

The EU project RECIPE: understanding and managing peatland restoration

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Introduction

A majority of European peatlands have been subjected to varying degrees of peat extraction. These cut-over mires have subsequently been used for a large range of activities and as a consequence the peatland regeneration potential is very much site dependent. Some activities have strongly modified the structure and the functioning of the ecosystem, especially in terms of biodiversity and C-sequestration. This is particularly true where commercial extraction has completely removed the surface vegetation over large areas of peatland. However, it is not only plant diversity that is impacted; the removal of vegetation and the upper peat layers will have a severe consequence for microbial biodiversity as well as exposing a peat stratum with very different physico-chemical properties to those of the original surface. Since the microbial flora and fauna are responsible for the ongoing decomposition of old peat and the transformation of any newly-formed peat, changes in microbial diversity may be expected to impact upon carbon cycling in peatlands that are undergoing regeneration. The carbon cycle within peatlands is a balance between fixation through photosynthesis and losses through respiration. Plant photosynthesis has to exceed both plant respiration and microbial respiration (the decomposition of both old and new carbon) before there is net fixation, i.e. the regenerating peatlands becomes a net carbon sink. There is the additional complication of the formation of methane within anaerobic zones, part of which may be oxidized to carbon dioxide.

The EU project RECIPE – Reconciling commercial exploitation of peat with biodiversity in peatland ecosystems (Chapman *et al.* 2003) – compared peatland regeneration at five cut-over sites: Finland, Scotland, Switzerland and two in France. We wished to see if sites that had been extracted commercially could be reinstated, what vegetative cover was most desirable, how the biodiversity might alter along the regeneration dynamic and at what stage these sites might change from net carbon sources to net carbon sinks. By gaining a better understanding of changes in microbial diversity we hoped to find potential indicators of the regeneration progress and reinstatement of carbon (C) sink functioning that might be more readily determined. Our aim was to compare the vegetation, microbiology, soil chemistry, carbon (C) dynamics and socio-economic aspects across these sites and to make some general observations and recommendations. In this paper we report on some aspects of the microbiology and C dynamics. Soil chemistry and further indicators will be discussed elsewhere in these proceedings (Laggoun-Défarge, 2007).

Methods

Five sites were selected across Europe for survey: Aitoneva (Finland), Middlemuir (Scotland), La Chaux-D'Abel (Switzerland), Le Russey and Baupite (both in France).

All were cut-over oligotrophic bogs except Baupste, which was a more fen-type peatland. Areas at each site were selected as representative of different ages of regeneration and, where possible, areas of bare peat and intact (pristine?) peat also selected. The dominant surface vegetation was determined and peat cores were taken from which we characterized the microbiology at four depths using molecular, biochemical and direct microscopical methods. Within each area we also determined the net carbon flux throughout the growing season using light and dark chambers. By collecting data on temperature, water table depth, photosynthetic photon flux density and plant cover, and by applying modelling methodology (see also Bortolluzzi and Chapman), we were able to calculate the annual net C flux and to see whether the peatland areas were net sources or sinks. In a further experimental study, we set up areas with different water table depths and planted them out with what we considered to be keystone species. The subsequent growth, C dynamics and the development of the microbial population was measured over two years using similar methods employed in the initial survey program.

Results and Discussion

We hypothesized that microbial activity and diversity in bare peat areas would be very low but would be stimulated by plant growth in regenerating areas. We further hypothesized that it might reach a maximum the later stages of regeneration before attaining a lower level characteristic of pristine bog since plant diversity at intermediate stages was often greater than that at the advanced regeneration stage. This was what we observed for microbial biomass, expressed either as microbial biomass C or as microbial biomass nitrogen (Figure 1). Taking all sites into consideration, microbial biomass increased over the regeneration stages reaching a maximum after approximately 25 years but becoming less at the most advanced stages surveyed. Values exceeded those typical of pristine bogs after approximately 10 years. Using molecular techniques, we also demonstrated significant shifts in the fungal community during the regeneration process (Figure 2; Artz *et al.*, 2007). A progression could be seen from bare peat, through early and advanced stages, through to intact communities. At Aitoneva (FI) the progression was from bare to vegetated (these were all of similar age) and the *Carex rostrata* (CR) plots were different to the *Eriophorum vaginatum* (EV) wet (W) and dry (D) plots. More detailed studies involving sequencing of extracted DNA showed a general increase in Ascomycetes through the regeneration stage. Significant shifts were also seen in other microbial groups (data not shown): there was a concomitant decrease in Archae (methanogens) and, in the surface vegetated layer, a decrease in diatoms and an increase in nematodes.

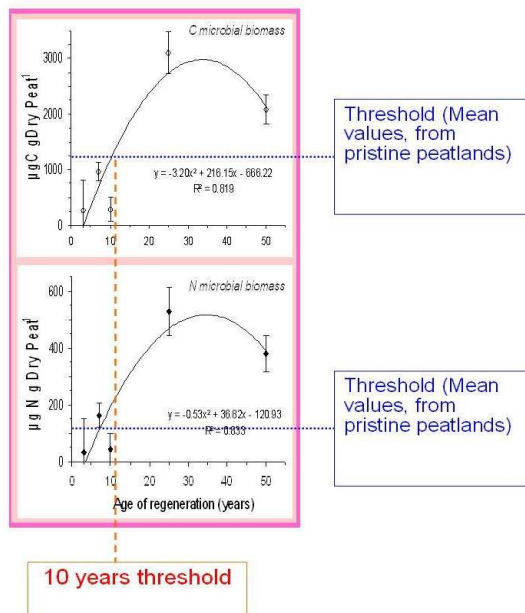


Figure 1.

Changes in microbial biomass C and microbial biomass N over regeneration time. The ten years threshold is the approximate age at which the microbial biomass C in the regenerating peatland achieves a level similar to that in pristine peatlands. Fitted lines are simple quadratics.

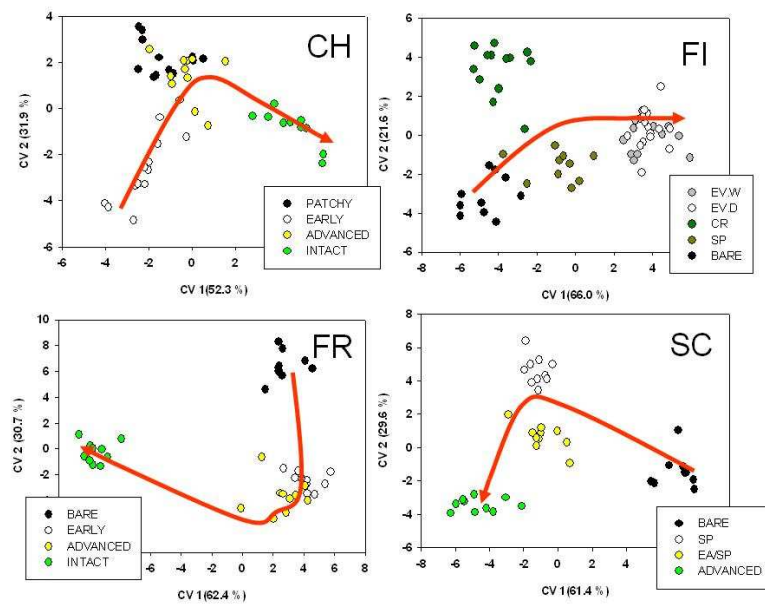


Figure 2. Shifts in the fungal community as assessed using canonical variate analysis of binary data from DGGE band patterns of fungal-specific ITS markers. Red arrows indicate the shift in community during regeneration as it progresses from bare/early regeneration peat to the advanced regeneration/intact state (after Artz and Chapman, in preparation).

As for microbial biodiversity, we hypothesized that there could be a maximum in carbon sequestration potential (Figure 3). Clearly, bare peat areas are net C sources with negligible C fixation. Even when some vegetation has established, it may not fix enough C to offset ongoing losses through decomposition. At some point in the regeneration dynamic C fixation exceeds all respiration losses and the peatland becomes a net C sink. It is generally assumed that the reestablishment of a *Sphagnum* cover suffices to restore the C-sequestration function. Indeed, we have seen the reestablishment of C sink function in both *Sphagnum*-dominated and *Eriophorum*-dominated cutover bog within 20 years. However this is not always the case. Secondary cutover bogs may function as C sinks, but usually not in the very early stages. Furthermore, the C-sequestration function may peak at an intermediate stage and then lessen.

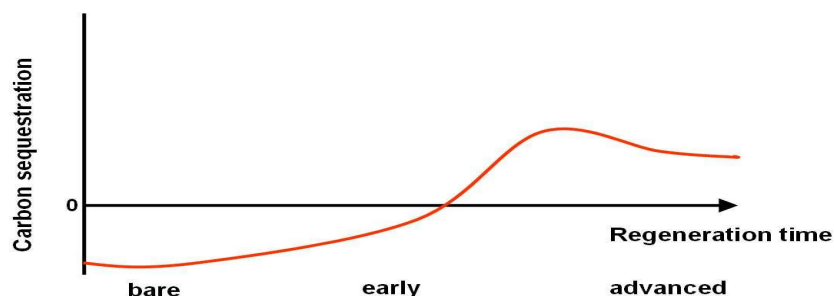


Figure 3. Hypothesized changes in carbon sequestration as regeneration proceeds, moving from C loss (negative sequestration) in bare peat to positive sequestration in the advanced stage.

At Aitoneva, where we used the experimental approach of a controlled water table (Figure 4), we observed bare peat to be a constant source of carbon. This figure also takes into account C loss through methanogenesis. Where Sphagnum was planted the system appeared to be approximately in balance but where sedges (*Eriophorum vaginatum*, *E. angustifolium* and *Carex rostrata*) were planted a net C sink function was attained (Kivimaki *et al.*, 2007). This effect varied however with the water table and was optimum where the water table was maintained close to the surface. Indeed, at low water tables some sedge communities were still operating as C sources. It is often stated that methane emissions could be reduced by keeping water tables so low that most of the CH₄ is oxidised to CO₂ before entering the atmosphere. In contrast, plant carbon sequestration is known to reach an optimum at high water levels. Thus, there is a trade off between these two variables but so far the effect on the peatland's total C budget has not been studied in detail. These results from Finland imply that water levels as low as -20 cm below the surface are enough for maintaining a carbon sink. However, since methane is 21 times stronger as a greenhouse gas compared to CO₂, very high water levels, ranging from -10 to -6 cm, are needed for a net cooling effect.

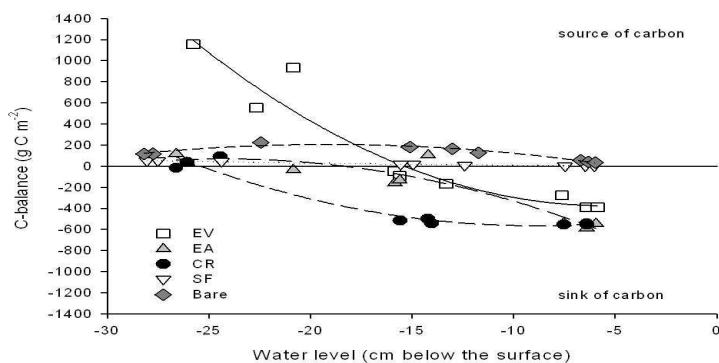


Figure 4. Seasonal carbon balance (June-September at Aitoneva Finland) of three sedge species, *Sphagnum* mosses and bare peat surfaces at different water levels. EV, *Eriophorum vaginatum*; EA, *E. angustifolium*; CR, *Carex rostrata*; SF, *Sphagnum fallax*; Bare, bare peat.

At La Chaux-d'Abel we observed an increase in C sequestration with regeneration stage (Figure 5). The early regeneration stage (~22 years) was a net C source but this had changed to a net sink after ~31 years and was greater still at the advanced regeneration stage (~44 years). Using further modelling methodology it has been possible to predict the effect of future climate change on source/sink functioning. Increased temperature increases respiration (decomposition) losses at the expense of C fixation such that the intermediate stage (~31 years) switches from being a sink to a source when future mean temperature increases by 1.5°C. Increasing the variability in water table depth has less impact, mainly increasing the C losses from the early regeneration stage. We also observed a positive sink function at Le Russey

(Bortuluzzi *et al.*, 2006; Bortuluzzi and Chapman, 2007); this was seen 20 years after abandonment and subsequent recolonization.

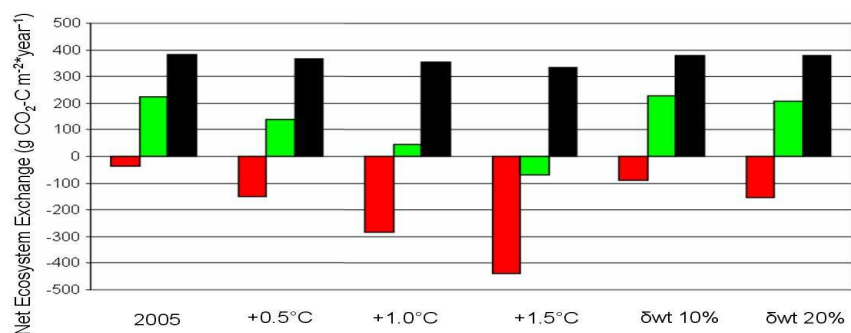


Figure 5. Net Ecosystem Exchange estimated at three regeneration stages at La Chaux-d'Abel: 22 years (red), 31 years (green) and 44 years (black) and for various climate change scenarios (temperature increases and water table depth variations) (Samaritani *et al.*, submitted).

On the socio-economic side, this project has highlighted that across Europe there are very varying attitudes to the exploitation, conservation and rehabilitation of peatlands. In many areas, exploitation continues to be a source of a valuable raw commodity and of income for rural communities. However, the tendency to conserve and rehabilitate rather than exploit varies inversely with the absolute area of peatland within each region though other cultural values also play a role and there is increasing pressure in many regions to promote peatland conservation.

Conclusions

These considerations indicate that peatland managers need ongoing monitoring of the C sequestration status of restored sites (if this is one aim of restoration). One cannot assume that the presence of *Sphagnum*, or even the accumulation of a new peat layer, is necessarily indicative of C accumulation as any C fixed may be balanced by C mineralisation from deeper horizons. However, it is our experience that once the new acrotelm has reached 20–30 cms we can be reasonably confident of net accumulation.

Changes in microbial communities across the regeneration sequences are related to differences in organic matter properties and the presence of certain plants. These results confirm the important role of labile carbon in determining the activity of the microbial communities. Microbial biomass dynamics over the 55 year chronosequence (considering all RECIPE sites) illustrated the poor conditions during bare peat recolonization. We observed a lag time of ca. 10 years in the early stages of succession. Vegetation colonization and increasing plant diversity have positive effects on the development of the microbial pools, which significantly increase at the intermediate stages (from 10 to ca. 40 years after abandonment). These results suggest that microorganisms and peat organic matter properties can be used as bioindicators for ecosystem regeneration and ecosystem function.

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