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Vegetation and CO_2 balance in an abandoned harvested peatland in Aitoneva, southern Finland

Kasvillisuus ja CO_2-tase käytöstä vapautuneella turvetuotantoalueella Kihniön Aitonevalla

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The vegetation and CO_2 balance (difference between CO_2 fixation rate and respiration rate) in an abandoned harvested peatland in Aitoneva, Kihniö (62°12′N, 23°18′E) were studied during the summer of 1994. The daytime CO_2 fluxes from sample plots representing different kinds of vegetation were measured using two different static chamber techniques. To investigate the compositional variation of vegetation and its relationship with CO_2 balance, data on the vegetation of the sample plots was analysed by global non-metric multidimensional scaling (GNMDS). A total number of 20 plant species was observed on the sample plots. The dominant plant species was *Eriophorum vaginatum* L. The main variation in GNMDS were connected with colonization stage (total cover of vegetation). The CO_2 fixation rate varied between –56 and 1869 mg m^{-2} h^{-1} and the respiration rate varied between 34 and 1168 mg CO_2 m^{-2} h^{-1}. The CO_2 fixation and respiration rate increased with increasing total vegetation cover. The highest respiration and the highest CO_2 fixation rates were found in sample plots dominated by mature *Eriophorum vaginatum* tussocks. Those sample plots were the only ones having positive CO_2 balance. Regression analysis indicated that the respiration rate depended on soil temperature. Variation in the water table had no influence on the respiration or the CO_2 fixation rate.

Key words: CO_2 balance, *Eriophorum vaginatum*, GNMDS, harvested peatland, plant colonization

INTRODUCTION

In Finland, about 52 500 hectares of peatland is exploited for peat harvesting, mainly by surface milling operations. Currently approximately 3 000 additional hectares are subjected to peat harvesting annually. The harvesting period of a peatland is 15–20 years after which the harvested peatland is abandoned. At the moment there are 2 500 ha of abandoned peatlands, and during this decade this area is predicted to increase by 1 500–2 000 ha annually. The largest portion of the abandoned peatlands has been forested, but a part has been left undeveloped (Taustatietoa turvesoiden jälki-käytöstä 1989, Lappalainen et al. 1992).

During peat harvesting a peatland is drained efficiently and divided into convex fields (Suoninen 1982). After abandonment the mean water table level stays well below the surface, but the water level fluctuation can be larger than in virgin mires (Roderfeld et al. 1994). The surface peat of a harvested peatland is usually highly decomposed, and has a low content of readily soluble nutrients (Kaunisto 1979, Ferm and Kaunisto 1983, Lumme et al. 1984, Hytönen 1994). The daily temperature fluctuation of surface peat can be large; on sunny days the dark surfaces warm efficiently and cool rapidly on cloudless nights. The fields remain without vegetation cover for a long period, because plant colonization in such extreme conditions is very slow (Curran and MacNaeidhe 1986, Salonen 1992).

The CO_2 balance of an ecosystem is the ratio between the amount of CO_2 fixed by plants in photosynthesis and the amount of CO_2 released by respiration of plants and decomposers. In a functional mire ecosystem, the CO_2 fixation rate is higher than the respiration rate, and the CO_2 balance of the ecosystem is positive. The ecosystem accumulates peat and acts as a sink for atmospheric carbon. In a non-vegetated harvested peatland there is no carbon fixation, but carbon is released by leaching, in anaerobic decomposition and soil respiration. During the warmest time of a year average respiration rates of 199 mg CO_2 m^{-2} h^{-1} in a *Sphagnum* peat production field and 176 mg CO_2 m^{-2} h^{-1} in a *Carex* peat production field have been measured (Silvola and Alm 1992). CO_2 fixation by harvested peatland begins with increasing plant colonization and the system evolves towards a functional mire ecosystem. Currently there is no information as to the extent and rate by which plant colonization changes the CO_2 balance.

In summer 1994, an experimental study was started in Aitoneva as a part of the Carbon Balance of Peatlands and Climate Change (SUOSILMU) project. The purpose of the study is to investigate the relationship between the vegetation and the carbon balance of harvested peatland, and the effect of rewetting on plant succession and carbon balance. Summer 1994 was a calibration period and the aim of this study was to examine the vegetation and CO_2 balance in an abandoned harvested peatland before rewetting, and to investigate the effect of vegetation and environmental variables on the CO_2 balance. Rewetting of the experimental area was achieved by blocking the drainage ditches with peat dams in autumn 1994.

MATERIAL AND METHODS

Research area

The study was carried out in harvested peatland in Aitoneva, Kihniö (62°12′N, 23°18′E) in a transitional area between the southern and middle boreal coniferous forest zones (Ahti et al. 1968). The annual mean temperature of the region is 3.5°C and the mean annual precipitation is 600 mm. The effective growing season is 160 days long on average and the cumulative temperature sum (threshold +5°C) is 1100 d.d.

The study site was abandoned in 1975 when peat harvesting ended. The thickness of the peat layer after abandonment was about one meter. The field is 3.5 ha in area and is divided into 20 meter wide strips by ditches. The drainage system was still functioning in summer 1994. After twenty years bare surfaces still form the major part of the field. The dominant plant species is *Eriophorum vaginatum* L.

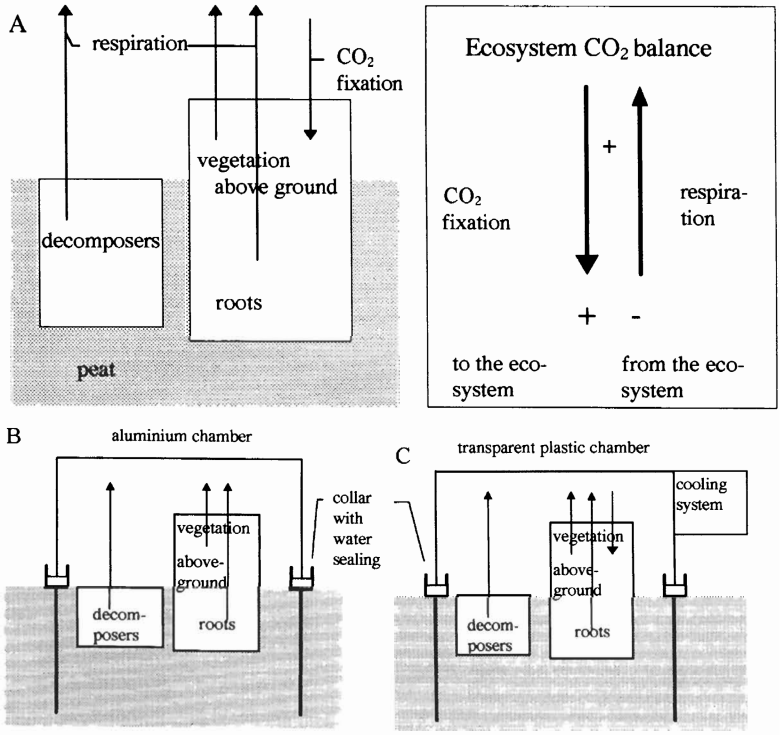
Data collection

Within the field 11 sample plots were established on different kinds of surfaces chosen subjectively to represent the variation of vegetation. Six of the sample plots were placed on almost non-vegetated surfaces (sample plots 2, 4, 5, 6, 8 and 11) and five of the sample plots were placed on more densely vegetated surfaces (sample plots 1, 3, 7, 12 and 13). Sample plots were surrounded with 0.36 m^2 (60 × 60 cm) aluminium collars (Fig. 1), which were inserted into the peat to a depth of 30 cm.

The vegetation of the sample plots was described using the percentage cover method. Seedlings, living tussocks and dead tussocks of *Eriophorum vaginatum* were recorded separately. *Eriophorum vaginatum* tussocks were classified

Fig. 1. A schematic representation of ecosystem CO_2 balance (A) and measurements with aluminium chamber (B) and transparent plastic chamber (C).

Kuva 1. Periaatepiirros ekosysteemin CO_2-taseesta (A) sekä mittauksista alumiinikammiolla (B) ja läpinäkyvällä muovikammiolla (C).



using classification of Fetcher and Shaver (1982). The nomenclature follows Hämet-Ahti et al. (1986) for vascular plants, Ahti (1981) for lichens and Koponen et al. (1977) for bryophytes.

Carbon dioxide fluxes from these sample plots were measured using two different chamber methods. With the first method, only the respiration rate could be measured. With the second method it was possible to measure both the respiration and CO_2 fixation rate (Fig. 1).

In the first method an opaque aluminium chamber (0.108 m^3) was placed on the collar and a series of air samples were taken from the chamber with 60 ml plastic syringes 5, 15, 25 and 35 min after closing the chamber. CO_2 concentrations in the samples were determined in the laboratory by gas chromatography (HP 5890 Series II, for the analytical method see Nykänen et al. 1995) within 24 hours of sampling. Sampling was done five times during June–September.

A transparent plastic chamber (0.108 m^3) was used in the second method. The CO_2 concentration in the air in the chamber was measured with a portable infrared gas analyser (ADC LCA 2) at intervals of 30 seconds for a 3 minute period after closing the chamber. Firstly, the CO_2 balance was measured with the chamber uncovered and exposed to ambient illumination. The chamber was then removed and aerated and the respiration rate measured with the chamber covered by a light-tight plastic blanket. The chamber was fitted with a cooling system to keep the air temperature within the chamber the same as the outside temperature. Measurements were made six times during July–August.

Simultaneously with CO_2 measurements, the solar irradiation (PAR), water table level and soil temperature at 5, 10 and 20 cm depths in the peat layer were measured.

Data analysis

Carbon dioxide balance and respiration rates were calculated from the linear change of CO_2 concentration as a function of time. Data from

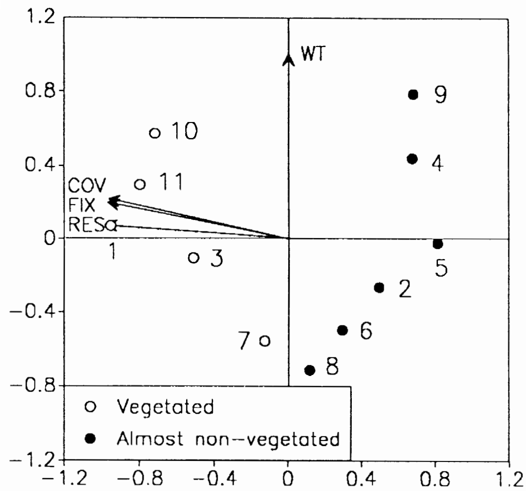


Fig. 2. GNMDS ordination diagram of sample plots (n = 11) and environmental variables in the abandoned harvested peatland at Aitoneva. The variables (arrows) are: FIX = mean CO_2 fixation rate, RES = mean respiration rate, COV = total plant cover, WT = mean water table depth. The correlations and p-values of variables are shown in Table 2.

Kuva 2. GNMDS-ordinaatiodiagrammi käytöstä poistetun Aitonevan turvetuotantokentän näytealoista (n = 11) ja niiden ympäristömuuttujista. Muuttujat (nuolet) ovat: FIX = *yhteytyksessä keskimäärin sitoutunut hiilidioksidi,* RES = *hengityksessä keskimäärin vapautunut hiilidioksidi,* COV = *kasvillisuuden kokonaispeittävyys,* WT = *pohjaveden pinnan keskisyvyys. Muuttujien korrelaatio ja p-arvo taulukossa 2.*

measurements with both the aluminium and the plastic chamber (method I and II) were used for respiration rate calculations, but for CO_2 balance and for CO_2 fixation rate calculations, only data from measurements made with the transparent chamber (method II) were used. The CO_2 fixation rate was calculated as the sum of CO_2 balance and respiration values from measurements made directly after each other.

Vegetation data was analysed by global non-metric multidimensional scaling (GNMDS) using DECODA-software package (Minchin 1991). The purpose of the analysis was to study the compositional variation in the vegetation and its relationship to the CO_2 balance. One- to five dimensional global multidimensional scalings were performed on the vegetation data, each with 20 random starts. In each dimensionality, minimum stress configurations were compared with procrustes analysis. The Bray-Curtis coefficient was used as a dissimilarity measure. The mean rate of CO_2 fixation and respiration, mean water table level, species richness and total vegetation cover were used as environmental variables. They were fitted as vectors of maximum correlation in the ordination spaces (Minchin 1987). A Monte-Carlo test was used for testing the significance of the correlations. No transformations were made to the data.

Dependence of respiration on the environmental variables was determined with a linear least square regression analysis for each sample plot using the SYSTAT-software package (SYSTAT 1992).

The differences in the respiration rates between the sample plots were compared using an analysis of covariance with respiration rate as the dependent variable, sample plot as the factor and soil temperature at 5 cm depth as the covariate. Following the results of the analysis of covariance, the similarity of a sample plot's mean respiration rates were tested using Tukey's pairwise comparison. Analysis of covariance and Tukey's pairwise comparison were done with the SYSTAT-software package (SYSTAT 1992).

RESULTS

Vegetation

A total of 20 plant species were observed on the sample plots and the number of species ranged from 2 to 13 in a single sample plot (Table 1). *Eriophorum vaginatum* tussocks in sample plots 3 and 12 were mature and without bryophyte cover. They belonged to tussock class II (*sensu* Fetcher and Shaver 1982). Tussocks in sample plots 1 and 13 were degenerated, covered and surrounded by bryophytes thus belonging to tussock classes IV and VI.

A two-dimensional solution of GNMDS was sufficient to describe the variation of vegetation in the data. The sample plots of almost non-vegetated surfaces (sample plots 2, 4, 5, 6, 8 and 9) were separated from the sample plots of more densely vegetated surfaces (sample plots 1, 3, 7,

Table 1. The vegetation and water table level (6.7.–24.8. 1994) of sample plots in the abandoned harvested peatland at Aitoneva.

Taulukko 1. Käytöstä poistetulla turvetuotantokentällä, Aitonevalla, sijaitsevien näytealojen kasvillisuus ja pohjaveden pinnan taso 6.7.–24.8. 1994.

Sample plot	Projection cover of plant species, %		Mean water table, cm	Range of water table level, cm
1	70.00	*Polytrichum strictum*	44.1	30.0–51.0
	25.00	*Eriophorum vaginatum*, dead tussock		
	0.50	*Betula pendula*		
	0.20	*Polytrichastrum longisetum*		
	0.02	*Betula* sp.		
	0.02	*Drosera rotundifolia*		
2	1.00	*Dicranella cerviculata*	32.3	30.0–35.0
	0.04	*Eriophorum vaginatum*, seedling		
	0.01	*Betula* sp.		
	0.01	*Pohlia nutans*		
3	95.00	*Eriophorum vaginatum*, living tussock	33.6	30.0–45.0
	10.00	*Eriophorum vaginatum*, dead tussock		
	9.00	*Dicranella cerviculata*		
	0.02	*Betula* sp.		
	0.02	*Pohlia nutans*		
4	0.03	*Eriophorum vaginatum*, seedling	43.1	42.0–44.0
	0.01	*Betula* sp.		
5	1.00	*Eriophorum vaginatum*, seedling	33.6	32.0–36.5
	0.01	*Betula* sp.		
6	10.00	*Dicranella cerviculata*	23.6	15.0–28.0
	1.00	*Eriphorum vaginatum*, seedling		
	0.01	*Betula* sp.		
	0.01	*Drosera rotundifolia*		
7	10.00	*Eriophorum angustifolium*	26.5	16.0–32.0
	5.00	*Dicranella cerviculata*		
	1.50	*Polytrichum strictum*		
	0.50	*Polytrichastrum longisetum*		
	0.40	*Carex rostrata*		
	0.03	*Betula* sp.		
	0.03	*Eriophorum vaginatum*, seedling		
	0.01	*Drosera rotundifolia*		
8	15.00	*Dicranella cerviculata*	25.3	16.0–29.0
	0.10	*Eriophorum vaginatum*, seedling		
	0.05	*Polytrichum strictum*		
	0.02	*Betula* sp.		
9	0.01	*Eriophorum vaginatum*, seedling	44.1	30.0–51.0
	0.01	*Pinus sylvestris*		
10	80.00	*Eriophorum vaginatum*, living tussock	44.8	43.0–44.8
	10.00	*Eriophorum vaginatum*, dead tussock		
	0.01	*Eriophorum vaginatum*, seedling		
11	40.00	*Eriophorum vaginatum*, living tussock	26.2	24.0–33.0
	40.00	*Eriophorum vaginatum*, dead tussock		
	9.00	*Sphagnum russowii*		
	7.00	*Sphagnum angustifolium*		

(Contnd.)

Table 1. contnd.

Sample plot	Projection cover of plant species, %		Mean water table, cm	Range of water table level, cm
	3.00	*Warnstorfia fluitans*		
	2.00	*Polytrichastrum longisetum*		
	1.00	*Polytrichum strictum*		
	0.50	*Dicranum polysetum*		
	0.50	*Pleurozium schreberi*		
	0.10	*Cladonia* spp.		
	0.03	*Dryopteris carthusiana*		
	0.02	*Bryum* sp.		
	0.01	*Aulacomnium palustre*		
	0.01	*Betula* sp.		

10 and 11). Sample plot 7, with a sparse *Eriophorum angustifolium* dominated vegetation, was nearer to almost non-vegetated sample plots than the more densely vegetated ones. Sample plots dominated by *Dicranella cerviculata* (sample plots 2, 6 and 8) were separated from the sample plots of almost bare peat surfaces (sample plots 4, 5 and 9) (Fig. 2).

The main variation in vegetation was related to the degree of colonization (total cover). The CO_2 fixation and respiration rate increased with increasing vegetation cover. The second dimension in vegetation variation was connected with the water table level. Sample plots 7, 6 and 8 had the highest mean water table level (Table 1), and they were separated from the other sample plots in the second dimension (Fig. 2). The correlations and p-values of the environmental variables are shown in Table 2.

There were more seedlings of *Pinus sylvestris* and *Eriophorum vaginatum* in the almost non-vegetated sample plots than in more densely vegetated sample plots. The majority of the species showed their graetest abundance in sample plots which were dominated by an *Eriophorum vaginatum* tussock, e.g. *Polytrichastum longisetum* and *Polytrichum strictum*. Mire species, such as *Sphagnum angustifolium*, *S. russowii* and *Warnstofia fluitans* were observed only in sample plot 11 with a degenerated *Eriophorum vaginatum* tussock. *Dicranella cerviculata*, *Carex rostrata*, *Drosera rotundifolia* and *Eriophorum angustifolium* were most abundant in sample plots with the highest mean water table level (Fig. 3).

CO_2 balance

The CO_2 fixation rate varied between –56 and 1869 mg m^{-2} h^{-1} under solar irradiation (PAR) of between 160 and 1020 µmol m^{-2} s^{-1}. The CO_2 fixation rate increased with increasing total vegetation cover, with the exception that the highest carbon fixation was measured in sample plots dominated by a mature *Eriophorum vaginatum* tussock (Fig. 4, see also Fig. 2).

The respiration rate varied between 34 and 1168 mg CO_2 m^{-2} h^{-1} and soil temperatures varied between 8 and 22°C. The respiration rate rose with increasing total vegetation cover (Fig. 2). The mean respiration rate was about three times higher in the sample plots dominated by a mature *Eriophorum vaginatum* tussock (sample plots 3 and 10) than the mean respiration rate in the sample plots with almost bare peat surfaces (sample plots 4, 5 and 9) (Table 3). Tukey's pairwise comparisons showed no significant differences within the more densely vegetated sample plots in their mean respiration rate, but they clearly differed from the almost non-vegetated ones. Like in GNMDS ordination, sample plot 7 with sparse *Eriophorum angustifolium*-dominated vegetation and sample plot 8 with *Dicranella cerviculata* were intermediate between almost non-vegetated and more densely vegetated sample plots (Table 4).

The mean CO_2 balance was +659 and +234 CO_2 m^{-2} h^{-1} in sample plots with a mature *Eriophorum vaginatum* tussock (sample plots 3 and 10). In sample plot 11 with a degenerated

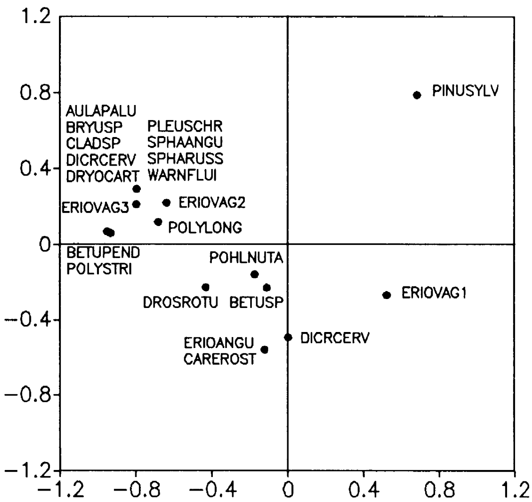


Fig. 3. GNMDS ordination diagram of plant species in the abandoned harvested peatland at Aitoneva. Plant species: AULAPALU = *Aulacomnium palustre*, BETUPEND = *Betula pendula*, BETUSP = *Betula* sp. seedling, BRYUSP = *Bryum* sp., CAREROST = *Carex rostrata*, CLADSPP = *Cladonia* spp., DICRCERV = *Dicranella cerviculata*, DICRPOLY = *Dicranum polysetum*, DROSROTU = *Drosera rotundifolia*, DRYOCART = *Dryopteris carthusiana*, ERIOANGU = *Eriophorum angustifolium*, ERIOVAG1 = *Eriophorum vaginatum* seedling, ERIOVAG2 = *Eriophorum vaginatum*, living tussock, ERIOVAG3 = *Eriophorum vaginatum*, dead tussock, PINUSYLV = *Pinus sylvestris*, PLEUSCHR = *Pleurozium schreberi*, POHLNUTA = *Pohlia nutans*, POLYLONG = *Polytrichastrum longisetum*, POLYSTRI = *Polytrichum strictum*, SPAHANGU = *Sphagnum angustifolium*, SPHARUSS = *Sphagnum russowii*, WARNFLUI = *Warnstorfia fluitans*.

Kuva 3. GNMDS-ordinaatiodiagrammi käytöstä poistetun Aitonevan turvetuotantokentän kasvilajeista. Kasvilajit kuten yllä.

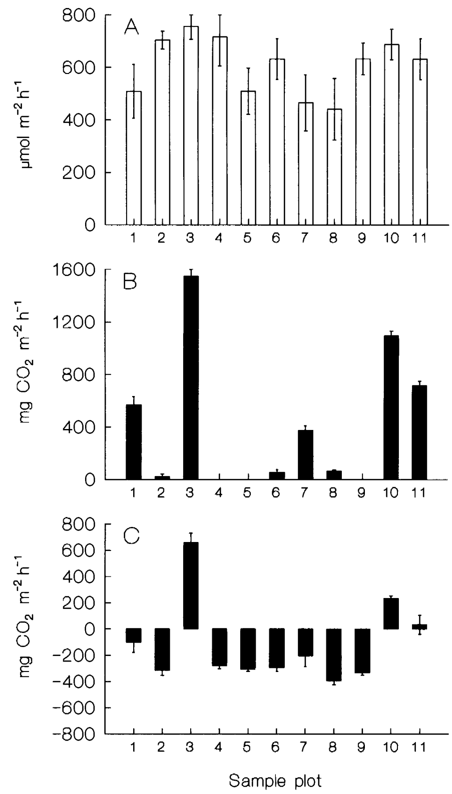


Fig. 4. Mean irradiation during measurements (A), mean CO_2 fixation rate (B) and mean CO_2 balance (C) of different surfaces (sample plots) in an abandoned harvested peatland according to 6 measurements during July–September.

Kuva 4. Mittausten aikainen keskimääräinen hajasäteily (A), yhteytyksessä sitoutunut hiilidioksidi (B) ja CO_2-tase (C) käytöstä vapautuneen turvetuotantokentän erilaisilla pinnoilla (näytealat) kuuden heinä–syyskuussa tehdyn mittauksen mukaan.

Eriophorum vaginatum tussock surrounded and covered by bryophytes (tussock class IV, Fetcher and Shaver 1982), the balance was 34 mg CO_2 m^{-2} h^{-1}. In all the other sample plots the respiration was higher than the CO_2 fixation and the mean CO_2 balance was negative (Fig. 4).

The most important abiotic factor within the measured variables affecting the respiration rate was the soil temperature at 5 cm depth. The relationship was linear in the range of soil temperatures prevailing during the measurements (Fig. 5). The effect of water table level was small; water table level did not correlate significantly with CO_2 fixation (r = +0.015) or respiration (r = –0.043).

DISCUSSION

Slow plant colonization, also observed in this

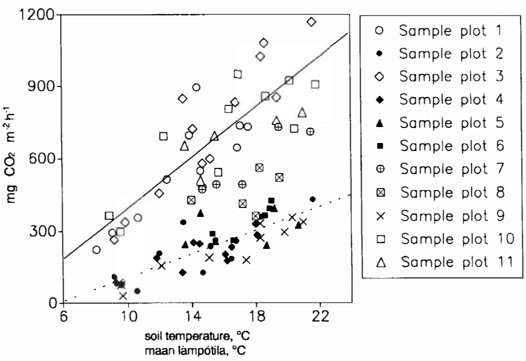


Fig. 5. Respiration rate of different surfaces of an abandoned harvested peatland site in relation to soil temperature in 5 cm depth. The dashed line shows the regression for almost non-vegetated and the solid line that for more densely vegetated sample plots. Sample plots 7 and 8 which belong partly to both groups according to Tukey's pairwise comparison were not included in the regressions. See Table 1 for sample plot vegetation description.

Kuva 5. Käytöstä poistetun turvetuotantoalueen erilaisilta pinnoilta hengityksessä vapautuvan hiilidioksidin määrä suhteessa maan lämpötilaan 5 cm syvyydessä. Katkoviiva esittää regression lähes kasvittomille näytealoille ja yhtenäinen viiva kasvipeitteisille. Näytealoja 7 ja 8, jotka Tukeyn testin mukaan kuuluvat kumpaankin ryhmään, ei ole otettu mukaan regressioihin. Näytealojen kasvillisuuden kuvaus Taulukossa 1.

study, has been found to be characteristic of abandoned harvested peatlands (Curran and MacNaeidhe 1986, Salonen 1992). The dominance of *Eriophorum vaginatum* is typical of abandoned harvested peatlands with thick peat layer (Salonen 1992).

The most important factor influencing the CO_2 balance was the presence and nature of the vegetation. The rates of CO_2 fixation and respiration seemed to be dependent on the composition of the vegetation and especially on the different growth form of plants.

The CO_2 fixation was highest in sample plots dominated by a mature *Eriophorum vaginatum* tussock. It has been suggested that efficient CO_2 fixation by *Eriophorum vaginatum* is a consequence of the uniform distribution of chlorophyll over the leaf and the presence of an intensive lacunar system throughout the mesophyll which provides efficient CO_2 diffusion into all parts of the leaf (Kummerow et al. 1988). *Eriophorum* species have a relatively deep root system (Metsävainio 1931) and hence can imbibe water during dry periods when the water level is low. The efficient CO_2 fixation of *Eriophorum vaginatum*-dominated vegetation may partly be a consequence of this efficient water uptake. This suggestion is supported by the fact that sparse

Table 2. The maximum correlations of environment factors with the main variation in vegetation of the abandoned harvested peatland at Aitoneva. For GNMDS ordination diagram, see Fig. 2.

Taulukko 2. Ympäristömuuttujien suurin mahdollinen korrelaatio käytöstä vapautuneen turvetuotantoalueen kasvillisuuden päävaihtelun kanssa. GNMDS-ordinaatiodiagrammi, ks. Kuva 2.

Variable	n	Max. r	P
Mean respiration rate	11	0.9006	0.000***
Mean CO_2 fixation rate	11	0.8160	0.000***
Mean water table	11	0.7951	0.000***
Species richness	11	0.6472	0.12
Vegetation total cover	11	0.8972	0.000***

Table 3. The mean respiration rate of samp le plots of an abandoned harvested peatland, adjusted to a soil temperature (at depth 5 cm) of +15.7°C by linear regression. For description of the vegetation of the sample plots, see Table 1.

Taulukko 3. Lineaarisen regression avulla +15.7°C maan lämpötilaan (syvyys 5 cm) sovitettu hengityksessä vapautuneen hiilidioksidin keskimäärä käytöstä vapautuneen turvetuotantoalueen näytealoilta. Näytealojen kasvillisuuden kuvaus, ks. Taulukko 1.

Sample plot	Mean respiration mg CO_2 $m^{-2}h^{-1}$	S.E.	n
1	647.6	35.2	10
2	263.2	32.9	11
3	729.5	30.2	13
4	253.9	33.1	11
5	255.1	44.6	6
6	270.6	49.1	5
7	500.8	49.1	5
8	390.7	49.0	5
9	205.2	34.4	10
10	690.5	34.4	10
11	638.4	48.8	5

Eriophorum angustifolium-dominated vegetation also showed relatively efficient fixation. The sample plots where bryophytes had colonized old or dead tussocks and their surroundings exhibited lower fixation rates than the plots dominated by a mature *Eriophorum vaginatum* tussock, although they did not differ markedly from each other according to the total vegetation cover.

The higher respiration rate in the more densely vegetated sample plots is partly explained by the respiration of the plants. However, the higher respiration rate may also be a consequence of decomposition of new carbon introduced into the soil as a result of fixation by living vegetation. The amount of easily decomposable organic matter restricts microbial activity and an increase in the amount of more easily decomposable material causes a rise in respiration rate (Waksman and Purvis 1932, Chase and Baker 1954, Salonius 1972). An addition of easily decomposable organic material to soil can also increase the decomposition of already existing organic matter within the soil (Sørensen 1974). The exudation of organic material from the plant roots to the soil has been found to have this 'priming effect'(Coleman 1976).

Under the environmental conditions prevailing in the abandoned harvested peatland of Aitoneva, *Eriophorum vaginatum* seems to have the most succesful growth form. Although the surfaces dominated by *Eriophorum vaginatum* had the highest respiration rate, they were also the most effective fixers of carbon and the only ones having a positive CO_2 balance.

Respiration rate has been found to be related to water table level in natural ecosystems (eg. Billings et al. 1982, Kim and Verma 1992). Despite the fact that sample plots in this study differed according to their mean water table level, differences in respiration rates between sample plots were not connected with the mean water table level (Fig. 2). Also, the variation of respiration rate within a single sample plot was not connected with the fluctuation of the water table. It is probable that the water table level, which varied between 15 and 51 cm in all the sample plots during the measurements, was sufficiently deep that the differences had no effect on the respiration rate.

Dependence of respiration rate on temperature has been found in peatland ecosystems (Silvola and Heikkinen 1979, Svensson 1980, Silvola et al. 1985, Kim and Verma 1992) and in mineral soil ecosystems (Svensson et al. 1975). The soil temperature influences the activity of the soil decomposers, and thereby soil respiration. Correlation between the soil temperature and the respiration rate is influenced not only by biological activity, but also by the diffusion rate (Schlesinger 1977). The increase in respiration rate with

Table 4. Matrix of Tukey's pairwise comparison probabilities for sample plot respiration rate adjusted to a soil temperature of 15.7°C.

Taulukko 4. Matriisi Tukeyn testin parittaisten vertailujen p-arvoista.Testissä on verrattu näytealojen hengityksessä vapautuneen hiilidioksidin määrää, joka on regressioiden avulla sovitettu 15.7°C maan lämpötilaan.

Sample plot	1	2	3	4	5	6	7	8	9	10	11
1	1.000										
2	0.000	1.000									
3	0.791	0.000	1.000								
4	0.000	1.000	0.000	1.000							
5	0.000	1.000	0.000	1.000	1.000						
6	0.000	1.000	0.000	1.000	1.000	1.000					
7	0.383	0.006	0.007	0.004	0.015	0.046	1.000				
8	0.003	0.545	0.000	0.447	0.608	0.806	0.877	1.000			
9	0.000	0.979	0.000	0.995	0.998	0.990	0.000	0.086	1.000		
10	0.999	0.000	0.999	0.000	0.000	0.000	0.073	0.000	0.000	1.000	
11	1.000	0.000	0.884	0.000	0.000	0.000	0.649	0.022	0.000	0.998	1.000

increasing temperature was steeper in the sample plots with more dense vegetation and hence recently bound carbon than in the almost non-vegetated sample plots. It is suggested that microbiological processes play a major role in the temperature dependence of the respiration rate.

Biological processes follow exponential functions in relation to temperature, and this exponential relationship has also been found between soil respiration and temperature in most of the studies concerning soil respiration (Svensson et al. 1975). In this study, the relationship was linear. During the respiration measurements the peat temperature varied between 8.1 and 21.8°C. Because the increase in respiration rate is different at lower temperatures (Svensson 1980), it seems probable that the relationship would have been found to be exponential in this study over a wider temperature range. For this reason, the measurements should be extended into cooler seasons.

During the long measurement period inherent in the aluminium chamber method, the CO_2 content of air within the chamber may become partly saturated, lowering the rate of CO_2 diffusion. This could cause systematically lower respiration rate estimations than those measured with the plastic chamber which was vented to maintain pressure equilibrium. On the other hand, sampling of gas from the closed aluminium chamber may cause low pressure inside the chamber and accelerate CO_2 efflux from the soil.

The mean respiration rates of almost bare peat surfaces measured in this study were comparable with those that Silvola and Alm (1992) measured in a peat production field. It is possible that the respiration rate of bare peat surfaces is quite similar over large areas of harvested peatlands. Our data indicates that the vegetation succession changes the CO_2 balance of an abandoned harvested peatland and that CO_2 balance is closely connected with the vegetation composition and the different growth form of plants. Salonen (1992) observed that abandoned harvested peatlands in an early successional stage can differ totally in the species composition and vegetation biomass. No *Sphagnum* species were found in his study sites. Studies made in old abandoned harvested peatlands show that fields with a high water table level have been colonized by *Sphagnum* species (Lainevesi and Tolonen 1985, Tolonen et al. 1985, Roderfeld et al. 1994). Because of the variation in the colonization stage of the abandoned harvested peatlands and the large spatial variation of vegetation in a single abandoned harvested peatland, it seems that we need to know more about the vegetation succession of abandoned harvested peatlands before it is possible to generalize the CO_2 balance results from vegetated surfaces.

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REFERENCES

Ahti, T. 1981. Jäkälien määritysopas. Helsingin yliopiston kasvitieteen laitoksen monisteita 72: 1–71.

Ahti, T., Hämet-Ahti, L. & Jalas, J. 1968. Vegetation zones and their sections in northwestern Europe. Annales Botanici Fennici 5: 169–211.

Billings, W. D., Luken, J. O., Mortensen, D. A. & Peterson, K. M. 1982. Arctic tundra: A source or sink for atmospheric carbon dioxide in a changing environment. Oecologia 53: 7–11.

Chase, F. E. & Baker, G. 1954. A comparison of microbial activity in Ontario forest soil under pine, hemlock and maple cover. Canadian Journal of Microbiology 1: 45–54.

Coleman, D. C. 1976. A review of root production processes and their influence on soil biota in terrestrial ecosystems. In: Andersson, J. M. and Macfadyen, A. (eds.), The role of terrestrial and aquatic organisms in decomposition processes, pp. 417–434. Blackwell, Oxford.

Curran, P. L. & MacNaeidhe, F. S. 1986. Weed invasion of milled-over bog. Weed Research 26: 45–50.

Ferm, A. & Kaunisto, S. Luontaisesti syntyneiden koivumetsiköiden maanpäällinen lehdetön biomassatuotos entisellä turpeennostoalueella Kihniön Aitonevalla (Summary: Above-ground biomass production of naturally generated birch stands in peat cut-over area at Aitoneva). Folia Forestalia 558: 1–32.

Fetcher, N. & Shaver, G. R. 1982. Growth and tillering patterns within tussocks of *Eriophorum vaginatum*. Holarctic Ecology 5: 180–186.

Hytönen, J. 1994. Effect of fertilizer application rate on nutrient status and biomass production in short-rotation plantations of willows on cut-away peatland areas. Suo 45: 65–77.

Hämet-Ahti, L., Suominen, J., Ulvinen, T., Uotila, P. & Vuokko, S. (eds.) 1986. Retkeilykasvio. 3. p. Suomen Luonnonsuojelun Tuki Oy. Helsinki. 598 p.

Kaunisto, S. 1979. Alustavia tuloksia palaturpeen kuivatuskentän ja suonpohjan metsityksestä (Summary: Preliminary results on afforestation of sod peat drying and peat cut-over areas). Folia Forestalia 404: 1–14.

Kim, J. & Verma, S. B. 1992. Soil surface CO_2 flux in Minnesota peatland. Biogeochemistry 18: 37–51.

Koponen, T., Isoviita, P. & Lammes, T. 1977. The bryophytes of Finland: An annotated checklist. Flora Fennica 6: 1–77.

Kummerow, J., Mills, J. N., Ellis, B. & Kummerow, A. 1988. Growth dynamics of cotton-grass (*Eriophorum vaginatum*). Canadian Journal of Botany 66: 253–256.

Lainevesi, S. & Tolonen, K. 1985. Korjuun jälkeisestä turpeen kasvusta ja suokasvillisuuden palautumisesta. Turveteollisuus 3: 52–55.

Lappalainen, E., Järvinen, T., Kemppainen, E., Leiviskä, V., Reinikainen, O., Fagernäs, L., Pihlaja, K., Saharinen, M., Hänninen, K. & Kaunisto, S. 1992. Turpeen moninaiskäyttö. Nykytilanne, markkinanäkymät sekä tutkimus- ja kehitystarpeet. Osa II. Osaraportit 1–9. Kauppa- ja teollisuusministeriö. Energiaosasto. Katsauksia B 116: 1–167.

Lumme, I., Tikkanen, E., Huusko, A. & Kiukaanniemi, E. 1984. Pajujen lyhytkiertoviljelyn biologiasta ja viljelyn kannattavuudesta turpeentuotannosta poistuneella suolla Limingan Hirvinevalla (Summary: On the biology and economical profitability of willow biomass production on an abandoned peat production area). Oulun yliopisto. Pohjois-Suomen tutkimuslaitos. C 54: 1–79.

Martikainen, P. J., Nykänen, H., Crill, P. & Silvola, J. 1992. The effect of changing water table on methane fluxes in two drained peat soils. Suo 43: 237–240.

Metsävainio, K. 1931. Untersuchunden Über das Wurzelsystem der Moorpflanzen. Annales Botanici Societatis Zoologicæ-Botanicæ Fennicæ Vanamo 1: 1–147.

Metsävainio, K. 1931. Untersuchunden Über das Wurzelsystem der Moorpflanzen. Annales Botanici Societatis Zoologicæ-Botanicæ Fennicæ Vanamo 1: 1–147.

Minchin, P. 1987. An evaluation of the relative robustness of techniques for ecological ordination. Vegetatio 69: 89–107.

Minchin, P. 1991. DECODA. Database for ecological community data. Version 2.04. Australian National University.

Nykänen, H., Alm, J., Lång, K., Silvola, J. & Martikainen, P. J. 1995. Emissions of CH_4, N_2O and CO_2 from a virgin fen and a fen drained for grassland in Finland. J. Biogeogr. 22: 1149–1155.

Roderfeld, H., Vasander, H. & Tolonen, K. 1994. Differences in carbon accumulation of two cut-over peatland. In: Kanninen, M. & Heikiñheimo, P. (eds.), The Finnish Research Programme on Climate Change. Second Progress Report. Publications of the Academy of Finland 1/94: 315–320.

Salonen, V. 1992. Plant colonization of harvested peat surfaces. Biological Research Reports from the University of Jyväskylä 29: 1–29.

Salonius, P. O. 1972. Microbiological responce to fertilizer treatments in organic forest soils. Soil Science 114: 12–19.

Schlesinger, W. H. 1977. Carbon balance in terrestrial detritus. Ann. Rev. Ecol. Syst. 8: 51–81.

Silvola, J. & Alm, J. 1992. Dynamics of greenhouse gases in virgin and managed peatlands. In: Kanninen, M. & Anttila P. (eds.) The Finnish Research Programme on Climate Change. Progress report. Publications of Academy of Finland 3/92: 193–198.

Silvola, J. & Heikkinen, S. 1979. CO_2 exchange in the *Empetrum nigrum-Sphagnum fuscum* community. Oecologia 37: 273–283.

Silvola, J., Välijoki, J. & Aaltonen, H. 1985. Effect of draining and fertilization on soils respiration at three ameliorated peatland sites. Acta Forestalia Fennica 191: 1–32.

Suoninen, A. 1982. Peat production. In: Laine, J. (ed.), Peatlands and their utilization in Finland, pp. 67–88. Finnish Peatland Society, Helsinki.

Svensson, B. H. 1980. Carbon dioxide and methane fluxes from the ombrotrofic parts of a subarctic mire. In: Sonesson, M. (ed.), Ecology of subarctic mire. Ecological Bulletins (Stockholm) 30: 235–250.

Svensson, B. H., Veum, A. K. & Kjelvik, S. 1975. Carbon losses from tundra soils. In: Wielgolaski, F. E. (ed.), Fennoscandian tundra ecosystems, pp. 279–286. Springer-Verlag, Berlin-Heidelberg-New York.

SYSTAT 1992. SYSTAT for Windows. Statistics. Version 5 edition. SYSTAT, Inc. Evanston, IL.

Sørensen, L. H. 1974. Rate of decomposition of organic matter in soil as influenced by repeated air drying-rewetting and repeated additions of organic material. Soil Biol. Biochem 6: 287–292.

Taustatietoa turvesoiden jälkikäytöstä. 1991. Vapo Oy, Jyväskylä. 8 p.

Tolonen, K., Davis, R. B. & Widoff, L. S. 1985. Peat accumulation rates in selected Maine peat deposits. Maine Geological Survey Bulletin 33: 1–97.

Waksman, S. A. & Purvis, E. R. 1932. The microbiological population of peat. Soil Science 34: 95–113.

TIIVISTELMÄ:

Kasvillisuus ja CO_2-tase käytöstä vapautuneella turvetuotantoalueella Kihniön Aitonevalla

Tutkimuksessa selvitettiin käytöstä vapautuneen turvetuotantokentän kasvillisuutta ja CO_2-tasetta mittaamalla erilaisten kasvillisuuspintojen hiilidioksidinvaihtoa ja siihen vaikuttavia ympäristötekijöitä.

Tutkimusalueena oli Kihniön Aitonevalla (62°12′N, 23°18′E) sijaitseva turvetuotantokenttä, jolta turpeen korjuu on lopetettu vuonna 1975. Kenttä on kooltaan 3,6 ha. Kentälle sijoitettiin 11 näytealaa kasvillisuudeltaan erilaisille pinnoille. Näytealat olivat kooltaan 0.36 m^2 ja ne oli ympäröity alumiinikauluksin. Näytealojen kasvillisuus kuvattiin arvioimalla kunkin kasvilajin projektiopeittävyys. CO_2-virtauksia mitattiin kahdella eri kammiomenetelmällä kesä–syyskuun aikana (Kuva 1). Ensimmäisellä menetelmällä voitiin mitata ainoastaan hengityksessä vapautuvan hiilidioksidin määrää. Alumiinikammion ilmasta otettiin näytteet, joiden CO_2-pitoisuus määritettiin laboratoriossa kaasukromatografilla. Toisessa menetelmässä voitiin mitata sekä hengityksessä vapautuvan että yhteytyksessä sitoutuvan hiilidioksidin määrää. Läpinäkyvän muovikammion ilman hiilidioksidipitoisuus mitattiin kannettavalla infrapunakaasuanalysaattorilla. Hengityksessä vapautuvan ja yhteytyksessä sitoutuvan hiilidioksidin määrä (hengitys- ja yhteytysaktiivisuus) laskettiin kammioiden ilman CO_2-pitoisuuden lineaarisena muutoksena ajan funktiona.

Kasvillisuuden vaihtelun ja kasvillisuuden ja CO_2-taseen välisen suhteen tutkimiseksi näytealojen kasvillisuustiedot analysoitiin globaalisella ei-metrisellä moniulotteisella skaalauksella (GNMDS). Hengitysaktiivisuuden suhdetta ympäristötekijöihin analysoitiin lineaarisella regressioanalyysillä. Yhtälöiden sovittamisessa käytettiin pienimmän neliösumman menetelmää. Näytealojen välisiä eroja verrattiin kovarianssianalyysiä käyttäen. Kovariaattina käytettiin maan lämpötilaa 5 cm syvyydessä, faktorina näytealaa ja selitettävänä muuttujana hengityksessä vapautuvan hiilidioksidin määrää.

Näytealoilta tavattiin ainostaan 20 eri kasvilajia ja paljaat turvepinnat olivat vallitsevia. Kasvillisuuden valtalaji oli tupasvilla (Taulukko 1). GNMDS:n mukaan kasvillisuuden päävaihtelu kytkeytyi läheisesti kasvillisuuden kolonisaatiovaiheeseen (kasvillisuuden kokonaispeittävyyteen). Toinen kasvillisuuden vaihtelusuunta liittyi pohjaveden pinnan tasoon (Kuva 2). Hengitys- ja yhteytysaktiivisuus korreloivat voimakkaasti kasvillisuuden vaihtelun kanssa (Kuva 2, Taulukko 2).

Yhteytyksessä sitoutuvan hiilidioksidin määrä vaihteli välillä –56–1869 mg CO2 m^{-2} h^{-1}. Mittausten aikana hajasäteilyn määrä oli 160–1020 µmol neliömetrille sekunnissa. Yhteytysaktiivisuus kasvoi kasvillisuuden kokonaispeittävyyden kasvaessa. Tehokkainta yhteytys oli niillä näytealoilla, joilla kasvoi elinvoimainen tupasvillamätäs (Kuva 4).

Hengityksessä vapautuvan hiilidioksidin määrä vaihteli välillä 34–1168 mg CO_2 m^{-2} h^{-1}. Mittausten aikana turpeen lämpötila (–5 cm) oli välillä 8–22°C. Hengitysaktiivisuus kasvoi kasvillisuuden kokonaispeittävyyden kasvaessa ja oli tupasvillaisilla näytealoilla lähes kolminkertainen kasvipeitteettömiin näytealoihin verrattuna (Taulukko 3). Tukeyn testi erotti kasvipeitteiset ja lähes kasvipeitteettömät näytealat toisistaan niiden keskimääräisen hengityksessä vapautuvan hiilidioksidin määrän perusteella (Taulukko 4)

Ainoastaan niillä näytealoilla, joilla kasvoi tupasvillamätäs, yhteytyksessä sitoutuneen hiilidioksidin määrä oli suurempi kuin hengityksessä vapautuneen. Kaikilla muilla näytealoilla CO_2-tase oli negatiivinen (Kuva 4).

Näytealojen väliset hengitysaktiivisuuden erot eivät olleet sidoksissa pohjaveden pinnan tasoon, vaikka näytealat erosivat toisistaan pohjaveden pinnan tason suhteen (Kuva 2). Pohjaveden pinnan tason vaihtelu ei selittänyt näytealan sisäistä hengitysaktiivisuuden vaihtelua.

Merkittävin hengitysaktiivisuuteen vaikuttava abioottinen tekijä oli maan lämpötila 5 cm syvyydessä. Hengityksen ja lämpötilan välinen suhde oli lineaarinen mitatulla lämpötilavälillä 8.1 ja 21.8°C (Kuva 5).

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