CARBON SEQUESTRATION AND THE RESTORATION
OF LAND HEALTH
An Example from Iceland

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Abstract. Carbon sequestration, the conversion of greenhouse gas CO₂ to organic matter, offers a powerful tool with which to combat climate change. The enlargement of carbon sinks stored in soil and biota is an essential tool in buying time while mankind seeks means to reduce emissions of greenhouse gases and to reduce the elevated levels of atmospheric CO₂. Carbon sequestration within the context of the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) also has great potential as an incentive for combating land degradation and desertification and restoring fertility to degraded land. Decisions regarding carbon sinks during finalization of the operational details of the Kyoto Protocol in 2001 fit well the needs of countries facing land degradation and desertification. However, incentives for such mitigation through the Clean Development Mechanism of the protocol are limited to forestry issues. Iceland provides a good example of the multiple role of carbon sequestration in meeting national commitments to UNFCCC, conserving and restoring biological diversity, combating soil erosion, revegetation of eroded land and reforestation. Linking carbon sequestration with such goals has resulted in increased funds for soil conservation and restoration of degraded land in Iceland.

1. Introduction

In the United Nations Framework Convention on Climate Change (UNFCCC), climate change is defined as a ‘change of climate which is attributed … to human activity that alters the composition of the global atmosphere…’ (Article 1). The UNFCCC’s objective is to achieve ‘stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system’.

2. Carbon and Climate Change

Carbon – usually in the form of carbon dioxide (CO₂) – is the main factor in climate change. The atmospheric concentration of carbon dioxide (CO₂) has increased by 31% since 1750. The present CO₂ concentration has not been exceeded during the past 420,000 years and likely not during the past 20 million years. About three-quarters of the anthropogenic emissions of CO₂ to the atmosphere during the past
20 years is due to fossil fuel burning. The rest is predominantly due to land-use change, especially deforestation (IPCC, 2001).

The location of carbon in the global systems has a pivotal impact not only on the achievement of the UNFCCC’s objectives but also on a multitude of environmental, social, and economic goals. In the form of CO₂, carbon is an important contributor to global warming. The same carbon atom located in soil as organic matter is the key to soil fertility and increased food production for the world’s ever-growing population.

Land degradation and desertification is a severe problem not only in the drylands, where food insecurity is a major problem (Lal, 2001), but also in many other parts of the world. In addition to reducing emissions, a major tactic in mitigating climate change and enhancing food security should be to replace some of the lost carbon to the soil and store it in long-term or permanent reservoirs – i.e., carbon sequestration.

The UNFCCC defines sink as ‘…any process, activity or mechanism which removes a greenhouse gas … from the atmosphere’ (UNFCCC, Article 1). In this way, reservoirs are generated or maintained, ‘…where a greenhouse gas … is stored’ (UNFCCC, Article 1). Vegetation acts as a carbon sink because plants convert the naturally occurring atmospheric greenhouse gas, CO₂, into organic material – the tissues forming trunks, shoots, roots, leaves, etc., forming a carbon reservoir comprising all live and dead organic material. Most is stored in the ground and has a direct relation to soil fertility.

3. Carbon in Iceland – A Resource Out of Place

Iceland is an example of a country where vast amounts of stored carbon have been released to the atmosphere due to degradation of woods and rangelands (Figure 1). Restoring these degraded lands to sustainable woodlands and fertile grazing lands would ensure the ongoing presence of significant carbon sinks.

The first settlers who came to Iceland about 1100 years ago saw a fertile land. Vegetation may have covered more than 60% of the country, and woodlands, mainly birch (Betula pubescens), covered at least 25% of the land area. The vegetative cover provided good protection for the fragile volcanic soils. With the settlement, the delicate balance between a hostile climatic environment and vulnerable vegetation was disrupted (Thorsteinsson, 1986; Arnalds, 1987). The woodlands were grazed, cut for fuel or timber, or burned to clear pasture. The initial causes of soil erosion in Iceland varied from place to place, but, clearly, the interaction of livestock grazing, and weak soil structure, harsh climate and volcanic eruptions is the main reason for the great ecosystem disturbance. Climatic fluctuations have also exacerbated this process, reducing further the ability of the vegetation to resist the unyielding pressure of man and livestock. Subsequent soil
Figure 1. Soil remnant in area of severe desertification in Iceland. More than 450 million tonnes of carbon may have been lost from Icelandic soil and vegetation in 1100 years, resulting in diminished land fertility and a great need for carbon sequestration.

erosion devastated large parts of the ecosystem, reducing vegetative cover by about half. Trees now cover only 1% of the land area.

Arnalds (1987) summarizes some of the various sources that can be used to reconstruct the vegetation of the past, and trace some of the major changes in cover and composition through the centuries. These include historical records, pollen studies and remnants of former vegetation. Many old site names, such as ‘Skogar’ (woods), indicate lush vegetation in areas that later became desertified, and the meaning of the word ‘holt’ has been reversed from a wooded area to a barren hill. Remnants of pits where charcoal was made out of birch, and other land use indicators, also tell a sad story of land degradation (Figure 2). The potential woodland distribution has also been assessed by meteorological data. The woodland cover may have been lost from at least 25,000 km² and at least 30,000 km² have become denuded.

Desertification continues to be a major threat to Iceland’s natural resources, despite ample precipitation in most parts of the country. A national assessment of soil erosion indicates that 40% of Iceland is experiencing severe soil erosion (Arnalds, 2000; Arnalds et al., 2001). The extent and severity of soil erosion in Iceland is indicated in Figure 3. The map gives an indication of the immense task ahead of both combating desertification and restoration of damaged ecosystems. Surfaces that become denuded are usually almost devoid of belowground plant tissue and subsequent vegetation succession can be considered primary. In addition to the loss of the woodlands, the vegetation composition in many parts of the country has been adversely altered by grazing and reduced soil fertility. Poor land health and
continued soil erosion are considered the most severe environmental problems in Iceland. There is an urgent need to improve land quality over vast areas, which combines well with political efforts toward carbon sequestration and permanent storage of carbon in the form of organic matter in both soil and biota.

4. Carbon Sequestration and the Kyoto Protocol

Carbon sequestration is one of the tools available in mitigating the potential risk of climate change. The operational details of the Kyoto Protocol to the Convention
on Climate Change were finalized in 2001, despite considerable controversy. It was decided that countries included in Annex I to the Protocol may choose to use carbon sinks created after 1990 by revegetation, forest management, cropland management, and grazing land management in addition to afforestation and deforestation, to meet country commitments. Some of these issues will be discussed here in relation to the mitigation of land degradation and desertification.

5. Revegetation

‘Revegetation’ is defined as a direct human induced activity to increase carbon stocks on sites through the establishment of vegetation that covers a minimum area of 0.05 ha but does not meet the UNFCCC definitions of afforestation and reforestation. For countries that have suffered much erosion, like Iceland, the acceptance of re-vegetation was particularly important, enabling carbon sequestration as an incentive to combat desertification and restore eroded land. This decision encourages the use of low growing, non-forest, species as carbon sinks, where appropriate. Limitations to ‘forestry’, especially under ‘tall tree’ definitions, might in many projects have encouraged the use of introduced trees and monoculture at the cost of native species, threatening local biodiversity and thereby contradicting the goals of fundamental international conventions, such as the Convention on Biological Diversity (CBD), Convention on Desertification, and UNFCCC itself.

6. Forestry Definitions

Each Party included in Annex I shall, for the purposes of applying the definition of ‘forest’, select a single minimum tree crown cover value between 10 and 30%, a single minimum land area value between 0.05 and 1 ha and a single minimum tree height value between 2 and 5 m. This selection shall be fixed during the first commitment period.

Care has to be taken that forest definitions, and thus the distinctions between forestry and revegetation as related to the Kyoto Protocol, meet the goals of land-care and biodiversity conservation. Degraded land in some parts of the world, especially the arid lands most prone to severe degradation or desertification, is often characterised by low growing species that would not fall under common ‘forest’ definitions, derived from tall timber uses. Iceland, with its ample rain, illustrates this well. Birch is the main native tree, but in many of the areas of re- and afforestation it only reaches 2–4 m in height at maturity, often less. Thus, if for instance the State of the World’s Forests definition (FAO, 1977, pp. 173–174) were used, only introduced species would meet ‘forestry’ definitions. Such definition could encourage the use of non-native trees for carbon sequestration in Iceland, contravening CBD goals. It is important to encourage the use of native, naturally
adapted species in areas prone to land degradation, including Iceland. The danger of exclusion of sinks because wooded areas do not meet classical forest definitions must be avoided.

From a carbon accounting perspective, soil carbon in forestry is important, as a large proportion of the carbon pool is below ground, and is often a more permanent storage form than the wood. Thus, planting trees in relatively fertile land may, at least initially, release carbon from the soil to the atmosphere. Using native trees or shrubs as reclamation species in unfertile land, in contrast, may yield large overall carbon sequestration rates in soil and biota, as indicated by preliminary research figures from Iceland (Aradottir et al., 2000; Arnalds, et al., 2000, 2002) and discussed later in this article.

7. Land Use Change

The inclusion of ‘cropland management’ provides great potential as an incentive for more sustainable crop production. This will encourage both improved practices for growing agricultural crops and temporary rest or non-use of land that may be damaged or too sensitive for cultivation.

The approval of ‘grazing land management’ may also provide an incentive for more sustainable use of pastoral lands, although the additional carbon sequestration may be difficult to monitor in the context of lightly vegetated extensive grazing areas. As an example of the importance of this category in degraded environments, about 40% of Iceland’s land area is affected by severe soil erosion. In many cases, protecting the most damaged land from grazing may be the most economic route to recovery. Annual carbon sequestration rates per unit area resulting from such land use change as improved management or protection from grazing may be low, but the potential areas are large.

The inclusion of land use changes such as grazing management, i.e., as a tool in meeting national greenhouse gas targets, could be very beneficial to sustainable land use in many parts of the world, and certainly in Iceland. From the community point of view, it would be economic for the government and other funding sources to assist in the development of options for improved management or protection of the most damaged rangelands from grazing, such as by improving through re-vegetation less sensitive land as an alternative grazing resource.

Using Iceland as an example, land use change has a strong linkage with re-vegetation of degraded land with grasses, legumes, native shrubs and trees. Such action increases carbon stocks in soil with low organic matter content, and provides multiple ecosystem and land use benefits. Measurement problems associated with the fate of existing soil carbon are relatively smaller where initial soil carbon levels are low.

The same would apply in many other countries where there is an urgent need to retire land from grazing or crop production in some areas, decrease the intensity of
land use in other areas by management changes, and halt soil erosion or improve land by reclamation activities. Carbon sequestration, especially in the soil, is an additional incentive in the attack on soil degradation.

8. Carbon Sequestration – Quality Considerations

According to the Kyoto Protocol, land-use, land-use change and forestry activities must adhere to several principles. They should be based on sound science, with consistent methodologies used for accounting and reporting, and their implementation should contribute to the conservation of biological diversity and sustainable use of natural resources.

Many nations have a large potential for carbon sequestration through additional activities incorporated in the Kyoto Protocol. This in particular applies to some agricultural countries, especially through improved management of agricultural land. Although carbon sequestration and reducing emissions are two different routes to the same goal, many environmental groups see this as an escape route for such countries to avoid reducing emissions. Therefore the overall quality and benefits of such projects must be considered with emphasis on the integrated management of carbon sequestration, the environment and sustainable livelihoods (Orlando et al., 2002).

Carefully designed projects that aim to mitigate land degradation and desertification link well the goals of the conventions on climate, on biodiversity and on desertification. It is important that these, and other projects that are used to meet part of national commitments on reducing greenhouse gases, are based on multiple objectives and be mutually supportive to the overall goals of the conventions.

9. Carbon Sequestration and the Clean Development Mechanism

Article 12 of the Kyoto Protocol includes provisions for the establishment of a ‘clean development mechanism’ (CDM). Its basic premise is that projects undertaken in developing countries can be counted towards meeting the emission targets of developed countries.

In the finalised Kyoto Protocol to the Convention on Climate Change carbon, sinks in the CDM were limited to forestry issues only. If forestry is defined in tall-timber terms this may limit the ‘win-win’ opportunity where developed countries would invest in actions for mitigating desertification and improve land fertility that help them meet their commitments under the Protocol. The developed and developing countries need to find means to enable more such mutually beneficial co-operative efforts to meet the climate-change challenge. Such projects should be used where possible to reinforce sustainable land use and food security. The ‘big winners’ would be the countries most affected by severe land degradation and desertification, especially the poorer countries.
10. Applications in Iceland and Further Opportunities

Iceland provides a good example of how carbon sequestration for preventing climate change can be linked to other goals of society. The degradation of the natural resources affects most parts of the country, and restoring land quality and preventing further ecosystem damage is a huge task for a nation of only 280,000 people. Carbon sequestration to meet part of the commitments of the Kyoto Protocol has become one of the additional incentives needed.

11. Repaying the Carbon Debt

Oskarsson et al. (2004) estimate that 120–500 million tonnes of organic carbon has been lost from the soils of Iceland, a country of 103,000 km², in the last 1100 years. Jonsson and Oskarsson (1996) estimate that at least 450 million tonnes of carbon in biomass and soil may have been lost during this period through land degradation and desertification. In terms of CO₂, this is 500 times emission of greenhouse gases in 1990, the baseline year of the Kyoto Protocol. As a consequence, there is both a high potential and a great need for carbon sequestration, as an added value to the urgent task of restoring land fertility and biodiversity.

Iceland’s Soil Conservation Service (SCS) and Forestry Service (FS) are among the oldest in the world (established 1907) and have a long history of successful soil conservation work. Based on this experience, and the great need for improved land quality, the Icelandic government decided to include carbon sequestration as a significant element in the national Climate Change Action Programme. To reach the goal of increasing 1990 annual carbon sequestration levels by 100,000 t CO₂ by 2000 the government provided 30% additional funds for reclamation and reforestation for 1997–2000. In the soil conservation sector, additional carbon sequestration programmes focused on selected sites where results can easily be documented and demonstrated. Funds are still increasing, and carbon sequestration as a tool in meeting targets in greenhouse gas emissions thus has become a major financial incentive for soil conservation and forestry.

12. Community Involvement in Carbon Sequestration

Based on this new incentive of using carbon sequestration to meet greenhouse gas emission targets, many projects were started or expanded to combat desertification and heal eroded land. Projects to reforest damaged land were also expanded, including a grass-roots-oriented programme termed ‘reclamation forestry’.

Land degradation has multidimensional consequences to society. These include reduced biological diversity, agricultural productivity and food security; loss of shelter against winds and snowdrifts; and degraded watershed hydrology. To build
a strong relationship between conservation and society, SCS has been developing new approaches in its operation (Arnalds, 1999). In general, mitigating land degradation is becoming more participatory, involving a wide cross-section of Icelandic society in ecosystem understanding and solution development. This also means widening the focus, from localized problems of soil erosion to the more complex issues of ecosystem management for multiple uses (Arnalds, 2000). SCS currently works with a wide range of community groups, including municipal and rural authorities, a wide range of clubs and associations, and many individual volunteers. Carbon sequestration adds a new dimension to strategy development, giving both projects and participants an additional role. In 2002 the Icelandic Parliament approved a national soil conservation and revegetation programme for 2003–2014. Carbon sequestration is included as one of its goals (returning the carbon back to the land), and it is also listed as one of the tools in Iceland’s strategy for meeting Kyoto commitments.

13. Farmers Heal the Land

The Icelandic farm community is by far the most active group in reclaiming eroded land, and thus the most efficient in carbon sequestration. Programmes that motivate and provide livestock owners with voluntary incentives to adopt sound conservation practices have been evolving in Iceland since 1990 (Arnalds, 1999). The most extensive is Farmers Heal the Land, a partly locally led programme centred on assisting landowners to reach their reclamation goals. The long-term goal is to increase conservation awareness and make the land users the true custodians of the land.

The farmers conduct the reclamation work, but receive 85% of fertilizer cost (which can be half of overall project cost), and grass seed as needed. Cost sharing is considered important, creating a feeling of ownership in the results. More than 30% of the sheep farmers are now actively participating, plus a number of other land users. The farmers have a big role in combining the goals of mitigating desertification and carbon sequestration in Iceland (Figure 4).

14. Carbon Sequestration Rates

All Icelandic soils exhibit andic soil properties to some degree because of their volcanic origin, which is usually basaltic in composition. Organic C values are generally $<3 \text{ g kg}^{-1}$ whereas undisturbed Andosols commonly contain 30 to 80 g C kg$^{-1}$ in A and B horizons (Arnalds and Kimble, 2001). As a result there is a high potential for carbon sequestration through revegetation of degraded and desertified land (Figure 5). The main aim of measures for mitigating desertification and revegetation is to establish conditions for native vegetation to thrive (Figure 6).
Figure 4. A participant in the Icelandic Farmers Heal the Land project dispersing seeds and fertilizers in an area of severe desertification.

Figure 5. Eroded areas in Iceland have a low initial carbon content and a high potential for carbon sequestration.
Aradottir et al. (2000) report annual rates of 0.01 to 0.5 t C ha\(^{-1}\) sequestration in aboveground biomass on ten sites in Iceland. The sites represented a range in climatic conditions, revegetation methods and age of projects. Revegetation methods included sown grasses and fertilizer applications, fertilizer application without seeding, seeding of the introduced legume \textit{Lupinus nootkatensis}, and seeding the sand stabilizer \textit{Leymus arenarius} in sand dunes. A total of 186 samples were analysed for organic carbon by dry combustion.

Arnalds et al. (2000) report carbon sequestration in soils by revegetation of severely degraded areas in Iceland. A total of 62 projects in 32 areas were sampled. For comparison, an attempt was made to sample adjacent treated and untreated areas. The results show an average sequestration rate in soils of 0.6 t C ha\(^{-1}\), and indicate that this rate can be maintained for more than 50 years. Arnalds et al. (2002) report a total of 1.2 t C ha\(^{-1}\) carbon sequestration in soils and aboveground biomass for revegetation of desert sites, and 2.2 t C ha\(^{-1}\) for restoration of birch woodlands on desert sites.

Preliminary results of the 1997–2000 carbon sequestration project of the Icelandic National Climate Change Action Programme indicate average rates of 0.8 t C ha\(^{-1}\) through re-vegetation of desertified land using grasses and fertilizers, with about 65% stored in the soil (Ministry of Agriculture, 2000). Many of the sites represented difficult condition where combating catastrophic soil erosion was the main goal. Average rates from afforestation, partly of severely degraded and desertified lands were 1.7 t C ha\(^{-1}\).

Based on these and other data the average annual sequestration rate of 2.75 t CO\(_2\) ha\(^{-1}\) has been used in reports to the IPCC for revegetation. About 50 km\(^2\) of denuded land were revegetated in Iceland in year 2000, resulting in an estimated 15,500 tonne CO\(_2\) increase in annual carbon sequestration. In addition land condition is improving, and carbon sequestration increasing in large degraded areas through improved grazing management and protection from grazing. Restoration of birch woodlands on desert sites is now classified as reforestation, but that may
change depending on decisions on tree height definitions for forestry with regard to the Kyoto Protocol.

15. Options for Funding Carbon Sequestration in Iceland

It may be feasible for the Icelandic government to greatly increase funds for carbon sequestration projects. Ecosystem degradation, making soil carbon sequestration so essential, is centuries old. Restoration could therefore be regarded as a communal duty of the current generation, especially for future food security. Partial funding by the government as seed money would also attract funds from other sources.

Carbon sequestration adds a new dimension to agricultural and rural support. Some projects would offer direct income to farmers and other rural people, but the main benefit to agriculture would come from the carbon sequestration itself, through increased soil fertility and better plant growth. Stakeholder cost sharing may be important in projects where land utilization might reduce carbon sequestration rates.

Utility fees are common in many countries, such as for waste disposal and recycling. Pollution fees, for instance on CO₂ from fossil fuel, could be used to fund carbon sequestration. Annual carbon sequestration through the revegetation of about 1.4 ha of degraded land, or establishing 0.7 ha of new woodlands, could balance CO₂ pollution from the average family car for at least the next 40 to 80 years. The cost of meeting CO₂ emissions from gasoline and diesel fuel by sequestration is variable, but may require 2–4% increase in fuel price.

16. Funding and Carbon Credits

Nationally, there is wide interest in ‘healing the land’, and a large number of individuals, companies and societies are active in reclamation and forestry. As an example of the diverse private sponsorship, the Retailers Association of Iceland operates an environmental fund based on the sales of plastic shopping bags in shops. The fund supports a wide range of soil conservation and forestry activities.

Carbon sequestration has hitherto not been an issue in the work or funding of reclamation and forestry projects by various sectors of society. However, laws on carbon sequestration rights may have to be set to make sequestered carbon tradable like emissions quotas.
17. Conclusions

Synergy – ‘a combined effect … that exceeds the sum of individual effects’ – is a characteristic of carefully selected and well-designed carbon sequestration projects. Many types of carbon sinks are clearly synergic, meeting multiple objectives.

The current rate of CO₂ increase in the atmosphere is unprecedented during at least the past 20,000 years (IPCC, 2001), and may have reached levels that may induce changes in Earth’s climate. However, there are both technological and economic constraints to reducing greenhouse gas emissions at the rate probably required to minimize the risk of climate changes. Carbon sequestration could be seen as a tool to ‘buy time’ for such measures reducing greenhouse gas emissions and also as a means to return part of a displaced resource back into organic matter.

The ‘greenhouse’ links may provide the additional source of funding needed for many projects combating desertification and improving land quality. In some countries, such as Iceland, this could augment both government and private sector funding for soil conservation projects. It could also encourage development of much-needed alternatives for land use changes in degraded areas. Projects should not be selected on the basis of carbon sequestration rates, but on their overall values for society, and evaluating their effect on biological diversity. The carbon sequestration comes as an added bonus to such projects.

References


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