



Optimising carbon sinks in restored peatlands

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Summary

Cutaway peatlands are net sources of carbon (C) to the atmosphere as the residual peat gradually decomposes. The release of C to the atmosphere can be stopped by rewetting. Further, the re-establishment of *Sphagnum* and sedge species may lead to the recovery of the C sink. The role of sedges in the C balance is slightly two-sided. As well as being large sinks of CO₂, sedges also promote high CH₄ emissions via their aerenchymatic tissues. As high water levels promote high CH₄ emissions, lowering of the water levels has sometimes been suggested as an option for minimising the CH₄ emissions from restored peatlands. On the other hand, the photosynthetic activity of the plants will decrease in low water levels. We measured the gas exchange of three sedge species (*Eriophorum vaginatum*, *E. angustifolium* and *Carex rostrata*) and a moss *Sphagnum fallax* in an experimental site where the water levels were regulated. Our results showed that C sinks in restored peatlands may be optimised by adjusting the water levels. High water levels close to the peat surface were found to be optimal for all the studied plant species and, in terms of GWP, the sedge plots even contributed to a net cooling effect.

Introduction

In pristine mires the high water table leads to a situation where the primary production exceeds the rate of decomposition; therefore they accumulate peat and act as a store for atmospheric carbon (C). In many countries the accumulated peat is used for horticultural purposes and for energy production. After cessation of peat harvesting the remaining cutaway peatlands are net sources of C to the atmosphere as the residual peat gradually decomposes (Nykänen, *et al.*, 1996; Tuittila *et al.*, 1999; Waddington *et al.*, 2002). The release of C to the atmosphere can be stopped by rewetting the cutaway peatland (Tuittila *et al.*, 1999; Waddington *et al.* 2002). Further, the re-establishment of *Sphagnum* and sedges after the restoration may lead to the recovery of the C sink.

The recovery of C sink function after restoration is not always self evident. Tuittila *et al.* (1999) and Bortoluzzi *et al.* (2006) found that the recovery of the C sink can be very fast and that the sinks may be greater than in pristine mires during the first years of restoration succession. In both of the previous studies, common cottongrass (*Eriophorum vaginatum*) had an important role in forming the C sinks. On the other hand, Marinier *et al.* (2004) for example, found that two Canadian *Eriophorum vaginatum* dominated rewetted peatlands still had little or no C accumulation to the peat surface. On top of that, the high measured CH₄ emissions from the *Eriophorum* tussocks in the previously mentioned sites further contributed to the GHG emissions.

Sedge species indeed have a two-sided role in the C balance, which makes them problematic from the climatic point of view. Compared to *Sphagnum* species, their pho-

tosynthesis may be very efficient providing large CO₂ sinks (Tuittila *et al.* 1999) but they also promote high CH₄ emissions via their aerenchymatic tissues. Additionally, high water levels also promote high CH₄ emissions. Since CH₄ is 22 times more effective as a greenhouse gas than CO₂, it has sometimes been suggested that lowering of the water levels would be an option to reduce CH₄ emissions from sedge dominated peatlands. This may not be wise since lowered water levels may also lead to reduced sedge photosynthesis, while the passive CH₄ emissions through the sedge aerenchyma would remain rather large.

In Europe, where most of the available peat of peat harvesting areas is usually utilised, the topography of the cutaway surfaces and the remaining fen peat properties favour natural re-establishment of sedge species which will sooner or later appear in rewetted areas. Sedge species also provide shelter for more slowly colonising *Sphagnum* species (Grosvernier *et al.*, 1995; Groeneweld and Rochefort, 2002). Therefore, it would seem reasonable to take advantage of the sedge colonisation instead of fighting against it.

We hypothesised that it would be possible to find water levels where sedge or *Sphagnum* photosynthesis and CH₄ emissions would compensate each other. Information on such compensation points for different peatland plant species could be used for optimising carbon sinks in restored cutaway peatlands. We studied this in an outdoor experiment in which we measured the CO₂ and CH₄ exchanges of three sedge species (*Eriophorum vaginatum*, *E. angustifolium* and *Carex rostrata*) and of a moss *Sphagnum fallax* at three different water levels.



Materials and methods

Study area and the experimental design

The study was carried out during the growing seasons 2004 and 2005 in Aitoneva (62°12'N, 23°18'E), in Kihniö, in southern Finland.

The experimental site was a gently sloping, south-facing peat terrace, which was built in a rewetted study area. In the spring of 2004, we collected 135 pieces of undisturbed peat monoliths from the study area using the corer described by Buttler *et al.* (1998). We removed the top layer of the highly oxidised peat before coring and used the corer to extract *ca.* 50 cm tall and 14 cm in diameter peat monoliths, which were then inserted in capped plastic tubes. The monoliths were inserted in three similar blocks, each having the same variation in water levels (hereafter WL), namely -10 cm, -20 cm and -30 cm from the peat surface. We collected young similar sized tillers of *Carex rostrata* and *Eriophorum angustifolium*, and planted four individuals in three replicate tubes (sample plots) in each water level treatment and in each block. For *Eriophorum vaginatum* we used eight individuals in the planting. Additionally, three replicate sets of five cm tall living *Sphagnum fallax* slices were inserted in the tubes. Three empty tubes in each block and treatment served as bare control plots. One replicate species in each block was equipped with a collar for gas measurements.

Gas exchange measurements

We determined instantaneous CO₂ and CH₄ exchange rates in the sample plots using the chamber methods described in Alm *et al.* (2007) with a modified chamber design.

We started our gas flux measurements in the mid-July 2004 and were able to continue the measurements until late August in 2005. We calculated carbon gas flux rates from the linear change of gas concentrations as a function of time (Alm *et al.*, 2007). Similarly to Alm *et al.* (2007), we follow the sign convention used traditionally by ecosystem ecologists. For the net ecosystem exchange of CO₂ (NEE) and CH₄, we use positive values when the ecosystem is gaining carbon from the atmosphere and negative when the ecosystem is losing.

CO₂ and CH₄ exchange models

We used the field data collected from July 2004 to August 2005 in the CO₂ and CH₄ model constructions. Models are adapted from and the response functions are discussed in more detail in Tuittila *et al.* (2004).

CO₂ and CH₄ balance

We used species specific model equations in the reconstruction of hourly gross photosynthesis (P_G), ecosystem respiration (R_E) values and CH₄ emissions for each of the measured sample plots over the growing season. The equations were integrated with continuous weather data from Hyytiälä weather station, 100 km east of the study site, from the beginning of June to the end of September 2005. We calculated NEE as the difference between P_G and R_E. The sum of the hourly NEE and CH₄ values represented the seasonal balance.

Water level effect on the species' carbon sink strength

The reconstructed seasonal CO₂, CH₄ and total C balances were used to estimate the species' carbon sink strength. This was described by applying a polynomial response between the mean WL of the sample plots and the reconstructed balances. This was repeated separately for each species.

Results and discussion

All the studied sample plots except *Eriophorum angustifolium* acted as sources of C at low water levels. *Carex rostrata* and *E. vaginatum* turned into sinks of C between -25 to -15 cm from the surface, but the *Sphagnum* plots were never able to turn into sinks. The optimum water level for photosynthesis seemed to be quite close to the peat surface for all the studied species.

As expected, the CH₄ emissions were highest in the sedge plots. The emissions were rather high even at low water levels and they also increased at high water levels. The emissions from *Sphagnum* and control plots were constantly small. Quite interestingly, the rate of CH₄ emissions did not seem to increase with the same speed along the rising water levels as did that of the photosynthesis.

Of the studied species *Carex rostrata* was most efficient in forming a C sink. *Eriophorum angustifolium* and *E. vaginatum* turned into sinks at little higher water levels (Table 1). The poor success of *E. vaginatum* at the low water levels was slightly surprising but is, in fact, in line with the observations of Marinier *et al.* (2004) where the water levels were also quite low. In the studies of Tuittila *et al.* (1999) and Bortoluzzi *et al.* (2006), WL were on average higher, which probably explains the difference in their results. Another small surprise was the weak carbon sequestration of *Sphagnum fallax*, which may partly have resulted from a too poor and dry contact with the underlying peat. However, high water tables also decreased peat oxidation in *Sphagnum* and bare control plots.

Transforming the methane emissions into GWP equivalents (Table 1.) allowed us to estimate the theoretical effect of our experiment on the global warming. Even after this transformation, the sedge species had a net cooling effect at the water levels close to the peat surface.

Conclusions

Our study indicates that discriminating the sedge species in cutaway peatland restoration may not be a very good alternative, after all. On the contrary, sedges are more likely to speed up the restoration process and the formation of carbon sinks. However, our results show again how crucial it is to maintain high water levels in restored peatlands. This is a task that may be becoming more and more difficult due to the changing climate.

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Table 1. Total carbon (C_{TOT}) and Total carbon in GWP equivalents (C_{TOTeq}) in $g\ m^{-2}$ of the studied species at different water levels (WL). The acronyms for species are: EV, *Eriophorum vaginatum*; EA, *Eriophorum angustifolium*; CR, *Carex rostrata*; SF, *Sphagnum fallax* and Bare, bare peat.

WL	EV		EA		CR		SF		Bare	
	C_{TOT}	C_{TOTeq}								
-5	375	-83	658	202	531	131	-4	-37	-6	-7
-10	295	40	329	-142	562	161	-11	-43	-122	-124
-15	26	-113	99	-345	488	132	-20	-52	-189	-190
-20	-432	-543	-33	-404	309	43	-31	-63	-205	-207
-25	-1078	-1249	-68	-321	25	-107	-45	-77	-171	-173
-30	-1913	-2232	-4	-95	-364	-317	-61	-94	-87	-88

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