Chapter

8

Combating Climate Change by Restoration of Degraded Land

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Chapter 8

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1 RESTORATION OF DEGRADED LAND IN THE CONTEXT OF CLIMATE CHANGE: DEFINITIONS AND HISTORICAL EVOLUTION

Source: Mansourian, S., (2005) Overview of Forest Restoration Strategies and Terms. In Mansourian, S., Vallauri, D., Dudley, N., Forest Restoration in Landscapes - Beyond Planting Trees, pp. 8-17, Springer.

1.1 Introduction

When forests are lost or degraded, we lose far more than just the trees that they contain. Forests provide a large number of goods and services, including habitat for species, homeland for indigenous peoples, recreational areas, food, medicines, and environmental services such as soil stabilisation. And as forest areas are reduced, pressure on remaining forests increases.

Efforts at reversing this trend have had only limited success. For many, restoration signifies large-scale afforestation or reforestation (mainly using fast growing exotic species), which have only limited conservation benefits. This has been the approach taken by many governments that are seeking to support a timber industry or create jobs or, equally, those who have taken a simplistic approach to flood or other disaster mitigation. On the other hand, some have sought to re-create original forests, a near-impossible feat in areas where millennia of human intervention have modified the landscape and local conditions.

Many different terms are used to describe these different approaches and can result in some confusion or misconceptions. We attempt here to cover most of the terminology used in English taken from the Society for Ecological Restoration International (SERI), which has made the best attempt at cataloguing and defining these different terminologies and concepts. It must be noted that this complexity is also apparent and sometimes exacerbated when translating these terms into other languages.

1.2 Definitions and examples

1.2.1 Ecological Restoration

Ecological restoration is defined as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. It is an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity, and sustainability.

Example 1: In 2000, in an attempt to re-create a native wild wood, the Scottish nongovernmental organisation (NGO), Borders Forest Trust, together with many partners, bought a 600-hectare plot of land, Carrifran, in the Southern Uplands of Scotland in order to restore its original forest. Thanks to fossil pollen buried deep in peat, it was possible to identify the nature of the variety of species previously found on this now near-denuded site and therefore to develop a restoration plan that aimed to re-create the species' mix that had occurred in the past. Thousands of native tree seeds from surviving woodland remnants in the vicinity were collected. A total of 103.13 hectares (165,008 trees) have been planted at Carrifran since the start of the project. The upper part of the site is being allowed to regenerate naturally.

1.2.2 Rehabilitation

Rehabilitation emphasises the reparation of ecosystem processes, productivity, and services, whereas the goals of restoration also include the reestablishment of the preexisting biotic integrity in terms of species' composition and community structure.

Example 2: Bamburi Cement's quarries in Mombasa (Kenya) were once woodland expanses covering 1,200 hectares. Starting in 1971, experiments began with the rehabilitation of the disused quarries. In the face of badly damaged soils, three tree species proved capable of withstanding the difficult growing conditions: Casuarina equisetifolia, Conocarpus lancifolius, and the coconut palm. The Casuarina is nitrogen fixing and is drought and salt tolerant, enabling it to colonise areas left virtually without soil. The Conocarpus is also a drought-, flood-, and salt-tolerant swamp tree. The decomposition of the Casuarina leaf litter was initially very slow due to high protein content, thus impeding the nutrient cycling process, although this problem was overcome by introducing a local red-legged millipede that feeds on the dry leaves and starts the decomposition process. Today this area contains more than 200 coastal forest species and a famous nature trail, attracting 100,000 visitors a year since opening in 1984.

1.2.3 Reclamation

Reclamation is a term commonly used in the context of mined lands in North America and the United Kingdom. It has as its main objectives the stabilisation of the terrain, assurance of public safety, aesthetic improvement, and usually a return of the land to what, within the regional context, is considered to be a useful purpose.

Example 3: A large open-cut bauxite mine at Trombetas in Pará state in central Amazonia is located in an area of relatively undisturbed evergreen equatorial moist forest. A reclamation programme has been developed to restore the original forest cover as far as possible. The project has treated about 100 hectares of mined land per year for the last 15 years. First, the mined site was levelled and topsoil replaced to a depth of about 15 cm using topsoil from the site that was removed and stockpiled (for lessthan 6 months) prior to mining. Next, the site was deep-ripped to a depth of 90cm (1-m spacing between rows). Trees were planted along alternate rip lines at 2-m spacings (2500 trees per hectare) using direct seeding, stumped saplings, or potted seedlings. Some 160 local tree species were tested for their suitability in the programme, and more than 70 species from the local natural forests are now routinely used. After 13 years most sites have many more tree and shrub species than those initially planted because of seeds stored in the topsoil or colonisation from the surrounding forest. Not surprisingly, the density of these new colonists is greater at sites near intact forest, but dispersal was evident up to 640 m away from old-growth forest. The new species, most of which have small seed, have been brought to the site by birds, bats, or terrestrial mammals.

1.2.4 Afforestation/Reforestation

Afforestation and reforestation refer to the artificial establishment of trees, in the former case where no trees existed before. In addition, in the context of the U.N.'s Framework Convention on Climate Change (UNFCCC) and the Kyoto protocol, specific definitions have been agreed on reforestation and afforestation.

Afforestation is defined by the UNFCCC as "the direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding, and/or human induced promotion of natural seed sources."

Example 4: During the middle years of the 20th century, very large areas of longdeforested land were planted in Scotland by the state forestry body, initially as a strategic resource. In contrast to the Borders Forest Trust project described above, these efforts made no attempt to re-create the original forest, instead using exotic monocultures, mainly of Sitka spruce from Alaska (Picea sitchensis) or Norway spruce (Picea abies) from mainland Europe. Planting was generally so dense that virtually no understorey plant species developed.

Reforestation is defined by the UNFCCC as "the direct human-induced conversion of nonforested land to forested land through planting, seeding, and/or the human-induced promotion of natural seed sources, on land that was forested but that has been converted to nonforested land."

Example 5: In Madagascar, large plantation projects were planned in the early 1970s to supply a paper mill on the "Haut Mangoro." By 1990 about 80,000 hectares had been planted, 97 percent of which was Pinus spp. This project created significant social and political tensions, as the local population systematically opposed a project that it felt was not providing much benefit.

Broad definitions and explanations of what restoration entails can be found in most conservation and forestry institutions. Nonetheless, little of this has reached the field. Because of its complexity, large-scale restoration requires a mixture of responses from practical to political and many practitioners are at a loss as to where to begin.

Some practical guidance is available:

- The Society for Ecological Restoration (SERI) has developed guidelines for restoration (see Guidelines for Developing and Managing Ecological Restoration Projects, 2000, at www.ser.org).
- The International Tropical Timber Organisation (ITTO) developed some guidelines on the restoration, management, and rehabilitation of degraded and secondary tropical forests.
- The International Union of Forest Research Organisations (IUFRO) runs a special programme on correct usage of technical terms in forestry called SilvaVoc, available on its Web site: www.iufro.org/science/special/silvavoc/.
- The Nature Conservancy (TNC)18 has identified some guidance on when and where to restore (see Geography of Hope Update, When and Where to Consider Restoration in Ecoregional Planning at www.conserveonline.org).
- In 2003, IUCN and WWF published a book, by David Lamb and Don Gilmour, 19 Rehabilitation and Restoration of Degraded Forests, which covers site-based techniques to restoration (summarised in a paper in this manual) but also highlights some of the gaps.
- Cambridge Press has produced a Handbook of Ecological Restoration, 20 which is a two-volume handbook containing a large amount of material on the diverse aspects of restoration.

1.3 Evolution

Source: Uriel N. Safriel (2007) The Assessment of Global Trends in Land Degradation. In MannavaV.K. Sivakumar and Ndegwa Ndiang'ui. Climate and Land Degradation, pp 2-36, Springer Berlin Heidelberg New York.

The motivation for quantitative assessment of land degradation at a global scale is its recognition as an environmental issue of global societal implications. Yet, due to the non-robust definition of "land degradation" and to the paucity of field data, the five global assessments carried out and presented between 1977 and 2003 differ in the selection of measurable attributes of land degradation, in the quality of the data sets, and in their spatial coverage. This resulted in a plethora of degradation estimates ranging 15% to 63% of global degradation and 4% to 74% of dryland degradation. Of these, the figure of 70% degradation (for the drylands only, comprising 41% of global land) has been cited more than the others. Though likely to be overly exaggerated (because it stands for a combination of degradation degree of a land unit and its spatial extent within the mapping unit of which it is a part), this high estimate has apparently served well the globality notion of the dryland degradation syndrome, essential to rallying support for international development assistance under the UNCCD. This thirst for development assistance aimed at "combating desertification" attracted to the UNCCD some 70 non-dryland developing countries (compared to 93 developing dryland country Parties) which experience land degradation that is not included in global assessments of desertification, since only dryland degradation qualifies as "desertification". The texts of the various assessments, including that of GLASOD as well as the UNCCD definition often trade off "desertification" with "susceptibility" to or "threat" of desertification. This suggests that an assessment of vulnerability to desertification rather than its actual occurrence are of higher credibility and utility for policy- and decision-making.

Though soil degradation featured highly in the currently available global degradation assessments, remotely-sensed vegetation attributes not only assess the most valued but threatened ecosystem service, but are also amenable for assessment at the global scale. However, caution is required when using this tool especially in drylands where productivity is tightly linked to rainfall variations. The monitoring required to meet the persistence criterion for qualifying desertification can be also used to detect current desertification trends, which are of relevance for policy-making even more than defining current desertification status. To discern changes of productivity due to state of the land from those due to rainfall features, the ratio of NPP to rainfall (RUE) could be useful were it not negatively correlated with rainfall itself. An alternative method for detecting degradation trends, the Residual NPP Trends (RESTREND) is currently under development. It is based on an analysis of the residuals of the productivity-rainfall relationship throughout a time period for each pixel in the explored region. A statistically significant negative regression of the residuals on time identifies a degradation trend, and the slope stands for its magnitude. To be reliable on a global scale such a remote-sensing approach would serve for guiding field observations required for its own verification.

2 CARBON FLUXES AND THE RESTORATION OF DEGRADED SOIL

Source: FAO (2004) Carbon sequestration in dryland soils, 129 pp, (http://www.fao.org/docrep/007/y5738e/y5738e0a.htm#TopOfPage)

2.1 Introduction

Land-use change and soil degradation are major processes for the release of CO_2 to the atmosphere. The increase in greenhouse gases (GHGs) in the atmosphere is now recognized to contribute to climate change (IPCC, 2001). Although uncertainties remain regarding the causes, consequences and extent of climate change, it is believed that human activities are having an impact on the energy balance of the earth. Its influence on the climate is a major concern in the twenty-first century. This concern has led to the 1997 international agreement in Kyoto (the so-called Kyoto Protocol), whereby most countries are committed to reducing their GHG emissions to the atmosphere. In this context, new strategies and policies within the international framework have been developed for the implementation of agriculture and forestry management practices that enhance carbon sequestration (CS) both in biomass and soils. These activities are included in Articles 3.3 and 3.4 of the Kyoto Protocol (KP) and are known as “land use, land-use change and forestry” (LULUCF) (IPCC, 2000).

The importance of these activities is that any action taken to sequester C in biomass and soils will generally increase the organic matter content of soils, which in turn will have a positive impact on environmental, agricultural and biodiversity aspects of ecosystems. The consequences of an increase in soil carbon storage can include increases in soil fertility, land productivity for food production and security, and prevention of land degradation. Therefore, they might constitute win - win situations.

A proper analysis of the impact of climate change must also consider other global concerns such as loss of biodiversity, changes in land use, growing food demand, and soil degradation. International United Nations conventions exist regarding these problems: the Convention on Biological Diversity (CBD), the Convention to Combat Desertification (CCD), the Ramsar Convention of Wetlands, and there are also several related United Nations programmes, e.g. the United Nations Environment Programme (UNEP), and the United Nations Development Programme (UNDP). Other initiatives, such as the Millennium Ecosystem Assessment, funded internationally by the World Bank, the United Nations Global Environment Facility (GEF), etc., aim to determine the state of the earth’s ecosystems, trying to take into consideration all global problems and the interactions among them.

2.2 The terrestrial carbon cycle

To help understand the concept of CS, Figure 2.1 presents a simplified diagram of the carbon balance of terrestrial ecosystems. The main entry of C into the biosphere is through the process of photosynthesis or gross primary productivity (GPP), that is the uptake of C from the atmosphere by plants. Part of this C is lost in several processes: through plant respiration (autotrophic respiration); as a result of litter and soil organic matter (SOM) decomposition (heterotrophic respiration) and as a consequence of further losses caused by fires, drought, human activities, etc.

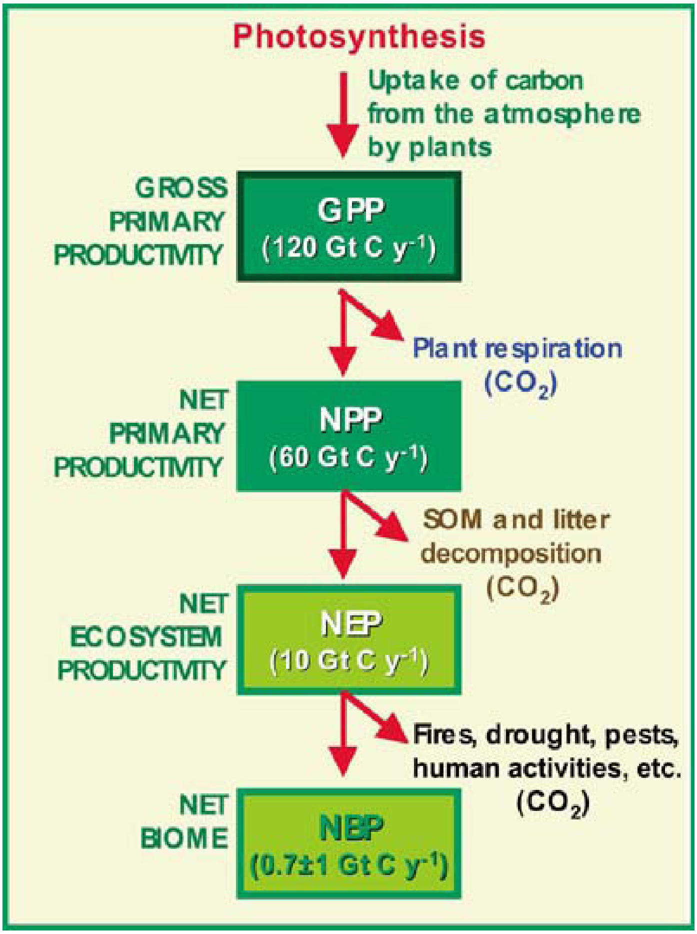

Figure 1 *Terrestrial global carbon balance (simplified)*

2.3 Soil degradation

Soil degradation is a global problem (UNEP, 1992), particularly the desertification of drylands. Most of the drylands are on degraded soils, soils that have lost significant amounts of C. Therefore, the potential for sequestering C through the rehabilitation of drylands is substantial (FAO, 2001). Lal (2000) estimated the magnitude of the potential for sequestering C in soils in terrestrial ecosystems at 50 - 75 percent of the historic carbon loss. Furthermore, Lal hypothesized that annual increase in atmospheric CO_2 concentration could be balanced out by the restoration of 2 000 000 000 ha of degraded lands, to increase their average carbon content by 1.5 tonnes/ha in soils and vegetation. The benefits would be enormous. Enhancing CS in degraded agricultural lands could have direct environmental, economic, and social benefits for local people. Therefore, initiatives that sequester C are welcomed for the improvement in degraded soils, plant productivity and the consequent food safety and alleviation of poverty in dryland regions.

The effects of soil degradation and desertification affect the global C cycle. Land use change leads to a loss in vegetation cover and subsequent loss in organic C in soils and soil quality. The processes of plant productivity, soil degradation and CS are closely linked. A decline in soil quality leads to a reduction in the soil organic C pool, and an increase in the emission of CO_2 to the atmosphere. The decline in soil quality and structure leads to a loss in the capacity to retain water, and therefore in plant productivity.

2.4 Desertification and carbon sequestration

The effects of desertification on soil quality include:

- loss in soil aggregation
- decrease in water infiltration capacity
- reduction in soil water storage · increase in erosion potential
- depletion in SOM, difficulty in seed germination
- disruption of biogeochemical cycles C, N, phosphorous, sulphur alterations in water and energy balance
- loss of soil resilience

All of these effects accentuate the emission of CO_2 to the atmosphere. Lal (2001) estimated the C loss as a result of desertification. Assuming a C loss of 8 - 12 Mg C/ha (Swift et al., 1994) on a land area of 1 020 000 000 ha (UNEP, 1991), the total historic C loss would amount to 8 - 12 Pg C. Similarly, vegetation degradation has led to a C loss of 4 - 6 Mg C/ha on 2 600 000 000 ha, adding up to 10 - 16 Pg C. The total C loss as a consequence of desertification may be 18 - 28 Pg C. Assuming that two-thirds of the C lost (18 - 28 Pg) can be re-sequestered (IPCC, 1996) through soil and vegetation restoration, the potential of C sequestration through desertification control is 12 - 18 Pg C (Lal, 2001). These estimates provide an idea about the loss of C as a result of desertification and the potential for CS through the restoration of soils in drylands.

Opportunities for improved land management as well as increasing CS should be developed in these areas. Agricultural systems contribute to carbon emissions through the use of fossil fuels in farm operations and through practices that result in loss of organic matter in soils. On the other hand, farming systems can offset carbon losses when accumulating organic matter in the soil, or when aboveground woody biomass is increased, which then acts either as a permanent sink or used as an energy source that substitutes fossil fuel. The potential for global benefits, as well as local benefits, to be obtained from increased CS in drylands should be an additional incentive for stronger support for reforestation and agriculture in drylands.

Although drylands have been studied (Heathcote, 1983; Thomas, 1997), the impact of desertification on the global carbon cycle and the potential impact of desertification control on CS in dryland ecosystems have not been widely investigated. There are few case studies, and little information. Consequently, there is little scientific evidence on the impact of desertification on carbon emission to the atmosphere. The aim here is to assess the state of knowledge, and the potential of different measures to increase CS.

3 CARBON FLUXES AND THE RESTORATION OF DEGRADED AGRICULTURAL AND FOREST LANDS

3.1 Restoration of degraded agricultural land

Source: Wade, M. R., Gurr, G. M., & Wratten, S. D. (2008). Ecological restoration of farmland: progress and prospects. Philosophical Transactions of the Royal Society B: Biological Sciences, 363(1492), 831-847.

The goal of ecological restoration is to shift an ecosystem towards its pre-disturbed state with respect to ecosystem structure, function and composition (Hobbs & Norton 1996). The approach emphasizes the use of quantitative practices for measuring and restoring ecosystem 'health', including its ability to deliver ecosystem services (Costanza et al. 1997). Sustainable agriculture 'refers to the ability of a farm to continue producing indefinitely with a minimum of outside inputs, or put another way, is defined as agriculture that meets the needs of the present generation while conserving resources for the use of future generations. The continuity of production by using minimal inputs and creating few negative effects is emphasized. 'Farmland' primarily refers to the land use comprising temporary or permanent crops and pastures. For the purposes of the review, this also includes non-crop vegetation, such as hedgerows and remnants of native vegetation, and waterways that are situated on farmland, but not plantation timber or farm forestry. Although farmland is often derived from grassland and woodland, these habitat types per se are generally excluded from the review unless the principles involved in the restoration of these habitats are relevant to that of farmland (Hooper et al. 2002; Ryan et al. 2002).

What causes farmland to become degraded and what are the symptoms of farmland in need of ecological restoration? Farmland and its environs are susceptible to inadvertent or deliberate degradation in their physical, chemical and biological condition by a range of farming activities that primarily result in changes to air quality, biological diversity, climate, soil condition and the quality and quantity of water (reviewed by Meyer & Turner 1992; Matson et al. 1997; Stoate et al. 2001; Robinson & Sutherland 2002; Tilman et al. 2002; Benton et al. 2003; Millennium Ecosystem Assessment 2005). Soil erosion results from the loss of vegetation cover due to burning, grazing and cultivation. Changes in the fertility, structure, acidification and salinization of soils are caused by cultivation, drainage, irrigation and tree removal. Pollution of ground water and eutrophication of rivers and lakes results from off-farm movement of silt, pesticides and nutrients, i.e. fertilizers or animal effluent. Flow rate of rivers is affected by the construction of weirs and levée-banks, diversion of overland water flows to on-farm reservoirs and direct removal for irrigation. There are global impacts on atmospheric constituents (principally carbon dioxide, methane and nitrogen dioxide) and climate (chiefly temperature and rainfall) as a result of forest removal, biomass burning, fertilizers and livestock. Finally, land cover changes lead to both habitat loss and fragmentation, which threaten aquatic and terrestrial taxa (Meyer & Turner 1992; Matson et al. 1997; Stoate et al. 2001; Robinson & Sutherland 2002; Tilman et al. 2002).

Symptoms of degraded farmland include algal blooms and pesticide residues in waterways, pest outbreaks, plant disease epidemics such as 'rural dieback' of native Australian eucalypts, which is principally caused by the root rot fungus Phytophthora cinnamomi, and disease epidemics of livestock, such as foot and mouth disease and influenza A virus (H5N1, 'bird flu'). In addition, there is evidence of yield decline, loss of topsoil through water and wind, hedgerows and field margins removed or sprayed with herbicides, and a general reduction in species richness and abundance of plants and animals (Wills 1993; Stoate et al. 2001; Tilman et al. 2002; Millennium Ecosystem Assessment 2005).

Importantly, agricultural practices have both local and landscape-scale impacts that transcend farm boundaries (Meyer & Turner 1992; Benton et al. 2003; Cramer & Hobbs 2005; Tscharntke et al. 2005). Local intensification includes adverse effects such as shortened crop rotation cycles and increasing input of agrochemicals. On a landscape scale, fields have been amalgamated and enlarged, resulting in simplified landscapes with few or no non-crop habitats remaining (Tscharntke et al. 2005). The total annual external (off-farm) costs of agriculture on natural resources (air, soil and water), biodiversity and human health (pathogens and pesticides) have been estimated for the United Kingdom at £1149–3907 million between 1990 and 1996 (Pretty et al. 2000) and £1514 million in 2000 (Pretty et al. 2005), and for the USA at £3256–9678 million in 2002 (Tegtmeier & Duffy 2004). This equates to £208 ha^{-1} of arable land and permanent pasture for the United Kingdom (UK) in 1996 and £17–55 ha^{-1} of arable land in the USA.

To put these costs into perspective with the external benefits provided by agriculture, the pivotal paper by Costanza et al. (1997) calculated the combined economic value of three ecosystem services (biological control, pollination and food production) from worldwide cropland to be USD$128.8 (£73.802) billion per year or USD$92 (£53) per ha. A caveat here is that Costanza et al. (1997) assigned a nil value to the ecosystem service of habitats or refugia for resident and transient taxa because this service 'do(es) not occur or (is) known to be negligible', hence the true value of cropland is likely to be underestimated. Nevertheless, by these calculations, the worldwide ecosystem service benefits from agriculture are estimated to be £53 $ha^{-1} yr^{-1}$, yet the external costs of intensive agriculture in countries like the UK are £208 $ha^{-1} yr^{-1}$. Equally compelling calculations estimated that the economic benefit to world society from biodiversity is USD$2928 billion. This value included the benefits of activities such as biological pest control, ecotourism, pollination and waste disposal (Pimentel et al. 1997). It is evident that more sustainable agricultural practices in conjunction with ecological restoration methods on farmland are necessary to reduce the unacceptably high external costs of agriculture that are borne by the community. In addition, 'ecological engineering' techniques are available to enhance ecosystem services on farmland, including habitat manipulation tactics for beneficial arthropods that are responsible for biological pest control and contribute to biodiversity in general.

Agriculture and biodiversity conservation have been traditionally viewed as incompatible, with agriculture considered a major driver of species loss for many plant and animal taxa, such as bumble-bees (Bombus spp.) and bird species like skylarks (Alauda arvensis L.) since 1945 (Stoate et al. 2001; Robinson & Sutherland 2002). Agriculture represents the dominant land use throughout much of Western Europe and a significant part of European biodiversity is associated with this habitat. Agroecosystems, however, are very hostile to a wide diversity of species owing to the conversion of complex natural ecosystems to simplified managed ones and the intensification of resource use. Firstly, there is a tendency for simplified cropping systems to be applied to increasingly consolidated land areas, leading to the loss of non-crop habitats, such as field margins and hedgerows, together with the decline in traditional mixed arable and livestock farming. As a result, remnant native vegetation has become fragmented into different patches and there are fewer 'nodes' where field corners join. These nodes can be rich 'hotspots' of invertebrate, vertebrate and plant diversity (Keesing & Wratten 1997). Secondly, there is intensification of resource use in the cropping systems themselves, including greater pesticide and fertilizer usage and shorter fallow periods (Stoate et al. 2001; Pywell et al. 2005). However, more recently, there has been an important move beyond conservation efforts to an appreciation of the value of natural, undisturbed remnants and to a better recognition of the role that highly modified landscapes play in maintaining native biodiversity (Tscharntke et al. 2005). As Novacek & Cleland (2001) pointed out 'we are obviously past any point where strategies that focus on preservation of 'pristine' habitats are sufficient for the job. Greater attention must be placed on human-dominated landscapes that surround the less disrupted areas. In this way, agriculture can make important contributions to high-diversity habitats, while also benefiting from ecosystem services provided from different land use types. We know that invertebrate natural enemies of crop pests visit different habitat types before colonizing agricultural fields (Silberbauer et al. 2004) and improved biological pest control and crop pollination may directly increase farmers' income (Östman et al. 2003; Ricketts et al. 2004).

3.2 Restoration of degraded forest land

Source: Biringer, J., and Lara J. Hansen J. L., (2005) Restoring Forest Landscapes in the Face of Climate Change. In Mansourian, S., Vallauri, D., Dudley, N., Forest Restoration in Landscapes - Beyond Planting Trees, pp. 31-41, Springer.

Climate change is arguably the greatest contemporary threat to biodiversity. It is already affecting ecosystems of all kinds and these impacts are expected to become more dramatic as the climate continues to change due to anthropogenic greenhouse gas emissions into the atmosphere, mostly from fossil fuel combustion.

While restoration is made more difficult by climate change, it can conversely be seen as a possible adaptive management approach for enhancing the resilience of ecosystems to these changes.

Climate change will result in added physical and biological stresses to forest ecosystems, including drought, heat, increased evapotranspiration, altered seasonality of hydrology, pests, disease, and competition; the strength and type of effect will depend on the location. Such stresses will compound existing non-climatic threats to forest biodiversity, including overharvesting, invasive species, pollution,and land conversion.

This will result in forest ecosystems changing in composition and location. Therefore, in order to increase the potential for success, it will be necessary to consider these changes when designing restoration projects. On the other hand, restoration projects can also be viewed as a key aspect of enhancing ecosystem resilience to climate change. Human development has resulted in habitat loss, fragmentation, and degradation. A first step in increasing resilience to the effects of climate change is enhancing or protecting the ecosystem's natural ability to respond to stress and change. Research suggests that this is best achieved with "healthy" and intact systems as a starting point, which can draw on their own internal diversity to have natural adaptation or acclimation potential and therefore greater resilience. Any restoration activities that enhance the ecological health of a system can thus be seen as creating or increasing the potential buffering capacity against negative impacts of climate change. It should be mentioned that there are obvious limits to the rate and extent of change that even a robust system can tolerate.

As a result it is only prudent to conduct restoration for enhancing resilience in tandem with efforts to reduce greenhouse gas emissions, the root cause of climate change.

For many with a forestry background, carbon dioxide sequestration might seem a concomitant advantage to restoration projects, which can aid in reduction of atmospheric concentrations of greenhouse gases. While forests do hold carbon, and their loss does release carbon, their long-term capacity to act as a reliable sink in the face of climate change, especially for effective mitigation, is not a foolproof strategy. Where restoration is promoted with a focus on capturing carbon, an analysis of climate change impacts should be integrated into project planning to determine whether there really are net sequestration benefits. Increased incidence of forest fires as a result of warming and drying trends, for example, could outweigh any efforts to reduce carbon emissions. Case studies of successful resilience-building efforts are not yet plentiful, due to relatively recent revelations about the scale and impact that climate change will have on ecosystems. However, the global temperature has risen 0.7°C as atmospheric concentrations have risen and extinctions and large-scale ecosystem changes are expected. A number of forest types are already being negatively impacted, including tropical mountain cloud forests, dry forests, and forests in the boreal zone, and climate-related extinctions are already thought to have occurred, for example amongst amphibians. Along the coasts, the rising sea level is increasing the vulnerability of mangroves. Restoration as a means to ensure healthy ecosystem structure and function will have a large part to play in adapting ecosystems to these broad-scale changes.

Framework for Understanding Intersection of Resilience-Building and Forest Restoration and Protection:

1. Protection: For some forests protection alone will not increase resilience to climate change. Many tropical montane cloud forests provide a case in point. Australia's Wet Tropics World Heritage Area is expected to experience a 50% reduction in habitat with warming of 1 degree Celsius, which will leave amphibians and other cool-adapted species no upland migration options as conditions become warmer and drier.

2. Sequestration via restoration: Many examples exist where the planting of trees stores carbon but is not coordinated with conservation or resilience-raising advantages. Nonnative trees, such as Eucalyptus, are often planted solely for the carbon benefit, though the planting may cause degradation of the landscape, and thus not provide a buffer against climate change.

3. Resilience/adaptation: Restoration is but one of the many types of management options that increase resilience. For example, actions that respond to changing dynamics such as insect infestations and changing fire patterns are aspects of good forestry that will receive special attention with the advent of climate change. Activities that increase the efficiency of resource use will also increase resilience. In Cameroon, mangroves are being aided by increasing the efficiency of wood-burning stoves so that 75 percent less mangrove wood is needed for cooking, thereby increasing the resilience of the system by reducing harvest levels. Such actions decrease degradation of the mangrove and raise the probability that it will be equipped to respond to the effects of climate change.

4. Sequestration and resilience/adaptation: Restoration and resilience go hand in hand when the impacts of climate change are taken into account in project planning. Whether passive or active restoration, activities target those areas that will be more suitable to climate change, and encourage use of species that will be hardier under new climatic conditions (successful seed dispersers, for example).

5. Intersection of protection, sequestration, and resilience/adaptation: Creating buffer zones through restoration can increase the resilience of protected areas to the impacts of climate change while at the same time sequestering carbon. This scenario is similar to the one above, except that restoration is focussed on increasing the resilience of protected areas by expanding boundaries to increase suitable habitat under changing climatic conditions.

6. Protection and adaptation: Protection can lead to increased resilience to the impacts of climate change, where suitable habitat is intact, and the expansion of boundaries is possible to accommodate species' needs with a changing climate. A successful protected area system includes identification and conservation of mature forest stands, functional groups and keystone species, and climate refugia.

4 MITIGATING CLIMATE CHANGE BY RESTORATION OF DEGRADED LANDS

Source: Alan J. Franzluebbers and Paul C. Doraiswamy (2007) Carbon sequestration and land degradation. In MannavaV.K. Sivakumar and Ndegwa Ndiang'ui. Climate and Land Degradation, pp 343-356, Springer Berlin Heidelberg New York.

Storing carbon in soil as organic matter is not only a viable strategy to sequester CO_2 from the atmosphere, but is vital for improving the quality of soil. This presentation describes (1) C sequestration concepts and rationale, (2) relevant management approaches to avoid land degradation and foster C sequestration, and (3) a summary of research quantifying soil C sequestration. The three primary greenhouse gases (CO_2, CH_4, and N_2O) derived from agriculture have increased dramatically during the past century. Conservation management practices can be employed to sequester C in soil, counter land degradation, and contribute to economic livelihoods on farms. Trees can accumulate C in perennial biomass of above-ground and below-ground growth, as well as in the deposition of soil organic matter. Minimal disturbance of the soil surface with conservation tillage is critical in avoiding soil organic C loss from erosion and microbial decomposition. Animal manures contain 40-60% C, and therefore, application to land promotes soil organic C sequestration and provides readily-available, recycled nutrients to crops. Green manures can be used to build soil fertility, often with leguminous plant species having symbiotic root associations with nitrogen-fixing bacteria. Grasslands have great potential to sequester soil organic C when managed properly, but can also be degraded due to overgrazing, careless management, and drought leading to accelerated soil erosion and undesirable species composition. Opportunities exist to capture and retain greater quantity of C from crop and grazing systems when the two systems are integrated. Fertilization is needed to achieve production goals, but when applied excessively it can lead to environmental pollution, especially when considering the energy and C cost of manufacture and transport. Agricultural conservation management strategies to sequester CO_2 from the atmosphere into soil organic matter will also likely restore degraded land and/or avoid further land degradation.

4.1 Introduction

Land degradation is an insidious process that threatens the sustainability of agriculture, not only in the arid and semi-arid regions, but also in the sub-humid and humid regions, as a result of the loss of agro-ecosystem capacity to meet its full potential. Resulting from complex, and little understood, interactions among periodic weather stresses, extreme climatic events, and management decisions, land degradation is a serious global concern in a world searching for sustainable development to meet the needs of a rapidly increasing human population, to reverse the negative impacts of our choices on the environment in which we live, and to fairly distribute the world's resources in a socially justifiable manner.

Atmospheric concentration of radiatively active trace gases [also called greenhouse gases (GHGs)] has been increasing dramatically during the past several centuries (IPCC 2001). Several of the important GHGs in the atmosphere are derived, at least partially, from agricultural activities. Three of the most important GHGs related to agricultural activities are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Carbon dioxide accounts for almost 75% of the global warming potential of GHGs. The source of this CO_2 is dominantly from fossil fuel combustion. Since 1750, the concentration of CO_2 has increased 31%, the concentration of CH_4 has increased 151%, and the concentration of N_2O has increased 17%. In the USA, the contribution of agriculture to GHG emission has been estimated to be only 7% of the country's total GHG emission.

Global concern for the rising atmospheric concentration of GHGs is also increasing, because of the important implications of these gases on global warming. Potentially dramatic consequences of even relatively minor climate change could cause devastating weather-related occurrences, such as increased frequency and duration of droughts, more widespread and severe flooding events, greater frequency and intensity of tornadoes and cyclones, and melting of polar ice caps that could threaten abundant human civilizations along coastal continental areas.

Understanding the linkages between agricultural land-use activities and GHG dynamics should help society to strengthen its resolve to avoid these potentially devastating impacts and design effective mitigation strategies to bolster ecosystem functioning and overcome human-induced land degradation.

Rising concentration of atmospheric CO_2 has been largely attributed to expanding use of fossil fuels as an energy source. Reducing net GHG emission is possible by:

- Reducing fossil fuel combustion and becoming more energy efficient
- Relying more on low-C energy sources, such as
    - Capturing solar energy

    - Generating wind power

    - Harvesting biofuels

- Sequestering C

Carbon sequestration can be defined as the long-term storage of C so that the accumulation of CO_2 in the atmosphere can be reduced or slowed. Carbon sequestration can occur globally in one of several compartments:

- Terrestrial biosphere
- Underground in geologic formations
- Oceans

This focuses on the terrestrial biosphere, which is directly manipulated by agriculture through changes in vegetation and soil disturbance. Carbon sequestration in the terrestrial biosphere can be accomplished by:

- Increasing the net fixation of atmospheric CO_2 by terrestrial vegetation with emphasis on enhancing physiology and rate of photosynthesis of vascular plants.
- Retaining C in plant materials and enhancing the transformation of C to soil organic matter.
- Reducing the emission of CO_2 from soils caused by heterotrophic oxidation of soil organic C.
- Increasing the capacity of deserts and degraded lands to sequester C.

Storing C in soil as organic matter is not only a viable strategy to sequester C from the atmosphere, but is also essential in improving the quality of soil. Soil organic matter plays a vital role in:

- Soil fertility, by slowly supplying nitrogen and many other essential elements and molecules to plants through mineralization/immobilization turnover.
- Water cycling, by contributing to soil aggregation and water-holding capacity.
- Soil biodiversity, by providing the C and energy sources needed for soil biological community development.
- Environmental detoxification, by supplying chemical bonds, physical support, and biological activity.
- Biogeochemical cycling, by storing and delivering many globally important elements interacting through the atmosphere, hydrosphere, lithosphere, and biosphere.

4.2 Management Approaches

The terrestrial C cycle can be simply divided into the two primary processes of photosynthetic uptake of CO_2 from the atmosphere (i.e., C input) and respiration of CO_2 from living organisms back to the atmosphere (i.e., C output). On a global scale under steady-state conditions, rates of C input and output have often been considered balanced (Schlesinger 1997). Terrestrial C sequestration efforts, therefore, must recognize the inherent balance between these processes.

Maximizing C input to the terrestrial biosphere from the atmosphere is possible in agricultural systems through a variety of management options, including:

- *Plant selection*, whereby large differences in photosynthetic capacity occur among species, cultivars, and varieties. Perennial plant species often have advantages over annual crops at capturing C, because of a longer growing season and more extensive root distribution (Liebig et al. 2005). However, selection of appropriate annual crops in rotation sequence can maximize growth potential under certain environments. A continuing effort has focused on cultivating high-biomass producing energy crops to maximize photosynthetic capture of CO_2 (Baral and Guha 2004).
- *Tillage management*, whereby the type and frequency of tillage is used to promote the most prolific plant production possible. Tillage is often used to improve the physical condition of soil so that crops can achieve maximum growth potential, but it is also a tool that disturbs soil and promotes oxidation of soil organic matter (Franzluebbers 2004).
- *Fertilization management*, whereby the source, rate, timing, and placement of fertilizer is used to optimize plant production potential. Sufficiently balanced and adequate nutrient supply are essential management considerations to maximize genetic potential of plants (Lal and Bruce 1999), but the high energy cost of mining and manufacturing inorganic sources of nutrients must be recognized as a source of GHG emission (Schlesinger 2000).
- *Integrated management*, whereby pests can be adequately controlled and environmental and socio-economic consequences of agricultural activities can be balanced with agronomic production considerations (Makumba et al. 2007).

Minimizing C loss from soil to the atmosphere has also been a major focus of agricultural research on C sequestration. Management options to minimize C loss from soil include:

- *Reducing soil disturbance* by less intensive tillage and erosion control (Lal et al. 1998).
- *More fully utilizing available soil water*, which not only promotes optimum plant growth, but also reduces the oxidative capacity of soil microorganisms to decompose soil organic matter and crop residues (Lal 2004).
- *Maintaining surface residue cover* to increase plant water use and production. Surface residue cover also fosters greater fungal abundance in the soil microbial community, which promotes greater stabilization of soil aggregates and resistance of soil organic C to decomposition (Nichols and Wright 2004).

In agriculture, there are many management practices that can be employed to sequester C and counter land degradation. The following sections describe some key management practices to combat land degradation. How these management practices might also contribute to soil C sequestration will be highlighted.

4.2.1 Tree Plantings

Trees can accumulate C in perennial biomass of above-ground and below-ground growth, as well as in the deposition of soil organic matter. The intentional mixing of trees or other woody perennials with agricultural crops, pastures, and/or livestock is defined as agroforestry. Agroforestry exploits the ecological and economic interactions of the different components to attain greater sustainability (Nair 1993). This section focuses on agroforestry-related changes in C accumulation rather than on natural or planted forests.

Issues of importance in agroforestry systems are:

- Climate
- Selecting adapted species
- Soil conditions
- Plant density
- Intended use

- Spatial arrangement of trees and other land uses.

The types of agroforestry practices include complex agroforestry systems, boundary plantings, hedgerow intercropping, and improved fallow (Albrecht and Kandji 2003). Carbon sequestration potential of tropical agroforestry systems has been estimated.

From plantation survey data in Australia (400-600 mm zone), mean C accumulation rate of 3.8 Mg ha^{-1} yr^{-1} occurred in the woody biomass from a variety of tree species. In the central Philippines, C sequestration in the above-ground biomass of Leucaena leucocephala during 6 years of growth was estimated at 10.7 Mg C ha^{-1} yr^{-1} (Lasco and Suson 1999).

Carbon accumulation in the soil is the major sink for hedgerow intercropping systems used to produce biomass for improving soil fertility. In Nigeria, L. Leucocephala and Gliricidia sepium intercropping systems sequestered 0.20 Mg C ha^{-1} yr^{-1} in the topsoil compared with sole cropping (Kang et al 1999). From two experiments in Malawi (6 to 9-year studies), a G. sepium intercropping system sequestered soil organic C at a rate of 1.2 Mg ha^{-1} yr^{-1} in the surface soil (0-20 cm), but at a rate of 6.2 to 11.7 Mg ha^{-1} yr^{-1} when calculated to a depth of 0-200 cm (Makumba et al. 2007). Deep rooting of the trees was considered a key feature of this difference in estimates. Using Century and RothC models in Sudan and Nigeria, soil organic C accumulation with tree plantings was estimated at 0.10 ± 0.05 Mg ha^{-1} yr^{-1} (Farage et al. 2007).

4.2.2 Conservation-Tillage Cropping

Minimal disturbance of the soil surface is critical in avoiding soil organic matter loss from erosion and microbial decomposition. Successful conservation-tillage cropping systems have been developed and evaluated throughout the world. As part of a system for conservation agriculture, conservation-tillage cropping can improve plant production, reduce environmental pollution, and store a greater quantity of soil organic C.

Climatic conditions can influence the amount of soil organic C expected to be sequestered with adoption of conservation tillage. With more extreme dry and/or wet conditions, soil organic C sequestration tended to be highest in milder and warm-wet climatic regions of North America. Mean soil organic C sequestration in North America is estimated at 0.33 Mg C ha^{-1} yr^{-1}. In the warm-moist climatic region of the southeastern USA, adding a cover crop to a conservation-tillage system can nearly double the rate of soil organic C sequestration due to additional plant biomass input and better crop growth due to surface residues (Franzluebbers 2005).

Maintaining adequate surface residue cover with conservation-tillage cropping systems has also been shown to be very important for efficiently utilizing rainfall and producing adequate crop yield. From the 12th year of an irrigated wheat–maize rotation in the volcanic highlands of central Mexico, the rate of water infiltration was 18 cm h^{-1} when crop residue was removed and 90 cm h^{-1} when crop residue was retained on the soil surface with no tillage management (Govaerts et al. 2007). The change in water delivery to the soil resulted in rather dramatic changes in crop yield during the last 7 years of the study, in which maize and wheat yields were 40% greater when crop residue was retained as compared to removal of crop residues.

Table 1 Predicted change in soil erosion and organic C sequestration by EPIC-Century modeling during a 25-year period in Mali (Doraiswamy et al. 2007). Traditional cropping and mean crop yield from 1985-2000 included maize (1.5 Mg ha^{-1}), cotton (1.2 Mg ha^{-1}), and millet and sorghum (1.0 Mg ha^{-1})

Management	Erosion (Mg ha^{-1} yr^{-1})	Change in organic C (Mg C ha^{-1} yr^{-1})
Conventional tillage (CT)	16.5	−0.023
CT with increased fertilizer	15.0	−0.006
Ridge tillage (RT)	6.6	0.001
RT with increased fertilizer	5.9	0.027
RT with fertilizer and residues	3.5	0.086

Fertilizer inputs averaged 24 kg N ha^{-1} and 7 kg P ha^{-1} with the low level and 39 kg N ha^{-1} and 9 kg P ha^{-1} with increased fertilizer level

Using a remote sensing–crop modeling approach in Mali, Doraiswamy et al. (2007) observed that modification of traditional cropping systems to better control erosion with ridge tillage could shift agricultural production in the region from a net emitter of CO_2 to a net sink for CO_2. Combining ridge tillage with other improvements in crop management could reduce soil erosion to 20-40% of that predicted in traditional cropping systems with conventional tillage (table 4.1).

4.2.3 Animal Manure Application

Since animal manure contains 40-60% C, its application to land should promote soil organic C sequestration. In a review of studies conducted in the southeastern USA, poultry litter application to crop and pasture lands led to significant change in soil organic C only when evaluations were conducted for more than 2 years. Conversion of C in poultry litter to soil organic C was 17 + 15% among these studies. Although soil organic C has been shown to increase with animal manure application, very few whole-system data have been collected. Manure application may simply transfer C from one land to another, while investing energy in transport and handling operations. A full C accounting approach is needed to adequately assess manure application as a viable C sequestration strategy.

Other long-term studies on farmyard (FYM) application to soil have clearly shown its benefit to soil fertility, yield enhancement, and soil organic C storage. In an 18-year field experiment in Kenya (23 °C, 970 mm), soil organic C increased by 0.17 ± 0.07 Mg C ha^{-1} yr^{-1} with FYM (10 Mg ha^{-1} yr^{-1}) compared to without FYM (Kapkiyai et al. 1999). Of the C applied in FYM, 9 ± 3% was retained in soil as organic C. Crop yield with FYM (5.3 Mg ha^{-1}) was 61% greater with FYM than without FYM.

In a 45-year field experiment in Nigeria (28 °C, 1070 mm), soil organic C increased by 0.21 ± 0.01 Mg C ha^{-1} yr^{-1} with FYM (5 Mg ha^{-1} yr^{-1}) compared to without FYM (Agbenin and Goladi 1997). In this naturally P-deficient soil, total soil P increased by 12 ± 12 kg ha^{-1} yr^{-1} with FYM.

In a 30-year field experiment at Ranchi, India (23 °C, 1450 mm), soil organic C was greater with FYM (3.9 g kg^{-1}) than without FYM (3.3 g kg^{-1}) (Manna et al. 2007). Total soil N was also 17% greater with FYM than without FYM application.

However, soybean and wheat yields were generally not affected by FYM application. In a 30-year field experiment at Hawalbagh, India (1035 mm), soil organic C increased by 0.56 ± 0.02 Mg C ha^{-1} yr^{-1} with FYM (10 Mg ha^{-1} yr^{-1}) compared to without FYM (Kundu et al. 2007). Above-ground crop biomass production with FYM (6.4 Mg ha^{-1}) was 2.4 times greater than without FYM application.

In a 22-year field experiment in Italy (14 °C, 760 mm), soil organic C increased by 0.20 Mg C ha^{-1} yr^{-1} with FYM (7.5 Mg ha^{-1} yr^{-1}) compared to without FYM (Govi et al. 1992). Soil humification index increased to 60% with FYM compared to 51% without FYM.

In a 20-year study of pearl millet–wheat cropping in India (26 °C, 440 mm), soil organic C increased with increasing FYM application rate. However as a percentage of C applied in FYM, increasing FYM application rate led to less efficient retention of C in soil (Gupta et al. 1992).

Reviewing the climatic influence of animal manure application on soil organic C storage, temperature regime appears to have a greater impact than precipitation regime. Retention of C in soil was 23 + 15% of C applied from animal manure in temperate or frigid regions, but was only 7 + 5% in thermic regions. Moist regions retained 8 + 4% of C applied with animal manure, while dry regions retained 11 + 14%. These data are consistent with environmental controls on soil microbial activity and suggest that future research will require increasing acknowledgement of the linkage between climate and potential C sequestration.

4.2.4 Green-Manure Cropping Systems

Green manures are used to build soil fertility, often with plant species having the capacity to fix nitrogen from the atmosphere through root associations with nitrogen fixing bacteria. The C contained in green manure biomass following its termination can be subsequently stored in soil organic matter.

On an abandoned brick-making site in southeastern China (16.5 °C, 1600 mm), planting of ryegrass as an understory crop under China fir for 7 years resulted in soil organic C sequestration of 0.36 ± 0.40 Mg C ha^{-1} yr^{-1} (Zhang and Fang 2007). With soybean as a green manure for 8 years in Columbia (27 °C, 2240 mm), maize yield with green manure (4.2 Mg ha^{-1}) was 20% greater than without green manure (Basamba et al. 2006). Soil organic C did not change during the 8 years of green manuring, probably because of rapid decomposition caused by abundant precipitation, warm temperature, and nutritious residue quality.

At the end of 12 years of Sesbania green manuring in India (24 °C, 715 mm), soil organic C sequestration was 0.09 ± 0.03 Mg C ha^{-1} yr^{-1} (Singh et al. 2007). At the end of 13 years of wheat/soybean–maize cropping with and without vetch as a green manure cover crop in southern Brazil (21 °C, 1740 mm), soil organic C sequestration was −0.30

± 0.15 Mg C ha^{-1} yr^{-1} under conventional tillage and 0.66 ± 0.26 Mg C ha^{-1} yr^{-1} under zero tillage (Sisti et al. 2004). These data suggest that climatic conditions, green manure nutrient quality, and placement in the soil are all important considerations in affecting soil organic C change with green manuring.

4.2.5 Improved Grassland Management

Degradation of permanent grasslands can occur from accelerated soil erosion, compaction, drought, and salinization. Strategies to sequester soil organic C in grasslands must, by necessity, improve the quality of grasslands. Strategies for restoration should include:

- Enhancing soil cover
- Improving soil structure to minimize water runoff and soil erosion

Achieving a balance between agricultural harvest and environmental protection is needed (i.e., stocking density should be optimized). On an oak-grassland in central Texas USA (18°C, 440 mm), water infiltration was highly related to percent ground cover. However, cattle stocking density played an even larger role in controlling water infiltration with time.

Establishment of bermudagrass pasture following long-term cropping in Georgia USA (16°C, 1250 mm) resulted in significant soil organic C accumulation during the first 8 years of management. How forage was managed had a large impact on the rate of soil organic C accumulation during the first 5 years, e.g. soil organic C sequestration rate was 0.30 Mg C ha^{-1} yr^{-1} when forage was removed as hay, 0.65 Mg C ha^{-1} yr^{-1} when forage remained unharvested, and 1.40 Mg C ha^{-1} yr^{-1} when forage was grazed moderately to moderately heavy by cattle during the summer (Franzluebbers et al. 2001).

4.2.6 Cropland-Grazing land Rotation

Opportunities exist to capture a greater quantity of C from crop and grazing systems when the two systems are integrated, because:

- Ligno-cellulosic plant materials can be utilized by ruminant animals
- Manure is deposited directly on the land

- Weeds can be managed with management rather than chemicals

Especially when combined with conservation-tillage cropping, significant potential exists to avoid loss of soil organic C that can accumulate during a perennial pasture phase. In Uruguay, soil erosion averaged 19 Mg ha^{-1} under conventional-tillage continuous cropping, 7 Mg ha^{-1} under conventional-tillage crop–pasture rotation, 3 Mg ha^{-1} under no-tillage continuous cropping, and <2 Mg ha^{-1} under under no-tillage crop–pasture rotation (Garcia-Prechac et al. 2004). Soil or ganic C with crop–pasture rotation was also greater than with continuous cropping in both tillage systems. In the long-term, crop yield was enhanced with crop–pasture rotation than with continuous cropping, especially with no tillage (Garcia-Prechac et al. 2004).

In Argentina, rotations with <7 years of conventional-tillage cropping alternated with >3 years of perennial pasture were able to maintain soil organic C and other important soil properties within acceptable limits to avoid degradation (Studdert et al. 1997). Diaz-Zorita et al. (2002) found that cattle grazing in crop–pasture rotations compacted surface soil only under conventional tillage, but not under no tillage. The ability of soil to resist compaction under no tillage was attributed to greater structural stability.

In warm-moist climatic regions of the world, sufficient opportunities exist to integrate crops and livestock to achieve greater agricultural sustainability through enhanced nutrient cycling, better pest control, and diversification of agricultural enterprises (Katsvairo et al. 2006, Franzluebbers 2007).

4.2.7 Optimal Fertilization

Fertilization of crops is often needed to overcome deficiencies in nutrients supplied by soils, especially in soils exhausted by years of (a) soil erosion, (b) intensive disturbance with tillage, and (c) continuous harvest of products that remove large quantities of nutrients. On the other hand, excessive fertilization can occur when maximum agronomic prescriptions exist without regard for economic and environmental consequences. Today, the C cost of fertilization has become increasingly scrutinized (Schlesinger 1999; Izaurralde et al. 2000).

In a review of data available from the warm-moist climatic region of the southeastern USA, there was a positive response of soil organic C with the application of N fertilizer. The mean N fertilizer rate to achieve maximum soil organic C sequestration was 171 kg N ha^{-1} yr^{-1}, within the range of values often reported to maximize plant yield. However, when considering the C cost of N fertilizer (i.e. C costs of manufacture, distribution, and application), the optimum N fertilizer rate was 107-120 kg N ha^{-1} yr^{-1} based on C costs of 0.98 to 1.23 kg C kg^{-1} N fertilizer (Izaurralde et al. 1998, West and Marland 2002). Also accounting for the global warming potential of assumed N2O emission associated with N fertilizer application (1.586 kg C kg^{-1} N fertilizer; IPCC 1997), optimum N fertilization to maximize C offset would then be reduced to 24-37 kg N ha^{-1} yr^{-1} to achieve soil organic C sequestration of 0.07-0.11 Mg C ha^{-1} yr^{-1} (Franzluebbers 2005).

5 ADAPTING RESTORATION OF DEGRADED LAND TO CLIMATE CHANGE

Source: Biringer, J., and Lara J. Hansen J. L., (2005) Restoring Forest Landscapes in the Face of Climate Change. In Mansourian, S., Vallauri, D., Dudley, N., Forest Restoration in Landscapes - Beyond Planting Trees, pp. 31-41, Springer.

After completing vulnerability analysis to determine how a forest system may be impacted by changing climatic conditions, the next step is to look at the range of adaptation options available in order to promote resilience.

An effective vulnerability analysis will determine which components of the system—species or functions, for example—will be most vulnerable to change, together with consideration of which parts of the system are crucial for ecosystem health. An array of options pertinent to adapting forests to climate change are available, both to apply to forest communities at high risk from climate change impacts as well as for those whose protection should be prioritised given existing resilience. Long-term resilience of species will be enabled where natural adaptation processes such as migration, selection, and change in structure are allowed to take place due to sufficient connectivity and habitat size within the landscape.

Restoration can provide a series of critical interventions to reduce climate change impacts. Basic tenets of restoration for adaptation include working on a larger scale to increase the amount of available options for ecosystems, inclusion of corridors for connectivity between sites, inclusion of buffers, and provision of heterogeneity within the restoration approach. Key approaches are as follows:

Reduce fragmentation and provide connectivity: Noss (2000) provides an overview of the negative effects of ecosystem fragmentation, which are abundantly documented worldwide. "Edge effects" threaten the microclimate and stability of a forest as the ratio of edge to interior habitat increases. Eventually, the ability of a forest to withstand debilitating impacts is broken. Fragmentation of forest ecosystems also contributes to a loss of biodiversity as exotic, weedy species with high dispersal capacities are favoured and many native species are inhibited by isolation. Restoration strategies should therefore often focus first on those areas where intervention can connect existing forest fragments into a more coherent whole.

Provide buffer zones and flexibility of land uses: The fixed boundaries of protected areas are not well suited to a dynamic environment unless individual areas are extremely large. With changing climate, buffer zones might provide suitable conditions for species if conditions inside reserves become unsuitable. Buffer zones increase the patch size of the interior of the protected area and overlapping buffers provide migratory possibilities for some species. Buffer zones should ideally be large, and managers of protected areas and surrounding lands must demonstrate considerable flexibility by adjusting land management activities across the landscape in response to changing habitat suitability. A specific case for a buffer zone surrounding tropical montane cloud forests can be made based on research that shows that the upwind effects to deforestation of lowland forests causes the cloud base to rise. Restoring forest around protected areas, for example to supply timber through continuous cover forestry, or for nontimber forest products, watershed protection, or as recreational areas, could help maintain the quality of the protected area in the face of climate change.

Maintain genetic diversity and promote ecosystem health via restoration: Adaptation to climate change via selection of resilient species depends on genetic variation. Efforts to maintain genetic diversity should be applied, particularly in degraded landscapes or within populations of commercially important trees (where genetic diversity is often low due to selective harvesting). In such places where genetic diversity has been reduced, restoration, especially using seed sources from lower elevations or latitudes, can play a vital role in maintaining ecosystem resilience. Hogg and Schwarz (1997) suggest that assisted regeneration could be used in southern boreal forests in Canada where drier conditions may decrease natural regeneration of conifer species. Similarly, genotypes of beach pine forests in British Columbia may need assistance in redistributing across the landscape in order to maintain long-term productivity. In addition, species that are known to be more resilient to impacts in a given landscape can be specifically selected for replanting. For example, trees with thick bark can be planted in areas prone to fire to increase tree survival during increased frequency and severity of fires.

6 FINANCIAL MECHANISMS TO PROMOTE RESTORATION OF DEGRADED LAND IN THE CONTEXT OF CLIMATE CHANGE

Source: Kirsten Schuyt, Opportunities for long term financing of forest restoration in landscapes. In Mansourian, S., Vallauri, D., Dudley, N., Forest Restoration in Landscapes - Beyond Planting Trees, pp. 161-176, Springer.

6.1 Introduction

The economic, social, and biodiversity values of forests are increasingly being recognised, and many countries have understood the need to better manage their forest resources. At the same time, in 1997 the Intergovernmental Panel on Forests (IPF) found that domestic financial resources were insufficient to achieve sustainable management, development, or conservation of forests. With the threat of worsening forest depletion in many parts of the world leading to further degradation of forest goods and services, it is recognised that there is a critical need to explore new and innovative ways of financing improved forest management and conservation, including the restoration of forest resources.

Forest landscape restoration is a long-term process and will generally require sustained sources of funding. All too often, overreliance on grants means that funds can only be obtained for short-term projects, and a long term-effort such as the restoration of forests suffers. Grants, however, are not the only source of funding, and a number of options for long-term financing of forest landscape restoration are highlighted below. Traditional financing sources for forestry in developing countries have been domestic public and private, foreign public and private, and international organisations, including NGOs. Depending on the objective of the forestry activities (environmental conservation, subsistence needs for local people, commercial purposes), different financing sources have been sought. However, global financing trends in general are changing, and a wave of economic liberalisation is providing impetus for increased private sector participation. These trends allow for new financing opportunities from the private sector for restoration activities. In light of declining external public funding and weak prospects for new and additional public funding of overseas development assistance in forestry, private capital flows represent potential opportunities for restoration initiatives.

The key to financing opportunities from both private and public funding sources for landscape-scale forest restoration lies in recognising its full economic and financial value. This requires estimating and recognising the economic values of forests and therefore recognising the benefits provided by restoring these forest values. The restoration or loss of these values can then be more realistically weighted against other possible uses of the land. In a landscape context, it then becomes possible to better select areas within the landscape for different uses, allowing a potentially more complete range of values and benefits to be offered. This also requires proper pricing of forest goods and services and setting up mechanisms where money is transferred to pay these prices.

One way to do this is by selling environmental services of forests, such as carbon sequestration, watershed protection, and biodiversity, to finance restoration—a mechanism called payments for environmental services (PES). The PES mechanisms ensure that those who supply environmental services are paid by those who use these services. These range from public payments to self-organised private deals. For example, private companies such as downstream bottling companies pay upstream communities for sustainably managing the forests in the watershed that provide services such as watershed protection on which the bottling companies depend. At the basis of sustainable watershed management should be restoration, where the key is convincing investors that such activities will ensure sustainable environmental services as sustainable "production inputs," thereby making landscape scale restoration financially and economically attractive. Another example of PES is paying for carbon sequestration; energy companies could invest money in restoration projects to increase the carbon sequestration service of forests for the purpose of meeting their carbon offsets, as is allowed under the Kyoto protocol.

6.2 Financing sources

6.2.1 Financing from Domestic Public Sources

General strategies to increase public sources for large-scale restoration involve activities like improving expenditure policies on forestry, reforming macroeconomic policies (including taxes and subsidies), and putting in place new incentives, subsidies, and technical and institutional changes to support restoration that provides wider benefits. It is, however, also important to improve the administrative capacity of forestry agencies themselves to increase their efficiency to collect revenue and to use the resources efficiently for restoration. Other ways to increase forest revenues from public funding are to ensure the proper pricing of forest goods and services (through charges, policies that demand full-cost pricing, permits, licensing, etc.) or setting up special forest trust funds with earmarked taxes to finance specific restoration activities. It is also possible to use tax measures that tax downstream beneficiaries to fund restoration upstream.

6.2.2 Multilateral and Bilateral Donors

Given the declining trend in ODA, efforts must be directed at maintaining current funds from multi- and bilateral aid. In general, however, environment is no longer a top priority of development and cooperation agencies, and it has now been mainstreamed in all development activities under the new sector approach embraced by many donor agencies. Therefore, successful proposals for forest landscape restoration from multilateral and bilateral donors increasingly need to explain how forest landscape restoration activities will address poverty alleviation. Furthermore, it is also useful to use ODA to leverage private funding for restoration. The World Bank's Sustainable Forest Market Transformation Initiative (SFMTI) is a good example, which promotes private sector participation in forest management.

6.2.3 Private Not-for-Profit Sources

Private not-for-profit sources include financing channelled from local communities, international foundations, and NGOs for forest landscape restoration activities. International NGOs have become important for providing new financing mechanisms, of which environment trust funds or foundations are particularly interesting for providing financing to natural resource management in general. Trust funds are not philanthropic foundations. Rather, they raise money to carry out their own programmes and have specific missions and interests and sometimes geographical focusses. The main purpose of setting up a trust fund has traditionally been to provide long-term stable funding for national parks and other protected areas or small grants to local NGOs and community groups for projects aimed at conserving biodiversity and using natural resources more sustainably. Such trust funds could be set up to support the restoration of forest values over the long term.

6.2.4 Private for-Profit Sources

Private for-profit sources range from mobilising households to invest in restoration to investments from large international corporations. Household investments will have an effect only if the projects offer short-term benefits with an acceptable level of risk. These benefits can be an increased income for households or indirect payments in, for example, alternative livelihoods, roads, schools, and so on. On the other hand, a more grant-type of financing from large private companies like dam, oil, plantation, and mining companies can be mobilised to pay for forest restoration as compensation for environmental disruption they may cause. This motivation may also come from business ethics and thus be part of a company's public relations campaign. An example is where environmental NGOs are invited by a plantation company to restore part of their land according to standards compatible with forest landscape restoration. Lastly, engaging conventional capital markets by channelling capital toward forest management and restoration has potential.

6.2.5 Payments for Forest Goods and Services

Market-based financing has both potentials and limitations but it does provide real opportunities for mobilising funds for forest landscape restoration. A good example of payments for environmental goods is the certification body, the Forest Stewardship Council (FSC), which developed a market for sustainably produced wood and wood products that come with a seal of approval or certificate. In terms of payments for environmental services, a good example is the increase in projects that create payment mechanisms where downstream beneficiaries pay for the sustainable management of forests upstream. Such systems provide significant opportunities for innovative funding for forest landscape restoration.

6.2.6 International Systems of Payments for the Environmental Commons

There has been some progress at international level to pay for the global commons. The best known is the Global Environmental Facility (GEF), which provides partial grant funding to eligible countries for projects that address threats to the environment in four areas: biodiversity loss, climate change, ozone depletion, and degradation of international waters. Under its biodiversity programme, the GEF can support conservation and sustainable use of significant biodiversity, including forest ecosystems.

Funding from GEF for forest landscape restoration could be mobilised under this area. In a landscape context, it will be possible to initiate a restoration activity with public funding in order to address immediate livelihood needs (e.g., provision of traditional medicines, reduction in people's vulnerability). In the longer term, and still within the context of landscapes and the restoration of many forest benefits, it may become possible to ensure sustained funding by the private sector in order to meet additional benefits (such as certified nontimber forest products, for instance).

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