourian and Vallauri [36•] identify a set of ecological, social, and economic indicators; Viani et al. [18•] propose ecological, socio-economic, and management indicators. WRI [37] proposes a Sustainability Index for Landscape Restoration that combines different types of measures around water, habitat connectivity and patchiness, carbon captured, soil quality, rural livelihoods, vulnerability to environmental risk, and governance. Buckingham et al. [20] cluster indicators around goal areas for restoration, namely, community, culture, food and products, water, energy, biodiversity, soil, and climate, as well as proposing a whole series of ecosystem services indicators. IUCN and its partners developed a Bonn Challenge Barometer (now the Restoration Barometer) which it claims is "the only tool already used by governments to track the progress of restoration targets across all terrestrial ecosystems including coastal and inland waters" [38]. This tool uses eight indicators, four on actions and four on impact. FAO and UNEP [39] developed a set of headline indicators for ecosystem restoration more broadly, aligned with the sustainable development goals (SDGs). While many of these indicator sets link to key FLR concepts and practices and may help some FLR practitioners identify suitable metrics to monitor their activities and goals, the proliferation of indicators and indicator categories is likely to appear overwhelming and confusing to those practitioners who are less familiar with monitoring. It may also lead to different people measuring different things within and between landscapes, making the aggregation and comparison of results a major challenge (see below for further discussion on the issue of scale).

Narrow Sets of Indicators Used in Practice

In spite of the large choice of potential metrics, to date, most projects have focused primarily on environmental indicators [40, 41]. Social or socio-economic indicators are measured very rarely [42, 43, 36•] and, where they are included, are often reduced to a simple dimension, such as jobs, as used in the Restoration Barometer [27]. A recent review of seven field projects conducting restoration noted that the top three indicators used are area planted, number of trees planted, and number of native species planted [36•]. Although these tree-planting metrics can be—theoretically—measured relatively easily, they raise several challenges. Firstly, they provide no indication of long-term survival. A recent review in Asia estimated that 44% of planted trees did not survive beyond 5 years [44]. Secondly, these indicators do not measure ecological functionality [45, 25] and how forests and species within them provide ecosystem services, especially at the landscape scale. Several recent articles have criticized this lack of rigor concerning ecological functionality or forest quality in FLR and associated forest restoration efforts [46–49]. Thirdly, these metrics omit entirely the human dimension intrinsic to FLR.

Overreliance on Maps

With greater availability of satellite-based remote sensing data, forest cover has become easier and cheaper to monitor [50, 51], and platforms such as Global Forest Watch [52] are providing near real-time changes in some variables. Maps continue to be a favored tool to measure restoration opportunity [53] and, in theory, progress (e.g., [27]). Yet they fail to address both the fine detail of ecological functionality and the human aspects of FLR. Even where satellite imagery provides sufficiently fine detail to measure indicators relating to the functioning, structure, and composition of forest ecosystems [54], to date, most monitoring systems continue to rely on a pure measure of area (e.g., hectares restored) that fails to account for age and species diversity, both of which are critical to restoring forest quality as well as quantity [55, 24]. Some interpretations using definitions of forests that have a low threshold, such as that by FAO (10% tree cover), may also fail to capture deforestation that remains above the 10% threshold [56].

Monitoring at Inadequate Spatial and Temporal Scales

Monitoring at large spatial and temporal scales poses challenges [57–59]. Many attributes of landscapes are hard to measure, and the scale of interventions and the lack of clear and agreed indicator frameworks mean monitoring seldom provides data on long-term environmental and social impacts [60, 9, 61]. An additional challenge is that landscapes rarely match jurisdictional or land tenure scales, so multiple and overlapping interests and remits are involved in managing the land and its resources. Therefore, if any monitoring is conducted, it is usually in the context of a specific project that may not cover the whole landscape, and once that is finished, monitoring stops. This has implications for the scale of impacts sought by restoration and inevitably leads to the selection of short-term process indicators at small spatial scales over longer-term impact indicators at large spatial scales. Very few planning and monitoring tools exist that are geared toward the landscape level.

Inadequate Data Aggregation

Restoration in general and FLR in particular are relevant to the three Rio conventions and have been prioritized by major donors such as the Global Environment Facility [62]. At an international level, the value of collecting data on FLR lies in its aggregation to gain a global overview of progress. However, as seen with FAO forest data [63], aggregating data across countries is limited by idiosyncrasies in terminology, data collection, and interpretation [64], which is further compounded by the general lack of data in national environmental reporting [65]. Because FLR seeks to meet dual objectives, data aggregation between social and ecological benefits also presents challenges. This is in part because different expertise and methods are required for each but also because of the nature of the change measured, including the timeframe over which this change may be visible. For example, the re-establishment of functional ecosystems requires decades, while the creation of new forest-related jobs might be achieved in a couple of years.

Limited Capacity and Resources

The complexity and the temporal and spatial scales of landscape approaches like FLR require significant financial, institutional, and human resources [66, 9]. The inadequate monitoring of FLR outlined above, with an over-emphasis on measuring short-term outputs rather than long-term outcomes and impacts, focusing only on a narrow selection of environmental metrics, may in part be attributed to short-term donor funding and the need to show results in a brief period. However, many environmental projects suffer from inadequate human, technological, or financial capacity to conduct monitoring [16•]; it is likely that this is also the case in many FLR initiatives. Investing in training local communities to collect data efficiently ensures long-term monitoring capacity in the landscape [41].

Key Lessons from Other Monitoring Initiatives and Indicator Frameworks

In this section, we review some of the lessons emerging from monitoring in other related disciplines and fields with a view to informing FLR monitoring. There are several initiatives and frameworks to produce standard sets of environmental indicators relevant at multiple scales, including at the landscape level.

Lesson 1: Best Practices—Follow widely accepted bestpractices in setting indicators

There is various guidance available on selecting suitable environmental and social indicators [57, 67, 68], but common key principles that are applicable to FLR include that.

  - Indicators should be
  - Credible (i.e., using established methods—both from Western science and Indigenous knowledge where relevant);
  - Feasible to apply (i.e., the facility, program, or project will be able to collect data either directly or through secondary sources using identified methods);
  - Measurable (in quantitative or qualitative terms);
  - Precise (defined the same way by everyone who uses them);
  - Consistent (always measuring the same thing);
  - Understandable (everyone who is concerned by the results can interpret what they mean);
  - Sensitive to the changes being measured.

- Indicators should link to the goals and activities of the program concerned and include both ecological and socio-economic measures.
- Ecological indicators will need to measure more than just forest cover and track broader biodiversity states.
- Nature's contributions and benefits to people, especially through ecosystem services, should also be monitored. Socio-economic indicators will need to measure the aspects of human well-being most relevant to the FLR goals in a given context and will range from access to key natural resources and ecosystem services to overall livelihoods.
- Indicators should be developed by key stakeholders in the context of a monitoring plan, which includes

  - Methods—"how" the indicators will be measured.
  - Timing/frequency—"when" the indicators will be measured
  - Roles and responsibilities—"who" will measure the indicators
  - Location—"where" they will be measured

Sharing a small set of common core indicators is key to aggregating data across a portfolio of projects or sites (57; 68; 69) and has also been proposed for FLR sites [70•].

Lesson 2: Indicators—Use feasible sets of scalable indicators linked to program goals that can be compared and aggregated and where at least some are of relevance to national and global frameworks

The pressure-state-response-benefit (PSRB) indicator framework is promoted by many conservationists to track linked indicators relating to the state of biodiversity, benefits of biodiversity accrued by people, pressures and threats, and responses such as policies and actions to address threats [71, 57]. This is a simplification and modification of the widely used driver-pressure-state-impact-response (DPSIR) framework and has been adopted by the UN to track progress against the goals of the CBD and the sustainable development goals (SDGs) (e.g., [72]). The PSRB model has also been proposed as appropriate for FLR by Dudley et al. [19] who note that successful monitoring systems for restoration need to consider the factors that caused degradation, changes to the ecosystem during restoration, and the steps taken by the restoration project. Rather than rely on largely theoretical indicator frameworks (e.g., [20]), it may prove more fruitful to use bottom-up approaches to choose feasible indicators of relevance to a given project [36•], and the PSRB model could help with that.

It may also prove more practical, and encourage adoption and data collection, if FLR indicators (wherever possible) were harmonized with indicators used already by multiple actors and in multiple initiatives (Table 1), such as indicators used to track delivery of the Kunming-Montreal Global Biodiversity Framework [11] and the sustainable development goals [73].

Many countries set environmental and social goals and indicators at a national level, either as part of national development strategies or to meet obligations under multilateral environmental agreements. For example, all parties to the CBD are obliged to develop NBSAPs (National Biodiversity Strategies and Actions Plans) and report against their delivery. FLR projects should try, wherever possible, to link to such national-level indicators. Examples of national metrics of potential relevance for FLR include indicators for.

- The Ghana@100 strategy [74], such as forest area as a percentage of land area, access to improved drinking water, and agriculture as % of GDP
- Colombia's national development plan 2022–2026 [75], which commits to reduce deforestation by 20% and to have 3.9 million ha under formal ownership by the end of the period
- Sri Lanka's sustainable 2030 vision [76], such as the number of community institutions implementing village development plans with over 80% household participation and over 50% women participation and levels of funding for community institutions in collaboration with local government and the private sector

One of the few tools aimed at the landscape level, LandScale [77], is a standardized approach for assessing and communicating the sustainability performance of landscapes where key commodities are produced. Although this approach focuses on agricultural landscapes, many of the proposed indicators are relevant to FLR (Table 1).

Common metrics across global indicator frameworks are measures of habitat cover, quality or health, species diversity and abundance, and human well-being and livelihoods. There are also metrics focused on key pressures and responses. Given that several of the global indicators, especially for the CBD, have not yet been finalized, there is an opportunity for the FLR community to help shape and influence the final list.

Lesson 3: Collecting Data—Use modern methods and technologies and existing data wherever possible to enhance monitoring

Modern tools and technologies, including satellite-based remote sensing, camera trapping, bioacoustics, and environmental DNA (eDNA), some deployed by aircraft, blimps, or drones, provide opportunities to enhance data collection [79], although every tool has its advantages and disadvantages [80, 32, 51, 81]. Application of such modern tools and technologies opens up new avenues to monitor FLR at larger spatial and temporal scales [82]. Artificial intelligence tools are progressively being integrated into web-based platforms to improve and speed up data analysis [16•]. However, large volumes of information collected by remote sensing "do not necessarily correspond to good knowledge and the ability to answer key questions of management and conservation significance" [59], and so the choice of method needs to be tailored to the specific needs and capacities of the project [16•].

Some environmental projects use secondary data to help with monitoring. Just as satellite-based remote sensing data on forest cover will be sourced externally by most FLR actors, many other indicators can also potentially be measured with secondary data. A range of often open-access global data sources are available that have potential use in the monitoring of environmental states, pressures, benefits, and responses [83], and many will be applicable to FLR.

Lesson 4: Counterfactuals—Monitoring counterfactuals will allow measurement of impact

In conservation projects, there is a growing push for measuring counterfactuals, where data are collected at both the intervention site and a similar site where no activity is undertaken (see, e.g., [84, 85]). This can be done for biodiversity indicators by monitoring the same species or habitats outside the area of intervention [68] and for socio-economic

Table 1 Summary of some of the indicators potentially relevant to FLR proposed by other international and national indicator systems

Indicator system	Examples of types of indicators potentially relevant to FLR
CBD—monitoring framework for the Kunming-Montreal Global Biodiversity Framework [11]	Headline indicators: A.2 Extent of natural ecosystems B.1 Services provided by ecosystems C.1 Indicator on monetary benefits received C.2 Indicator on non-monetary benefits 2.2 Area under restoration 10.1 Proportion of agricultural area under productive and sustainable agriculture 10.2 Progress toward sustainable forest management
Sustainable development goals [78]	2.3.2 Average income of small-scale food producers, by sex and indigenous status 2.4.1 Proportion of agricultural area under productive and sustainable agriculture 6.3.2 Proportion of bodies of water with good ambient water quality 6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources 6.6.1 Change in the extent of water-related ecosystems over time 8.9.2 Proportion of jobs in sustainable tourism industries out of total tourism jobs 15.1.1 Forest area as a proportion of total land area 15.2.1 Progress toward sustainable forest management 15.3.1 Proportion of land that is degraded over total land area 15.5.1 Red list index
IUCN guidelines for planning and monitoring corporate biodiversity performance [68]	Benefits: • Abundance of species used sustainably by farmers and local communities • Income generated from sale of harvested resources (e.g., agroforestry crops) • Index of human well-being measures • Ecosystem integrity index States: • Forest area as a proportion of land area • Species richness and diversity • Abundance of key species • Water quality • Habitat health • Red List of Species Index • Green Status Index Pressures: • Habitat fragmentation • Number of incidents of illegal or unsustainable activity • Populations trends of key invasive species Responses: • Protected area cover • Protected area management effectiveness • Number of trees planted and % survivorship • Number of farms applying sustainable techniques • Proportion of products or raw materials from certified sources
LandScale [77]	Ecosystems • Area of natural ecosystem converted (ha), disaggregated by land cover type • Natural ecosystem fragmentation (index) • Status (e.g., abundance) of indicator species that are associated with intact ecosystems • Restoration rate (ha/yr) or total area restored (ha), disaggregated by restoration type • Changes in populations of, or threats to, threatened species • Soil health (% Soil Organic Carbon) in a representative sample of production sites across the landscape Human well-being and governance • Percentage of (rural) population living on < $1.90/day (or below national poverty line) • Locally relevant measures of economic development (e.g., land ownership, access to credit/financial services) • Percentage of landscape with formalized land tenure rights that has clearly defined boundaries shown in publicly accessible maps • Number of new or continuing unresolved land or resource conflicts or grievances including land grabbing • Percentage of landscape covered by land use or zoning plans that are formally adopted and enforceable

indicators by monitoring, for example, control households not impacted by the project [86, 87].

While the use of scalable linked indicators, such as the PSRB model, allows the monitoring of results along a project's theory of change and can help identify actual and potential reasons for success [57], the use of randomized control trials [88] and before-after control intervention analyses [85] can measure success against counterfactuals and enhance attribution of results [89]. FLR interventions will need to follow suit in order to assess impact.

Lesson 5: Date Analysis and Use—Use data for adaptive management and share results and lessons as widely as possible

Data collected by monitoring needs to be used for planning and decision-making, especially for adaptive management where successful approaches are replicated and less successful approaches are modified or replaced [59, 16•]. The use of data can be enhanced by the development of easy-to-use data-derived products that facilitate interpretation and analysis, such as maps, graphs, and dashboards [90, 68, 15]. The most effective products are likely to be those that cater to the needs of stakeholders with differing priorities and mandates and are therefore simple and openly accessible [91]. As noted earlier, using maps to track forest cover can be a challenge, but maps can also be useful ways of presenting other types of state data as well as data on pressures, responses, and benefits that help facilitate decision-making [90].

Several studies have noted that, for the monitoring of environmental projects to succeed, it is essential to increase the sharing of data [91, 83] and the sharing of lessons and experiences [69, 92]. Learning and information sharing are also seen as key success factors for collaborative monitoring in FLR [93].

Lesson 6: Partnerships—Stakeholder collaboration and partnerships facilitate effective monitoring as well as planning

Effective monitoring requires strong partnerships between different actors, including scientists, policy-makers, communities, and managers [94, 93, 68, 16•]. Increasingly too, monitoring involves Indigenous peoples and local communities in what is often referred to as "citizen science," and several new technologies, including camera trapping, acoustic monitoring, and eDNA, lend themselves to community involvement [51].

Landscape inhabitants have a critical role to play in FLR. This is also the case in monitoring FLR, where their local knowledge and experience may provide cost-effective and long-term measures of landscape change. "Stakeholders need to explore ways of including indigenous, traditional, local and under-utilised ecological knowledge in the mix of data collected" [16•]. In many tropical countries where FLR is implemented, this may require structural and institutional changes centered on trust building and empowerment.

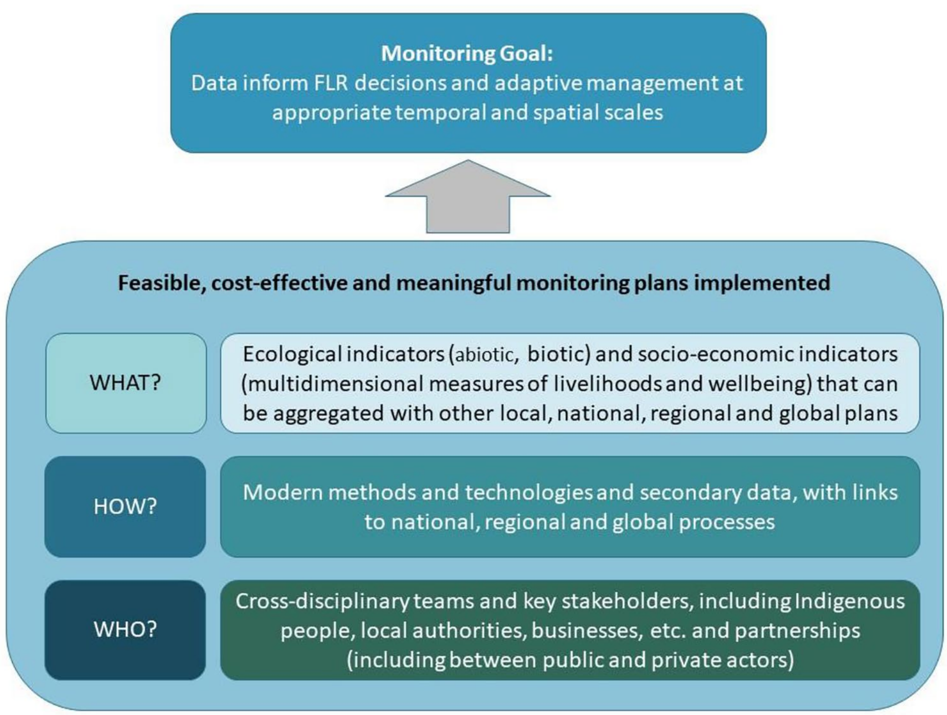

Fig. 1 Key considerations in FLR monitoring

Businesses are increasingly striving for, or being legally obliged to strive for, sustainability and to contribute to nature-positive ambitions [95]. Furthermore, in many sectors, companies are legally obligated to conduct environmental impact assessments or strategic environmental assessments before commencing operations. Many companies opting to have their production certified as sustainable also require assessments. This means that going forward, corporate entities are liable to become increasingly important partners in collecting, using, and sharing environmental data. New frameworks being finalized for the corporate sector, such as the Science-Based Targets Network guidance [96] and the Taskforce for Nature-related Financial Disclosures [97], will also provide scope for helping businesses identify suitable metrics, many of which should be relevant to FLR initiatives.

Conclusions and Way Forward

Monitoring is essential for assessing progress, learning, and adaptive management. FLR monitoring is complicated by the spatial and temporal scales of the process and the dual social and ecological dimensions. A review of the current situation illustrates that, although many frameworks exist or are being developed, in practice, monitoring of FLR continues to be challenging and, as a result, is likely to impede effective progress and implementation of restoration at the scales required.

Moving forward, FLR practitioners would benefit from learning from practices in other environmental areas. Lessons that we identified include the need to choose appropriate indicators, collect primary and secondary data using the latest technologies and approaches (including counterfactuals to assess impact), share data and lessons, and engage diverse stakeholders in data collection and use.

If FLR initiatives are to scale up data collection to the levels needed to monitor progress and impact, the lessons learned from other environmental monitoring experiences suggest three key points to address going forward (Fig. 1).

Firstly, choosing a small set of common, scalable indicators across landscapes and sites within landscapes will help facilitate data aggregation and monitoring at the spatial and temporal scales needed. Adoption of the PSRB indicator framework would align FLR initiatives and suggest that, for FLR, state indicators would look at biotic factors such as habitat cover and quality and populations of key species, benefit indicators would include socio-economic measures around livelihoods and ecosystem services, pressure indicators would look at threats facing the landscape and its wildlife and people, and response indicators would measure progress in the actions, strategies, and policies employed to restore landscapes (including some of the management metrics proposed by some authors). Clearer definitions of what sorts of benefits humans gain across FLR initiatives would help identify the best livelihood and well-being indicators to use and strengthen the link between forest restoration and its outcomes. While indicators need to be chosen to measure FLR goals, they also need to be linked insofar as possible to existing local, national, regional, and global frameworks to enhance the likelihood of adoption and successful application. Many of the FLR-specific frameworks proposed to date (e.g., [18•, 19, 20]) can be used as a menu of options to consider if and where relevant. A small number of well-chosen and feasible indicators are better than a long list that will never be implemented. Keeping the system as simple as possible while gaining adequately meaningful data will also help ensure cost-effectiveness and the long-term scale needed for data collection. It is also essential that monitoring plans are regularly assessed, and indicators that are not working or providing no information are modified or removed.

Secondly, methods and approaches to collect FLR monitoring data should make use of the diversity of modern tools being applied in other areas. Satellite-based remote sensing can measure not only forest cover but also many aspects of forest structure and composition [54, 79] that will allow measures of ecosystem function, especially when complemented with ground-truthing surveys. Other tools, such as camera trapping, eDNA, and passive acoustic monitoring could help in particular to measure the diversity and abundance of species within restored forests and, in turn, reflect the functionality of those forests. In at least some cases, artificial intelligence can support data analysis. The choice of tool for FLR monitoring will need to be influenced by capacity and budget, as well as the taxa and habitats being monitored. Use of such methods would also help to reduce the current emphasis on maps and areal measure of success in FLR.

Thirdly, to be effective in monitoring the biological and social aspects of restoration, cross-disciplinary teams with the expertise to measure and interpret data across both social and ecological dimensions will be essential. Indigenous peoples and local communities, and non-traditional environmental actors like businesses, also need to be engaged. Data use across stakeholder groups will be facilitated by improved presentation and sharing of data. For FLR, dashboards would need to focus on indicators that are aggregated across the target landscape that meet the needs of key stakeholders. Online data portals established by relevant partners could help with generating and sharing such dashboards and other derived products. Examples of the types of portals that could be evolved to include such products include the IUCN Restoration Barometer (https://restorationbarometer.org/), Restor (https://restor.eco/map), and UNEP's World Environment Situation Room (https://wesr.unep.org/).

Collaboration and wide stakeholder engagement have been flagged as important for planning and implementing FLR, especially the involvement of local communities [98]. Engaging local partners to collect data collaboratively has already been proposed for FLR sites [70•] although this is challenging to implement

[99]. Governance challenges related notably to tenure and property rights [100, 101] may also create tensions and conflicts in FLR planning and implementation and may, therefore, also affect monitoring. Partnerships can help to share the responsibility for monitoring across large scales. Management of watersheds in forest landscapes might provide a suitable scale at which partnerships can operate in at least some cases. For example, in Brazil, the Cerrado Waters Consortium (Consórcio Cerrado das Aguas) is a multi-stakeholder coalition involving government, business, and civil society actors that facilitates restoration, as well as climate-smart agriculture and water management, in target watersheds [15, 102]. In some cases, a landscape may match some form of local government jurisdiction (e.g., a district) or have a research institute or other form of government body operating within the boundaries of the landscape, and in such cases, these organizations can take a lead in rallying partners around suitable monitoring systems.

Ultimately, FLR stakeholders need to be pragmatic when monitoring their progress and impact. At such large spatial and temporal scales, it will never be possible to measure everything that is happening or being restored. The key is to gauge the appropriate amount of effort required and to focus on a small set of key indicators to provide enough information to inform adaptive management while being feasible to measure within the constraints of available resources and stakeholder capacity. If these indicators are harmonized with those used in other frameworks, it should be possible to measure the impact of FLR not just against the social and environmental goals within the landscape but also against global ambitions for a sustainable planet.

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Compliance with Ethical Standards

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