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Source: Tropical Conservation Science, 10(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/1940082917697265

Conservation Letter

Tropical Conservation Science
Volume 10: 1–8

DOI: 10.1177/1940082917697265
journals.sagepub.com/home/trc

Protocol for Monitoring Tropical Forest Restoration: Perspectives From the Atlantic Forest Restoration Pact in Brazil

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Abstract
Monitoring protocols are needed to evaluate the millions of hectares of land that are being proposed for forest restoration in the coming decades. Standardized proposals are critical to evaluate efficacy of restoration strategies, identify triggers for corrective actions, compare results across projects, and generally learn from past projects to inform future restoration efforts. We describe an iterative process, including over 200 stakeholders, to develop a protocol for monitoring Brazilian Atlantic Forest restoration. We give an overview of the ecological, socioeconomic, and management criteria, indicators, and metrics included in the protocol. Strengths of the protocol include the following: (a) testing and use across sites with a range of ages, forest types, past land uses, restoration techniques, and implementing institutions; (b) participation by a broad range of government, nongovernment, private, and academic institutions in the protocol development process; and (c) inclusion of socioeconomic and management criteria. Next steps for facilitating the broad adoption of the protocol in the Atlantic Forest region include providing in person and online training courses, establishing an online repository for storing and comparing monitoring data, and developing smartphone applications to facilitate data collection. Although the protocol was developed for the Atlantic Forest context and further refinements are needed, we think that the Atlantic Forest Pact monitoring protocol may serve as a model to inform the development of similar protocols in other regions, which ultimately could be integrated to produce a pantropical protocol for common use by several restoration forest programs worldwide.

Keywords
ecological indicators, ecological restoration, large-scale restoration, restoration success, socioeconomic evaluation

Introduction

Ambitious forest and landscape restoration targets, such as the Bonn Challenge, Aichi Biodiversity Targets, and New York Declaration on Forests (Suding et al., 2015), demonstrate an unprecedented recognition of restoration as a global priority for addressing biodiversity conservation and human well-being. International commitments are being converted into large-scale on-the-ground restoration projects, and many regional and national initiatives are being implemented worldwide (Aguilar et al., 2015; Bae, Joo, & Kim 2012). Ongoing monitoring is critical to determine whether projects are achieving stated goals and objectives and to identify problems to be addressed by adaptive management interventions (Hobbs, Hallett, Ehrlich, & Mooney, 2011). The large amounts of private

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Received 8 December 2016; Accepted 25 January 2017

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and public financial resources needed for such ambitious restoration goals, estimated at US$18 billion per year (Menz, Dixon, & Hobbs, 2013), require transparency, up-to-date monitoring information, and adequate reporting to communicate restoration outcomes (Jørgensen et al., 2014). However, traditional restoration monitoring approaches have been implemented at limited temporal and spatial scales, often with minimal analysis of data and application of results to inform subsequent management interventions.

The use of high-resolution satellite images has allowed unparalleled achievements in monitoring changes in forest cover globally (Global Forest Watch, 2014; Hansen et al., 2013), and shows promise to assess restoration at large scales. Such technologies, however, have been used more to date for assessing deforestation, a discrete land use change that can be easily identified by satellites, compared with reforestation, a gradual and less predictable change that may take decades. Many ecological filters must be overcome by restoration interventions to allow the reestablishment of tree cover, which is only a single component of forest restoration (Holl & Aide, 2011; Suganuma & Durigan, 2015). Consequently, on-the-ground, local monitoring assessments are still essential to support decision-making in adaptive management and to thoroughly assess restoration outcomes (Wortley, Hero, & Howes, 2013). A key challenge is standardizing local monitoring assessments in the context of large-scale and multistakeholder restoration programs.

Standardized protocols are critical to ensure comparability of local monitoring efforts across regional and even global scales (Holl, & Cairns, 2002). Restoration projects vary widely in their goals, making it critical to clearly define both general goals and specific, measurable, time-limited objectives in order to select monitoring indicators that evaluate restoration success. Many ecological indicators are used to evaluate forest restoration (Orsi, Genelettia, & Newtonb, 2011; Wortley et al., 2013), and each of them can be measured using a variety of methods and sampling designs (Reyers et al., 2013; Ruiz-Jaen & Aide, 2005). Consequently, if monitoring protocols are not integrated from the outset, their results often are not comparable. This limits the ability to evaluate the overall success of large-scale restoration programs, to compare effectiveness of different restoration methods, and to establish reference values for specific ecosystem types.

A restoration monitoring protocol consists of a group of indicators selected for restoration assessment based on ecosystem and socioeconomic characteristics and project goals, and technical guidance for measuring such indicators (Block, Franklin, Ward, Ganey, & White, 2001). To be most useful, monitoring protocols should be designed to be used across sites employing different restoration methods after a range of degradation scenarios and at varying successional stages of recovery. Monitoring methods must be cost effective and repeatable by different people (Holl, & Cairns, 2002). Additionally, reference values should be collected from multiple sites or literature sources, given natural variation, and should be tailored to the ecosystem type and successional stage that is targeted for specific projects (Ehrenfeld, 2000).

Although forest restoration monitoring protocols have been developed for some regions and ecosystems (e.g., Elliott, Blaskesley, & Hardwick, 2013; Savage, Derr, Schumann, & Abrams, 2005), they usually focus on a narrow suite of ecological parameters and do not include management and socioeconomic indicators (Le, Smith, Herbohn, & Harrison, 2012; Wortley et al., 2013). In addition, there are few published studies reporting failure of projects and underlying reasons (González, Sher, Tabacchi, Masip, & Poulin, 2015; Le et al., 2012), so monitoring can identify problems and save money in future projects.

Here, we present the perspectives of the monitoring protocol developed by the Atlantic Forest Restoration Pact (Pacto) in Brazil, a national coalition with the goal of promoting the restoration of 15 million ha of the Atlantic Forest by 2050 (Calmon et al., 2011). The Pacto is a multistakeholder initiative formed by 267 institutions, including nongovernmental organizations (NGOs), private companies, governments, and research institutions, launched in 2009 to foster large-scale forest restoration in the biome (Brancalion, Viani, Calmon, Carrascosa, & Rodrigues, 2013). One main goal of the Pacto was to develop a common monitoring protocol to standardize monitoring efforts. We describe the protocol and the development process, as well as review the strengths and weaknesses. We think that the Pacto monitoring protocol may serve as a model for the development of similar protocols in other regions, which ultimately could be integrated to produce a pantropical protocol for use by restoration forest programs worldwide.

Protocol Development History

After the Pacto launch in 2009, the coalition prioritized developing a common monitoring protocol to (a) collect more data about the restoration projects registered and provide better accountability for Pacto supporters; (b) identify general barriers and common needs for Atlantic Forest restoration projects; (c) inform corrective actions in ongoing restoration projects and enhance success of future ones; and (d) standardize restoration monitoring, thereby reducing the work of member institutions, enabling comparison of results, and defining reference values. The aim was to establish a protocol applicable to all forest restoration projects and programs in the Atlantic Forest, regardless of their age, restoration technique, or region. The group was committed to developing a multifaceted monitoring protocol, given that restoration success depends not only on ecological but appropriate socioeconomic and management conditions.

A 2-day workshop was held in 2011 to prepare, discuss, and validate a first version of the protocol; 70 members from 53 Brazilian and 2 international institutions, including 27 NGOs, 13 governmental organizations, 8 private companies, and 7 research institutions participated. The protocol was reviewed by a working group based on discussions at the meeting and widely distributed in August 2011.

This version was field tested across different regions of the Atlantic Forest. A large dataset of selected ecological indicators, including data from over 1,000 ha of sites undergoing restoration and 1,315 monitoring plots, was gathered in a partnership between the University of São Paulo, private companies, and NGOs. The dataset was used to estimate monitoring labor requirement and costs, as well as to model protocol sampling effort. In addition, the full protocol was pilot tested on selected projects.

In March 2013, a second 2-day workshop focused on learning from the field-testing and discussing changes to improve the protocol. This workshop included participation of 27 government, private, NGO, and academic institutions from several Brazilian states, all of whom were directly involved in monitoring forest restoration. Products of the workshop were (a) a simpler and easier-to-apply version protocol and (b) a list of recommendations to facilitate widespread use of the protocol. Both products were developed because the earlier version was not widely adopted, presumably due to its complexity and low practicality for restoration managers given the resources and time required to implement it. Recommendations for improvement ranged from simplifying methods to reformulating protocol layout and communication tools with practitioners.

Protocol Overview

The most recent Pacto monitoring protocol was adopted in 2013 and it is available for download in Portuguese and English (http://www.pactomataatlantica.org.br/publicacoes). The protocol is hierarchically structured into principles (ecological, socioeconomic, and management), criteria, indicators, and metrics (Table 1), which is an adaptation from environmental certification protocols. Within each principle, there are "criteria" (e.g., forest structure, vegetation composition) each of which are assessed by groups of "indicators." "Metrics" are the methods for measuring or evaluating an indicator. A criterion may have several indicators, and there may be multiple metrics for evaluating a specific indicator (Table 1). Overall, the protocol has 19 criteria (Table 1), 41 indicators, and 74 metrics. Ecological criteria are evaluated for individual restoration projects, whereas socioeconomic and management criteria are evaluated for restoration programs (i.e., multiple restoration projects within a watershed or region implemented by a given institution or group).

Ecological Principle

The Ecological Principle presumes that forest restoration must reestablish ecological processes with native species and ensure the self-sustainability of restored ecosystems. The Ecological Principle was divided into two recovery phases because (a) most of the money spent on restoration projects in the Atlantic Forest, and arguably in most forest restoration initiatives, is focused on establishing a canopy cover, so it is important early on to evaluate success toward this endpoint and take corrective actions, if needed; (b) assessing other ecological indicators (e.g., biomass accumulation, shrub, and tree seedling regeneration) is more appropriate once an initial canopy cover is established. Although the protocol distinguishes two monitoring phases, simultaneous monitoring of metrics from both phases can be done any time during a restoration project, if desired.

Phase I is focused on the successful development of tree cover, and, based on experience, Pacto members agreed 70% is the minimum canopy cover level needed to reduce cover of invasive grasses and facilitate tree establishment. Phase I is composed of four criteria (vegetation structure, vegetation composition, edaphic, and degradation factors) with 11 indicators and 12 metrics. Canopy cover is the main indicator and the only one that must be assessed. In cases where the 70% canopy cover target has not yet been achieved, measuring a set of indicators, such as ground cover by invasive or hyperabundant herbaceous species, soil compaction, and incidence of herbivory by leaf-cutting ants, is recommended to identify which barriers most strongly limit recovery.

Once the 70% canopy cover is reached, monitoring moves to Phase II, which focuses on ecological trajectory. Phase II has two criteria, tree structure in different size classes, including recruits, and composition (Table 1). The protocol includes details on recommended sampling intensity, how to collect and verify each indicator, worksheet templates, and a glossary. The Pacto members decided to focus on vegetation attributes because most Atlantic Forest restoration projects are targeted at restoring forest cover, and plant regeneration can indicate ecological processes mediated by fauna, such as seed dispersal (Ribeiro et al., 2015).

Socioeconomic Principle

Success or failure of forest restoration projects depend also on a number of socioeconomic considerations such as stakeholder involvement, economic costs and benefits, and labor conditions. These considerations motivated the inclusion of a Socioeconomic Principle, which is organized as 7 criteria (Table 1), 15 indicators, and 29 metrics, aimed at capturing information related to the financial fluxes involved in the project, as well as effects on the workers and the local community. Data on restoration program costs, revenues, incentives, and sources of funding are useful to understand the economic viability of projects and to better illustrate economic benefits. These benefits can accrue to the landowners (e.g., income from products or services generated by the project), but also to the wider society (e.g., job creation and poverty reduction). Information on the working conditions is crucial to avoid the proliferation of projects with inappropriate workforce conditions (e.g., lack of labor security or health risks). Finally, indicators on the relationship between the project and the surrounding communities are central to assess whether a participatory approach is being followed, which is not only ethically appropriate but essential to the long-term project viability.

Data for the Socioeconomic Principle are collected using semi-structured interviews of stakeholders, participant observation, and document analysis. The general recommendation is to evaluate forest restoration programs every 3 years.

Management Principle

Prior to the protocol, many Pacto members observed a lack of planning and documentation of projects, which resulted in restoration failure and a lost opportunity to learn from past mistakes. Thus, the Management Principle was developed with a set of 6 criteria (Table 1), 9 indicators, and 26 metrics to document the existence of information and records regarding preimplementation planning, socioenvironmental diagnosis, selection and implementation of restoration techniques, as well as lists of regional and planted species, data and photographic records, mapping, periodical reports, and other information to assist in understanding possible causes of restoration success or failure. The application of the Management Principle can identify gaps in the various planning and implementation activities that are likely to lead to an unsuccessful restoration program and enable project leaders to communicate their successful experiences.

Management Principle data are collected in the same way as described for the Socioeconomic Principle. Additionally, the protocol suggests writing a brief project report summarizing the monitoring data and highlighting the most relevant positive and negative points related to management and socioeconomic impacts.

Protocol Strengths and Limitations

The Pacto monitoring protocol represents a potential starting point for developing tropical forest monitoring protocols for other regions. To that end, we review the strengths, weaknesses, and lessons learned from the process, recognizing that there will necessarily be improvements and refinements to tailor subsequent protocols to specific project goals and forest types. The protocol was developed for and pilot tested in Atlantic Forest restoration sites that include a range of ages, forest types, past land uses, restoration techniques, and implementing institutions, enhancing the likelihood that it will be useful in other tropical forest regions.

A strong point is that the protocol was collectively constructed by regional, national, and international collaborators and therefore, the protocol is not restricted to the vision and opinion of a single person, sector, or institution. Instead, many stakeholders involved with forest restoration, including policy makers, practitioners, managers, and scientific institutions provided input. Restoration is a multidisciplinary area with science and practice demands (DellaSala et al., 2003), and the inclusion of different points of view is important to ensure effective large-scale ecological and restoration monitoring (Lindenmayer & Likens, 2010). Moreover, inclusion of a range of stakeholders throughout the process is critical to ‘‘buy in,’’ so the protocol is actually used.

Another benefit is the development of a large suite of metrics, which offers practitioners a view of the whole forest restoration process and the possibility of selecting the appropriate indicators depending on their objectives and goals. If a primary goal is restoring biodiversity then indicators of species richness may be selected, whereas to evaluate carbon sequestration, basal area is a more appropriate metric. Most of the ecological metrics focus on vegetation structure, arguably the most common goal of forest restoration projects. Additional indicators and metrics would need to be developed for substantially different project goals, such as efforts targeted to restore individual species or certain guilds of fauna.

Although we consider the range of metrics as a strength, we recognize that guidance may be needed to help the user select specific indicators and metrics for their specific goals and objectives. Monitoring budgets are often limited so it is critical to carefully select the most efficient set of metrics to evaluate whether specific objectives are being achieved (Holl & Cairns, 2002). As an example, São Paulo State developed a protocol to evaluate restoration success in mandatory and public-funded restoration projects which requires only three

Table 1. Principles, Criteria, and Examples of Indicators for the Forest Restoration Monitoring Protocol Established by the Atlantic Forest Restoration Pact.

Principles		Criteria	Example of indicators
Ecological	Phase I (Canopy structure: $<70\%$ of canopy cover)	1—Forest structure	Canopy cover[a] and invasive herbaceous species cover.
		2—Tree and shrub species composition	Density and composition of invasive tree species.
		3—Edaphic	Soil chemical and physical properties and information on soil compaction and conservation.
		4—Degradation factors	Fire occurrences, domestic animals grazing within restoration sites and leaf-cutting ants attacks.
	Phase II (Ecological trajectory: $\geq 70\%$ of canopy cover)	1—Forest Structure	Density of small ($\geq$ 0.5 m-height; CBH $<$ 15 cm) and large (CBH $\geq$ 15 cm) woody plants and basal area of trees with CBH $\geq$ 15 cm.
		2—Species composition	Numbers of native and invasive woody species.
Socioeconomic		1—Work and/or income from the restoration areas	Generation of jobs and level of investment in the program.
		2—Revenues and financial incentives associated with restoration	Payment of environmental services (PES), tax incentives, commercialization of timber and non-timber products.
		3—Source of resources for restoration	Investigation of resources invested in the restoration project.
		4—Job opportunities, training and other services to local communities	Hiring of labor and income generation for local economy.
		5—Well-being of workers in forest restoration	Securing benefits to worker health and responsibility for ensuring compliance with the appropriate sanitary and environmental conditions.
		6—Ensure appropriate work safety conditions	Availability of personal protective equipment (PPE) for workers.
		7—Relationship of the program with the surrounding community	Participation of communities and local stakeholders. Environmental education actions.
Management		1—Planning and documenting program execution	Information and records of socioenvironmental diagnosis, regional, and planted (if this is the case) species lists, program implementation schedule and budget, mapping and photos of restoration sites.
		2—Partnership with the rural property owner concerning the execution of forest restoration activities[b]	Partnership agreement with the landowner.
		3—Technical ability of the restoration practitioners	Qualification of managers and the technical team.

(continued)

Table 1. Continued

Principles	Criteria	Example of indicators
	4—Restoration monitoring	Existence of a monitoring follow-up protocol used to evaluate restoration results.
	5—Communication	Flow of external and internal information between management, practitioners, and community.
	6—Technological and methodological innovations	Usage, discovery, or establishment of any successful technological or methodological innovations.

Note. All the indicators and details on how to collect their data are described in the Protocol (available at Pacto website). CBH: stem circumference at 1.3 m.
[a]Canopy cover is the mandatory indicator in this phase and the others are suggestions to investigate filters enabling forest community to reach a desirable forest cover.
[b]In cases where the owner is not directly responsible for program execution.

ecological indicators from the Pacto protocol: (a) native vegetation ground cover; (b) density of native plants spontaneously regenerating; and (c) number of spontaneously regenerating native plant species (Chaves, Durigan, Brancalion, & Aronson, 2015).

We recognize that the protocol lacks trigger points (e.g., specific target values to be achieved by a certain time) that if not reached require additional management actions. The only specific target value is 70% of canopy cover, which is the threshold to move from ecological monitoring Phase I to II. Trigger points are critical to the adaptive management cycle and to ensure that corrective actions are taken if restoration targets are not being achieved (Holl & Cairns, 2002). That said, trigger points will vary depending on project objectives and the forest type and, therefore, are problematic to specify in a general protocol. For example, based on their experience in Thailand, Elliott et al. (2013) recommend a target of 3,100 woody stems ha^{-1} for all tropical forest restoration projects, a target that is quite different from those of many forest restoration projects in Latin America. Likewise, the 70% forest cover threshold separating Phase I and II of the Ecological Principle would likely need to be modified if applied in a different region. Another strong point of the Pacto protocol is the possibility of frequent updating based on learning through its application by stakeholders. We contend that such a cycle of learning should be incorporated in any similar regional monitoring efforts to best adapt protocols to local ecosystems and user needs. For the Pacto protocol, this testing and learning was incorporated between the first and second workshops, and we anticipate further periodic workshops will be organized when more data and feedback become available from practitioner use.

Although there have been calls to include socioeconomic factors in restoration planning and assessment (DellaSala et al., 2003; Brancalion, Viani, Strassburg, & Rodrigues, 2012), to date evaluation of restoration success has focused on ecological attributes (Wortley et al., 2013). Thus, the inclusion of Socioeconomic and Management principles is noteworthy. We acknowledge that these principles are less well developed and tested than the Ecological Principle, given that there was more prior experience with and technical capacity on ecological criteria and metrics. We anticipate that over time, the socioeconomic and management metrics will be a focus of improvements to the protocol.

Perspectives

Efforts are underway to improve the implementation of the protocol in the Atlantic Forest, which also provide insight for applying a revised version in other regions. We prioritized the next issues to be addressed based on stakeholder inputs at the second workshop. First, it is necessary to provide training for restoration stakeholders on use of the protocol. Hence, training courses are being offered throughout the region, and an online tutorial video, that will be freely available and include detailed training modules, is being prepared in partnership with the Environmental Leadership and Training Initiative (elti.yale.edu).

Second, an online database is being developed to provide restoration practitioners with an easy-to-use, web-based GIS platform where monitoring data from individual projects can be loaded. To incentivize Pacto members to upload their data, there are plans to deliver an automatic feedback report, which will include comparisons of individual project values for the most commonly collected quantitative indicators (e.g., canopy cover, tree density, tree richness) with values for other similarly aged restoration projects in that region and vegetation type. In addition, the report will suggest general management actions when values are lower than expected for some of those indicators. This system is essential to generate regional reference variables for the most important ecological indicators, a step necessary for defining trigger points for corrective actions. Finally, members requested applications (apps) to facilitate data collection. The initial goal is to create an app to load ecological data collected in the field directly into smartphones and tablets, thus reducing field and office work.

We see extensive potential for the Pacto protocol to be used more widely both regionally and globally. Seventeen Brazilian States are within the Atlantic Forest, and their governments will need monitoring protocols to evaluate success of their ambitious restoration goals (Soares-Filho et al., 2014). Following on the São Paulo State example (Chaves el al., 2015), other states could take advantage of the previous multistakeholder approach and officially adopt a version of the Pacto protocol tailored to their needs. Although the Pacto monitoring protocol was designed for the Atlantic Forest, the participatory process through which it was developed may make it a starting point to develop related forest restoration monitoring protocols throughout the globe in order to face the coming challenge of large-scale forest restoration (Suding et al., 2015). Regardless, we are certain that the lessons learned through the experience of developing the protocol will be informative to others involved in a similar process.

Implications for Conservation

A forest restoration monitoring protocol with ecological, socioeconomic, and management indicators is available for monitoring Brazilian Atlantic Forest restoration projects, and can serve as a starting point for developing forest restoration monitoring protocols in other regions of the world. The regular use of the Atlantic Forest Restoration Pact monitoring protocol will provide a large amount of data for defining regional reference values for the most important indicators and for improving restoration efforts, and their benefits, including conservation. The integration among restoration stakeholders (scientists, policy-makers, practitioners, managers, environmental, and private bodies) is essential for developing and implementing an effective monitoring protocol.

Acknowledgments

We thank all the institutions that participated in the 2011 and 2013 workshops to discuss the Pacto monitoring protocol.

Declaration of Conflicting of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Ricardo A. G. Viani, Fabiano T. Farah, Ricardo R. Rodrigues, and Pedro H. S. Brancalion are supported by Grant #2013/50718-5, São Paulo Research Foundation (FAPESP).

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