B A
S E

Biotechnol. Agron. Soc. Environ. 2000 **4** (4), 311–314

Carbon stocks in Norwegian forested systems. Preliminary data

O. Janne Kjønaas [(1)], Harald Aalde [(2)], Lars S. Dalen [(1)], Helene A. de Wit [(1)], Toril Eldhuset [(1)], Bernt-Håvard Øyen [(1)]

[(1)] Norwegian Forest Research Institute (NISK). Hogskoleveien, 12. N–1432 Ås (Norway). E-mail: Janne.Kjonaas@nisk.no
[(2)] Norwegian Institute of Land Inventory (NIJOS). Postboks, 115. N–1431 Ås (Norway).

Between 1990 and 2010 the projected emissions of greenhouse gases in Norway is assumed to increase 24%. As a signatory to the Kyoto Protocol, Norway is supposed to limit the greenhouse gas emissions in the period 2008–2012 to 1% above the 1990 level. Potentially, forestry activities may contribute as a means to achieve the set target of emission reductions. The initial Norwegian views and proposals for definitions and accounting framework for activities under Articles 3.3 and 3.4 of the Kyoto Protocol was reported to the UNFCCC August 1 2000 by the Norwegian Ministry of Environment. There was also an annex to the submission with preliminary data and information on Articles 3.3 and 3.4 of the Kyoto Protocol. This paper is based on this annex, and focuses mainly on data for forests and other woodlands. Preliminary data indicate that approximately 85% of the carbon (C) pool of forested systems is found in the soil. The major part of the annual C sequestration takes place in living biomass and soil, while sequestration in wood products and landfills etc. has been found to be of minor importance. It must be noted that the reported data are preliminary and contain large uncertainties.
Keywords. Kyoto Protocol, carbon pools, carbon sequestration, Norway.

1. INTRODUCTION

There has been an active policy to promote sustainable forest management and to increase the standing volume of Norwegian forests since 1900. In 1990, the estimated total terrestrial carbon stock was 2 billion tons. About 85% of this carbon stock was stored in the soil, only 10% was stored in aboveground woody biomass of forests and other wooded lands, and less than 1% was found in wood products and waste. Of the estimated soil stocks, approximately 61% was found in forest soils, 28% in soils of other wooded lands, and 11% in agriculture lands (MD, 2000). Preliminary data on area distribution and carbon stocks in forestlands and other wooded lands in Norway 1990 are given in **table 1**.

Norway follows the FAO definition where forestland is defined as an area with a minimum of 10% crown coverage, and where the trees should be able to reach a minimum height of 5 meters at maturity. The category "Other wooded lands" includes areas with a minimum of 5% crown coverage and tree heights over 5 meters at maturity, or a crown coverage of more than 10% and tree heights under 5 meters at maturity. The areas can be temporarily without crown coverage due to harvesting. Since 1925 the total standing volume in Norwegian forests has almost doubled (**Table 2**), while the harvest has been quite stable (Tomter, 2000; SSB, 1995). The large increase in forest biomass over the last 70 years has resulted in an increase in the forest residues (NIJOS, 1997), most probably followed by an increase in the sequestration of soil organic carbon. In 1998, the estimated net sink of carbon was equivalent to 35% of the total emissions of CO_2 in Norway (MD,

Table 1. Data from the Norwegian United Nations Framework Convention on Climate Change (UNFCCC) report.

	Area (Mha)	**Total carbon stock in 1990** (Mt C)	**Above ground woody biomass** (Mt C)	**Below ground woody biomass** (Mt C)	**Soil carbon stock** (Mt C)
Forest lands	9	1,400	200	40	1,100
Other: Other wooded lands including wetlands	3	500	10	2	500

Source: MD, 2000

2000). The total greenhouse gas (GHG) emission in Norway calculated as CO_2 equivalents, was in 1998 52 Mt (SFT, 2000).

According to the Climate convention, a National Communication (NC) on climate policy and climate gas inventories is reported every 3–4 years. In addition, national climate gas inventories is reported anually. In Norway, the NC1 was reported in September 1994, while the second was send in April 1997. The Ministry of Environment (MD) is responsible for the NCs while the Norwegian Pollution Control Authority (SFT) is responsible for reporting the annual national climate gas inventories.

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

Data on C stocks in forests, other wooded areas and soils has been compiled mainly by the National Forest Inventory (NFI, Tomter, 2000). The aim of the inventory is to provide data on natural resources and environment for forestland in Norway. The inventory was started in 1919 and consists of seven inventory cycles between 1919 and 1998. The first samplings were carried out as strip sampling inventories. In the mid 1950s the strip sampling was replaced by a systematic sample plot inventory, and in the period 1986–1993 (NFI 6) permanent sample plots were established in a 3 × 3 km grid. The NFI covers about 1/3 of the total Norwegian land area, excluding some carbon pools in e.g. mountain areas and lakes. Most of the forest area in Norway is included, except the county of Finnmark and the mountain birch forests. The database consists of 16,000 inventory plots, where approximately 10,500 permanent sample plots are located on productive forest and other wooded land below the coniferous forest limit. The plots are re-measured every 5th year (Tomter, 2000). The observations from the NFI form the basis for the calculations of C stock in biomass and annual growth increment. The carbon stock figures consist of above ground biomass (including stem wood, tops and branches) and below ground biomass (including stumps and coarse roots). The level of uncertainty related to the estimation of some carbon pools may be rather high. However, for Norway, the uncertainty in the estimated numbers for carbon stocks in above and below ground forest biomass and in wood products, have been viewed to be relatively low (MD, 2000).

Table 2. Emissions of CO_2 and gross and net biomass increment in Norwegian forests in million tons CO_2. (The Ministry of Environment, 1998).

	Year					
	1965	**1975**	**1985**	**1990**	**1996**	**2010**
CO_2 emission			32	36	41	51
Gross increment	19	21	24	28	33	
Harvesting and natural loss	15	16	15	19	15	
Net increment	6	5	9	9	18	13–17

The estimates of C stocks in soils (de Wit, Kvindesland, 1999) were based on data from approximately 1,000 soil profiles from the NFI 7 (1994–1998) and the Norwegian Monitoring Program for Forest Damage (Esser, Nyborg, 1992; Esser, 1994), as well as statistics on area distribution of soil types (Tomter, 1996). Median soil C content in the O horizon plus the mineral soil of different soil types was estimated at 13.2 $kg \cdot m^{-2}$ for productive forest land, 12.5 $kg \cdot m^{-2}$ for non-productive forest land, and 24 $kg \cdot m^{-2}$ for wooded mire (de Wit, Kvindesland, 1999). According to Tomter (1996), wooded mire makes up 27% of the area covered by wooded mire and non-productive forestland. Thus, the average soil C content of other wooded lands was estimated to 15.6 $kg \cdot m^{-2}$ (MD, 2000). There are relatively large uncertainties related to the estimates of carbon in soils. The soil data bases include for example only to a limited extent information on soil density and stoniness (de Wit, Kvindesland, 1999), which is a problem for soil C pool estimates. A summed uncertainty of the calculated C-stocks of a profile consisting of an organic and a mineral horizon was estimated to 28%, which is a conservative estimate. This number is based on uncertainties in estimates of bulk density, stoniness and chemical analysis. Other sources of error such as the sampling method, the representativity of the data and the area distribution have not been quantified. This may add to a considerable uncertainty (*ibidem*).

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

The Norwegian UNFCCC submission includes data on changes in C pools due to afforestation, reforestation and deforestation, both according to the different FAO definitions as well as to the IPCC definitions (MD, 2000). In **table 3**, changes based on the IPCC definitions are reported.

Calculations of changes in C stocks due to afforestation were based on figures from the National Forest Inventory (Tomter, 1998) and Statistics Norway (SSB, 1999). Current estimates indicate that approximately 31,000 ha are subjected to afforestation annually. This afforestation is mostly due to conversion from other wooded land to forestland due to changes in land use (e.g reduced grazing activities). No empirical data from Norway is currently available on changes in soil C stocks due to afforestation. Instead, estimates were based on soil pool changes in Sitka

Table 3. Preliminary data on area and carbon stock changes related to Article 3.3 activities based on IPCC definitions (MD, 2000).

	Definitions	**Accounting framework**	a_I (ha)	ΔC_I (Mt C)	a_{II} (ha)	ΔC_{II} (Mt C)	a_{cp} (ha)	ΔC_{cp} (Mt C)
Afforestation								
Reforestation	IPCC	Activity based	186,500	0.052	311,000	0.12	715,000	0.25
Deforestation	IPCC/FAO	Activity based	15,000	-0.14	25,000	-0.25	57,500	-0.16

a_I: Area afforested or reforested, or deforested since 1990 up to 1995 (including 1995).

ΔC_I: Carbon stock change since 1990 up to 1995 on land afforested, reforested or deforested.

a_{II}: Area afforested or reforested, or deforested since 1990 up to 1999 (including 1999).

ΔC_{II}: Carbon stock change since 1990 up to 1999 on land afforested, reforested or deforested.

a_{cp}: Projected area afforested or reforested, or deforested since 1990 up to 2012.

ΔC_{cp}: Projected carbon stock change over the first commitment period on land afforested, reforested or deforested since 1990 up to 2012.

spruce (*Picea sitchensis* (Bong.) Carr.) plantations in Scotland (Billett *et al.*, 1990). These forest systems were assumed to be fairly similar to the western and northern areas of Norway where the major part of the afforestation currently takes place. Based on preliminary estimates and on data gathered outside of Norway, the numbers are largely uncertain.

Approximately half of the harvested area in Norway is regenerated through planting. The other half is regenerated naturally through different forest practices, e.g. seed tree and shelterwood systems. Estimates on effects of reforestation were based on figures of replanted areas obtained from the Ministry of Agriculture and from distributions of site quality from the NFI. The figures from the Ministry of Agriculture probably give a good picture of the situation, since tree planting is subsidized in Norway. Data on changes in soil C pools during a rotation period, and especially in connection to reforestation, is currently not available in Norway. Thus, data from Finland (Liski *et al.*, 1998) and Canada (Kurz *et al.*, 1992) were used, which increase the uncertainty and inconclusiveness of the reported data.

The size of the area subjected to deforestation in Norway was estimated to 2,500 ha annually. Without empirical data on deforestation regarding both area distribution and changes in C stock, again, there is great uncertainty.

Several forest management experiments have been performed over the years at the Norwegian Forest Research Institute, and these may be used for future estimates of the effects of management strategies for C sequestration in the biomass. Data on soil C are, however, scarce. Preliminary estimates on forest management practices such as fertilization have been included in the UNFCCC submission as an example of an accounting approach (MD, 2000). The use of such management strategies presupposes no conflict with any article in international conventions on biological diversity or other relevant international conventions. Additional evaluation of potentials for terrestrial and aquatic eutrophication due to N fertilization is needed (MD, 2000).

In general, due to the slow growth rates of forests in the boreal regions, the effects of any human-induced activities to stimulate afforestation and reforestation will be minor or negligible within a time frame of 20 years. For the same reason, the effects of improved forest management in Norwegian forests will be minor in the short term. In the longer run, there is a higher potential for increased carbon sequestration and stock enhancements through improved forest management. This potential is, however, difficult to quantify (MD, 2000).

4. PERSPECTIVES AND RESEARCH NEEDS

Future research on national carbon stocks and sources and sinks for CO_2 will to a large extent be guided by the decisions on accounting strategies made at the COP6 meeting in The Haag. Preliminary evaluations of research needs based on the available data for the UNFCCC submission August 2000 indicate that the data sources on C stocks and calculated changes in C stocks in living biomass are relatively good. However, there is a need for empirical data, as well as a need for an improved understanding of effects of management strategies on C-sequestration. The data source on soil C pools needs to be expanded and improved. Empirical data on C and CO_2 fluxes within the Norwegian forest system are currently limited, and there are limited data available on non-CO_2 greenhouse gases. There is currently also limited information on the relative importance of different processes that govern the buildup and losses of C from Norwegian forest systems, which may limit the reliability of modeling tools.

The IPCC Special Report underlines the importance of the soil as a carbon reservoir, which is also the area with the greatest need for research. To improve our understanding of the soil C processes, a new project, "Carbon dynamics in forest soils", has been started at the Norwegian Forest Research Institute (2000–2004). The project focuses on carbon stocks and fluxes on a plot scale, and includes studies in an age chronosequence of Norway spruce as well as studies on the effects of nitrogen (N) input on C sequestration. The latter study has been co-funded by the EU as part of the project CNTER (Carbon-Nitrogen inTERactions in forest ecosystems). This project links C and N interactions on a plot/catchment scale as well as on a European scale. In addition, funding from the Norwegian Research Council and the Nordic Council (Nordisk Ministerråd, SNS) is currently supporting research on C and N interactions in originally an N limited forest system. Informal interactions has been established with the Swedish LUSTRA project (Land Use STRAtegies for reducing net greenhouse gas emissions) and the EU projects FORCAST and CarboAge.

Bibliography

Billett MF., FitzPatrick EA., Cresser MS. (1990). Changes in the carbon and nitrogen status of forest soil organic horizons between 1949/50 and 1987. *Environ. Pollut.* **66**, p. 67–79.

de Wit H., Kvindesland S. (1999). Carbon stocks in Norwegian forest soils and effects of forest management on carbon storage. *Rapp. Skogforsk. Suppl.* **14**, p. 1–52.

Kurz WA., Apps MJ., Webb TM., McNamee PJ. (1992). *The carbon budget of the Canadian forest sector. Phase I. Forestry Canada, Northwest Region, Northern Forestry Centre, Edmonton, Alberta*. (Information report; NOR-X-326).

Esser J. (1994). *Jordsmonn i bjørkeskog. En oversikt for Norge.* Ås, Norway: NIJOS. (NIJOS rapport; 4/94).

Esser J., Nyborg Å. (1992). *Jordsmonn i barskog. En oversikt for Norge*. Ås, Norway: NIJOS. (NIJOS rapport; 3/92).

Liski J., Ilvesniemi H., Mäkelä A., Starr M. (1998). Model analysis of the effects of soil age, fires and harvesting on the carbon storage of boreal forest soils. *Eur. J. Soil Sci.* **49**, p. 407–416.

MD (2000). *Submission to the UNFCCC 1 August 2000. Views and proposals for definitions and accounting framework for activities under articles 3.3 and 3.4 of the Kyoto Protocol*, FCCC/SBSTA/2000/Misc.6/Add.1, <http://www.unfccc.de/resource/sbsta00.html>.

Ministry of Environment (1998). *Norges oppfølging av Kyotoprotokollen*. Oslo: Ministry of Environment, p. 90.

SFT (2000). *Greenhouse gas emissions in Norway 1990–1998. Reporting according to the UNFCCC-guidelines*. Oslo: The Norwegian Pollution Control Authority (SFT).

SSB (1995). *Historical statistics 1994*. Oslo; Kongsvinger: Statistics Norway.

SSB (1999). *Forest statistics 1997*. Kongsvinger, Norway: Statistisk Norway.

NIJOS (1997). *Resultatkontroll Skogbruk/Miljø. Rapport 1995*. Ås, Norway: NIJOS. (NIJOS rapport; 3/97).

Tomter S. (ed.) (1996). *SKOG 1996. Statistics of forest conditions and resources in Norway*. Ås, Norway: NIJOS.

Tomter S. (ed.) (1998). *SKOG 1998. Statistics of forest conditions and resources in Norway*. Ås, Norway: NIJOS.

Tomter S. (ed.) (2000). *SKOG 2000 Statistics of forest conditions and resources in Norway*. Ås, Norway: NIJOS.

(15 ref.) Manuscript received 18 October 2000