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C and N storage in living trees within Finland since 1950s

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Abstract

Living biomass contains 45 to 60% carbon and 0.05 to 3% nitrogen, in dry weight. Like throughout Europe, the amount of living biomass in Finnish forests has increased on average over the last decades, largely because of changes in forest management. The storage of organic C and N in biomass has also increased.

Changes in biomass vary between regions. Data were analysed on changes in the last 30–40 years in C and N storage in living trees in Finland, subdivided into 20 regions. Tree biomass increased in 17 regions, and decreased in 3 regions. The storage rate varied between -170 and + 480 kg C ha^{-1} a^{-1}, and between -0.5 and + 1.2 kg N ha^{-1} a^{-1}.

Nitrogen accumulation in trees was less than 15% of atmospheric N deposition in all regions. Although the eventual increase of the nitrogen concentration in tree tissues was omitted, it is not possible that living biomass has been the major sink for atmospheric N deposition to forests. A hypothesis is presented that the main sink is litter layer and organic soil. Carbon can also be accumulating in soils essentially faster than hitherto estimated in analyses of carbon budgets of European forests.

Introduction

The growing stock (=the stem volume of living trees) in forests has increased in the 1980s in West European countries which report on their forests to the UN-ECE/FAO (The Forest Resources of the Temperate Zones...,1992). In Europe, carbon has been estimated to build up in living forest biomass at a rate of 70–105 million tonnes per year (Kauppi et al., 1992). The role of forests in the national carbon budget has been negligible in the UK, Netherlands or Belgium but very important in Sweden and in Finland (Kauppi and Tomppo, 1993). Accumulating biomass serves also as storage for nitrogen and other nutrients.

The aim of this paper is to estimate on a subnational level the current importance of living biomass as a sink or source of C and N. We compare the estimates of growing stock in the early 1950s to those in the late 1980s in different regions within Finland, and calculate the mean rate of change of N and C storage in whole tree biomass over that period.

Methods

Regular forest inventories have been carried out in Finland since the early 1920s. The data are organized into 20 geographical regions within Finland (Fig. 1). The inventory rotates from region to region, and has been repeated ca. every 10 years in each region. The forested area varies between 929 km^2 in Åland (Region 0) and 51,580 km^2 in Lapland (Region 19).

The growing stock was measured in Finland in 1951–53 (Ilvessalo, 1958a,b) and in 1984–1992 (Kuusela and Salminen, 1991; Tomppo, 1993). Both inventories were based on several tens of thousands of temporary sample plots. A linewise survey sampling, lines passing through the country from S-W to N-E was applied in 1951–53, and detach L -shaped tracts were employed instead of continuous lines in 1984–1992. Both systems represented statistically all Finnish land, a total of about 305,000 km^2. The geographical coverage was the same in both inventories.

On each plot, tree species, diameter at breast height, and two other variables were measured from talley trees. More thorough measurements, such as height,

* Died on September 2, 1994.

Table 1. Mass of needles, branches, and roots as a fraction (percentage) of stemwood. (Albrektson, 1980; Cannell, 1982; Hakkila, 1991; Mälkönen, 1974, 1977; Ovington, 1959)

	% of stemwood mass								
	Scots pine age (yrs)			Norway spruce age (yrs)			Birch (and other dec.) age (yrs)		
	-40	41-80	81+	40	41-80	81+	-40	41-80	81+
Foliage	10	5	5	20	15	15	5	4	3
Branches	20	15	15	35	30	30	15	15	15
Roots	60	40	20	40	40	35	35	35	30

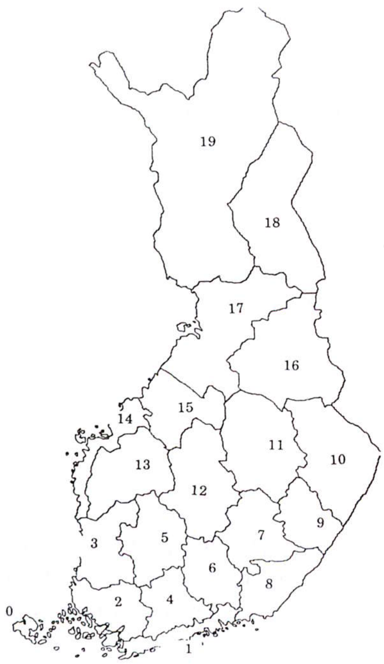

Fig. 1. Forest board districts of Finland.

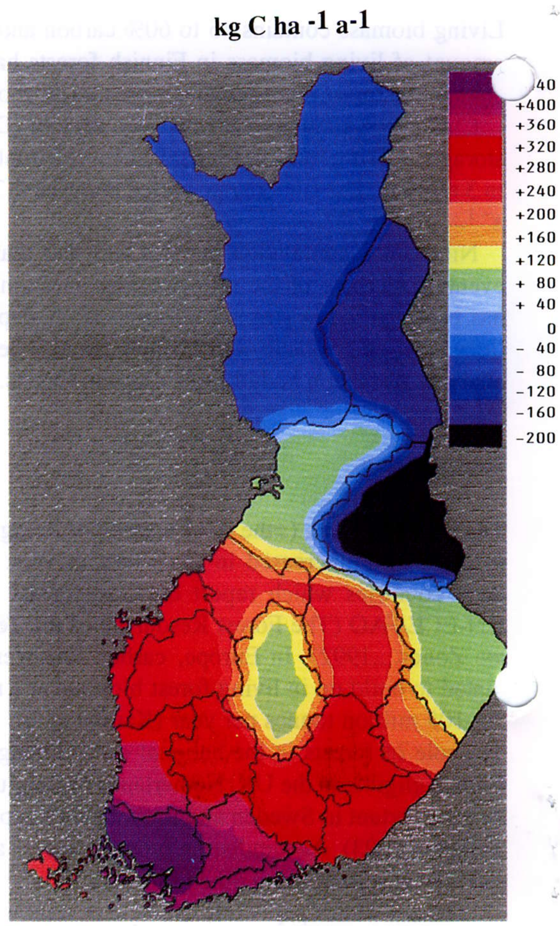

Fig. 2. Change in C storage from 1950s to 1990s.

Table 2. Nitrogen concentration (percentages of dry biomass) in different parts of Finnish tree species. (Helmisaari, 1990; Mälkönen, 1974, 1977; Mälkönen and Saarsalmi, 1982; Nurmi, 1993)

	% of dry biomass		
	Scots pine	Norway spruce	Birch (and other dec).
Stem	0.08	0.08	0.12
Needles/ leaves	1.3	1.3	2.0
Branches	0.4	0.4	0.5
Roots	0.2	0.2	0.3

upper diameter, height increment and diameter increment were taken from sample trees.

In the first step, we estimated the growing stock subdivided into region, species, and stand age class. Deciduous trees occur mainly mixed in conifer stands. In inventory data, the growing stock in each region

Table 3. The areas of forest and scrub land in latest inventory, total volume of growing stock in the beginning the of 50's and 1982–92, the interval and absolute and relative differences of volume by Forestry Board Districts

FBD	Area, ha	Volume, 1000 m^3 51–53	Volume, 1000 m^3 82–92	Interval Years	Difference	Difference, %
0	92900	7200	9800	34	2600	36
1	426600	36100	53900	34	17800	49
2	563100	42200	68200	34	26000	62
3	725600	55600	79000	35	23400	42
4	506700	56700	74200	35	17500	31
5	794400	75200	99400	35	24200	32
6	586500	64900	80900	35	16000	25
7	828200	80400	107200	36	26800	33
8	648400	57700	76900	34	19200	33
9	513400	53600	67200	36	13600	26
10	1452400	120500	131000	37	10500	9
11	1358200	113300	147000	38	33700	30
12	1268000	116400	137000	39	20600	18
13	984100	56700	88400	39	31700	56
14	499800	34000	48400	39	14400	42
15	847900	39100	63600	40	24500	62
16	1898000	131900	112000	30	-19900	-15
17	1868000	77300	95000	30	17700	23
18	2178000	112300	88100	30	-24200	-22
19	5158000	207100	193800	32	-13300	-6
Whole country	23200000	1540000	1820000		283000	18

is reported by tree species and age classes but only with reference to the dominant tree species. These data would underestimate the contribution of deciduous species. Therefore, the estimate of growing stock, derived from standwise data for each tree species, age class, and region, was corrected in such a way that the sum over age classes equaled the estimate for the species as derived from talley tree measurements for each region. In other words, we assumed that species mix was independent of age class. Stemwood biomass was estimated for the main tree species assuming a bulk density of 420, 380, and 480 grams dry matter per liter of wood/bark, for Scots pine, Norway spruce, and deciduous trees, respectively (Hakkila, 1979). Bulk density 480 g L^{-1} represents the main deciduous species, birch.

An estimate of the total biomass was obtained by multiplying stemwood biomass by a set of coefficients to account for roots, branches and foliage (Table 1). Carbon storage was calculated assuming C content of 50% in dry biomass (Nurmi, 1993). Nitrogen storage was estimated applying different N concentrations for different tree species and plant components (Table 2).

Results

According to the latest inventory results (1984–1992), the growing stock in Finland is 1820 million m^3. Of this, 1330 m^3 is in southern Finland that is, in regions 0–15, and 489 million m^3 is in northern Finland, regions 16–19 (Table 3). The corresponding estimates for early 1950s were 1540, 1010, and 528 million m^3, respectively. When the results from all regions were updated with a model to the year 1990, the growing stock of Finland was estimated at 1880 million m^3.

Over the time period 1950–1990, more than 2000 million m^3 were cut for industrial, energy and other uses. This equals about 400 million tonnes C. Yet, the growing stock increased by 18% (or by 22%, with

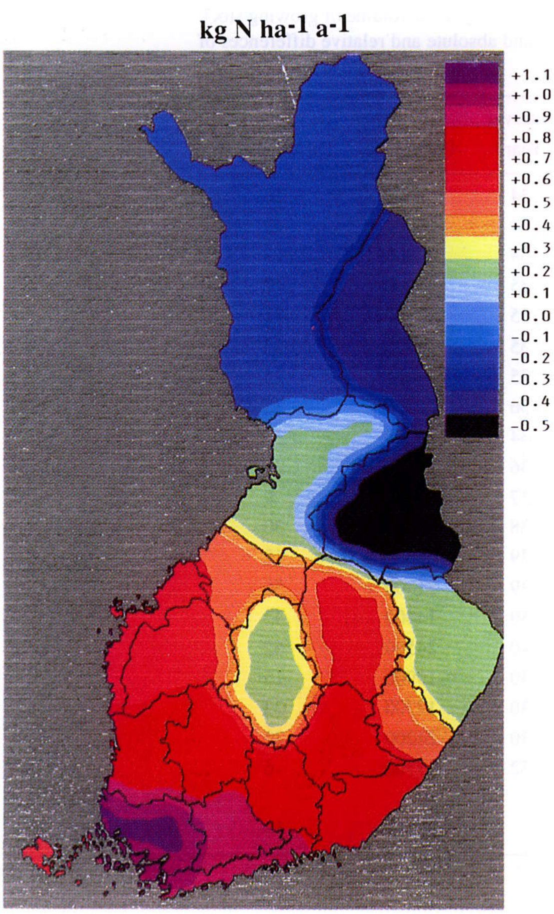

Fig. 3. Change in N storage from 1950s to 1990s.

Table 4. The carbon storage in the beginning of 50's and 1982–92 and the absolute and by Forestry Board Districts

FBD	Carbon, 1000 tn		Difference	Difference, %
	51-53	82-92		
0	2500	3400	900	35
1	12600	18800	6200	49
2	14300	23600	9300	65
3	18100	27400	9300	52
4	18900	26000	7100	38
5	25200	34600	9400	37
6	21900	28300	6400	29
7	27300	37300	10000	37
8	20100	26900	6800	33
9	19500	23400	3900	20
10	40100	45400	5300	13
11	38300	51600	13300	35
12	42500	48000	5500	13
13	19300	30400	11100	57
14	10900	16800	5900	55
15	13200	22100	8900	67
16	43200	32600	-10600	-25
17	25800	32100	6300	24
18	37900	27700	-10200	-27
19	72300	63600	-8700	-12
Whole country	524000	620000	96000	18

the updated estimate as the reference). The growing stock in southern Finland increased by 35% but decreased in northern Finland by 7.4%. The largest relative increase of growing stock was in regions 1, 2, 13 and 15 (49%, 62%, 56%, and 62%, respectively). The growing stock increased in these regions because forest increment exceeded the sum of removal and mortality. Large regeneration cuttings were commenced in northern Finland in the 1950s and 1960s. That was the reason for the decrease of growing stock (by 15%, 22%, and 6% in regions 16, 18, and 6, respectively). After 1970 there has been less regeneration cuttings in these regions, and the growing stock is expected to increase in the future.

Proportions of tree species were fairly stable between the early 1950s and late 1980s: Scots pine increased from 43.7% to 44.6%, Norway spruce increased from 35.7% to 37.6%, while other species (mainly birch) decreased from 20.6% to 17.8%. The proportion of spruce increased most strongly in southern Finland, from 38.6% to 42.9%. This was due to the natural succession in favour of shade tolerant species but also because of the silvicultural practices. There was little industrial demand for birch wood in the 1950s and 1960s, and silvicultural thinnings were made in favour of conifers.

The average storage rate of carbon and nitrogen varies substantially between regions following the variation of growing stock. For carbon, the range of storage rate was estimated at -170 to + 480 kg C ha^{-1} yr^{-1} (Table 4, Fig. 2). For nitrogen the range was estimated at -0.5 to +1.2 kg ha^{-1} yr^{-1} for N (Table 5, Fig. 3).

Atmospheric deposition of nitrogen in southern Finland is 5 to 12 kg ha^{-1} yr^{-1} and 3 to 6 kg ha^{-1} yr^{-1} in northern Finland (Tuovinen et al., 1990). The nitrogen accumulation in trees thus was less than 15% of atmospheric N deposition in all regions.

Table 5. The nitrogen storage in the beginning of 50's and 1982–92 and the absolute and relative differences by Forestry Board Districts

FBD	Nitrogen, 1000 tn 51-53	82-92	Difference	Difference, %
0	5.4	7.4	2.0	38
1	29.0	43.5	14.5	50
2	31.9	53.4	21.5	67
3	40.9	62.8	21.8	53
4	45.7	62.7	17.0	37
5	59.1	81.7	22.6	38
6	50.3	67.5	17.2	34
7	60.6	85.1	24.5	40
8	45.3	61.3	15.9	35
9	43.8	53.5	9.7	22
10	88.7	100.8	12.2	14
11	90.1	121.9	31.9	35
12	98.0	110.8	12.8	13
13	43.0	66.8	23.8	55
14	25.7	39.1	13.3	52
15	29.0	48.5	19.5	67
16	96.0	70.4	-25.5	-27
17	56.2	68.7	12.5	22
18	82.3	59.1	-23.3	-28
19	153.7	130.9	-22.8	-15
Whole country	1170.0	1400.0	220.0	19

Discussion

The changes in forest biomass have been quite substantial over the past decades both in Finland and in other countries. There is a good reason to adopt a view of a dynamic forest landscape as Lugo (1992) suggests. Growing stock (stemwood volume of living trees incl. bark) has been reported for each of the 20 regions on both inventories. The confidence interval of the estimate (95% probability) was ca. 1.5% for large regions and ca. 3% for small regions (Kauppi et al., 1992b; Salminen, 1993).

The standard case in western Europe is an increase of forest biomass and, notably, an increase of carbon and nutrient storage in living vegetation (Kauppi and Tomppo, 1993). There are exceptions of this general trend in certain regions within Finland. On average, however, living trees in Finland have served as sinks of both carbon and nitrogen.

Much stemwood has been removed from Finnish forests. The amount of removed growing stock over the past 40 years is about the same as the stock in forests at the present time (Yearbook, 1992). Part of the removed biomass in wood structures or in landfill sites has resisted decay and served as a fairly large additional C sink. This biomass has less significance as a sink of nitrogen, since stem doesn't contain much nitrogen (Table 2).

The same coefficients were used for old and new data to convert biomass estimates to estimates of N storage. It is possible that nitrogen concentration in tree tissues has increased due to eutrofration of the forest environment (for a more complete discussion, see Kauppi et al., 1992). This can imply an underestimation of the flux density of nitrogen.

The increase of biomass compensates less than 15% of the atmospheric deposition. Although the estimate can be low, additional sinks of N must exist in terrestrial systems, since nitrogen has not been observed in lake water in large quantity (Forsius et a1., 1990).

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