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A Cost-Benefit Framework for Analyzing Forest Landscape Restoration Decisions

GLOBAL FOREST AND CLIMATE CHANGE PROGRAMME

This report has been produced by the International for the IUCN Global Forest and Climate Change Programme, with funding from UK aid from the UK government.

Published by: IUCN, Gland, Switzerland

Citation: Verdone, M. (2015). *A Cost-Benefit Framework for Analyzing Forest Landscape Restoration Decisions.* Gland, Switzerland: IUCN.

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June, 2015

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Acronyms and Abbreviations

CBA	Cost Benefit Analysis
CDM	Clean Development Mechanism
CER	Certified Emission Reductions
ERU	Emission Reduction Units
EUA	European Union Allowances
FAO	Food and Agricultural Organization of the United Nations
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
IUCN	International Union for the Conservation of Nature
LDD	Land Degradation and Deforestation
MD	Man Days
MEA	Millennium Ecosystem Assessment
NPV	Net Present Value
NTFP	Non-Timber Forest Products
PES	Payments for Ecosystem Services
REDD	Reducing Emissions from Deforestation and Forest Degradation
ROI	Return on Investment
SLCP	Sloping Land Conversion Project
TEV	Total Economic Value
UN	United Nations

"It is impossible to devise effective environmental policy unless it is based on sound scientific information."

- *Kofi Anan, former UN Secretary-General*

1. Introduction

Land degradation significantly reduces the productivity of the land base upon which the well-being of humanity relies. Global estimates suggest that between 1 and 6 billion hectares, approximately 8% – 52% of the Earth's vegetated land base, are degraded (Daily, Restorign Value to the World's Degraded Lands , 1995). This in turn negatively impacts the provision of ecosystem services, with approximately 60% (15 out of 24) of the ecosystem services examined under the Millennium Ecosystem Assessment being degraded or used unsustainably, including the provision of fresh water, food, fuel, and fibre, air and water purification, and climate regulation (Millennium Ecosystem Assessment, 2005). Together, emissions from agriculture, forestry and other land use land accounted for 20-24% of global annual greenhouse gas (GHG) emissions, or net emissions of 12 Gt CO_2e in 2010 (International Panel on Climate Change, 2014). More specifically, and conversion and land degradation alone are estimated to account for 4.4 Gt of CO_2e emissions each year (Mathews & van Noordwijk, 2014).

Locally, degradation and deforestation directly impact many of the world's poorest or most vulnerable communities (FAO, 2008). It is well established that the degradation and deforestation of landscapes can cause downward spirals into poverty (Dasgupta, Diechmann, Meisner, & Wheeler, 2005). High population growth and lack of agricultural intensification can encourage farmers to continuously cultivate, which reduces soil fertility and future crops yields. Degradation and deforestation have also been routinely linked to the frequency and intensity of natural disasters, particularly floods and landslides (UNU-EHS, 2012).

The pressure on landscapes to serve extractive or consumptive use is not likely to decrease in the coming decades. Demand for energy, food, and water - all potentially sourced from the land - is forecast to increase.[1] Such predictions emphasize the need to restore the productive capacity of degraded and deforested lands and restoration has now become a global priority (Lambin & Meyfroidt, 2011). Each of the Rio conventions have adopted goals focused on forest landscape restoration: the Convention on Biological Diversity's Aichi target 15 requires signatories to restore 15 percent of degraded ecosystems by 2020 (CBD, 2011); The UN Framework Convention on Climate Change has also adopted the global goal to slow, halt, and reverse forest cover and carbon loss (UNFCCC, 2013); and the UN Convention to Combat Desertification is focusing on restoring unproductive lands (UNCCD, 2013).

[1] According to estimates from Mckinsey and Company 175 – 220 million hectares of additional cropland would be needed to meet the expected increase in food demand alone.

Forest Landscape Restoration (FLR)[2] is one approach for restoring degraded land and focuses explicitly on restoring important ecosystem services of forests, woodlands, and agricultural land across different land-use systems. The types of benefits FLR returns to society include carbon sequestration, timber and non-timber forest product supplies, biomass for energy production, drinking water filtration, soil and water conservation, improved soil productivity, erosion control and improved biodiversity conservation, among many others.

Recently there has been a growing interest in the contribution forest landscape restoration can make to climate mitigation goals. However, the same holds true for those concerned with food security, water supply, climate adaptation, and other seemingly unrelated sectors (e.g. local economic development). In 2011 a high-level event organized by the Government of Germany and IUCN established the Bonn Challenge – a practical implementation platform to support governments and others in meeting existing international and national commitments related to FLR – with the aim of achieving 150 million hectares of new restoration activities by 2020. To date 15 government and other actors have already contributed over 60 million hectares.

In 2014, the New York Declaration on Forests from the 2014 Climate Summit – which was endorsed by more than 100 governments, civil society and indigenous organizations, and private enterprises – explicitly built upon and extended the ambition of the original Bonn Challenge target of 150 million hectares by 2020 in its call for restoration of at least an additional 200 million hectares by 2030.

Forest Landscape Restoration activities are often misunderstood as involving high up-front costs and low rates of return and these ideas persist because few evaluations of restoration activities include a comprehensive and objective accounting of restoration's ecological and economic impacts. Accounting for the impacts of restoration activities provides an opportunity to determine if their current designs warrant investments by governments, investors, and stakeholders, and when they do not preliminary analysis offers an opportunity to adjust restoration models so that investors see restoration as an investible opportunity.

To address this gap in knowledge this report presents a cost-benefit framework for accounting for the ecosystem service and economic impacts of forest landscape restoration activities in a way that allows the results to be structured to inform multiple types of restoration decision-making that can help decision makers understand the trade-offs of different restoration scenarios. The results can be used to set prices for payment for ecosystem services, identify sources of restoration finance, identify low-cost/high-benefit pathways towards carbon sequestration, and identify priority landscapes for restoration based on return-on-investment analysis.

[2] In this paper restoration is defined to include reforestation, afforestation, agro-forestry, on farm trees, natural regeneration, and other tree-based technologies that improve the production and ecosystem goods and services. See Annex 1 for additional information

2. Cost-Benefit Analysis for restoration decision making

Restoration decision-making is not based on the Total Economic Value[3] of a landscape, but rather on restoration's ability to *change* that value. When identifying areas of restoration potential it is important to know how much the value of ecosystem goods and services would change if the landscape were restored. This allows you to assess the desirability and tradeoffs of different restoration options for the same landscape.

The results from analysis using the framework presented in this report can be used to identify landscapes that would better meet strategic local and national priorities if some restoration activities were to take place. When ecological goals are prioritized over economic ones, the framework can still be used to identify landscapes that produce the desired ecological outcomes for the least cost. Still, it is important to recognize that each landscape is composed of a number of land uses that work together to create ecosystem goods and services that people rely on. While landscapes can be targeted for possessing particular land uses, unless restoration targets the *entire* landscape the benefits of an individual intervention may not be realized (Maginnis et al., 2007).

2.1 Steps in the cost-benefit analysis

There are nine steps in the application of the cost-benefit analysis:

1. Specify the set of restoration transitions: Define which degraded land uses will be restored and the activities that will be used to restore them

2. Define the stakeholders who will be impacted by restoration: Define the groups of people who will be impacted by the restoration transitions

3. Catalogue the impacts and define how they will be measured: Which impacts matter most to the stakeholders who will be impacted by restoration and what units of measurement are most useful for measuring them?

4. Predict the impacts quantitatively over the time horizon of the project: Use ecosystem service models, household surveys, stakeholder engagement, and other estimation methods to quantify the expected impacts of restoration activities

5. Monetize all of the impacts: Use appropriate direct and indirect methods to value the estimated impacts

[3] The Total Economic Value of a resource is defined as the total value people derive from the resource compared to not having it.

6. Discount benefits and costs to obtain present values: Select appropriate discount rates to make streams of future benefits and costs comparable at the present moment

7. Calculate the Net Present Value of each alternative: Subtract the discounted stream of implementation, transaction, and opportunity costs from the discounted stream of benefits

8. Perform sensitivity analysis: The results of the CBA depend on assumptions and the sensitivity of the results to changes in the underlying assumptions should be evaluated

9. Make policy recommendations: From a Pareto-efficiency perspective the restoration activities with the largest NPV should be recommended

2.2 Step 1: Define each restoration transition

Many types of land uses can become degraded through human or natural causes. Primary forest can be deforested or encroached upon so that the diversity of species and the functioning of the ecosystem are degraded. Overharvesting can degrade woodlands and forest plantations and agricultural land can be degraded through poor cropping practices that mine soil nutrients or result in excessive erosion. Some of the functionality of the original land use can be restored with restoration activities that are compatible with the existing land use.

Identifying degraded land uses is not a straightforward exercise because in practice degradation is difficult to define and therefore difficult to measure. Degradation is typically defined as a process whereby the productivity of land as measured through the production of ecosystem goods and services declines over time as a result of biophysical and anthropogenic causes. Since certain land uses can increase the production of some ecosystem services at the expense of others a reference land use must be defined to clearly show that the production of services has declined compared to the reference land use. For example, agricultural land that was formerly primary forest could be considered degraded forestland if the reference land use is defined as primary forest, but if the reference land use is agriculture it may not be defined as degraded.

There are a number of ways to identify degraded land uses. The first attempt to identify degraded land was made by the Global Assessment of Human-induced Soil Degradation (GLASOD) and used a survey of expert opinion to identify the land area being affected by different degrees of soil degradation. The method was subjective, inconsistent, and non-replicable, which limited its use in policy-relevant decision making. Recently, remote sensing scientists have begun measuring degradation through changes in net primary production (NPP) by arguing that changes in NPP are a proxy for changes in other important ecosystem services and therefore represent a valid measure of degradation. Hybrid approaches that combine stakeholder and expert opinion with remote sensing information have also been used to identify degraded land uses.

Once degraded land uses have been identified restoration activities that can restore the productivity of the degraded land have to be proposed. In practice, the productivity of degraded land can be restored to meet a number of environmental and social objectives and stakeholder dialogues will be necessary to identify the most appropriate restoration activities. For example, the productivity of degraded agricultural land can be restored with agroforestry activities that increase crop productivity, provide fuelwood and other wood products to households, increase soil retention, and decrease sedimentation in watersheds. Alternatively, the productivity of degraded agricultural land could also be restored by allowing that land to return to secondary forest.

Together the set of degraded land uses and the corresponding restoration activities constitute restoration transitions. If the main degraded land uses were identified to be agriculture, woodlots, and bare land and the restoration activities associated with each degraded land use were agroforestry, improved management of woodlots, and planted forests, respectively, the restoration transitions would be:

1. Degraded agriculture → Agroforestry
2. Degraded woodlots and plantations → Woodlots with improved management
3. Bare land → Establishment of planted forests

Box 1: Identifying restoration transitions in Rwanda

In Rwanda, IUCN and WRI used consultative workshops with government and non-government stakeholders to identify three degraded land uses that could benefit from restoration through the strategic introduction of trees and improved management practices. Through the consultative workshops, the following land uses in need of restoration were identified:

1. Degraded agriculture
2. Poorly managed woodlots and timber plantations
3. Deforested land

Five broad restoration activities that could be used to improve the ecological and economic productivity of the degraded land uses were proposed by stakeholders:

- Agroforestry on steep sloping land in conjunction with other soil conservation measures such as radical and progressive terracing
- Agroforestry on flat or gently sloping land, including those areas principally managed as pasture and rangelands
- Improved silviculture and rehabilitation of existing, sub-optimally managed woodlots and plantations, including very small (<0.5 hectare) areas
- Protection and restoration of existing areas of natural forests, mainly in or around protected areas but also extending to small isolated fragments
- Establishment or improvement of protective forests on important and sensitive sites such as ridge tops with steep (20-55%) and very steep sloping land (>55%), riparian zones and wetland buffer zones and margins

Based on the degraded land uses and the proposed restoration activities, the following restoration transitions were defined:

1. Traditional agriculture→ Agroforestry on steep sloping land and flat or gently sloping land
2. Poorly managed eucalyptus woodlots and plantations →Improved silviculture and rehabilitation of existing, sub-optimally managed woodlots, spacing only
3. Poorly managed eucalyptus woodlots and plantations→ Improved silviculture and rehabilitation of existing, sub-optimally managed woodlots with spacing and erosion and fire-prevention best practices
4. Deforested land →Protection and restoration of existing areas of natural forests
5. Deforested land → Establishment or improvement of protective forests on important and sensitive sites

2.3. Step 2: Define the groups of people who will be impacted by each restoration transition

Since restoration transitions affect stakeholders at every level from local to global there are potentially many groups of people who could be included in a CBA study. A truly comprehensive estimate of the costs and benefits would include a global group of stakeholders. Federal governments may only be interested in taking national costs and benefits into account and local governments may restrict their stakeholder groups to community members only. The private sector might limit CBA estimates to private landowners since it remains largely concerned with the financial costs and benefits of restoration transitions. When there is doubt over which stakeholders to include a national or global perspective should be taken as this allows the costs and benefits to be analyzed from multiple stakeholder perspectives.

2.4 Step 3: Which impacts matter most to the stakeholders who will be impacted by restoration and what units of measurement are most useful for measuring them?

The third step in the cost-benefit framework is to document the physical impacts of the restoration transitions. Impacts are broadly defined to include both the physical inputs that are needed to restore degraded land, such as seedlings, labor, and equipment, as well as the physical outputs that will be created as a result of the restoration transition. The inputs can be thought of as items that will represent the costs of restoration transitions while the outputs can be thought of as the ecosystem services that will represent the benefits.

2.4.1 Costs

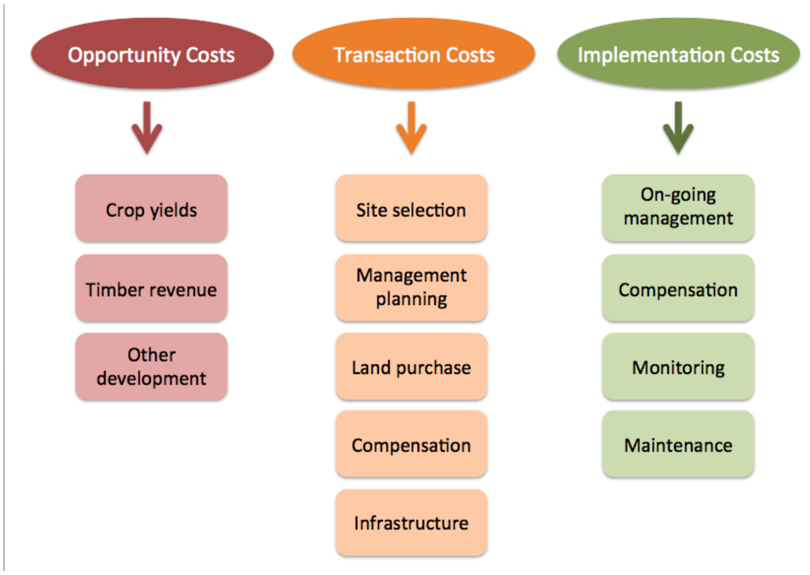
Restoring degraded land requires land, labor, materials, and time. Costs are incurred both directly through the physical process of restoring degraded land and indirectly through foregone production and negotiation and planning processes. The costs of restoration can be placed into one of three categories (See Figure 1):

1. Implementation costs: Implementation costs represent investments in land, labor, and materials and include any expense directly related to the establishment and operation of a restoration project, which could include hiring, training, and managing employees or buying materials.

2. Transaction costs: Transaction costs represent the cost for landowners and implementing agencies to identify viable land to restore and negotiate over terms that ensure restoration meets both local and national priorities.

3. Opportunity costs: Opportunity costs represent the tangible goods and services that were foregone to make restoration possible.

Figure 1: General cost categories of restoration activities



Note: Elements below the cost categories describe different activities and sources of cost. For example, forgone crop yields represent a source of *Opportunity Cost*, while monitoring activities represent a source of *Implementation Costs*.

For this step of the cost-benefit framework the inputs that will be needed for each restoration transition should be catalogued and listed. These inputs come under the Transaction and Implementation cost categories. Opportunity costs are reflected under the physical outputs. For example, in areas where farm inputs are sparingly used, such as East Africa, restoring degraded agricultural land with agroforestry may require a modest number of inputs:

Transaction Costs

- Extension services (Man days; hour)
- Labor (Man days; hour)

Implementation Costs

- Labor (Man days; hour)
- Seeds/Seedlings (Kg; units)
- Organic fertilizer (Kg; bag)
- Farm equipment (units)
- Land (Hectare; Hectare Year^{-1})

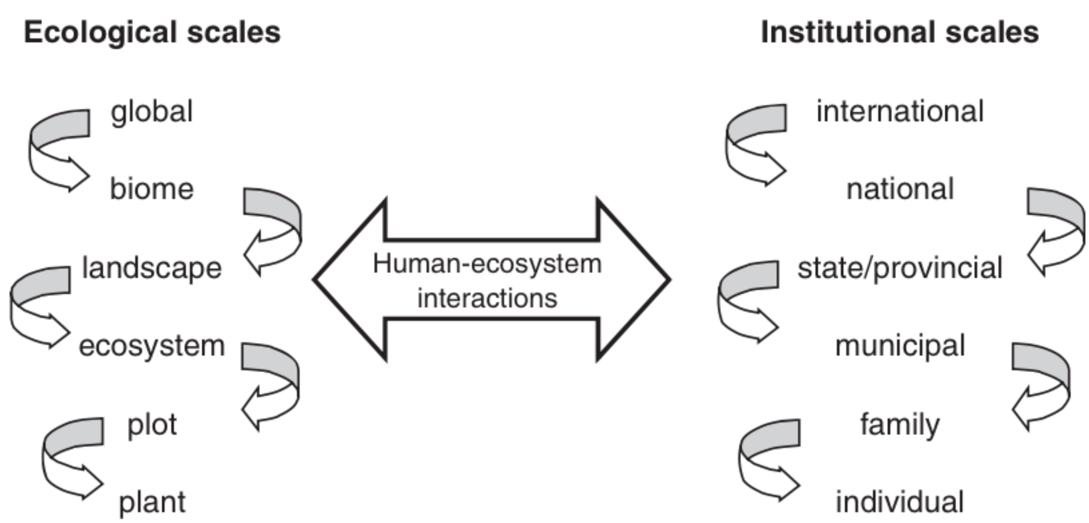
The Transaction costs are accounted for through number of man days or hours of extension services that need to be provided to landowners to train them on how to transition their land to an agroforestry system and the amount of time land owners need to devote to learning about the agroforestry system. Most of the costs are Implementation Costs as the land will require seedlings, fertilizer, farm equipment, and labor to be restored. It is important in this step to define the physical units that will be used to measure the amount of each input that will be needed.

2.4.2 Benefits

Knowing who the stakeholders are and where they are located helps to identify the impacts that will affect them because restoration creates impacts at multiple ecological scales. For local residents, private companies, national and local governments, and society at large all depend on the ecosystem services provided by restored land. Local residents and private companies directly depend on restored land to produce commodities like fuelwood, crops, and timber in addition to providing regulating services that underpin their livelihoods. National and local governments and society at large also depend on restored land to regulate the functioning of ecosystems, but they can also benefit from restored land directly.

Figure 2 shows how the scale of ecosystem services relates to the types of stakeholders who are impacted by them. For example, restoring degraded land within a watershed could benefit landowners by improving the productivity of degraded woodlots and agricultural land while also benefiting downstream fishing communities by reducing eutrophication in important fisheries. The global community could also benefit if the restoration transitions helped regulate the global climate by sequestering carbon.

Figure 2: Benefits of restoration at different ecological scales



The Millennium Ecosystem Assessment (MEA (Millennium Ecosystem Assessment), 2005) defined four categories of ecosystem services and each category of services can impact different groups of stakeholders.

- Supporting services – Services that are necessary for the production of all other services.

- Provisioning services – The benefits from products, like food, fuel, fiber, and water that are obtained directly from nature. Private landowners and companies can harvest commodities directly from restored land like fuelwood, crops, or timber. Downstream stakeholders, such as fishing communities or water users, can also benefit if restoration improves the productivity of a fishery or enhances water quality.

- Regulating services – The benefits from processes like carbon sequestration, nutrient cycling, and water and air purification that regulate the functioning of ecosystems. While regulating services are generated at a parcel or landscape scale they can provide benefits to local, national, regional, and international stakeholders alike. For example, carbon sequestrations affects on regulating the global climate everyone equally, although other regulating services like flood control may only benefit stakeholders within specific areas of a watershed.

- Cultural services – The nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and scenic beauty. These types of services are also improved by restoration at different spatial scales and therefore impact different groups of stakeholders. Local residents benefit from restoration through the enhancement of aesthetic, cultural, and natural quality of ecosystems. Eco-tourism is becoming an increasingly popular benefit for local communities, national and local governments, and international tourists. It is important to note that the value of cultural services depends on the cultural backgrounds of each stakeholder group and for that reason restorations impact on cultural values is often left out of cost-benefit analysis despite being an important impact.

Box 2: Ecosystem Service Impacts Identified in Rwanda

In Rwanda, the stakeholder groups used in the cost-benefit analysis were local communities, including private landowners and the global community. Local stakeholders were most concerned about the ecosystem service impacts that restoration would have on provisioning and regulating services. Specifically, stakeholder feedback received during workshops held in the North, South, East, West, and Central part of the country all indicated that stakeholders were primarily concerned with the impact restoration would have on:

- Timber production (M^3 $Year^{-1}$)
- Fuelwood production (M^3 $Year^{-1}$)
- Crop Yields (T ha^{-1} $Year^{-1}$)
- Prevented erosion (T ha^{-1} $Year^{-1}$)
- Carbon sequestration (T ha^{-1} $Year^{-1}$)

The physical units of each impacted ecosystem services were defined in biophysical units with a time dimension to reflect the fact that provisioning and regulating ecosystem services provided benefits over time. Timber and fuelwood production was measured in cubic meters per year, while crop yields, prevented erosion, and carbon sequestration were measured in tons per hectare per year.

2.5 Step 4: Predict the impacts quantitatively over the time horizon of the project

The impacts of restoration transitions are felt over long time periods. Step 4 of the cost-benefit framework is to quantify all of the impacts for each land use (degraded and restored) for the relevant time horizon of the project. Predictions about the levels of inputs (i.e. costs) and the production of ecosystem services must be made for each year and for each land use in a restoration transition. This can be the most challenging aspect of CBA because there is not always a complete scientific understanding of how complex natural systems work, especially when significant changes to their structure are made.

Time horizons should be selected that are compatible with the time scales of the restoration transition and of the stakeholders included in the analysis. The benefits of restoring degraded land can take anywhere from a few years to more than two centuries to occur and short time horizons may unintentionally exclude large benefits that occur far into the future. If society at large is given standing as a stakeholder then time horizons of 50-100 years may be appropriate since the analysis is interested the welfare impacts restoration will have on both current and future generations. In other cases, stakeholders interested in profitability and returns on investment may only be operating on time horizons of a few years to a few decades.

2.5.1 Quantifying the inputs of each degraded land use and restoration activity

An annual site-level budgeting approach can be used to quantify the inputs that make up the implementation and transaction costs of each degraded land use and restoration activity. The approach records each activity and material input that is needed for each land use and restoration activity on an annualized, site-level basis. This information can be collected using published enterprise budgets or by using a combination of peer-reviewed data and expert opinions.

Box 3: Quantifying inputs of restoration transitions in Rwanda

In Rwanda, IUCN and WRI used peer reviewed publications, stakeholder consultation, and expert opinion to quantify the inputs that would be needed for different restoration transitions.

Figure 3: Annual enterprise budget for Maize in Rwanda

Annual maize farm budget for Rwanda (1 hectare)				
Items	Unit	Quantity	Unit Price	Total cost (RWf)
Variable input costs				
Hired labor	Work days	22	1,000	22,000
Household labor	Work days	199	500	99,500
Seeds	Kg	40	93	3,720
Organic fertilizer	Kg	3,000	2	6,000
Capital costs			660	660
Fixed costs				
Small agricultural equipment			1,900	1,900
Discounted value of costs				2,932,635

The inputs considered in the analysis were hired and household labor, which covers activities including: bush clearing, planting, monitoring, demarcation, regeneration assistance, thinning, coppicing, beating-up, and establishment and maintenance of anti-erosion ditches, seeds, seedlings, organic fertilizer, and small agricultural equipment. Figure 3 shows the budget for degraded maize agriculture in Rwanda. The third column lists the quantities of each input.

There are two biological production function based approaches to quantifying the impacts restoration transitions have on benefits. Biological production functions relate the structure of an ecosystem to the outputs of goods and services that particular ecosystem produces (Daily, et al., 2009). They accomplish this task by representing ecosystem structure (e.g. soil nutrients, precipitation, slope, land cover) as inputs into production functions that produce various outputs (e.g. carbon sequestration, crops, fuelwood, water purification). Common services, like carbon sequestration and erosion prevention have been represented by generalized functions that can be applied to different field settings by changing the parameters. For less common services (like?) production functions need to be empirically estimated.

One approach to modeling the impacts of restoration transitions can be called the ad-hoc approach because the impacts are modeled on an ad-hoc basis following the results from Step 3. Once the ecosystem services that will be impacted by the restoration transition are identified, biological production functions and location-appropriate parameters are identified through a review of peer-reviewed and grey literature. This approach is highly adaptable in that the impact of restoration on virtually any service can be modeled so long as a production function and location-appropriate parameters exist. The drawback to this approach is that it can be time intensive to locate the production functions and parameters and in some cases they may not exist at all.

Box 4: Ad-hoc approach to erosion modeling in Rwanda

In Rwanda erosion on steeply sloped agricultural land is a widespread problem that reduces soil fertility, introduces additional costs into water provisioning, and reduces the output of hydroelectric facilities. As part of the assessment of restoration opportunities in the country it was therefore important to quantify the impact that converting steeply sloped agricultural land to agroforestry would have on erosion. This was done by parameterizing the Universal Soil Loss Equation (USLE) for Rwanda (Hudson, 1993). The equation of the USLE is:

$$Erosion = R * K * L * S * C * P \qquad [7]$$

Where
R = Energy delivered during each precipitation event.
K = Soil erodibility index.
LS = Plot length and Slope.
C = Soil cover factor.
P = Management practice factor.

Table 1 displays the information used to estimate the impact that converting steeply sloped agricultural land to agroforestry would have on erosion. Monthly precipitation data from Meteo Rwanda was combined with soil erodibility and soil cover values from a GIS database provided by the Rwandan Natural Resources Authority, and slope estimates from the 2008 Rwandan Agricultural Survey, at the provincial level, to estimate the amount of erosion associated with each land use and restoration intervention.

Table 1: Prevented erosion from restoration transitions in Rwanda

Restoration transition	Land use	Universal Soil Loss Equation					Average Annual Erosion (t/ha/year)	Prevented erosion (t/ha/year)
		R	K	LS	C	P		
Steeply sloped agricultural land to Agroforestry	Steeply sloped agriculture	332	0.12	1.5	0.3	1	17.93	11.95
	Agroforestry	332	0.12	1.5	0.1	1	5.98	

According to the estimates shown in Table 1, converting steeply sloped agricultural land to agroforestry would reduce erosion by 11.95 tons per hectare per each year.

The second approach to modeling the impacts of restoration transitions is to use ecosystem service modeling tools that are now widely and freely available. While economic valuation methods for ecosystem services and biophysical models of natural processes have existed for decades, the development of dedicated tools for ecosystem services modeling has occurred more recently. This notably followed the release of the Millennium Ecosystem Assessment and, shortly after, the launch of systematic and sustained ecosystem services modeling approaches like InVEST and ARIES (Bagstad et al. 2013). Improved functionality and documentation with new versioning has occurred for several ecosystem services tools; others have been renamed, rebranded, or embraced new funding models (i.e., moving from free/open source to fee for use/proprietary). Some tools appear to no longer be supported or in use, while new other new tools have emerged.

In light of the continuing evolution of ecosystem service tools and in support of their use in large-scale forest ecosystem service assessment in the developing world IUCN, in partnership with Earth Economics and USGS, undertook a review of the ecosystem services tool landscape to identify tools that could be used in a cost-benefit analysis applied to restoration decision making. The advantage of using open-access ecosystem modeling tools rather than an ad hoc modeling approach is that tools are sufficiently developed to run reliably, use validated models, produce replicable results, and have their methods, assumptions, strengths, and limitations well documented as part of a user manual and peer-reviewed journal articles, which may include validation exercises. Tools that are well developed and documented have greater transparency and credibility, which generates trust with decision makers and the public.

Table 2 provides the results of this list. Each tool provided in this table was chosen based on the simple criteria shown above.

Table 2: List of ecosystem service modeling tools

Abbreviation	Model Name	Developer	Tool Description
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs	Natural Capital Project	Spatial mapping and modeling of multiple ecosystem services. The 17 models of ecosystem services range from wave energy and off shore wind energy, to recreation value and scenic quality. The models provide spatially explicit results in either biophysical or economic terms.
ARIES	Artificial Intelligence for Ecosystem Services	BC3	Links multi-scale variability (Spatial, Temporal and Structural) and spatially explicit ecoservices directly to beneficiaries. Models map services as a flow from ecosystem, to service, to those that receive the benefit in an attempt to reduce double-counting. This tool also uses a "Probabilistic Bayesian approach to [adjust for] data uncertainty and scarcity."
MIMES	Multiscale Integrated Models of Ecosystem Services	Affordable Futures	Open Source Modeling Platform which attempts to model the cause-effect relationship/link between ecosystems and the economy. MIMES allows for an individual to map decisions/policies and illustrate how those choices with ripple through the economy and ecosystems.

EcoMetrix	EcoMetrix	EcoMetrix Solutions Group and Parametrix	Field based tool, designed for use at relatively fine spatial scales. Primary use is to illustrate the effects of human activities on natural capital/ecosystem services. This software could aid in deciding how to sustain ecosystem services over the long run through human action.
NAIS	Natural Assets Information System	Spatial Informatics Group	NAIS is an integrated database of valuation literature and reporting engine. The database is integrated with proprietary spatial modeling tools to characterize ecosystems and flow of services on the landscape.
EVT	Ecosystem Valuation Toolkit	Earth Economics	EVT provides monetary values for natural assets under multiple modules: Researcher's Library: Researchable database of ecosystem service values, SERVES, a web-based tool for calculating ecosystem service values and performing natural capital appraisal. Resources: General materials on ecosystem services and valuation as well as links to further resources around the web.
SolVES	Social Values for Ecosystem Services	USGS	Spatial mapping and modeling of cultural ecosystem services. A GIS application that estimates the social values of ecosystem services such as recreation, culture and scenic quality.
ESR for IA	Ecosystem Services Review for Impact Assessment	World Resources Institute	The model provides a six step method to address project impacts and dependencies on ecosystem services as part of the environmental and social impact assessment process. First, it identifies measures to mitigate project impacts on the benefits provided by ecosystems. Second, it identifies measures to manage operational dependencies on ecosystems.

MESP	Marine Ecosystem Services Partnership	Duke	Database of publications that report economic outputs of ecosystem services. Provides an interactive map (through filters) to show publications by region. The tool specifically targets oceanic and coastal (marine) ecosystem services and provides databases specified by region/ecosystem.
Tessa	Tessa	Bird Life International	A site-specific look at ecosystem services. The tool allows for an “alternate state” which can be directly compared to with the current state of an ecosystem. Uses flow charts to map where the ecosystem services are benefiting society.
Co$ting Nature	Co$ting Nature	King’s College London and AmbioTEK	Spatial mapping and modeling of multiple ecosystem services using global coarse-resolution datasets. Understands ecosystem services as an opportunity cost (avoided cost of producing those services from a non-natural capital substitute). This tool emphasizes the importance of conservation measures.
EnSym	Environmental Systems Modelling Platform	State of Victoria, Australia	EnSym is an environmental systems modeling platform and framework for scientists and researchers to test and apply empirical and process-based scientific models. EnSym provides users with an evidence-based framework to support decision-makers on how and where to invest to maximize environmental outcomes.

LUCI	Land Utilisation and Capability Indicator	Victoria University of Wellington	Formerly known as PolyScape. ”LUCI explores the capability of a landscape to provide a variety of ecosystem services. It compares the services provided by the current utilization of the landscape to estimates of its potential capability, and uses this information to identify areas where change might be beneficial, and where maintenance of the status quo might be desirable” (quoted from website)
Wildlife Habitat Benefits Estimation Toolkit	WHBET (**Specific Paper)**	Defenders of Wildlife and Colorado State University	Spreadsheet for monetary valuation (function transfer). Models include: residential property values and open space, wildlife recreation, and total value of habitat/wetland services.
Envision	Envision	Oregon State University	Open Source GIS-based tool for scenario based planning and environmental assessment. Able to complete “multiagent modeling” to represent human decisions on landscape simulations.
iTree	iTree	USDA	Provides urban forest analysis and benefit assessment tools. This tool specifically identifies ecosystem services from tree (be it a single tree or forested park, neighborhood, city or state). The tool aids in urban forest management activities.
Madrona	Madrona	EcoTrust	Open source software used for a decision support and area-based planning that can be used by a broad audience. Madrona creates a framework for modeling a specific goal, audience, geography and culture in decision making process.
EcoSET	Ecosystem Services Evaluation Tool	Biodiversit y Institute Oxford	The model's aim is to generate a user-friendly automatic ecosystem service evaluation tool to calculate on-demand maps of ecosystem service provision anywhere globally.

MIDAS	Marine Integrated Decision Analysis System	Boston University	Software tool that acts as a management mechanism for predicting Marine Management Areas effects based on ecological, socioeconomic and governance variables, as well as outputs showing results of various management actions.
RIOS	Resource Investment Optimization System	Natural Capital Project	Spatial mapping and modeling of multiple ecosystem services. The tool combines biophysical, social, and economic data to help users identify the best locations for protection and restoration activities in order to maximize the ecological return on investment, within the bounds of what is socially and politically feasible.
SWAT	Soil and Water Assessment Tool	Texas A&M University, USDA	SWAT is a small watershed to river basin-scale model to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change.
PA-BAT	Protected Area Benefit Assessment Tool	World Wide Fund for Nature (WWF)	The PA-BAT aims to help collate information on the full range of current and potential benefits of individual protected areas. This toolkit provides the necessary data to assess the benefits of protected areas as well as the beneficiaries (how/where benefits are transferred).
Open NSPECT	Open NSPECT	NOAA	Open-source version of the Nonpoint Source Pollution and Erosion Comparison Tool (more), to investigate potential water quality impacts from development, other land uses, and climate change. The tool specifically simulates erosion, pollution and their movement/accumulation from overland flow including elevation data.

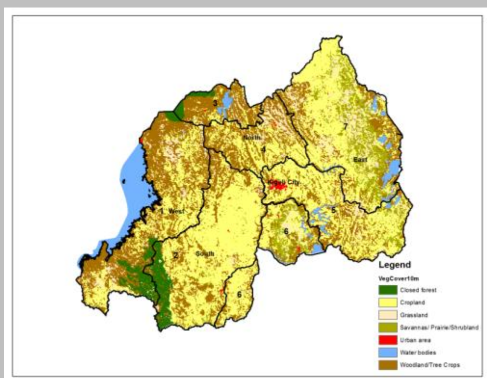
All of the tools in Table 2 produce biophysical outputs that can be valued with market and non-market valuation methods and used in CBA. Selecting an appropriate tool depends on many factors. Each tool in Table 2 is capable of producing results at different spatial scales although the accuracy of the output of each tool may be sensitive to changes in scale. Additionally, each tool requires specific types of data to produce results. Some tools require several GIS inputs, such as elevation, slope, soil types, etc., depending on the ecosystem service of interest, while other tools require less data but produce less accurate results. Running a tool can also be time consuming depending on whether input data has already been collected and formatted, whether the person running the tool has used it before, and how many outputs are needed to depict different scenarios. It is also important that an ecosystem service-modeling tool can characterize the uncertainty of its results. Reporting uncertainty and providing mechanisms and/or methods to counter large error margins will strengthen ROAM user projects. Reporting a single value can inspire false confidence in the certainty of results, so uncertainty estimates are a valuable addition to the set of model outputs.

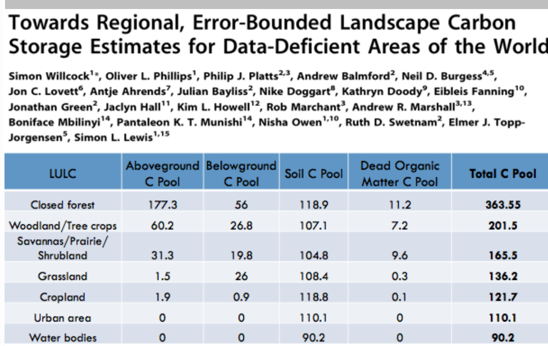
For a more detailed discussion of each tool presented in Table 2 and their applicability to a specific CBA see EE/USGS/IUCN report. Forthcoming.

Box 5: Ecosystem service tool modeling approach: Application of InVest Carbon model in Rwanda

To support the ongoing restoration work in Rwanda The Integrated Valuation of Ecosystem Services and Tradeoffs (InVest) tool was used to model the carbon storage of the current Rwandan landscapes. The output from the model was used to identify low-carbon landscapes that were also identified through stakeholder workshops as being degraded and could potentially be restored. Identifying degraded landscapes with low-carbon storage could present an opportunity to attract carbon finance that could be used to pay for restoration activities that improve the landscapes carbon storage.

Figure 4a: Land use cover map for Rwanda Figure 4b: Carbon storage values by land use





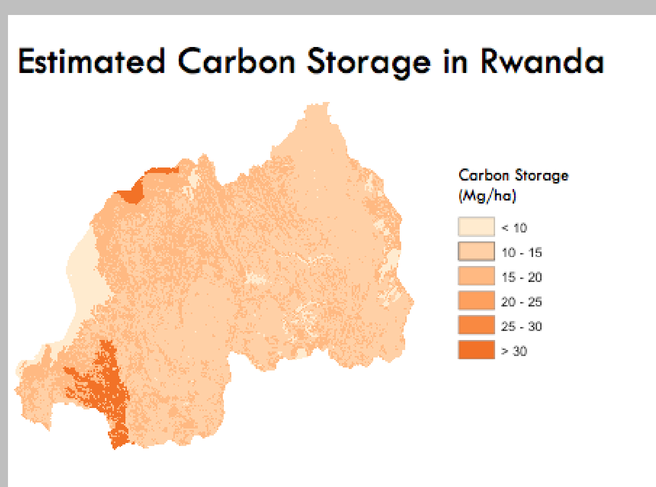
Towards Regional, Error-Bounded Landscape Carbon Storage Estimates for Data-Deficient Areas of the World

Simon Willcock[1*], Oliver L. Phillips[1], Philip J. Platts[2,3], Andrew Balmford[2], Neil D. Burgess[4,5], Jon C. Lovett[6], Antje Ahrends[7], Julian Bayliss[2], Nike Doggart[8], Kathryn Doody[9], Eibleis Fanning[10], Jonathan Green[2], Jaclyn Hall[11], Kim L. Howell[12], Rob Marchant[3], Andrew R. Marshall[3,13], Boniface Mbilinyi[14], Pantaleon K. T. Munishi[14], Nisha Owen[1,10], Ruth D. Swetnam[2], Elmer J. Topp-Jorgensen[5], Simon L. Lewis[1,15]

LULC	Aboveground C Pool	Belowground C Pool	Soil C Pool	Dead Organic Matter C Pool	**Total C Pool**
Closed forest	177.3	56	118.9	11.2	**363.55**
Woodland/Tree crops	60.2	26.8	107.1	7.2	**201.5**
Savannas/Prairie/ Shrubland	31.3	19.8	104.8	9.6	**165.5**
Grassland	1.5	26	108.4	0.3	**136.2**
Cropland	1.9	0.9	118.8	0.1	**121.7**
Urban area	0	0	110.1	0	**110.1**
Water bodies	0	0	90.2	0	**90.2**

The spatial InVest tool models carbon storage across a landscape by assigning carbon storage values to each land use represented in land-use land-cover (LULC) map of Figure 4a. A total of seven (7) different land covers were represented by Rwanda's LULC map and each land-use had to be associated with a carbon storage value for the InVest tool to represent the carbon storage in a spatially explicit way. Estimates from Willcock et al. (2012) in Figure 4b were matched with LULC data from Rwanda and used to estimate the carbon storage of each land use from five carbon pools (aboveground live carbon, litter, coarse woody debris, belowground live carbon and soil carbon) shown in Figure 4c.

Figure 4c: Estimated carbon storage in Rwanda from the InVest model



The output from the InVEST carbon model showed that the Nyungwe National Park in the southwest and Volcano's National Park in the northwest part of Rwanda are the most carbon-dense areas of the country. The output also showed that many areas of Rwanda have low-carbon density that could be improved with restoration activities like agroforestry or improved management of timber and fuelwood plantations. The output was also useful for calculating the change in carbon storage that would occur from restoring degraded agricultural land and degraded timber and fuelwood plantations to closed forest.

2.6 Step 5: Monetize all of the impacts: Use appropriate direct and indirect methods to value the estimated impacts

Economic valuation places monetary value on changes in ecosystem goods and services and puts ecological and biodiversity values on an equal footing with other economic benefits and costs. Not all values of ecosystem goods and services can be measured because they may be intrinsic or religious nature, but they need to be recognized none-the-less. Other ecosystem goods and service, like the existence value people place on knowing a certain species exists even though they may never actually see it in person, can be valued but are difficult to turn into real flows of financial values. Finally, there are ecosystem goods and services, like carbon storage or water yield, that can be both valued and monetized. Choosing a valuation technique generally depends on the impact to be valued and the availability of resources, time and data for the study.

Economists have proposed several methods for valuing ecosystem goods and services depending on the nature of the good or service in question and the methods can be classified into one of three broad categories: 1. Revealed preference methods, 2. State-preference methods, 3. Benefit transfer methods. Each method has its relative strengths and weaknesses and the method that is best for a particular CBA context depends on many factors.

Table 3: Valuation methods for restoration decision making

Methods	Revealed preference methods	Stated preference methods
Direct	Market prices	Contingent valuation
	Simulated markets	
Indirect	Travel cost	Attribute based models
	Hedonic property values	Conjoint analysis
	Hedonic wage values	Choice experiments
	Avoidance expenditures	Contingent ranking

Revealed preference methods use human behavior that is either observed directly or non-directly, to value ecosystem goods and services. For example, fuelwood and timber production can be valued by observing the market prices people are able and willing to pay for different quantities and qualities of fuelwood and timber. Indirect revealed preference methods rely on observing market transactions for other goods and services that can be used to infer the values of ecosystem goods and services. For example, the hedonic property method uses sales data from the housing market to value ecosystem goods and services like species-density and water quality.

Box 6: Valuing crop yields in Rwanda

In Rwanda, the value of improving crop yields by restoring degraded agricultural land with agroforestry was estimated using revealed preference methods. Restoring degraded agricultural land with agroforestry in Rwanda is expected to increase crop yields by returning nutrients to the soil, but the value of increasing crop yields had not been estimated. Expected maize yields of degraded agriculture and agroforestry were estimated with regression analysis using information on crop yields, land area devoted to each crop, growing season precipitation, soil type, growing season temperature, and other variables that influence yield.

Table 4: Value of crop yields for agriculture and agroforestry in Rwanda

Restoration transition	Land use	Expected average maize yield (t/ha)	Annual crop yield value (RWF)
Degraded agriculture to agroforestry	Degraded agriculture	0.8	463.2
	Agroforestry	0.92	532.68
Notes: Price per ton of maize was assumed to be 579 RWF per ton and was retrieved from Rwanda Agricultral Board.			

The estimated maize yields, reported as tons per hectare per year, for degraded agriculture and agroforestry are shown in Table 4. Market prices for maize, reported as Rwanda Francs (RWF) per ton of maize, were collected from the Rwandan Agricultural Board in order to estimate the value of maize production for each land use. Expected yields were multiplied by market prices in order to calculate annual revenues from the sale of crops under each management system.

Stated-preference methods rely on hypothetical human behavior to value ecosystem goods and services, such as existence values for rare species, that are not bought or sold in markets and that are often not experienced through direct use. These methods elicit valuations by asking people, either through surveys or questionnaires, how much they would be willing to pay for a change in the level and quality of an ecosystem good or services. While stated-preference methods can elicit valuations for many goods and services that would not otherwise be valued the method is relatively more time consuming and costly than observed preference approaches. Additionally, the hypothetical nature of stated-preference methods has led to criticism and skepticism over the validity of the valuations.

Benefit transfer methods value specific ecosystem goods and services by transferring the results of valuation studies of the same goods and services from other locations. For example, tourism values for rare primates in one country could be estimated by transferring tourism values for rare primates estimated in a nearby, but different country. Benefit transfer methods are useful when valuation information is needed, but time and funding are not available to implement more rigorous valuation methods. There are several drawbacks to using benefit transfer. Estimates adapted from other study areas are likely to be less accurate in new settings and it may be difficult to know how much the accuracy of the valuation estimates are affected by the transfer. In other cases, high-quality valuation studies on the goods or services in question may not exist and primary valuation research will be necessary.

2.7 Step 6: Discount benefits and costs to obtain present values

Restoration decisions have impacts that occur at different times sometimes several decades or even a century or more in the future. Discounting makes events at different points in time comparable by assigning a weight to future events based on society's preference for events that occur at different points in time. While the concept of discounting is not contentious, the choice the appropriate discount rate is because it has large influences on which projects are approved and which are not and it also reflects the way current generations think about future generations. The long time horizons of restoration projects, which can range between 5 – 200 years, mean that restoration decision-making is especially sensitive to the choice of discount rate.

The costs and benefits of each degraded and restored land use are discounted with the following equation:

$$PV(X) = \sum_{t=0}^{T} X_t * (\frac{1}{1-r})^t \qquad [1]$$

Where the PV(X) is the present value of a stream of benefits or costs, X, that flow over time according to X_t. The time horizon is given T and the discount rate is represented by r. The term $(\frac{1}{1-r})^t$ is known as the discount factor and its value is bounded between 0 and 1. The larger the value of t, that is the further into the future something happens, the smaller the discount factor is and the less weight that event has. Similarly, the larger the value of r for a given t the smaller the discount factor and the less weight that event has.

While the streams of benefits and costs are estimated in Step 4 and are empirical problems, the choice of the appropriate discount rate is a conceptual problem. The idea of discounting applies to goods and services as well as our preference for time. Discounting goods and services reflects the fact that financial capital has an opportunity cost because it can be spent on other investments that could yield returns earlier. This sort of discounting is often referred to as the opportunity cost of capital and it is measured by observing the market yields on government bonds and other low risk investments. The other type of discounting reflects the different weight society places on the welfare of current and future generations and is commonly referred to as the rate of social time preference. Unlike the opportunity cost of capital, which discounts the consumption of goods and services at different points in time, the rate of social time preference discounts the welfare of aggregate welfare of generations at different points time. It is the tension between these two concepts that leads to disagreement over the appropriate rate of discount to apply to environmental decisions.

These issues are still being debating in the academic and policy literature because of the profound role the discount rate plays in environmental decision-making. Without a clear consensus on which discount rate is most appropriate for different decision-making contexts analysts must come up with their own rationale for which rate to use. Stern (2007) used a discount rate of 0.001% to estimate the optimal global response to climate change by arguing that the welfare of future generations should not be discounted at all. Most environmental CBAs use discount rates of between 0-4%, but national and global oversight agencies generally give their own recommendations for appropriate discount rates to apply to projects in their jurisdictions.

2.8 Step 7: Calculate the Net Present Value of each alternative

Local communities, regional and national governments, and conservation organizations must decide whether or not to invest scarce human and physical resources into restoration projects. CBA helps inform these decisions by producing information that describes how efficient different restoration transitions are in terms of their resource use. In other words, is the sum of the discounted flow of benefits greater than the sum of the discounted flow of costs? The net present value (NPV) concept formalizes this logic and allows discounted flows of benefits and costs to be compared on equal terms across alternative projects.

The NPV of each restoration transition is calculated by subtracting the NPV of each degraded land use from the NPV of the restoration activity. If the NPV of the restoration transition is greater than zero it suggests that restoring the degraded landscape is a worthwhile endeavor. A NPV less than zero would suggest that restoring the degraded land use will generate fewer benefits than costs. The NPV is calculated following:

$$NPV = \sum_{t=0}^{T} \delta^t (B_t - C_t) \qquad [2]$$

Where B_t is the annual benefit received from the degraded land use or restoration activity, C_t is the annual cost associated with that revenue, and δ^t is the discount factor. The decision rule for the NPV concept is straightforward. If the NPV of the restoration transition is positive then the land should be restored. In the case where multiple restoration transitions are being evaluated for the same unit of land the transition with the largest NPV should be selected. If the NPV is negative and a full accounting of the benefits has be done it suggests the benefits of the transition are less than the costs and the land should not be restored because they human and physical resources could be invested elsewhere with a larger impact.

2.9 Step 8: Perform sensitivity analysis on the results of the CBA

The costs and benefits of restoration transitions depend on inherently variable economic and ecological parameters, including market prices, interest rates, precipitation, and tree growth rates. Lingering uncertainty over these values introduces an element of risk into the cost-benefit analysis. There are a number of ways to account for this uncertainty.

In order to take account of this uncertainty we use a well-worn “repeated random sampling technique” known as Monte Carlo simulations. Several authors have used Monte Carlo simulations in forestry settings to account for risk in economic analyses (e.g., (van Kooten, van Kooten, & Brown, 1992) (Moore, Ruel, Lapointe, & Lussier, 2012)). This technique also allows confidence intervals to be constructed around the estimated NPV of restoration (Naidoo & Ricketts, 2006) on transitions as well as to identify the situations under which a restoration transition is unlikely to create a benefit.

A Monte Carlo simulation creates data by drawing values from the distribution of a given variable instead of assuming a single average value. This allows for the incorporation of data into your analysis in a way that accounts for the range in values that might be observed in the field (e.g., changes in rain-fall year to year). Table 5 lists the assumptions and data sources used in our Monte Carlo simulations. Since ecological outcomes such as tree growth determine the profitability of each restoration transition we used the Monte Carlo method to generate data representing a range of outcomes one might expect on different land uses.

Table 5: Distributions and data sources for Monte Carlo analysis

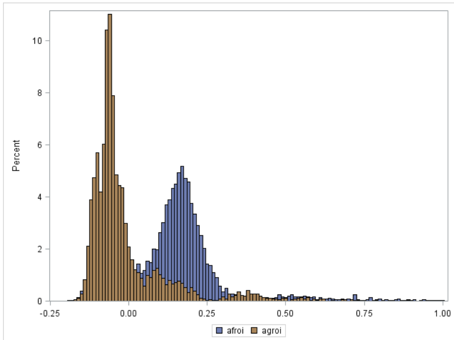
Transition	Distribution Assumptions for Monte Carlo			Sample Size
	Timber	Crop Increase	Carbon	
TAG to AFCL	MAI~N(1.44,0.6)	Increase~Tri(-0.35,0.6)		100,000 draws of 20-year time horizons
PME to IME	MAI~N(10.4,1.6)			100,000 draws of 28-year time horizons
DF to NR			CO2e ~N(300,100)	1,000 draws
DF to PF	MAI~N(4.8,0.8)			100,000 draws of 30-year time horizons

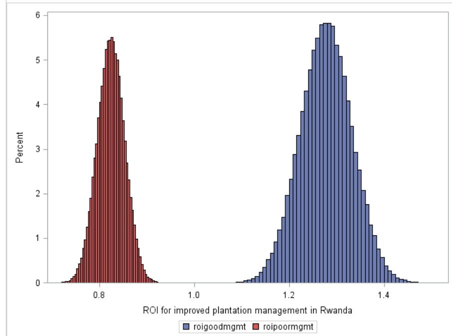
Notes: MAI for TAG to AFCL is for Grevillea robusta at a stocking density of 300 trees/ha. MAI for PME to IME is for Eucalyptus tereticornis and a stocking density of 1600 trees/ha. MAI for DF to PF is for Pinus petula and a stocking density of 1600 trees/ha.

To detail the method we use an example from Rwanda. For timber growth we parameterize distributions for three tree species using peer-reviewed or secondary data sources and assume mean annual increments are normally distributed (generally bell shaped). Detailed data was not available on the distribution of crop increase effects of agroforestry so we assume the effect is triangularly distributed because the distribution does not require information on standard errors. We sample from each distribution 100,000 times in most cases and calculate the NPV and ROI of each restoration transition based on the data from the Monte Carlo simulation. The results from the Monte Carlo analysis are themselves distributions of values as shown in Figure 5.

Figure 5a: Degraded agriculture to agroforestry

Figure 5b: Poorly managed plantations to well managed





The results from the Monte Carlo analysis generate histograms of ROI's for each degraded land use and restoration intervention that show how sensitive the results are to the values of key parameters. In Figure 5a the histogram shows the return on investment of agroforestry (blue) is larger than the return on traditional agriculture (yellow) across most of the range of ecological values simulated in the Monte Carlo analysis**.** The minimally overlapping distributions suggest that agroforestry would noticeably improve the financial performance of agricultural land by making it more productive across most of the modeled range of tree growth and yield scenarios. Figure 5b shows the return on investment of improved woodlot management (blue) versus poor woodlot management (red) is positive across the range of ecological values simulated in the Monte Carlo analysis**.** The non-overlapping distributions suggest that improving the management of existing woodlots would noticeably improve their financial performance.

2.10 Step 9: Make policy recommendations

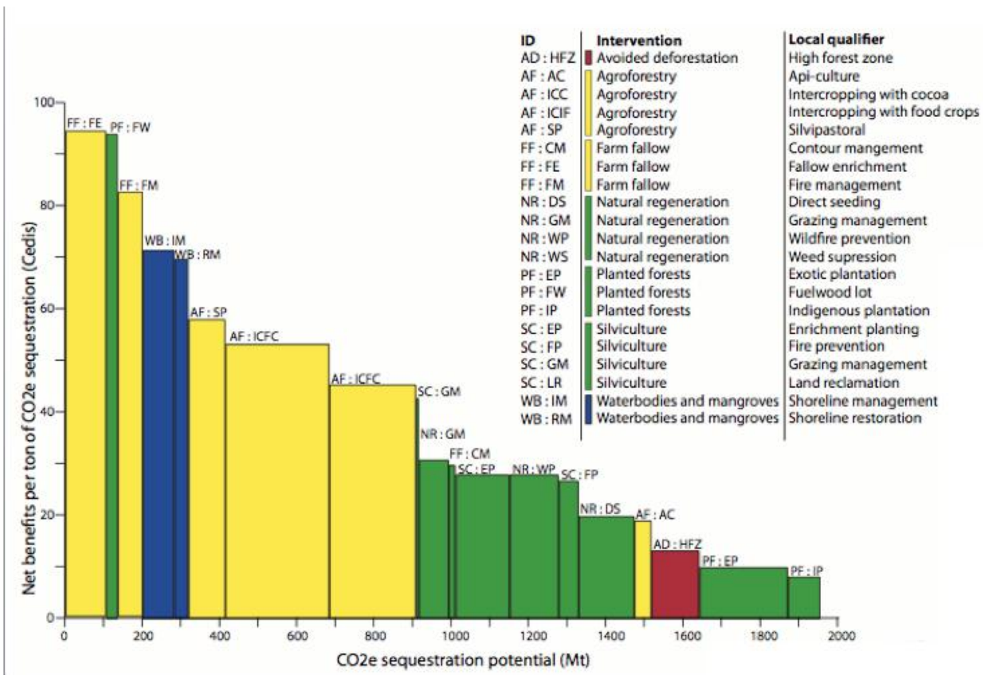
From a pure efficiency perspective, the restoration activity with the largest NPV should be recommended. Of course, other factors will also enter the conversation and influence the ultimate decision about the best way to restore degraded land to meet environmental and social objectives. That is, the NPV concept provides helpful information that can influence the conversation about what to do and where, but it is not the whole conservation.

The output from the CBA can also be used to create other decision-making metrics, like Return on Investment (ROI) that can help start a conversation with investors or other private sector actors who may not be as familiar with NPV, cost-benefit ratios, or other metrics commonly reported with CBA. Output can also be used to identify land use policies to encourage land owners to restore degraded land or it can be used to create carbon cost abatement curves, which show the restoration activities that provide the largest number of benefits for each ton of carbon they sequester.

2.10.1 Ghana carbon cost abatement curve

In Ghana, deforestation and degradation are an increasingly important economic problem. The deforestation rate has remained near 2% per year since 1990, while 70% of the population depends on forests to meet at least some part of their basic food, water, and energy needs (FAO, 2010). With Ghana's Forestry Commission, IUCN used a stakeholder led process to identify restoration opportunities for GHG abatement that also created significant ecosystem service benefits. i.e. increased fuelwood, non-timber forest products, timber, and crop yields, and decreased erosion, . A carbon-abatement curve (Figure 6) was constructed to graphically illustrate that restoration was a cost-effective way for Ghana to increase terrestrial carbon stocks rather than focusing solely on avoided deforestation (red rectangle in Figure 6).

Figure 6: Carbon abatement curve for restoration activities in Ghana



Each bar of the abatement curve in Figure 6 represents a restoration activity in two dimensions: total carbon sequestration on the x-axis and ecosystem services per ton of CO_2e on the y-axis. The wider the bar the more CO_2e that activity sequesters. Similarly, the taller the bar the more ecosystem goods and services it produces for each ton of CO_2e sequestered. For example, the first bar, FF:FE (Farm fallow; Fallow enrichment) indicates that if all opportunities to restore agricultural land with improved farm fallow were taken, Ghana could increase national terrestrial carbon stocks by 100 Mt CO_2e. It also indicates that each sequestered ton of CO2e would be associated with approximately 95 GHC of ecosystem services reflecting gains in fuelwood and timber, decreased erosion, non-timber forest products, and increased crop yields.

The carbon abatement curve helped Ghana secure USD 50 million in financing for forest restoration activities, by identifying additional cost-effective opportunities to increase terrestrial carbon stocks in addition to avoided deforestation. The curve demonstrated that nearly all restoration activities considered in the analysis produced more ecosystem goods and services for each ton of sequestered CO2e compared to avoided deforestation. Restoring degraded land can result in greater gains in ecosystem services compared to avoided deforestation because the baseline level or the production of ecosystem services of degraded land is low.

2.10.2 Rwanda ROI Analysis

In Rwanda, livelihoods are largely based on subsistence agriculture and energy production. With this high dependence on limited land resources a major challenge is to manage the existing stock of resources to meet the needs of an increasing rural population. To this end Rwanda has set a target of “border to border” landscape restoration. In order to support restoration activities with private sector investment, the Rwandan Government wanted to estimate the ROI for each activity. The ROI metric was used to show which activities would be expected to generate positive financial returns to investors assuming a standard set of benefits.

Table 6: NPV and ROI for restoration transitions in Rwanda

Restoration transition	Land Use	Present value of Ecosystem Good/Service				Present value of land use (RWf)	Present value of transition (RWf)	Present value of transition cost (RWf)	ROI of transition
		Timber (RWf)	Carbon (RWf)	Crops (RWf)	Erosion (t/ha)				
Traditional agriculture ->	**AG**	-	-	4,752,296	18	4,752,296	919,477	843,600	9%
Agroforestry	**AF**	81,123	36,019	5,554,631	6	5,671,773			
Poorly managed woodlots ->	**PME**	714,243	145,225	-	15	859,468	184,905	80,558	130%
Improved management	**IME**	847,033	197,340	-	10	1,044,373			
Deforested land ->	**DF**	-	-	-	10	-	68,791	881,674	-92%
Protective forests	**PF**	-	68,791	-	1	68,791			

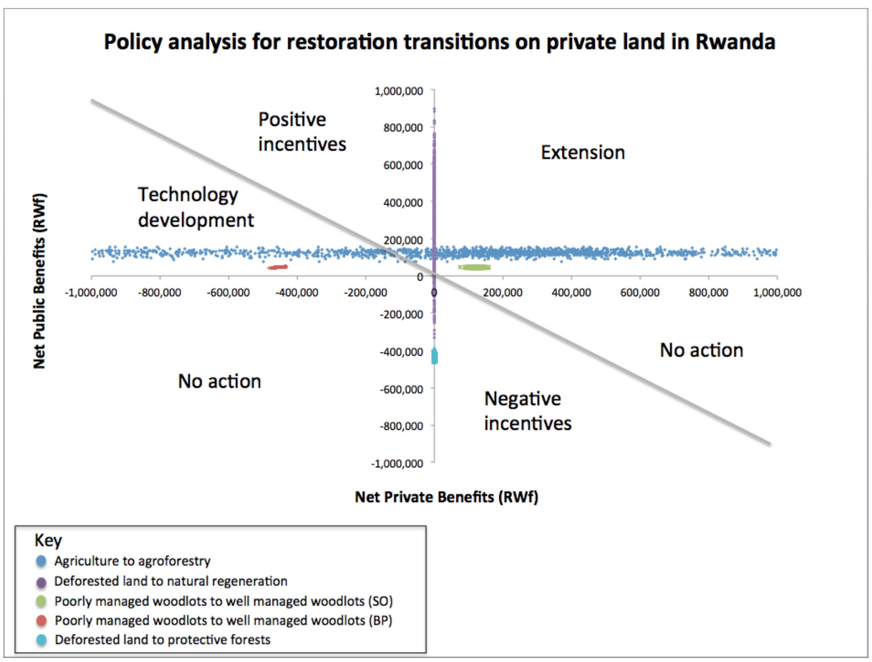
The return on investment (ROI) displayed in Table 6 shows that ROI varies from a low of -92% to as much as 130%. The transition from deforested land to protective forests on ridge tops and steep slopes has the lowest financial return amongst the restoration transitions because the costs of establishing the forests are relatively high compared to the discounted future carbon revenues that are used to offset the costs, and given our assumptions that carbon prices are and complete protection of such lands with no access to NTFPs, no valuation of water provisioning or water quality services, no explicit valuation of the erosion reduction services provided, no pollination services for adjacent agricultural land, no explicit valuation of biodiversity, no existing fire and erosion-protection measures in place on deforested lands, etc. The transition from poorly managed woodlots to well managed woodlots will generate average returns of 130% assuming some fire and erosion-prevention measures are already in place. The transition from traditional agriculture to agroforestry generates an average ROI of 9% as the additional crop, timber, and carbon revenues more than compensate for the additional costs.

2.10.3 Rwanda land use policy analysis

To support their restoration ambitions, Rwanda recently reformed its land tenure system so that landowners now have secure property rights over their land and its use. This poses a challenge to achieving Rwanda's restoration target because restoration activities will only be adopted by landowners if the benefits of the activities outweigh the costs.

The Rwandan Natural Resource Authority (RNRA) used a stakeholder led process which policies could create incentives for private landowners to restore degraded land. Policies were selected using a land-use policy framework from Pannell (2008) and shown in Figure 7, which plots the output of a cost-benefit analysis of restoration activities in Rwanda. The distribution of costs and benefits was estimated by distinguishing between public and private benefits. Public benefits measured the value of ecosystem services produced off-site, namely carbon storage and erosion prevention. Private benefits were estimated based on gains in crop yields, fuel wood and timber production, and on-site erosion prevention.

Figure 7: CBA Policy Chart for Rwanda



The framework assesses not only the magnitude, but also the distribution of benefits to the public and to land managers to identify appropriate instruments to create incentives for landowners to undertake restoration for the least cost. For each activity, the costs and benefits were estimated by assigning financial values to the physical units of ecosystem services based on their public and private benefits. For example, to estimate the value of restoring land from degraded agricultural land to an agroforestry system, the value of incremental crop and timber production, and erosion prevention, were balanced against restoration costs. The difference between these estimates represents the value of additional services produced by restoring the land with agroforestry. Using this convention, we value the public and private benefits of each restoration transition.

The results from the policy analysis in Figure 7 indicate that most restoration activities change the production of both public and private goods as measured through carbon storage, erosion prevention, crop yields, and fuelwood and timber production. In Rwanda, restoring degraded woodlots through the adoption of improved management practices and restoring degraded agricultural land with agroforestry both generated benefits to landowners in excess of their costs, suggesting that landowners would be willing to invest in the practices if extension services introduced the activities to them. These results suggest that restoration activities could be scaled up through modest investments in extension services provided they could reach a large number of landowners.

Figure 7 also shows that restoration activities need to be carefully negotiated with landowners and applied to suitable land because it is possible for restoration activities to negatively impact landowners. For example, in some cases restoring degraded agricultural land with agroforestry reduced crop yields to such an extent that the additional ecosystem service benefits of reduced erosion and additional timber and fuelwood do not fully compensate landowners. Additionally, the benefits society receives are smaller than the amount of compensation that landowners would require to restore the land using agroforestry. While these results could be misconstrued as evidence that restoration is not cost-effective, instead it should be viewed as evidence that investments in restoration, like any other investment, need to be fully evaluated and understood.

3. Conclusions

The amount of money available for restoration is increasing thanks to growing international attention and commitments like the Convention on Biodiversity's (CBD) Aichi Target 15, which calls for the restoration of 15 percent of all degraded ecosystems. Still, the amount of money available for restoration is far less than what is needed, creating a need to identify landscapes that will provide the most value in ecosystem services per unit of cost. In other words, there is a need to target the landscapes that provide the largest return on investment. In the Rwandan context, our analysis found that, if carbon prices are low and constant, and reforestation of deforested steep and very steep slopes yields no quantifiable benefits other than carbon, then landscapes with large areas of poorly managed woodlots are likely to generate the largest returns due to the low costs of restoring productivity, the relatively large amount of timber that could be produced, and the assumption that this timber can be harvested and sold. However, if priority is given to restoration interventions that produce the largest variety of ecosystem goods and services then restoring agricultural landscapes may be a high priority. What is clear is that any landscape has a unique set of costs and revenues that create different ROIs to be evaluated and compared.

While restoration decisions can be based on a wide variety of criteria, including ecological priorities and restoration costs, an integrated approach that accounts for both the costs and benefits of restoration is one most likely to lead to successful outcomes. This framework shows how ecological and economic information can be combined in order to provide actionable information to decision-makers - information that can allow them to direct limited financial resources to the most promising landscapes. Given the amount of degraded land across the world, it will be important to have a tool that gives one the ability to identify the most beneficial landscapes to restore first.

The framework presented in this report is useful for prioritizing investments in restoration across a variety of criteria including NPV, ROI, and multi-criteria decision-making. This information is useful for policy makers, restoration professionals, and natural resource managers who are interested in understanding more about the economic opportunities and trade-offs of restoring deforested and degraded landscapes. The information provided by the framework can help these professionals to use the limited funds available for restoration as efficiently and effectively as possible.

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