BOREAL ENVIRONMENT RESEARCH 8: 245–250
Helsinki 29 September 2003 ISSN 1239-6095

Success of re-introduced *Sphagnum* in a cut-away peatland

Eeva-Stiina Tuittila*, Harri Vasander and Jukka Laine

*Peatland Ecology Group, Department of Forest Ecology, P.O. Box 27, FIN-00014 University of Helsinki, Finland (*e-mail: eevastiina.tuittila@helsinki.fi)*

Tuittila, E.-S., Vasander, H. & Laine, J. 2003: Success of re-introduced *Sphagnum* in a cut-away peatland. *Boreal Env. Res.* 8: 245–250. ISSN 1239-6095

In a four-year field experiment, we studied the establishment success of re-introduced *Sphagnum angustifolium* in a restored (rewetted) cut-away peatland. The importance of (1) the presence of capitula and (2) water table level for re-colonisation was tested. The ten times greater cover produced by moss material with capitula revealed that using only the top few centimetres of moss surface the re-colonisation success can be remarkably accelerated. Each year the mean cover was higher in drier conditions than in the regularly flooded conditions. Similarly the length of mosses increased more evenly in drier conditions. The weaker establishment at wetter conditions was a result of peat erosion and the disappearance of mosses due to periodical flooding. The development of *Sphagnum* carpet was not linear but the cover decreased during years with periods of flooding and drought. The dynamic state of the *Sphagnum* surfaces showed that the moss cover was not permanently established during the four years study period, but was sensitive to variation in water table level.

Introduction

Peat is commonly used for energy or horticultural purposes in northern Europe and North America. Peat harvesting causes drastic changes in mire ecosystems: ending the carbon sink function but promoting CO_2 emissions to the atmosphere (Tuittila *et al.* 1999, Waddington *et al.* 2001). After harvesting a cut-away site is vegetationless and the surface is dry during most of the growing season, although high water table fluctuations are characteristic (Schouwenaars 1993, Price 1997). Establishment of mire plant communities to these areas is very slow without human activities promoting the regeneration of the mire ecosystem, i.e. restoration (Joosten 1995, Pfadenhauer and Klötzli 1996, Klötzli and Grootjans 2001, Girard *et al.* 2002).

The goal of peatland restoration is to re-establish a naturally functioning, self-sustaining ecosystem (Wheeler and Shaw 1995), i.e. to promote the carbon sink function. The formation of a *Sphagnum* carpet is considered as the best indicator of the restoration success (Joosten 1992) and the stabilisation of the water table close to the soil surface is considered as an antecedent of this (Heathwaite *et al.* 1993). Since vegetation has a key role in the restoration process, it is essential to establish the relevant species as soon as possible (Pfadenhauer and Grootjans 1999).

The re-introduction of *Sphagnum* fragments has been found to be a promising method for restoring a *Sphagnum* carpet (Wheeler and Shaw 1995, Rochefort 2000). The method is based on the observation that *Sphagna* have the ability to produce new shoots from any plant part except for the leaf, in addition to the plant apex (capitulum) (Karunen and Kälviäinen 1985, Clymo and Duckett 1986, Cronberg 1992). Although new shoots can grow from *Sphagnum* material collected even from a depth of 30-cm (Clymo and Duckett 1986), Campeau and Rochefort (1996) have shown that the moss material taken from the first 10 cm of the mire surface has the best regeneration potential. They suggested that one reason for this is the presence of capitula.

This paper presents a study of the dynamics of *Sphagnum* establishment on bare peat surfaces over a period of four growing seasons. The aim was to quantify the effect of water table level and presence of capitula on the re-colonisation success of *Sphagnum angustifolium* (Russ.) C. Jens. Because *Sphagnum* fragments including capitula have an active growth point, more rapid re-colonisation was expected. Further, moist conditions are considered to be more favourable for *Sphagnum*, therefore we hypothesised that increase in *Sphagnum* cover and length would be higher in conditions with high water table level.

Table 1. The quality of water (mean values) in the feeder ditch during 1995–1998.

	1995[a]	1996[b]	1997[c]	1998[d]
Alkalinity	0.61	0.30	0.49	0.46
Ca mg l^{-1}	31.1	22.6	46.4	39.7
P mg l^{-1}	74.3	47.7	43.3	59.5
NH_4-N μg l^{-1}	457.1	478.0	332.8	364.1
Fe μg l^{-1}	7354	7131	4559	6733
TOC mg l^{-1}	24.85	39.77	34.36	40.24
pH	6.0	5.1	5.8	5.7

[a] In 1995 sampling was done on 4 and 23 October.
[b] In 1996 on 16 April, 9 May, 23 June, 17 July, 22 October, 13 and 28 November, and 10 December.
[c] In 1997 on 11, 20 and 29 May, 23 September, and 30 October.
[d] In 1998 on 11 June and 10 November.

Material and methods

Study site and experimental design

The experiment was carried out in a cutaway peatland, in Aitoneva, Kihniö (62°12´N, 23°18´E), in southern Finland. The site is situated in the transitional zone between the southern and middle boreal coniferous forest zones (Ahti *et al*. 1968). The long-term annual mean temperature of this region is 3.5 °C, and the mean annual precipitation is ca. 700 mm. The average growing season is 160 days, and the accumulative temperature sum (threshold value +5 °C) is 1100 degree days.

Originally the study site had been a wet treeless mire but no information on the mire site type was available. It was first ditched in 1938. Peat was harvested by block cutting between 1944 and 1951, and by milling from 1951 to 1975. During the last years of harvesting pumping was also used to drain the site. The site was abandoned in 1975 when drainage was no longer economically feasible; therefore the residual peat layer was unusually thick, one metre on average. The peat was highly decomposed *Sphagnum–Eriophorum* peat.

The *Sphagnum* re-introduction experiment was established in September 1994. Later in autumn 1994 the site was rewetted by blocking the ditches with peat dams and re-routing water to the site from surrounding areas via a feeder ditch (Table 1).

Sphagnum angustifolium was chosen for the study because it was found to spontaneously colonise a moist depression inside the 3.5 ha study area (Tuittila and Komulainen 1995), and because of its relatively broad ecological amplitude (Horton *et al*. 1979; Rydin 1993 and references therein). Our choice was also supported by the experience of Campeau and Rochefort (1996), who found *S. angustifolium* to show good regeneration success in a field experiment.

Living *Sphagnum angustifolium* material (top 10-cm layer) was collected from an *Eriophorum vaginatum* pine bog in southern Finland (61°51´N, 24°17´E) in September 1994. The moss material was cut into two to three centimetre fragments, and divided into (1) material consisting of stems and branches only and (2) material including capitula.

The experimental site sloped down and formed a moisture gradient from drier upper to lower wetter conditions. Ten sample plots, each 60 × 60 cm, were set up across the lower and upper ends of one strip between ditches forming two moisture levels. The uppermost ten cm of peat was cut away from the sample plots in order to keep the added moss material in its place. In September 1994, moss material was spread into the sample plots and an even layer was formed by hand, after randomising five sample plots for stem material and five for capitulum material in the drier and wetter conditions. The number of capitula in plots with capitulum material was 13 500 ± 800 m^{-2} (mean ± .S.E.). A tube was established next to each sample plot for water level measurements.

Presence of vascular plants has been shown to facilitate the colonisation of mosses on bare peat surfaces (Grosvernier *et al*. 1995, Tuittila *et al*. 2000). Therefore, in order to focus on the effect of water table level and presence of capitula, vascular plants that emerged in the sample plots during the study period were removed.

Field measurements

The cover of *Sphagnum* capitula was recorded annually at the end of August during 1995–1998. In each sample plot, a circular subplot with a diameter of 10 cm was mapped in a transparent plastic film. The area covered by capitula on these maps was measured with a digitising pad. In 1998, when the sample plots in the wetter conditions were continuously inundated, the cover was visually estimated.

Five random *Sphagnum* individuals were picked from each sample plot at the end of August, 1995–1997, and relocated after measuring their total lengths. The mean of the annual measurements was used to represent the *Sphagnum* length of a plot in each year.

Water table level relative to soil surface was measured from one to four week intervals over the growing seasons 1995–1998 from the tubes located next to each sample plot. Measurements were carried out 14, 8, 10, and 11 times during 1995, 1996, 1997, and 1998, respectively.

Data analysis

The effects of the moss material treatment (the moss material used in re-introduction including or excluding capitula: capitulum plots and stem plots, respectively), and the moisture level (drier and wetter level) on the cover of *Sphagnum* capitula during 1995–1998, and on the moss length during 1995–1997 were analysed separately using ANOVA of repeated measures. Two grouping factors: moisture level and moss material treatment, and one within factor: year, together with their interactions were used in both analyses. The linearity of the moss cover and length development in time were tested using the Polynomial Test of Order 1 (SYSTAT 1998).

Results

Sphagnum surfaces were in a dynamic state (Fig. 1a): There was a significant difference between years (year effect $p < 0.001$), but the development of cover was non-linear (Polynomial Test of Order 1: $p = 0.491$). Although the cover developed differently in the two moisture levels (year × moisture level effect $p < 0.001$), the cover decreased in all four treatment combinations in 1997 (Fig. 1a).

First year after re-introduction, the *Sphagnum* capitula cover was similar in drier and wetter moisture levels, being 48% in the capitulum sample plots and 8% in stem plots (Fig. 1a). In each of the four years the cover was higher in capitulum plots than in stem plots at both moisture levels (moss material effect $p < 0.001$, Fig. 1a).

After the first year the mean cover was always higher in the drier moisture level than in the regularly flooded wetter level (moisture level effect $p < 0.001$, Figs. 1a and 2). There was no interaction between the moss material treatment and moisture level (moisture level × moss material effect $p = 0.149$).

The moss length increased linearly during the three years measurement period (year effect < 0.001 and Polynomial Test of Order 1: $p < 0.001$, Fig. 1b). At the drier moisture level the length was significantly higher in the capitulum plots than in the stem plots in each of the three meas-

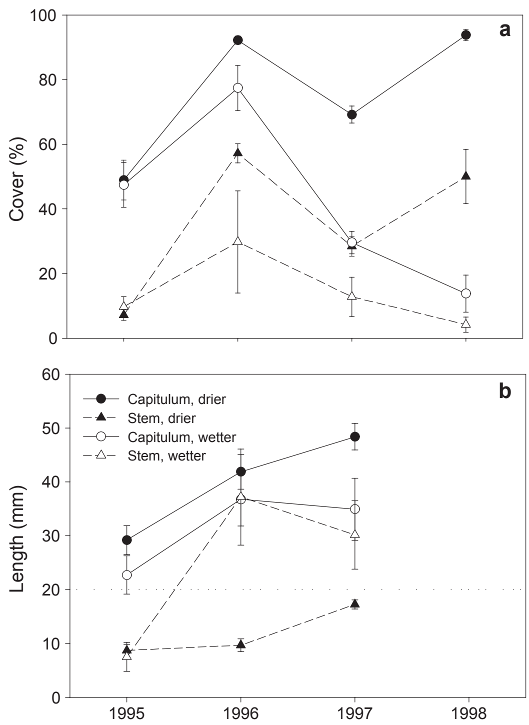

Fig. 1. (**a**) The development of capitulum cover and (**b**) moss length in sample plots where *Sphagnum angustifolium* material consisting of stems and branches (stem) and material including capitulum (capitulum) were spread in drier and moister conditions ($n = 5$). The initial average size of capitulum fragments is shown by dotted line in **b**. Bars indicate standard error of the mean.

urement years (moss material effect $p < 0.001$, Fig. 1b), but in the wetter moisture level the effect of the moss material treatment was insignificant ($p = 0.563$).

Discussion

The dynamic state of the *Sphagnum* surfaces showed that over the four-year period, the moss cover was not permanently established but was sensitive to variations in water table level, especially to flooding effects. The lack of a linear trend in the development of the capitulum cover indicates that an inventory after a favourable growing season may give too optimistic a view of establishment success, and restoration trials should cover a period of several growing seasons.

Sphagnum re-introduction succeeded rather well, although the moisture conditions in our experiment did not resemble those typical of natural habitats of *Sphagnum angustifolium*: lawns or low hummocks of relatively dry oligotrophic bogs and fens (Horton *et al*. 1979, Gignac and Vitt 1990). In the drier conditions the water table was mainly at the level of a high hummock of pristine bog and in the wetter conditions at the level of a hollow (Lindholm and Markkula 1984).

The ten-fold higher cover in the capitulum plots (Fig. 1a), which was in accordance with the hypothesis, clearly demonstrated the high potential of capitula for the rapid development of a *Sphagnum* carpet. The capitulum cover, even in the stem plots one year after re-introduction, was higher than that found in short-term trials in Canada (Campeau and Rochefort 1996, Ferland and Rochefort 1997). This might be due to the higher initial density of re-introduced moss material.

The result of a higher capitula cover in drier conditions (Fig. 1a), was contrary to the results from a greenhouse experiment, where *Sphagnum angustifolium* showed higher regeneration in water levels of –5 cm than –15 and –25 cm (Campeau and Rochefort 1996) as well as to our hypothesis. In our experiment the weak success in wetter conditions was a result of peat erosion and the disappearance of mosses due to periodical flooding. Such a phenomenon was also observed by Money (1995) and Sliva and Pfadenhauer (1999). Sliva and Pfadenhauer (1999) found that vascular plants stabilise the peat surface, and thus enhance the success of *Sphagnum* establishment.

The increase in cover in 1998 in drier conditions, after the decrease during the year 1997 with a long period with deep water table level (Figs. 1a and 2), indicated that when the *Sphagnum* apexes were injured by drought, lateral buds started to grow. The re-introduced moss material had retained the ability to recover, which is typical of *Sphagnum* (Clymo and Hayward 1982).

Conclusions

The ten times greater cover produced by moss material with capitula reveals that using material

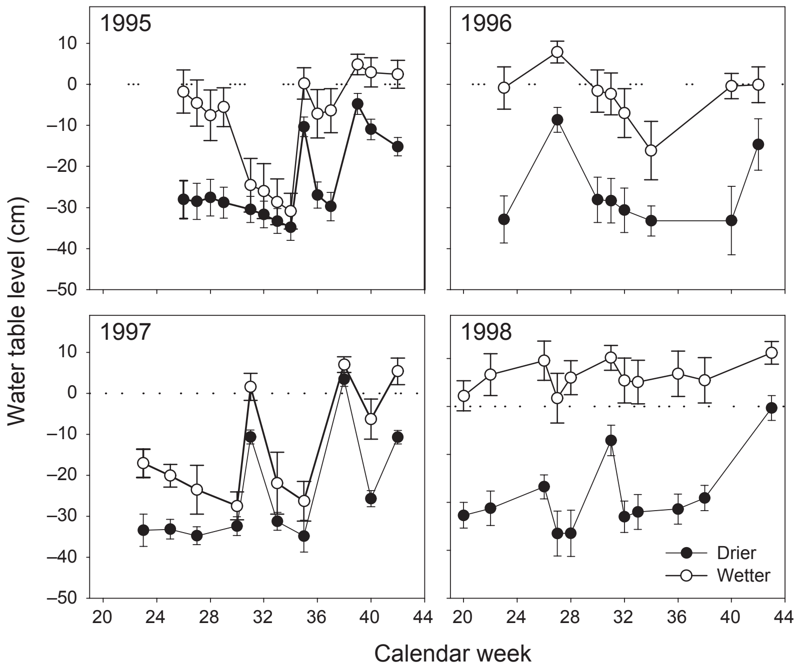

Fig. 2. Mean water table level in drier and wetter conditions (n = 10) during the growing seasons 1995–1998. The water level was measured relative to the soil surface. Positive values were obtained when the water table was above the soil surface. Bars indicate standard deviation of the mean.

with capitula in *Sphagnum* re-introduction, the restoration success can be remarkably accelerated. A high water table level showed to be risky for the restoration success: flooding had a negative effect on *Sphagnum* establishment. Our study demonstrated the sensitivity of a recently established moss layer to variations in the environment and indicated the need for stabilising factors, like companion species, for restoration success.

Acknowledgements: Our warmest thanks are due to Ilkka Korpela for his help with the capitula cover measurements. The Finnish Cultural Foundation supported the study. Vapo Oyj made our work possible by providing access to the experimental site and technical support in blocking the ditches.

References

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

Campeau S. & Rochefort L. 1996. *Sphagnum* regeneration on bare peat surfaces: field and greenhouse experiments. *J. Appl. Ecol*. 33: 599–608.

Clymo R.S. & Duckett J.G. 1986. Regeneration of *Sphagnum*. *New Phytol*. 102: 589–614.

Clymo R.S. & Hayward P.M. 1982. The ecology of *Sphagnum*. In: Smith A.J.E. (ed.), *Bryophyte ecology*, Chapman and Hall, London, pp. 229–289.

Cronberg N. 1992. Reproductive biology of *Sphagnum*. *Lindbergia* 17: 69–82.

Ferland C. & Rochefort L. 1997. Restoration techniques for *Sphagnum*-dominated peatland. *Can. J. Bot*. 75: 1110–1118.

Gignac L.D. & Vitt D.H. 1990. Habitat limitations of *Sphagnum* along climatic, chemical, and physical gradients in mires of Western Canada. *Bryologist* 93: 7–22.

Girard M., Lavoie C. & Thériault M. 2002. The regeneration of a highly disturbed ecosystem: A mined peatland in Southern Québec. *Ecosystems* 5: 274–288.

Grosvernier P., Matthey Y. & Buttler A. 1995. Microclimate and physical properties of peat: New clues to the understanding of bog regeneration processes. In: Wheeler B.D., Shaw S., Fojt W.J. & Robertson A. (eds.), *Restoration of temperate wetlands*. Wiley, Chichester, pp. 435–450.

Heathwaite A.L. Eggelsmann R. & Göttlich K. 1993. Ecohydrology, mire drainage and mire conservation. In: Heathwaite A.L. & Göttlich K. (eds.), *Mires. Processes, exploitation and conservation*. Wiley, Chichester, pp. 417–484.

Horton D.G., Vitt D.H. & Slack N.G. 1979. Habitats of circumboreal-subarctic *Sphagna*: I. A quantitative analysis and review of species in the Caribou Mountains, northern Alberta. *Can. J. Bot*. 57: 2283–2317.

Joosten H. 1992. Bog regeneration in the Netherlands: A review. In: Bragg O.M., Hulme P.D., Ingram H.A.P. & Robertson R.A. (eds.) *Peatland ecosystems and man: An impact assessment*. Department of Biological Science, University of Dundee, Dundee, pp. 367–373.

Joosten H. 1995. Time to regenerate: Long-term perspectives of raised bog regeneration with special emphasis on paleoecological studies. In: Wheeler B.D., Shaw S.C., Fojt W.J. & Robertson R.A. (eds.), *Restoration of temperate wetlands*. Wiley, Chichester, pp. 379–404.

Karunen P. & Kälviäinen E. 1985. Senescence and post-mortem changes in the ultrastructure of *Sphagnum fuscum* (Schimp.) Klinggr. leaf cells. *New Phytol*. 100: 419–427.

Klötzli F. & Grootjans A.P. 2001. Restoration of natural and semi-natural wetland systems in Central Europe: Progress and predictability of developments. *Restor. Ecol*. 9: 209–219.

Lindholm T. & Markkula I. 1984. Moisture conditions in hummocks and hollows in virgin and drained sites on the raised bog Laaviosuo, southern Finland. *Ann. Bot. Fennici* 21: 241–255.

Money R.P. 1995. Re-establishment of a *Sphagnum*-dominated flora on cut-over lowland raised bogs. In: Wheeler B.D., Shaw S.C., Fojt W.J. & Robertson R.A. (eds.), *Restoration of temperate wetlands*. John Wiley & Sons, Chichester, pp. 405–422.

Pfadenhauer J. & Grootjans A. 1999. Wetland restoration in Central Europe: aims and methods. *Appl. Veg. Sci*. 2: 95–106.

Pfadenhauer J. & Klötzli F. 1996. Restoration experiments in middle European wet terrestrial ecosystems: an overview. *Vegetatio* 126: 101–115.

Price J. 1997. Soil moisture, water tension, and water table relationships in a managed cutover bog. *J. Hydrol*. 202: 21–32.

Rochefort L. 2000. *Sphagnum* — keystone genus in habitat restoration. *Bryologist* 103: 503–508.

Rydin H. 1993. Mechanisms of interactions among *Sphagnum* species along water-level gradients. *Advances in Bryology* 5: 153–185.

Schouwenaars J.M. 1993. Hydrological differences between bogs and bog-relicts and consequences for bog restoration. *Hydrobiologia* 265: 217–224.

Sliva J. & Pfadenhauer J. 1999. Restoration of cut-over raised bogs in southern Germany — a comparison of methods. *Appl. Veg. Sci*. 2: 137–148.

SYSTAT 1998. *Systat 8.0 for Windows: Statistics*. SPSS Inc., Chicago.

Tuittila E.-S. & Komulainen V.-M. 1995. Vegetation and CO_2 balance in an abandoned harvested peatland in Aitoneva, southern Finland. *Suo* 46: 69–80.

Tuittila E.-S., Komulainen V.-M., Vasander H. & Laine J. 1999. Restored cut-away peatland as a sink for atmospheric CO_2. *Oecologia* 120: 563–574.

Tuittila E.-S., Rita H., Vasander H. & Laine J. 2000. Vegetation patterns around *Eriophorum vaginatum* L. tussocks in a cut-away peatland in southern Finland. *Can. J. Bot*. 78: 47–58.

Waddington M., Warner K.D. & Kennedy G. 2001. Cut-over peatlands: A persistent source of atmospheric CO_2. *Global Biogeochem. Cycles* 16: 21–27.

Wheeler B.D. & Shaw S.C. 1995. *Restoration of damaged peatlands with particular reference to lowland raised bogs affected by peat extraction*. Department of the Environment, University of Sheffield, London, 211 pp.

Received 24 September 2002, accepted 14 March 2003