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IMPACT OF DRAINAGE AND RESTORATION ON VEGETATION AND CARBON GAS DYNAMICS IN CENTRAL EUROPEAN PEATLANDS.

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SUMMARY

We studied the impact of drainage and restoration by ditch blocking on different peatland plant communities and carbon gas dynamics in Šumava National Park, Czech Republic. Our results showed that total C balance was strongly linked to the existing plant communities which were the most important and reliable factor predicting carbon gas fluxes on studied peatlands. Drainage did not lead to a negative ecosystem C balance in all cases although it had significantly changed plant species composition in most areas. Original peatland species and functions appeared to be preserved in the less drained parts of the drained sites; those could facilitate future ecosystem restoration. Water regime restoration caused neither a significant change in plant composition nor any major changes, such as plant die-back or increased CH_4 emissions during the first growing season after the restoration measures.

KEY WORDS: CO_2, CH_4, drainage, restoration, plant community

INTRODUCTION

Natural peatlands play an important role in the global carbon (C) cycle as long-term sinks of atmospheric CO_2 and sources of methane (CH_4); at the landscape level, they contribute significantly to biodiversity. These natural functions are significantly altered by drainage, e.g., for forestry, agriculture or peat extraction. Drainage may turn peatlands from long-term sinks to sources of CO_2 (Moore and Dalva, 1993) while CH_4 emissions may decrease (Minkkinen et al., 2002). During the first decade of the 21st century, there has been an increasing focus on restoring disturbed peatlands and their C sink, biodiversity and flood control functions (Kimmel and Mander, 2010). Currently, peatland restoration is also implemented in the Bohemian Forest, Czech Republic, where almost 70% of peatlands have been affected by drainage. Therefore understanding is required on how drainage alters peatland vegetation and C sink functioning and how peatlands respond to rewetting.

The aim of this study was to quantify the variability and controls of vegetation and CO_2 gas dynamics in mountain peatlands planned for restoration. More specifically, we aimed to, (i) quantify the ecosystem potential to fix and release C (as CO_2 and CH_4), (ii) to estimate C balance for specific plant community types and, (iii) to evaluate the effect of drainage and restoration on ecosystem functioning. Mountain mires (bogs and fens) under different levels of alteration (pristine, drained and restored) were studied. We hypothesised that (1) drained sites were net sources of C due to increased soil respiration and changed vegetation structure, (2) a restored site had smaller C emissions to the atmosphere than a drained site belonging to the same peatland type and, (3) methane emissions were higher on restored than on pristine bogs because of increased input of organic substrate from dying vegetation.

MATERIAL AND METHODS

Three ombrotrophic bogs and two minerotrophic fens were chosen as sites representing the two main types of peatlands in the Bohemian Forest (Czech Republic) and they were affected by anthropogenic impacts to different extents: intact bog (BOG), drained bog (BOGD), restored bog (BOGR), intact fen (FEN) and drained fen (FEND).

Static closed chambers were used to measure CO_2 and CH_4 fluxes (Laine et al., 2009). On BOGD, FEND, BOGR sites, three sample plots were placed along the margins of ditches and three were placed in the wetter part farther away from the ditches. On BOG, three sample plots were located in wetter *Trichophorum* lawns and three in drier shrubby parts. On FEN, only four sample plots were used due to the homogenous vegetation structure of the entire site. CO_2 and CH_4 exchange measurements were carried out at two- to three-week intervals during the 2009 growing season. The net ecosystem exchange (NEE) was measured using a transparent plexiglass chamber and ecosystem respiration (R_{ECO}) was determined under darkened conditions. During measurements, the CO_2 concentration in the chamber headspace, photosynthetically active radiation (PAR) inside the chamber and chamber temperature (T) were recorded. CH_4 flux was measured on the same dates as the CO_2 exchange using closed opaque chambers and analysed in the laboratory using gas chromatograph.

The vascular green area (VGA) was measured according to Wilson et al. (2007). Water table (WT) and soil temperature (depth of 5, 10 and 20 cm) were measured simultaneously with the CO_2 and CH_4 flux measurements. The study sites were supported by two automatic meteorological stations located on BOGR and FEND.

Process-based non-linear regression models for the CO_2 exchange were constructed and parameterised individually for each gas exchange sample plot following Laine et al. (2009). The relationship between P_G (calculated as NEE+R_{ECO}) or R_{ECO} and environmental variables (WT, T, VGA, PAR) was determined and the combination of factors was tested to obtain an unbiased residual distribution. The equation for photosynthesis was: $P_G = P_{max} * PAR / (k + PAR) * VGA$, where P_{max} denotes the maximum light-saturated photosynthesis rate and the parameter k is equal to the PAR value at which the photosynthesis rate is half its maximum. Equation for ecosystem respirarion was: $R_{ECO} = \exp(c * T) + v * VGA$, where T denotes the temperature of air or soil and the parameters c and v are multipliers for temperature and VGA, respectively.

RESULTS

Based on vegetation composition and environmental variables (WT, pH, EC) altogether 10 plant community groups were identified. These reflected well the spatial variation characteristic in the mires (Table 1).

Table 1.

group	dominant species	n	water level	locality
flex-rostrata	*Sphagnum flexuosum, Carex rostrata, Carex nigra*	4	-7.2	FEN
girg-holcus	*Sphagnum girghensohnii, Holcus molis, Carex nigra*	3	-16.6	FEND
sedge-grass	*Carex nigra, C. brizoides, Deschampsia caespitosa, Nardus stricta*	3	-39.6	FEND
trich lawn	*Trichophorum cespitosum*	3	-2.9	BOG
low shrub	*Andromeda polifolia, Eriophorum vaginatum, Vaccinium uliginosum, Sphagnum rubellum*	3	-10.6	BOG
trich lawn	*Trichophorum cespitosum*	3	-9.8	BOGR
high shrub	*Vaccinium myrtillus, V. uliginosum, Sphagnum magellanicum, S. capillifolium*	3	-18.5	BOGR
high shrub	*Vaccinium myrtillus, V. uliginosum, Polytrichum strictum, Sphagnum magellanicum*	1	-53.1	BOGD
inter shrub	*Vaccinium uliginosum, Eriophorum vaginatum, Molinia caerulea, Calluna vulgaris, Polytrichum strictum*	3	-19.5	BOGD
molinia	*Molinia caerulea*	2	-24.2	BOGD

The measured net CO_2 exchange in the study plots varied between -600 and 800 mg CO_2 -C m^{-2} h^{-1}. The largest instantaneous CO_2 uptake fluxes were measured for BOGD molinia and FEND sedge-grasses groups, while the CO_2 fluxes on BOG and BOGR were the smallest. The trends in flux changes during the growing season followed those in temperature and PAR.

Measured and integrated CH_4 emissions followed the sequence: pristine > restored > drained on bog sites and pristine > drained on the studied fen sites. The highest CH_4 flux (48 ±28 mg CH_4–C m^{-2} h^{-1}) was measured in FEN flex-rostrata at the beginning of August. By contrast, no CH_4 emissions were measured in FEND sedge-grass and BOGD high shrub during the whole growing season.

The most important factor controlling the both P_G and R_{ECO} on the studied sites was the VGA. The differences in P_G and R_{ECO} between the peatland sites were significant in many cases. P_G and R_{ECO} were significantly higher on FEND compared to FEN and in the FEND the sedge-grass group near the drainage ditch had significantly higher P_G ($F = 36.9$, $P < 0.01$) and R_{ECO} ($F = 20.4$, $P < 0.05$) than the girg-holcus group in wetter parts farther from the ditch. The large R_{ECO} in the FEND sedge-grass group is a result of the large aerobic peat volume (low WT) and also of the large VGA. However, resulting NEE is the lowest for this FEND sedge-grass group. Both P_G and R_{ECO} followed this sequence: pristine < restored < drained on bogs.

R_{ECO} was significantly higher on BOGR and BOGD compared to BOG. Therefore, the resulting NEE was also significantly higher on BOG compared to the BOGR and BOGD. P_G and R_{ECO} were significantly higher on FEN than on BOG, however, the opposite was true for NEE. Seasonal R_{ECO} fluxes had a negative relationship with mean seasonal WT (r = -0.64, P < 0.05) and a lower WT was associated with higher R_{ECO}.

All study sites acted as clear CO_2 sinks except the most heavily drained BOGD high shrub group, which was the net source of CO_2, and the FEND sedge-grass which was a weak sink (Fig. 1). When the seasonal CH_4 emissions were taken into account, the net C balance was also slightly negative for FEN with a high WT, due to the high CH_4 emissions. In the other groups, the CH_4 fluxes were so low that they did not affect the net C balance (Fig. 1). On the BOGR, seasonal C balance was lower than on the BOG due to the enhanced R_{ECO}. The seasonal C balance in the wetter parts of drained sites (FEND girg-holcus, BOGD inter shrub) differed only slightly from the balance estimated for the pristine sites (FEN and BOG). The BOGD molinia group with more drained locations along the margins of ditches was an exception to the highly positive seasonal C balance.

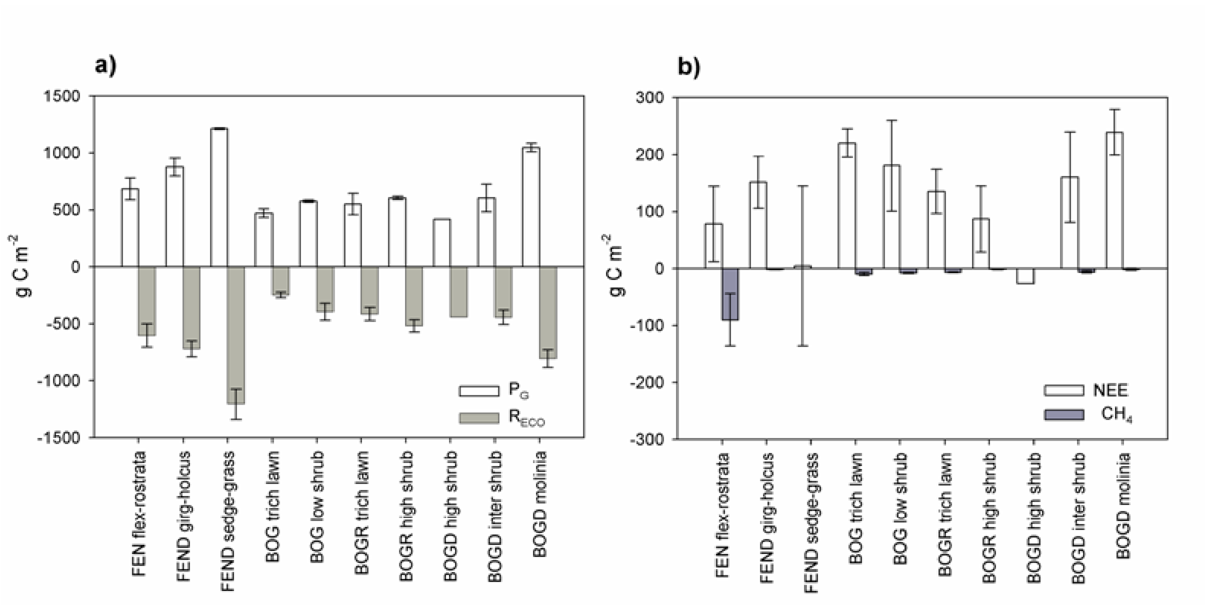

Figure 1.

DISCUSSION

All study sites acted largely as sinks of C during the growing season except some areas near the drainage ditches, where a negative C balance was calculated. Results from the present study support our first hypothesis since net losses or just slightly positive C balances were recorded at the most heavily drained parts of the drained bog and fen where the vegetation structure changed most from the original towards forest or meadow communities and peatland species were not found there. The community with dense cover of *Molinia caerulea* formed an exception to this. Net C balance depended mostly on the present plant communities which could be used together with other environmental characteristics (e.g. WT) as indicators of positive or negative C balance. Drained areas farther from the drainage ditches preserved their original function and acted as C sinks, despite the changes in vegetation composition towards a drier successional stage. These less drained parts could facilitate future ecosystem restoration. However, they could be more threatened by future climate changes (e.g., lower precipitation, drought periods) than pristine sites and their C balance could change easier from sink to source with a further decrease of the water table.

Our results suggest that the WT position is much less important than T in explaining temporal respiration dynamics in one growing season, especially on sites with a stable WT close to soil surface (FEN) or, in contrast to sites with a very low WT (deeper than -30 cm) where the WT does not vary enough to affect R_{ECO}. However, the seasonal mean position of the WT showed a significant relationship with seasonal R_{ECO} ($r = -0.64$) and R_{ECO} increased with a decreasing WT. The mean annual WT is cited as a good proxy for greenhouse gases fluxes assessing from peaty soils and together with vegetation (which reflects long-term WT) can be used as good indicators of greenhouse gas fluxes (Couwenberg et al., 2011).

The CH_4 emissions from the pristine fen were quite high compared to values reported in the literature (Saarnio et al. 2007 and references therein). Plant composition and a very stable WT (-6.5 cm ±3.5; mean seasonal WT ±SD) were probably key factors leading to extremely high CH_4 emissions on FEN. Present plant species such as *Carex rostrata* and *Eriophorum angustifolium* are known to significantly contribute to CH_4 emissions due to the aerenchymatic tissues (Schimel, 1995) and they also stimulate microbial activities by releasing labile organic substrate via exudation (Saarnio et al., 2004). Our previous study showed a higher availability of substrate for soil microorganisms on the pristine fen (FEN) compared to bogs and drained fen. CH_4 production and number of methanogenic Archea on FEN were more than 10 times higher compared to other sites and half of the mineralised C was in the form of CH_4 (Urbanová et al., 2011).
Water regime restoration caused neither significant change in plant composition nor dramatic events, like plant die-back or increase of CH_4 emissions during the first season after restoration. C balance was positive for the two typical plant communities found on the restored bog although the C balance was still lower than for the pristine bog.

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