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THE RESILIENT FUTURE FOREST LABORATORY GUIDEBOOK

John A. Stanturf

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John A. Stanturf

InNovaSilva, Vejle, Denmark; Estonian University of Life Sciences, Tartu, Estonia

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Ioana Maria Boar
Layout:
Ioana Maria Boar

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TABLE OF CONTENTS

List of Tables v

List of Figures v

Abbreviations vii

Terminology Used in this Guide viii

Chapter 1. Introduction 1

The Resilient Future Forest Laboratory Global Network 1

The Context: RFFL, Forest Landscape Restoration and the Role of IUFRO 2

Purpose, Target Audience, and Intended Use of the RFFL Documentation Guide 6

Organization of the Guide 7

Chapter 2. Useful Concepts 9

Landscapes 9

Stakeholders 10

Themes 11

Terminology 11

Adaptive Management 12

Demonstration, Research, and Monitoring (DRM) Plots 13

Questions for Chapter 2 14

Chapter 3. Getting Started 16

Examples of RFFL Projects 16

Describe the Project 19

Engage Stakeholders 19

State Objectives and Design Treatments 19

Select the RFFL Location(s) 20

Identify the Project Location and its Boundaries 20

Describe the Location(s) 21

Questions for Chapter 3 23

Chapter 4. Conceptualizing the RFFL Project **25**
Objectives, Themes, and Treatments 25
Underlying Experimental Design 29
Treatments by Themes 30
Managing Existing Stands for Wood/Non-Wood Products and Multiple Uses 30
Restoration of Degraded or Bare Sites 32
Conservation or Restoration for Biodiversity or Wildlife Habitat 35
Integrating Trees into Agriculture (Agroforestry) 37
Adapting to Changed Climate 40
Questions for Chapter 4 44

Chapter 5. RFFL Location **46**
Selecting a Location 46
Describing the RFFL Location 49
Concept Paper 50
Questions for Chapter 5 55

Chapter 6. Implementation **57**
Installing Plots 57
Split-Plots 61
Landscape Level RFFL Projects 62
Measurement Plots 63
Existing Stand Examples 65
Carolina Vegetation Survey 66
Growth Dynamics in Mozambique 67
Forest Inventory Plots 69
Questions for Chapter 6 70

Chapter 7. Biodiversity Sampling **72**
Biodiversity Sampling Priority Levels 73
Priority 1: Sampling of forest structures as habitats and indicators for biodiversity 74

Priority 1: Survey of vascular plant species and ground dwelling bryophytes 74
Priority 2: Arthropods at the ground (ground dwelling beetles and spiders) 75
Priority 2: Full sampling of bryophytes as potential indicators for microclimatic conditions 75
Priority 3: Birds – often used as biodiversity indicator 75
Questions for Chapter 7 76

Chapter 8. Measuring and Analysis **78**
Measuring/Monitoring 78
Biophysical Indicators (Measurements) 82
Soil Sampling 85
Financial and Socioeconomic Measurements 88
Analyzing Treatments 89
Questions for Chapter 8 90

Chapter 9. Preliminary Planning **92**
Conduct Pre-Project Monitoring as Needed 92
Install Any Infrastructure Needed to Facilitate Project Implementation 92
Prepare a Preliminary Budget 93
Train Personnel 95
Schedule Tasks 95
Long-term Management and Monitoring 98
Documentation 99
Plot Documentation 99
Labeling System 100
Photo-Points 101
Questions for Chapter 9 102

Chapter 10. Data Management **104**
Reporting 106
Project Plan/Proposal 108

Establishment and Monitoring Reports 108

Publications (including authorship) 109

Questions for Chapter 10 110

Appendices 111

1. Sample Field Sheet with Tree Map 111
2. Sample Budget Spreadsheet 112
3. Concept Template for the Paraguay RFFL Location 113
4. Useful Apps and Websites 122
5. Useful Manuals and Guidelines 126

References 130

List of Tables

Table 1. The range of treatments evaluated in an RFFL Project. 2

Table 2. Examples of innovative treatments. 28

Table 3. Potential innovative treatments in existing stands. 31

Table 4. Active restoration designs. 32

Table 5. Potential treatments for conserving or restoring biodiversity or wildlife habitat. 37

Table 6. Potential treatments for integrating trees into agriculture. 39

Table 7. Potential treatments for adapting to climate change. 40

Table 8. Strategies for species provenancing. 42

Table 9. A Concept Paper template with essential features of an RFFL Project plan. 51

Table 10. The four categories of monitoring activity. 80

Table 11. Vegetation measurements. 83

Table 12. Example of a (partial) project task timeline. 96

Table 13. Example of a remeasurement schedule for the overstory trees. 98

List of Figures

Figure 1. The supporting role of RFFL field locations within the FLR implementation process. 5

Figure 2. Stakeholder groups. 11

Figure 3. The adaptive management framework. 13

Figure 4. Site preparation, Bornholm Denmark. 16

Figure 5. The Sharkey Restoration Research and Demonstration Site. 17

Figure 6. An example of a multi-location, landscape project. 18

Figure 7. Two questions for framing objectives. 26

Figure 8. Common stock types. 34

Figure 9. Water collecting planting sites. 35

Figure 10. Livestock grazing. 48
Figure 11. Example landscape description from the Aktash Basin in Uzbekistan. 54
Figure 12. A four-treatment cluster. 58
Figure 13. Example of a treatment plot with 6 measurement plots and a buffer. 58
Figure 14. The basic Randomized Complete Blocks (RCB). 59
Figure 15. Potential design for BAU and mixed species. 60
Figure 16. A split-plot design. 61
Figure 17. Alley cropping design. 62
Figure 18. Steppingstone example from Sri Lanka. 63
Figure 19. Plot design for silvicultural treatments. 66
Figure 20. Design of a permanent growth plot in Mozambique. 68
Figure 21. Forest Inventory plot layout. 69
Figure 22. Biodiversity monitoring. 73
Figure 23. Soil profiles illustrate variability. 86
Figure 24. Layout of the soil sampling in a permanent, unmanipulated plot. 87
Figure 25. Micro-nursery. 92
Figure 26. Major cost categories in a project budget. 95
Figure 27. Drone image of a Danish forest. 99
Figure 28. Examples of permanent label. 101
Figure 29. Photo-point identification. 101
Figure 30. A generalized process for documenting, reporting, and communicating an RFFL Project. 107

ABBREVIATIONS

AM	Assisted Migration
ANOVA	Analysis Of Variance
APC	Author Processing Charge
BACI	Before–after, control–impact experimental design
BAU	Business-as-usual
DRM	Demonstration, Research, Monitoring
DRYFLOR	Dry Tropical Forest Floristic Network
ha	hectare
IRR	Internal Rate of Return
IUFRO	International Union of Forest Research Organizations
FLR	Forest Landscape Restoration
LEV	Land Equivalent Value
LiDAR	Light Detection and Ranging
MOU	Memorandum of Understanding
NGO	Non-Governmental Organization
NWFP	Non-Wood Forest Products
RCB	Randomized Complete Block
REDD+	Reducing Emissions From Deforestation and Forest Degradation In Developing Countries
RFFL	Resilient Future Forest Laboratory
ROI	Return On Investment
RP	Research Plot
SDG	Sustainable Development Goal
SFM	Sustainable Forest Management
SOC	Soil Organic Carbon
TDR	Time Domain Reflectometry
UN	United Nations

TERMINOLOGY USED IN THIS GUIDE

RFFL Project	RFFL Project is the general term for an activity within the global RFFL Network. A RFFL Project may consist of a single or multiple locations where DRM plots are located.
RFFL Location	RFFL Location is the area where DRM plots are located. The simplest RFFL Location would have several DRM plots that show, in side-by-side comparison, different management techniques (Do-Nothing, Business-As-Usual, and Innovative treatments). More complex RFFL Locations are possible, for example with more than one innovative treatment.
DRM Plot	A Demonstration, Research, and Monitoring (DRM) plot receives a specific treatment, applied at operational scale. In statistical terminology this is the experimental unit. Also called the treatment plot.
Measurement plot	Sometimes it is more practical to sub-sample particular variables in smaller plots than the entire DRM Plot, for example survival in a large, planted plot. These Measurement Plots (or subplots) are areas within a DRM Plot where subplot measurements are taken. Often these are named by the target of measurement, e.g., herbaceous plot.
Split plot	A Split Plot is an area within the larger DRM Plot where variations on the treatment may be compared. For example, within a planting treatment plot, Split Plots may consist of different stock types (bare root vs. container), or provenances (e.g., with different drought tolerances).
Research Plot	An existing forest/agriculture/ecological research plot (RP) at the time of starting an FLR process.

Block	A block is a group of DRM Plots (experimental units) that show some similarity/homogeneity between each other. Blocks can be side-by-side or in different locations. Random allocation of treatments to plots within blocks reduces experimental error. When a block contains plots with all of the treatments applied, it is the same as a replicate.
Sub-Block	A Block may need to be split into several Sub-Blocks when there is not enough space for a whole block at any of the areas available for an RFFL location. This is often the case in an already forested area, where the available experimental areas are those available after harvesting. The Sub-Blocks for each a Block should be as similar as possible.
Replicate	A replicate is the number of independent instances of a treatment that occur within an experiment, i.e., several experimental units receive the same treatment. For RFFL, we require a minimum of two replicates. When a block contains plots with all of the treatments applied, it is the same as a replicate.
Randomized Complete Block (RCB) design	This is the preferred RFFL experimental design with blocks of equal size, each of which contains all the treatments. Thus, in an RCB, a block contains a full replicate of treatments.

1

CHAPTER 1. Introduction

The UN Sustainable Development Goals and the Rio Conventions[1] on climate change, biodiversity and land degradation identified the need for new approaches to managing forested landscapes that were more resilient and better adapted to global environmental change. The Resilient Future Forests (RFFL) Network responds to this challenge with designed, landscape-level field trials that support implementation of new silvicultural techniques and restoration methods. With a globally distributed network of landscape-level field trials, the RFFL Network aims to generate the information needed to select a portfolio of species and management methods that provide economically desired, climate-adapted species and silvicultural methods that meet the needs of society.

The Resilient Future Forest Laboratory Global Network

The Resilient Future Forests Laboratory (RFFL) is a global network of long-term, operational-scale plots that demonstrate forests managed for resilience and adaptation to change. The RFFL Network covers large gradients of climatic and socio-economic condition. The aim of the RFFL Network is to show how to transform landscapes and land use to greater resilience under future conditions. The RFFL Network does this by engaging with the forestry and agriculture sectors, conservation community, land managers and investors, as well as government decision-makers. The RFFL Network is supported by the International Union of Forest Research Organizations (IUFRO) and is open to partners that agree to contribute to the overall objectives of establishing field trials that meet mutually accepted criteria, conducting inventories and monitoring activities, and sharing relevant data and results.

The RFFL approach is conceptually simple: Compare current (Do-Nothing and Business-As-Usual) with Innovative Methods in large, operationally established plots that have an underlying experimental design. The Do-Nothing "treatment" illustrates what passive management produces over the long-term (**Table 1**). Existing land-use and local conditions are the starting point, with the assumption that current management and/or conditions can be improved. Current conditions may be a degraded location (bare ground), abandoned pasture or agriculture (bare ground), an unsustainably managed existing forest, or an existing forest maladapted to future climate. Including a Do-Nothing treatment is a control; it may also be a Business-As-Usual treatment (**Table 1**).

[1]United Nations Framework Convention on Climate Change (UNFCCC), United Nations Convention on Biological Diversity (UNCBD), United Nations Convention to Combat Desertification (UNCCD)

Alternatives to Business-As-Usual (BAU) management must produce added value and rest on a solid scientific foundation. These two demands, demonstrated efficacy under operational conditions and rigorous experimental validation, are the foundation of the RFFL Network of demonstration plots, which are underlain by a research design that support long-term monitoring.

Table 1. The range of treatments evaluated in an RFFL Project.

Treatment	Description
Do-Nothing	Passive or Non-Management; could be the baseline condition as it changes over time. Also functions as the Control.
Business-As-Usual (BAU)	Current practice, presumably using the best available technology or most common tree species.
Innovative	New, improved practice or new genetic material that could be developed elsewhere but locally innovative; could be a silvicultural method; new plant material and/or species, provenances, hybrids, clones; or a new sensor.

The Context: RFFL, Forest Landscape Restoration and the Role of IUFRO

Humanity is facing triple threats from the loss and degradation of natural systems, declining biodiversity, and a warming and less predictable climate. In many regions of the world a rapidly degrading natural environment coupled with drastic declines in socio-economic conditions demands a more active role of forest science in designing future resilient landscapes by integrating trees for a wide range of goals and purposes. Fortunately, forest science has in its disciplinary DNA the ability to respond to challenges.

We can look back to a wealth of knowledge generated through research plots in all types of forest ecosystems around the globe. The objectives of those efforts have included understanding growth performance of tree species in their native habitat, species introduced to localities outside of their natural habitat, and improved management methods. Early field-based research using permanent monitoring and experimental plots dates back at least to the 19th Century with emphasis on provenance trials and monitoring of performance. Examples of such long-term research in Europe include trials of Douglas fir (*Pseudotsuga menziesii*) seed sources for use in British forests (Fletcher and Samuel, 2010), survival of Douglas fir provenances in Austria (Chakraborty *et al.*, 2019), or the studies on the influence of exposure and suitability for different tree species on marginal agriculture lands in North Wales (Kerr, 2014). Comprehensive research on the adaptability of Norway spruce (*Picea abies*) under changing environmental conditions in 13 European countries under the leadership of IUFRO that started in 1964 generated important insights useful for developing future forest management strategies (Liepe *et al.*, 2019). In North America, a wide range of field research trials were established for investigating provenance performance in relation to abiotic conditions, particularly climate. These were subsequently monitored over decades (Risk *et al.*, 2021; Park and Rodgers, 2023).

Starting in the early 20th Century, permanent sample plot systems were established in tropical high forests in Southeast Asia, West and Central Africa and Central and South America with the aim to monitor the impacts of timber logging on the regeneration and recovery of tree species of commercial value (Alder and Synnott, 1992; Picard *et al.*, 2010; Cho and Mesh, 2016).

Comprehensive ecological monitoring focusing on species diversity, growth, mortality, regeneration of woody vegetation, and various other ecological parameters has been ongoing since the early 1980s in different initiatives throughout the tropics. The international network established by the Smithsonian Center for Tropical Forest Science aims to improve the understanding of tropical forests. The network includes long-term research on large, 50-ha (hectare) permanent forest census plots on Barro Colorado Island, Panama; Pasoh Malaysia; Bukit Timah, Singapore; and Korup, Cameroon (Condit, 1998). Similar objectives of ecological monitoring are pursued on long-term permanent sample plots in dryland forests by the DRYFLOR Initiative (Latin American Seasonally Dry Tropical Forest Floristic Network[2]) that provides guidance for the assessment of woody vegetation.

In response to increasing concern for deforestation and forest degradation in the tropics, permanent sample plot systems were expanded to serve for research and demonstration of improved forest management practices, particularly addressing reduced impact

[2]The DryFlor Field Manual for Plot Establishment and Remeasurement: http://www.dryflor.info/files/Protocol_v1.2_English.pdf

logging, silviculture treatments, and restoration of degraded forest stands (Sist and Bertault, 1997; Priyadi *et al.*, 2006). Many of the earlier initiatives are today part of a pan-tropical network (i.e., Tropical Managed Forest Observatory) investigating the response of tropical forests to logging, in terms of biomass dynamics, timber volume recovery, and changes in species composition over time[3].

Large-scale operational plot systems for monitoring, demonstration, and learning are one way of making innovative solutions work for policy and on-the-ground management. Demonstrating various management options on the ground, including other land uses (not only forests), drive home the landscape implications of innovative forest management. Recent initiatives working towards this end include the Experimental Forest Management Project in Switzerland (Forrester *et al.*, 2019), or the EU-funded project "Superb – Upscaling Forest Restoration"[4]. While the former systematically exploits the wealth of past permanent plot measurements of Swiss forests to inform stand management regimes, the latter forward plans to link practical and scientific knowledge for the establishment of concrete restoration actions in 12 large-scale demonstration areas throughout Europe.

IUFRO scientists have developed the Resilient Future Forest Laboratory initiative (RFFL) to translate established scientific knowledge into the design of future forest landscapes. The goal is to focus past field research, experiments, and other scientific work toward landscapes that are resilient under climate change and at the same time able to provide desired good and services providing more benefits to nature and people[5]. The core elements of the RFFL are operationally established, large demonstration, research, and monitoring plots that compare Business-As-Usual (BAU) with Innovative Management Techniques.

The RFFL Network supports efforts to develop climate-adapted forestry and offers a significant opportunity for synergy with Forest Landscape Restoration (FLR) efforts (Spathelf *et al.*, 2018; Stanturf *et al.*, 2019). Therefore, the RFFL Network can be integral to FLR projects that support participatory decision making by all relevant stakeholders, demonstrating feasible options in managing forests and other natural resources in a specific local context, and ultimately contributing to progress by integrating innovation into conventional wisdom and current practices.

[3]Tropical Managed Forest Observatory, https://tmfo.org/
[4]Superb, https://forest-restoration.eu/
[5]RFFL Website 2023, https://www.iufro.org/science/special/spdc/netw/rffl/

The establishment of RFFL locations on the ground can be viewed as a tool within the broader FLR process that generates multiple benefits (**Figure 1**). The FLR context involves long-term processes of stakeholder engagement addressing broad land management issues across agriculture, forestry, water management and other sectors using land and vegetation resources. In getting started with an FLR initiative, existing research plots (RPs) can illustrate past and ongoing research on designing not only climate-resilient but also productive landscapes. In many countries forest and agricultural research organizations have existing field experiments that could serve as nuclei for shaping the direction of initial discussions with stakeholders on establishing an RFFL Project. These can be combined with innovative techniques into pilot projects for FLR, using various forest species mixtures, reduced impact harvesting systems, agroforestry with multiple layers of vegetation for agriculture production integrated with trees, soil conservation measures, and the like.

FLR Implementation supported by Resilient Future Forests Laboratories (RFFL)

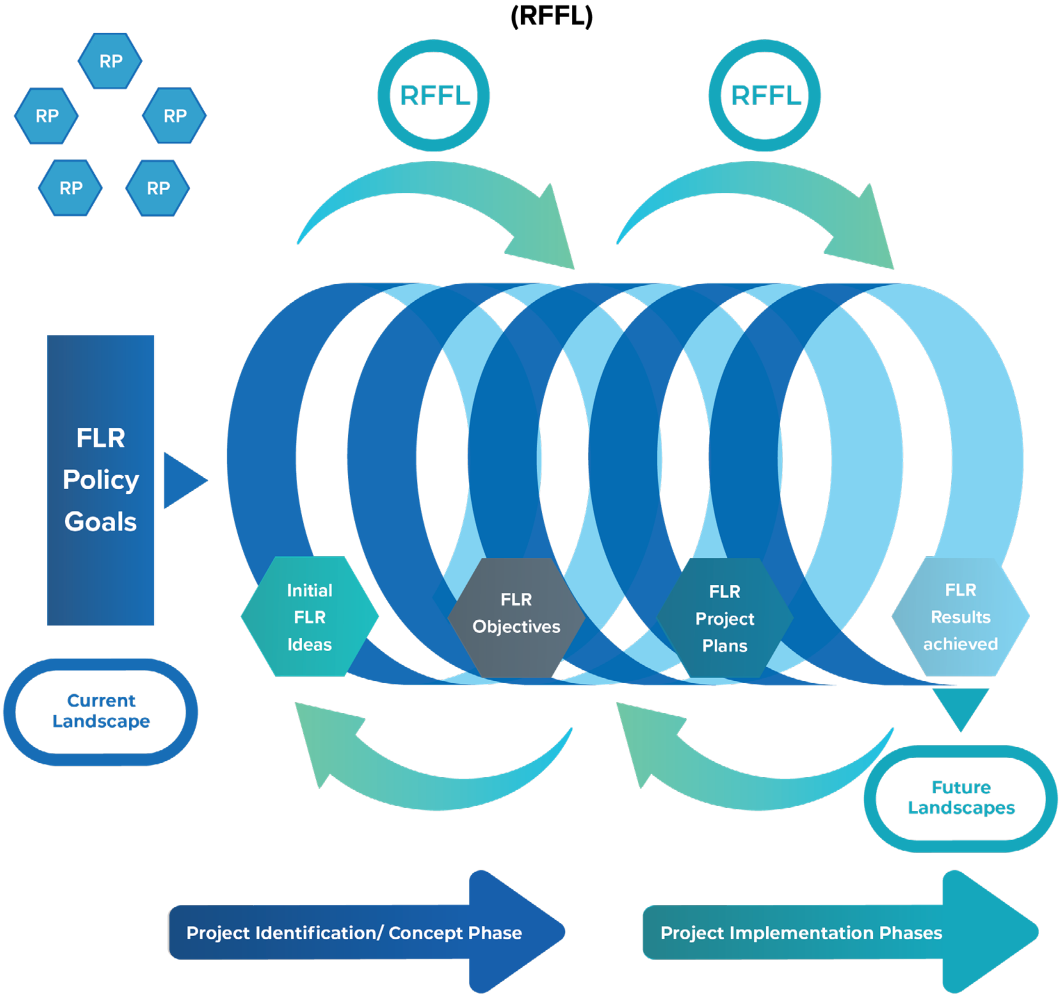


Figure 1. The supporting role of RFFL field locations within the FLR implementation process.
RP – existing forest/agriculture/ecological research plots at the time of starting an FLR process.
RFFL – field installations established based on FLR goals, specific objectives, or expanded existing RPs. RFFL is a long-term endeavor like the FLR process. (Amended from Stanturf *et al.*, 2017)

During the process of *conceptualizing* an FLR project, efforts by front-runners should be supported. These early adopters (Innes, 2009) are testing innovative approaches in land management that can be discussed as alternatives to established BAU management approaches.

Investing further into expanding such RFFL field sites and adding new components across the landscape will provide excellent opportunities for demonstration and capacity building on FLR for a wide range of stakeholders during the *implementation* phase of an FLR project.

IUFRO, as the global network for forest science cooperation, will support the emerging Resilient Future Forests Laboratory Global Network as this is in line with IUFRO's objectives of promoting science collaboration across the globe. More specifically, IUFRO will promote the sharing of best practices in long-term monitoring of forests based on past and ongoing projects; contribute to capacity building in proven RFFL procedures and census protocols; assist IUFRO members and partners around the globe in generating results of long-term field projects on RFFL by involving scientists from various regions and disciplines; and incorporating relevant RFFL results into its interaction with policy and practice at regional and global levels.

In conclusion, the RFFL initiative is intended to complement existing and ongoing local and national field research efforts that have been established to design forest management strategies leading to more resilient forests able to cope with the rapidly changing climatic and socio-economic conditions.

Purpose, Target Audience, and Intended Use of the RFFL Documentation Guide

This RFFL Guide provides guidance on establishing and maintaining an RFFL Project, collecting data, and sharing results. This Guide is intended primarily for anyone directly involved in proposing and establishing an RFFL Location. Scientists, practitioners, consultants/advisors, and landowners (individuals or organizations responsible for the land on which the RFFL is located) all will benefit from this Guide. Other users who could find this Guide useful include staff of agencies, donor organizations, civil society, and non-governmental organizations (NGOs) who are interested in the results of an RFFL Project. This Guide can also help to explain the project to visitors who are interested in the comparison of BAU with innovative treatments. Visitors might include school groups or clubs, farmer organizations, or others generally interested in forestry and conservation.

Organization of the Guide

The Guide describes three main activities: (1) Visualizing and Conceptualizing an RFFL Project [Chapters 1-4], (2) Detailed descriptions of the main activities needed to Implement an RFFL Project [Chapters 5-9], and (3) activities needed to Sustain an RFFL Project over the long-term [Chapter 10]. Various appendices follow, with examples of forms and further resources.

2

CHAPTER 2. Useful Concepts

The RFFL concept focuses on improving landscapes through adaptive management, incorporating stakeholder participation in design and implementation. In this chapter, these concepts are briefly described. The RFFL is based on Demonstration, Research, and Monitoring (DRM) plots that serve two purposes, demonstration and research (Gardiner *et al.*, 2008). They demonstrate to stakeholders, local communities, foresters, wildlife managers, and the public ways to manage forests sustainably, including costs and benefits that can be extrapolated to inform practice. Even operational scale, however, might not reflect all the costs and benefits of upscaled and fully implemented practices. Especially, innovative methods could easily be more expensive at the outset than BAU, until innovations are widely implemented, and economies of scale are realized. The research focus documents stand development, including response to climate change. Research can also estimate biomass production and carbon sequestration, structural development related to wildlife habitat, biodiversity, visual effects, and economic benefits.

Landscapes

Landscapes can be viewed from multiple perspectives based on their attributes, including what they mean and how their resources are used (Greider and Garkovich, 1994). Landscapes have biophysical features (e.g., mountains, streams, forests, and soils) and constructed features (e.g., buildings, roads, drainage ditches, and mines). Physically, landscapes are large areas, on the order of 1,000s to 10,000s of ha (Forman and Godron, 1986), comprised of a collection of heterogeneous, smaller units that are themselves more or less a homogeneous mosaic of microhabitats. Topographic features (i.e., slope, aspect, shape, and elevation) contribute to this heterogeneity.

In practice, landscape definition is a function of the phenomenon under consideration. For example, in geomorphology a landscape is defined by the diverse landforms it contains (Garner, 1974). Ecologically, a landscape is a mosaic of interacting ecosystems (Forman and Godron, 1986). Landscapes are not defined, however, only by what is found within a geographical space. Nearby external factors (e.g., transportation, migration) and distant factors (e.g., international agreements, globalization, climate warming) affect the landscape and outside actors and the choices they make can shape the landscape in ways that are not completely apparent (IPBES, 2018).

From a human perspective, a cultural landscape has associations and uses that yield a sense of place (Kibler *et al.*, 2018). The biophysical attributes are tied together to give a sense of a place connected to other places physically, culturally, or economically. A socioeconomic landscape encompasses the linkages of a place with other places through trade and governance. Different segments of the population residing in a landscape may perceive and value the landscape differently. For example, long-term residents may have a stronger emotional attachment than newcomers to some features of a landscape (Vorkinn and Riese, 2001; Stedman, 2003).

Stakeholders

In the most general sense, a stakeholder is an individual or group that has an interest in any decision or activity of an organization (ISO 26000:2010[6]). The person or organization that owns (or is responsible) for the land on which an RFFL plot is located is an important stakeholder, but many others are, by our definition, stakeholders (**Figure 2**). Stakeholders' perceptions and visions about the future landscape will drive the selection and implementation of new silvicultural methods, choice of trees species, and forest structures. Our own experience, and the experience of others, has shown that early communication and involvement of local communities can improve project success (Höhl *et al.*, 2020). RFFL Projects are unlikely to proceed in total isolation; to be successful, potential conflicts between personal, professional, and stakeholders' interests must be acknowledged, and such conflicts addressed through open communication, appropriate reporting and incentive systems and, where necessary, third party review.

Stakeholders are diverse, with varied interests and different levels of familiarity and understanding of forestry. Stakeholder identification and engagement is a key component of RFFL Projects, especially, but not limited to, societies with complicated land tenure and governance (Bryson, 2004; Reed *et al.*, 2009; Kusters *et al.*, 2018; Ceccon, 2021; Elias *et al.*; van Oosten *et al.*, 2021; Nousiainen and Mola-Yudego, 2022). Even in industrialized societies with well-defined land ownership, forest managers must involve the public in forest planning and management as well as environmental impact assessment of management interventions (Kangas, 1994; Buchy and Hoverman, 2000; Sheppard, 2005; Fischer, 2018; Lieffers *et al.*, 2020; Mansuy *et al.*, 2020; Hansen *et al.*, 2021).

[6] https://www.iso.org/iso-26000-social-responsibility.html

Figure 2. Stakeholders groups.
Stakeholders come from all walks of life, from both public and private sectors.
(Source: Broadhurst *et al.*, 2023)

Themes

Because of the diversity of local contexts and objectives, this Guide includes a section of local examples that illustrate the translation of landscape-level and/or national/Sustainable Development Goals (SDG) into concrete designs for restoration and Sustainable Forest Management (SFM) on the ground. These Visions are organized as Themes, including the following:

- Managing Existing Stands for Production and Multiple Uses
- Restoring Degraded or Bare Sites for Erosion Control or Biodiversity
- Conserving or Restoring Biodiversity or Wildlife Habitat
- Integrating Trees into Agriculture (Agroforestry)
- Adapting to Changed Climate

This list of possible Themes is not exhaustive, but it captures the main challenges that RFFL is designed to address. These Themes are described in greater detail, with some potential treatments, in Chapter 3.

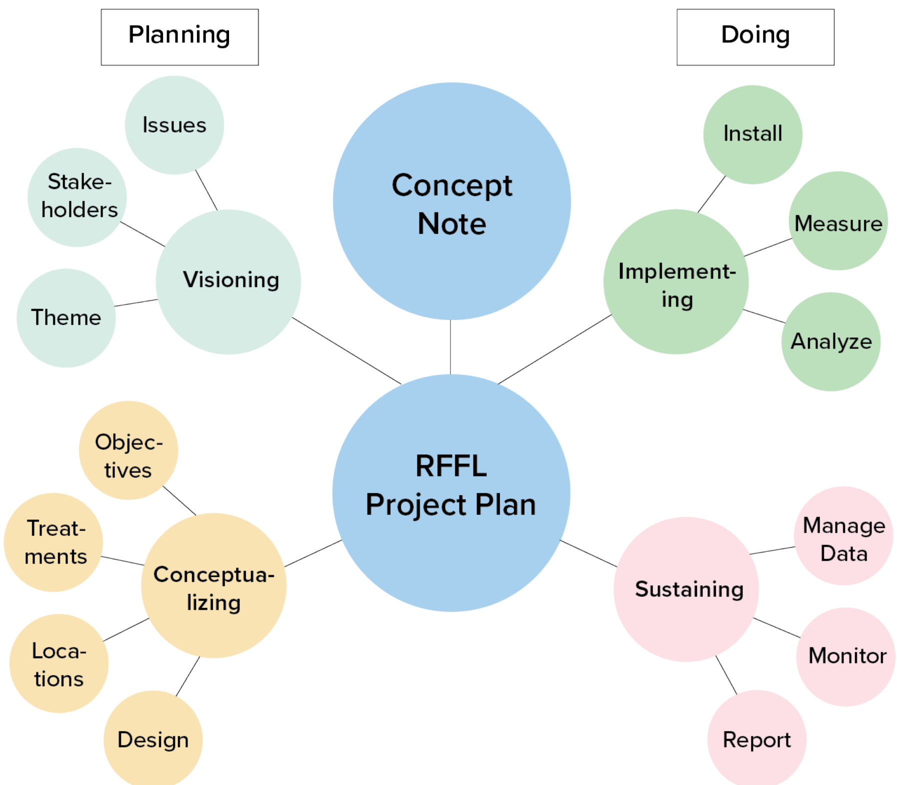
Terminology

A quick note on the terminology used in the Guide. An RFFL Project is specific to an organization, for example a landowner, company, or agency hosting one or more RFFL Locations. An RFFL Location is the place where treatments are applied to Demonstration, Research, and Monitoring (DRM) plots.

The simplest type of RFFL Location has at least two blocks of DRM plots that each has the full set of treatments (i.e., BAU, Innovative, and Do-Nothing plots). An RFFL Project may have multiple locations to account for spatial and/or temporal variation, or to demonstrate different treatments. An RFFL Location may have more than one BAU method, Innovative treatment, or both. In practice the requirement for large plots may constrain the number of treatments and replications at an RFFL location, since the available experimental area may be restricted. Plot design and variations are discussed in Chapter 6.

Adaptive Management

The aim of the RFFL Network is that results from RFFL Projects are embedded in an adaptive management framework (**Figure 3**), to guide sustainable forest management in a local context. Simply using techniques developed elsewhere without testing their effectiveness under local conditions can lead to failure. Adaptive management is a process for evaluating results and adjusting actions, or triggering intervention, on the basis of what has been learned (Walters and Holling, 1990; Williams, 2011). Learning occurs from feedback from monitoring. By comparing current practices (Do-Nothing, Business-As-Usual) to methods that are locally innovative or novel, an RFFL Project provides a basis for management choices, economic decisions, and the application of chosen regimes.



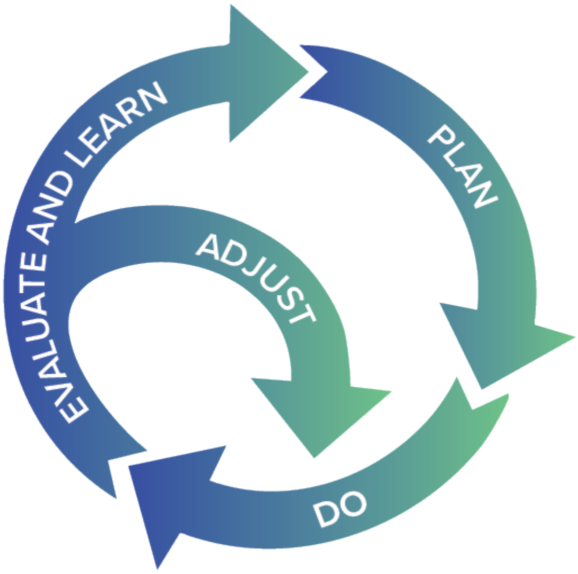


Figure 3. The adaptive management framework.
More detailed steps in the planning phase (upper figure) in the Framework for an RFFL Project (lower figure).

The Planning and Doing phases of adaptive management are treated in greater detail in Chapters 4-9 of this Guide. Building a Project Plan begins by Visioning the future landscape, identifying issues of concern with stakeholders. The resulting Theme of the RFFL Project guides the Conceptualizing steps of identifying Objectives, selecting Locations, devising Treatments and a Design. The Doing phase implements the RFFL Project Plan by installing the treatments, measuring and analyzing data. The long-term effort of an RFFL Project is Sustained by archiving and managing data, continued monitoring, and periodic reporting (Chapter 10).

Demonstration, Research, and Monitoring (DRM) Plots

The DRM plots are the key element of an RFFL Project. They are large, operationally established, at least 0.5 ha but preferably 1 ha or larger. Large plots generally increase the costs of installation and measurement over smaller plots, but they have four advantages. First, large plots enhance the visual impact of treatment effects. Second, they enable visitors to visualize how the treatments would look on the visitors' home landscapes. Third, large plots provide treatment effects more comparable to what is normally occurs in practice, incorporating micro-site variations, and reducing edge-effects. Fourth, large plots allow for layering of additional studies within the framework of the primary study (e.g., biodiversity, provenance, insects, pathogens, soils, micro-climate).

DRM Plots

DRM plots help to uncover conflicts and synergies with other sustainable development and biodiversity targets by:

- Addressing key local questions related to forest landscapes management
- Demonstrating innovative silvicultural techniques
- Testing new materials–provenances, species
- Utilizing new sensors and monitoring/inventory techniques to document benefits
- Communicating and openly sharing information locally, regionally, and globally to improve public understanding, engagement, ownership, and participatory decision making.

Questions for Chapter 2

- Have stakeholders (people and agencies) been identified, contacted, informed, (and if appropriate, invited to participate)?
- Have traditional owners been contacted about cultural sensitivities, location access, traditional ecological knowledge on the target species, and potential participation in the project?
- Are there any resource, social, cultural, ethical, or legal barriers to stakeholder engagement?
- Is there a clear statement outlining stakeholders' roles, responsibilities and expectations for the life of the RFFL Project?
- How will any different treatment objectives among stakeholders be addressed?
- Are there any procedures for addressing conflicts of interest?
- Does a project or research partnership need to be developed or formalized?

3

CHAPTER 3. Getting Started

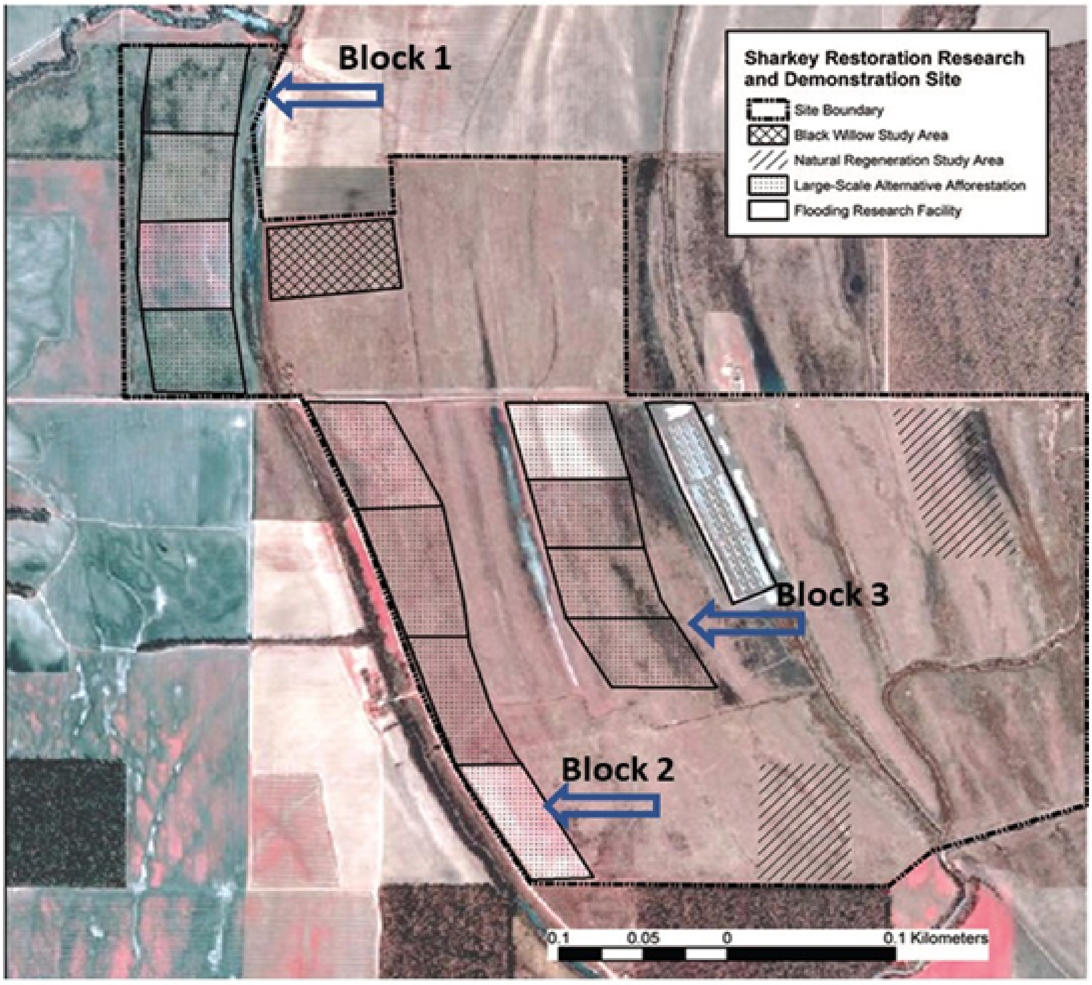
A flexible approach to developing an RFFL Project is project cycle management (European Commission, 2004; Stanturf *et al.*, 2017), as we have adapted it in **Figure 2.** *Visioning* produces the overall *Theme* of the RFFL Project by engaging with Stakeholders and identifying the Issues to be addressed. The generalized Theme of the RFFL Project is turned into concrete, measurable *Objectives* in the *Conceptualization* phase. This develops the *Treatments* and selects the *Locations*. An idealized *Design* structures the layout of the Treatments on the Location, which is comprised of the DRM Plots. *Implementing* and *Sustaining* are the doing phases, that is, the steps needed to turn the idealized project Design into reality, an Installed RFFL Location where Treatments are Measured, and the data produced are Analyzed. The long-term nature of RFFL Projects is secured by Sustaining activities that include Data Management, Monitoring, and Reporting. This approach is systematic, stepwise, but flexible. In practice, it likely is iterative, and some steps may proceed simultaneously. The central record, the *Project Plan*, starts out as a somewhat informal *Concept Paper* that becomes the formal design document. A template for the Concept Paper is included in Chapter 5. A Concept Paper summarizes important information about an RFFL Project and can be used to quickly inform stakeholders of the overall nature of the RFFL Project.

Examples of RFFL Projects

The RFFL Network can accommodate projects at different scales, for example stand- or landscape-level. An RFFL Project may be comprised of one or more RFFL Locations. The basic RFFL unit is a group of at least three DRM plots that compare Control and Business-As-Usual Treatment with an Innovative Technique. All are established operationally (**Figure 4**).

Figure 4. Site preparation, Bornholm Denmark.
The previous unstable spruce plantation was removed, and the site prepared (left) for planting several productive species mixtures of either conifers or broadleaves (right), ranging from native species to non-native species mixtures. The no-planting treatment relying on natural regeneration represents Do-Nothing; a low-stocked native broadleaves planting is a non-productive treatment. Both this and the Do-Nothing treatment represent what some stakeholders see as a "biodiversity forest."

An *RFFL Project* could compare, for example, different regeneration methods (e.g., natural regeneration, direct seeding, and planting), as seen in the Sharkey Restoration Research and Demonstration Site in Mississippi, USA (**Figure 5**). Here the treatment plots were established in former soybean fields. The natural recolonization plot (i.e., Do-Nothing) functioned as the control. Two BAU treatments, direct seeding and planting Nuttall oak, were compared to the Innovation of a cottonwood nurse crop interplanted with Nuttall oak.



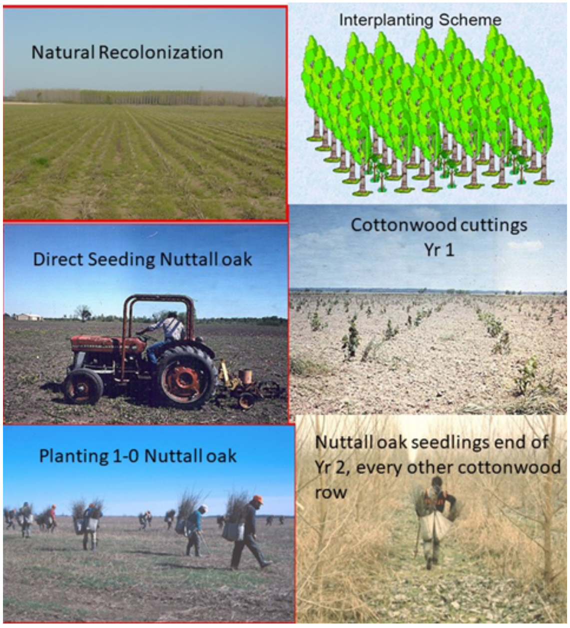


Figure 5. The Sharkey Restoration Research and Demonstration Site.
The aerial view of the stand-level project above shows four treatments and three blocks. Also in this view are other experimental installations at the Sharkey Site. The panels to the left show the four treatments (natural recolonization, direct seeding Nuttall oak, planting bareroot Nuttall oak, and interplanting Eastern cottonwood and Nuttall oak, a two-step process (Gardiner *et al.*, 2008; Stanturf *et al.*, 2009; Strickland *et al.*, 2017).

An *RFFL Project* can be comprised of multiple *RFFL Locations*, possibly to illustrate different stand-level treatments imposed on different portions of the landscape (e.g., even-aged vs. uneven-aged management, variable density thinning, corridor designs). An example from the Missouri Ozarks Ecosystem Project (**Figure 6**) illustrates a *multi-location RFFL Project*. This landscape is an area of publicly owned forests, with selected compartments (**Figure 6A**). Within a compartment (**Figure 6B**), locations were delineated by slope, aspect, and forest type (e.g., yellow = ridges, red = side slopes with south and west aspect, green = side slopes with north and east aspect, grey = side slopes north and east aspect with dry mesic limestone forest type). Within locations (**Figure 6C**), four treatments were assigned to stands: regeneration cut, intermediate cut, no management, old-growth set aside.

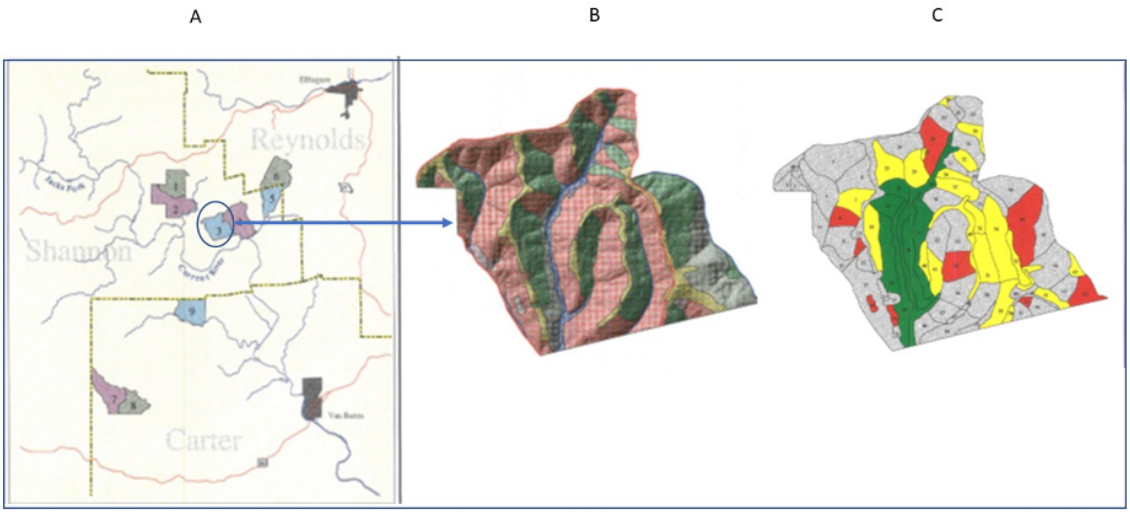


Figure 6. An example of a multi-location, landscape project.
(A) Compartments within a forest management unit based on public ownership; (B) locations (blocks) within compartments based on slope, aspect, and forest type; (C) stands within a location that receive particular silvicultural treatments (Examples from the Missouri Ozarks Ecosystem Project (Brookshire *et al.*, 1997).

Describe the Project

Early in the RFFL Project life a general description of the project helps with planning, communicating to potential partners, and securing funding. A description may begin as a general statement and become more specific and detailed as planning progresses. Each RFFL Project has a "Theme," a vision (Stanturf *et al.*, 2017) for addressing the key issues that the innovative treatments are designed to mitigate or improve. Defining the themes can develop from participatory planning with stakeholders or discussions between researchers and managers, or from formal assessments made by agencies or third parties. The Theme need not specify treatments or interventions at this point.

Engage Stakeholders

Identifying and engaging stakeholders occurs throughout the planning and design of an RFFL Project. Stakeholders with the power to approve or veto the project and location, such as landowners and agencies, are the most critical stakeholders to engage early in the planning process. As the project takes shape and specific locations and treatments are selected, a broader group of stakeholders will emerge.

State Objectives and Design Treatments

The process for setting objectives and deciding on treatments is described in greater detail in Chapter 4. Objectives should reflect a shared understanding of the initial environmental and social conditions and address the identified environmental issues expressed in the theme. Treatments should meet sustainability criteria of ecologically appropriate, economically viable, and socially acceptable. An RFFL Project should include a Business-As-Usual (BAU) or current management intervention, compared to Innovative treatments (i.e., treatments are innovative or novel in the local context) as well as a control (Do-Nothing).

Stakeholder Engagement

Seven useful principles for stakeholder involvement come from business management*:

1. Acknowledge and actively monitor the concerns of all legitimate stakeholders, and take their interests appropriately into account in decision-making and operations
2. Listen to and openly communicate with stakeholders about their respective concerns and contributions, and about the risks that they assume because of their involvement with the project
3. Adopt processes and modes of behavior that are sensitive to the concerns and capabilities of each stakeholder constituency
4. Fairly distribute the benefits and burdens of project activity among stakeholders, considering their respective risks and vulnerabilities
5. Work cooperatively with other entities, both public and private, to ensure that risks and harm arising from project activities are minimized and, where they cannot be avoided, appropriately compensated.
6. Avoid activities that might jeopardize human rights or give rise to risks that would be unacceptable to relevant stakeholders.

*Clarkson Principles of Stakeholder Management, source: https://www.stakeholdermap.com/principles-stakeholder-management.html

Select the RFFL Location(s)

Identify the Project Location and its Boundaries

Locating an RFFL Project can be complicated. The motivation for an RFFL Project may come from researchers or land managers who may approach a research organization or landowner. Either way, selecting an appropriate location should follow the general guidelines outlined below, particularly representativeness and accessibility. The location selection process likely will involve examining maps and stand descriptions as well as site visits.

Ownership of a potential RFFL Location is an important consideration for the long-term integrity of the project. Most of the time, public ownership is more stable than private ownership, although not always. Even though a location may remain in public ownership, management staff can change, and new staff may be unaware of the need to maintain the location. Also, organizational objectives and activities might compromise location integrity if communication is not maintained with land management staff, whether in public agencies or private organizations.

The size of an area needed for an RFFL Location depends on the number of treatments and replications. A "minimum-sized" project might have three treatments and 2 replications, resulting in 6 DRM plots. An individual DRM plot will have one treatment over the whole area (at least 0.5 ha, preferably 1 ha or larger). With buffers and access, this location could require 7 or more ha. A more realistic size would be upwards of 50 ha to allow for more treatments and more replications; even larger plots (> 1ha) could be desirable.

One (or usually more) measurement plots will be contained within a DRM plot. The variable being measured determines the size of the measurement plot (e.g., smaller measurement plots are used for seedling survival but larger ones for DBH of large trees). To examine more questions of interest, it may be desirable to divide the treatment plot into split plots to evaluate additional treatments. For example, the whole treatment plot may be one species and the split plots may test different stock types (e.g., bareroot vs. container). Of course, each split plot will need to be measured separately. For example, in the Sharkey Location (**Figure 5**) the cottonwood/red oak plots divided into four split plots with different cottonwood clones.

Once a location (or several potential locations) has been agreed upon, it is time to engage with a broader group of stakeholders. While there may be an expectation that the land owning organization has the legal right to treat the location as it wishes, in reality there are more organizations, and individuals with an interest in how the land is treated. Some stakeholders are easily identified–other government agencies (e.g., agriculture, water, or mining ministries), local communities, environmental NGOs. Some stakeholders may not be readily apparent, especially low-status or marginal groups in society that could include women, youth, or landless farmers (Mansourian, 2016; Mansourian *et al.*, 2019; Dawson *et al.*, 2021). The local context is critical in determining who are the stakeholders.

Describe the Location(s)

A more detailed description of the Project Location is needed for implementation and documentation. This should include any restrictions on use such as deed restrictions, legal constraints, and permits required by government agencies. This can also include informal restrictions. We can provide two examples from our own experience. (1) In planning a large research project on National Forest land in Louisiana, USA, a site that was ideal in all respects was ruled out because of restrictions on ground disturbance; the site had been used by the military and potentially unexploded ordinance remained in the soil. (2) Informal restrictions may not render a site unacceptable but nevertheless, must be considered. In the Kyrgyz Republic, one of our RFFL Locations was annually harvested for forage by local agency staff to feed their own livestock. This posed a risk to the survival of planted seedlings. Collaborating with staff, we were able to mitigate this risk by clearly communicating the risk and marking planting spots to be avoided. This allowed staff to continue reaping their forage benefit without harming the planted seedlings.

General Guidelines

- Select sites that are representative of the landscape in terms of bio-physical conditions, species composition (remnant or potential), and the targeted management techniques.
- If applicable, emphasize the landscape level and delineate different land uses.
- Select easily accessible areas; a demonstration area inaccessible to the intended audience is of little value. For example, some visitors to a site may be unprepared or unwilling to trek long distances across inhospitable terrain. This is particularly true of visitors who routinely do not work in the field, such as policymakers.
- While accessibility is important, the location should not be disproportionately more exposed to human influence simply because it is more accessible.
- Involve managers in the design and installation of experiments. This assures visitors that innovative treatments can be replicated on their own sites with existing equipment and materials.
- Choose treatments with the economic, ecological, and social potential to be replicated over large areas.
- Compare Innovative Treatments with Business-As-Usual Management
- Install treatments by operational methods to generate information on realistic costs and benefits.
- Locate treatments near to one another or side-by-side for visual comparison on a common location.
- Geo-reference and permanently mark locations, with established and geo-referenced photo points.
- Develop a data management system at the outset to archive and protect data, set out terms of use by the research community, that is accessible to managers, with analysis and interpretation for adjusting management practices.
- Commit to long-term location maintenance and monitoring to realize the full value of the DRM plots.

Questions for Chapter 3

- What are the key questions or issues to be addressed?
- Have project objectives been defined?
- What are the treatments? Do they include innovations?
- Have the key selection criteria for a location been identified?
- Is there a need for a target/reference location?
- Have the attributes of the location been identified and documented?
- Are stakeholders engaged in designing the project?

4

CHAPTER 4. Conceptualizing the RFFL Project

The goal of RFFL is to address key local issues related to managing forest landscapes. Objectives are answers to the key questions raised by the issues, a realized vision of the desired future landscape. Themes are the RFFL way of bundling objectives into coherent strategies for selecting treatments. Objectives determine the Theme, whether it is production forest management (e.g., for CO_2-sequestration, timber or other wood or non-wood outputs), afforestation, erosion control, agroforestry, or conservation or restoration of natural areas for biodiversity or wildlife.

Beginning an RFFL Project can seem daunting, with so much required, including a large enough land area. Sometimes it makes sense to start small and slowly develop an RFFL Project. The reality is that often large projects began with a nucleus of smaller plots and expanded to become a larger installation. As mentioned in Chapter 1, an RFFL Location can be a pilot for a large Forest Landscape Restoration (FLR) effort. The RFFL approach facilitates progressively developing a large project, in that a Project can have multiple Locations, which can be established over several years. Indeed, a Project may be designed to develop over time, such that results from initial stages are expected to influence later treatments. While our goal is large RFFL Projects covering 100s of ha, it is not necessary that the entire Project is established at the outset.

Objectives, Themes, and Treatments

Deciding on objectives begins with a shared understanding of the initial environmental and social conditions. Existing land-use and biophysical conditions represent the starting point at each RFFL Location. From this common foundation, two general questions arise: Do we have the conditions we want; and do we want an existing condition (**Figure 7**)? Answering these questions should lead to a consensus determination of feasible objectives. There are four general types of objectives, meant to Achieve a desired condition or outcome, Avoid an undesirable outcome, Preserve a desirable existing condition, or Eliminate an undesirable condition. The point of RFFL is that the landscape needs restoration or that current management can be improved to be more sustainable or better adapted to future climate.

Deciding on treatments should proceed from a shared understanding of objectives among stakeholders and treatments should meet the sustainability criteria of ecologically appropriate, economically viable, and socially acceptable. Consideration should be given to long- and medium-term, primary and secondary objectives as well as the specific targets to be achieved in the shorter time horizon. This is indeed challenging, as multiple objectives can be remarkably diverse and require some compromise and balancing of the interests and priorities of stakeholders. In some instances, innovative treatments may face regulatory obstacles. For example, current legislation or regulations may preclude use of novel (non-native) species or genetic material. Notwithstanding legal obstacles, dispensation may be obtainable for scientific experiments like the RFFL and for innovations that could increase capacity to adapt to climate warming.

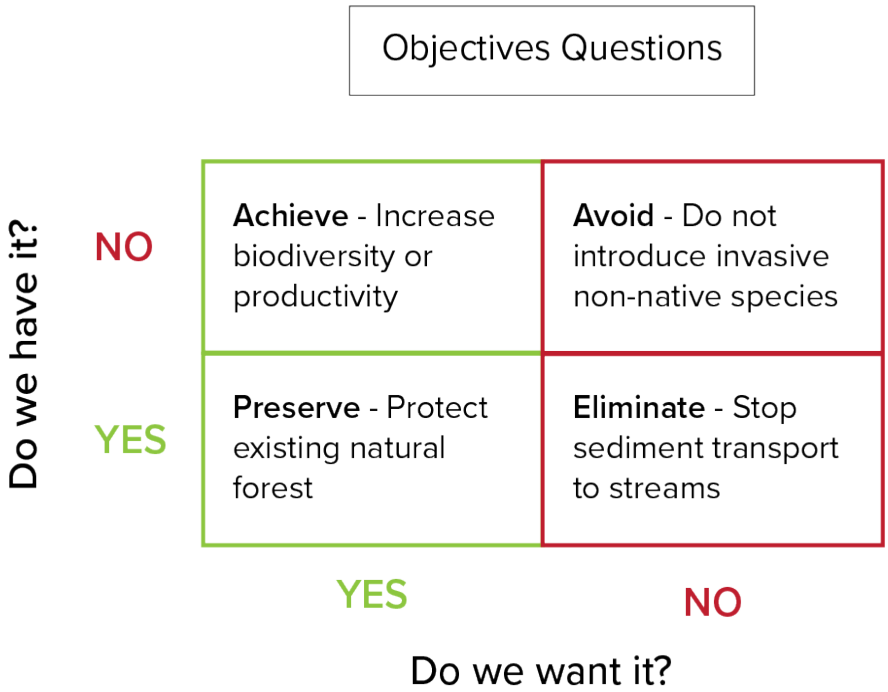


Figure 7. Two questions for framing objectives.

The RFFL approach requires comparing current practice to an innovation. The current practice, Business-As-Usual (BAU), covers a range of initial conditions and common management interventions. In some locations, BAU may be a degraded site that is grazed (or overgrazed), abandoned pasture or agriculture, or a spent mine site. At other locations, BAU may refer to current forest management that is unsustainable now or will be maladapted to future climate conditions.

The third treatment in our RFFL design is a control or do nothing and see how the system develops. On the one hand, a non-intervention control might be inappropriate in some cases, such as when the current condition is unacceptable to stakeholders. On the other hand, the non-intervention control could be to allow natural regeneration. Whether or not to include a non-intervention control should be decided in each case, keeping in mind the need for a true control to evaluate the effectiveness of a treatment and the experimental design underlying the DRM plots.

An RFFL Location may have multiple objectives and each objective may need one or more treatments appropriate to local conditions. Some examples of objectives and potential treatments are shown in **Table 2** at landscape and stand scales. The treatment possibilities shown are suggestions to demonstrate departures from current practice (BAU). Treatments are determined by management objectives that may require stakeholder consultation. The treatments shown in **Table 2** do not preclude the design of other treatments that are based on specific conditions of the RFFL Location and the experience of forest managers.

Table 2. Examples of innovative treatments.

Objective	Landscape Treatment	Stand Treatment
Reduce soil erosion	Achieve (establish) protective forests on ridgetops and slopes greater than 55%	Plant multispecies with local and climate adapted provenances
	Preserve existing forest cover through continuous cover silviculture	Use variable density thinning to change stand structure
	Eliminate row crop agriculture on sloping lands	Convert to agroforestry
	Avoid clear-felling	Use (institute) uneven-age management
Increase biodiversity	Achieve (establish) multispecies stands	Plant multiple climate adapted provenances and translocated species
	Preserve corridors between protected areas	Protect and enlarge remnant stands by natural regeneration
	Avoid harmful exotic plantations in buffer areas around protected areas	Plant multispecies stands with local and climate adapted provenances
	Eliminate harmful plantations of exotic species	Convert exotic plantations to native species by creating gaps and underplanting broadleaves
Improve water quality and/or quantity	Install and/or maintain riparian buffers	Plant multispecies buffer strips with local and climate adapted provenances
	Avoid/remove water consumptive species plantings in headwaters	Reduce overstory density in stands in headwaters

Objective	Landscape Treatment	Stand Treatment
Improve productivity	Concentrate management on responsive sites, increase stocking or reduce rotation age	Quickly regenerate stands after harvesting or disturbance by planting site-adapted, genetically improved material
Increase climate adaptivity	Re-introduce prescribed fire according to future climate	Plant species or provenances adapted to future climate
	Replace monospecific stands with multi-species, multi-layer stands	Reduce stocking levels at planting or by thinning to increase drought tolerance

Underlying Experimental Design

The RFFL Project serves both demonstration and research purposes. For research purposes, we prefer the underlying experiment to be a Randomized Complete Block (RCB) experimental design, where all treatments are applied to units within a block. Blocking allows for spatial replication of treatments; thus, no treatment is assigned twice to the same block. Treatments are randomly assigned to plots. All manipulated locations (i.e., where vegetation is manipulated) should be treated within the same year so that year-to-year variation in growth drivers do not confound the replication, unless year-to-year variation is one of the treatment factors (e.g., planting in successive years to capture climate variability).

The RCB design assumes that the blocks are considered independent of one another. Blocking can be used to capture variability in the landscape. Plots are assigned to blocks by visual observation, based on their subjectively determined similarity (e.g., similar topography and vegetation density). For example, in the Sharkey location (**Figure 5**), the plots in Block III were wetter than the other two blocks.

Treatments are randomly assigned to plots within a block by first ordering the plots from each block using a random numbers table. Each plot within the randomly ordered list for a block is assigned a treatment number in its turn, again, using a random numbers table. Then, someone assigns a treatment to each treatment number, without having any prior knowledge of the previous randomization results. Thus, each treatment is randomly assigned to a plot within a block.

An RCB design is flexible and extra blocks can be added in subsequent years or at other locations. Also, possible destruction of a site, say from a wildfire, can be accounted for within a block design. As a practical matter, if plots are very large it may be convenient to install permanent measurement plots that are randomly or systematically located within each treatment plot (experimental unit). If the available experimental area is restricted in size, it may be impractical to locate all treatments in a block in contiguous plots. In this case, the plots within a block should be as similar as practical.

Treatments by Themes

Managing Existing Stands for Wood/ Non-Wood Products and Multiple Uses

These plots are designed to document Sustainable Forest Management (SFM) practices; SFM is understood as "the production of forest goods and services for the present and future generations" (MacDicken *et al.*, 2015). Production forests can be managed for multiple uses or functions, but often emphasize CO_2-sequestration, timber, or other wood or non-wood outputs. The scientific basis for forest management has been the discipline of silviculture, which is evolving from the traditional command and control paradigm (as codified in Matthews (1991) to a more nuanced view of managing forests for complexity (Messier *et al.*, 2013). This shift in perspective has not occurred everywhere, but the trend internationally is to favor greater diversity of species composition and complex stand structures.

The following treatment possibilities are only suggestions to demonstrate departures from current practice (BAU). Innovative treatments are determined in a local context, and management objectives could require stakeholder consultation. The treatments listed in **Table 3** are illustrative and do not exclude the design of other treatments that are based on local conditions and experience.

Table 3. Potential innovative treatments in existing stands.

Forest Condition	Potential Treatments
Degraded forest (lacking desired species)	Clear fell and plant novel species
	Enrichment planting
	Framework species method
	Assisted natural regeneration
	Blowdown: with or without salvage logging; retention harvest; plant novel species
	Agroforestry methods
	Partial overstory removal, underplanting
	Erosion control (re-seed native understory; mulching); with or without salvage logging; plant desired species
Degraded forest (lacking desired structure)	Partial overstory removal (retention thinning, gap creation)
	Clear fell with residuals; variable density thinning
Degraded forest (lacking natural fire regime)	Fuel reduction by mechanical or chemical means
	Re-introduce prescribed fire

Restoration of Degraded or Bare Sites

Severely degraded areas and bare ground likely will require some form of artificial regeneration, given the limited dispersal distance of many desirable species. Nevertheless, local stakeholders may prefer species with specific desirable attributes, such as fast growth, high quality timber, multi-purpose use, soil conservation, and provision of NWFPs. The choice of species should be made in consultation with stakeholders.

Planting is the most likely regeneration/ restoration method for bare sites. Depending upon site conditions and distance to seed sources, natural regeneration and planting may combined, but this is likely to be a rare occurrence. Direct seeding is a lower cost alternative to planting but often unsuccessful (Grossnickle and Ivetić, 2017) although techniques such as seedballs may be candidates for small-scale experimentation. To be successful, species must be adapted to current site conditions and robust enough to endure future changes in climate (e.g., increased drought and wildfire).

Selecting which species to plant, by what method, and in what density and pattern are decisions based on objectives and site conditions (Stanturf *et al.*, 2019). Possible decisions are illustrated in **Table 4**. High-quality stock, planted correctly at the proper time, maximizes survival. Good quality seedlings provide an opportunity to influence the genetics available for adapting to climate change. Nursery stock also can be selected for desirable traits, such as growth rates, tree form, fruit or nut production, fodder, utility for wildlife, and soil improvement potential (Sacande and Berrahmouni, 2016).

Table 4. Active restoration designs.
Active restoration designs, from simple to complex, based on number of species and cohorts and spacing (terminology from Stanturf *et al.*, 2014).

Number of species	Number of cohorts	Spacing	Variations	Options
Single	Single	Uniform	Bare ground	Planted into cover crops or with partial overstory retained
			Taungya	Trees interplanted with agricultural crops until canopy closure

Number of species	Number of cohorts	Spacing	Variations	Options
		Dispersed	Cluster planting	Later infilling by natural regeneration
			Applied nucleation	Later infilling by natural regeneration
Multiple	Single	Uniform	Temporary mixture	Inter-planting or nurse crop that is removed early
			Permanent, simple mixture	Single species rows or blocks
		Random	Permanent intimate mixture	High density plant-ing, Framework species
		Uniform	Permanent intimate mixture	Designed mixture
		Dispersed	Framework species planting	Complemented by natural regeneration
	Multiple	Dispersed	Permanent, intimate mixture	Cluster with multiple species and natural regeneration between clusters
			Permanent, intimate mixture	Nucleation and natural regeneration to fill-in open spaces
		Uniform or random	Underplanting	With or without partial overstory removal
		Random	Release advance regeneration	With or without partial overstory removal

A single species, planted in rows at a designated spacing between rows and plants within rows, results in a uniform planting that often is described as a plantation. Cluster planting and applied nucleation are dispersed alternatives to uniform planting and can be of single species or mixtures, in one or more cohorts (age groups). Nurse crops are another alternative to a uniform planting of a single species. A nurse crop could combine a fast and a slow growing species (for example, the Sharkey locations; **Figure 5**); the nurse species could be a shrub or a tree that is either removed or suppressed as the slower growing species becomes dominant. Whatever the planting design chosen (Stanturf *et al*., 2014), plant material can vary by stock type (container, bareroot, rooted cutting) and by genetics (local or seed sources or improved material) or from introduction of novel species or provenances (assisted migration). Availability of nursery material and cost often determine the stock type used (**Figure 8**).

Figure 8. Common stock types.
Top left to right, polybag, very common (DH), bareroot, typical for many conifers (TL), hard- and soft-sided containers (KD), Jiffy 7© pot with air pruned roots (EB).Container types or systems allowing air pruning are generally recommended to ensure symmetric and well-structured root systems. Bottom left to right, different sized seedlings for different objectives (TL), bareroot seedling that began in a container then outplanted for additional growth (TL), Populus unrooted pole (JS), Populus cuttings with maximum diameter 45 cm and at least one bud (JS). (Sources: Diane Haase (DH), Thomas Landis (TL), Kasten Dumroese (KD), Evgeniy Botmann (EB), John Stanturf (JS).

Site preparation may improve survival, establishment, and growth. Trenching, mounding, bedding, or subsoiling may be needed to improve physical soil conditions. Land forming by creating terraces on sloping land, water harvesting micro-catchments in semi-arid environments, and traditional methods such as zai pits that are dug in the soil during the dry season to catch water and collect compost are other possibilities (**Figure 9**). Site preparation may also reduce invasive species. New plantings may need protection from livestock (fencing or seedling protectors) and wildfire.

Figure 9. Water collecting planting sites. Pits dug with the excavated soil forming a berm to capture runoff water in semi-arid plantings. A zai pit would be shaped as a half-moon. (Source: IUFRO Archive)

Conservation or Restoration for Biodiversity or Wildlife Habitat

Management to conserve or restore biodiversity can be a primary or secondary objective. We see four approaches to this theme: (1) Restoring degraded stands within protected or conservation areas where biodiversity is the primary objective; (2) Converting production forests to more natural structure and/or composition; (3) Rewilding landscapes; and (4) Increasing biodiversity at the stand level, which often will be a secondary objective. Some potential treatments are shown in **Table 5**.

Restoring degraded stands within protected areas might be needed to counteract the effects of encroachment by farmers, loggers, or miners, or following natural disturbances such as extreme fires, cyclones, or mass movements (e.g., landslides). Many of the planting techniques described for restoring degraded stands (**Table 4**) can be used. Relatively undisturbed stands in protected areas can be useful as a counterfactual to restoration of degraded stands. Monitoring permanent plots in undisturbed stands will demonstrate growth over time, demonstrating changes in biodiversity and carbon storage under non disturbance conditions. Because they will be sensitive to wildfire and browsing, plots in undisturbed stands probably need some level of protection.

Another possible starting point is production forests that are to be converted to more natural composition and structure. Biodiversity can be increased by creating gaps in the overstory of a monospecific plantation, for example, and relying on natural regeneration, direct seeding, or planting in the gaps to increase species diversity. Of course, entirely removing the plantation overstory or partially removing by retention harvesting (Gustafsson *et al.*, 2012; Thom and Keeton, 2020) and planting a mixture of native or non-native species are quicker ways to change composition. Altering stand structure by transformation through continuous cover methods is a longer-term process that can also change composition toward more shade tolerant species (Nyland, 2003; Pommerening, 2006; Stanturf *et al.*, 2014).

Rewilding is a landscape-level technique to restore biodiversity through an interconnected network of reserves and re-introduction of apex carnivores (e.g., wolves) or large herbivores. This 3Cs approach (core, corridors, and carnivores) of trophic rewilding is an ecological restoration strategy that relies on increasing populations of extant, large fauna or species introductions to restore top-down trophic interactions and promote self-regulating biodiverse ecosystem (Soulé and Noss, 1998; Donlan, 2005; Corlett, 2016; Svenning *et al.*, 2016). Herbivores, rather than carnivores, are emphasized as the active restoration agent in Europe but spatial connectivity has been emphasized in both Europe and North America. Another form of rewilding involves the release of captive-bred animals to the wild, a form of assisted migration or species reintroduction (Novak *et al.*, 2021).

Biodiversity can be increased in stands under any intensity of management using simple tools such as retaining microhabitats in downed woody debris, standing snags, or old, low-value trees (so-called wolf trees). Multiple taxa that rely on microhabitats associated with old forests can be artificially enhance by wounding trees, creating nest cavities, and leaving high stumps after thinning (Vanha-Majamaa *et al.*, 2007). Belowground biodiversity is mostly an unexamined topic (Prescott and Grayston, 2023) except for inoculating seedlings with mycorrhizae before planting on non-forested sites or stockpiling topsoil in mined land reclamation (Macdonald *et al.*, 2015; Frouz, 2021).

Table 5. Potential treatments for conserving or restoring biodiversity or wildlife habitat.

Forest Condition	Potential Treatments
Bare ground	Afforest with desired species
Monoculture	Clearfell and regenerate (natural, plant, or sow), use nurse trees or sacrificial trees or shrubs
	Thin and leave to create deadwood
Secondary forest	Retention thinning or gap creation, underplant with desired species
	Transform structure by continuous cover methods
	Create artificial nest holes
	Assisted translocation of rare or threatened species
Rewilding	Fence and introduce large herbivores

Integrating Trees into Agriculture (Agroforestry)

Agroforestry, or the broader term of trees-on-farms, uses trees mixed with crops, livestock, or both on the same area of land (Zomer *et al.*, 2014; Bishaw *et al.*, 2022; Gassner and Dobie, 2022; Chirwa *et al.*, 2023). The mixtures may be intimate (the stricter definition of agroforestry) or dispersed (e.g., woodlots, riparian buffer, or one or a few trees next to a field or house). The benefits of these systems are many: increased habitat, biodiversity, corridors for animals, pollen and seeds, and especially food production and food security. Besides growing timber, fuelwood, fruit, nuts, and fodder for farmers to use or sell, agroforestry improves soil fertility and regulates water supply and quality. Agroforestry systems can be a simple combination of a single crop species with one tree species, or complex mixtures of several crop and tree species, even with livestock mixed in (**Table 6**). Agroforestry systems have been used not only to increase food production but also for landscape restoration (Erdmann, 2005; Djanibekov *et al.*, 2016; Hardy *et al.*, 2018; Bargués-Tobella *et al.*, 2020).

Agroforestry systems must be appropriately designed to provide benefits, including the right species in combination, suitable for local soil and climate conditions, and acceptable to local cultural practices and available resources. Agroforestry can deliver significant environmental benefits but usually, delivery of these benefits is up to the smallholder. Perhaps more so than any other theme, agroforestry themed projects must engage stakeholders. Typically, the smallholder who might adopt an innovative practice is at best a part-time farmer who relies on other income sources. The target audience, then, often has limited resources, avoids risky investment (including own time and labor), and looks for short-term return. Treatment design therefore should closely involve small-holders and prioritize beneficial social as well as environmental outcomes (Mercer, 2004; Ollinaho and Kröger, 2021; Gassner and Dobie, 2022).

Co-Designing Agroforestry Systems

Knowledge needed in co-designing treatments with farmers incudes:

- The needs, aspirations, and capacities of farmers and their families
- The profitability of different agroforestry products
- Local conditions that might affect the profitability or feasibility of such products
- Different agroforestry systems in which selected products can be grown
- Farmers experience with agroforestry techniques
- Tenure arrangements (vague or insecure tenure favors very short-term returns).

(Adapted from Gassner *et al.*, 2022b)

Table 6. Potential treatments for integrating trees into agriculture.
Diverse systems available that must be adapted to social and ecological conditions (Gassner *et al.*, 2022a)

Agroforestry Method	Potential Treatments
Silvopasture	Combine trees and livestock
Linear plantings	Wide-spaced, single or multiple rows of trees bordering agriculture fields
	Living fences and zero-grazing units
Multi-strata perennial crops	Cacao or coffee under timber or N-fixing tree species
	Crops under two tree species (fruit and timber)
	Cacao and banana under timber species
	Home garden (mixtures of cacao with fruit, timber, legume trees)
	Cacao or coffee under thinned native forest
Alley cropping	Trees and other crops (spacing between trees rows narrower than intercropping); often to establish monoculture timber planting (taungya)
Rainforestation	Successional, multi-strata system to restore native forest cover; multiple crop and tree species

Adapting to Changed Climate

Forests are critical to climate change mitigation and adaptation, particularly in the short-term. For RFFL Projects, a primary objective could be to sequester and store more carbon. Increasing productivity, planting longer-lived species, or lengthening the rotation/cutting cycle have been advocated but may also increase vulnerability to disturbances from fire, wind, or pests. Adaptation is critical to maintaining any gains from mitigation as well as to conserve carbon stocks. Potential treatments are shown in **Table 7**. Key approaches are increasing diversity in forests by creating mixtures, reducing water use and drought stress through density management, and restoring native fire regimes (Spittlehouse and Stewart, 2004; Stanturf *et al.*, 2015; Vilà-Cabrera *et al.*, 2018; Jandl *et al.*, 2019).

Table 7. Potential treatments for adapting to climate change.

Adaptation Strategies	Potential Treatments
Increase forest area	Afforest with mixtures of climate-adapted local or novel species
Increase climate-adapted species	Favor minor species that are better adapted to future climate in thinning and regeneration
	Regenerate by planting mixtures of climate-adapted local or novel species (assisted migration)
	Rehabilitate degraded stand composition by underplanting with climate-adapted local or novel species
Reduce vulnerability	Reduce stand density for drought adaptation
	Reduce stand density and use prescribed burning to avoid megafires
	Restore natural disturbance processes (e.g., fire, flooding)
	Increase connectivity between forested patches

Assisted migration (AM) is an adaptation strategy for overcoming the gap between a changing climate and an evolutionary response by forest trees. AM is the movement of species and populations to facilitate natural range expansion in response to climate change (Pedlar *et al.*, 2012; Williams and Dumroese, 2013; Dumroese *et al.*, 2015; Winder et al., 2020; Clark *et al.*, 2022). While AM may be used to avoid losses in forest growth and productivity, AM may also be used to prevent species extinctions and to sustain ecosystem services and biodiversity. Target migration distances are a way to differentiate among the three approaches: assisted population migration (moving species or provenances within their current range), assisted range expansion (moving from the current range to suitable areas adjacent to the current range), or assisted species migration (moving a species far outside its current range). Details on some of the genetic implications of AM are summarized in **Table 8**.

AM is fraught with uncertainty about future climate conditions and risks that include failure to successfully establish a sustainable population or adversely impacting the receiving ecosystem by genetic pollution, hybridization, impairment of ecological function and structure, or introduction of insects or pathogens (Williams and Dumroese, 2013; Stanturf *et al.*, 2024). Projections of future climate are uncertain at the temporal and spatial scales relevant to determining how, when, and where to implement AM and manage resulting forests. Initially, the important question is which species? Some guidance may come from bioclimatic models to delineate current and projected distributions. This must include genetic information for species of interest. When to implement AM is an iterative question; climatic and landscape conditions will change. For this reason, risk status also will change over time. When and where to move a species is important; maladaptation is a risk if a species is introduced too soon or to an improper receiving environment. An RFFL Project that includes translocating species or provenances to adapt to climate change might utilize existing guidance on provenance testing, such as (McLeod *et al.*, 2009). The DREAM project, implemented in North America, suggests a complete experimental approach (Royo *et al.*, 2023).

Table 8. Strategies for species provenancing.

Provenancing strategy	Brief description	Advantages	Disadvantages	Best to use	Source
Local	Collection of seeds vary in the focal site. Risk level depends on original population size.	No risk of maladaptation and outbreeding depression. Low failure rates.	Risk of genetic drift. Low production of new genotypes. Conditions driving local adaptation can change.	Where only local populations remain, and no substantial change of distribution is predicted.	(Broadhurst *et al.*, 2008; Sgrò *et al.*, 2011; Breed et al., 2013)
Site-adjusted	Use of a comprehensive landscape genomic approach to select the best mixture of genotypes for focal site.	Minimize outbreeding depression and at the same time increase genetic diversity and reduce the risk of inbreeding depression.	High costs associated with genomic analyses and the complexity of bioinformatic and statistical analyses.	Restore sites ranging between moderately disturbed and highly degraded.	(Carvalho *et al.*, 2021)
Regional admixture	Seeds are sourced from multiple populations within the same region as the focal site and mixed prior to use.	Increase the genetic diversity, while restricting seed origins to a regional scale will maintain regional adaptation.	Risk of outbreeding depression. Conditions driving local adaptation can change.	When risk of non-local provenances to disrupt natural patterns of within-species biodiversity exists and will affect ecological networks.	(Bucharova *et al.*, 2022)

Provenancing strategy	Brief description	Advantages	Disadvantages	Best to use	Source
Composite	Mimic natural gene flow patterns by use of seed mixture from populations at various distances to the focal site.	Encourages production of new genotypes, potentially facilitating rapid adaptation to novel conditions.	Using seed from distant sources may result in maladaptation to local conditions. Outbreeding depression risk.	Where no significant range shifts are predicted, and only small local populations remain.	(Breed *et al.*, 2013; Breed *et al.*, 2018; Broadhurst *et al.*, 2023)
Admixture	Collection of seeds from wide array of provenances, capturing a wide selection of genotypes from various environments with no spatial bias towards the focal site.	Build evolutionary resilience by introduction of more additive genetic variation.	Risk of introducing invasive genotypes. High risks of introducing maladapted seed. Substantial risk of outbreeding depression.	Where drastic changes are confidently predicted, growth data is lacking.	(Breed *et al.*, 2013)
Predictive	Use of genotypes that are determined to be adapted to projected conditions. Requires data on local adaptation of many populations. Requires climate projections for the target species and planting site.	Low risk of maladaptation, inbreeding depression, and outbreeding depression. Low risk of failure if seed source is matched well with predicted environments.	Substantial risk of failure if seed source is poorly matched with predicted environments. Lack of data on local adaptation for most species. Uncertainty of climate change predictions.	For species expressing local adaptation to environmental variables.	(Sgrò *et al.*, 2011; Breed *et al.*, 2013)

Provenancing strategy	Brief description	Advantages	Disadvantages	Best to use	Source
Climate-adjusted	Combine genetic diversity and adaptability, targeting projected climate change directions. Collection of seeds biased toward the direction of predicted climatic change, but not exclusive to it.	Enhance climate-resilience of planting material by mixing genotypes from a climatic gradient, including local genotypes as well.	Risk of outbreeding depression. Risk of disruption of local adaptation to non-climatic factors. Lack of future climate-matching populations.	Where data on inter-population genetic variation are available.	(Prober *et al.*, 2015)

(Source: updated from Ivetić and Devetaković, 2016 and Stanturf *et al.*, 2024).

Questions for Chapter 4

- What are the key questions?
- What Theme is your RFFL Project?
- Are innovative as well as BAU treatments part of the design?
- Which experimental layout will be used (e.g., randomized complete block design, split plot design, or something else)?
- Will blocking be needed to minimize local variability?
- How will the treatments be randomized?
- Which of the properties affected by the treatments will be measured?
- If assisted migration is a component, are there restrictions on use of novel species?
- How will costs to implement the project be tracked?

5

CHAPTER 5. RFFL Location

Selecting a location should involve stakeholders who might provide land for the project or have concerns about treatment outcomes. Fully describing the project can begin with a Concept Paper that evolves into a complete project description.

Selecting a Location

Selecting an RFFL Location begins by defining the landscape of interest; this could be a watershed, an administrative jurisdiction, or ownership type (e.g., private forest estate or public land). Locations should be representative of the conditions of the region in which innovative treatments eventually may be applied. While it might be easier to set up DRM Plots on a flat, uniform location, they will be of little value if most of the target locations are on slopes or rocky areas. Nevertheless, individual locations should be reasonably uniform in terms of aspect, slope, soil parent material, and soil type so that the treatment results reflect treatment differences rather than environmental differences. Blocking may be needed to account for variable conditions (e.g., different slope positions). Locations with existing forest cover should be as uniform as possible with respect to tree species and density, deadwood, etc., except when any of these form part of the experimental design. Take care to minimize partially hidden variability, e.g., old skid trails.

Often the landscape is a mosaic of different land uses, including farms. Attention to land use history may uncover evidence for hidden variability caused by past management or utilization such as changes in inundation regime caused by dams and other flow obstructions, invasive species, or hazardous fuel buildup from fire suppression. Current conditions, such as high ungulate populations that make it extremely difficult to naturally regenerate forests, must be considered when demonstrating how to build a diverse, climate-adapted forest.

Locating potential areas for RFFL Locations can be challenging and local knowledge can be extremely helpful in finding and selecting from potential areas. Forest managers and local stakeholders can have detailed knowledge and experience that could be invaluable; especially if this can be documented on topographic or soil maps, aerial photographs, or from management records.

Drones can be beneficial in reducing the amount of field effort required to assess the suitability of possible locations in terms of proximity to human disturbance, ephemeral drainage, and other factors that might otherwise result in inappropriate locations. A consumer drone carrying a basic video camera can be effective and they are relatively affordable and available; more advanced sensors (e.g., LiDAR or multispectral cameras) can provide even more information.

Locations should be large enough to accommodate all the treatments along with appropriate buffers. For landscape-level demonstrations, each treatment plot should be 8-10 ha to encompass a range of variability, thus locations should be >40 ha in area. For stand-level demonstrations, treatment plots should be a minimum of 0.5 ha to mimic operational methods and 1 ha is better. In woodlands or low-density stands, larger plots may be needed to ensure that mortality estimates are accurate (in the wet tropics, the guideline is >200 stems are needed for accurate estimates of mortality over time (SEOSAW Partnership, 2021).

Adequate access is an important consideration in selecting an RFFL Location. Certainly, locations should be accessible to fulfill the demonstration purpose of DRM plots, but accessibility is important as well for maintenance and protection operations and for regular monitoring. Inclement weather (rain or snow) access may be crucial if maintenance or monitoring activities need to take place during the season.

Drones and Remote Sensing

Drones (uncrewed aerial vehicles) are the remote sensing platform and with an RGB camera, LiDAR, or other sensors, they can inventory and monitor DRM plots. Drones expand information and documentation available relative to traditional and manual field methods but can also considerably reduce costs per ha. This allows increasing the size and/or number of plots or the frequency of measurement. Additionally, drones can provide information on the surrounding landscape. Drones can inventory initial DRM plot conditions and during stressful periods such as drought or frost, particularly for novel species.

Drones with LiDAR can describe growth variability at micro-scale. LiDAR is exceptionally precise, often measuring distances down to the cm resolution. Additionally, LiDAR can penetrate dense vegetation and capture ground elevation data beneath the canopy, measuring vertical structure that is essential for canopy height estimation, biomass assessment, and habitat analysis.

Land ownership and access rights may be clearly defined or somewhat fluid. Even in countries with legal land ownership systems (*de jure*), there may be informal or traditional rights (*de facto*) to access and use land. Landowners and informal land users need to be apprised of the DRM plots, what treatments they will receive, and the kind of access needed (such as by foot, horse or motorized vehicles, season and frequency, etc.) and have given informed consent for the plots to be established and accessed by visiting groups.

The long-term integrity of the DRM plots should be considered in location decisions. Even though land ownership may change, it may be possible to ensure continued access and use of the plots if it can be included in documents transferring ownership. Even plots on public land may be vulnerable to human disturbance, such as intensive grazing (**Figure 10**). As much as possible, steps should be taken to secure sufficient long-term institutional support for, and integrity of, the DRM plots. It is important to maintain good relations and communicate with landowners, agency staff, and important stakeholders for early warning of any activities (e.g., change of ownership, management activities, disturbances) that threaten integrity of the plots.

Figure 10. Livestock grazing
(Left) Horses grazing a walnut plantation in Kyrgyzstan, with negative effects on soil erosion and understory diversity. (Right) A silvopastoral system used in South America that was adapted to restoration plantings subject to livestock or wildlife browsing. (Source: John Stanturf)

Describing the Project Location

The RFFL Location should be documented once it has been selected. This requires describing in greater detail the location and its characteristics, including the existing conditions, history, and previous land use. The location can be documented on applications such as GoogleEarth or a mapping app (**Figure 11**). Driving instructions to the plots should be written, with a map, in a project file (Chapter 10).

Several factors that must be considered in designing and implementing an RFFL Project will determine plot sizes, layouts, and measurement protocols. Of paramount, practical concern always are, "Is the available land large enough to accommodate the project? Are the available finances sufficient (short-term) to establish the plots and (long-term) to continue monitoring the plots long enough to adequately answer important questions?"

Within the constraints posed by the answers to these questions, uncertainty is another influential factor. Because RFFL plots are meant to last and be useful for the long-term, new questions may arise for which the RFFL plots may provide answers. Since we have incomplete knowledge of potential future uses of the RFFL plots, they should be easy to maintain and monitor even if future funding is limited, so that there is continuity of measurement.

Future environmental conditions are uncertain due to climate change and other impacts, therefore the RFFL design should be robust enough to remain relevant. On the bright side, emerging innovation and technology such as Uncrewed Aerial Vehicles (UAV or drones) and LiDAR could make monitoring quicker, less expensive, and more precise (Sparrow *et al.*, 2020). Some examples of plot layouts and measuring schemes are provided in Chapter 6.

General Location Description

A location description should include the following biophysical information:

- Location: describe the site's location in terms of the country, state and district, and its latitude, longitude and elevation; indicate location on a map or a visualization such as Google Earth.
- Climatic conditions: general climatic data are available from WorldClim and other websites if local weather summaries are not available.
- Remnant vegetation: describe any natural vegetation on or near the site, specifying the dominant species present.
- Geology: identify the underlying bedrock or regolith type from geological maps or field observations
- Topography: note the landform (e.g., valley flat, hillcrest, hillslope), slope gradient, and aspect.
- Soil type: provide generalized soil associations or descriptions if detailed soil maps are not available.
- Management history: describe the history of the site and its past and current land-use.

Concept Paper

The idea for an RFFL Project can begin in many ways, from a casual conversation among colleagues, a proposal written in response to a Request For Proposals from a funding agency, or an idea submitted to an agency responsible for implementing a new program. Early ideas will evolve into better defined concepts and eventually into an implementation plan. Writing down these ideas, knowing they are subject the change, is the beginning of project planning. Describing the project location can be the beginning of planning and documenting the RFFL Project. A Concept Paper using the template such as the one in **Table 9** helps to organize thoughts, present critical issues to consider, and can evolve into a complete project plan. An early draft of a plan to restore the Atlantic Forest in Paraguay using the template is illustrated in Appendix 3.

Table 9. A Concept Paper template with essential features of an RFFL Project plan.

Directions: Fill in this template as best you can at this stage of development. The items listed in each section are just examples, to give you an idea of what we are looking for. We are looking for a comprehensive overview of your RFFL concept, not all the details. If you cannot complete a section now, do the best you can. The template can be refined and completed over time.	
PROJECT TITLE	The title should include some reference to the RFFL Location, like a place name.
LOCATION	Give the best geographic location that you can, preferably latitude and longitude, nearest town, etc.
SCALE	What is the size of the RFFL Location? How representative is the RFFL Location in the region and/or country?
GOVER-NANCE	Who owns or controls access to the land the RFFL will be located on? For example, • Public land (forest reserve, nature reserve or park, etc.) • Corporate owner • Private owner • Community managed land • Traditional tenure Who are the main stakeholders in the landscape? For example, • Communities • Government agencies • NGOs

VISION	State the problem or problems that are being addressed addressing one or two main issues, for example: • Resiliency of forests at risk from climate change requiring adaptation to future climate. • Overgrazing, illegal logging, and wildfire have deforested the watershed, increasing soil erosion and mass movements. • Deforestation and conversion to cattle grazing have reduced biodiversity and other ecosystem services. • Monocultures of non-native species have reduced biodiversity and other ecosystem services. • Invasive species have reduced biodiversity and other ecosystem services. • Wildfire suppression has altered natural fire regimes and increased frequency and intensity of large fires that endanger local communities and reducing biodiversity and other ecosystem services.
CONCEPT	State the objectives of the treatments to be demonstrated at the RFFL Location, for example, to: • Increase forest and agricultural productivity, climate benefits and biodiversity of degraded agricultural land. • Reduce soil erosion and mass movement. • Introduce or create value chains for marketable products and/or services. • Convert monoculture plantations of non-native species to native, mixed species stands. • Restore natural fire regime and reduce frequency and/or intensity of wildfires.
ACTIONS	Briefly describe the treatments to achieve the objectives, including: • Do nothing (this could be natural regeneration). • Business-as-Usual (BAU) treatment (for purpose of comparison with innovation). • Innovative treatment(s).

SUSTAIN-ING	Short-term and long-term monitoring schedule, including what will be monitored, by what measurement, at what interval, by whom, applying what type of technology, for example: • From year 1 to year 5, assess survival at end of growing season and measure seedling height, by student crews or local communities etc. • From year 6 to year 20, measure height and diameter of trees, by student crews. • From year 1 to year 20, measure biomass of herbaceous species in clip plots, by student crews. • From year 1 to year 20, monitor direct expenditures and volunteer time for maintaining the RFFL Location. • From year 1 to year 20, record sales of non-timber forest products, firewood, and medicinal plants including amount (volume/mass) and quality and related market value or incomes.
BENEFITS	Project local, regional, and national benefits from the RFFL Project including products and materials needed for a sustainable future, for example: • Sale of non-timber forest products, firewood, medicinal plants. • Controlled grazing after establishment and height growth above browse line. • Jobs created for seedling production, tree planting and maintenance of plantations. • The planted forests facilitated natural regeneration and enhanced tree species composition and diversity. • Improved soil fertility, and increased carbon sequestration due to increased tree cover. • Conversion of degraded forests to plantations can restore key tree species that dominated the original forest and other critical ecosystem services. • Contributes to the national landscape restoration agenda, restoration of ecosystem services, climate change mitigation/ adaptation efforts, as well as disaster risk reduction. • Meeting national restoration commitments under the Bonn Challenge, LAC 20x20, or AFRI100. • Meeting national biodiversity commitments. • Meeting national climate change mitigation commitments (NDC). • Management options, techniques, strategies and governance lessons for engaging local communities that were developed, may guide future landscape restoration projects/ initiatives.

A project description should explain the contemplated interventions and needed resources, including labor, equipment, and biotic material and sources. The plot sizes, layouts, and measurement protocols need to be consistent with each purpose. In all cases, the goal of a plot is to both demonstrate management objectives and activities as well as provide a basis for conducting research into the efficacy of forest management techniques and their effects on environmental factors. A project description is useful in negotiating with partners for in-kind donations, for example with forest agency staff to prepare planting sites and other establishment activities. In some cases, location establishment costs can be covered by agency budgets as part of their normal activity. In one RFFL Location on private land, the RFFL Project covered establishment costs that were over and above "normal" costs that were covered by the landowner. This included the higher costs for non-native seedlings.

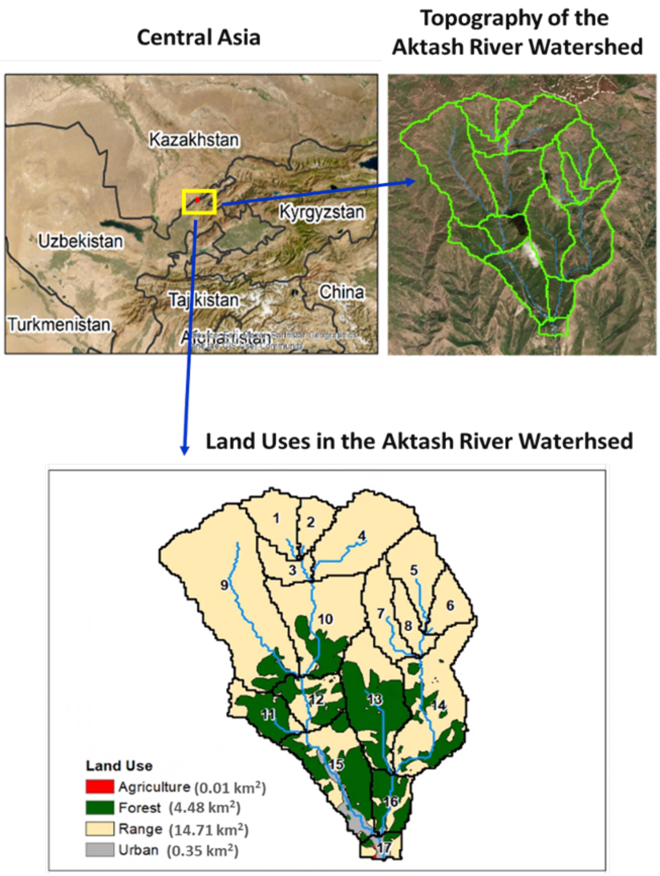


Figure 11. Example landscape description from the Aktash Basin in Uzbekistan.
The Aktash watershed is located in Uzbekistan, in the western Tien Shen mountain range, at 41°39'23.73"N, 69°45'51.82"E. Elevation is 110-1600 masl. Portions of the watershed were afforested in the late 19th, early 20th Century. Two RFFL Locations will be established in the watershed, on different aspects. Older afforestation (from the late 1800s) is the reference condition (Ouyang *et al.*, 2023).

Questions for Chapter 5

- Is the selected location easy to access?
- Are there any seasonal limitations on access?
- Is the area available large enough to accommodate proposed treatments?
- Are there significant legacies of past land use?
- Are there any ethical considerations related to accessing or using the location (e.g., cultural heritage values, threatened species presence)?
- How secure is tenure at the location?
- Are there any permits, permissions, or licenses required to access the location?
- Are there any human health and safety or ethical risks that need to be considered, and how will these be mitigated?
- Is the selected location at risk for any disturbances (e.g., fire, flood, clearing, encroachment, browsing/grazing)?
- Is any location preparation or maintenance work necessary, including infrastructure (e.g., weed management, herbivore-exclusion fencing)?
- How long will location maintenance be required?

6

CHAPTER 6. Implementation

The Block of DRM plots at a Location are underlain by an experimental approach. This requires properly defined treatments, randomization, and replication to determine cause and effect. If done properly and results differ among treatments, cause and effect can be inferred. Managers can use information from the DRM Plots to adjust their use of the treatments in the future, i.e., by adaptive management (**Figure 2**). Thus, the DRM Plots will become more valuable as time passes and deserve some thought as to long-term integrity.

DRM plots are designed to compare management methods. This could be different regeneration methods such as natural regeneration, direct seeding, and planting, as for example in **Figure 5**. Treatments are imposed operationally; therefore, treatment plots should be a minimum of 0.5 ha plus buffers. Large plots may cost more to install and measure, but they have several advantages over smaller plots. First, large plots enhance the visual impact of treatment effects. Second, large plots let visitors visualize the treatment in other landscapes (i.e., their own). Third, large plots allow for layering of additional studies within the framework of the primary study. In the Sharkey example (**Figure 5**), the interplanting treatment was a split-split plot with four cottonwood clones and disking between the cottonwood rows in year 1 or years 1 and 2, before the oaks were planted. Splitting the innovative treatment addressed two additional questions (which clones were best adapted to the site conditions and whether disking was needed in the second year) without adding more treatment plots. This was possible because the treatment plot was large (8 ha).

Installing Plots

The basic DRM unit is the Treatment Plot or Experimental Unit. This plot receives one of the treatments being demonstrated, applied operationally to the whole plot (and possibly to a buffer around the plot). Underlying the RFFL concept is the Randomized Complete Blocks (RCB) experimental design. A block of treatment plots is where each and all treatments are implemented (**Figure 12**).

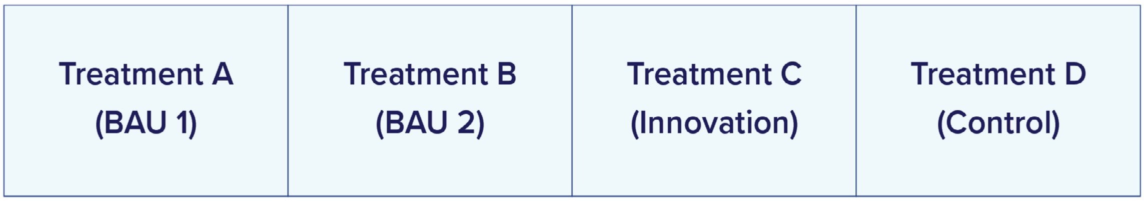


Figure 12. A four-treatment cluster. The cluster shown here has four treatments: BAU 1 and BAU 2, Innovation, and Control (which could be natural regeneration or do nothing).

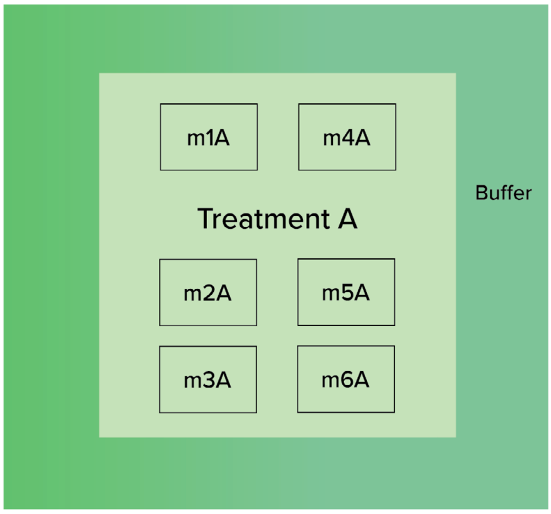


Figure 13. Example of a treatment plot with 6 measurement plots and a buffer. The numbering scheme here is treatments = A, B, C, D, and measurement plots are labeled as m1TreatmentA to m6TreatmentA.

Because the Treatment Plots are large (ideally, at least 1 ha), measuring everything within each Treatment Plot could consume a lot of time and resources. The solution is to measure a sample of Measurement Plots within each Treatment Plot (**Figure 13**). The data from several Measurement Plots can be averaged to give a result for the Treatment Plot. The number, size, and shape of measurement plots are a function of the variable of interest, the variability of environmental conditions within the treatment plot, and the size of the treatment plot. It is often desirable to include a buffer around each Treatment Plot to avoid cross contamination. In the example plot in **Figure 13**, Treatment A is surrounded by a buffer; within the Treatment plot are 6 Measurement Plots labeled m1A to m6A, systematically placed to cover the variability within the plot.

This example in **Figure 13** of a treatment plot with several embedded measurement plots is fairly easy to implement but other plot layouts are acceptable. To gain explanatory power and increase the probability of detecting a significant difference between treatments, sample size can be increased by adding additional treatment plots. Blocking also can be used to minimize the effects of site variability that is unrelated to treatment effects and to increase chances of detecting meaningful differences between treatments (Broadhurst *et al.*, 2023). Blocks within a location can be across a known environmental gradient or attribute (e.g., soil type). Treatments must be randomized within each block to distribute any remaining or unknown environmental variation (**Figure 14**). In some cases, the desired number of blocks may not fit within a single location, and several nearby locations may be used.

Blocks also can be distributed across multiple locations to extend the applicability of the experiment (Broadhurst *et al.*, 2023). Such 'across-location' replication increases the overall power of the experiment (i.e., the ability to detect statistically significant results). Replicating at different locations allows the results to be generalized to a wider range of conditions and to test how well an innovative treatment performs under different climates and other location-related factors. Additionally, having more replicates protects the viability of the demonstration and experiment against the risk of failure because of disturbances such as floods, fires, or windstorms. For example, our Sharkey experiment (**Figure 5**) suffered a tornado after 20 years that damaged one plot of direct seeded oaks.

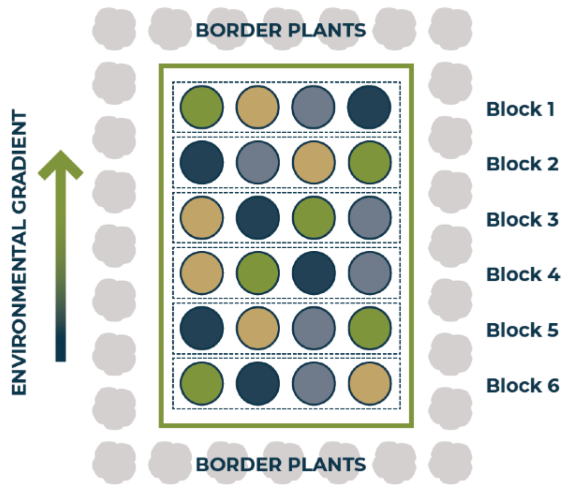


Figure 14. The basic Randomized Complete Blocks (RCB).
This is the preferred design for RFFL Projects. Each color represents a plot with one of the four treatments (e.g., four seed provenances or four species), with six replicate plots of each treatment. Randomized complete block is established at a location with an environmental gradient (e.g. soil water availability). Border plants in the grey area surrounding the experiment can provide a buffer around the edges. Th RCB design can accommodate various plot sizes. Each circle can represent one plant (e.g. a single-plant plot), a group of plants, or a native vegetation patch treated in a particular way. (Adapted from Broadhurst *et al.*, 2023)

Another example proposed from Estonia (**Figure 15**) compares different species in single-species plots (BAU) with some mixtures (Innovative). This includes a "Do-Nothing" treatment, basically natural regeneration. The distance between trees in the rows is varied, requiring larger plots. Plots vary in size to make the balance of species possible in larger group sizes. With a regular plot size of 0.5 ha, 9 treatments and 2 blocks, the design needed 10 ha plus buffers (including the larger 1 ha plots needed for the 0.125 ha group mix to evenly represent each species in squared groups).

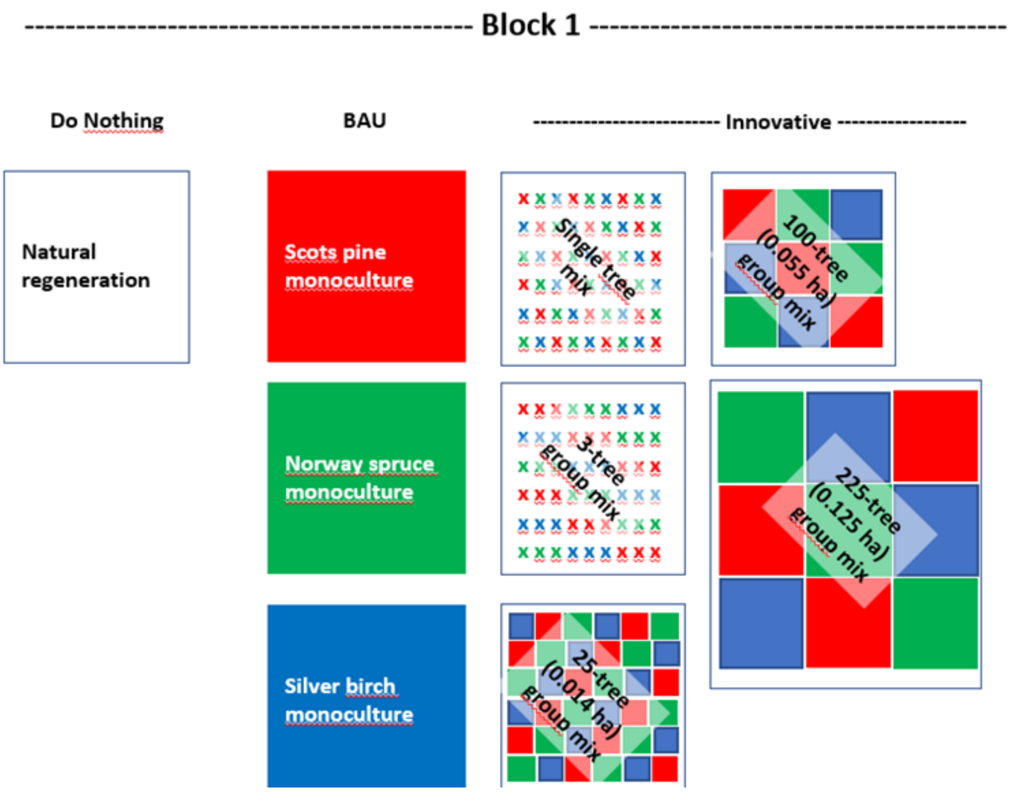


Figure 15. Potential design for BAU and mixed species.
Innovative treatments with three species (Norway spruce, silver birch, and Scots pine) in different mixture configurations (single seedlings of each species, three seedlings of each species in a row planting, three configurations of a block planting with 25, 100, or 225 seedlings of each species planted in a cell). Species are color-coded.

Split-Plots

The effect of two different factors can be examined in a small area by using a split-plot design of one factor embedded within the other (**Figure 16**). Effectively there are two experimental units of different sizes. A typical example of a split-plot design is an irrigation experiment where irrigation levels are applied to large areas (the main plot), and factors like varieties and fertilizers are assigned to smaller areas (split-plots) within irrigation treatments. In an RFFL example, the main treatments could be different site preparation methods and the split-plots of different species mixtures or provenances of a target species. A landscape example might have a retention harvest applied to a large area (main plot) with different patterns of retained trees (dispersed versus clumped), or different percentages of retained basal area in the split-plots.

For our RFFL purposes, two blocks with all treatments in each block is a good design. Even better would be more blocks. While we prefer the RCB experimental design, other designs could be acceptable as long as the demonstration purpose is met (i.e., operationally established, easily accessible, large plots) and the statistical design is appropriate to answer the critical questions.

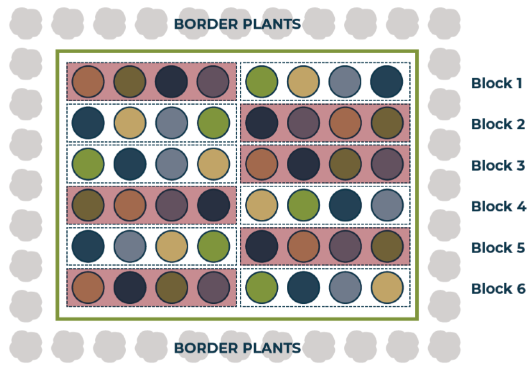


Figure 16. A split-plot design.
This split-plot has two factors (e.g., fencing and prescribed burning treatments). Each circle represents a 'sub-plot' randomly assigned to one of the four fencing treatments, given different colors (beige = open, green = low fence, light blue = wide mesh high fence, dark blue = fine mesh high fence). The red transparent rectangle represents the burning treatment, that has been randomly assigned to 'whole plots' (in this case half of the block), for comparison with the unburned control in white. (Adapted from Broadhurst *et al.*, 2023)

Some RFFL Projects require a plot design that differs from the preceding examples. In agroforestry, for example, alley cropping is a common management technique. This consists of widely spaced tree rows interspersed with "alleys" of forage or vegetable crops. One effect of interest is whether yields of the ag crop is affected by the trees (e.g., reduced by competition for water or light or increased by protection from wind or frost). In RFFL, we may be interested in testing new tree species, different spacing of the trees, or some other management activity as well as the effect on the vegetable crop. A typical plot design might be similar to that shown in **Figure 17** where measurement plots for the vegetables are placed at several distances from the trees. Not shown are the plots to measure the trees.

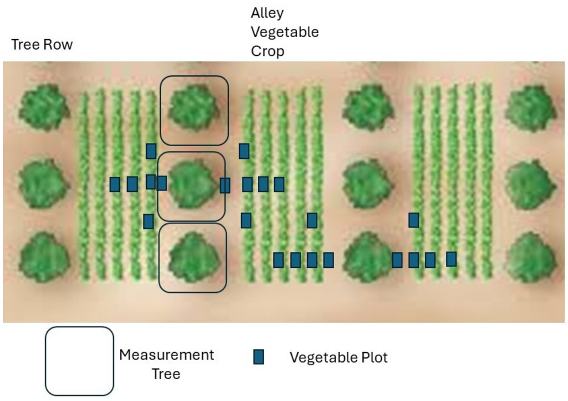


Figure 17. Alley cropping design.
Sampling design for an alley cropping agroforestry experiment. The trees are measured along the rows and the understory between trees is measured in 1 m^2 plots. The crops in the alleys are measured along transects in 1 m^2 plots; the first plot is 0.5 m from edge of the tree row, and then in plots in the next 3 vegetable rows. Additional vegetable plots are between tree influence.

Landscape Level RFFL Projects

A Landscape RFFL Project incorporates different stand-level treatments imposed at operational scale, for example in different management compartments within a forest management unit. While terminology used in different countries may vary, generally there is a hierarchy of units: a larger ownership or landscape unit is divided into compartments that are based on easily recognized geographic features such as roads or waterways. Stands within a compartment usually are delineated by landscape features such as slope and aspect, by vegetation features such as age, species composition, and tree density, or a combination of these features. Treatments that can be compared at the landscape scale could be, for example, even-aged vs. uneven-aged management, variable density thinning, or corridor designs such as the steppingstone (**Figure 18**).

A Landscape RFFL may correlate with an administrative unit or a physiographic feature such as a watershed. Within the landscape, the compartments may be used as blocks in an experimental design. Locations within a compartment may be delineated by relatively stable features such as slope and aspect, with individual stands within a location delineated by vegetation characteristics such as age or density of the overstory, for example the Missouri Ozarks Ecosystem Project shown in **Figure 6** (Brookshire *et al.*, 1997). The spatial arrangement of locations can be part of the treatment, as in the steppingstone approach connecting forest fragments in Sri Lanka (**Figure 18**).

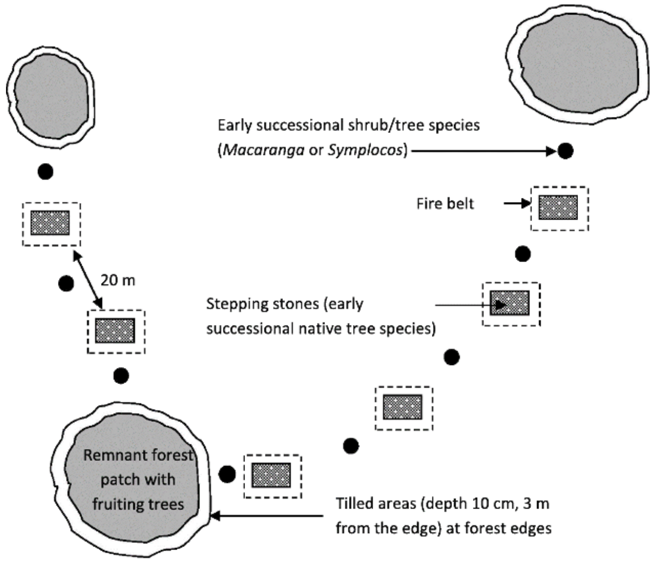


Figure 18. Steppingstone example from Sri Lanka.
A landscape-level experiment to connect remnant forest patches with planted "stepping stone" plots of early successional native trees. Early successional trees or shrubs can be directly seeded or naturally regenerated between the planted plots. Remnant patches are surrounded by tilled areas to encourage natural regeneration. (Source: Gunaratne *et al.*, 2014)

Measurement Plots

A quick review of terminology is in order here. The RFFL is based on DRM Plots where the main treatments are applied. These plots ideally are 1 ha or larger, but 0.5 ha is acceptable if the area of the RFFL Location is limited. In experimental design (statistical) terminology, these are the experimental units. In all RFFL Projects, vegetation will be measured and commonly all overstory trees in the treatment pot are measured. But other measured variables, such as clip plots for herbaceous plant biomass, soil samples, etc. cannot be measured on the entire plot either because it is too laborious or because it would disturb the plot too much. Therefore, subsampling the treatment plot is a useful strategy and these measurement plots should be representative of the whole treatment plot conditions and robust to small-scale variation. The number and size of measurement plots must balance available resources with scientific rigor, and the features that are being measured.

For most RFFL Projects, 3 or more measurement plots within each treatment plot should be sufficient, depending on size and initial condition of the treatment plot (bare ground or with forest cover). Local experience should be a good guide for the necessary measurement intensity. If a split plot design is used, where the treatment plot is subdivided and other treatments are applied to the split plots, then each split plot may also be sampled with a sufficient number of measurement plots. Because of the inherent species diversity and spatial variation in different biomes, the necessary plot size varies. For example, stand dynamics of relatively undisturbed tropical fo-Wrests require plots as large as 50 ha to encompass the high diversity of species. Temperate and boreal forests are often less diverse, such that 1 ha plots are sufficient to study dynamics (Pretzsch, 2009). In grasslands, smaller, 1 m^2 plots are sufficient but many more plots are required due to the high spatial variability (Sparrow *et al.*, 2020).

Initial conditions influence the types of measurement plots. Remember that RFFL is a long-term endeavor so that while measurement plots in young stands can be small, plot size must increase as trees grow and the stand develops. There are at least five situations where measurement plots would be needed.

1. Degraded or bare sites: Plots on these sites measure the effect of different active regeneration/ restoration treatments including site preparation techniques, planting designs, and species selections. The underlying research objective is to determine the cost-effective measures for restoring degraded sites. Possible planting designs are varied (**Table 4**) and measurement plots are needed in each group of planted seedlings in dispersed designs (e.g., cluster planting). In the simplest single cohort designs, measurement plots would need to capture microsite variability and can be placed systematically (for example, as shown in **Figure 13**). As the stands develop (e.g., reach canopy closure), measurements should be similar to those of existing stands. Other variables of interest include soil (e.g., pits or core samples) and competing vegetation (clip plots) that should be measured outside of the plots measuring effects on the target vegetation to avoid disturbance.
2. Manipulation of Existing Stands: There are many options for measuring the effect on vegetation of manipulations of existing stands, depending on how intensively the stand is manipulated and the spatial arrangement of the interventions (e.g., thinning or retention levels vs. clear-cut) and which vegetation layer is being measured. Measurement plots are usually comprised of nested sub-plots of different sizes to capture growth of different-sized plants (e.g., 1 m^2 plots for tree seedlings and herbaceous plants versus 0.1 ha plots for overstory trees). The overall measurement plot can be rectangular (**Figure 19** and **Figure 20**) or variations on circular (e.g., **Figure 21**). Vegetation sampling can be combined with other variables in biodiversity sampling (**Figure 22**, **Chapter 7**).
3. Growth Dynamics or Reference (unmanipulated) Stands: Plots placed in unmanipulated forested areas provide information on forest conditions as they change over time,

such as changes due to changing climate. In this case there are no "treatment plots" as there is no intervention. The size and number of measurement plots is dictated by species diversity and spatial variability. These measurement plots are generally large (as noted above, in tropical forests as large as 50 ha) and may utilize any of the plot layouts shown (**Figure 19** and **Figure 20**), in particular for biodiversity sampling (**Chapter 7**).

4. Natural Regeneration: Natural regeneration could be a treatment on its own (e.g., after a clearcut) or at the edge of a remnant stand as in the steppingstone example (**Figure 18**). A regeneration plot size of 4 m² should be large enough to accommodate at least one tree stem as the stand matures. The number of measurement plots needed is determined by the area of the treated plot. Recommendations for plot size in regeneration surveys vary from 4 m² (moist temperate) to 50 m² (wet tropics). As the stands develop (e.g., reach canopy closure), measurements should be similar to those of existing stands.
5. Agroforestry: The great variety of agroforestry techniques precludes any standard approach to measuring/monitoring. Generally, however, the objectives require that both the trees and the food/forage crop be measured, to determine whether proximity to the trees reduces or improves yield of nearby crops plants. Even if competition for light, water, and nutrients affects the crop plants, protection from wind and reduced evaporation may benefit the crop plants near the trees. Placement of the treatment plots relative to predominant wind direction during the growing season and aspect could be critical. Assuming rows of trees (single or multiple tree rows), measurement plots could be rectangular, incorporating several trees, and in a transect projecting into the crop alley far enough that plants in the measurement plots at end farthest from the trees are essentially growing in the open (**Figure 17**).

Existing Stand Examples

To illustrate possible measurement plots in existing stands, here are three documented methods in use. The Carolina Vegetation Survey (**Figure 19**) and the US Forest Service Forest Inventory (**Figure 21**) are used extensively in temperate forests. The example for dry tropical forests (Miombo) comes from Mozambique (**Figure 20**).

Carolina Vegetation Survey

Measurement plots in existing stands (manipulated or not) might use this modification (**Figure 19**) of the Carolina Vegetation Survey (Peet et al., 1998; Lee et al., 2008). The 50 m X 20 m plot consists of a 5 by 2 array of 10 main modules (each 10 m x 10 m), for a total of 1,000 m^2 (0.1 hectare). There is an interior array of four intensive modules (in a 2×2 array). Within the intensive modules there are 1 m^2 intensive corner sub-plots (Figure 19). If larger plots are desired, the 50 m X 20 m plot can be enlarged by adding another array (e.g., 50 x 40 m plot).

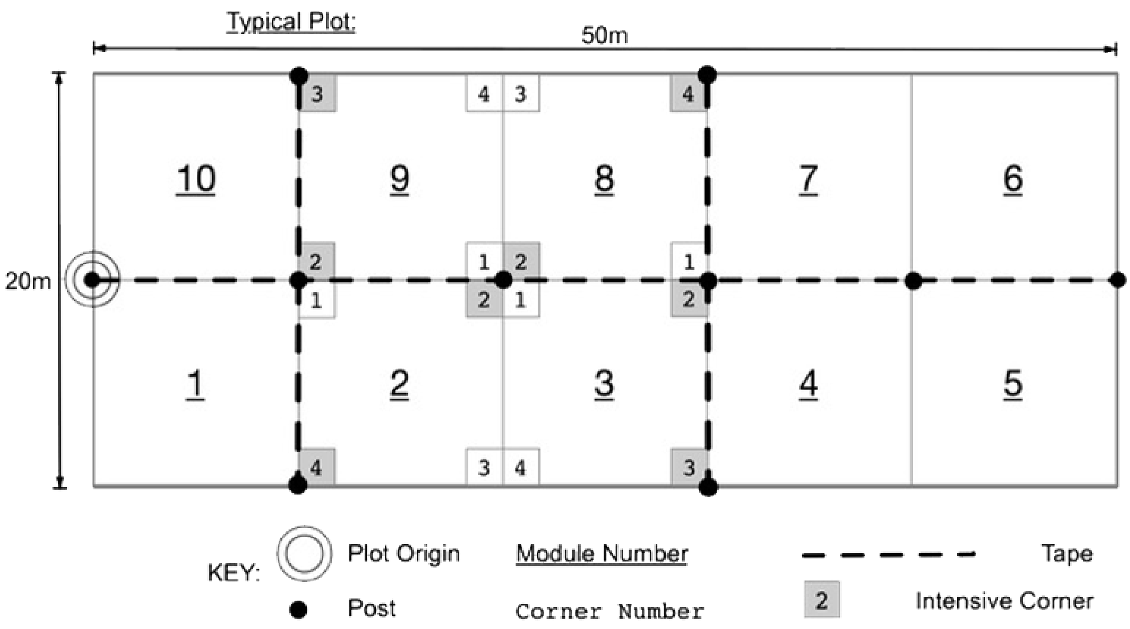


Figure 19. Plot design for measuring silvicultural treatments.
Design of the Carolina Vegetation Survey 0.1 ha modular measurement plot, an array of 10 main modules (each 10 m x 10 m) where all trees 10 cm DBH or larger are measured. Four of these modules are designated for more intensive measuring of stems smaller than 10 cm but larger than 5 cm DBH. Within the 4 intensive modules there are intensive subplots of 1 m^2 for measuring seedlings (advance regeneration); two shaded subplots in each module are for measuring herbaceous species. (Sources: Peet *et al.*, 1998; Lee *et al.*, 2008)

To measure these plots, start at the plot origin, run a tape measure along the plot centerline. Once established, the center line position should be permanently marked with a permanent marker every 10 m including both ends of the tape (this results in six markers). Next mark the edges and outer corners of the four intensive modules with perpendicular tapes. Place permanent markers at the four outside corners of the intensive modules. The far outside corners of the 20×50 m plot are marked with temporary flagging. Modules are numbered in counter-clockwise order starting in the lower left. In contrast, corners of the modules are numbered in a clockwise fashion.

In each main module, measure all trees with dbh ≥ 10 cm for species, vigor and health, and crown condition. In the intensive modules, measure the trees and shrubs as well with diameters between 5 cm ≥ dbh <10 cm. In all the intensive sub-plots, measure the number of seedlings of natural regeneration by tree species (individuals with dbh <5cm and height less than 2 m). In the shaded intensive sub-plots, measure the cover class of each herbaceous species (grass, herbs, forbs).

Growth Dynamics in Mozambique

The growth dynamics plots were designed as permanent plots similar to those of the Mozambique Permanent Sampling Plots (Fernandes *et al.*, 2020) that were compatible with national REDD+ monitoring. Standard forestry measurement techniques were assumed. These plots were designed to demonstrate the growth of Miombo types and for determining changes in biodiversity and carbon storage under non-disturbance conditions. Because the area was vulnerable to wildfire and browsing, the plots needed a level of protection. The measurement plot layout is shown in **Figure 20**.

The recommended plots are one ha squares (100 m x 100 m). This size and shape includes the greatest variability possible while reducing variance and standard error. It also facilitates calibration with satellite and drone images used for quantifying aboveground biomass. To minimize human interference, there should be a buffer 25 m wide around the periphery of the plot.

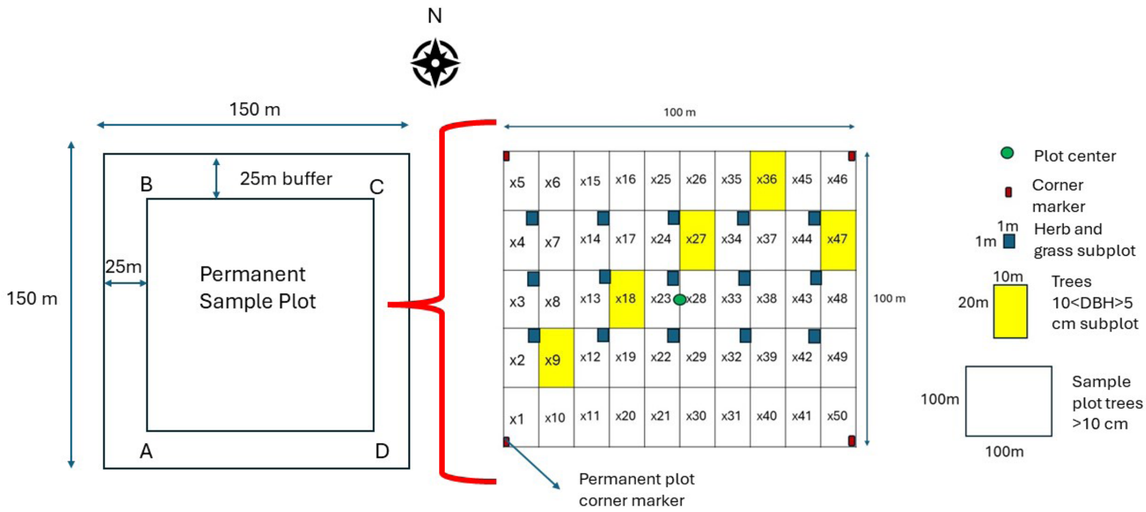


Figure 20. Design of a permanent growth plot in Mozambique.
The left panel shows the dimensions of the permanent plot (100 m x 100 m) that can be used to track growth and stand dynamics over time. This plot is surrounded by a 25 m buffer. The right panel shows details of the measurement plot, subdivided into subplots for traversing the measurement plot. Five subplots (in yellow) are for measuring saplings and 15 microplots (shown in blue) are for measuring herbaceous plants and tree seedlings. Permanent plot markers are placed at the four outer corners. (Source: Adapted from Fernandes *et al.*, 2020)

To facilitate measurement, divide the 1 ha plot into 50 sub-plots, each 20 m x 10 m. Start measurements in the southwest corner A(SO). This is the point where the plot coordinates are taken to facilitate the re-measuring team. All trees with dbh ≥ 10 cm are measured and species, vigor, and crown condition noted.

To measure trees and shrubs with diameters between 5 cm ≥ dbh <10 cm, select 5 of the 20m x 10 m subplots (shown in yellow in **Figure 20**). These measurement subplots are selected systematically. The 20 m x 10 m measurement sub-plots are labeled according to the scheme shown in **Figure 20**, beginning at the southwest corner, traversing the 1 ha plot in a continuous loop.

Smaller sub-plots of 1m x 1m ($1m^2$, shown in blue in **Figure 20**) are for measuring the herbaceous layer (grass, herbs, forbs) and natural regeneration of tree species (individuals with dbh <5cm and height less than 2 m). These 15 sub-plots are to be established in the North-South direction, excluding the first and last rows of sub-plots. Each 1 m^2 subplot should be in the upper northeast corner of the 20m x 10m subplot.

Forest Inventory Plots

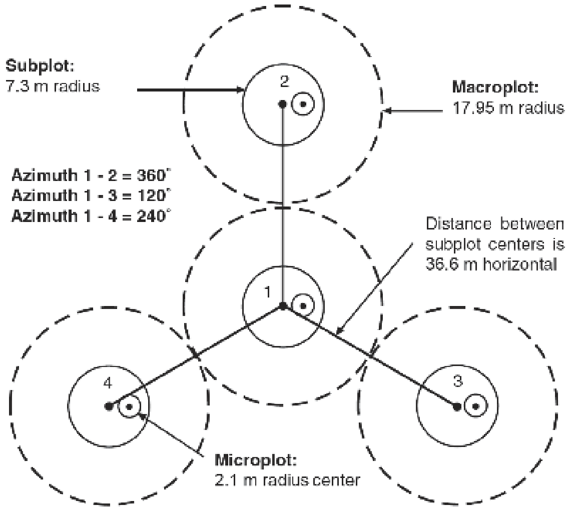


Figure 21. Forest Inventory plot layout. This example of a forest dynamics plot is from the US Forest Service Inventory and Analysis program that samples forests nationwide. (Adapted from Bechtold and Scott. 2005; Tinkham *et al.*, 2018)

The design used nationwide for continuous forest inventory by the US Forest Service is another type of permanent growth plot. (**Figure 21**). At each permanent sample location, there are clusters of four points arranged such that point 1 is central, with points 2 through 4 located 36.6 m from point 1 at azimuths of 0°, 120°, and 240°. Each point in the cluster is surrounded by a 7.3 m fixed-radius subplot. All live and standing dead trees over 12.7 cm DBH are inventoried on the subplots. Each subplot is surrounded by a 17.95 m fixed-radius macroplot, which is used for sampling rare occurrences such as large trees (e.g., 100 cm DBH and greater) or mortality. In each subplot there is a microplot with 2.1 m radius, offset 90° from plot center to avoid trampling, where saplings and seedlings are measured. On a subset of sample locations, additional site-level (e.g., litter and soil) and tree-level (e.g., crown condition) variables are measured.

Questions for Chapter 6

- Which experimental layout will be used (e.g. completely random design, randomized block design, split plot design, incomplete block)?
- What are the response variables?
- Which predictor variables will be monitored?
- Are there any nearby sources of competing vegetation that may interact with the project?
- Have planting materials or seed sources sufficient for the project been identified?
- Are they available in sufficient quantity in a timely manner for the project?
- Who will be responsible for location maintenance and its costs?

7

CHAPTER 7. Biodiversity Sampling

Forest landscapes are important for biodiversity, comprised of a mosaic of management systems and tree species that allow for natural processes. Such diverse forest landscapes should integrate other forest functions and services beyond biodiversity (Simons *et al.*, 2021). A standard protocol for sampling and monitoring biodiversity will be useful for RFFL Locations that have the primary theme of conserving or restoring biodiversity or wildlife habitat. The same protocol could be useful for monitoring the effects on biodiversity of RFFL Locations with forest management themes, whether for producing timber, watershed protection, carbon sequestration, or for adapting to changing climatic conditions. Some of the sampling requires specialized knowledge and the ability to identify species within different taxa.

The biodiversity monitoring protocol will rely on measurement plots within each operational (experimental) unit to be able to cover the heterogeneity within treatments in the same way as among treatments (Burrascano *et al.*, 2021). For simplicity, the standard operational unit is assumed to be 1 ha, but survey arrangements can be adjusted for RRFL Locations based on their plot arrangements. In this way, the protocol allows for covering all components of biodiversity including the plot level (= alpha-diversity), the within and among plot level (= beta-diversity), and the level of the RFFL Location representing mosaic landscapes (= gamma-diversity) for different taxonomic groups.

Biodiversity monitoring should be preceded by site characterization in terms of water and nutrient availability (including soil type characterization) to exclude site effects that could influence biodiversity. In addition to measurements taken within the DRM plots, characterize surrounding habitats within a radius of 2,000 m from the DRM plot center in order to consider landscape-level effects on biodiversity (Le Provost *et al.* 2021). Use satellite images for this characterization. Additionally, sample ground vegetation for each identified habitat type in the surrounding area.

Based on the sampled biodiversity data and measured data on other ecosystem services, use methods proposed by Schall *et al.* (2020) and Neyret *et al.* (2021) to simulate the effect on combining different management alternatives on biodiversity and other services to visualize the effect of management decision. Results will be compared to pure business-as-usual landscapes to evaluate the potential of alternative approaches for a sustainable future. Data on economics will be provided by local partners and stakeholders.

Biodiversity Sampling Priority Levels

The biodiversity monitoring protocol contains different priority levels (**Figure 22**): A minimum requirement for each location is measurement of forest structures and vascular plants (priority 1). These features are indicators for the biodiversity of other taxonomic groups (Neff *et al.*, 2021; Vandekerkhove *et al.*, 2021). Vegetation monitoring may show the effects of global warming and can demonstrate the suitability of different management strategies for maintaining species of the natural forest communities (Heinrichs *et al.*, 2019; Heinrichs et al., 2021).

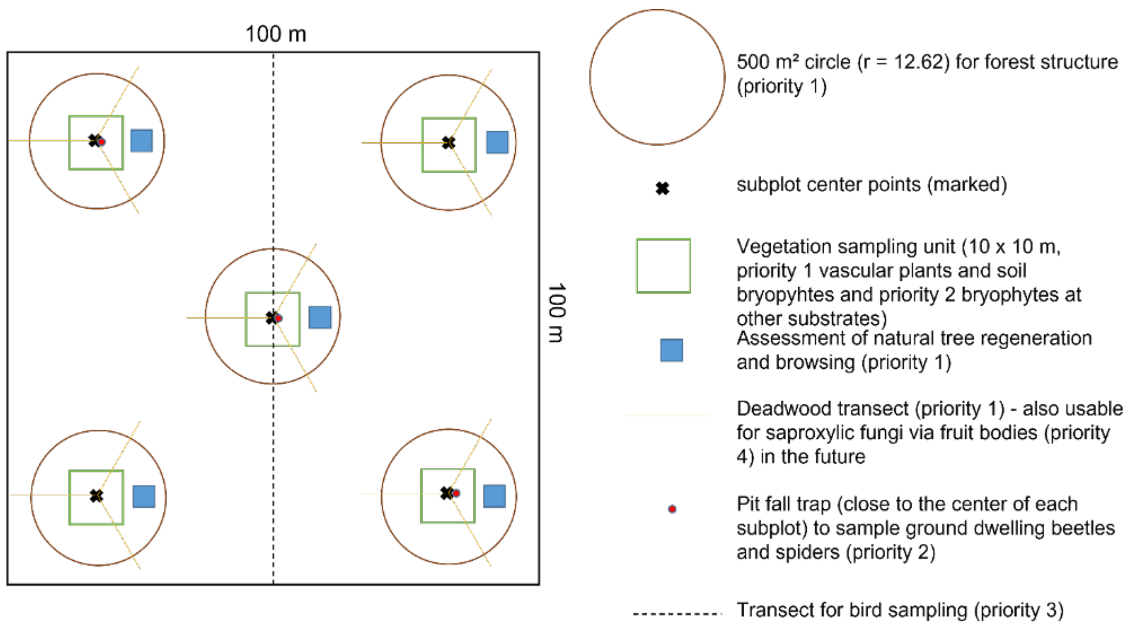


Figure 22. Biodiversity monitoring.
A general scheme for monitoring biodiversity at three priority levels. (Source: Steffi Heinrichs)

Priority 1: Sampling of forest structures as habitats and indicators for biodiversity

Depending on the RFFL Location, this will cover potential relicts of the former forest stands at the sites (e.g., stumps, deadwood), but mainly newly developing structures with time since establishment of the RFFL Locations such as tree-related microhabitats. Although new restoration sites probably will not carry many structures in the beginning, regular monitoring will demonstrate the pace of forest structure development. The development and decomposition of deadwood is also a critical component of carbon stocks.

Sampling of forest structures will include the measurement of living trees (> 7 cm DBH), standing dead trees (> 7 cm DBH), downed dead trees (> 7 cm diameter), and tree-related microhabitats (Larrieu et al., 2018). Assessments will be conducted in 5 x 500 m² circular subplots per treatment plot (assuming 1 ha in size) for living trees and standing dead trees, as well tree-related microhabitats. From the center of the circular subplots, assess structure along three 15 m transects for downed deadwood using a line-intersect method (Commarmot et al. (2013); **Figure 22**). In addition, assess natural forest regeneration and browsing intensity on a 4 x 4 m plot in the east of each circular subplot. For this, the naturally occurring regeneration will be assigned to different height classes (< 20 cm, 20 – 50 cm, > 50, > 100, > 150, > 200, ...up to a DBH of 7 cm) and each individual stem will be assessed for browsing impact.

Priority 1: Survey of vascular plant species and ground dwelling bryophytes

Next to their function as primary producers and their bottom-up effect on higher trophic levels (Neff *et al.*, 2021), vascular plants are also good indicators for changing environmental conditions. Species in the herb layer, with their distinct niches, can respond quickly to changing conditions either by local colonization or abundance shifts but also by local extinction (Verheyen *et al.*, 2017).

Conduct vegetation surveys on five, 10 x 10 m subplots covering the tree layer (woody species > 5 m), shrub layer (woody species 0.5 to 5 m), herb layer (herbaceous species and woody species < 0.5 m), and soil dwelling bryophytes on all plots. Directly estimate the cover value of each species in each layer as a percentage. A recommendation is to take hemispheric photographs at each subplot center and in the four corners; this reflect the light availability for the understory.

For this species group, conduct annual monitoring to disentangle treatment effects from annual fluctuations. Depending on phenology, two surveys per year are sufficient, one in spring and one in late summer. Annual sampling may be contributed to worldwide databases such as LOTVS (Long-Term Vegetation Sampling; https://lotvs.csic.es/).

Priority 2: Arthropods at the ground (ground dwelling beetles and spiders)

Sampling arthropod diversity within and among treatments should focus first on epigean arthropods covering ground dwelling beetles (mainly ground beetles and a few saproxylic beetles) and spiders (and harvestmen). Ground beetles contain a high number of conservation relevant species and are often included in monitoring schemes (Kotze *et al.*, 2011). Spiders are considered good indicators for structural complexity. Install pit fall traps at three subplot centers of the forest structure and vegetation sampling. This allows a direct connection to the vegetation and forest structure. Traps should be emptied at least once a month during the growing season. Ground dwelling arthropod species often show a strong dependence to vegetation structures that are covered by the vegetation sampling (Samu *et al.*, 2014; Schall *et al.*, 2018).

Priority 2: Full sampling of bryophytes as potential indicators for microclimatic conditions

Bryophytes are susceptible to micro-climatic changes within forests and have been shown to benefit from untouched forests (Paillet *et al.*, 2010). While soil dwelling bryophytes will be sampled in the course of the annual vegetation surveys, other substrates are an extension of the sampling protocol. This includes bryophytes on deadwood, living trunks up to 2 m, and rocks. For each species, the cover value will be estimated directly in percent based on the specific sample unit (e.g., trunk area). Only substrates will be sampled that are in the 10 x 10 m vegetation survey plots. One survey per year is sufficient.

Priority 3: Birds – often used as biodiversity indicator

Birds are the most sampled taxonomic group worldwide and they often rely on structural features within forest stands and/or forest landscapes (Schall *et al.*, 2020). They can also function as ecosystem engineers by creating tree-related microhabitats. A point-stop transect sampling can be used through the plot center ranging from north to south. Sampling will last for 1 minute (individuals are noted based on sightings and calls) at the start and end point; for 5 minutes at the plot center; and at 2 points within the plot (25 m from the edge and plot center). Two measurements per year (one in spring and one in summer) are recommended.

The monitoring protocol may be expanded to sampling additional organismic groups including different fungi groups (priority 4, **Figure 22**). On newly established RFFL Locations (i.e., bare ground or following clear-felling), investigate successional stages of forest establishment using a space-for-time approach (i.e., chronosequence) by sampling nearby stands, especially older, reference stands.

Questions for Chapter 7

- Will additional expertise be required and is there a plan to secure it?
- Is there sufficient budget to contract for additional expertise?
- Does any special equipment need to be obtained (by purchase, lease, or loan)?
- Will any training be required and, if so, who needs it and who will do the training?

8

CHAPTER 8. Measuring and Analysis

RFFL Projects are located in many different environmental and social situations, thus there is no one-size-fits-all prescription for what to measure and monitor. Different objectives and starting points (bare ground or existing forest cover in varying stages of development and/or degradation) mean there is no universal set of variables to measure, nor how they should be measured. Nevertheless, in this chapter we present some general principles to follow and some suggestions of what to measure.

In simple terms, measure what matters; data should be matched with objectives. RFFL Projects are meant to be long-term, so that measurements will be repeated and analyzed accordingly. The intensity (number) and frequency (how often) of a measurement will be determined by objectives and variability in the property being measured (both spatial and temporal). Use technology if it helps (easier, quicker, or cheaper to use) and if it does not introduce bias or limitations. Whatever methods are used, they should be compatible with local standard measurements in order to be comparable. Be sure to document all measurement procedures and use the information for training the people who will take the measurements.

Measuring/Monitoring

The distinction between measuring and monitoring is fuzzy but the rationale relates to the intensity of effort. Hutto and Belote, (2013) provide a useful characterization of different forms and intensities of monitoring (**Table 11**).

In the early years of an RFFL Project, measurements could be more extensive (i.e., more things will be measured) and more intensive (i.e., measured more frequently). For example, newly planted seedlings might be measured within a few months of planting to detect early mortality and then at the end of each of several growing seasons to measure survival and growth. After a while, perhaps 3 to 5 years, growth measurements might be monitored every 5 years or so. Another example is soil organic matter (SOM), something that is depleted quickly but replenishing takes a long time. Soil organic matter could be measured before treatments are imposed to provide a baseline, perhaps again after the first year to detect any treatment-imposed variation, then not measured again until 5-10 years later simply because change is too gradual to detect on a short-interval. If the research interest is in very labile fractions of soil organic matter, however, sampling would be more frequent. The determining factor is what question(s) are we asking, which relates back to the theme and objectives of the RFFL Project.

A common acronym for measurements is they should be SMART–Specific, Measurable, Achievable, Relevant, and Time-Bound. Dey and Schweitzer (2014) provided more targeted guidance on what to measure. As they pointed out, not everything that can be measured should be measured.

SMARRT Indicators

Measure variables that important for decisions with small changes traits attributable to the imposed treatments (i.e., specific and time-bound). Use standard measures that are easy, affordable, and give results that are understood by stakeholders. Indicators (measurements variables) should follow the SMARRT acronym:

- Simple to measure, such as percent cover, number of species, etc.
- Measurable with ease, requires little expertise, and are affordable
- Relevant by being linked to key stages of ecosystem change, management actions, succession, and function;
- Reliably related to ecosystem state and function in predictable ways with known certainty;
- Timely in that their remeasurement can be done coincident with key stages of ecosystem change, and they provide data for preemptive adaptive management.

(Adapted from Mansourian *et al.,* 2005; Dey and Schweitzer, 2014)

Table 10. The four categories of monitoring activity.
The type of monitoring can be distinguished by the goal-oriented questions they are designed to address. Each type of monitoring can be useful for an RFFL Project. (Adapted from Hutto and Belote, 2013)

Type of monitoring	Goal-oriented question	Design approach	Source	RFFL Uses
Surveil-lance	Are landscape properties changing in some undesirable way through time?	Re-sampling landscape response variables through time; establishing time series data; looking for correlations between land-use and the presence or absence of some indicator	Continuous Forest Inventory, Soil Survey, Land Use Inventories, other information available from public and private sources.	Description of the landscape context for an RFFL Project; site selection; description of baseline conditions.
Implemen-tation	Was a management prescription implemented according to contract specifications?	Project-specific qualitative and quantitative data collection (not necessarily requiring statistical design)	Monitoring following treatment implementation for contract purposes, establishment reporting.	Initial measurements of how treatments are implemented, useful for reporting and accountability.
Effective-ness	Did management actions achieve the social, economic, or ecological goals and objectives outlined in the prescription?	Before–after, control–impact (BACI) experimental design of treatments. Can be analyzed by ANOVA, correlation, or hierarchical statistical modeling	RFFL measurements using the Randomized Complete Blocks (RCB) or another design.	The scientific foundation of an RFFL Project, used to compare BAU to innovative treatments and demonstrate their relative effectiveness and/or utility in meeting objectives.

Type of monitoring	Goal-oriented question	Design approach	Source	RFFL Uses
Socio-Ecological effects	Did management actions result in socio-ecological tradeoffs or unintended consequences? Were innovative treatments successful over the long-term?	Before–after, control–impact (BACI) experimental design of treatments. Can be analyzed by ANOVA, correlation, or hierarchical statistical modeling	RFFL measurements using the Randomized Complete Blocks (RCB), or another design of the project combined with data from surveillance monitoring.	Periodic assessment of results from the RFFL Project enables adaptive management, additional interventions, or changes to management.

Only those measurements that are appropriate to the objectives of the RFFL Project are valuable (i.e., measurable, achievable, and relevant). Dey and Sweitzer (2014) prefer to measure variables that detect small changes in ecosystem traits attributable to the imposed treatments (i.e., specific and time-bound). Their preferred indicators are standard measures that are easy, affordable, and give results that are understood by stakeholders.

Following Dey and Sweitzer (2014), use standard methods and do not replace local instructions that might already exist, except to update them in the light of the climate/biodiversity crises. Since the RFFL is about forests, a lot of attention will be paid to plant-related measurements. But keep in mind the theme and objectives; if the RFFL Project is focused on improving watershed conditions, for example, soil erosion and water quality will need to be measured; this is what Hutto and Belote (2013) called outcome monitoring.

Measuring and collecting data can use remote sensing platforms and sensors, with drones and advanced sensors such as LiDAR increasingly available. Traditional methods, manually on the ground, however, remain the most available methods. Mobile telephone-based applications are increasing productivity and lowering the cost of these labor-intensive methods. Schweizer *et al.* (2024) identified 43 phone-based apps aimed at forest restoration monitoring. These apps either estimated a monitoring indicator or helped field data entry. Some of the date they measured included plant diameter and height, canopy openness, ground cover, individual leaf area, soil parameters, seedling planting and survival, and identification of plant and bird species. Most produced digital field data sheets. While the ubiquity of mobile phones suggests that measuring and monitoring apps have great potential, they found identifying plant species in biodiverse forests is challenging and still requires local botanical expertise. Most of the apps need internet access to function, a critical drawback in remote areas.

Here are some criteria for choosing what to measure. Measurement variables should:

- Have spatial and temporal characteristics, that is, they should measure variation over space and time)
- Be the smallest set that can be simply and easily measured to sufficiently monitor change
- Be easy to measure, reliable, and have predictive capability

When resources are limited, focusing on key indicators or surrogates may be a valid compromise. They should still meet the objectives, even though they might not be as accurate as more costly measurements. Similarly, measurements at multiyear intervals may miss significant variation due to weather or other factors (e.g., insect infestation) but still give a valid sense of the effectiveness of an innovative treatment compared to BAU methods. In some cases, the trajectory of change may be more important than static measurements in time, such as long-term growth decline due to changing climate.

Biophysical Indicators (Measurements)

The vision of the RFFL Network is to establish and maintain long-term DRM plots, thus somewhat intensive measurements are called for, including following the growth of individual target trees over time. All RFFL Projects will measure vegetation and because there is much variation in size criteria for seedlings, saplings, and trees, the size criteria should be documented. In the plot layout examples described in Chapters 7 and 8, the cutoff between sapling and tree varied from 4 to 8 cm DBH. This reflects local tradition and usage and highlights that these criteria should be well documented in the RFFL Project Plan and suggests the need to measure by individual plants rather than by size class. Suggested indicators to measure are shown in **Table 11**.

Table 11. Vegetation measurements.

Type Class	Unit	Indicator	Notes
Woody plants	Seedling	Species	Use a standard 3-letter abbreviation, e.g., PSY for *Pinus sylvestris*
		Height	For natural regeneration, average of 5 dominant individuals in the plot; for planted seedlings, measure each individual
		Root Collar Diameter (RCD)	For natural regeneration, average of 5 dominant individuals in the plot; for planted seedlings, measure each individual
		Damage	For natural regeneration, average of 5 dominant individuals in the plot; for planted seedlings, measure each individual
		Browse intensity	For natural regeneration, average of 5 dominant individuals in the plot; for planted seedlings, measure each individual
	Sapling	Species	Use a standard 3-letter abbreviation, e.g., PSY for *Pinus sylvestris*
		Height	Locally defined, often less than 2 m high, typically growing vigorously and without dead bark or more than an occasional dead branch. Definition should be documented.
		Diameter	Locally defined, often 4 cm DBH or less; document definition.
		Damage	Note damage from biotic agents (e.g., ungulates, rodents, insects, disease) and abiotic agents (frost, drought, inundation)
	Tree	Number	Record trees as cut, dead if missing or new if recorded for first time.
		Species	Use a standard 3-letter abbreviation, e.g., PSY for Pinus sylvestris

Type Class	Unit	Indicator	Notes
		Height	Count each stem on multi-stemmed plants as individuals
		Diameter (DBH)	Paint (with permanent paint) a narrow strip at dbh on measured trees. This will standardize the measurement point and help recognize recorded trees versus in-growth. When new trees appear, paint the dbh point.
		Crown projection	Optional
		Crown condition	Optional
		Crown depth	Optional
		LAI	Leaf area index
Understory	Herba-ceous plants	Species	Use a standard 3-letter abbreviation; if identity uncertain, use a number and verify later by herbarium botanist
		Weight	Multiple 1 m^2 clip plots in the measurement plot
	Ground layer	% cover	Cover can be summarized to family, genus, species, growth-form levels, or as fractional cover (e.g., fraction of photosynthetically active vegetation, dead vegetation, and bare substrate)
Necromass	Stem	Broken	If possible, record species and DBH
		Tipped	If possible, record species and DBH
	Downed	Size	Transect and planar intercept method
		Decay class	For larger material
	Litter	Weight	Multiple 1 m^2 sample plots in the measurement plot

Soil Sampling

The importance of soils for forest productivity has long been recognized; consequently, soils are frequently manipulated to increase survival of planted seedlings or amended to overcome moisture and nutrient deficiencies. Recently, the critical contributions of soils to biodiversity and ecosystem services has gained widespread appreciation (Williamson *et al.*, 2016). Information on soil and landscape properties is necessary for location selection design and most importantly, for identifying the properties that affect treatment outcomes. Understanding soil characteristics and especially variability (**Figure 23**) is important to design of an RFFL Project in three ways: (1) soil variability in the Project Location might affect plot design, (2) soils could have characteristics that need to be manipulated to improve success of the treatments, and (3) proposed treatments could degrade soils and adversely affect their functioning. Some characteristics (e.g., soil depth) can be infeasible to modify, in which case blocking plot locations is sufficient.

Soil and topographic maps, including digital elevation models, can provide an initial perspective on important properties. Interpretive maps might be available for predicting productivity, soil erosion, or nutrient runoff based on soil properties. In some countries, ecological site classification systems are available based on soil, topographic, and climate variations. A management interpretation summary for each of the FAO's subgroups is accessible through the LandPKS app (https://landpotential.org/). Vegetation or soil patterns visible on aerial or satellite imagery can highlight areas where soil properties vary. Local knowledge and information, including BAU practices such as soil preparation, will be helpful. Nevertheless, actual sampling of soils is necessary for describing the baseline conditions and identifying changes in soil properties such as bulk density and organic carbon content (Herrick *et al.*, 2023). Some properties are relatively static, such as texture and depth, and initial profile sampling may be sufficient. Other relatively dynamic properties that are affected by treatments will need repeated measurements (e.g., soil organic carbon (SOC) content, moisture and nitrogen availability). For these properties, sampling depth and frequency will need to be specified in the measurement and monitoring plan.

Two traditional ways to sample soil are to open a pit or by penetrating the surface. Soil pits that expose the horizons are described by their visual characteristics and by horizontal sampling. Sampling by core samplers from the surface produces volumetric samples. Both methods provide essential descriptive baseline data but periodic remeasurement to detect change is best done by core samplers that remove material for analysis or by probes such as suction lysimeters, TDR (time domain reflectometry), or other specialized instruments. The choice of method depends on objectives and the details are beyond the scope of this general manual. Accordingly, only sampling location and general methods are described.

A soil profile pit for baseline descriptions and location characterization could be opened on each block, depending on soil variability (Herrick *et al.*, 2023). The pit should be opened outside of the treatment plots, in the buffer zone. Open the profile where it presents the same characteristics as the soil in the central part of the plot. The profile should have minimum dimensions of 1.5 m x 1 m, to a depth of 1.5 m. This will allow a description of the distribution of the large roots in the profile and for assessing the depth of the active rooting zone. Describe the profile according to international standard methods (Jahn *et al.*, 2006). A larger pit is more useful for demonstrations and tours and in that case, orient the pit so that the afternoon sun strikes the best long face of the profile.

Figure 23. Soil profiles illustrate variability.
These profiles are of the 12 major orders of soil taxonomy. Top, from left to right: Entisols, Inceptisols, Alfisols, Mollisols, Ultisols, Oxisols. Bottom, from left to right: Aridisols, Andisols, Vertisols, Histosols, Spodosols, Gelisols. - Modified from US Department of Agriculture, Natural Resources Conservation Service; https://www.nrcs.usda.gov/resources/education-and-teaching-materials/the-twelve-orders-of-soil-taxonomy

For periodic measurements of potential change in dynamic characteristics such as soil organic carbon, use core sampling in designated measurement plots or in the buffer outside of treatment plots (**Figure 24**). Alternate sampling spots in remeasurements so that successive samples are taken from different spots. An effective technique is to sample the litter layer (i.e., dead plant material including freshly fallen leaves) from a larger area, for example a 1m² rectangular or circular sample. Deposit the litter in a single paper bag, resulting in one sample from each measurement plot. Within the exposed surface, remove 4 mineral soil subsamples with a round corer (e.g., 5 cm diameter). Retain one sample for bulk density determination separately and combine the other samples. These combined samples account for some spatial variability in soil properties.

The depth to sample the mineral soil is a matter of objectives and expected change; the IPCC recommends a minimum depth of 30 cm for evaluating changes in SOC. If determining treatment effects on soil organic carbon, then sampling 0-5 cm or 0-10 cm provides the highest likelihood of detecting short-term change. Over the long-term, deeper sampling to 1 m may be needed to show the effects of deeply rooted trees and shrubs as compared to the shallow roots of herbaceous plants.

Smith *et al.* (2020) compared several soil sampling designs to evaluate the effect of site-specific variability on precision of estimates. They found that at the local (farm-scale), regular grid sampling designs provided adequate precision and avoided potential bias from clustering around "hot-spot" carbon locations. Nevertheless, a large number of soil samples is often required (Garten Jr. and Wullschleger, 1999; Vanguelova *et al.*, 2016; Smith *et al.*, 2020).

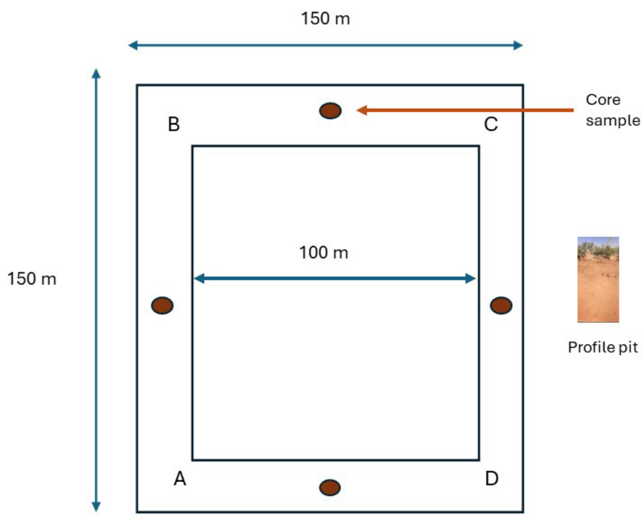


Figure 24. Sampling baseline soil conditions or in plots that are not manipulated by treatments can be done in buffer zones so as to leave the measurement plot undisturbed. Four core samples (brown circles) are in the buffer zone. A profile pit is dug outside (shown at the right) of the entire plot. (Source: Adapted from Fernandes *et al.*, 2020)

Detecting short-term changes in soil organic carbon (SOC), of great interest in climate change mitigation (e.g., carbon sequestration), is challenging due to inherent spatial and temporal variability and slow change in SOC. The basic method in forest soils is to quantify the fine earth (<2 mm) and coarse mineral (>2 mm) soil fractions and the organic carbon concentration (%) of the fine earth fraction. Converting C-concentration to C-content requires estimating soil bulk density, assuredly difficult in rocky soils (Page-Dumroese *et al.*, 1999; Throop *et al.*, 2012; Poeplau *et al.*, 2017). Because management can change bulk density (either denser by compaction or erosion, or less dense by tillage and root growth), the amount of soil can change within a given sampling depth (Mayer *et al.*, 2020). The recommendation, therefore, is to sample by equivalent mass basis (Ellert and Bettany, 1995; Wendt and Hauser, 2013; Upson *et al.*, 2016). Other complications with bulk density measurement arise in soils with shrink-swell clay minerals (e.g., Vertisols).

Financial and Socioeconomic Measurements

Estimates of the cost for reforestation or restoration vary widely, from USD 14/ha for natural regeneration to USD 34,000/ha for large scale, active restoration (Crouzeilles *et al.*, 2017; Crouzeilles *et al.*, 2020). Objectives and the type of interventions are the driving variables. The timeframe for including costs also vary among estimates; some costs only consider the immediate treatments; others look at the entire life cycle of a stand, including long-term management expenses. A very few estimates include monitoring. Labor costs are notably higher in the Global North and vary among countries in the Global South. As noted in Chapter 9 on preparing a project budget, a full cost accounting will include donated and in-kind resources, in addition to direct project expenses. Exact cost figures are less important than reasonable estimates of all appropriate costs.

A critical step in cost estimation is to clearly define the project objectives and appropriate intervention strategies (Chapter 9). Different approaches will likely have different costs. Landscape projects might include multiple treatment types, with different costs, so they will need to be budgeted separately. Within the same landscape, or for stand-level RFFL Projects, different treatments will have different cost components.

A complete comparison of different treatments (i.e., BAU vs. Innovative) requires estimating benefits as well as costs, which raises three sticky methodological issues. Perhaps the most difficult is how to estimate non-market costs and benefits that include most ecosystem services. Another vexing issue is identifying who will receive benefits and who will bear the costs, that is, issues of distributional effects and intergenerational equity. A full analysis of costs and benefits requires estimates over time with proper discounting. Some form of maintenance is usually needed for at least a couple of years. Determining when the project is considered "completed" for the sake of estimating costs (e.g., 3 years, 5 years, 20 years) is a challenge, and some benefits may not accrue until much later (e.g., returns from timber harvest). Financial analysis for comparing forest management interventions when benefits have well-defined value such as stumpage is straightforward, using land equivalent value (LEV), internal rate of return (IRR), and return on investment (ROI) see for example Clutter *et al.* (1983; Zhang and Pearse (2011).

Fortunately, these are areas of active research, and some tools are already available. Tools for extended cost-benefit analysis for environmental projects are well established and have been applied toward forest restoration (Verdone, 2015). There are multiple methods for estimating carbon benefits (e.g., Hoover *et al.*, 2000; Nair, 2011) and several accounting methods are developing for other ecosystem services including watershed modeling (e.g., Logsdon and Chaubey, 2013; Costanza *et al.*, 2017; Carlucci *et al.*, 2020). Most RFFL Projects, however, will only be able to document readily quantified costs and benefits.

Analyzing Treatments

The recommended experimental design of RCB underlying the DRM plots lends itself to using analysis of variance (ANOVA). The simplest model estimates a response variable at the location level by examining block and treatment effects. The error term is the interaction of the block and treatment effects. This model is used to compare response variables measured at only one point in time, i.e., after one time step.

The simple model can only use data from one year at a time or by pooling data over the years. If the DRM plots are maintained as planned and the same plots are measured repeatedly over several years, a repeated measures ANOVA is needed to analyze the data. This is also called a split-plot-in-time design. This model is needed to analyze pre-treatment, post-treatment, and one-year and later post-treatment data. The error term for treatment effects is the interaction of block x treatment. The error term for time effects is the 3-way interaction of time, block, and treatment effects.

For more complicated designs, it is best to consult a statistician. As an example, the restoration plots on bare ground could be divided into split plots to test the effects of different planted species or stock types. Measurements over time would require a split-plot repeated measures ANOVA.

Questions for Chapter 8

- What will be measured and why?
- Over what timeframe and frequency will properties be measured?
- What methods will be used to monitor the location?
- How frequently will the location be monitored?
- Does anyone require training to conduct the measurements?
- How will the data be recorded, both at the location and in the record keeping system?
- How will costs and benefits be measured?

9

CHAPTER 9. Preliminary Planning

Conduct Pre-Project Monitoring as Needed

Some RFFL Projects might need to monitor conditions prior to implementing treatments. As an example, projects that seek to improve watershed conditions using paired watersheds will need to establish pre-treatment streamflow or water quality conditions. Characterizing the landscape context using surveillance monitoring (Hutto and Belote, 2013) and remote sensing data will facilitate setting objectives and defining treatments. For more detail on monitoring, see Chapter 8.

Install Any Infrastructure Needed to Facilitate Project Implementation

Some locations could require considerable preparation before implementing treatments, including needed infrastructure. Watershed projects might need a stream gauging station to measure streamflow or groundwater observation wells. Other projects that use non-native plants or different provenances of native plants might have to grow their own seedlings if appropriate material is not available. In our Central Asia project, the innovative treatment required material that was not available locally and we also used an innovative nursery technique to grow the seedlings that we needed (**Figure 25**). We had to acquire the components, build a platform, assemble and test the irrigation system before planting seeds. Container seedlings will be ready for outplanting in 4 months.

Figure 25. Micro-nursery.
Micro-nursery set up in Uzbekistan, Left photo shows the table holding the trays that are flood irrigated with the Jiffy 7© pots; under the table the water reservoir and pump. The right photo shows the germinated walnut and pistachio seedlings, about 2-weeks old. (Photos Palle Madsen)

Prepare a Preliminary Budget

A preliminary budget should be prepared once the location and treatments have been selected. Along with specifying the resources needed, including who is responsible, a project budget should Identify the costs of the project activities. Listing all of the costs might indicate that the project design has to be modified to keep costs reasonable or within budget. It is critical to anticipate all costs and compare that to the funding available. If necessary, the location design can be modified to bring costs, labor, and other resources in line with available support.

The preliminary budget also serves as a template for documenting expenditures for establishing the RFFL Location and to document the costs of innovative treatments. Specifying a project budget at the outset also facilitates documenting actual project costs, both direct and indirect (including in-kind contributions by partners). One objective of RFFL Projects is to document actual costs of innovative versus business-as-usual treatments and a projected project budget begins that process. Once the treatments have been finalized and the tasks scheduled for establishing the RFFL Location, circle back and update the budget to include all costs.

Budgeting and accounting principles distinguish major categories of costs, primarily fixed versus variable costs (**Figure 26**). Fixed costs remain the same regardless of the level of use or output. Fixed costs may include lease and rental payments, and infrastructure. Take for example a nursery to produce seedlings for an afforestation project. Land lease, machinery rental, and construction material to build a greenhouse would be fixed costs. Once the number of seedlings needed to be produced annually is determined, the size of the nursery could be designed accordingly. These costs would not change, even if the nursery was operated at less than full capacity. The variable costs would include labor, soil amendments, containers, electricity to operate irrigation, among other consumables. These costs would vary depending on how many seedlings were produced.

Another distinction is between personnel and capital costs, usually because they are accounted for differently for tax purposes (equipment may only be a capital cost if its useful life exceeds some threshold number of years). Donors may differ in what they allow in a grant: equipment purchase might not be allowed, or only salaries of temporary employees are allowed.

Other distinctions in budgeting by donors are between direct costs paid by a grant or by a project versus in-kind contributions of land, labor, or other items such as vehicles furnished by the project partners. For example, an RFFL Project involving several universities and installed on company land by company staff could have a number of in-kind contributions. Often a donor will not pay the salary of senior staff (e.g., university faculty); the time they contribute to the project would be an in-kind contribution. Some donors require a percentage of total project costs to be paid by the partners (e.g., 25%) and allow in-kind contributions to cover this amount. Other donors may not require in-kind contributions, yet it can be helpful to show this in a grant application.

Projects need support staff, administrators and office workers who support project staff with a myriad of business activities including purchasing, travel arrangements, and many kinds of reporting. Buildings (offices, laboratories, garages, etc.) are other necessary but usually shared expenses that seldom can be charged directly to a project. Donors and public agencies who are accustomed to granting to universities allow a percentage of direct project costs to be added to cover these overhead expenses. At times, this may be a fixed percentage set by donor policy, or it could be a negotiated amount between a university and an agency. And to make matters even more complicated, some direct costs may be excluded from the calculation of allowable overhead. An example budget spreadsheet is shown in Appendix 2.

Budget Direction From a Donor

- Salaries: includes salaries of employees (in case you are in the exceptional situation that salaries for the PI or other senior contributors are requested, please explain).
- Consumables: includes consumables, service fees, and other operative costs.
- Knowledge Transfer: please specify the different sub-categories such as publication*, participation at and travel to conferences, or workshops, study visit, etc.
- Equipment: specify which equipment and how many.
- Other costs: include costs that are not reflected in the previous categories (indicate type of costs in the column "Description").

***Note that we encourage open access publication and support costs if needed and budgeted. As many institutes have agreements with publishers, we request an invoice for Open Access publications.**

Figure 26. Major cost categories in a project budget.

Train Personnel

RFFL Projects include innovations that could require specialized training of staff who will supervise and implement establishment and monitoring. In addition to technical tasks, some concepts underlying the innovations may be new to local staff and ensuring that everyone knows the why, as well as the how, contributes to the likelihood of successfully implementing the treatments. Capacity building and knowledge sharing is a goal of the RFFL Network, requiring training of all staff. Training is critical if local community members will measure and monitor (i.e., citizen science (Kosmala *et al.*, 2016; Pocock *et al.*, 2017; Miller-Rushing *et al.*, 2019). The Project Concept Paper or Plan should be useful for developing needed training.

Schedule Tasks

Even the simplest project is comprised of many steps that must be taken in the proper sequence, at the appropriate time. Some steps are best taken simultaneously and completed before beginning a subsequent step that depends on their results. For example, planting a site can require preparatory work to be completed months before planting; plant material needs to be grown, starting months or even years before outplanting, and seed must be collected before plants can be raised in the nursery. In the case of masting species such as *Quercus* spp., seed years may be infrequent and acorns cannot be stored for long, creating special problems for scheduling.

Along with a detailed task timeline, it is advisable to specify who will be responsible for each of the tasks and when they must be completed. Project management software is available for complex projects, but a spreadsheet is often sufficient. A simple example is shown in **Table 13** for the RFFL Project in Uzbekistan. The partial timeline covers the stages in setting up a micro-nursery (**Figure 25**) to grow container seedlings for outplanting.

Table 12. Example of a (partial) project task timeline.
This partial timeline lists the activities needed to set up a micro-nursery to grow container seedlings.

Year	Date	Activity	Responsible	Comments
2022	Fall	Assemble and test micro-nursery	Timur	Done November 2022
	Fall	Walk through instructions from the nursery expert	Timur, Evgeniy, Daria, and?	Preliminary training done November 2022, waiting on video from Peter to complete
	Fall	Find out stratification needs for almond	Evgeniy	Contacting expert
	Fall	Purchase additional materials for nursery, greenhouse	Timur, Palle	Spare pump, plastic for cover, sand or vermiculite to cover seeds
	Fall	Get seed for early and late planting	Evgeniy	Get acorns from nursery; split into two lots, store half for late planting
	Fall	Pre-germination treatments, as needed	Evgeniy	Seed for early planting
	Fall	Prepare all planting sites at Burchmulla	Leshoz	Same for both Jiffy and bareroot, 1m x 1m per plant, depends on slope; also, for late planting
	Fall	Order/reserve bareroot seedlings	Evgeniy	Depends on what species are available

Year	Date	Activity	Responsible	Comments
2023	Late January	Sow all seeds in Jiffy pots, cover with sand or vermiculite	Nursery staff	Per manual directions
	Late January	Moisten seeds with sprinkler until germination	Nursery staff	Per manual directions
	By April 10	Plant Pilot Jiffy seedlings	Burchmulla	Timur or Daria should supervise on-site
	By April 10	Plant Pilot bareroot seedlings	Burchmulla	Timur or Daria should supervise on-site
	Summer	Irrigate all seedlings	Burchmulla	Irrigate 4-5 times over the season; weed around seedlings and break up soil surface so that all water goes into the soil; same amount of water for each seedling
	May	Measure initial height on all Early Pilot seedlings	Field Staff	Both Jiffy and bareroot seedlings
	October	Measure survival and growth all Early Pilot seedlings	Field Staff	Both Jiffy and bareroot seedlings

Long-term Management and Monitoring

The Project Plan should include a description of the intended management of the DRM Plots over time, including a re-measurement schedule. The long-term plan should indicate what measures are needed and who is responsible for maintaining the integrity of the site, controlling access, refreshing plot corner markers, etc. The monitoring and re-measurement plan should indicate the intervals between measurements, which depend on objectives, nature of the treatments, and rate of change in the measured property. For example, planted seedlings need to be measured until established, presumably at least annually for 3-5 years to determine survival/mortality, browsing or other damage, and growth. From then on, measurements can be on the same schedule as overstory trees. In comparison, SOC changes slowly and it is likely a remeasurement sooner than 5 years after treatment will not show a meaningful difference. Whenever a remeasurement occurs, a monitoring report should be written and stored in a knowledge management system and sent to partners on the agreed upon schedule. The knowledge management plan, including who has access to the data, authorship guidelines, and other topics are described in Chapter 10.

	Measurement Interval					
Unit	Indicator	Time 0	Time yr 1	Time yr 2	Time yr 3	Time yr 5 and 5 yr intervals
Tree	Number	x	x		x	x
	Species	x	x		x	x
	Height	x	x		x	x
	Diameter (DBH)	x	x		x	x
	Crown projection	x	x		x	x
	Crown condition	x	x		x	x
	Crown depth	x	x		x	x

Table 13. Example of a remeasurement schedule for the overstory trees.
Time 0 is before any treatments are applied; Time 1 is the first measurement immediately after treatments. Times 0 and 1 could be in the same year, for example to measure how much biomass was removed in a thinning. Instead, the measurements could be separated by a year (growing season). Intervals between measurements depend on objectives, nature of the treatments, and rate of change in a property.

Documentation

Thorough documentation is necessary to maintain the integrity of long-term installations like the RFFL Locations. Descriptions of locations, treatments, plot designs, and project management have been discussed in previous chapters. Here we describe the measures needed to mark, reference, and document plots.

Plot Documentation

All types of plots (i.e., treatment and measurement) should be thoroughly documented, beginning with geo-referencing plot locations. To enable later researchers to locate plots, a map should be included in documentation that shows access routes, georeferenced locations, and paths to plots including waypoints using GPS.

The following are some general guidelines:

- Geo-reference the plot corners and the plot center.
- A sketch map of tree locations can aid in re-measurement (see Appendix 1). Alternatively, map the canopies of each measurement plot by drone, pre- and post-treatment (**Figure 27**).
- For treated plots, if possible, measure the amount of material removed (by stem size and species).
- For individual tree growth response on larger trees, label each stem post-treatment.

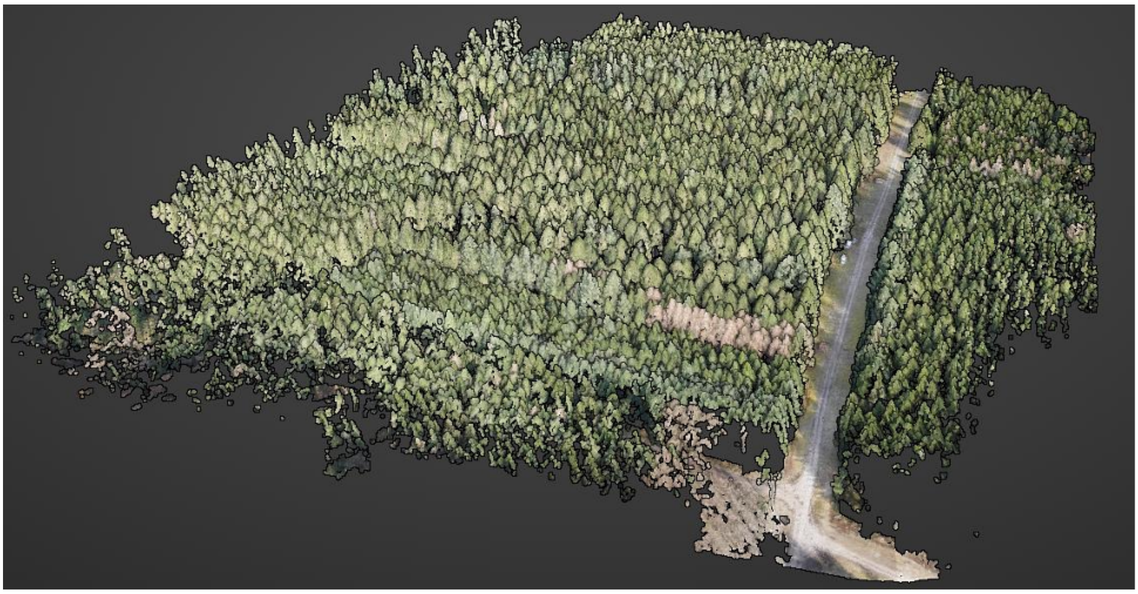


Figure 27. Drone image of a Danish forest.
Processed image combining RBG image with LiDAR taken from a drone of a forested area in Denmark. Further development of high-resolution drone based remote sensing is likely to change future monitoring by providing geolocated information at higher precision and lower costs that before. Scientists or other professionals responsible for RFFL projects need to be aware of how data taken from their project by different technologies can be meaningfully linked and remain loyal to the long-term project objectives. (Photo Palle Madsen)

Labeling System

Develop a labeling system and apply it consistently for all samples. For example, a system could begin with a location reference, possibly an abbreviation of the geographic location. Then use an alphanumeric system to indicate block, treatment plot, measurement plot, etc. What is important is that each sample has a unique label and the key to the labeling is documented in the knowledge management system as well as the data sheets.

In plots with large trees, we recommend labeling individual stems for tracking growth and mortality over time. All individuals with DBH 10 cm and larger should be identified to species (botanical name). Number stems in plots consecutively as they will be measured. For example, in the plot layout in **Figure 19**, stems would be numbered from 1 in each 20 m x 10 m sub-plot. Each tree can be labeled with a unique code on a metal plate affixed to the tree above dbh (**Figure 28**). In this way the growth of individual trees can be measured over time. If a tree is removed or dies, the label is kept and is not assigned to any other individual.

A simple diagram of tree locations on each plot can aid in re-measurement and help identify missing trees or in-growth. An example of a stand map in a field inventory form is shown in Annex 1. A more advanced method is to fly a drone over the plots and record the stand on video and identify large individual trees. Drones can fly small LiDAR equipment to develop more precise maps and even measure tree heights, although this requires relatively expensive equipment and specialized data processing capability (**Figure 27**).

Smaller trees, 10cm < DBH ≥ 5cm, are to be labeled with a similar code. In subsequent re-measurements, if a tree moves into the larger size class (i.e., 10 cm or greater), it gets a new label with the appropriate number. In this way, recruitment and mortality can be tracked over time.

The metal identification labels should be affixed to the trees on the side of the direction in which the sub-plot is walked during measurement, at 5 cm above the DBH measurement. If the trunk has anomalies that prevent this placement, put the label below the dbh measurement point. To allow for diameter growth without having to remove and re-affix the label, the label should be attached with a galvanized steel nail, leaving a free space of 2-3 finger widths between the label and the trunk (**Figure 28**).

Figure 28. Example of permanent label. Label affixed to trees of different diameters with metal plates attached with a galvanized nail that allows for diameter growth over time. (Photo Michael Kleine)

Another approach to labeling individual trees is to use radio frequency identification (RFID) tags (Bowman, 2010; Marczewski *et al.*, 2016). RFID technology allows field crews to locate individual trees repeatedly under natural conditions. RFID tags are a microchip with an attached antenna, and together with an appropriate reader, data can be read from the chip. RFID tags can be used in conjunction with other marking techniques such as physical tags and GPS coordinates. For example, the largest tree in each sub-plot could be marked with an RFID tag embedded in the bole just above ground level so that even if the tree is removed, the stump can identify the tree.

Photo-points

Document conditions with photos of the plots (Hall, 2002; Watson and Novelly, 2004). Photograph the surrounding landscape from a fixed photo-point that is georeferenced; take photos from plot corners, looking towards the plot center. Use the same camera with the same zoom and resolution settings for all photos. Set the camera to the widest possible zoom setting and the highest resolution.

At each photo point, place a numbered metal pole for future reference, using a plot numbering scheme with additional labeling for the photo points (**Figure 29**). Frame each picture to include the top of the pole (showing the pole ID number) in the lower right-hand corner. Use a compass to record the direction of the photo. Repeat photo-monitoring in the mid-dry and wet seasons and at each re-measurement. Transfer photos to the knowledge management system as soon as possible and rename the files with unique identifiers that include plot identification and photo date.

Figure 29. Photo-point identification. Photo-point identified by a pole showing the plot ID number. (Photo courtesy of Stephen Elliott)

Questions for Chapter 9

- Has the project location/s been selected according to stated selection criteria?
- Is the project location easy to access?
- Are there any potential risks to the project location (e.g., fire, flood, clearing, disturbance)?
- Have any necessary permissions, licenses, or permits been obtained?
- Are there any ethical considerations related to accessing or using the location (e.g., cultural heritage values, threatened species presence)?
- Will any preparation work or maintenance be required (e.g., feral, animals and weed management, herbivore-exclusion fencing)?
- Will removal of natural regeneration within the experimental plots be required to prevent confounding or biasing of the results?
- Has a preliminary budget been developed and agreed to by the relevant stakeholders (e.g., partners, funding body, scientists)?
- Are all relevant stakeholders in agreement about their financial and in-kind contributions and allocations for project components?
- Has a person/party been designated responsible for financial management?
- Have project reporting timeframes and requirements been identified (e.g., for funders)?
- Will major equipment need to be purchased?

10

CHAPTER 10. Data Management

Data management is critical for maximizing the value of an RFFL Project. Increasingly, funding agencies ask for a data management plan and require data from funded activities be made publicly available. Journal publishers commonly require data used in articles to be freely available. A well-structured data management system is invaluable for analyzing the collected data, documenting the results obtained, and disseminating information to be incorporated into adaptive management that makes changes as understanding is deepened or new conditions arise. The value to the RFFL Network is that partners can compare results, make connections between RFFL Projects and RFFL Locations, and ensure that the information from the long-term study will be accessible in the future.

A data management system should be designed with data capture, retrieval, and use in mind. Critical questions to be considered in designing a system are how will data be described, stored, updated, retrieved, and used? Who will perform these tasks? Who will have access to the data, and what constraints will there be on access? Sharing data among partners is one of the principles of the RFFL Network. Publicly sharing data (i.e., open data) provides opportunities to standardize data collection methods and data analysis techniques (Reichman *et al.*, 2011), but requires agreement in how to share, use and cite data (Zimmerman, 2008).

The crux of a data management system is data standards, the rules governing how data are described and recorded. Data standards are a common format that allows partners to freely share, exchange, and understand data. A simple example of a data standard is "tree diameter will be measured at breast height, defined as 1.3 m above ground level, using a diameter tape or caliper, and recorded to 2 decimal places." Funding agencies often require adherence to the FAIR Guiding Principles (findable, accessible, interoperable, reusable) for data description and recording. The FAIR principles seek to facilitate the reusability of data and enhance the ability of machines to automatically find and use data (Wilkinson *et al.*, 2016).

Metadata, data that provide information about the primary (i.e., collected data), are critical when collecting and synthesizing data from long-term, large-scale, and trans-disciplinary projects such as RFFL. Adequate metadata ensures that differences in the way data were collected over time or by different individuals or groups can be taken into consideration. Absence of sufficient metadata, or lack of confidence in how primary data were collected, may prevent analysis or render interpretation questionable.

Earlier (Chapter 8) we talked about what to measure and offered the advice of Dey and Schweitzer (2014) to use standard measures that are easy, affordable, and give results that are understood by stakeholders (i.e., SMART). Using standard measuring methods make possible comparisons between locations or between measurement years. Nonetheless, sometimes a non-standard method is necessary, or possibly innovative, and this should be noted in the metadata. As an example, measuring DBH at the standard height of 1.3 m may be infeasible if the tree has buttresses; the actual measurement height should be noted in the metadata file.

Another example of the need for metadata is that even when using a standard, accepted taxonomy for species (which is recommended), taxonomies can change, and species can be renamed. Users of the data need to be certain of species identifications and metadata should document the taxonomic authority that was followed and when standards have changed. Moreover, technological advancements including applications, sensors, and remote sensing platforms such as drones make it easier to collect field data, but different hardware and software can introduce variation in data. Manufacturers and equipment models, software versions, flight specifications, dates of data collection, are examples of the kinds of metadata that should be recorded.

Protocols for how and where to store primary data and metadata are yet to be agreed upon but for the time being, the best practice is to store data in multiple locations for security and to control access. Today, local storage by each partner is advised as well as cloud storage.

Access to data might be needed between landowners and stakeholders, e.g., forestry agencies, research institutions, NGOs, and local communities. Levels of access to the primary data and their use can be defined in Memoranda of Understanding (MOU). Individuals or organizations could be granted different levels of access (for example, read only versus the ability to add or revise data). The data sharing protocol may differentiate between raw plot data and stand summaries, for example. There are platforms for sharing forest data, see for instance http://www.forestplots.net/ and https://seosaw.github.io/.

Reporting on project outputs and outcomes may be required by funding agencies and partners. Having a system set up for reporting on your projects may save time when reports are due and may also provide valuable information for communicating project outcomes in other fora such as scientific meetings or briefing decision makers.

Access and use of data can be controlled though request systems that require potential users of the data to contact specific researchers who maintain control of the data. An example of an agreement for use of data comes from the Southwest Experimental Garden Array (SEGA) in Australia that outlines the conditions for data (sidebar).

Reporting

Communicating about the RFFL Project is an important task with different objectives depending on the target audience. A generalized process for communicating (**Figure 30**) begins with putting your ideas down on paper (real or electronic). Before implementing a Project, getting funding and enlisting partners probably will require a written statement of purpose, expected results and/or benefits, and an idea of necessary resources. These topics can be summarized in a Concept Paper (Appendix 3). Turning the concept into a concrete Project Plan or funding proposal is the next step. Once Project implementation begins, there likely will be some necessary deviations from the plan so an Establishment Report tells the story of what was actually done, as opposed to the planned

Example User Agreement

- The user agrees to notify the RFFL scientists who gathered data prior to use in any publication or presentation. The user will provide them with formal recognition that, at the researcher's discretion, may include co-authorship or acknowledgements on publications. The level of recognition should be negotiated between the data producer and end user before manuscripts are started.
- The user realizes that the researchers who gathered these data may be using them for scientific analyses, papers or publications that are currently planned or in preparation, and that such activities have precedence over any that the user might wish to prepare. In this case, the user should be prepared to delay publication of their research until the data producer has published their own.
- Because it may be possible to misinterpret a data set if it is taken out of context, the user will seek the assistance and opinion of those RFFL researchers involved in the design of a study and the collection of the data as the user analyzes the data. Moreover, the user realizes that these datasets may not be complete, and it may contain errors.

(https://www.sega.nau.edu/data)

implementation. Over time, periodic Monitoring (or Re-measurement, Progress) Reports document results and let partners and stakeholders know how the Project is progressing. At some point it may be necessary to prepare a final report that documents the completed project, or at least the results at the end of the funding. At different stages in the process, technical and popular publications should be prepared to publicize the project and update the RFFL website. The following sections detail the different phases of the communication process.

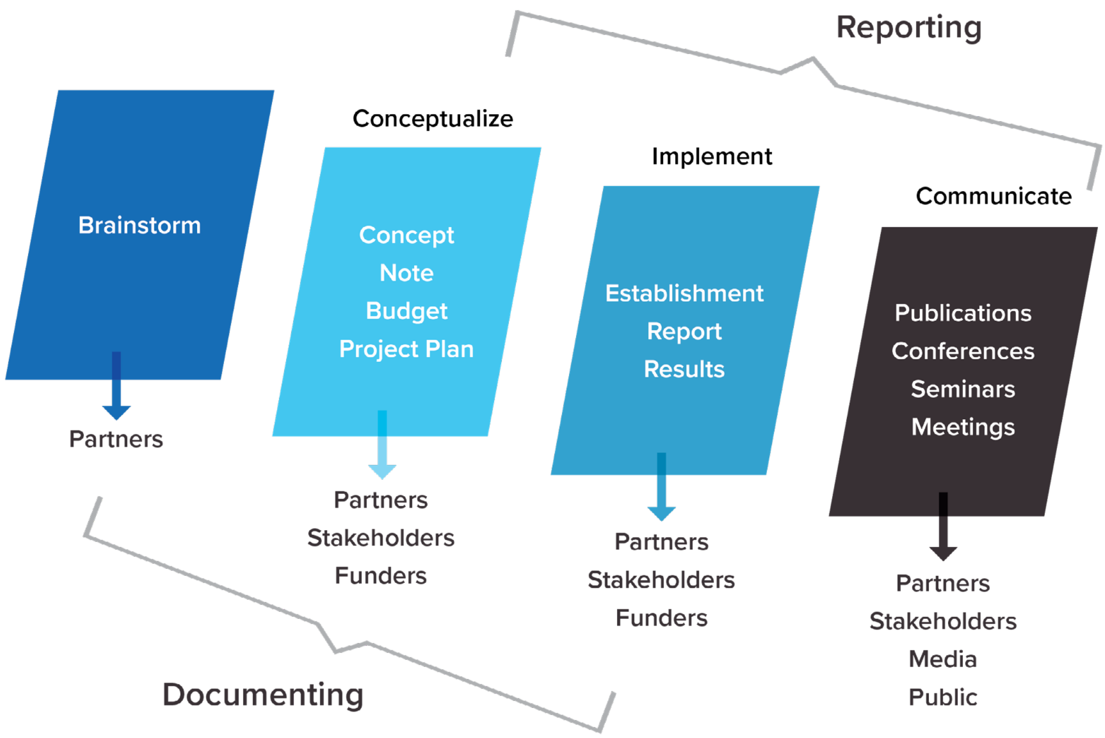


Figure 30. A generalized process for documenting, reporting, and communicating an RFFL Project.

Project Plan/Proposal

A written Project Plan is a guide to implementing and maintaining an RFFL Project and its Locations. A study plan keeps everyone on track as to how to implement the project, hopefully anticipating issues that can arise in the field. A Project Plan also protects the integrity of the project so that over time, as conditions and personnel change, the original objectives, methods, and data collected are maintained and preserved. A Project Plan requires all involved to clearly define objectives. The Project Plan begins to document the study and provide a sound basis for analysis and interpretation of the results.

The Project Plan can follow different structures and use various names for component sections. A Project Plan can simply be a more detailed version of the Concept Paper, or it may use the structure as required by a funding agency's proposal. At a minimum, the Project Plan should include a statement of the specific objectives; a description of the initial Baseline Conditions; the treatments to be imposed; and a description of the field, and laboratory methods planned for use in the research. The plan should also include a schedule of activities, an estimated budget, and a description of the people responsible for implementing the project and data archiving plans.

Funding agencies often require a statement of what results are anticipated and who might benefit if the project is successful. A plan for disseminating the results also might be required that discusses anticipated applications and venues for presenting expected results. Additionally, funding agencies often ask for identification of potential obstacles or problems, any safety and health hazards associated with the project, and ways to deal with them.

Establishment and Monitoring Reports

Project Plans represent the best possible outcome, an idealized version of the RFFL Project. In the course of installing a Project, it is common to encounter conditions or situations where the project cannot be implemented as planned. As an example, seedlings of all species might not be available in the first year so that some species are planted later than others. Or drought conditions or herbivore browsing might cause unacceptable levels of mortality. An Establishment Report is used to document details of anything that differs or deviates from the Project Plan or provides more detail of treatments and methods than were provided in the Project Plan, for example, GPS locations of plot corners.

Some minimum topics to include in the Establishment Report are:

- The date of establishment
- The person supervising the establishment or preparing the report
- Actual locations, including maps, directions to the location, GPS coordinates, and plot layout
- Identification/numbering scheme used for plots and samples
- Significant observations that may facilitate later interpretation and analysis, and
- Actual costs for materials and time for labor.

The Project Plan should have a Monitoring Plan with a schedule for re-measurement of the RFFL Project locations. The data collected at each monitoring date should be documented in a Monitoring Report. Some information (or metadata) to include, besides the actual measurement data, include the following:

- Dates of measurement
- Names of persons who did the measuring
- Any disturbances, damage, or changes that affect the integrity of the DRM plots such as wildfire, windstorms, grazing, insect attacks, etc.
- Any further treatments that were applied as planned, such as thinning
- Significant observations that may facilitate later interpretation and analysis.

All reports should be included in the data management system.

Publications (including authorship)

The reports described above can be considered internal to the RFFL Network, but they provide the content for wider dissemination. RFFL Projects supported by external funding undoubtedly will be required to report on progress to funding agencies and partners, who likely will have their own requirements for structure, content, and style. Other reporting opportunities include fact sheets, brochures, and field trip handouts.

Two formal venues for disseminating results are scientific journal articles and publishing on the RFFL website (https://resilientfutureforest.org). Publishing in journals involves issues of data access and credit. Journals credit authorship to those who have made a substantial contribution.

Authorship Decisions

There should be an agreed process for deciding on use of data and authorship of publications. The criteria should be based on who has made a substantial contribution. The policy of the Journal of Forestry is one example of a policy. It states that
"authorship constitutes the following roles in manuscript development:

- The individual has participated sufficiently in the research, design, or analysis of the study
- The individual has participated in the drafting, critical review, and evaluation of the manuscript.
- The individual agrees to be accountable for the work following publication."

These are reasonable requirements that govern authorship of publications based on RFFL Projects.
(Source: https://academic.oup.com/jof/pages/general_instructions#AuthorshipPolicy)

Questions for Chapter 10

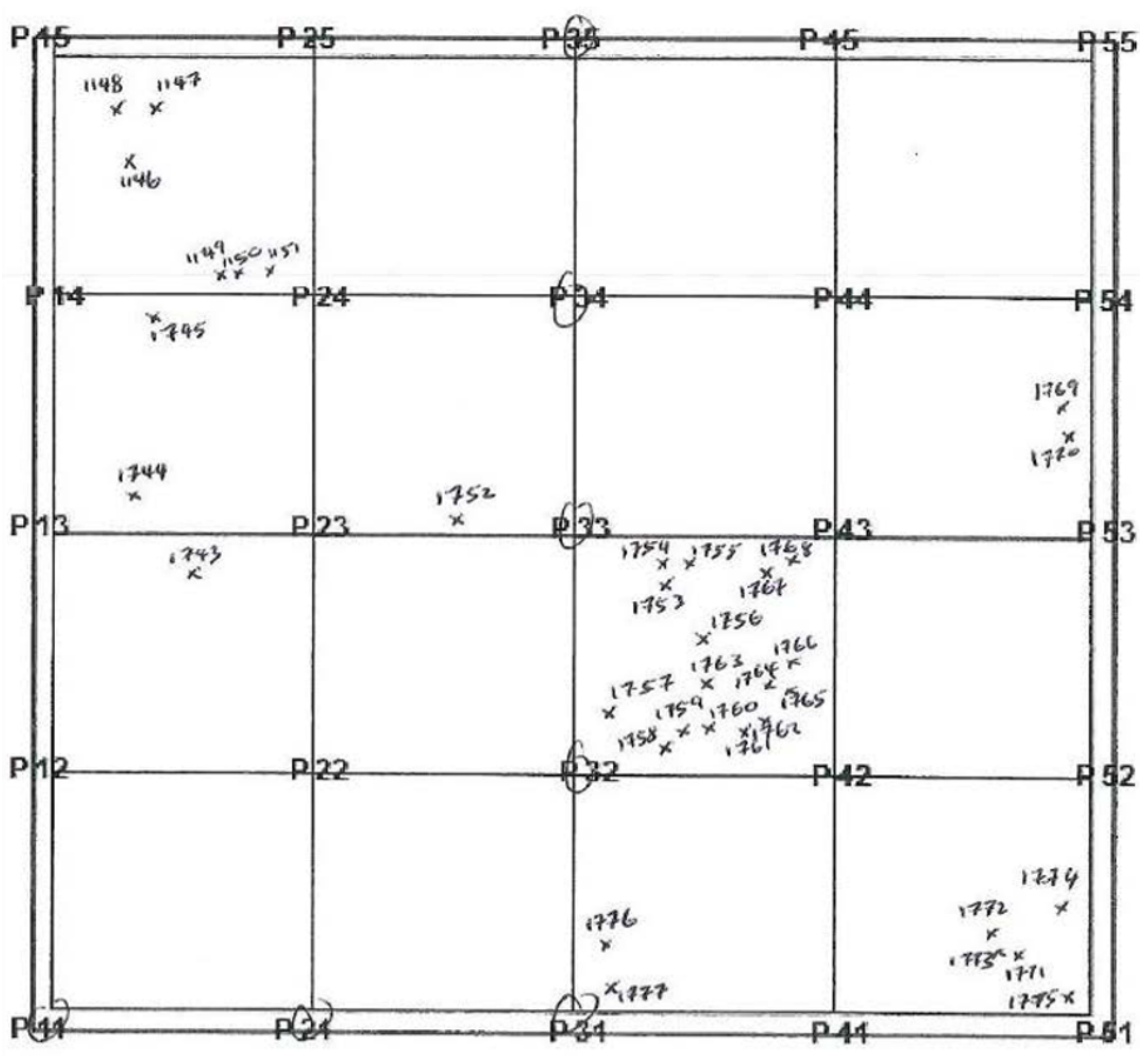
- Who will establish and maintain metadata (dataset descriptions) and ensure consistency (data custodian)?
- Who will have access to the database, including read/write authority?
- Are there agreed upon protocols for managing sensitive data?
- Is the database platform appropriate to hold the data and is its ongoing maintenance supported?
- Who will analyse, review and report the data?
- What are the intellectual property (i.e., data) sharing arrangements?
- Is there a communication and outreach plan?
- How will authorship of reports and research papers be determined?
- How will results and interpretations be disseminated and by whom?
- How will all contributions be acknowledged?

Appendices

1. Sample Field Sheet with Tree Map

Field Inventory 2021
Supporting Information from the 2019 field inventory
Plot name: **1434**

Tree location map



2. Sample Budget Spreadsheet

Total budget (total requested budget for all partner institutions)	Currency (please use the local currency of the PI's institution)	*Enter Currency*	Exchange Rate	*Enter exchange rate(s) if applicable*

		Year 1		Year 2		Year 3		Year 4		Total	
Category	Descrip-tion	ABC ORG	Other sources	ABC ORG	Other sources	ABC ORG	Other sources	ABC ORG	Other sources	ABC ORG	Other sources
1. Salaries	*Jane Smith (position)* *John Smith (position)*									0 0 0	0 0 0
2. Consu-mables	*Animal costs* *Lab consu-mmables* *....*									0 0 0	0 0 0
3. Know-ledge Transfer	*Publication* *Participation at conferences* *...*									0 0 0	0 0 0
4. Equip-ment										0 0 0	0 0 0
5. Other costs										0 0 0	0 0 0
Total		0	0	0	0	0	0	0	0	0	0

Total Project costs: 0

3. Concept Template for the Paraguay RFFL Location
(Completed at a workshop by Lila Gamarra Faculty of Agrarian Sciences National University of Asuncion and Haroldo Silva, Action Environmental Division, Itaipu Binacional)

PROJECT TITLE	Towards to the Forest Restoration Landscape of Eastern Region of Paraguay
Location	Itabó Natural Reserve of Itaipu Binacional District of Santa Fé of Paraná, Department of Alto Paraná, Paraguay Site 1: 21 J 732630.00 m E 7218900.00 m S Site 2: 21 J 747086.00 m E 7211667.00 m S  Potential sites
Scale	The RFFL plot is part of the Itaipu Biosphere Reserve. It is located within the formation of the Alto Paraná Atlantic Forest, shared by countries such as Paraguay, Brazil and Argentina. Considered a biodiversity hotspot and with a high level of threat today. The study area will have 80 hectares.

Gover-nance	Who owns or controls access to the land the RFFL will be located on? • Private land (Itaipu Binacional) • Who are the main stakeholders in the landscape? • Producers mainly of extensive agriculture and livestock • Cooperatives • Indigenous Communities • Private protected areas of Itaipu Binacional (autonomous) • Government agencies (INFONA, MADES) • NGOs
Vision	State the problem or problems that are being addressed, addressing one or two main issues • Deforestation and conversion to cattle grazing and agriculture have reduced biodiversity and other ecosystem services • Resiliency of forests at risk from climate change requiring adaptation to future climate • Erosion and compaction of the soil (mechanical and physical properties) • Reduced ecosystem services • Biodiversity loss and endangered species • Reduced socioeconomic benefits of the forest to people
Concept	State the objectives of the treatments to be demonstrated at the RFFL Location: • Increase forest productivity, climate benefits and biodiversity of degraded agricultural land • Reduce soil erosion and mass movement • Introduce or create value chains for marketable products and/or services • Convert monoculture plantations of non-native species to mixed species stands • Reduce forest restorations costs • To maximize forest uses and improve life quality.

Actions	Briefly describe the treatments to achieve the objectives, including: • Do nothing (this could be natural regeneration). **Treatment 1** Passive restoration In this treatment, the behavior of the plant species present on the site will be observed without any type of intervention. • Business-as-Usual (BAU) treatment (for the purpose of comparison with innovation). **Treatment 2** Reforestation with tree native species selected just for one criterion (forest cover) Currently the main criterion for the selection of tree species for restoration purposes is growth, and the size and density of the crown. In this way, the rapid formation of a forest cover is achieved, the presence of competing plants is reduced, and the maintenance cost is reduced. The use of this method is spreading in the eastern region of Paraguay. • Innovative treatment(s). **Treatment 3** Reforestation with tree native species selected for multiple criterion and uses of other groups of plants This treatment proposes to use, in addition to the treatment 2 criterion, multiple selection criteria that consider aspects such as: conservation status of the species, quality of the wood, medicinal and honey. This will also include other groups of plants such as certain shrubs, herbaceous plants and epiphytes of known economic value. **Treatment 4** Reforestation with exotic fast-growing species (Eucalyptus) mixed with native tree species (high timber value)

	This treatment poses an option for the restoration of legal reserve forests in Paraguay seeking to be attractive to producers and reduce the costs of establishing plantations for forest restoration purposes. In the first stage, eucalyptus trees will be planted in strips only once. Once the eucalyptus trees are harvested at 7 years old, native species with high economic value will be established for sustainable use. **Treatment 5** Reforestation with Yerba Mate This treatment proposes the use of fast-growing native forest species in association with Yerba mate, considering the cultural and economic importance of the latter for the Paraguayan population. In principle, fast-growing native forest species will be planted until there is sufficient coverage for yerba mate to be installed, since it is a species that does not tolerate direct exposure to the sun. It should be noted that the part used to make tea is the leaves and the harvest cycle is 4 years.
Sustaining	Short-term and long-term monitoring schedule, including what will be monitored, by what measurement, at what interval, by whom, applying what type of technology: **1st year (each 3 months)** • Chemical, physical and biological properties of the soil • Taxonomic identification of seedlings • Ground cover plant • Coverage of grasses and other competitors • Height, neck diameter and breast height and seedling cover • Classification in successional groups, dispersal syndrome, origin • Survival • Herbivory rate • By student crews.

2nd year (each 6 months)

- Taxonomic identification of seedlings
- Height, neck diameter and breast height and seedling cover
- Classification in successional groups, dispersal syndrome, origin
- Regeneration studies
- Ground cover plant
- Coverage of grasses and other competitors
- By student crews.

3-5 year (each 1 year)

- Height, neck diameter and breast height and seedling cover
- Classification in successional groups, dispersal syndrome, origin
- Regeneration studies
- Ground cover plant
- Coverage of grasses and other competitors
- By student crews.

6-10 year (each 2 year)

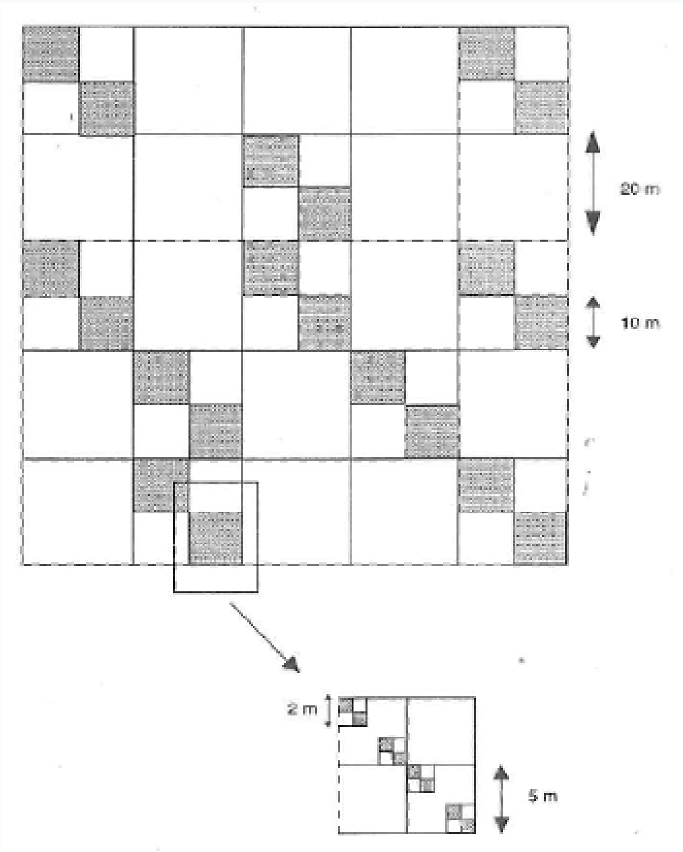
- Height, diameter and seedling cover
- Classification in successional groups, dispersal syndrome, origin
- Regeneration studies
- Ground cover plant
- Coverage of grasses and other competitors
- By student crews.

11-20 year (each 3 year)

- Chemical, physical and biological properties of the soil
- Diversity, biomass, structure and composition treatment
- Diversity (trees species, groups of plants, functional diversity)
- Regeneration studies
- By student crews.

Benefits	Project local, regional, and national benefits from the RFFL Project including products and materials needed for a sustainable future, for example: • Production of medicinal plants for self-consumption and for sale. • Production biomass and timber for self-consumption and for sale. • Improve connectivity between remnant forests. • Jobs created for seedling production, tree planting and maintenance of plantations. • The planted forests facilitated natural regeneration and enhanced tree species composition and diversity. • Improved soil fertility, and increased carbon sequestration due to increased tree cover. • Conversion of degraded forests to plantations can restore key tree species that dominated the original forest and other critical ecosystem services. • Contributes to the national landscape restoration agenda, restoration of ecosystem services, climate change mitigation/ adaptation efforts, as well as disaster risk reduction. • Meeting national biodiversity commitments. • Meeting national climate change mitigation commitments (NDC). • Meeting national forest restoration plan commitments. • Management options, techniques, strategies and governance lessons for engaging local communities that were developed, may guide future landscape restoration projects/initiatives. • Building local capacity and knowledge in landscape forest restoration

<table>
<tr><td>Potential Partners</td><td>Who are the partners?
Actual
• National University of Asuncion: Students, Professor: Plot monitoring, data processing, research, communication
• Itaipu Binacional: Provide the land and the plots establishment and support for monitoring
• IUFRO: Research, communication

Potential
• Paracel S.A. (Private sector - Pulp industry)
• Agro Industrial Guarapi S.A. (Private sector)</td></tr>
<tr><td>Design</td><td>• What size area?
1 ha (100x100 m)

</td></tr>
</table>

Work Plan	**Year 0** • Pre-treatment activities • Objectives • Design for each treatment • Species selection for each treatment • Get seedlings • Define activities dates for each treatment **Year 1** • Establishment activities (treatments, immediate post-treatment tending) • Soil analysis • Plantation • Maintenance activities (plant competitor control, ants control, trees reposition) Measurement schedule Monitoring diversity, biomass, structure and composition treatment • Year 1 (each 3 months) • Year 2 (each 6 months) • Year 3 - 5 (each 1 year) • Years 6 - 10 (each 2 year) • Years 11 - 20 (each 3 year) **Grass cover** • Year 1 - 2 (each 3 months) • Year 3 - 4 (each 4 months) • Year 5 (each 6 months) • Year 6 - 10 (each 2 year) • Years 11 - 20 (each 3 year) **Soil** • Years 5, 10, 20 Success or adaptive management

Data Management	Where will data be stored (locally and IUFRO) • National University of Asuncion - Itaipu Binacional - IUFRO Who will have access (edit, add, read-only) • National University of Asuncion - Itaipu Binacional (edit - add) • IUFRO (add suggestions, read) • Forestry National Institute INFONA (read only) • Environmental and Sustainable Development Ministry MADES (read only)
Budget and Finance	**Budget** *01_21062023_RFFL Budget Template.xlsx* • Grant proposals, funding sources (actual and potential) • Owner land and treatment installation costs: Itaipu Binacional **Potential** • Owner land and treatment installation costs: Paracel S.A. (Private sector - Pulp industry) and Agro Industrial Guarapi S.A. (Private sector)
Reporting and Documentation	What stakeholders need reporting? How frequently? What financial reporting is required (who needs it, what do they need) • Semester expense list • Study Plan (the fully described concept note) • Establishment report (how was it actually done, how did it deviate from the plan, what problems were encountered that might affect results, etc.) After the establishment • Monitoring reports (after each re-measurement) • Annually
Communication	• Stakeholder communication • Community outreach • Media (press, on-line, etc.)

4. Useful Apps and Websites

Africa Tree Finder: shows data on the distribution of indigenous tree species in different natural vegetation types, combined with information on the products and services that the tree species can provide. Currently maps are only available for Kenya and Uganda.
https://lnkd.in/e4JxrwDB

Capfitogen: software for eco-geographical characterization of the germplasm collecting sites - identifies seed zones.
http://www.capfitogen.net/

Climate Data Online: CDO provides free access to NCDC's archive of global historical weather and climate data in addition to station history information.
https://www.ncei.noaa.gov/cdo-web/

CORDEX: Regional climate projections are results from regional climate model simulations which have been generated by multiple independent climate research centres.
https://confluence.ecmwf.int/display/CKB/CORDEX%3A+Regional+climate+projections?src=contextnavpagetreemode

Diversity For Restoration - decision-making on the use of appropriate tree species and seed sources for tree-based restoration.
https://www.diversityforrestoration.org/

EFI: European Forest Institute has several online databases on different aspects of European forests, forestry and forest research. These include **EFISCEN** - The European Forest Information Scenario Database a forest inventory database of European countries, used in particular by the **EFISCEN** forest scenario model. **LTFRA** - Long Term Forest Resources Assessment Database on forest resources in the **UNECE** region. **FPTF** - Forest Products Trade Flow Database, has precise estimates of the trade flows. **DFDE** - Database on Forest Disturbances in Europe. **EFIMED** allows searching data on the state of the Mediterranean forests, the quantity and value of wood and non-wood forest goods and services. These databases can be accessed free of charge after registering.
https://efi.int/knowledge/databases

ESA Climate Change Initiative: open data portal, free and open access to all Essential Climate Variable data products developed by the ESA Climate Change Initiative.
https://climate.esa.int/en/data/#/dashboard

FAO Forest Restoration Monitoring Tool (FAO, 2012): operational guidelines for the restoration of degraded areas particularly in dry land forests.
http://www.fao.org/sustainable-forest-management/toolbox/tools/tool-detail/en/c/233276/

ForestPlots: focuses on the tropics, includes over 6.8 million tree measurements from more than 21,000 species. The first was made in 1939.
http://www.forestplots.net/

Global Temperature Data Sets: overview & Comparison Table. Global surface temperature data sets are an essential resource for monitoring and understanding climate variability and climate change.
https://climatedataguide.ucar.edu/climate-data/global-temperature-data-sets-overview-comparison-table

iNaturalist: a place to record and organize nature findings, meet other nature enthusiasts, and learn about the natural world. It encourages the participation of a wide variety of nature enthusiasts, including, but not exclusive to, hikers, hunters, birders, beach combers, mushroom foragers, park rangers, ecologists, and fishermen.
https://www.inaturalist.org/

LandPKS: a mobile app to identify land potential and monitor change over time. The mobile device can be used for soil identification, land cover and soil health monitoring, land management and farm record keeping.
https://landpotential.org

LOTVS: Long-Term Vegetation Sampling; a collection of temporal vegetation data recorded using permanent plots worldwide. At present, it includes vegetation time-series from 79 datasets, for a total of ~8000 plots and ~4500 plant species recorded.
https://lotvs.csic.es/

Monitoring & Inventory Tools: Northwest Natural Resources Group. Includes sample forms for small landowners.
https://www.nnrg.org/resources/monitoring-and-inventory-tools/

Northeast Temperate Network Long-term monitoring protocols: US National Park Service, temperate forests; various protocols.
https://www.nps.gov/im/netn/protocols.htm

Open FORIS: a collection of free open-source solutions for forest and land monitoring. Includes applications for field data collection, Data management, visual interpretation, and geospatial analysis.
https://openforis.org/

Regreening App: phone-based app for gathering insights into how farmers are preserving and nurturing trees on their land. Developed as part of the Regreening Africa project, which aims to combat land degradation across Ethiopia, Ghana, Kenya, Mali, Niger, Rwanda, Senegal, and Somalia.
https://lnkd.in/eGBShNxV

Restor: open-data platform, to access ecological insights at the site level, show current and potential tree cover, which species of flora could exist, and how much potential carbon could be stored - monitor recovery and impact.
http://www.restor.eco/

Restoration Diagnostic: a method for developing forest landscape restoration strategies by rapidly assessing the status of key success factors.
https://www.wri.org/publication/restoration-diagnostic

Restoration Opportunities Assessment Methodology: to evaluate restoration readiness prioritize restoration sites, support decisions on intervention types, collaborative costing and benefit-sharing.

https://www.iucn.org/theme/forests/our-work/forest-landscape-restoration/restoration-opportunities-assessment-methodology-roam

RFFL: the Resilient Future Forest Laboratory is a global network of demonstration and research plots that cover large gradients of climatic and socio-economic condition.
https://resilientfutureforest.org

SeedIT: phone app, to track, manage and diversify seed collections.
https://seedit.io/

SEOSAW: The Socio-Ecological Observatory for Studying African Woodlands is a network of scientists and woodland survey plots in Africa with the long-term goal of is to understand the response of African woodlands to global change.
https://seosaw.github.io/

SER 5-Star Recovery System: assessing and ranking a site's degree of recovery over time compared with the reference ecosystem.
https://www.ser.org/page/SERNews3113

SUPERB: Systemic solutions for upscaling of urgent ecosystem restoration for forest-related biodiversity and ecosystem services; 12 large-scale demonstration areas representing the diversity of stressors on European forests and the wide range of necessary restoration actions that consider entire socio-ecological systems.
https://forest-restoration.eu/

Tropical Managed Forest Observatory: a pan-tropical network aiming at understanding the long term effects of logging on tropical forest ecosystems. TmFO encompasses more than 600 permanent forest plots spread across three continents (Latin America, Africa and South East Asia).
https://tmfo.org/

Vegetationmap4Africa web-based vegetation map with complementary species/site matching tool for Africa.
https://vegetationmap4africa.org/

WePlan-Forests: a range of advanced forest ecosystem restoration planning and spatial modelling solutions to support decision makers and policy development.
http://weplan-forests.org/

World Bank Group, Climate Change Knowledge Portal: climate data aggregations at national, sub-national, and watershed scales.
https://climateknowledgeportal.worldbank.org/

WorldClim: database of high spatial resolution global weather and climate data. These data can be used for mapping and spatial modeling.
https://worldclim.org/data/index.html

WorldClim Bioclimatic variables: derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables. These are often used in species distribution modeling and related ecological modeling techniques.
https://www.worldclim.org/data/bioclim.html

5. Useful Manuals and Guidelines

Plot Design

Andrew, Ian. 1986. **Simple experimental design for forestry field trials** (revised edition). FRI Bulletin No. 71. Forest Research Institute, New Zealand Forest Service. Private Bag, Rotorua, New Zealand. https://scion.contentdm.oclc.org/digital/collection/p20044coll6/id/90/

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IUFRO Headquarters

Marxergasse 2, 1030 Vienna, Austria
Tel: + 43-1-877-0151-0
Fax: +43-1-877-0151-50
www.iufro.org