

Vegetation change in peatland buffers as an indicator of active areas of run-on from forestry

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Our aim in this study was to evaluate whether coverage change in the vegetation of a forestry buffer wetland can be used to reveal a possible increase in nutrients. To achieve this, we followed changes in vegetation on two peatland buffers, and biomass with nitrogen content in one of them. Nutrient concentrations were periodically lower in the water inflow than in the outflow. Flooding caused a species change in favor of flood-tolerant grasses and *Sphagna*, but this species composition did not indicate a higher trophic level. Nitrogen content in the reference site's original surface peat layer, which was rich in woody remains, was higher than that of the newly formed, more acidic *Sphagnum* peat of the spruce swamp buffer. Changes in biomass did not indicate an increased nutrient-binding capacity of the spruce swamp buffer vegetation. On the other hand, the changes in species cover outlined the area of effective water flow paths within the buffer and suggested that severe eutrophication of peatland forestry buffers does not seem likely.

Key words: above-ground biomass, buffer zone, detrended correspondence analysis, peatland forestry, nitrogen content, tree stand, vegetation change

Introduction

The area of forestry in Finland covers about 26 million ha (Peltola 2008), of which 4.8 million ha are on drained peatlands. Forestry operations are shown to increase concentration of nutrients in soil solution leaching from the catchment (e.g. Sollins & McCorison 1981, Nieminen 2004, Piirainen *et al.* 2004, Piirainen *et al.* 2007, Morris 2009). In the year 2007, 688 000 ha of

the total forest area was under harvesting operations, on 130 000 ha soil preparation was being carried out, on 67 000 ha ditch cleaning was in progress and 35 000 ha was under fertilization (Peltola 2008). Clear-cuttings do not always significantly increase the leaching of phosphorus (P), even though extra nitrogen (N) is liberated (Nieminen 2004, Piirainen *et al.* 2004, Manerkoski *et al.* 2005). However, soil preparation and ditch cleaning in drainage operations can

cause a short-term (from 1 to 2 years) release of both P (Joensuu *et al.* 2001b, Piirainen *et al.* 2007) and N (Piirainen *et al.* 2007). Fertilization in peatlands also adds to the liberation of nutrients (e.g. Saura *et al.* 1995, Liljaniemi *et al.* 2003). However, several forestry operations may take place in different parts of the catchment simultaneously, or the operations may be timed to occur over a time span of several years.

Peatlands drained for forestry, having a short water retention time due to the effective ditch network, constitute an important threat to water quality. Forestry operations in peatlands and the associated ditch cleaning will increase in the near future as first generation forests mature. With the aim of diminishing the pollution risk to watercourses due to peatland forestry, buffers have been established for capturing solids and nutrients from the forestry operations already in the catchments. Waters from such catchments may be distributed to a peatland buffer area through a sedimentation pond, often delimited by a dam. The solids are assumed to sediment in the pond and the dam to raise the waters into an overland flow. The terminology concerning wetlands under artificial flooding is diverse. In this article we call peatland areas affected by water flooding through the pond (peatland) buffers.

Nutrient binding is thought to occur physically, chemically and biologically. Silvan *et al.* (2004) estimated that most of the N load and some of the P was captured by plant growth and tissues. Much of the trapped P is chemically bound in soil (e.g. Väänänen *et al.* 2006) or immobilized in microbial biomass (Silvan *et al.* 2003). Several previous studies assessed the role of vegetation biomass in nutrient binding. In a fertilization experiment carried out on a peatland forestry buffer and a peat mining overland flow wetland, the total plant biomass increased by about 20% during one year after fertilization (Silvan *et al.* 2004), or as compared with that in the control area (Huttunen *et al.* 1996). Plant biomass doubled during ten years in a wetland constructed for purifying the run-off from peat mining (Liikanen *et al.* 2006). A great increase in the biomass of *Eriophorum vaginatum* and various *Sphagnum* species was recorded by Silvan *et al.* (2004), but they did not note enhanced N concentration in the tissues of buffer vegetation.

By contrast, Huttunen *et al.* (1996) measured a 40% increase in total N in the plant biomass, but a simultaneous decrease in P content.

Changes in vegetation structure have been reported earlier. According to Liikanen *et al.* (2006), *Sphagnum angustifolium* and *S. papillosum* had decreased in abundance in a buffer zone capturing peat mining waters ten years after buffer construction, while *Carex lasiocarpa* and *Potentilla palustris* had increased. It would seem from this study that vascular plants store the nutrients in the long run, since *E. vaginatum*, *C. lasiocarpa* and *P. palustris* have large below-ground biomass, extending deep into the peat, where the possibly slow turnover of dead roots may pass the active nutrient cycle.

Controlling the true functioning of the peatland buffer is difficult, and no indicators for good nutrient retention are available. Hitherto, a large buffer area has been considered the most important factor for nutrient binding (e.g. Väänänen *et al.* 2008). Here we assume that the distribution of vegetation and the species composition displays the effective area of the water paths flowing in the buffer. We compared vegetation cover changes in two peatland forestry buffer wetlands with those in reference areas outside the influence of flooding. We postulated that changed vegetation could be an indicator of the extent of the buffer area receiving nutrient-rich waters, in a way that is similar to the way in which ground vegetation indicates fertility between forest or mire site type. Finding such indications, familiar in forestry practice, would help planners to evaluate whether the buffers were in the first place constructed in areas critical for water protection. We also aimed to investigate whether other, more indirect factors than nutrients, such as changed pH or increased light in gaps created by fallen trees, affect vegetation change.

Material and methods

Study sites

A spruce swamp (63°38'N, 29°25'E, 192 m a.s.l.) peatland buffer and a brook margin meadow peatland buffer (63°37'N, 29°30'E, 186 m a.s.l.) were established in 1997 in the catchment of

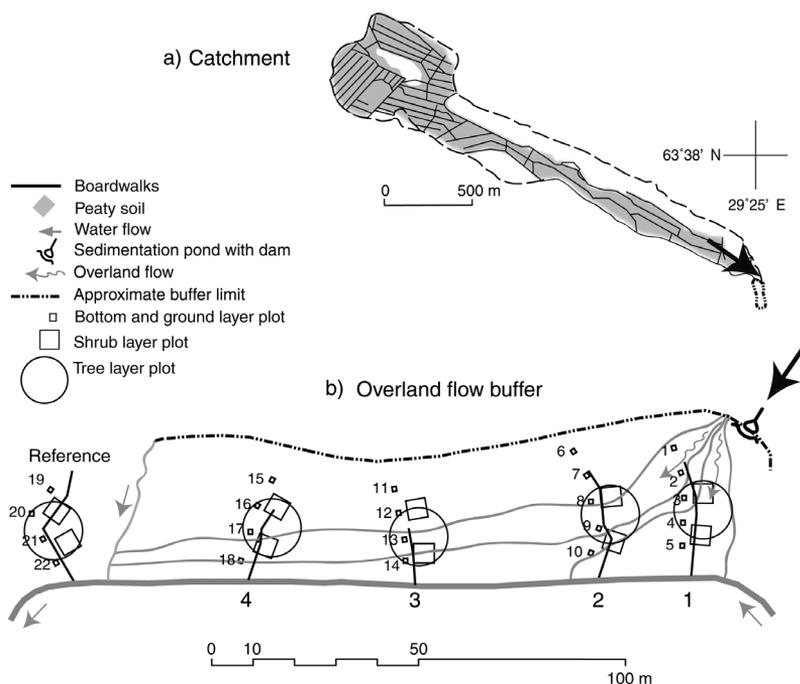


Fig. 1. Map of the spruce swamp study area.

Kuohattijärvi, a lake in Nurmes, eastern Finland (Fig. 1). In the Nurmes area, the annual mean temperature and precipitation calculated for the sampling years are +3.0 °C and 533 mm, respectively (Finnish Meteorological Institute). The study sites consisted of a sedimentation pond and a dam to guide the incoming waters to a surface flow through the buffer. The spruce swamp buffer represented 0.5% of the 72 ha forest catchment which was under forestry operations, including ditch cleaning, PK fertilization, thinning, and harvesting. The brook margin meadow represented 0.16% of a 29 ha catchment under thinning, ditch cleaning and PK fertilization.

In the spruce swamp, five transects were positioned at increasing distances from the inflow. Of the transects, number 5 was established outside the buffer as a reference (Fig. 1). The peat depth was 50–60 cm in the buffer and about 30 cm in the reference. In the brook margin meadow, three transects were located below the sedimentation pond and the reference at a paludified upstream bank of the brook (Fig. 2). The peat depths in the brook margin meadow buffer and in the reference were 190 and 150 cm, respectively. Permanent vegetation plots (moss and ground layer plots, shrub plots and tree layer plots) were located

along the transects at different distances from the sedimentation pond (Figs. 1 and 2).

Vegetation characteristics

The coverage of vascular plants and moss species projection was estimated in July 2005, 2006 and 2007 separately for moss and ground layers at both study sites using the following scale: + (species present), 0.5%, 1%, 2%, 3%, 5%, 7%, 10% and above at 5% increments to 100%. The proportion of litter and dead plants was also estimated on 22 and 16 1-m² plots along the transects in the spruce swamp and in the brook margin meadow, respectively (Figs. 1 and 2).

The coverage of the shrub layer (arborescent plants with a height of at least 0.5 m) was also estimated as a percentage (0.5%, 1%, 2%, 3%, 5%, 7%, 10% and above at 5% increments to 100%). The surveys were conducted in July 2005, 2006 and 2007 on ten and five 25-m² plots in the spruce swamp and in the brook margin meadow, respectively. A trunk diameter at 1.3 m for each tree species was measured in 2007, and the tree stand density and canopy coverage were estimated on five 0.01-ha circular plots. The

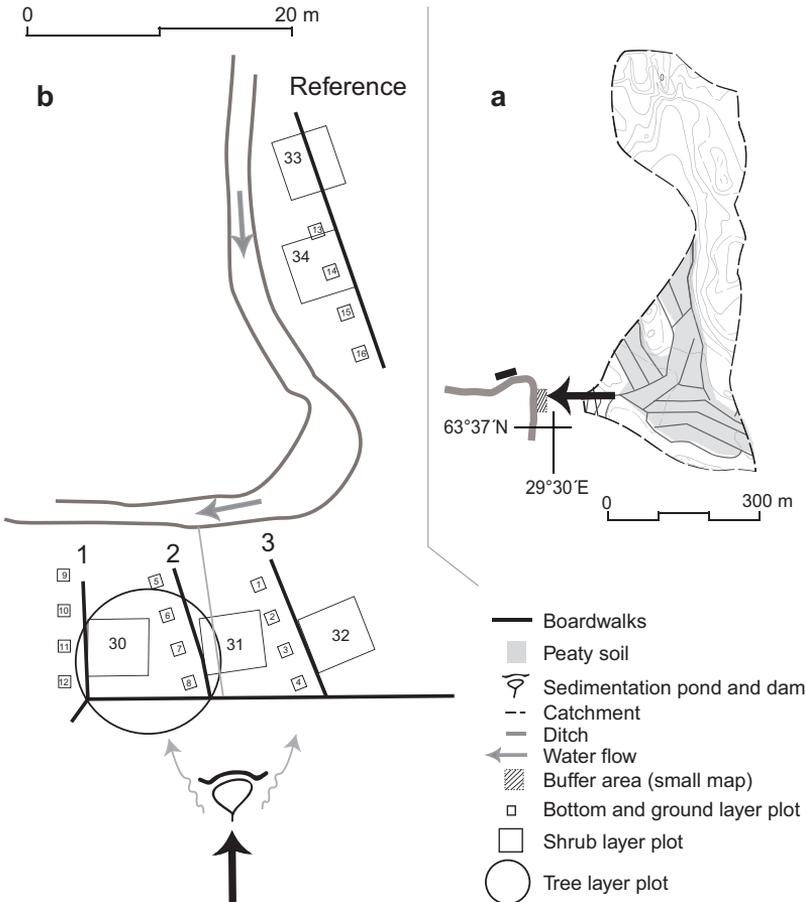


Fig. 2. Map of the brook-margin meadow study area. — **a:** Catchment — **b:** Overland flow buffer.

partially overlapping canopy areas were summed per each plot and presented as a percentage of the maximum value. The lower percentages are assumed to indicate less light extinction in the canopy. The circular plots were examined first in October 2005 and again in May 2007. Only one circular plot was examined in the brook margin meadow. Due to the small size of the plots, combined with the timing and short duration of our monitoring period, we were unable to monitor the mortality rates. We, therefore, counted and measured all live and dead trees in the spruce swamp where the amount of dead or dying trees was high. The live or dead status for all trees or old stumps from an earlier harvest was recorded along the study transects with the aim of estimating the effects of buffer construction on the tree stand at different distances from the sedimentation pond towards the reference.

Water levels and water quality

Water table levels, indicating flooding and the depth of the aerobic peat layer, were measured weekly from 4–5 water wells (50-cm deep, 32 mm in diameter) along each transect. Water samples for pH measurements (PHM 92 Radiometer) were taken at least once a month from June 2005 to May 2006 during the frost-free period.

Water samples for analysis of N_{TOT} , NH_4^+ , and $\text{NO}_2^- + \text{NO}_3^-$ were taken from the sedimentation pond (inflow) and the outflow beyond transect 4 during the years 2000–2005, 2–10 times per year, and analyzed spectrophotometrically. Total N, $\text{NO}_2^- + \text{NO}_3^-$ and NH_4^+ were analyzed using the standards SFS-EN ISO 11905-1, SFS-EN ISO 13395 and SFS 3032, respectively. Total P and PO_4^{3-} were analyzed using spectrophotometric methods (standard SFS-EN ISO 6878).

Ground vegetation and tree biomass and their total nitrogen content in the spruce swamp

Above-ground parts of vascular plants and moss capitula were collected from one 0.25–1 m² vegetation plot per transect and the reference (plots 4, 9, 14, 18 and 21). Peat samples were cut at a depth of 10 cm below the moss capitula. Vegetation, moss and peat samples were dried at 40 °C, homogenized, and measured for moisture using the standard ISO 11465 and total N content using the standard VYH-76.

We estimated the potential N and P liberation from trees killed by increased water table after buffer construction by comparing the amounts of N and P bound by dead and live tree biomass for the different species reported by Finér (1989) and Repola *et al.* (2007).

Analysis of plant communities and environmental variables

We used the approach familiar from the Finnish forest site type classification for characterizing the vegetation change where peatland fertility and moisture are displayed in ground vegetation and tree stand (Cajander 1913, Laine & Vasander 2008). The biotope types on the buffer and the reference were classified in the field according to the Finnish ecological mire site type classification system (Eurola *et al.* 1995).

Changes in vegetation coverage from 2005 to 2007 were illustrated as re-location of plots according to axis score values for the consecutive years computed using detrended correspondence analysis (DCA). The analysis was run using standard options, but with down-weighting of rare species. The matrix consisted of 71 vegetation plots and 47 species in the spruce swamp and 48 plots and 46 species in the brook margin meadow.

In the spruce swamp and brook margin meadow data, a linear mixed model was used for testing the differences in water table level and pH (y_{ijklm}) between the different parts of the study site (Eq. 1):

$$y_{ijklm} = m + \text{fixed effects} + \text{random effects} + e_{ijklm} \quad (1)$$

where m is the intercept. Fixed effects include the following parameters: transect_{*i*} (i.e. the distance from the inflow), ditch_{*j*} (i.e. the distance of the study plot from the margin ditch [Spruce swamp, Fig. 1]), brook_{*j*} (i.e. the distance of the study plot from the margin brook [Brook margin meadow, Fig. 2]), season_{*k*} (i.e. the seasonality effect), well_{*l*} (i.e. the location of the plot), the random term, and e_{ijklm} (i.e. the residual term for the m th measurement of the well_{*ijklm*}). It was assumed that the distributions of the error vectors $e_{ijkl} = (e_{ijkl1}, e_{ijkl2}, e_{ijkl3}, \dots, e_{ijklm})$ are independent multivariate normal random vectors with homogenous variance and a first order autoregressive covariance structure. The normality of the marginal distribution of the residuals and the homogeneity of the variance of the residuals were checked graphically, and the selection of the covariance structure was based on Akaike's information criteria.

Results

Vegetation composition

In DCA analysis of the vegetation composition on the spruce swamp (Fig. 3), Axis 1 (eig. = 0.74) divides the vegetation plots mainly into two different mire types, fern spruce mire and *Myrtillus* spruce mire, while Axis 2 (eig. = 0.42) separates the areas of overland flooding and non-flooded forest. Correspondingly, at the species level (Fig. 4), the indicators of flooding (e.g. *Calamagrostis purpurea* and *Juncus filiformis*; Eurola *et al.* 1995) were found to the left of the Axis 1 origo, while the forest dwarf shrubs and mosses, such as *Vaccinium myrtillus*, *V. vitis-idaea*, *Pleurozium schreberi* and *Hylocomium splendens* to the right. The separation of the two groups on Axis 1 was based on indicators of the spruce mire site type (Eurola *et al.* 1995, buffer–*Myrtillus* spruce mire, e.g. *Equisetum sylvaticum* and *Sphagnum centrale*). The flood indicators, such as *Sphagnum riparium*, *S. girgensohnii* and *Straminergon stramineum*, occupied the lower end of Axis 2 as compared with the original vegetation of forest herbs and mosses, e.g. *Oxalis acetocella* and *Dicranum polysetum*.

On the spruce swamp, the original gradient in vegetation from the *Myrtillus* spruce mire type to

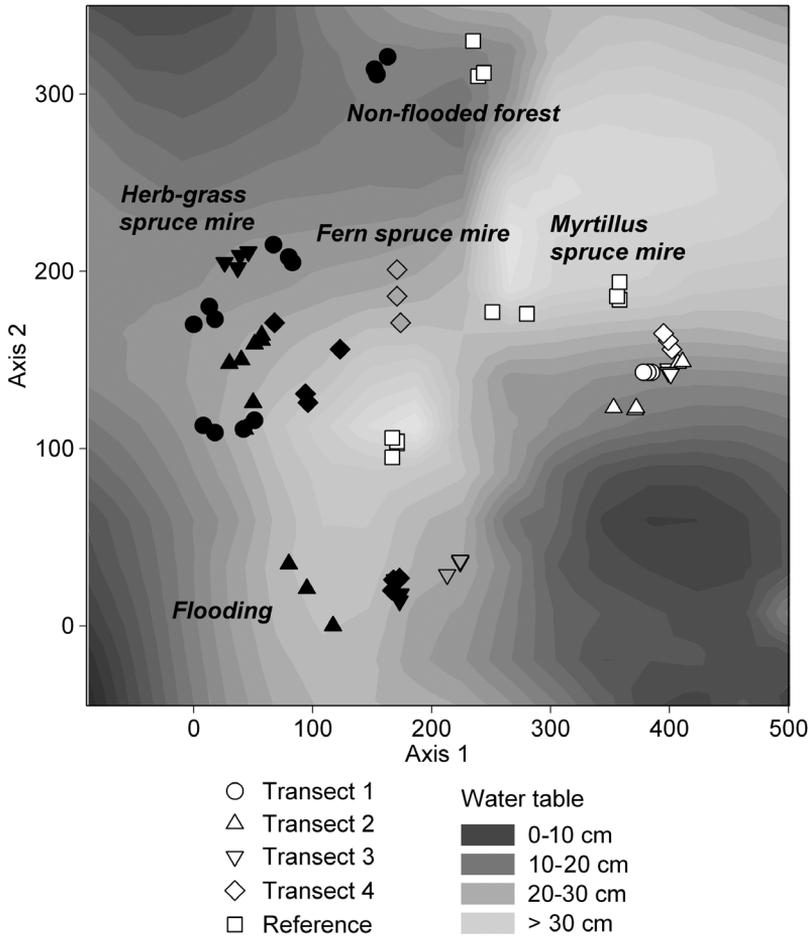


Fig. 3. DCA analysis of the spruce swamp with spatially smoothed average summer 2005 water table level for vegetation plots. Black symbols describe the flooded end, white symbols the non-flooded end of the buffer or reference, and gray symbols the vegetation plots with occasional flooding.

the fern or *Equisetum sylvaticum* spruce mire type was even steeper in the DCA ordination (Axis 1, Figs. 3 and 4) ten years after buffer construction than that resulting from the overland water flows (Axis 2). Although Axis 2 was shorter than Axis 1, this does not mean that the vegetation change due to flooding was insignificant, but rather that the α diversity in the flooded area (average number of species 7.6) was lower than that in the reference and the non-flooded margin (10.1). The coverage of the shrub layer averaged 15% near the inflow to the buffer (transect 1), decreasing further away to 0.5% on transect 2 and 4.5% on transect 3, 4 and outside the buffer at the reference site. *Salix phylicifolia* was found only on transect 1, where *Picea abies*, a typical species for the shrub layer elsewhere, was missing.

In the brook margin meadow, DCA segregated the vegetation plots in the buffer and in

the reference into two separate groups on Axis 1 (eig. = 0.91; Fig. 5), here named “Herb-grass spruce mire buffer” and “Swamp fen reference”, respectively. Probably the development of the buffer meadow and the reference had been different, partly because of their different positions with respect to the brook sediment accumulation. The buffer meadow’s development was affected by slower current and sediment accumulation, while the peat layer in the reference was apparently formed by terrestrialisation of the riparian zone. For this reason, the sub-site intended as a reference did not properly correspond to the conditions prior to buffer establishment, and we could not utilize the reference–buffer comparison. The heterogeneity on Axis 2 (eig. = 0.18) was due to differences in species abundance along the reference (Fig. 5), so that plots 13 and 14 had flooding indicators such as *Calla palus-*

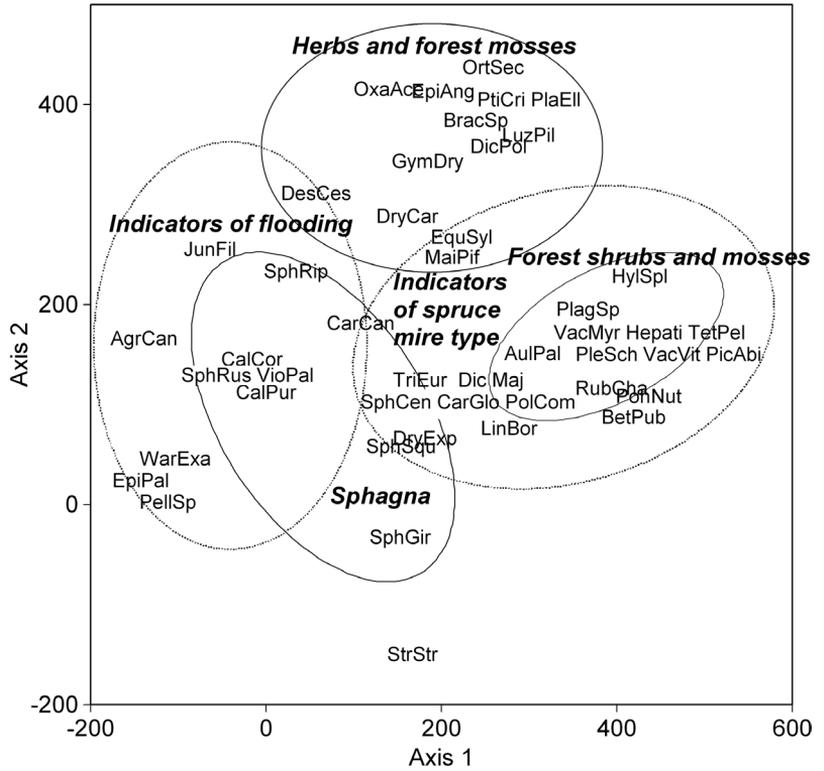


Fig. 4. DCA analysis for the species on the spruce swamp. The abbreviations of species were constructed by taking three first letters from both words of the species names (see Appendix 1).

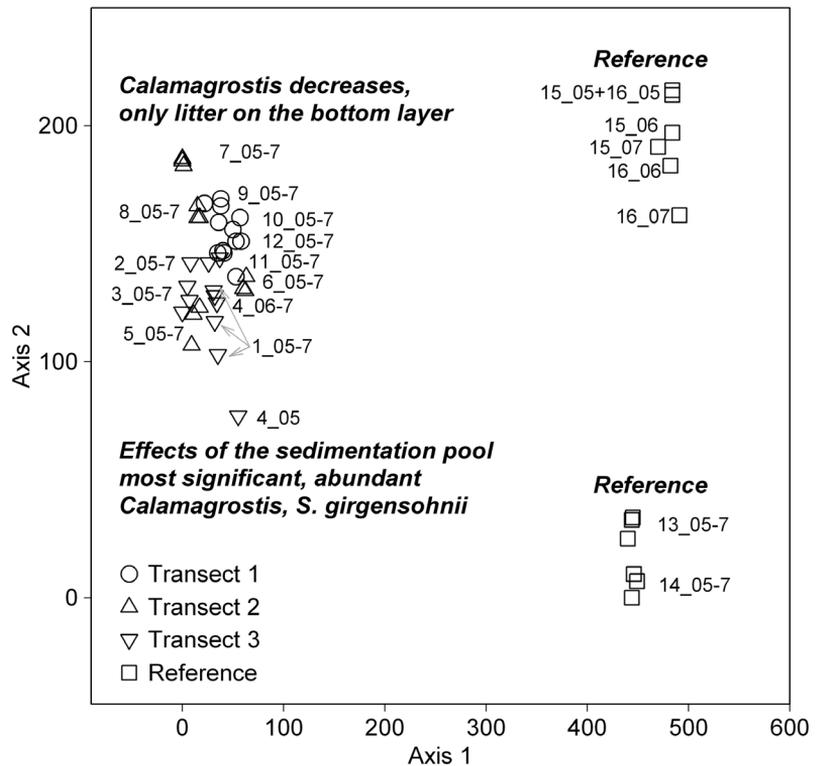


Fig. 5. DCA analysis for vegetation plots on the brook margin meadow. The numbers refer to vegetation plots (1–16) and years (2005–2007).

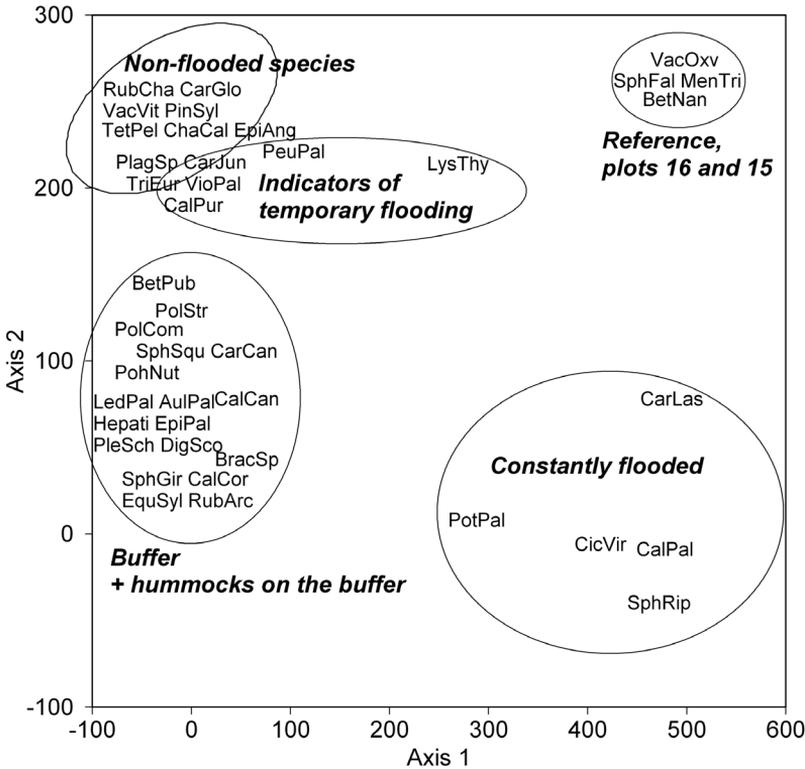


Fig. 6. DCA analysis for species on the brook margin meadow. Abbreviations of species were constructed by taking three first letters from both words of the species names (see Appendix 2).

tris, *Potentilla palustris*, *Sphagnum riparium*, and plots 15 and 16 also had in abundance indifferent fen species such as *Carex lasiocarpa*, *Vaccinium oxycoccos* and *Sphagnum fallax*. In addition, the heterogeneity on Axis 2 was due to microsite variation (Fig. 6). *Bryophytes* were found on hummocks and some were found on old stumps. Flat surfaces were either dwarf shrub dominated non-flooded areas or temporarily flooded with *Calamagrostis purpurea* and *Viola palustris*. The coverage of the shrub layer was 7%–50% on the buffer and 1%–30% on the reference. Both *Betula pubescens* and *Salix phyllifolia* were found on the buffer and on the reference, but one difference between the two was that no *Pinus sylvestris* or *Salix aurita* was found on the buffer and no *Alnus incana* was found on the reference.

Tree stand

There was no change in the amount of dead trees or tree canopy coverage on the spruce swamp or the brook margin meadow circular plots between

years 2005 and 2007 (Table 1). However, more trees were alive in the dry areas of the spruce swamp buffer (transect 4) and in the reference area. No dead trees were found on the brook margin meadow, where the present trees were low-growing (height 4–12 m) and the species were adapted to flooding even before the buffer construction.

Comparison of the proportion of tree deaths between the spruce swamp transects revealed that about 40% of trees were dead on the wettest transect 1 (Table 2). On transects 2, 3 and 4, the proportions were 35%, 19% and 20%, respectively. On the reference only 4% of the tree stand was dead. The tree canopy opened after the trees had lost their needles and the trunks had fallen (Table 1). Most of the dead trees, especially on transects 1–3, were colonized by saprotroph fungus *Fomitopsis pinicola*.

The biomass of live trees was highest on the reference, where the proportion of dead trees was low, and there were no stumps from previous cuttings (Table 2). Within the buffer, the decomposing tree biomass apparently released nutrients such as N and P (Table 2). Based on the

Table 1. The number of live and dead trees with relative canopy cover of live trees on tree-stand circles in the spruce swamp and brook margin meadow between 2005 and 2007. There was no change in the numbers of live and dead trees and canopy coverage between the years. (n.a. = not applicable).

Study site	Plot	<i>Picea abies</i>		<i>Betula pubescens</i>		<i>Betula pendula</i>	<i>Alnus glutinosa</i>	Relative canopy coverage (%)
		Live	Dead	Live	Dead	live	live	
Spruce swamp	1	2	2	–	–	–	–	48
	2	–	3	2	–	–	–	51
	3	1	2	1	–	–	–	100
	4	4	2	–	–	–	–	95
	5	5	–	1	–	–	–	98
Brook margin meadow	1	–	–	–	–	12	2	n.a.

Table 2. Number and biomass (kg) of live and dead trees and stumps, and their estimated contents of N and P (kg) in the 0.5 ha spruce swamp buffer and on the 0.1 ha reference.

Transect	Number		
	Live trees	Dead trees	Stumps
1	78	18	13
2	71	21	4
3	86	15	1
4	97	5	14
Reference	97	4	0
Transect	Biomass (kg)		
	Live trees	Dead trees	Stumps
1	7916	5472	1133
2	4795	6077	108
3	9501	4245	92
4	12017	1484	713
Reference	19276	1204	0
Transect	N (kg)		
	Live trees	Dead trees	Stumps
1	20.5	15.8	1.7
2	13.7	20.8	0.2
3	30.5	11.4	0.1
4	33.5	4.4	1.1
Reference	49.8	3.3	0
Transect	P (kg)		
	Live trees	Dead trees	Stumps
1	1.7	1.3	0.15
2	1.0	1.8	0.01
3	2.3	0.9	0.01
4	2.5	0.4	0.09
Reference	4.1	0.3	0

biomass estimates, the potential release of N was over 50 kg (about 150 kg ha⁻¹) and that of P more than 4 kg (ca. 13 kg ha⁻¹) when all dead biomass had decomposed.

Ground and bottom layer biomass and its total nitrogen content in the spruce swamp

Our limited data on N_{TOT} content in live plant biomass allowed only for a comparison between the above-ground parts of vascular plants and mosses, and peat. The total N content of above-ground vegetation and peat dry mass ranged from 16.0 g kg⁻¹ on transect 4 to 22.6 g kg⁻¹ at the wet end of the buffer (Table 3). The N_{TOT} content of peat varied from 9.2 to 21 g kg⁻¹, the lowest value being obtained on the wet part of the buffer and the highest on the reference. Within the buffer, the peat layer was weakly decomposed

Table 3. N_{TOT} contents in vegetation and peat dry mass (g kg⁻¹), in living biomass (no peat), in peat, in vascular plants and in mosses of the spruce swamp.

Transect	N _{TOT} contents (g kg ⁻¹ dry mass)				
	Total	Living biomass	Peat	Vascular plants	Mosses
1	22.6	20.8	9.2	23.0	18.0
2	20.3	21.4	15.0	22.5	17.0
3	22.0	24.5	12.0	26.3	19.0
4	16.0				
Reference	20.2	20.1	21.0	22.4	16.3

and dominated by *Sphagnum* residues, while on the reference the peat was more decomposed, containing abundant wood remains. The dry mass per area of the moss layer on the reference, consisting mainly of forest mosses, was somewhat lower than that of the more *Sphagnum* dominated buffer (Table 3).

The above-ground dry biomass varied from 129 g m⁻² to 177 g m⁻² (Table 4). About 80% of the plot in transect 1 was subject to a strong overland inflow, which may have affected the vegetation coverage. However, the total moss biomass, including green parts of mosses or capitula of *Sphagna*, was generally lowest in the reference. The moss biomass increased towards the dry areas of the buffer, while the biomass of vascular plants decreased: e.g. *Calamagrostis purpurea* was more abundant and lush in the wet areas of the buffer. In the reference, herbs were more common than on the buffer. Overland flow had evidently led to the replacement of perennial dwarf shrubs by annual grasses and herbs.

Water levels and water quality

In the spruce swamp, the water table differed between seasons ($p \leq 0.0005$), being higher during the spring flood and summer (–13 cm from the soil surface) than in winter during the non-frost season (–23 cm), but no statistical significance emerged between the transects (Table 5). However, the small systematic differences were apparently critical for the non-flood tolerant vegetation. The water table level in the reference was actually lower and the aerobic

Table 4. Vegetation biomass, the biomass of mosses capitula and vascular plants and ferns of the spruce swamp. The overland water flow covered about 80% of the vegetation plot on transect 1.

Transect	Vegetation biomass (g m ⁻²)	Biomass of mosses (g m ⁻²)	Biomass of vascular plants (g m ⁻²)
1	129	22	107
2	167	80	87
3	177	105	72
4	159	132	27
Reference	151	26	125

peat layer thicker than shown in Table 5, but it could not be documented as the water wells did not extend deep enough to capture the lowest water tables in summer. All the other transects can thus be compared with each other, but not with the reference.

The values of pH differed between transects ($p = 0.001$) and seasons (0.014) on the spruce swamp. The wet areas of the buffer differed from the reference, and transect 3 differed from transect 4 (Table 5). Also, transects 1 and 2 differed indicatively from transect 4 ($p = 0.062$ and $p = 0.063$, respectively).

In the brook margin meadow, the water table showed differences between the transects ($p = 0.036$), but the linear mixed model could not resolve the full patterns of difference. Only transect 1 (–8 cm, SE = 1.5) differed indicatively from transect 2 (–20 cm, SE = 1.8, $p = 0.080$). The water tables on transect 3 and the reference were –8 and –17 cm (SE = 0.95 and 1.77, respectively). pH values did not differ significantly. In the buffer area, pH was 6.12 ± 0.03 and in the reference 6.06 ± 0.10 .

During the sampling period, the concentration of P_{TOT} in the spruce swamp buffer inflow decreased (Fig. 7), while in the brook margin meadow, the concentrations of P_{TOT} and PO₄³⁻ increased. In both buffers, the concentrations of N_{TOT}, NO₂ + NO₃, P_{TOT} and PO₄³⁻ were occasionally higher in the outflow than in the inflow. Due to the diffuse water flow within and outside the buffer, we were not able to measure the nutrient balance in the buffer. Assuming a low ratio of precipitation and evapotranspiration within the relatively small buffer area, most of the water flows through the buffer. Nearly similar inflow and outflow concentrations of N and P in those conditions would indicate low net binding of the nutrients.

Table 5. Average water table depth ± SE) and pH (minimum and maximum) in the spruce swamp.

Transect	Water table (cm) ± SE	pH	Min–Max
1	–9 ± 1.2	5.15	4.52–5.99
2	–10 ± 1.5	5.12	4.58–6.53
3	–19 ± 2.2	4.92	4.33–6.39
4	–28 ± 1.9	5.70	4.74–6.60
Reference	–32 ± 2.2	5.83	4.54–6.56

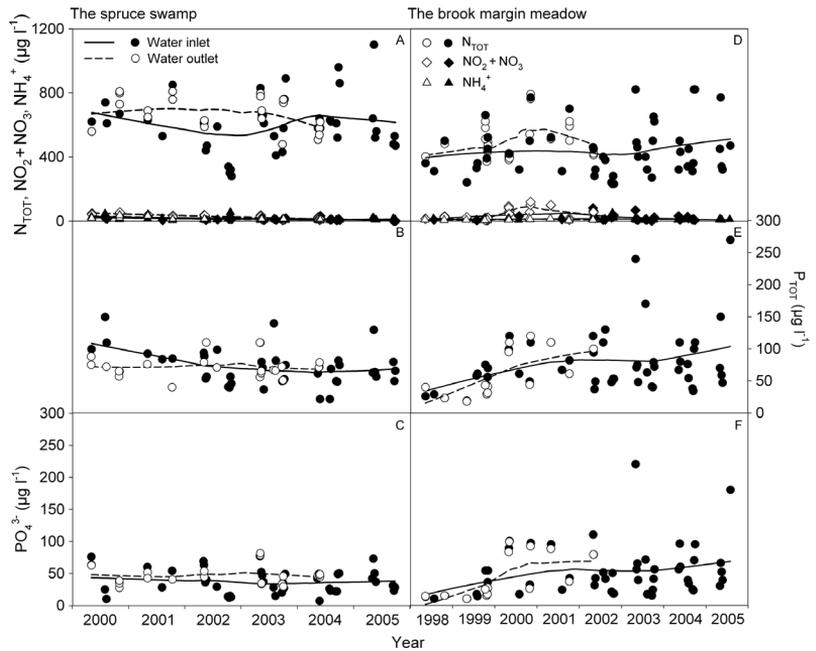


Fig. 7. Concentrations of N_{TOT} , $\text{NO}_3 + \text{NO}_2$, NH_4^+ (A and D), P_{TOT} (B and E) and PO_4^{3-} (C and F) in the water inlet and outlet in the spruce swamp and the brook margin meadow.

Discussion

Our buffer sites differed in many respects. Peat depth was lower in the spruce swamp than in the brook margin meadow. The spruce swamp had a significant Norway spruce stand, while the brook margin meadow was a flooded habitat dominated by grasses and herbs, and it supported a much lower tree stand consisting of deciduous species. However, although the spruce swamp and the brook margin meadow were probably very different before the buffer construction, they had developed some similarities during the ten years following the buffer construction, including the presence of common flooding-tolerant species such as *Calamagrostis purpurea*, *Carex canescens* and *Viola palustris* on both sites. *Viola palustris* was probably an original species at both sites, adapted well to the habitat under the influence of the overland flow. *Sphagnum girgensohnii* and *Calliergon cordifolium* were abundant in the moss layer at both sites. On the other hand, *Rubus chamaemorus* and *Carex globularis* may be originally abundant species, but they are probably declining, although they can still survive on hummocks.

Rather than the disappearance or appearance of species, we found a decline or expansion of

some species already occupying the sites. In the spruce swamp, the species indicating flooding according to mire biotope descriptions (Eurola *et al.* 1995), e.g. *Calamagrostis purpurea*, *Sphagnum riparium*, *S. girgensohnii*, increased, while the forest mosses and shrubs (e.g. *Vaccinium myrtillus*, *Pleurozium schreberi* and *Hylocomium splendens*) decreased in coverage. The decline of original spruce swamp species especially seems a more prominent sign of flooding than colonization of the buffer by new, flood-tolerant species. Some species, such as *Viola palustris* and *Trientalis europaea*, kept their positions in the communities of the buffer. Needle loss after the death of trees and the gaps formed by fallen trunks increased light penetration to the ground vegetation. Together with a lowered pH due to the spread of acidic *Sphagnum* species in the buffer, the improved irradiation conditions may have favored *C. purpurea* and impaired the growth of ferns and forest species. The change in vegetation is probably still ongoing, since the greatest exchange of forest species for aquatic-tolerant species has taken place predominantly at the uppermost end of the buffer.

On the brook margin meadow, the buffer vegetation type represented at least temporarily flooding herb-grass spruce mire, while the refer-

ence sub-site was swamp fen (Figs. 5 and 6). The natural flooding effect was indicated by *Calla palustris*, *Lysimachia thyrsoiflora* and *Sphagnum riparium* on the herb-grass spruce mire type especially, on plots close to the brook; the presence of these species was decreasing towards the sedimentation pond. Annual thawing could release nutrients from soil, which may also affect the vegetation of the buffer. *Calamagrostis purpurea* and *Carex canescens* may have increased after buffer construction, as they were the most abundant species just below the sedimentation pond. Some species known to indicate flooding conditions in mires (*Potentilla palustris*, *Calliergon cordifolium* and *Sphagnum riparium*) were common in the entire buffer area. Similarly to our observations, Huttunen *et al.* (1996) found no great differences in the flora between the overland flow area and a sedge-dominated mesotrophic fen reference, although some species were favored on the flooded sites. It was not possible to show in our brook margin meadow, which changes were caused by buffer construction and which by spring flooding of the brook. It is notable that buffers should not be constructed at sites affected by frequent natural floods (e.g. Joensuu *et al.* 2004).

The decrease in forest species and the increase in flooding-tolerant species may have affected the vegetation biomass (Table 4) on the spruce swamp buffer. The total above ground vegetation biomass was quite similar on all five plots in the spruce swamp (Table 4), but overland water flows seemed to increase the moss biomass. Also, the combined vascular plant biomass was higher in the wet areas of the buffer as compared with that in the dry ones, but still lower than in the fern spruce mire type reference. This suggests that the vegetation change is still continuing. Liikanen *et al.* (2006) measured an almost two-fold growth in plant biomass after a ten-year monitoring period in a wetland receiving runoff from a peat mining site, the below-ground biomass also being significantly higher in the buffer (Huttunen *et al.* 1996). Silvan *et al.* (2004) reported a significant increase in plant biomass after experimental nutrient addition in a peatland forestry buffer, observing the greatest increase in *Eriophorum vaginatum* and *Sphagnum*, although the proportional increase in

above-ground herb biomass was highest. No species that are abundant on our spruce swamp site are known to have a large below-ground biomass. Thus it does not seem possible that large quantities of nutrients could be bound in below-ground biomass there. Only peat-forming *Sphagnum* species could have the potential to trap nutrients from the active nutrient cycle.

In the spruce swamp, the N content in the total above-ground vegetation and surface peat layer appeared to be similar in the buffer and in the reference, with reservations due to our limited data set (Table 3). Although we measured lower peat N concentrations in the buffer than in the reference, live vegetation N content varied inversely. In a constructed wetland receiving peat mining runoff waters, the increase in total N content may be as high as 40% (Huttunen *et al.* 1996). In a buffer prepared for peatland forestry an increase of 25% (Silvan *et al.* 2004) in the above-ground biomass was reported after a nutrient addition experiment. Since no such change was found in our buffer, and the nutrient inflow was low (Fig. 7), the retention of nutrients was probably also low.

Buffers may bind nutrients in the plant biomass by microbial immobilization and chemical absorption (Heikkinen *et al.* 1995). The retention capacity by plant and microbial uptake may initially be high, but the ecosystem becomes biologically and chemically saturated within only a few years (Heikkinen *et al.* 1995). With our meagre data on peat and plant biomass and N content, we were not able to show a significant increase or clear difference in the total N binding capacity at different distances from the water inlet as compared with the reference (Tables 3 and 4). Furthermore, we did not measure the P content of the biomass, which could be more important than N binding as regards water protection measures. According to Silvan *et al.* (2004), P concentration in plant tissues did not increase after nutrient addition to the buffer, but the increased plant biomass after fertilization bound more P. On the other hand, Huttunen *et al.* (1996) reported a 5% decrease in total P storage in the buffer plants as compared with that in the reference area, in spite of an increase in total phytomass. Väänänen *et al.* (2006) also reported

negligible P retention in mosses and vascular plants after fertilizer addition. Laiho *et al.* (2006) showed in a chronosequence study, that drainage increased the net P uptake of the vascular plant compartment. The flooding or rewetting of a peatland ecosystem that takes place in buffer establishment may produce a contrary effect.

A significant reason for nutrient release in a buffer such as the spruce swamp may be the dying and decomposing tree stand. Needles release nutrients rapidly after the death of the tree, while stem wood holds the nutrients longer (*see* Palviainen *et al.* 2004). At least some of these nutrients may leach, while some may be bound. Furthermore, as nutrient consumption is reduced by tree death, more nutrients become available. If trees were harvested in association with buffer construction, pressure for nutrient leaching could be reduced accordingly.

A practical problem is the formation of bypass water channels in the tracks of forest machinery. The channels may reduce the contact time of inflow water with the soil. The N and P concentrations in the water inflow and outflow of the spruce swamp buffer and in the brook margin meadow were typical of surface or vadose waters in drained peatlands (*see* Joensuu *et al.* 2001a), suggesting that only little enrichment occurred before the buffer. Furthermore, nutrients cannot accumulate if the buffer is constructed in an area vulnerable to spring floods, which may flush the nutrients already adsorbed by the buffer.

Conclusions

On the basis of what is empirically known on species indication of flooding and nutrient status in peatland biotope classifications, raising of the water table rather than increased nutrient load seems to be the factor causing vegetation changes in peatland buffers. A decrease in canopy coverage as a result of degeneration of the conifer stand is important in creating gaps and reducing canopy light extinction. The vegetation change in favor of flood-tolerant species can be used as a tool indicative of the effective area of water flows in the original area reserved as a peatland buffer.

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Appendix 1. List of species on the spruce swamp.

Ground layer: *Agrostis canina*, *Betula pubescens*, *Calamagrostis purpurea*, *Carex canescens*, *Carex globularis*, *Deschampsia cespitosa*, *Dryopteris carthusiana*, *Dryopteris expansa*, *Gymnocarpium dryopteris*, *Epilobium angustifolium*, *Epilobium palustre*, *Equisetum sylvaticum*, *Juncus filiformis*, *Linnaea borealis*, *Luzula pilosa*, *Maianthemum bifolium*, *Orthilia secunda*, *Oxalis acetosella*, *Picea abies*, *Rubus chamaemorus*, *Trientalis europaea*, *Vaccinium myrtillus*, *Vaccinium vitis-idaea*, *Viola palustris*

Bottom layer: *Aulacomnium palustre*, *Brachythecium* sp., *Calliergon cordifolium*, *Straminergon stramineum*, *Dicranum majus*, *Dicranum polysetum*, *Hepaticae*, *Hylocomium splendens*, *Pellia* sp., *Plagiomnium ellipticum*, *Plagiothecium* sp., *Pleurozium schreberi*, *Pohlia nutans*, *Polytrichum commune*, *Ptilium crista-castrensis*, *Sphagnum angustifolium*, *Sphagnum centrale*, *Sphagnum girgensohnii*, *Sphagnum riparium*, *Sphagnum russowii*, *Sphagnum squarrosum*, *Tetraphis pellucida*, *Warnstorfia exannulata*

Appendix 2. List of species on the brook margin meadow.

Ground layer: *Betula nana*, *Betula pubescens*, *Calamagrostis canescens*, *Calamagrostis purpurea*, *Calla palustris*, *Carex canescens*, *Carex globularis*, *Carex juncella*, *Carex lasiocarpa*, *Chamaedaphne calyculata*, *Cicuta virosa*, *Epilobium angustifolium*, *Epilobium palustre*, *Equisetum sylvaticum*, *Galium palustre*, *Ledum palustre*, *Peucedanum palustre*, *Lysimachia thyrsiflora*, *Menyanthes trifoliata*, *Pinus sylvestris*, *Potentilla palustris*, *Rubus arcticus*, *Rubus chamaemorus*, *Trientalis europaea*, *Vaccinium oxycoccos*, *Vaccinium uliginosum*, *Vaccinium vitis-idaea*, *Viola palustris*

Bottom layer: *Aulacomnium palustre*, *Brachythecium* sp., *Calliergon cordifolium*, *Dicranum scoparium*, *Hepaticae*, *Marchantia*, *Plagiothecium* sp., *Pleurozium schreberi*, *Pohlia nutans*, *Polytrichum commune*, *Polytrichum strictum*, *Sphagnum fallax*, *Sphagnum fimbriatum*, *Sphagnum girgensohnii*, *Sphagnum riparium*, *Sphagnum squarrosum*, *Tetraphis pellucida*