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Measuring progress in status of land under forest landscape restoration using abiotic and biotic indicators

Running title: Measuring progress in forest landscape restoration

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Abstract: The paper suggests a minimum set of abiotic and biotic threshold indicators, and progress indicators for Forest landscape restoration, then also briefly discusses progress indicators of pressures and project outputs. Forest landscape restoration (FLR) aims to restore multiple functions of forests at a landscape scale. It is predicated on the hypothesis that restoration produces enabling conditions for ecosystem services, including *regulating services* such as carbon sequestration and pollination, and *provisioning services* such as food and energy. As FLR gains greater uptake, it is increasingly important to monitor progress. The types of indicators required are influenced by the degree of forest loss and degradation. To measure status of land under restoration, one or more abiotic and biotic ***threshold indicators*** are required, measuring the return of enabling conditions for restoration (soil quality, water etc), along with ***progress indicators*** measuring the re-emergence of the ecosystem services. While all elements of the proposed monitoring framework are well known, compiling them into a coherent system, suitable for application in a wide range of conditions, will take much further development.

Keywords: ecosystem functions, ecosystem services, forest; restoration, monitoring; thresholds.

Implications for practice:

- Large-scale restoration programmes need a broad suite of progress indicators, with clear indication that thresholds have been crossed to demonstrate achievement of an improved condition class.
- In badly degraded landscapes this will include *threshold indicators*, to show attainment of key ecosystem functions and *progress indicators*, to show the extent that the restoration programme is meeting scheduled activities
- In severely degraded sites it is important to include abiotic indicators to measure the return of primary ecosystem functionality, e.g., relating to soil properties, alongside biotic indicators

- Given the need to implement FLR at scale and work with many user groups, indicators that are easily understood and measured by a wide range of stakeholders should be deployed wherever possible.

Introduction

Current rates of global forest loss and degradation are ecologically and socially unsustainable. The total area of tropical forest declined by 5.5 million hectares a year from 2010 to 2015 (Keenan et al. 2015) and an even larger area, not fully quantified, underwent partial canopy loss and degradation (Sloan & Sayer 2015). Many natural forests in temperate and boreal regions have been degraded or converted to secondary forest or plantations. Up to 70 per cent of global forests are at risk of further degradation (Hansen et al. 2013; Haddad et al. 2015). Unintended consequences of forest degradation and loss include biodiversity loss, reduced ecosystem services and increased carbon emissions (Foley et al. 2005). The consequent need for forest restoration (Aronson & Alexander 2013; Chazdon et al. 2015; Hanberry et al. 2015) and the potential for scaling up restoration (Chazdon 2008; Murcia 2015) are both increasingly recognised.

Restoration means many things to many audiences, from ecological restoration of habitats to reclamation or rehabilitation of mining sites to re-wilding extensive landscapes in order to restore the structure, function or ecological complexity of ecosystems (e.g., Allison 2007; Clewell & Aronson 2013; Navarro & Pereira 2012). Many terminologies exist, for example distinguishing between rehabilitation, reconstruction, reclamation and replacement (Stanturf et al. 2014). *Forest landscape restoration* (FLR) is an approach that aims to regain ecologically and socially important forest functions at a landscape scale, using strategies negotiated between affected stakeholders (Orsi et al. 2011; Maginnis & Jackson 2012). The term was defined by a group of experts in 2000 as "*a planned process that aims to regain ecological integrity and enhance human wellbeing in deforested or degraded landscapes*" (Mansourian et al. 2005). The FLR approach recognizes that while forest restoration at the site scale may legitimately aim to produce a fairly narrow set of benefits, at the landscape scale, restored forests usually need to supply multiple functions to address the multiple

needs of the stakeholders in the landscape. The complex planning processes needed to balance and trade-off different restoration functions and aims require the involvement and support of multiple stakeholders, with cultural as well as biological drivers (Bhagwat et al. 2014). Our approach to restoration therefore adopts the notion of multifunctionality at the landscape level and incorporates both ecological integrity and human wellbeing in one framework; as opposed to re-wilding where the focus is generally more directed towards conservation outcomes alone (e.g. Fernandez et al. 2017).

Given the scale of the task and relative shortage of resources, forest landscape restoration focuses on places where restoration is feasible (Orsi et al. 2011). Efforts are predicated on the hypothesis that restoration produces enabling conditions for a range of the ecosystem services, including *regulating services* such as carbon sequestration and pollination, and *provisioning services* such as food and energy (MEA 2003). Recent studies point to the need to begin restoration activities by focusing on "functionally important" species (Montoya et al. 2009; Galetti et al. 2017). At a landscape scale restoration aims will likely embrace multiple aspects including the regaining of a range of ecosystem services including climate mitigation (Stanturf et al. 2015), biodiversity conservation (Rey Beneyas et al. 2012), biomass production (Ciccarese et al. 2012) and a range of other social, cultural and spiritual values.

Current policy context of restoration

Restoration is increasingly included amongst targets set by the global community. In 2010, the Convention on Biological Diversity set 20 biodiversity targets (the so-called Aichi targets) which include: Target 14: "By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable"; and Target 15 "By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification" (www.cbd.int/sp/targets/). In the UN Convention to Combat

Desertification, initiatives such as the Great Green Wall in Africa bring profile and funding to restoration efforts in drylands. The 15th UN Sustainable Development Goal includes a commitment to "halt and reverse land degradation" and successful restoration projects will possibly address a number of additional SDG goals. Efforts under the UN Framework Convention on Climate Change (UNFCCC), such as the program of Reducing Emissions from Deforestation and forest Degradation + (REDD+), are also increasingly using restoration to mitigate climate change. There are also a growing number of regional initiatives, such as the Atlantic Forest Restoration Pact, which aims to restore 15 million hectares of tropical forest by 2050 (Calmon et al. 2011).

In this context, the Bonn Challenge is a global aspirational challenge to restore 150 million hectares of the world's degraded and deforested lands by 2020 and 350 million hectares by 2030 (Laestadius et al. 2011). It is overseen by the Global Partnership on Forest Landscape Restoration, involving over 20 institutions. The Bonn Challenge already has commitments in excess of two thirds of the 2020 goal, for instance 2 million hectares from Rwanda (IUCN 2015) and 13 million hectares from India (www.bonnchallenge.org/). The Bonn Challenge builds on the experiences of major restoration initiatives that have already proved effective, such as the case of the Republic of Korea (Lee et al. 2016). Efforts are being made to develop technical expertise to match the political commitments. The World Resources Institute and Food and Agriculture Organization of the United Nations have been collaborating on approaches to monitoring FLR at landscape and national scale, based around production (energy, products and culture), conservation (soil, water and biodiversity) and impact (community, market and climate). Independently, recent work in the Brazilian Atlantic Forest has used a stakeholder-driven approach to developing a monitoring protocol for restoration (Viani et al. 2017).

Rising political commitments and funding levels mean that it is also increasingly important to measure success or failure in restoration. Such measurements are important to ensure that restoration delivers the ecosystem services that were targeted and is important both at the local level and national levels to ensure that stakeholders understand what restoration efforts provide, and to help justify

investments. Lack of sufficient monitoring was identified as a major lesson in a ten year review of WWF's restoration programme (Mansourian & Vallauri 2014). Proving success in forest landscape restoration is hampered by lack of understanding about monitoring, yet experience suggests that good monitoring systems are amongst the most important components of project success in natural resource management (McShane & Wells 2004). Monitoring needs to be against a baseline and clearly stated targets, and if possible should compare the results of active restoration against passive restoration in similar sites (Burton 2014). Particular challenges in this context include the need for straightforward assays of restoration outcomes, choosing sufficient indicators to measure multiple ecosystem functions, monitoring at landscape scale and the long time-scales involved in restoration, necessitating monitoring changes over decades (Dale & Beyeler 2001; Montoya et al. 2012). An additional requirement is for monitoring systems that work without huge financial resources or specialised expertise. While this paper primarily addresses ecological monitoring, parallel efforts to assess societal benefits will also be needed.

Measuring forest landscape restoration

There are many ways to measure restoration success, mostly, in terms of comparison with reference states (Wiegleb et al. 2013), application of biotic and abiotic indicators and, rarely, use of social (Egan & Estrada-Bustillo 2011) or ecosystem service indicators. Monitoring of wildlife, including population dynamics of carefully chosen umbrella species, has been identified as an important component of some restoration projects (Block et al. 2001). Most monitoring systems to date have focused only on ecological attributes, with ecosystem services and social benefits remaining at best on the fringes of the monitoring protocol (Wortley et al. 2013), however aspects of this are increasingly integrated, such as in Brazil (Melo et al. 2013). Furthermore, many restoration protocols require specialist knowledge and are costly and difficult to implement (e.g. Herrick et al. 2006), thus severely limiting their application.

Successful monitoring systems for restoration need to consider three key elements: the factors that caused degradation to occur (the status); the changes to the ecosystem during restoration (the

outcomes) and the steps taken by the restoration project (the outputs): the well-known pressure-state-response model. In this paper we look predominantly at outcome or state indicators, although other indicators are also briefly considered below (see Table 1 and Figure 2).

Status indicators in this case focus on specific pressures causing the original degradation. Restoration efforts will likely fail if the reasons why restoration is needed are not addressed either before or during the restoration programme. Effective restoration planning therefore first identifies the causes of forest loss and degradation (e.g. Hosonuma et al. 2012), and proposes steps to address these if they are still present (Hobbs & Harris 2001). Monitoring systems will vary depending on the nature of the pressure. Some will be relatively straightforward (e.g. number of grazing livestock in an area; volume of fuelwood collected) while others may be more complex (e.g. changing climate, impacts of long-term soil degradation).

Monitoring responses (in other words the outputs of restoration programmes) will vary depending on the nature of restoration and the status of the site, but will often involve monitoring both the steps needed to reduce degradation pressure and those put in place to achieve active or passive restoration. Indicators can be drawn from the project work plan and will include both quantitative measurements of actions (e.g. number of trees planted, length of livestock fences installed) and more qualitative aspects of restoration (e.g. changes in attitude or behaviour amongst resident communities, or attitudes towards restoration).

With regard to changing conditions at the site, the state of the land under restoration and the outcomes of any restoration project, restoration requires indicators at both site and landscape scale. Measuring the attainment of a series of abiotic and biotic thresholds (Figure 1) can help to trace the steps in successful restoration initiatives. These thresholds together represent the *enabling conditions* for a functioning ecosystem; in other words certain physical and biological factors (e.g. soil condition, hydrology, presence of keystone species) allow the ecosystem to sustain itself.

The types of indicators required are influenced by the extent and longevity of forest loss and degradation. One or more ***threshold indicators*** will be needed for each threshold, along with more general ***progress indicators***; thus measuring both the return of enabling conditions and the re-emergence of the ecosystem services that it provides. This means first identifying and finding indicators for the mainly abiotic barriers and their thresholds that affect early stages of restoration, in cases where deforestation or degradation have been more extreme; next indicators for the mainly biotic barriers and their thresholds which are important later; and finally longer term indicators to determine the success of regaining specific ecosystem services and meeting restoration objectives, and is consistent with current EU guidance (Lammerant et al, 2013), but goes further than the recent SER Standards, which aim simply to provide indicators of condition across five attribute groups, and no clear indication of the importance of thresholds or the need to have crossed all indicator thresholds before moving to the next class of condition (McDonald et al, 2016). Threshold indicators measure a definite target threshold, and will tend to phase out as components of ecosystem functioning return, while progress indicators generally measure trends rather than a specific end point (Figure 2). If many stakeholders have been involved in planning restoration, selection of indicators may be participatory.

Monitoring takes place over various timescales and usually with varying data quality and technical capacity. Because FLR by definition operates at a landscape scale, this means that indicators also need to function at a range of scales, with some measuring site-level success and others considering more landscape scale parameters. For example it might be important to measure trees established at a series of sites, and also to consider the impacts that this had on flooding throughout the watershed. This implies different levels of monitoring complexity, ranging from simple, field-based systems to more technical approaches requiring laboratory analysis and equipment. Any general monitoring framework therefore requires *a suite of potential indicators that can be used selectively depending on the baseline, project aims, skills, capacity and available information*. This also avoids wasting time measuring indicators that will not yet show results. Monitoring officers may need to be imaginative in selecting indicators for which information can be obtained with available resources.

Potential indicators

Far more is known about abiotic than biotic indicators (Feld et al. 2009) although the use of indicator species for measuring restoration success is already quite widespread (Siddig et al. 2015). Experience suggests the need for a range of biotic indicators and that for example a narrow focus on plant community composition may not provide accurate projections of future progress (Herrick et al. 2006). Nonetheless, understanding is growing for biotic indicator groups such as lichens (Giordani et al. 2012), mycorrhizal fungi (Asmelash et al. 2016; Ingleby et al. 2000; Vogelsan et al. 2006), bryophytes (Karger et al. 2012), herbs (McLachlan & Bazely 2001), overall soil quality (Ritz et al. 2009), soil invertebrates (Lavelle et al. 2006) including earthworms (Guéi & Tondoh 2012), arthropods (Longcore 2003; Pearce & Vennier 2006; Schmidt et al. 2013) including ants, (Folgarait 1998; Anderson & Majer 2004), saproxylic beetles (Lachat et al. 2012; Audino et al. 2014) and single-species indicators (Siddig et al. 2016). A recent review found 54 empirical studies that used invertebrates as indicators of restoration success, particularly at mine sites. These have been successful in indicating a wide range of restoration objectives and have often used assemblages of invertebrates rather than individual species (Lindenmayer et al. 2015).

There may sometimes be a choice between biotic and abiotic indicators and selection will depend on factors such as ease of measurement, cost and the how well the indicator tells a story to other stakeholders.

1. *Abiotic threshold indicators*

Measurement of the following could all be useful, depending on ecosystem type, level of degradation and restoration aims; specific indicators and methodologies for measurement exist (Schoenholtz et al. 2000; Ecologic Institute & SERI 2010). These are primarily abiotic although some (e.g., soil properties and decomposition rate) will have a biotic component:

1. Contamination
2. Contour – appropriate landform (e.g. in post mining site restoration)

3. Micro-topography
4. Stability of substrate
5. Soil properties (organic matter content and other nutrients, infiltration, bulk density, soil development, pH, carbon dioxide evolution)
6. Soil profile development
7. Hydrology: water quantity and quality (e.g. stream colour)
8. Basic net primary productivity
9. Decomposition rates
10. Climate/disturbance regimes (flooding, fire presence, frequency or intensity, drought)

All of these measurements will require some level of expertise and in most cases simple laboratory facilities. These indicators aim to record whether the basic conditions suitable for healthy forest growth have been regained following major forest loss or degradation.

2. Biotic threshold indicators

Representation of the following key attributes and functional groups (rather than taxa) could provide useful information; each of which will have an identifiable threshold which will need to be identified and monitored against:

1. Ground / canopy cover (e.g., percentage cover)
2. Recruitment – rate of addition to the population through reproduction or migration
3. Appropriate symbionts (e.g., mycorrhiza, some epiphytes)
4. Nitrogen fixation
5. Structure/pattern/architecture (e.g. diversity, connectivity, age class, dead wood, vertical structural components)
6. Pollinators
7. Dispersers (e.g., seed and fruit)
8. Reduction in harmful invasive species
9. Decomposers

10. Microbial community phenotype and genotype
11. Macro-fauna (e.g., population size of flagship species, persistence and expansion of key species)
12. Native species

These indicators attempt to measure more complex interactions, including the overall health of the restoring ecosystem and the return of significant ecosystem services. In most cases less is known about them than the abiotic indicators, making each use slightly experimental or requiring knowledge about the species at the site.

Measuring all these indicators would require a major effort. Box 1 presents a minimum list of indicators to measure a set of thresholds. Choice of indicators depends on a range of factors including budget, availability of equipment and expertise, willingness of stakeholders to engage in monitoring and to some extent also the aims of the restoration. Recovery of pollinators is a necessary prerequisite of a functioning ecosystem but likely to be particularly significant in places where restoration is taking place near farmed areas or where beekeepers operate.

3. Progress indicators

Progress indicators are more complex and are heavily influenced by the aims of the restoration project so that suggesting a standard list is problematic. They might include indicators of specific project objectives, for example the return of particular species; or reduction in flooding; or availability of non-timber forest products. Success in identifying process indicators is strongly tied to the clarity with which project objectives have been set (Failing and Gregory 2003). Some examples of progress indicators are given below along with potential ways of measurement:

1. Reduction in dust storms due to increased vegetation cover, using meteorological data or information on flying conditions from local airports
2. Changes in flood frequency and intensity, using number of floods, extent, or households affected

3. Provision of fuelwood or non-timber forest products to local communities, through harvest levels or volume of products collected
4. Increases in tourist numbers following forest restoration, as measured by expenditure, numbers of nights spent in local accommodation, or counts of visitor numbers
5. Return or recovery of threatened and endangered species of conservation concern, through population counts or breeding success
6. Increases in honey production following restoration of plants supporting pollinator species

An underlying assumption of FLR is that success depends heavily on negotiating support from a wide range of stakeholders. Agreeing progress indicators is an important step in gaining this support because in total they define the range of benefits expected from restoration, and provide the means of verifying that all stakeholder needs are being met in practice (Dudley et al. 2006). An FLR plan will generally include a range of outputs; each of these requires at least one measurable indicator of progress. In some cases, abiotic and biotic threshold indicators will also supply information useful for tracking progress indicators.

Conclusions

In the current paper, we have focused on the abiotic, biotic and progress indicators that will measure changing conditions and hopefully the return of forests at various sites and ecosystem services across a wider landscape. Monitoring systems are a key element of measuring success in restoration, but also potentially an enormous drain on time and resources; success depends on maximising efficiency.

An iterative process is required. Specialist knowledge is needed to suggest some indicators (e.g. laboratory methods of measuring soil conditions) while others require local knowledge and the final list needs to be influenced and agreed by all relevant stakeholders. This list then needs further elaboration, to indicate the frequency at which particular indicators are measured, the scale to which they refer and the information provided by each (as noted, for instance, some threshold indicators will also provide information about progress towards agreed goals). Time and money can be saved if

indicators collected through other processes (e.g. government social monitoring) can also provide useful data about the progress of FLR (Dudley et al. 2003). Finally, the indicators need to be put together with those agreed for measuring changes in pressures on the system, and outputs from the restoration programme, to provide an overall status-pressure-response monitoring system.

The ideas presented can contribute to further development of a consistent monitoring framework for large-scale restoration projects. It should be stressed that whilst individual elements of the framework are already well understood, substantial gaps in our knowledge remain (Wortley et al. 2013). Application of the framework is hampered by lack of knowledge about key areas: in particular the links between biological indicators and ecosystem service delivery. Much of this information exists but has yet to be collated and analysed. Another potential block on applying these to some of the very major restoration initiatives planned or underway comes from lack of understanding of either the theory or practical application of monitoring systems of the scale and complexity required. A detailed programme of field testing, capacity building and engagement is required to enable such monitoring schemes.

None of these challenges are insurmountable but all require time and effort. Such monitoring systems need to be practical and feasible for a variety of field technicians to carry out, in conditions of varying governance quality. An effective monitoring framework for forest landscape restoration will help ensure that the growing commitment to reversing catastrophic forest loss provides maximum returns.

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Table 1: Pressure-state-response indicators in restoration
Examples of potential indicators and units of measurement

Pressure (status)		**State (outcomes)**		**Response (outputs)**	
Indicator	**Units**	**Indicator**	**Units**	**Indicator**	**Units**
				Indicators for removing pressure	
Grazing pressure from livestock	Number of animals	Condition of soil	Soil properties	Fencing restoration areas against livestock	Kilometres of fence installed
	Length of time that livestock grazes in the region		Soil profile	Agreement to reduce fuelwood collection	Voluntary agreements
Fuelwood collection	Estimates of volume of wood removed	Forest cover	Number of trees successfully established		Observations of changes in behaviour
	Number of charcoal burners operating	Hydrological impacts	Changes in water retention in soil		Introduction of laws controlling fuelwood collection
			Changes in stream flow	**Indicators of restoration efforts**	
				Tree planting	Number of trees planted

Figure 1: **Conceptual model for ecosystem degradation and restoration** (Parks Canada & The Canadian Parks Council 2008; adapted from Whisenant 1999 and Hobbs & Harris 2001). The numbered balls represent different levels of degradation, down to 6. Resilience of the system is represented by the width and depth of the "cup". Barriers or thresholds exist between some ecosystem states (e.g., states 2 and 3) that require active management to overcome. Restoration attempts to move the ecosystem back towards a more structurally "intact", well functioning state, (i.e., towards state 1).

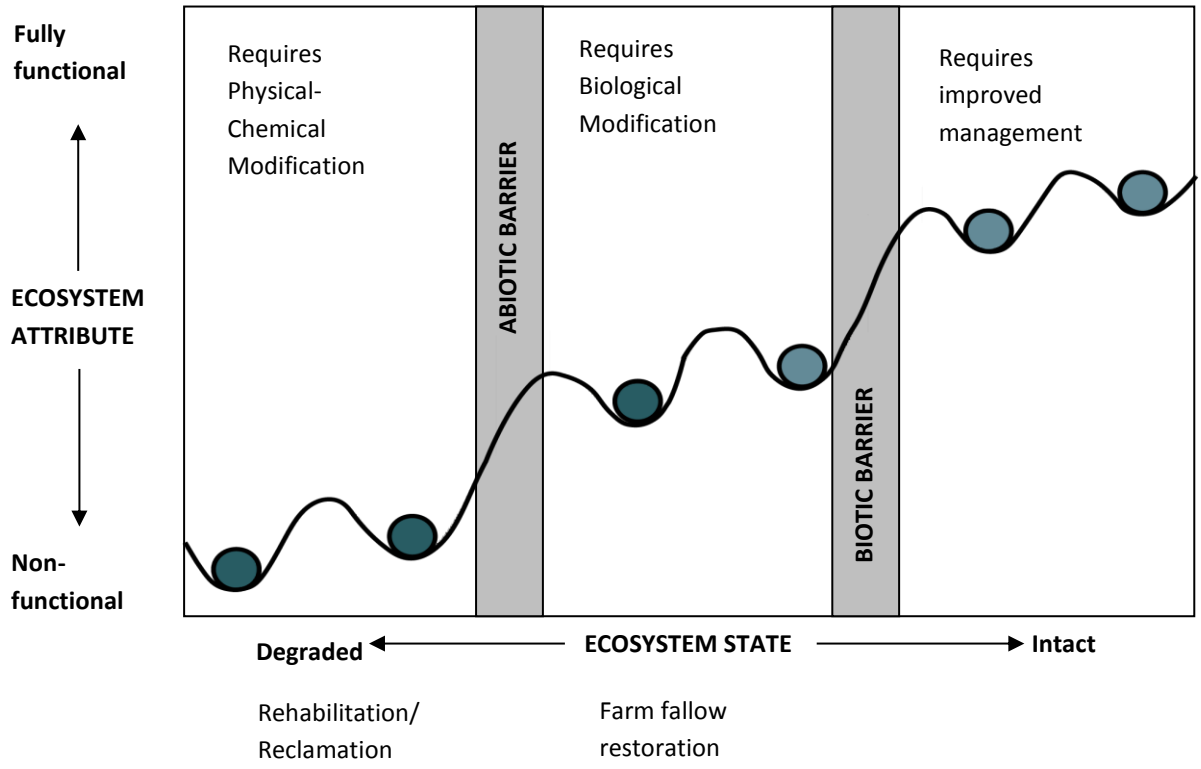
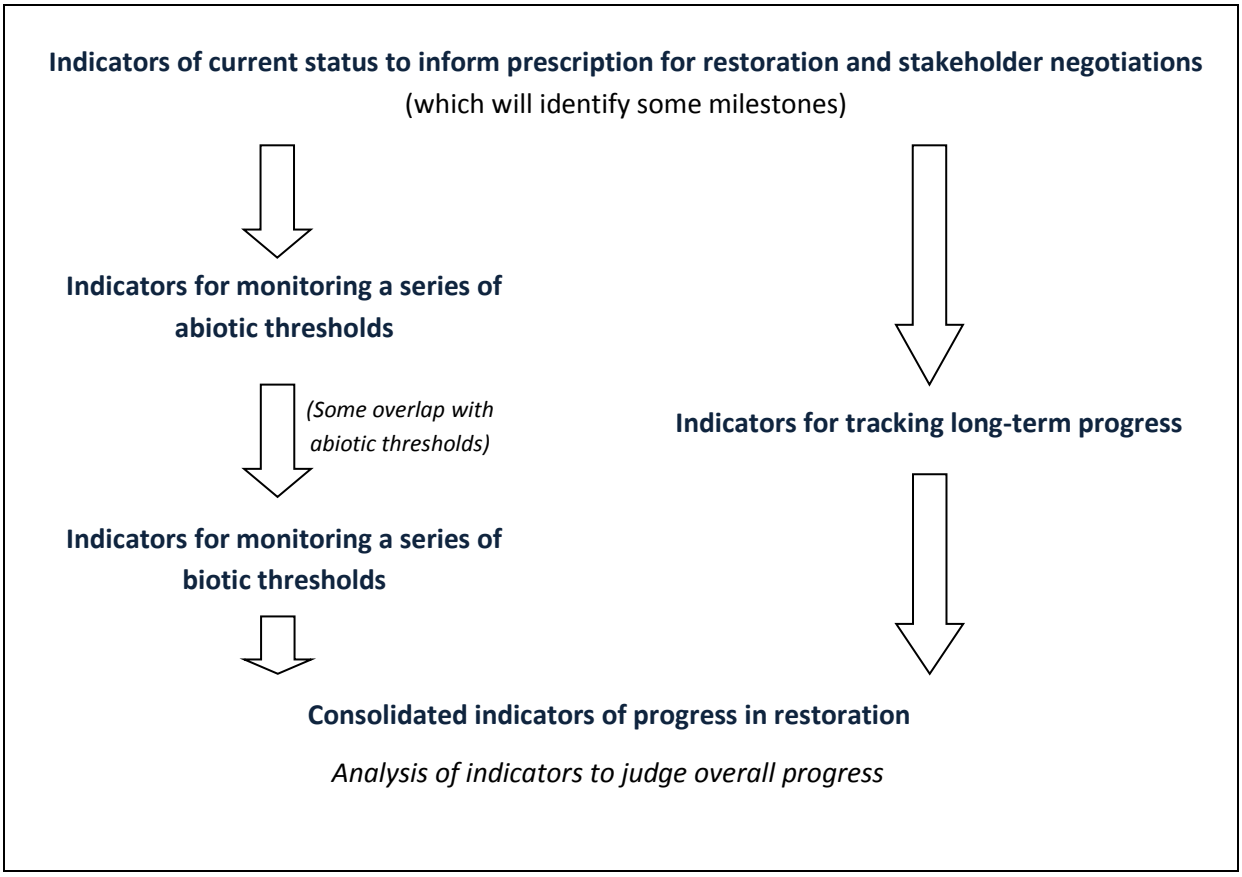


Figure 2: Flowchart for monitoring forest landscape restoration



Box 1: A minimum list of indicators to measure a set of thresholds

Suggested minimum threshold indicators

Abiotic

Suitability

Soil properties (infiltration, organic matter content, bulk density, soil/profile development, aggregation, textural class)

Hydrology: water quality and quantity at landscape scale

Biotic

Ground / canopy cover / biomass

Pollination – minimum biotic activity

Dispersal – minimum biotic activity

Recruitment

Decomposition rates

Appropriate symbionts (e.g., mycorrhizae, nitrogen fixers)

Nitrogen fixation

Structure/pattern/architecture (e.g. connectivity, desired composition, age classes of wood, age structure of vegetation), vertical structural components)

Invasive species that can prevent restoration

Diversity – genetic, taxonomic and functional

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Measuring progress in status of land under forest landscape restoration using abiotic and biotic indicators

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