B A
S E

Biotechnol. Agron. Soc. Environ. 2000 **4** (4), 303–307

Carbon sequestration by afforestation and revegetation as a means of limiting net-CO_2 emissions in Iceland

Bjarni D. Sigurdsson [1], Arnor Snorrason [2]

[1] Department for Production Ecology. Swedish University of Agricultural Sciences. P.O. Box 7042. SE–75007 Uppsala (Sweden). E-mail : bjarni.sigurdsson@spek.slu.se
[2] Icelandic Forest Research. Mogilsa. IS–116 Reykjavik (Iceland).

Iceland has lost about 95% of its woodlands and 50% of its vegetative cover during the 1,100 years of human settlement. Efforts to reclaim lost woodlands and herbaceous ecosystems have been continuing since the early 20th century. It is emphasised that for Icelandic conditions, effective carbon sequestration can be achieved by restoring (reclaiming) herbaceous ecosystems on carbon-poor soils. Since 1990, about 4,000 ha per year have been afforested or revegetated. In 1995, the estimated C-sequestration of those areas was 65,100 t CO_2, or 2.9% of the national emissions for that year. In 1999, the estimated sequestration was up in 127,600 t CO_2, or 4.7% of the predicted CO_2 emissions for the year 2000.
Keywords. Afforestation, ARD, C-sequestration, mitigation, revegetation, Iceland.

1. INTRODUCTION

Iceland has lost about 95% of its woodlands and 50% of its vegetative cover during the 1,100 years of human settlement. This massive loss of woodlands and vegetated areas is a combined effect of intensive land use, volcanic catastrophes and variation in climate over the past millennium. Today, native and planted woodlands cover only about 1% of the land surface, which is the lowest forest cover in Europe, and only some 28% of the land surface has a fairly extensive vegetation cover. Glaciers, rivers and lakes cover 17%, and the remaining 55% are described as barren land.

Apart from protecting the native birch woodlands, the main effort in Icelandic forestry since the early 20th century has been the planting of new forests of both native birch and exotics. The first forest plantation was established in year 1899, but it was not until 1946 that the number of trees planted annually exceeded 100,000 (**Figure 1**). Today, about 84 million trees have been planted in Iceland. Five tree species account for about 80% of the plantings; Russian larch (*Larix sukaczewii*, 22%), the native birch (*Betula pubescens*, 21%), lodgepole pine (*Pinus contorta*, 15%), Sitka spruce (*Picea sitchensis*, 14%) and Norway spruce (*Picea abies*, 6%) (Petursson, 1999). Prior to 1970, exotics were mainly planted into the remaining birch woodlands, but after 1970 afforestation on treeless areas increased. Planting of exotics into birch woodlands has not been practised since 1990. The increase in tree-seedling production in the 1990s (**Figure 1**) was mainly caused by the launch of a country-wide project for afforestation of eroded/degraded areas, and by a major afforestation project among the farmers in East-Iceland. This increase in afforestation in the early 1990s was a positive coincidence in relation to Art. 3.3 of the Kyoto protocol.

Today, only 1.4% of Iceland's surface is under cultivation, but some 24% are considered as arable. Afforestation does therefore not have to compete with cultivation to the same extent as in most other

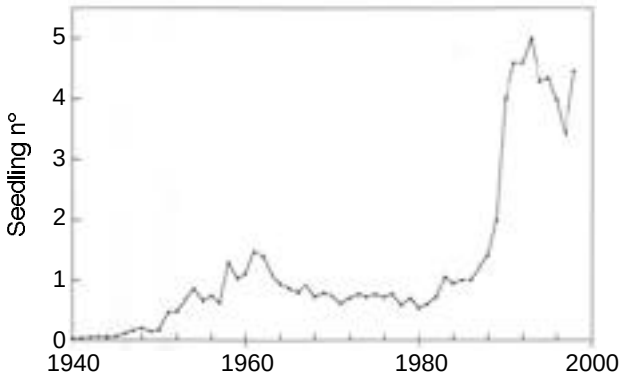

Figure 1. Annual tree planting (in million tree seedlings) in Iceland from 1940 to 1998.

countries. Extensive eroded lands are also found in climates that allow primary production, which gives a potential for long-term C-sequestration by revegetation and reclamation forestry in those carbon-poor areas. The small economy (low emissions) and large surface area make it practically possible to use afforestation and revegetation as an important tool to reduce the national net-emissions of CO_2. The political body in Iceland has, however, not yet taken any major decisions about role of afforestation in the nation's CO_2-policy. In 1997, the Government launched a special programme for increasing the C-sequestration in forests, vegetation and soil by 100,000 t CO_2 in the year 2000, from what it had been in year 1990. For this purpose the budget for afforestation and land reclamation was increased by about € 6,000,000, or about € 23 per capita.

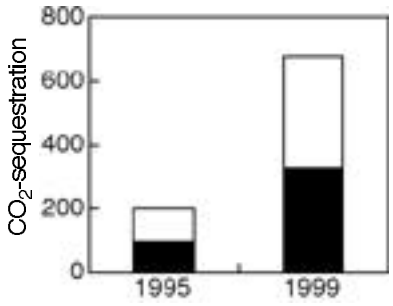

Figure 2. CO_2 sequestration (in 1,000 t CO_2) since 1990 by afforestation (Art. 3.3 activities; filled columns) and revegetation (Art. 3.4 activities; open columns) in Iceland (Ministry for the Environment 2000, revised numbers).

2. REFERENCE VALUES FOR GREENHOUSE GAS INVENTORIES

Iceland ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1993, but has not yet signed or ratified the Kyoto protocol. The first National Communication (NC) to UNFCCC was in 1996, the second in 1997 and the third is due in 2001. In absolute terms, Iceland is by far the smallest OECD emitter of CO_2, with 2,147,000 t CO_2 in 1990 and 2,282,000 in 1995 (6% increase; Ministry for the Environment 1997). The increase is, however, expected to be around 15% in year 2000, the reason partly being an expansion of one aluminium smelter. Other greenhouse gases than CO_2 increased the total greenhouse gas emissions to 2,730,000 t (in CO_2 equivalents) in 1990, and to 2,640,000 t in 1995 (3% reduction; Ministry for the Environment 1997).

In the first two NCS to UNFCCC, no values were given for C-sequestration or emissions due to land use, land-use change or forestry (Ministry for the Environment 1997). A preliminary national estimate was, however, recently published for C-sequestration (Ministry for the Environment, 2000). There it was emphasised that human-induced C-sequestration in Iceland should not be considered in isolation from activities under Article 3.4.

Accumulated C-sequestration by afforestation in so called "Kyoto-forests" (afforested since 1990) was estimated 98,000 t CO_2 in 1995 and 327,000 t CO_2 in 1999 (**Figure 2**). This estimate was obtained from information about the afforested area and the mean sequestration rate of mature forest stands in Iceland (1.7 t C·ha^{-1}·y^{-1}; Oskarsson, 2000). It includes changes in aboveground biomass and coarse roots, but does not incorporate any changes in C-stocks in soil, litter or ground vegetation after afforestation (**Table 1**). To account for total C-sequestration by direct human actions, revegetation of barren lands should be included (**Figure 2**). Revegetation since 1990 accounted for 105,000 t CO_2 in 1995 and 350,000 t CO_2 in 1999 (**Figure 2**). These values were estimated from information about the revegetated area and the mean sequestration rates for such ecosystems (0.75 t C ha^{-1}·y^{-1}; Aradottir *et al.*, 2000; Arnalds *et al.*, 2000; Ministry for the Environment, 2000, revised numbers). The total afforested and revegetated area in Iceland since 1990 was about 17,500 ha in 1995 and 36,400 ha in 1999. The annual sequestration of those areas was estimated at 65,100 and 127,600 t CO_2 for 1995 and 1999, respectively. The estimated C-sequestration in 1995 was 2.9% of the total national CO_2 emissions for the same year. Sequestration accounted for 4.7% of the CO_2 emissions for year 2000.

Table 1 shows the first attempt to estimate C-stock and C-sequestration of Icelandic plantation forests. However, since the mean C-sequestration rates and the average C-stocks are based only on a limited number of studies (Snorrason *et al.*, 2000), some corrections may be necessary to account for local differences in growth potentials. C-stock of wood in plantations in Iceland more than doubled from the beginning of year 1990 to the end of year 2000, as it went from 220,000 to 450,000 t C (**Table 1**). Total ecosystem C-stock in forest plantations increased from 1,600,000 to 3,800,000 t C during the same period.

Iceland has not reported any CO_2-emissions because of deforestation (Ministry for the Environment, 2000). It should be borne in mind that the estimated national CO_2-sequestration is only from forest plantations established during the 20th century, and which are therefore still within their first rotation. Weighted mean age of all plantations established in Iceland is only 17 years (**Table 1**). Tree harvesting is therefore still primarily done by thinning, and clear-cutting is not practised.

Table 1. Estimated C-sequestration in wood (expressed as AI) and total C-stocks in forest plantations in Iceland during 1900–2000.

	Tree No (million)	Area [1] (1,000 ha)	AI [2] (1,000 t C)	Age [3] years	Trees [4] t C·ha^{-1}	C-stock (1,000 t C) Trees	Litter[5]	Soil	Total
Accumulated during each period									
1900–1970	18.7	3.5	6	11	20	70	20	700	800
1900–1989	35.4	6.6	11	20	33	220	50	1,300	1,600
1971–1989	16.7	3.1	5	8	13	40	20	600	700
Accumulated at the end of year 2000									
1900–1970	18.7	3.5	6	41	69	240	20	700	1,000
1900–1989	35.4	6.6	11	31	51	340	50	1,300	1,700
1971–1989	16.7	3.1	5	19	32	100	20	600	700
1990–2000	48.7	9.1	15	6	10	90	60	1,800	2,000
1900–2000	84.0	15.8	26	17	29	450	110	3,200	3,800

[1] Estimated area of plantations from number of planted seedlings (**Figure 1**); [2] AI = C-sequestration in the last year of each period, estimated from mean annual increment and area. MAI was assumed to be 1.7 t C·ha^{-1}·y^{-1} for all plantations (Oskarsson, 2000). [3] Weighted mean age of plantations. [4] Average C-stock in trees per unit area. [5] This includes also ground vegetation.

3. WORKING GROUP 1 RELATED ACTIVITIES (Inventory of C sinks and sources)

Forest inventories have not been practised in the same way in Iceland as in the other Nordic countries. The native birch woodlands, which are the main woody cover of Iceland, have been inventoried twice in the 20th century. The first inventory was made in 1972–1975. Birch woodlands were identified on aerial photographs, and their mean height and crown cover were described for each homogenous area (polygon), but no direct measurements of standing biomass were made (**Table 2**). The total woodland area was estimated at 125,469 ha (Skograekt rikisins and Skograektarfelag Islands, 1977). The second inventory took place in 1987–1991. Then, more data were compiled, at both landscape- and tree-level. Some 9,900 plots where sampled and 300 sample trees were harvested (ThH. Jonsson, personal communication). The total woodland area in Iceland (including some exotic plantations situated in birch woodlands) was estimated at 118,336 ha. Total woody C-stock (aboveground wood and coarse roots) was estimated from these data at 1,300,000 metric tons in 1990, with an average of 11 t C·ha^{-1}.

Table 2. Mean height and crown cover of the native birch woodlands of Iceland in 1972–1975 (Skograekt rikisins and Skograektarfelag Islands, 1977).

	Area (ha)	% of total
Mean height		
8–12 m	2,151	2
4–8 m	3,020	2
2–4 m	18,970	15
< 2 m	101,328	81
Crown cover		
80–100%	21,632	17
60–80%	28,443	23
40–60%	31,246	25
20–40%	21,869	17
0–20%	22,279	18

The two inventories were not a repetition of the same methodology, and can therefore not be directly compared to show changes in area or wood stock during this period. The apparent reduction in woodland area was not due to woodland degradation, but rather to better geographical information in the second inventory. It is a common opinion of natural scientists in Iceland that the birch woodlands, which in the first inventory where in a bad state because of high grazing pressure, are now expanding, mainly due to decreasing grazing pressure. No scientific evidence for these positive changes of C-stock in birch ecosystems exists, however.

No general inventory has been made of the plantation forests of Iceland. Direct estimates are therefore not available for the total afforested area, wood production or total wood stock of these plantations. A new database is, however, under construction, where tree-based measurements from about 2,500 plots are being compiled for the ten most common tree species (Snorrason, unpublished). This database can be used to give a fairly good estimate of the wood production of different forest plantations in Iceland. The number of seedlings planted annually has, however, been well documented during the past century (**Figure 1**). Total plantation area can therefore be estimated. Here it was assumed that the planting

density was 4,000 seedlings ha^{-1}, and that 25% of the afforested area was lost for various reasons. The only trees not included in these numbers are urban trees and ornamental trees in the countryside. As long as no direct estimate of the total plantation area exists, total C-stock estimates must be interpreted with care.

Estimated changes during the past 11 years (1990–2000) in total area and total C-stock of native woodlands and forest plantations are summarised in **table 3**. Native birch woodlands were assumed to have remained constant in C-stock during this period, in the absence of scientific evidence to the contrary. It should be noted that the 138% increase in the C-stock of forest plantations was mainly due to land-use change, i.e. C of soils, litter and ground vegetation moved from the grassland class into the forestland class when new areas were afforested. In fact, only 10% of the total stock was estimated to have been sequestered by the trees themselves since the time of afforestation (**Table 1**).

A group of scientists from different research institutions in Iceland has been working jointly since 1998, trying to establish sound estimates for long-term average C-sequestration rates in different ecosystems by the stock-change approach. This project contains four components:

– C-sequestration in woody biomass after afforestation,
– C-sequestration in other ecosystem components than wood after afforestation,
– C-sequestration in herbaceous ecosystems after revegetation (reclamation or restoration),
– measurement of C-fluxes to and from forests and herbaceous ecosystems.

All these scientists are potential candidates for participation in the Working Groups, and could contribute with their knowledge and expertise to this action (Aradottir *et al.*, 2000; Arnalds *et al.*, 2000; Snorrason *et al.*, 2000).

At the moment there are no European co-ordinated research programmes on carbon balance or C-sequestration running in Iceland. Icelandic scientists were, however, participating in the EUROFLUX programme that ended recently (Valentini *et al.*, 2000). Furthermore, Icelandic scientists were linked to the ECOCRAFT programme, through a Nordic research project named "The Likely Impact of Rising CO_2 and Temperature on Nordic Forests at Limiting and Optimal Nutrient Supply" (Sigurdsson *et al.*, 2001).

Table 3. Total area (in 1,000 ha) and total C-stock (in 1,000 t) of native woodlands and plantation forests in Iceland in year 1989 and year 2000.

Forest ecosystems	Area (1,000 ha)		Total C-stock (1,000 t)	
	1989	**2000**	**1989**	**2000**
Native birch woodlands	115	115	25,300	25,300
Plantation forests	7	16	1,600	3,800

4. WORKING GROUP 2 RELATED ACTIVITIES (Analysis of forest management practices)

Because of the moderate extent of forestry activity in Iceland, relatively little research has been devoted to forest management practices, other than afforestation. As forestry expands, demands for such research are, however, increasing. No direct analysis has been done on how different management practices could change the C-sequestration potential of the existing woody ecosystems, but comparison of different sequestration rates between species and sites does exist (Snorrason *et al.*, 2000).

5. PERSPECTIVES AND RESEARCH NEEDS

Because of the potential importance of C-sequestration by afforestation (and by revegetation of barren lands) in Iceland, it is judged to be of utmost importance that Icelandic researchers participate in the COST E21. Not only to be well informed about standard methods for accounting for C-sequestration by afforestation, but also to interact and seek expertise on different subjects related to the carbon balance of forest ecosystems. The main expectations and desired outcomes by COST E21 are therefore an exchange of knowledge on carbon accounting, including both methods to estimate stocks and fluxes.

Bibliography

Aradottir AL., SvavarsdottirK., JonssonThH., GudbergssonG. (2000). Carbon accumulation in vegetation and soils by reclamation of degraded areas. *Icelandic Agric. Sci.* **13**, p. 99–113.

Arnalds O., Gudbergsson G., Gudmundsson J. (2000). Carbon sequestration and reclamation of severely degraded soils in Iceland. *Icelandic Agric. Sci.* **13**, p. 87–97.

Ministry for the Environment (1997). *Second status report for Iceland. Pursuant to the United Nations framework convention on climate change*. Reykjavik: Ministry for the Environment, 81 p.

Ministry for the Environment (2000). *Land-use, land-use change and forestry. Submission by Iceland. Special report to SBSTA*. Reykjavik: Ministry for the Environment, 13 p.

Oskarsson U. (2000). *Kolefnisbinding i grodri og jardvegi. Afangaskyrsla 1999. [C-sequestration in vegetation and*

soil]. Verkefnisstjorn ataks i landgraedslu og skograekt 1997–2000, Reykjavik, 31p. (Extended English summary).

Petursson JG. (1999). Skograektaroldin. Samanteknar tolur ur Arsriti Skograektarfelags Islands. [The first 100 years of tree planting in Iceland]. *Skograektarritid* (2), p. 49–53. (English summary).

Snorrason A., Jonsson ThH., Svavarsdottir K., Gudbergsson G., Traustason T. (2000). Rannsoknir a kolefnisbindingu raektadra skoga a Islandi. [Carbon sequestration by afforestation in Iceland]. *Skograektarritid* (1), p. 71–89. (Extended English summary).

Sigurdsson BD., Thorgeirsson H., Linder S. (2001). Growth and dry-matter partitioning of young *Populus trichocarpa* trees during three years of elevated CO_2 and fertilisation. *Tree Physiol.* (accepted).

Skograekt rikisins and Skograektarfelag Islands (1977). *Skoglendi a Islandi. Athuganir a staerd thess og astandi [Woodlands of Iceland. Inventory of area and condition]*. Reykjavik: Skograekt rikisins and Skograektarfelag Islands, 38 p. (In Icelandic).

Valentini R., Matteucci G., Dolman AJ., Schulze ED., Rebmann C., MoorsEJ., Granier A., Gross P., Jensen NO., Pilegaard K., Lindroth A., Grelle A., Bernhofer C., Gruenwald P., Aubinet M., Ceulemans R., Kowalski AS., Vesala T., Rannik U., Berbigier P., Loustau D., Gudmundsson J., Thorgeirsson H., Ibrom A., Morgenstern K., Clement R., MoncrieffJ., Montagnini L., Minerbi S., Jarvis PG. (2000). Respiration as the main determinant of carbon balance in European forests. *Nature* **404**, p. 861–865.

(10 ref.) Manuscript received 16 October 2000