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The carbon dynamics of surface peat layers in southern and central boreal mires of Finland and Russian Karelia

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The carbon pool of surface layers (up to 500 years old) in 73 boreal mires was investigated in order to assess its significance in the carbon cycle. Peat columns were collected from mires of varying depth, age and degree of natural state in the aapa mire and raised bog regions and coastal mires of southern and central Finland and Russian Karelia. The quantities of carbon sequestered during recent centuries and over the entire lifetimes of the mires were determined using a total of 367 dates (186 ^{14}C AMS and 181 conventional dates) and age-depth models derived from bulk density measurements. Particular attention was paid to accumulation over the last 100 and 300 years, as these periods encompass the best estimates of the acrotelm age across the range of sites investigated. The average carbon pool of layers younger than 300 years was determined as 101 ± 8 tonnes ha^{-1} in the aapa mire region, 115 ± 9 tonnes ha^{-1} in the raised bog region and 184 ± 20 tonnes ha^{-1} in coastal mires. Overall, the mean carbon pool of layers younger than 300 years was calculated to be 121 ± 7 tonnes ha^{-1} (range 44–259 tonnes ha^{-1}) and of layers younger than 100 years 63 ± 4 tonnes ha^{-1} (range 17–141 tonnes ha^{-1}). The size and dynamics of the carbon pool represented by these surface layers depends upon the mire site type, vegetation and natural state; variations reflect differences in plant communities as well as factors that affect biomass production and decay rates. The high carbon accumulation in surface layers is temporary and mainly related to the development of the mire. The surface layers are still undergoing a rapid carbon cycle. A relatively rapid accumulation and turnover of carbon is taking place in surface layers (<300 years) in the same way as in a growing forest. Therefore, this “pre-peat” in the surface layers of mires should be distinguished as a separate class from the peat underneath. Our results indicate how important it is to understand the carbon accumulation rates of surface layers and the long-term dynamics of mire carbon accumulation in order to set the current flux estimates in perspective.

Key words: acrotelm, carbon pool, Finland, peat accumulation, peatland, turnover.

Introduction

The surface layers of mires are composed of living, below-ground biomass, dead organic matter (wood and litter) and soil organic matter, which are defined as terrestrial carbon pools by the Intergovernmental Panel on Climate Change IPCC (2003). Although a relatively high proportion of the litter produced by mire plants decomposes aerobically, part accumulates as peat because air is excluded by waterlogging before decomposition is complete.

The above-ground dry biomass in Finnish mires has been reported to range from 200 g m^{-2} in wet fens to 20000 g m^{-2} in forested spruce swamps (Reinikainen et al. 1984, Laine & Vasander 1996). Peat-forming species differ in their capacities for production and decay. The intrinsic capability of each species, in addition to water and nutrient availability, controls its rate of production. However, the rate of decomposition is mainly determined by the carbon quality of the litter and abiotic factors such as oxygen availability, humidity and temperature.

The data of Sjörs (1991) and Saarinen (1996) suggest that primary production may exceed 1000 g m^{-2} yr^{-1} in *Carex*-dominated boreal peatlands, whilst *Sphagnum* production ranges from 10 to 500 g m^{-2} yr^{-1} depending on the plant species and location (Lindholm & Vasander 1990). According to Klarqvist (2001), production rates are probably determined by the spatial densities of the different species, an effect that clouds the distinction between raised bogs and aapa mires in this context.

Whilst above-ground biomass and primary production have been quite intensively studied in mire ecosystems, information on below-ground production is scarce. In ombrotrophic raised bogs, most of the carbon is bound into the *Sphagnum* biomass. As the *Sphagnum* carpet grows upwards, burying older material, the majority (about 90%) of the litter is decomposed within the periodically aerobic layer above the water table, termed the acrotelm by Ingram (1978). In minerotrophic aapa mires, sedge roots grow into deep peat layers and the functional distinction between the acrotelm and the permanently anoxic catotelm beneath is less clear than in bogs (Laine et al. 2004). The majority of below-ground biomass is found in the uppermost 30 cm. However, indirect ^{14}C labelling has revealed that almost 80% of the biomass of *Carex rostrata* (2290 g m^{-2}) is in fine roots (Laine & Vasander 1996), and living roots of this species are found to a depth of 230 cm (Saarinen 1996). As much as 50% of the annual production for *C. rostrata* and *C. lasiocarpa* has been found to be below ground (Bernard & Fiala 1986), and the proportion of biomass produced below ground in older peat ranges from 70% to 97% (Sjörs 1991, Aerts et al. 1992, Saarinen 1996). The continuous penetration of roots, mostly of sedges but also particularly of *Rubus chamaemorus*, results in carbon input to the underlying peat. Although the biomass of these deep-growing roots is relatively small, they may contribute significantly to the accumulation of carbon because decomposition in the catotelm is slow (Saarinen 1996).

The annual production of biomass in a mire exceeds the annual production of peat, because peat formation involves considerable losses of organic matter. Most of the transformation occurs in the biologically active acrotelm, which is typically <40 cm thick. The annual balance between production and decay determines the net rate of peat accumulation, for which decay rates are more critical than production rates (Clymo 1983). Production rates are fairly similar for *Sphagnum* (which occurs in bogs and poor fens) and Bryales mosses (in medium and rich fens), but decomposition is more intense in nutrient-rich aapa mires than in nutrient-poor bogs and fens. Moreover, *Sphagnum* litter is usually more resistant to decay than *Carex* litter (Verhoeven & Toth 1995, Szumigalski & Bayley 1996, Scheffer et al. 2001). For such reasons, it has been suggested that more peat will accumulate in *Sphagnum*-dominated mires than in sites dominated by Bryales mosses (Vitt 1990).

The carbon released by decomposition in the oxic acrotelm returns to the atmosphere as carbon dioxide (CO_2). Most of the roots of vascular plants are confined to the acrotelm, and when they die they rapidly decompose. In Finland, the age of the lower part of the acrotelm ranges from 50 to 200 years, at which stage some 2–20% of the primary plant biomass production remains undecomposed and is added to the catotelm as peat (Laine & Vasander 1996). On average, 10% of net primary production has been estimated to enter long-term storage as peat (Reader & Stewart 1972). This differs from the carbon accumulation rate, however, because decomposition continues slowly under anoxic conditions, a small proportion of the carbon deposited in the catotelm being subsequently converted to methane (CH_4). In boreal mires, 4–10% of the carbon that is fixed photosynthetically during the growing season is thus released to the atmosphere (Alm et al. 1997). Some carbon and nutrients are also lost from the ecosystem through leaching, herbivory, fires and erosion. However, the amount of peat in long-term storage at any time is largely determined by the differences between production in various plant communities and decay in different peat layers, integrated through time. In Finland, the accumulation rate has varied significantly during the Holocene (e.g. Mäkilä 1997, Mäkilä & Saarnisto 2005), but the long-term balance has been positive (i.e. peat has been formed) throughout. The average long-term net rate of carbon accumulation has been estimated at 17 g m^{-2} yr^{-1} for aapa mires and 21 g m^{-2} yr^{-1} for raised bogs (Turunen et al. 2002), although Mäkilä et al. (2001) suggested that the amount of accumulated carbon may have been overestimated.

This paper describes a comparative study of rates of carbon accumulation in the near-surface layers of three types of boreal mires, with and without artificial drainage. The approach involves the derivation of mean carbon accumulation rates over the last 100–500 years, as well as over their full Holocene lifetimes. We focus especially on the data for 100-year and 300-year time periods, which were chosen to encompass the best estimates of acrotelm age across the different mire types considered.

Materials and methods

Net rates of carbon accumulation over different time periods were determined by ^{14}C dating of material from peat columns. These were collected in connection with a Geological Survey of Finland peat inventory from 73 mires in southern and central Finland and four mires in Russian Karelia. The quantities of carbon sequestered during recent centuries and over the entire lifetimes of the mires were determined using total of 367 dates (186 ^{14}C AMS and 181 conventional dates) and age-depth models derived from bulk density measurements. Several datings were performed for different depth zones of some mires (3–19 dates per column).

Study sites

The locations of the study sites relative to the principal Finnish mire regions (aapa mire and raised bog) are indicated in Fig. 1. Although aapa mires and raised bogs are generally restricted to different geographical (mire complex type) zones,

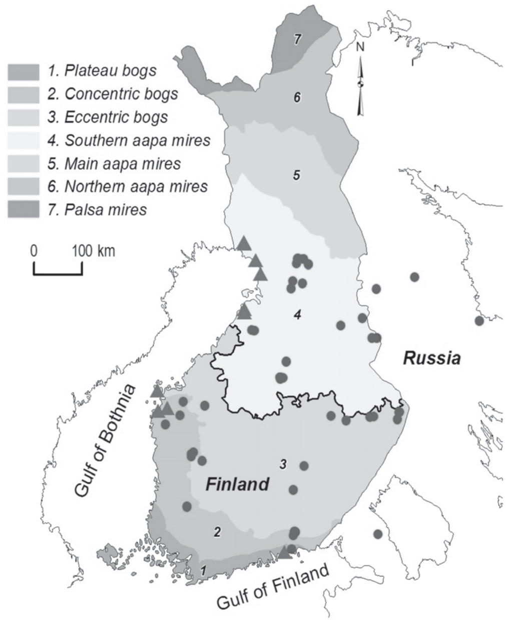


Fig. 1. Locations of the study sites superimposed on the mire complex type regions (numbered 1–7) of Finland according to Ruuhijärvi & Hosiaisluoma (1989). Coastal mires are marked with triangles. The raised bog region occurs to the south of the black line (Regions 1–3) and the aapa mire area to the north (Regions 4–7).

Kuva 1. Tutkitut suot ja suoyhdistymätyypit. Mustan viivan alapuolinen osa on keidassuoaluetta ja yläpuolinen osa aapasuoaluetta. Kolmiot osoittavat rannikon nuoria soita.

Fig. 2. A mire surface profile, revealed during the collection of a shallow volumetric peat sample (photo M. Mäkilä).

Kuva 2. Turpeen pintakerroksen tarkkatilavuuksisen näytteen otto (kuva M. Mäkilä).

some overlap exists between the types. The difference between them is principally morphological. Aapa mires have thin peat and the mire centre lies at or below the level of the surrounding mineral ground, whereas raised bogs have thicker peat and are domed. This leads to several hydrological and ecological differences (Seppä 1996). The sites were also classified as pristine or drained. A pristine mire is defined here as one that appears to largely be in a natural condition and undrained, although marginal ditches may be present.

Sample collection

Shallow volumetric samples of 10x10 cm square and 20 cm deep were obtained using a metal frame. The frame was sunk into the mire surface and the sample was cut out with a knife, or with a saw if the surface layer had many woody roots or was frozen (Fig. 2). A hole was dug with a spade in front of the sample to loosen it, and any water accumulating in the hole was baled out. The living moss and green plants were cut from the sample with scissors. Deeper samples were obtained using a volumetric piston sampler (8 cm diameter, 20 cm long) or a 5-cm-diameter Russian peat sampler (see Mäkilä 2005).

For each sample, the main peat type and the proportions of any minor constituents were determined by visual inspection (see Lappalainen et al. 1984), and humification was estimated on the 10-point scale of von Post (1922). For 30 subsamples from surface layers, plant components were recorded and their degree of decomposition was assessed on the basis of the state of preservation of moss remains.

Dry bulk density measurements, carbon and nitrogen analysis

Dry bulk density and water content were determined from volumetric samples (1000–2000 cm^3) dried to constant weight at 105 ^{o}C. A Leco CHN 600 analyser was used to determine carbon and nitrogen as proportions of total dry matter.

AMS ^{14}C dating

In order to obtain high-resolution records, samples for ^{14}C dating were taken from slices (3–5 mm thick) of the *ca*. 2 × 2 cm columns. The material selected was mostly pure *Sphagnum*, because this species forms the bulk of most peat deposits. Moreover, being a moss, it does not have roots and grows only upwards from the shoot apices. Where *Sphagnum* was absent, other types of plant material were used for ^{14}C dating. As the amount of pure *Sphagnum* available in each sample was small, the only suitable method for ^{14}C dating was accelerator mass spectrometry (AMS), which was carried out at the Poznan Radiocarbon Laboratory (Poz) in Poland. AMS dating can provide more accurate dating results than conventional ^{14}C dating because it requires much less material for the analysis and is often more precise (smaller error estimate). This is why AMS dating has been used with surface peat layers. The samples taken before 2003 were dated in the ^{14}C laboratory of the Geological Survey of Finland (Su).

The samples that were ^{14}C dated in Poznan were chemically treated according to the standard AAA (acid-alkali-acid) procedure (*e.g*. de Jong 1981). This involved sequential treatments with 0.5M HCl at 50 °C for two hours, 0.1M NaOH at 50 °C for two hours and 0.5M HCl at 50 °C for two hours. Between these stages, the samples were rinsed with deionised water until they reached pH 7. After chemical pre-treatment, the samples were combusted in sealed quartz tubes (with CuO and Ag), and the CO_2 produced was purified and then graphitised by reduction with H_2 using Fe powder catalyst (Czernik & Goslar 2001). The graphite tablets were loaded into the spectrometer, which measured the ratios of ^{14}C to ^{12}C and ^{13}C to ^{12}C (Goslar et al. 2004). Modern ^{14}C ages (>100 pMC = percent modern carbon) were indicated for the younger parts of the peat profiles, reflecting the bomb peak of atmospheric ^{14}C.

Age-depth models

Age-depth models for peat growth were fitted to the data using a numerical algorithm by Räsänen et al. (2007), which minimised the value of fit quality (F_q).

$$F_q = \chi^2 + W_c \cdot B$$

where χ^2 is the sum of squared differences between ^{14}C ages of dated samples and ^{14}C ages derived from the ^{14}C calibration curve, divided by squared errors of ^{14}C dates; and B is the curvature of the age-depth line (Fig. 3), normalized using weight W_c. The weight W_c was set for each profile so that the value of χ^2 was approximately equal to the number of dated samples at minimum F_q. The age-depth models were used to determine the thicknesses of the peat layers accumulated during the last 100–500 years (100-year increments) in individual profiles.

Calculation of accumulation rate and C pool

The long-term apparent rate of carbon accumulation (LARCA) for the entire peat deposit, and the actual rate of carbon accumulation ($ARCA_{100}$ and $ARCA_{300}$ = layers <100 and <300 years old) were calculated using peat columns of known dry bulk density, carbon content and age according to Clymo et al. (1998). The following equation was used to the calculate carbon accumulation rates:

$$A^c = r \times \rho \times C \times 1000$$

where A^c = carbon accumulation rate (g m^{-2} yr^{-1}), r = rate of vertical peat increment (mm yr^{-1}), ρ = dry bulk density (g cm^{-3}) and C = carbon content as a proportion of dry bulk density. Carbon pools (tonne ha^{-1}) were derived by integrating carbon accumulation rates over the period of interest (last 100 years, last 200 years *etc*. and the whole period of peat growth). Separate mean values were calculated for different mire site types, regions and on the basis of the natural status of mires, i.e. pristine v. drained.

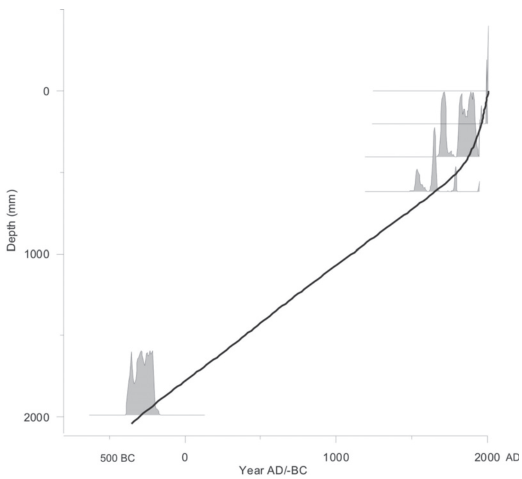


Fig. 3. Diagram illustrating the construction of the age-depth model for the Törmäjänkä profile. The probability distributions of calibrated ^{14}C ages for individual samples are shown as grey silhouettes, positioned vertically according to sample depth. The thick smooth line is the age-depth curve.

Kuva 3. Diagrammi, joka kuvaa Törmäjänkän profiilin ikä-syvyys mallin rakennetta. Yksittäisten näytteiden kalibroitujen ^{14}C ikien todennäköinen jakauma näkyy harmaina varjokuvina sijoitettuna kohtisuoraan näytteen syvyyden mukaisesti. Paksu viiva on ikä-syvyys käyrä.

Results

Carbon accumulation rate

The LARCA values are 14.6 g m^{-2} yr^{-1} for the aapa mire region, 19.8 g m^{-2} yr^{-1} for the raised bog region and 43.0 g m^{-2} yr^{-1} for coastal mires (Table 1). The mean value of $ARCA_{300}$ is 33.8 ± 2.6 g m^{-2} yr^{-1} for the aapa mire region, 38.4 ± 3.0 g m^{-2} yr^{-1} for the raised bog region, 61.3 ± 6.8 g m^{-2} yr^{-1} for coastal mires and 40.5 ± 2.5 g m^{-2} yr^{-1} overall; whilst the overall mean of $ARCA_{100}$ is 63.2 ± 3.7 g m^{-2} yr^{-1} (Table 2). The carbon accumulation rate generally declines during the first 100 years, and the mean accumulation rates for 300-year-old layers amount to 17–36% of those in the uppermost organic matter and litter layers (Fig. 4).

The highest accumulation rates for layers younger than 300 years were measured in the ombrotrophic mire site types (*Sphagnum fuscum* bog and *Sphagnum fuscum* pine bog), and the second highest rates in wet, treeless oligotrophic and minerotrophic mire site types. The lowest values of $ARCA_{300}$ were obtained for the most transformed, sparsely forested and forested mire site types (Fig. 5), where the water table was lowest.

Dry bulk density, carbon and nitrogen contents

The dry bulk density in layers younger than 100 years was determine to range from 25.4 to 91.5 kg m^{-3} (average 58.0 kg m^{-3}) and in layers younger than 300 years from 28.3 to 106.2 kg m^{-3} (average 62.2 kg m^{-3}). The average dry bulk density in layers younger than 100 and 300 years was highest in the raised bog region and lowest in coastal mires. In layers younger than 300 years, the proportion of carbon ranged from 40% to 55% of dry weight with an average of 46.3%, and the nitrogen proportion varied between 0.57% and 3.33% of dry weight with an average of 1.25% (Table 2). The C:N ratio increased as the proportion of nitrogen decreased, and higher carbon accumulation rates correlated with a low nitrogen content and high C:N ratio (Table 3).

Peat increment rate

The peat increment rate was determine to range from 0.4 to 7.3 mm yr^{-1} (mean 2.6 mm yr^{-1}) in layers younger than 100 years, and from 0.3 to 3.5 mm yr^{-1} (average 1.5 mm yr^{-1}) in layers younger than 300 years. In general, wetter local surface conditions were associated with higher peat increment rates. However, the highest peat

Table 1. Mean values of age, thickness, apparent carbon accumulation rate (LARCA) and carbon storage for entire peat layers, calculated for each of the three mire regions.

Taulukko 1. Koko turvekerrosten keskimääräinen ikä, paksuus, näennäinen hiilenkertymä (LARCA) ja hiilivarasto laskettuna kullekin kolmelle suoyhdistymätyyppialueelle.

Region		Age of base (yr)	Peat thickness (m)	Carbon accumulation rate (g m^{-2} yr^{-1})	Carbon pool (t ha^{-1})
Aapa mire	Mean	7440	2.43	14.6	1077
n = 25	Median	7900	2.26	14.6	1001
	Std. Deviation	2043	1.27	4.5	452
Raised bog	Mean	6548	3.04	19.8	1236
n = 29	Median	6520	2.54	17.7	1098
	Std. Deviation	2425	1.36	6.9	553
Coastal mire	Mean	1545	1.79	43.0	566
n = 12	Median	1445	1.97	37.7	558
	Std. Deviation	679	0.43	19.3	135
All studied	Mean	5976	2.58	22.0	1054
mires	Median	6455	2.37	17.4	962
n = 66	Std. Deviation	2958	1.28	14.0	519

increment rates were found in coastal mires, where species of *Sphagnum* sect. *Acutifolia* with a low nitrogen content are prevalent (Table 2). A higher peat increment rate correlated with a low dry bulk density, low nitrogen content and high C:N ratio (Table 3). The peat increment and carbon accumulation rates were lower in drained mires than in pristine mires, whereas dry bulk density and carbon content were higher in drained mires than in pristine mires (Table 4).

Table 2. Mean values of peat thickness, apparent carbon accumulation rate (ARCA), carbon pool, proportion of total carbon pool, dry bulk density, %C, %N and C:N ratio for 100-year-old and 300-year-old surface layers of the study sites, calculated according to mire region.

Table 2. Tutkittujen soiden alle 100 ja alle 300 vuoden ikäisten pintakerrosten keskimääräinen paksuus, näennäinen hiilen kertymisnopeus (ARCA), hiilivarasto, osuus koko hiilivarastosta, kuiva-aineen määrä, hiili- ja typpipitoisuus sekä C:N suhde.

Region		Thickness (m)	C-acc. rate ($g\ m^{-2}\ yr^{-1}$)	C-pool ($t\ ha^{-1}$)	% total C-pool (%)	Bulk density ($kg\ m^{-3}$)	C conc. (%)	N conc. (%)	CN ratio
				<100 years old					
Aapa mire									
n=27	Mean	0.24	60.2	60	6.7	58.3	45.7	1.46	35.5
	Median	0.27	66.3	66	5.7	56.9	44.9	1.54	30.9
	S.D.	0.13	30.1	30	4.4	13.9	2.5	0.52	13.8
Raised bog									
n=34	Mean	0.23	58.0	58	6.1	60.6	46.5	1.22	44.2
	Median	0.19	49.8	50	4.3	57.0	45.6	0.99	45.5
	S.D.	0.17	31.7	32	5.0	16.2	2.7	0.59	14.3
Coastal mire									
n=12	Mean	0.41	84.4	84	15.4	50.1	44.5	1.02	48.7
	Median	0.36	91.0	91	15.7	48.6	44.8	0.88	50.7
	S.D.	0.14	27.2	27	5.3	19.1	1.2	0.46	13.0
All mires									
n=73	Mean	0.26	63.2	63	8.0	58.0	45.9	1.27	41.7
	Median	0.23	57.2	57	7.0	56.7	45.2	1.06	42.9
	S.D.	0.16	31.5	31	5.9	16.1	2.5	0.56	14.6
				<300 years old					
Aapa mire									
n=27	Mean	0.36	33.8	101	11.6	60.8	45.9	1.41	37.1
	Median	0.35	32.3	97	9.5	58.7	45.0	1.17	37.9
	S.D.	0.15	13.4	40	9.7	13.0	2.4	0.52	14.1
Raised bog									
n=34	Mean	0.41	38.4	115	11.3	66.1	47.1	1.22	44.5
	Median	0.39	37.3	112	8.2	60.5	46.0	0.98	47.4
	S.D.	0.23	17.6	53	7.4	18.2	2.7	0.59	14.7
Coastal mire									
n=12	Mean	0.73	61.3	184	33.2	54.2	44.6	0.97	47.7
	Median	0.76	67.2	202	37.4	53.2	45.0	0.98	45.0
	S.D.	0.21	23.6	71	13.0	15.2	1.1	0.18	9.4
All mires									
n=73	Mean	0.45	40.5	121	15.4	62.2	46.3	1.25	42.3
	Median	0.40	37.5	112	10.9	59.3	46	1.07	43.3
	S.D.	0.24	19.6	59	12.6	16.3	2.6	0.53	14.2

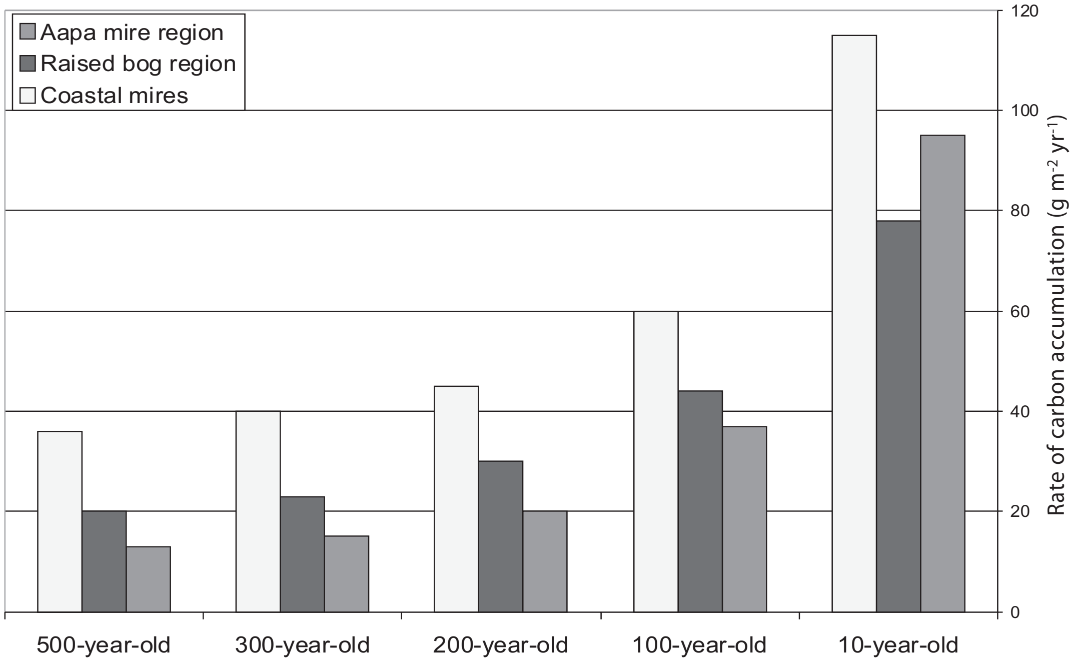


Fig. 4. Mean carbon accumulation rates in the uppermost layer (10 years old), and at the ages of 100, 200, 300 and 500 years old for the aapa mire, raised bog and coastal mire regions.

Kuva 4. Keskimääräinen hiilen kertymisnopeus suon ylimmässä kerroksessa(10 vuoden ikäinen) ja 100, 200, 300 ja 500 vuoden ikäisissä kerroksissa kullakin kolmella alueella.

Table 3. Correlation matrix for surface layers less than 300 years old. Correlations that are significant at the 1%-risk level (2-tailed) have been marked by bold.

Taulukko 3. Alle 300 vuoden ikäisten pintakerrosten korrelaatiomatriisi. Korrelaatiot, jotka ovat merkitseviä 1% -riskitasolla on lihavoitu.

	Surface layer <300 years old (S)									Entire (total) peat layer (T)		
Layer	Attribute	Thick.	$ARCA_{300}$	C-pool	Bulk density	C	N	CN ratio	Prop. C pool	Age	Thick.	LARCA
S	Thickness	1										
	$ARCA_{300}$	**0.85**	1									
	C pool	**0.86**	1.00	1								
	Bulk dens.	**–0.44**	0.02	0.02	1							
	C	–0.21	0.02	0.02	**0.40**	1						
	N	**–0.51**	**–0.44**	**–0.44**	**0.36**	0.11	1					
	C:N ratio	**0.44**	**0.45**	**0.45**	–0.21	0.06	**–0.89**	1				
	Prop. C pool	**0.73**	**0.70**	**0.70**	–0.16	–0.26	**–0.39**	**0.35**	1			
T	Age	**–0.53**	**–0.40**	**–0.40**	0.29	**0.42**	**0.39**	–0.31	**–0.74**	1		
	Thickness	–0.02	0.09	0.09	0.08	**0.53**	–0.06	0.19	**–0.40**	**0.49**	1	
	LARCA	**0.52**	**0.58**	**0.58**	–0.03	–0.08	**–0.33**	**0.38**	**0.55**	**–0.65**	0.04	1
	C pool	–0.27	–0.07	–0.07	0.28	**0.58**	0.11	0.06	**–0.59**	**0.69**	**0.91**	–0.13

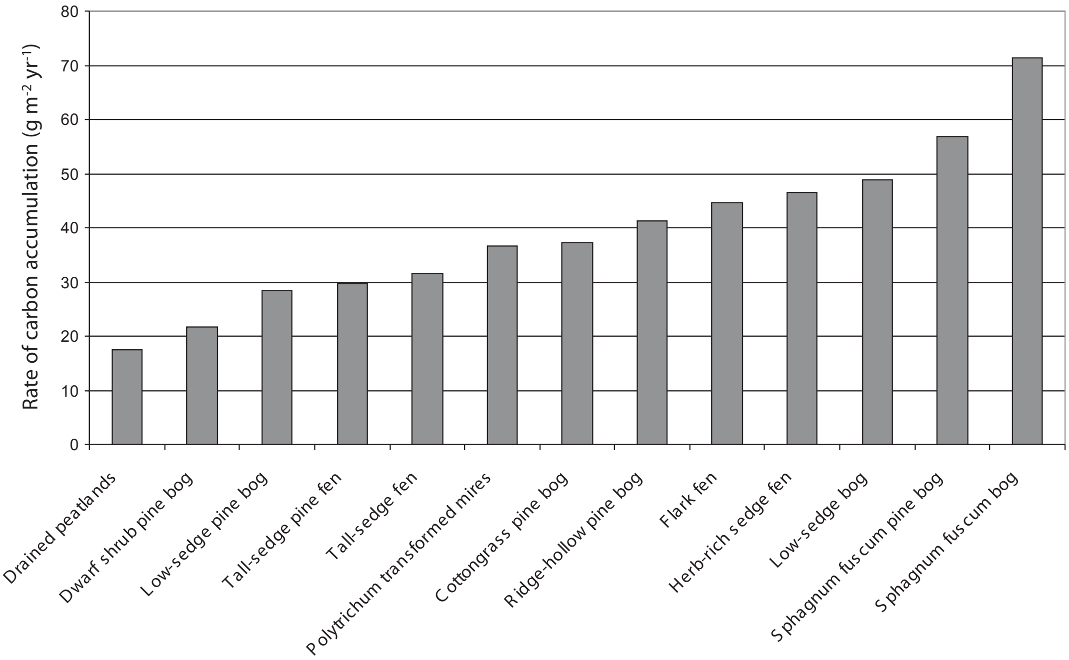


Fig. 5. Average carbon accumulation rates over the last 300 years, calculated for the different mire site types and drained peatlands represented amongst the study sites. English names of mire site types according to Laine & Vasander (1990).

Kuva 5. Keskimääräinen hiilen kertymisnopeus alle 300 vuoden ikäisissä kerroksissa eri suotyypeillä ja muuttuneilla suotyypeillä. Suotyyppien englanninkieliset nimet Laine&Vasanderin (1990) mukaan.

Table. 4. Mean values of attributes of surface layers younger than 300 years old in drained and pristine mires. SD=standard deviation.

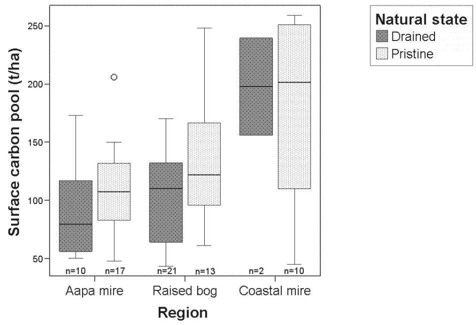
Taulukko 4. Alle 300 vuoden ikäisten pintakerrosten ominaisuuksien keskiarvot ojitetuilla ja luonnontilaisilla soilla. SD=keskihajonta.

Surface layer <300 years old									
State of mire		Thickness (m)	ARCA300 ($g\ m^{-2}\ yr^{-1}$)	C pool ($t\ ha^{-1}$)	% total C pool (%)	Bulk density ($kg\ m^{-3}$)	C conc. (%)	N conc. (%)	C:N ratio
Drained	Mean	0.34	34.5	104	13.2	68.9	46.7	1.37	40.1
(n = 33)	Median	0.28	36.3	109	8.8	65.0	46.0	1.09	42.2
	SD	0.18	15.7	47	11.6	16.6	2.6	0.63	15.0
Pristine	Mean	0.53	45.3	136	17.0	56.7	45.9	1.15	44.1
(n = 40)	Median	0.46	41.0	123	11.0	57.1	45.0	1.03	44.1
	SD	0.25	21.3	64	13.2	14.0	2.6	0.42	13.4

Entire (total) peat layer					
State of mire		Age of base (yr)	Thickness (m)	LARCA ($g\ m^{-2}\ yr^{-1}$)	C pool ($t\ ha^{-1}$)
Drained	Mean	6138	2.31	19.4	1014
(n = 28)	Median	6300	2.29	15.7	1055
	SD	2440	0.74	11.0	314
Pristine	Mean	5857	2.78	24.0	1083
(n = 38)	Median	7005	2.42	18.8	898
	SD	3315	1.54	15.7	632

Carbon pool of surface layers

The mean carbon pool in peat younger than 300 years was calculated as 121 ± 7 tonnes ha^{-1} (range 44–259 tonnes ha^{-1}) overall, 101 ± 8 tonnes ha^{-1} for the aapa mire region, 115 ± 9 tonnes ha^{-1} for the raised bog region, 184 ± 20 tonnes ha^{-1} for coastal mires (Table 2 and Fig. 6), 104 ± 8 tonnes ha^{-1} for drained mires and 136 ± 10 tonnes ha^{-1} for pristine sites (Table 4). For layers less than 100 years old, the average carbon pool was 63 ± 3.7 tonnes ha^{-1} (range 17–141 tonnes ha^{-1}) (Table 2).



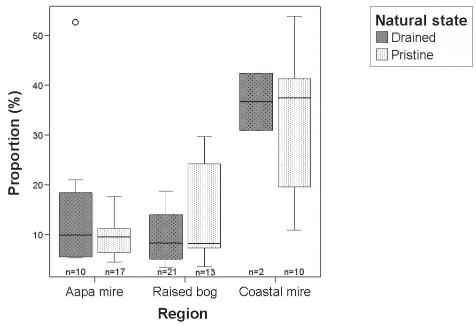


Fig. 6. Boxplot comparisons of the mean surface carbon pool in peat layers younger than 300 years in drained and pristine study sites in the aapa mire, raised bog and coastal regions. The boxplots show the median, interquartile range, extremes and outliers of the surface carbon pool dataset as absolute values in tonnes ha^{-1} (above) and as proportions (%) of the appropriate total carbon pool (below).

Kuva 6. Alle 300 vuoden ikäisen turvekerroksen keskimääräisen hiilivaraston boxplotvertailu aapa- ja keidassuoalueen sekä rannikon soiden ojitetuilla ja luonnontilaisilla näytteenottopaikoilla. Boxplotit näyttävät pinnan hiilivaraston mediaanin, todennäköisimmät arvoalueet ja poikkeavat arvot tonneina hehtaarilla (yläpuolinen kuva) ja pinnan hiilivaraston osuuden prosentteina kokonaishiilivarastosta (alapuolinen kuva).

Discussion

Uncertainty in age-depth models of peat growth

Accurate dating is extremely important when using age-depth models to calculate the rates of peat increment and carbon accumulation, because deviations in calibrated ^{14}C ages (which may be as large as hundreds of years) can give misleading accumulation rates, especially for short time intervals. When modelling age-depth curves, the model must be very flexible to determine the best curve fit and should incorporate calibrated data as well as the uncertainty from the analysis. ^{14}C dating of young peat profiles was extensively studied by Goslar et al. (2005), who presented age-depth relationships as smooth curves hand-drawn over the probability distributions of calibrated ^{14}C dates. From this work it is clear that the complicated shape of the radiocarbon calibration curve between *ca*. 1650 and 1950 AD precludes accurate age determination within this time window unless many ^{14}C dates are determined.

Whilst there is considerable scatter in the thickness values for 100-year and 300-year layers derived for the group of profiles studied here, the model errors for individual profiles are mutually independent, and so can be assumed to be well represented by the standard deviations of means calculated for groups containing many profiles. The standard deviations for <100-year-old layers representing the different mire regions oscillate around *ca*. 50% of the mean layer thickness, and for <300-year-old layers they amount to *ca*. 40% of the average thickness (Table 1). These values are close to a conservative estimate of the uncertainty within individual age-depth models, so that the differences between 100-year and 300-year layer thicknesses derived for individual profiles may lie below the sensitivity threshold for the method. Many more ^{14}C dates than the 367 values measured for the present study would be required to improve this. However, although the uncertainty of the age-depth model for each peat profile is rather large, this drawback is not critical to the approach adopted here, because many peat columns were studied in the same way and conclusions are drawn from statistical patterns rather than from features of individual profiles.

Carbon accumulation rate

Large variations in carbon accumulation rates are often observed in the topmost layers of mires. Accumulation analyses for the fire layers of Lakkasuo mire in central Finland indicated accumulation rates of 40–81 g m^{-2} yr^{-1} in the uppermost 7–58 cm (ca. 150–200 years) of the profile and 29–43 g m^{-2} yr^{-1} in slightly deeper peat (*ca*. 100 cm depth, age 1,000 years) (Laine et al. 2004). Carbon accumulation rates for the topmost 0–56 cm of 41 mires in different parts of Finland ranged from 5.4 to 119.5 g m^{-2} yr^{-1} (mean value 37.8 g m^{-2} yr^{-1}) (Mäkilä 2005). Within the *Sphagnum*-dominated site in Canada examined by Kuhry et al. (1992), the mean carbon accumulation rate in the topmost 0–90 cm was 31.7 g m^{-2} yr^{-1}, whereas between depths of 87 and 154 cm the average rate was just 12.5 g m^{-2} yr^{-1}. Turunen et al. (2002) obtained values of 17 g m^{-2} yr^{-1} for minerotrophic mires and 21 g m^{-2} yr^{-1} for ombrotrophic bogs, which are slightly higher than the corresponding long-term carbon accumulation rates (LARCA) derived in the present study for the aapa mire (14.6 g m^{-2} yr^{-1}) and raised bog (19.8 g m^{-2} yr^{-1}) regions (Table 1).

According to Klarqvist et al. (2001), the rate of carbon accumulation in 11 mires in northern Sweden was closely related to the peat increment rate and dry bulk density and less strongly correlated with the carbon content. In the present study, $ARCA_{100}$ and $ARCA_{300}$ were most strongly linked to the rate of vertical peat increment and, to a lesser extent, to the dry bulk density and carbon content (Table 3) (Tolonen et al. 1992, Ikonen 1995, Mäkilä 1997). On the other hand, the correlation with dry bulk density and carbon content was more significant in coastal and pristine mires.

Variation in carbon accumulation rate in relation to mire site type and peat type

Due to natural mire succession and variations in local conditions, spatial variation in the carbon accumulation rate can largely be explained in terms of the composition of the vegetation and decomposition rates. Connections between mire vegetation, its nutrient content and its moisture status have commonly been observed (Laine & Vanha-Majamaa 1992, Laine et al. 1995, Laiho 2006), whilst carbon allocation and nutrient use efficiency are important processes in overall plant function that also control the quantity and biochemical content, or “quality”, of dead organic matter (litter) produced. Litters of different quality decompose at different rates (Aber & Melillo 2001). For *Carex* species, production is mainly determined by the availability of nutrients such as nitrogen and phosphorus, whereas decay rates vary according to the nutrient contents of their different parts (Thormann et al. 2001). In the present study, the lowest nitrogen and carbon contents were found in coastal *Sphagnum* bogs and the highest in the *Carex* aapa mire region, whilst the C:N ratio was slightly higher in coastal mires than in the raised bog region (Table 2). In order to use the C:N ratio as an index of the degree of decomposition, the C:N ratio of the biomass must be constant. Strictly, this condition is fulfilled only if plant material of the same species and tissue is used for all assessments, as pointed out by Kuhry & Vitt (1996).

Plant components and the degree of decomposition estimated from the preservation state of moss remains (Fig. 5) indicate that the apparent carbon accumulation rate for layers younger than 300 years is highest on acid *Sphagnum fuscum* hummocks and wet *Sphagnum balticum* lawns. An increase of *Eriophorum* species reduces the thickness of these layers. All deeply penetrating roots of mire plants are equipped with well-developed aerenchyma, through which some oxygen diffuses into the deeper layers. Some anaerobic breakdown of readily decomposed plant substances can thus take place immediately below the oxic zone (Eggelsmann et al. 1993).

The thinnest <300-year-old *Sphagnum* layers occur in the wettest areas (hollows), where the surface layers are composed of *S. cuspidatum* and *S. majus*. Although these hollow species (*Sphagnum* Section *Cuspidata*) tend to have higher production rates than hummock-forming species (Section *Acutifolia*) (Rochefort et al. 1990, Malmer & Wallén 1999), hollow species generally decay more rapidly than hummock-forming species (Johnson & Damman 1991, Belyea 1996). In studies focusing on individual species, 70% of *Sphagnum* (both hummock and lawn species) (Malmer & Wallen 1999) and 40–80% of *Carex rostrata* (Ohlson 1987) in the acrotelm of mires were found to be decomposed. The thinnest <300-year-old surface layers of all are found where *Carex* species dominate and *Sphagnum* moss is mainly decomposed.

Moisture, and especially its temporal distribution, is the main factor controlling *Sphagnum* production (Backeus 1988). Thus, both the amount of precipitation and the depth of the water table are important for *Sphagnum* production. However, other climatic factors (e.g. mean annual growing season, temperature and growing degree-days) have also been shown to correlate with moss growth (Thormann & Bayley 1997). Carbon accumulation rates are higher in coastal *Sphagnum* bogs than in raised bogs not only for climatic reasons, but also because bogs developing along the uplifting coastline of Finland are naturally mostly younger than those inland (see e.g. Rehell 2006). This younger bog type produces more moss than an old bog, and the amount of peat decayed and compacted is lower (Johnson et al. 1990). Generally, high net rates of carbon accumulation are found in wet unconsolidated lawns, in places where the mire basin is characterised by filled-in water bodies, and in marginal areas of mires that have been devastated by forest and peat fires during the earliest stages of their development. They tend to be lower in mires developed on sloping mineral ground where the irrigating water is moving and therefore oxygen-rich, because significant decay can occur beneath the water table under these conditions.

Effect of drainage on carbon accumulation

It is difficult to compare peat properties and carbon accumulation rates between drained and pristine mires because the drained areas generally have thinner peat layers. Organic matter decomposes more rapidly here, giving a higher nitrogen content, whereas the peat increment and carbon accumulation rates are lower — although carbon density is higher than in pristine mires (Table 4). The slower rate of vertical growth is explained by secondary compaction, reflected by the greater dry bulk density values for drained areas (Table 4), which in turn are confirmed by the data of Mäkilä (1994) for almost 50000 volumetric samples collected from pristine and drained mires in various parts of Finland.

The low bulk density and high total porosity of peat means that drainage causes subsidence of the mire surface, which may be in the order of 15–40 cm during the first decades after drainage. Initially, most of the subsidence occurs through physical collapse of the peat matrix as water is removed, but later the phenomenon is increasingly attributable to oxidation and decomposition of the peat (Minkkinen & Laine 1998). For the <300-year-old peat layers studied here, the average thickness was 19 cm less and the carbon accumulation rate 10 g m^{-2} yr^{-1} lower in drained areas than in pristine areas.

As a direct result of drainage, buoyancy is lost and the moss carpet collapses, causing the surface of the mire to sink. Later, subsidence continues as the rate of oxic decomposition in the surface layers increases. However, upward growth of mosses and the accumulation of organic matter at the surface of the peatland may continue simultaneously with decomposition and compaction of sub-surface peat (Laine et al. 2004). The observed change in surface altitude is thus the net result of these two processes. In drained peatlands, a *ca*. 10 cm layer of raw humus formed by mosses and tree litter is often found on the original surface (Laine et al. 2004). Examples included in the present study are the Sarvisuo and Lautasuo mires (Appendix 1).

Variability in carbon accumulation rates

Recent carbon accumulation rates are generally higher than longer-term rates (Fig. 7). This is mainly because little of the organic matter in the uppermost layers has decayed, but apparent ac-

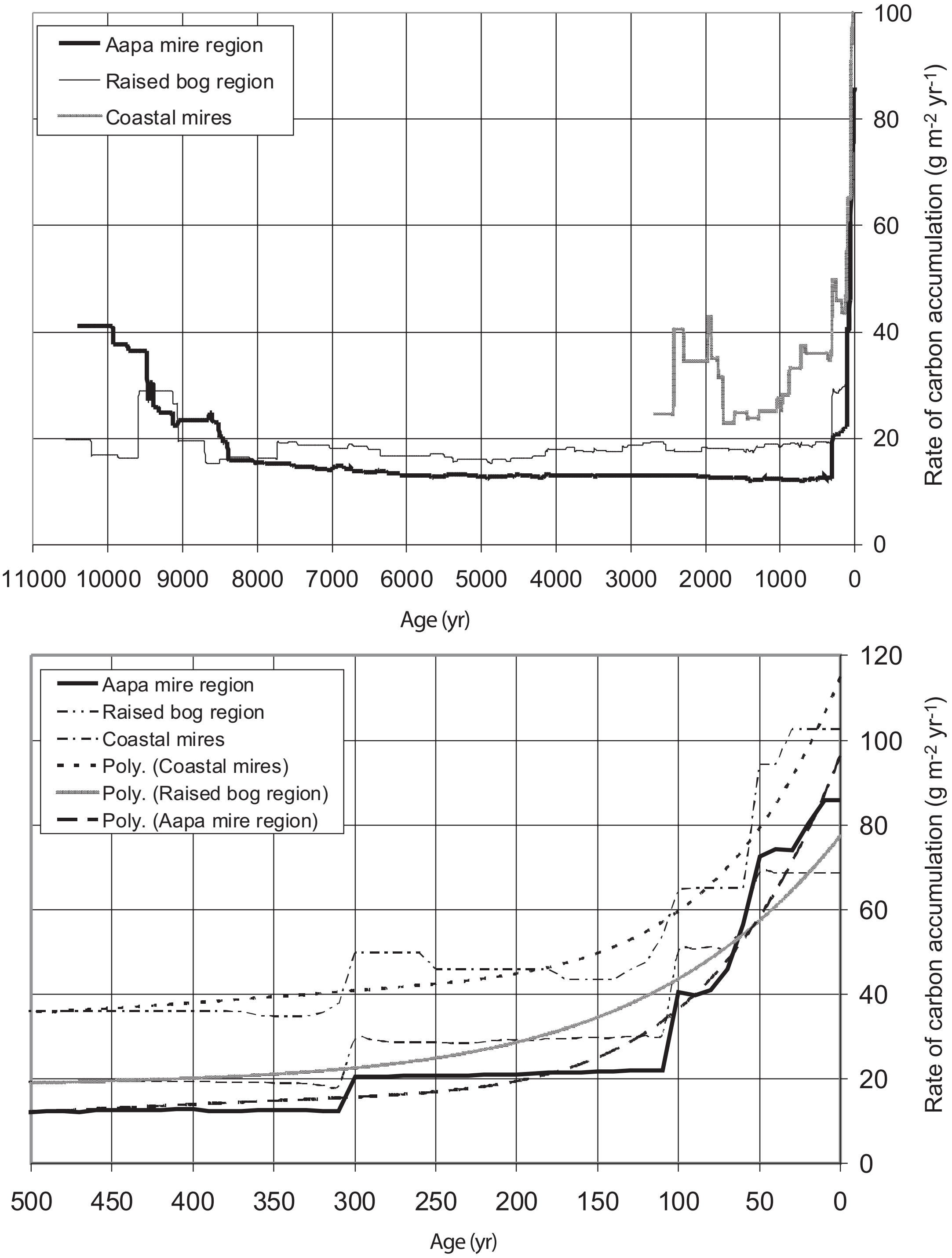


Fig. 7. Variation in mean carbon accumulation rates calculated over different time periods for the aapa mire, raised bog and coastal mire regions.

Kuva 7. Hiilen kertymisnopeuden vaihtelut aapa- ja keidassuoalueella sekä rannikon nuorissa soissa eri aikakausina.

cumulation rates in the older peat are also affected by losses due to fires. The rate of carbon accumulation is higher in raised bogs than in minerotrophic aapa mires because aerobic decay is more efficient in aapa mires, which receive nutrients and oxygenated water from adjacent mineral soils, whereas ombrotrophic raised bogs are fed only by rain water (e.g. Damman 1996). In minerotrophic aapa mires, oxygen is transported into the peat *via* the roots of sedges, where it contributes to the decay of peat layers. Disregarding the uppermost layers, a retrogressive trend in carbon accumulation rates from base to surface is observed in aapa mires. This indicates that, after the most productive initial stages of development, net carbon accumulation rates in aapa mires generally decline (Mäkilä et al. 2001, Mäkilä & Moisanen 2007). Hydrological, topographical and edaphic factors also influence carbon accumulation rates. Rates of litter accumulation under anoxic conditions below the water table primarily depend on organic matter production, and thus on the fertility of the mire water (Damman 1996). Natural succession, interacting with local factors and climate, leads to changes in species composition and thus in the productivity of the vegetation. This, in turn, affects the susceptibility of plant products to decay, in a way that is specific to each plant association Mäkilä et al. (2001).

The stratigraphy of raised bogs suggests that carbon exchange and accumulation have always been sensitive to the climatic fluctuations that have characterised the entire Holocene (Mäkilä & Saarnisto 2008). High net carbon accumulation rates can be attributed to low decomposition rates associated with humid periods (with high precipitation/evaporation ratios), and a marked decline in the carbon accumulation rate may indicate a period of relatively dry and warm climate. Thus, the levelling-out and subsequent increase in carbon accumulation rates in the raised bog region after 4,500 cal BP indicates the development of *Sphagnum*-dominated plant associations connected with an increasingly humid climate (Mäkilä & Saarnisto 2008)

Carbon balance

Wet conditions favour CO_2 accumulation (Alm et al. 1997, Nykänen et al. 2003), whereas on drier sites or in drier years the net flux is from the mire to the atmosphere (Alm et al. 1999, Frolking et al. 2002). The highest rates of carbon accumulation loss occur in the surface layers of aapa mires (Fig. 4).

Saarnio et al. (2007) calculated annual carbon balances for pristine mires in south-eastern Finland. The simulated 30-year CO_2 balances ranged from -100 to +17 g C m^{-2} yr^{-1} for ombrotrophic mires and from +36 to +91 g C m^{-2} yr^{-1} for minerotrophic mires, the corresponding annual CH_4 effluxes being –7 to –9 g C m^{-2} and –17 to –19 g C m^{-2}. Negative values indicate net efflux from the mire ecosystem. These results indicate a higher net CO_2 uptake for minerotrophic than for ombrotrophic mires. Numerous studies on CH_4 release have clearly shown that, on average, minerotrophic mires release more CH_4 than ombrotrophic bogs (Vasander & Kettunen 2006, Saarnio et al. 2007). The general trend is for topographically lower-lying areas such as hollows, pools and peatland margins to have higher CH_4 emissions and lower CO_2 uptake than the adjacent topographically higher areas such as hummocks, ridges and plateaux (Waddington & Roulet 1996).

For the pristine minerotrophic site studied by Saarnio et al. (2007) we carried out ^{14}C datings, together with bulk density and carbon content measurements, at seven depths. The *Carex*-dominated wet peat layer was 1.6–2.3 m thick and the age of the basal peat was 900–2,400 cal BP. Carbon accumulation rates in the surface layers of this type of wet mire should be very high. The average carbon accumulation rate in the layer younger than 100 years was 106.2 g m^{-2} yr^{-1}, in the layer younger than 300 years it was 45.8 g m^{-2} yr^{-1}, and the long-term carbon accumulation rate was 22.3 g m^{-2} yr^{-1}.

Conclusions

These data indicate a steep decline in the apparent rate of carbon accumulation within the 'pre-peat' of the surface layers. Indeed, we may anticipate relatively rapid cycling of a large part of the biomass — and thus of carbon — within the surface layers of all mires, due to the intensive decomposition that occurs here as part of the peat formation process. For an individual plant starting at the mire surface, the apparent carbon accumulation rate thus declines progressively over the first few centuries until the residue becomes waterlogged and combines with the peat deposit proper, where carbon turnover becomes extremely slow. In other words, the high carbon accumulation rate in the surface layers, although necessary for the development and maintenance of the mire, is temporary. This means that carbon accumulation rates measured in the uppermost layers cannot be used for estimating long-term carbon sequestration rates. Only sub-surface carbon accumulation rates can indicate any real (delayed) long-term trends in net carbon accumulation rates, which incorporate the effects on primary production and decomposition of autogenetic development of the mire and climatic change over five hundred years.

The high carbon accumulation in surface layers is temporary and mainly related to the development of the mire. The surface layers are still undergoing a rapid carbon cycle. A relatively rapid accumulation and turnover of carbon occurs in surface layers (<300 years) in the same way as in a growing forest. Therefore, this "pre-peat" in the surface layers of mires should be distinguished as a separate class from the peat underneath. Our results indicate how important it is to understand the carbon accumulation rates of surface layers and the long-term dynamics of mire carbon accumulation in order to set the current flux estimates in perspective.

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Tiivistelmä:

Etelä- ja keskiboreaalisten soiden pintakerroksen hiilidynamiikka

Soiden pintakerroksen hiilivarasto (alle 100 ja alle 300 vuotta) tutkittiin, jotta ymmärrettäisiin paremmin nuorten kerrosten merkitys hiilen kierrossa. Hiilivaraston selvittämiseksi otettiin eri syvyyksiltä 367 ajoitusnäytettä 73 turvekerrostumasta. Turvekerrostumista määritettiin kuiva-ainemäärä ja hiilipitoisuus. Tutkimuskohteet edustavat eri syvyisiä ja ikäisiä, sekä luonnontilaisia että ojitusasteeltaan erilaisia rahka- ja sarasoita eri puolelta Suomea lukuun ottamatta Lappia. Soista kolme sijaitsee Karjalan Tasavallassa ja yksi Karjalankannaksella. Tutkitut suot on jaettu kolmeen ryhmään: aapasuoalueen, keidassuoalueen ja rannikon soihin.

Hiilen pitkäaikainen näennäiskertymisnopeus (LARCA) koko turvekerrokselle ja viimeaikainen kertymisnopeus ($ARCA_{100}$ ja $ARCA_{300}$ = alle 100 ja alle 300 vuoden ikäinen pintakerros) laskettiin hiilimäärältään ja iältään tunnetuista turvekerroksista. Turpeen ^{14}C -hiukkaskiihdytinajoitus AMS-tekniikalla mahdollisti pienten näytteiden käytön ja siten tarkat iät. ^{14}C-ajoituksiin on käytetty Poznanin radiohiililaboratoriossa Tomasz Goslarin kehittämää kalibrointiohjelmaa ja ikä-syvyys-mallia.

Alle 100 (ja alle 300) vuoden ikäisten kerrosten hiilen kertymisnopeus on aapasuoalueella 60,2 (33,8) g m^{-2} a^{-1}, keidassuoalueella 58,0 (38,4) m^{-2} a^{-1} ja rannikon nuorissa soissa 84,4 (61,3) g m^{-2} a^{-1}. Suurin hiilen hävikki tapahtuu viimeksi kuluneiden 100 vuoden aikana, jonka jälkeen hävikki pienenee vakioituen n. 500 vuoden jälkeen. 300 vuoden vanhan kerroksen hiilen kertymisarvot ovat 17 – 36 % pinnan orgaanisen aineksen ja karikekerroksen arvoista. Koko turvekerrosten hiilen pitkäaikainen kertymisnopeus on 14,6 g m^{-2} a^{-1} aapasuoalueella, keidassuoalueella 19,8 g m^{-2} a^{-1} ja rannikon nuorissa soissa 43,0 g m^{-2} a^{-1}.

Alle 300 vuoden ikäisten kerrosten suurimmat hiilen kertymisnopeudet havaittiin ombrotrofisilla suotyypeillä (rahkanevalla ja rahkarämeellä). Märillä oligotrofisilla ja puuttomilla suotyypeillä oli seuraavaksi suurimmat kertymänopeudet. Veden pinnan korkeus on merkittävä tekijä hiilen kertymiseen, koska ratkaisevaa on orgaanisen aineksen viipymisaika hapekkaassa pintakerroksessa. Pienin hiilikertymä on muuttuneilla ja metsäisillä suotyypeillä. Tällaisissa soissa vedenpinta on syvällä. Alle 100 ja alle 300 vuoden ikäisten kerrosten hiilivaraston määrä vaihtelee suotyypin (ravinnepitoisuus ja kosteus), kasvillisuuden ja luonnontilaisuuden mukaan. Alueelliset vaihtelut ovat merkittäviä, ja pintakerroksen hiilivarasto ja sen osuus kokonaishiilivarastosta eroavat suuresti viereisilläkin soilla. Vaihtelut kuvastavat kasviyhdyskuntien monimuotoisuutta ja sellaisten tekijöiden moninaisuutta, jotka vaikuttavat eri kasviyhdyskuntien biomassan tuotantoon ja hajoamiseen.

Soiden pintakerrosten intensiivisestä hajoamisesta johtuen niiden hiilen kertymisnopeutta ei voi käyttää turpeen pitkäaikaisen hiilen kertymisnopeuden arvioimiseen. Pintakerrosten runsas hiilen kertyminen on lyhytaikainen tapahtuma suhteessa suon kokonaiskehitykseen. Soiden pintakerrosten hiilenkierto on nopeaa. Hiilen kertyminen ja vapautuminen tapahtuu pintakerroksissa samaan tapaan kuin kasvavissa metsissä. Tämä soiden pintakerroksen heikosti maatunut ”esiturve” voitaisiin erottaa alapuolisesta turpeesta omaksi luokakseen. Tulokset osoittavat, että on tärkeää ymmärtää hiilikertymän dynamiikkaa suon sekä pinta- että syvissä kerroksissa asetettaessa nykyiset kasvihuonekaasuarviot oikeaan mittasuhteeseen.

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Appendix 1. List of the 73 study sites in Finland and Russian Karelia*, arranged according to region, natural state and age (where known). Data for thickness, apparent carbon accumulation rates ($ARCA_{100}$, $ARCA_{300}$, LARCA) and the carbon pool are given for peat layers <100 and <300 years old, and for the entire peat layer.

Liite 1. Luettelo 73 tutkimuspaikasta Suomessa, Karjalan Tasavallassa ja Karjalankannaksella* järjestettynä alueittain luonnontilan ja iän mukaan. Alle 100 ja alle 300 vuoden ikäisten sekä koko turvekerroksen näennäiset hiilikertymäarvot (*$ARCA_{100}$*,* $ARCA_{300}$*, LARCA) ja hiilivarasto.*

Region Status	Municipality	Mire	<100-year-old peat layer			<300-year-old peat layer			Entire peat layer			
			Thickness m	$ARCA_{100}$ C g m^{-2} yr^{-1}	C-pool t ha^{-1}	Thickness m	$ARCA_{300}$ C g m^{-2} yr^{-1}	C-pool t ha^{-1}	Age yr	Thickness m	LARCA C g m^{-2} yr^{-1}	C-pool t ha^{-1}
Aapa mire												
Pristine	Kiuruvesi	Iso Aittosuo	0.34	96.5	96	0.44	46.0	138	4,910	2.11	18.0	885
Pristine	Pudasjärvi	Hautasuo	0.32	70.7	71	0.37	27.3	82	6,390	1.39	11.5	735
Pristine	Pudasjärvi	Saarisuo	0.31	66.3	66	0.38	30.0	90	6,950	2.56	17.7	1,232
Pristine	Pudasjärvi	Hautasuo	0.33	87.3	87	0.52	45.3	136	7,060	2.26	13.8	976
Pristine	Pudasjärvi	Paskokorvensuo	0.17	39.3	39	0.22	21.6	65	7,760	2.43	14.2	1,105
Pristine	Pudasjärvi	Leppisuo	0.30	66.4	66	0.34	32.3	97	7,900	2.60	14.6	1,157
Pristine	Kar.tasav.*	Kontokkisuo	0.12	39.7	40	0.32	44.1	132	8,070	2.88	15.1	1,220
Pristine	Pudasjärvi	Kettusuo	0.13	18.3	18	0.31	16.0	48	8,380	1.69	9.2	774
Pristine	Kuhmo	Löytösuo	0.51	102.2	102	0.72	50.0	150	8,460	2.09	10.0	849
Pristine	Pudasjärvi	Hautasuo	0.12	36.0	36	0.29	28.3	85	8,600	2.77	15.5	1,335
Pristine	Pudasjärvi	Hautasuo	0.51	103.1	103	0.60	43.8	132	9,060	3.08	14.6	1,324
Pristine	Pudasjärvi	Hautasuo	0.10	24.4	24	0.20	16.3	49	9,130	1.90	10.4	947
Pristine	Pudasjärvi	Ruosuo	0.37	87.8	88	0.47	35.8	107	9,390	2.78	12.0	1,126
Pristine	Pudasjärvi	Ruosuo	0.34	116.3	116	0.54	68.7	206	9,440	2.73	15.5	1,461
Pristine	Pudasjärvi	Ruosuo	0.18	68.1	68	0.22	27.7	83	9,470	1.79	9.2	875
Pristine	Kar.tasav.*	Ypäyssuo	0.28	71.6	72	0.45	37.5	112	9,930	3.23	14.7	1,463
Pristine	Kuhmo	Härkösuo	0.16	56.5	57	0.35	41.4	124	10,410	7.78	26.8	2,787
Drained	Pudasjärvi	Hautasuo	0.13	36.2	36	0.35	31.7	95	2,090	0.50	8.6	180
Drained	Kiuruvesi	Pieni Lehmisuo	0.09	23.0	23	0.22	18.5	55	4,160	1.90	24.1	1,001
Drained	Kiuruvesi	Tulponsuo	0.04	16.6	17	0.13	16.8	50	4,650	1.72	17.8	830
Drained	Kiuruvesi	Iso Aittosuo	0.09	24.4	24	0.22	21.5	64	5,470	2.66	21.2	1,162
Drained	Kiuruvesi	Sarvisuo	0.37	93.5	94	0.59	57.8	173	5,680	2.13	14.6	828
Drained	Pudasjärvi	Hautasuo	0.45	82.5	83	0.54	36.3	109	6,580	1.59	10.5	689
Drained	Kiuruvesi	Liinalamminsuo	0.27	78.8	79	0.41	40.2	121	7,620	1.65	11.4	871
Drained	Pudasjärvi	Koivusuo	0.21	44.3	44	0.23	19.6	59	8,440	2.53	13.2	1,118
Drained	Kuhmo	Pitkänlehdonsuo	0.13	37.5	38	0.13	18.7	56				
Drained	Eno	Karhurimpi	0.27	57.1	57	0.27	39.0	117				
Raised bog												
Pristine	Anjalankoski	Hangassuo	0.73	106.2	106	0.98	45.8	138	2,390	2.30	21.7	518
Pristine	Isokyrö	Hangasneva	0.18	43.5	44	0.43	38.9	117	2,410	2.90	37.8	911
Pristine	Huittinen	Nanhiansuo	0.64	137.2	137	0.97	82.5	248	3,160	2.56	26.4	834

Pristine	Anjalankoski	Haukkasuo	0.31	47.3	47	0.64	40.6	122	3,460	2.43	15.1	521
Pristine	Lapua	Kakkaraneva	0.58	141.4	141	0.81	77.0	231	4,360	2.52	21.1	919
Pristine	Anjalankoski	Haukkasuo	0.08	20.7	21	0.25	21.2	64	4,670	2.27	17.2	801
Pristine	Anjalankoski	Haukkasuo	0.40	57.0	57	0.56	32.0	96	7,720	3.38	15.3	1,179
Pristine	Kar.kannas*	Suurisuo	0.19	67.9	68	0.45	55.6	167	7,730	4.47	32.4	2,506
Pristine	Kar.tasav.*	Virmosuo	0.09	29.0	29	0.19	20.3	61	8,680	4.39	19.6	1,703
Pristine	Hausjärvi	Kilpisuo	0.28	86.3	86	0.75	76.9	231	9,590	7.25	29.2	2,803
Pristine	Anjalankoski	Haukkasuo	0.12	26.0	26	0.40	33.6	101	10,570	7.08	23.7	2,501
Pristine	Tuusniemi	Silmäsuo	0.16	34.0	34	0.40	28.3	85				
Pristine	Vihanti	Verkaneva	0.15	50.9	51	0.38	44.7	134				
Drained	Huittinen	Nanhiansuo	0.23	69.0	69	0.34	31.9	96	2,950	2.11	28.8	851
Drained	Kotka	Suurirahka	0.19	48.5	48	0.49	44.0	132	4,600	4.27	33.6	1,544
Drained	Anjalankoski	Haukkasuo	0.26	72.9	73	0.45	44.0	132	5,320	1.73	14.3	762
Drained	Anjalankoski	Haukkasuo	0.13	30.0	30	0.17	14.5	44	5,370	1.72	18.5	991
Drained	Ilomantsi	Lautasuo	0.36	87.6	88	0.48	41.6	125	5,420	2.02	15.8	858
Drained	Parkano	Untilanneva	0.11	46.5	47	0.20	37.8	113	5,680	2.43	22.2	1,259
Drained	Parkano	Huhdanneva	0.07	16.7	17	0.19	15.6	47	6,250	2.60	18.2	1,135
Drained	Parkano	Isonkivenneva	0.23	54.3	54	0.26	21.3	64	6,350	2.39	18.4	1,165
Drained	Anjalankoski	Haukkasuo	0.48	104.8	105	0.63	51.0	153	6,520	2.23	12.5	817
Drained	Vihanti	Kuuhkamonneva	0.25	53.8	54	0.62	52.3	157	7,030	3.38	15.6	1,098
Drained	Parkano	Krouvineva	0.12	42.1	42	0.23	26.7	80	7,460	2.16	13.8	1,031
Drained	Anjalankoski	Haukkasuo	0.15	57.2	57	0.44	56.7	170	7,590	3.71	17.7	1,345
Drained	Ilomantsi	Kaitoinsuo	0.09	31.8	32	0.13	17.4	52	7,710	2.34	14.0	1,079
Drained	Anjalankoski	Haukkasuo	0.10	31.7	32	0.28	36.8	110	8,100	3.19	16.9	1,371
Drained	Ilomantsi	Kaitoinsuo	0.23	89.5	89	0.27	36.8	110	9,130	2.69	15.0	1,370
Drained	Anjalankoski	Haukkasuo	0.20	88.7	89	0.33	50.8	152	9,600	2.43	11.3	1,088
Drained	Parkano	Rihkaanneva	0.06	24.1	24	0.10	16.1	48	9,860	2.54	14.2	1,399
Drained	Ilomantsi	Rahesuo	0.07	26.3	26	0.20	25.1	75	10,220	2.54	14.5	1,479
Drained	Hirvensalmi	Suurisuo	0.23	64.6	65	0.32	29.3	88				
Drained	Haukivuori	Kivikankaanalussuo	0.20	48.6	49	0.46	40.7	122				
Drained	Outokumpu	Iso-Loukko	0.08	17.3	17	0.23	17.3	52				
Coastal mires												
Pristine	Maalahti	Långträskmossen	0.25	69.5	70	0.76	71.4	214	720	1.95	77.3	556
Pristine	Mustasaari	Storslätmossen	0.51	98.4	98	1.05	70.6	212	870	2.40	59.3	516
Pristine	Maalahti	Långträskmossen	0.25	89.9	90	0.75	85.6	257	880	1.74	70.2	618
Pristine	Ii	Mätässuo	0.65	86.0	86	0.88	63.8	191	1,280	1.20	27.8	355
Pristine	Maalahti	Helne Vitmossen	0.55	129.0	129	0.97	86.3	259	1,610	2.31	44.2	712
Pristine	Kuivaniemi	Ihananlamminaapa	0.29	96.5	96	0.55	61.7	185	1,830	1.33	24.5	449
Pristine	Siikajoki	Hummastinjärviensuo	0.35	38.1	38	0.38	15.2	45	1,960	1.08	21.3	417
Pristine	Keminmaa	Törmäjänkä	0.35	42.3	42	0.58	36.6	110	2,290	1.99	24.5	560
Pristine	Siikajoki	Hummastinjärviensuo	0.40	60.8	61	0.51	29.1	87	2,420	2.03	28.9	701
Pristine	Keminmaa	Himokummunjänkä	0.64	114.4	114	0.97	83.7	251	2,670	2.00	31.3	835
Drained	Pyhtää	Muurainsuo	0.36	92.0	92	0.59	51.9	156	970	1.98	52.0	504
Drained	Maalahti	Långträskmossen	0.30	95.5	95	0.79	79.8	239	1,040	1.50	54.3	564