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REGULARITIES AND DRIVING FACTORS OF SPONTANEOUS RE-VEGETATION OF EXTRACTED MILLED PEATLANDS IN ESTONIA

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SUMMARY

To reveal the regularities and driving factors in re-vegetation we synthesized the results of inventory data from 64 extracted peatlands from all over Estonia (carried out by the Estonian Geological Survey) and the results of a fresh seed bank study from greenhouse experiments with peat blocks from three extracted peatlands. In the flat areas the species number is positively correlated with the time elapsed since the cessation of mining. In ditches, the re-vegetation is largely influenced by the depth of the well decomposed peat layer. The number of species, accumulated from the seed rain during last year, was similar in edges and centres, but there was a difference in species composition. Fertilization had a larger effect on species composition than on species number.

KEYWORDS: environmental variables, landscape scale, propagules, time

INTRODUCTION

The climate and topography of Estonia are favourable for paludification. Peatlands cover more than 22% of the country's territory (Orru, 1992) and there is a long tradition of peat mining for fuel and agriculture. Since the 1950s vacuum mining technology has been employed and the number, and especially the size of peat extraction areas has increased rapidly. At present, about 20,000 ha of peatland are being mined and the area of abandoned cutaway peatland is 9,371 ha (Ramst and Orru, 2009). The exploitation time of a peat mine is 20–30 years, after which it is usually abandoned and left for natural re-vegetation.

During milling of a peatland, the uppermost peat layer with its seed bank and other propagules is removed. Therefore, the regeneration of bog vegetation can occur only by long-distance immigration of diaspores from neighboring areas (Salonen, 1990; Campell *et al*., 2003). The summer water table is often more than one meter below the surface because the exposed peat layers have poor water-holding capacity, but the water table fluctuates extensively during the year. Occasional surface floods during the wet season and the complete drying-out during dry periods creates unfavourable moisture conditions for plant growth (Price *et al*., 1998). Milled peatlands are also exposed to wind erosion (Campbell *et al*., 2002) and frost heaving (Groeneveld and Rochefort, 2002) which inhibits both plant growth and seed germination.

Un-vegetated mining areas are sources of greenhouse gas emission (mainly CO_2) (Paavilainen and Päivanen, 1995; Laine and Minkkinen 1996), have high risk of fires (Puhkan, 2004), and their biological diversity is reduced. Therefore, speeding up the re-vegetation of abandoned cut-over peatlands is a relevant issue at both the local and the global scales level. The aim of our study is to clarify the relative importance of environmental factors which have been shown to drive/favour spontaneous re-vegetation in abandoned peatlands. Our second aim is to clarify if the species composition of extracted peatlands is influenced more by the arrival of viable propagules or their germination and plant survival.

MATERIALS AND METHODS

Our study is the first country-wide analysis of the re-vegetation of abandoned milled peatlands in the world, which covers the whole territory of a country. We used the inventory data for 64 abandoned milled peatlands scattered across the whole country carried out by the Geological Survey of Estonia (Ramst *et al*., 2005, 2006, 2007, 2008). On these peatlands, presence-absence data of the vegetation were recorded separately in three mining field microforms (microhabitats): 103 in flats (central parts of peat fields), 60 in ditch margins and 73 in ditches. In total, 236 vegetation records were analyzed.

In the analyses the following environmental factors were considered: years since peat field abandonment, the total area of the peatland, the total area of abandoned mining fields in one peatland, the average depth of the slightly- and well-decomposed residual peat, and special treatments (sowing seeds *etc*.). In addition, the results of the laboratory analyses of peat samples (peat botanical composition, ash content, pH, moisture and degree of decomposition) were used. The data was supplemented with cartographic analysis: land uses in the neighboring area (active mining area, mire, forest or intermixed area) and distance from the sea were estimated.

The relationship between vegetation data and environmental variables was evaluated by the Canonical Correspondence Analysis. To establish the species assemblage types for separate microforms, the Cluster Analysis was performed. The dependency of species richness on environmental variables was elucidated using the General Linear Model (GLM) analysis.

In addition we carried out a measurement of fresh seed bank size, using greenhouse experiment on peat blocks collected from three extracted peatlands – Tähtvere, Viru and Visusti bogs. They were abandoned at the same time (~30 years ago). From these extracted peatlands randomly placed peat samples (upper 10 cm) from the centre (n=10) and edge of the extracted peatlands (~10 m from edge, n = 10) were taken and sampled as peat blocks (28 x 42.5 cm) for greenhouse experiment. The germination experiment commenced in early-May 2010 in the University of Tartu greenhouse, peat samples were held in the greenhouse till mid-September 2010. Half of the samples from every area were treated with 25 g complex-fertilizer (N:P:K 11-11-21; Yara Mila Cropcare). Also, vegetation analysis was also carried out in the same extracted peatlands (in centre areas, edges and nearby areas).

RESULTS

The majority of the registered plant species in inventory data (93%) occurred with a frequency less than 25%. The total number of recorded species was 181, of which 111 were vascular plants and 70 were mosses and lichens. The average number of plant species was highest in flats. According to the results of the GLM analysis of species richness, in flats and ditch margins it is positively related to the time elapsed since the cessation of peat mining ($p=0.002$). In ditches, the factors supporting species richness positively are the depth of the well-decomposed residual peat ($p<0.010$) and peat ash content ($p<0.030$), whereas distance from the sea has a negative relationship with species richness ($p<0.001$).

The CCA biplot made for the environmental factors and species in the flat parts of milled areas and ditch margins shows that the first axis is positively correlated with the pH and ash content of the upper peat layer, but negatively with the depth of the residual peat layer and with the depth of the slightly decomposed peat (Fig 1). The third axis is mostly explained with the time elapsed from the mining and with the size of the abandoned milled peatland. In this way the CCA biplot shows a strong influence of peat trophicity and pH on vegetation: occurrence of fen species and temporary pioneer species is positively correlated with the areas of eutrophic peat where the peat is more decomposed, has higher pH and ash content; while areas with oligotrophic slightly decomposed and deeper peat are vegetated with bog species.

In flat areas and ditch margins three vegetation types were found, which refer to the following successional stages: *Eriophorum vaginatum–Calluna vulgaris* type, *Phragmites australis–Eriophorum angustifolium–Trichophorum alpinum* type, *Betula* spp.–*Polytrichum strictum–Cladonia* spp. type.

The number of species in the seed bank of edges and central areas was similar. The main species in un-fertilized areas were *Betula* spp., *Bryum* spp., *Marchantia polymorpha* and *Pohlia nutans*, also frequent was *Salix* spp.; and in fertilized areas *Betula* spp., *Eriophorum vaginatum*, *Taraxacum* spp., *Marchantia polymorpha* and *Pohlia nutans*.

The total number of species on fertilized and un-fertilized peat samples was almost similar: in all fertilized peat samples 19, in un-fertilized peat samples 18. Still, the species composition on fertilized and un-fertilized peat samples in the greenhouse experiment was substantially different – in un-fertilized peat samples the most abundant plant species were *Betula* spp., *Salix* spp and *Bryum* spp. In fertilized peat samples the most frequent species were *Betula* spp., *Eriophorum vaginatum* and *Taraxacum* spp.

The species composition in the greenhouse and that of the species composition from extracted peatlands and their forest edges were totally different. Many species like *Marchantia polymorpha*, *Taraxacum* spp., *Senecio vulgaris*, *Pteridium aquilinum*, *Leptobryum pyriforme* and *Pohlia nutans* that germinated in the greenhouse boxes were not present on the study sites or nearby areas.

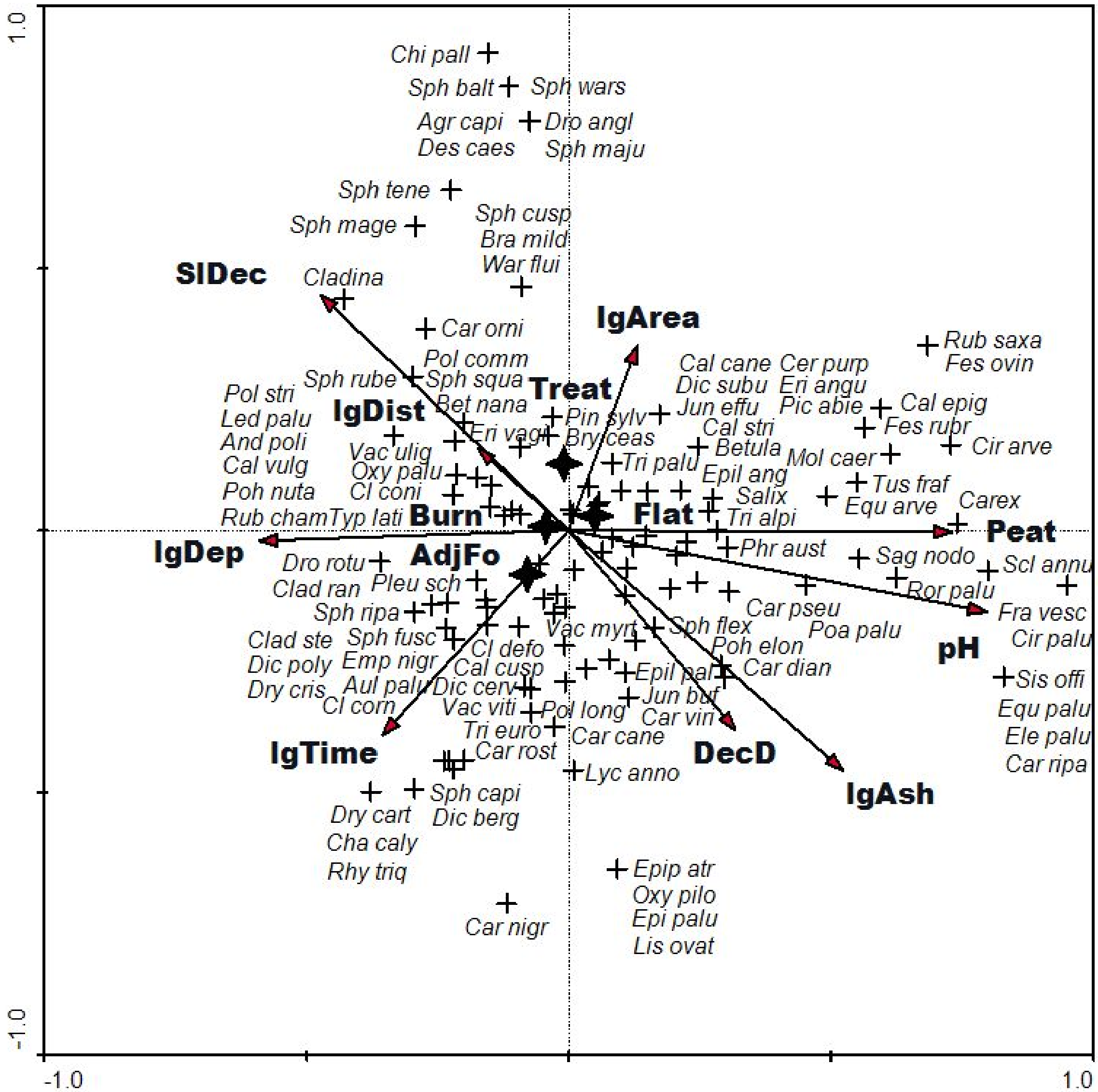

Fig. 1. Canonical Correspondence Analysis biplot of the environmental factors and vegetation data in flats and ditch margins by axes 1 and 2. Crosses are the plant species; arrows show the strength of the relationship. Notations: DecD – decomposition degree of the peat upper layer, lgArea – logarithm of size of the abandoned milled peatland, lgAsh – ash content of the peat upper layer, lgDep – logarithm of depth of the residual peat layer, lgDist – logarithm of distance from the sea, lgTime – time since peatland abandonment, Peat – peat trophic level, pH – pH of the peat upper layer, SlDec – depth of the slightly-decomposed peat; categorical features: AdjFo – the area is adjacent to the forest, Burn –burning of the area, Flat – flat area, Treat – treatment. Nominal environmental variables are marked with diamonds.

CONCLUSION

Generally the flat central areas of milled peat fields can remain devoid of vegetation for decades because of their large area, which aggravates the arrival of propagules and un-favourable conditions for their germination and survival. Still, according to the GLM, the species richness in flats (and also in ditch margins) is positively related with time elapsed since the abandonment of mining activities. This arises from the fact that the pioneer species can persist in some microhabitats, primarily on ditch margins and on road verges, and for several species, the establishment of closer cover creates suitable conditions for germination and/or growth of other species (Soro *et al*., 1999).

The initial community types in abandoned areas show that different residual peat parameters lead to different re-vegetation processes; the vegetation in the areas with thin slightly-decomposed or well-decomposed peat in the upper layer appears to be more similar to the vegetation of fens, while thick slightly-decomposed peat layer promotes the typical ombotrophic peatlands plant growth.

According to our seed bank study it became evident that the number of species is high all across the area, independent of the distance to the natural area (forest etc.). Fertilization does not increase the affects the emerging species composition. The seed bank study shows that most of seed rain arriving species are those not adapted for peatlands or plants that are not able to sprout because of the unfavourable conditions.

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