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DEVELOPING HYDROLOGIC THRESHOLDS FOR *SPHAGNUM* RECOLONIZATION ON AN ABANDONED CUTOVER BOG

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Abstract: After 30 years of abandonment, a block-cut peatland near Cacouna, Quebec, Canada, has naturally regenerated *Sphagnum* mosses on $< 10\%$ of its area, typical for these disturbed systems. Distinct hydrologic conditions were observed where *Sphagnum* has successfully recolonized, providing a basis for establishing thresholds that can be targeted by peatland restoration managers. Sites where *Sphagnum* mosses recolonized were characterized by high water table (mean-24.9 ± 14.3 cm), soil moisture (θ) $> 50\%$, and soil-water pressure (Ψ) >-100 mb. These hydrologic indicators were spatially organized according to the morphology of block- cut trenches, which typically include raised baulks, shallow ditches, and the convex skag (unused turf) deposits along the central axis of the trench. Topographically low areas like the shallow ditches (D) and lower parts of the skag (LS) adjacent to the ditches maintained θ and $\Psi > 50\%$ and -100 mb, respectively, for 100% of the summer period. About 83% of all *Sphagnum* recolonization that occurred in the study trench did so in these areas. In more raised areas like the mid- and center portion of the skag, θ and Ψ eventually fell below these thresholds, and these areas generally did not support *Sphagnum,* except in a few localized microtopographic depressions in the lower (downslope) end of the trench. While this lower end of the trench had all the *Sphagnum* species that were present in the trench, even there it was only 38% of the total area. It seems that even short periods of low Ψ may restrict *Sphagnum* reestablishment in an otherwise favorably wet site.

Key Words: peatland, restoration, hydrology, *Sphagnum*-water relations, soil moisture, water table

INTRODUCTION

Hydrologic, edaphic, and ecological impacts caused by drainage and peat harvesting in bogs are severe, and the capacity to regenerate natural functions is lost, at least for a very long time (Van Seters and Price 2000). The need for post-harvesting management has been demonstrated by Quinty and Rochefort (1997) and Price et al. (2000), but little is known about the hydrologic thresholds that facilitate or limit the reestablishment of *Sphagnum* mosses and the return of hydrologic and ecological functions.

Bogs are characterized by a diplotelmic soil structure, where the acrotelm (Ingram 1978) regulates the water storage and maintains a high water table and adequate supply of water to non-vascular plants, notably *Sphagnum* mosses. Removal of the acrotelm following bog drainage exposes the underlying formerly waterlogged peat of the catotelm (Ingram 1978), resulting in subsidence caused by oxidation and compression (Schothorst 1977, Van Seters 1999, Waddington and Warner 2000). The smaller sized pores of this more decomposed and compacted peat (Okruszko 1995) have a reduced water-storage capacity (Beets 1992), lower saturated hydraulic conductivity (Boelter 1965, Päivänen 1973, Van Seters 1999), and higher water-retention capacity (Schlotzhauer and Price 1999). Consequently, the water table is more variable and deeper in summer (Price 1996, 1997). Upward capillary flow of water from the deeper water table does not meet evaporative demands at the peat surface, so soil moisture and soil-water pressure decrease, and water demands are supplied mainly by changes in unsaturated zone storage (Price 1997). Furthermore, when soil-water pressure in the cutover peat drops below -100 cm (mb), *Sphagnum* can no longer generate the capillary forces (Hayward and Clymo 1982) needed to extract moisture from the cutover surface (Price 1997). *Sphagnum* cannot survive extended dry periods (Sagot and Rochefort 1996). In bare cutover peat, soil-water pressure can drop to values lower than -300 cm (Price et al. 1998), and hence, such peats present a hostile environment for *Sphagnum.* However, there is still little empirical evidence that relates the hydrologic and physiological processes of *Sphagnum* establishment. Campeau and Rochefort (unpublished data 1996) found pre-saturated then isolated *Sphagnum* diaspores (plant fragments) in an enclosed chamber

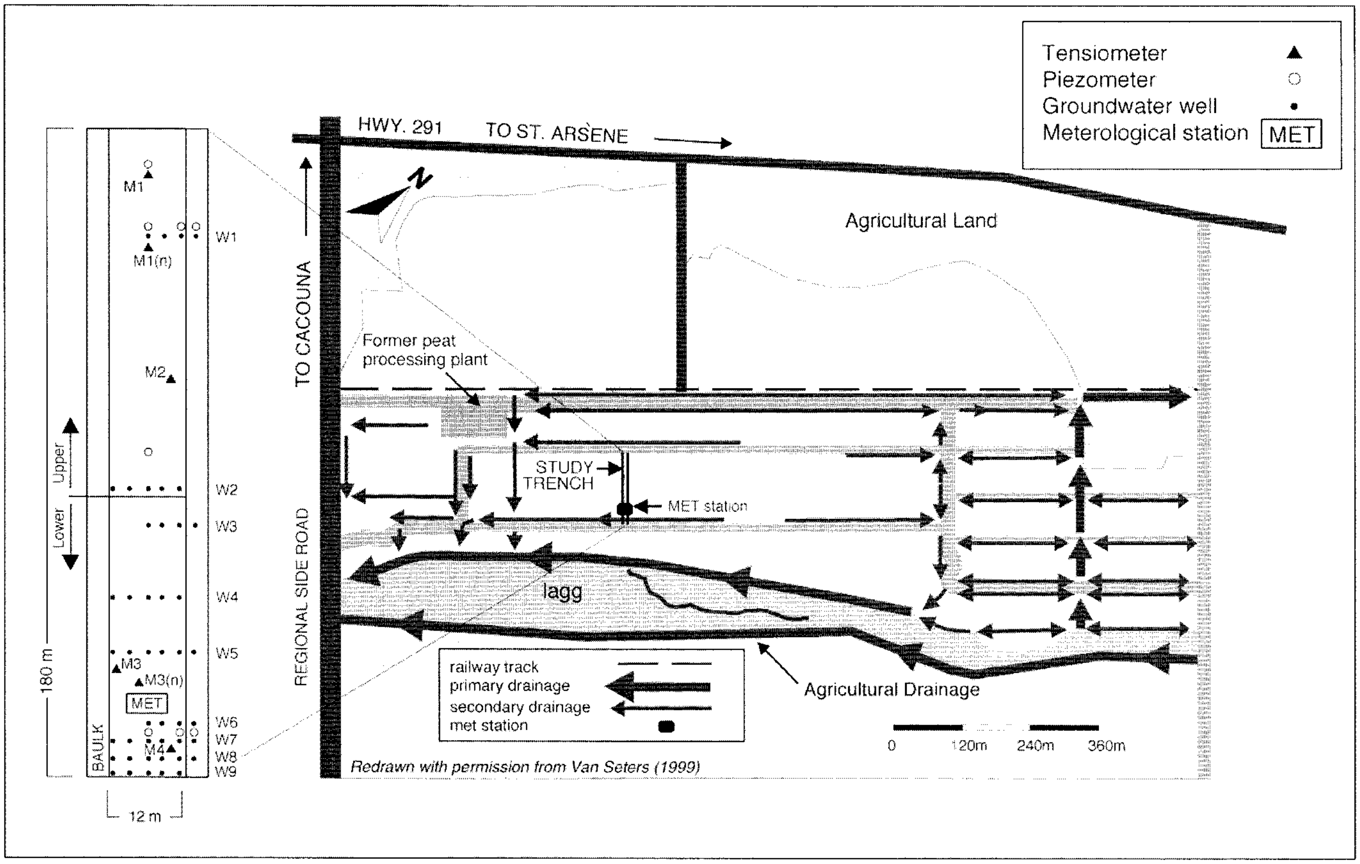

Figure 1. Location and study area.

could not endure relative humidity less than 74% for periods greater than one week, and even less time for lower humidity. Establishment under field conditions is more difficult, however, because of the variability of soil-water supply and the duration of inhospitable conditions. However, the recolonization of *Sphagnum* in some abandoned peatlands, although very limited (e.g., Lavoie and Rochefort 1996, Girard 2000), indicates that suitable hydrologic and microclimatic conditions can occur, and these may provide clues for establishing hydrologic thresholds useful to restoration managers. Therefore, the objectives of this paper are

(1) to understand and quantify soil moisture, soil-water pressure and water-table relationships of peat in block cut trenches in an old abandoned cutover bog, and
(2) to establish thresholds of soil moisture and soil-water pressure by associating the distribution of these variables with the observed patterns of *Sphagnum* recolonization.

STUDY AREA

The Cacouna peatland (47° 52′ N, 69° 27′ W), located approximately 10 km northeast of Rivière-du-Loup, Québec, Canada is a domed bog of the Low Boreal Wetland Region (NWWG 1988). Data from the St. Arsène weather station (2 km from the study site) indicate that the climate is humid continental with a mean annual total precipitation (1963–1990) of 924 mm (27% as snow) (Environment Canada 1993). The mean annual temperature (1963–1990) is 3°C, with mean temperatures in January and July of −12°C and 18°C, respectively (Environment Canada 1993).

The bog began to form approximately 9800 ± 100 years ago (Van Seters 1999) upon a clay substrate of low hydraulic conductivity deposited by the Goldthwait Sea (Dionne 1977). The bog originally covered an area of 210 ha, but agricultural development and road building along the periphery have reduced the size of the peatland to 148 ha (Girard 2000). A railway bisects the peatland roughly along a natural groundwater divide, which has subsequently compressed the underlying peat, creating a barrier that has separated the bog into two distinct hydrologic sections (north and south). The southern section of the bog (80 ha) was the focus of this study (Figure 1).

Harvesting of the southern area began in 1942 and was progressively abandoned between 1968 and 1972 (Girard 2000). Approximately 88% (~70 ha) of this bog section was exploited for peat using the manual block-cut harvesting technique. Exploitation using this method has left behind a landscape of alternating raised baulks 3-m wide and mined trenches typically 10-m wide and 180-m long. The trenches are dominated by ericaceous shrubs and trees. *Sphagnum* has recolonized less than 10% of the southern section, exclusively in trenches (Girard 2000).

A trench that had typical form and vegetation structure was selected to study the hydrologic and ecological patterns and processes (Figure 1). Trenches have a distinct microtopography characterized by a convex cross-sectional profile. Although there is some variability, the center-skag (CS) is typically the highest point of this convex profile, which is then followed in decreasing elevation by the mid-skag (MS), lower skag (LS), and ditch-edge (D). A description of their position with respect to local topography is explained later. Hydrologic variables were analyzed for these morphological units within the trench.

The trench had a slope of 0.013 along its long-axis. Vegetation, including *Sphagnum,* was densest at the lower end of the trench. Here, the secondary drains that collect water from the tertiary ditches bordering all trenches were at least partly occluded from slumped peat. Van Seters and Price (2000) suggested that, in general, tertiary ditches (i.e., ditch-edge, D) are no longer important for peatland drainage, secondary ditches have lost much but not all their capacity, and primary ditches remain fully functional.

METHODS

Data were collected from 18 June to 15 August 1997 (59 days) and 09 May to 14 August 1998 (97 days). Meteorological data were collected at a meteorological station located in the south end of the trench (Figure 1). *Precipitation* (P) was measured with a manual and a tipping bucket rain gauge 0.5 m above the cutover peat surface. Evapotranspiration, Et (mm), was calculated for *Sphagnum*-covered and bare, cutover surfaces with the combination model of Priestley and Taylor (1972) where

$$\mathrm{Et} = \alpha(s/(s + q))(Q^* - Q_G)/L\ \rho_w \qquad (1)$$

and where L is the latent heat of vaporization (J kg^{-1}), ρ_w is the density of water (kg m^{-3}), s is the slope of the saturation vapour pressure-temperature curve (Pa °C^{-1}), q is the psychometric constant (0.0662 KPa °C^{-1} at 20 °C), Q^* is the net radiation flux (J d^{-1}), and Q_G is the ground heat flux (J d^{-1}). In equation (1), based on a calibration done with soil lysimeters, $\alpha = 1.07$ for areas with *Sphagnum* regeneration and 0.85 for locations in the trench where it was absent (Van Seters and Price 2000). Net radiation was recorded using two net radiometers positioned 1.5 m above a *Sphagnum*-ericaceous, and bare, peat-ericaceous surface. The ground heat flux was measured with two soil heat flux plates 0.5 cm beneath bare peat surface and *Sphagnum* moss surface in 1997, and with one plate beneath bare peat in 1998. Air temperature was measured with a shielded thermistor located 1 m above the peat surface.

Water table was monitored twice a week with nine well transects oriented transverse to the long axis of the trench (Figure 1). Each transect consisted of four to six 2.0 cm i.d. PVC wells slotted along their entire length, covered with 200-mm geotextile screen, and spaced approximately 3 m apart, to depths ranging from 1.0 to 2.0 m below the surface depending on peat thickness. Piezometers had only the bottom 20 cm of pipe slotted. All pipe intakes were above the peat-mineral interface, except for one that extended into the clay for the purpose of measuring hydraulic conductivity. Field estimates of saturated hydraulic conductivity (bail tests) were conducted on all piezometers in early July and August in both years using the hydrostatic time-lag method of Hvorslev (1951).

Volumetric soil moisture (θ) was measured using Time Domain Reflectometry (TDR) at 18 transects positioned 10 m apart along the trench. Each transect was divided into seven sampling units, which coincided with the general microtopography of the trench (i.e., CS, MS, LS, and D). TDR probes with 10-cm-long wave-guides were inserted into the peat surface at a 23 degree angle to obtain an average θ over a 4 cm depth. Sampling was done once in each of the months of June, July, and August 1998.

Soil-water pressure (Ψ) in surface peat was measured using a series of L-shaped tensiometers 2 cm below the surface at locations shown in Figure 1. Soil-water pressure was also measured in cutover peat covered by a *Sphagnum* cushion, in the manner described above. A TDR probe with 10-cm wave-guides was inserted into the peat surface at four different points closely surrounding the tensiometer tip, and measurements of θ and Ψ were taken every 2–3 days.

Dry bulk density (ρ_B) of peat was determined gravimetrically, where

$$\rho_B = M_{\mathrm{dry}}/saturated\ sample\ volume \qquad (2)$$

where M_{dry} is the dry sample mass (g), dried at 95 °C until peat mass remained constant. Cores were cut into 5 cm blocks, saturated in standing water, weighed ($M_{\mathrm{saturated}}$) and then drained for 24 hours to find its drained mass (M_{drained}), to determine specific yield (Sy), where

$$Sy = ((M_{\mathrm{saturated}} - M_{\mathrm{drained}})/\rho_w)/(M_{\mathrm{saturated}}/\rho_w) \qquad (3)$$

and ρ_w is the density of water, assumed to be 1000 kg m^{-3}.

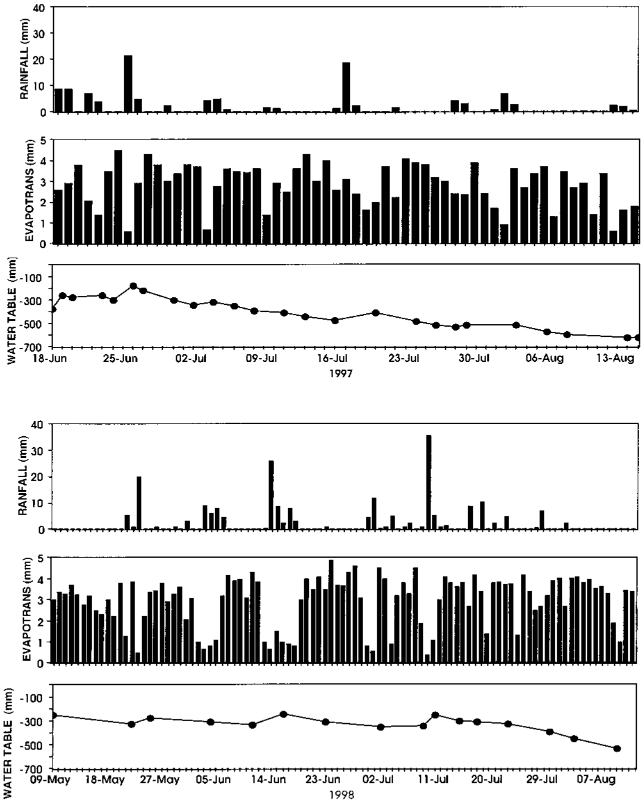

Figure 2. Rainfall, evapotranspiration, and mean water tables at the Cacouna bog, 1997 and 1998.

To calibrate TDR probes, a peat block (40 × 34 × 20 cm) was instrumented with two sets of tensiometers and TDR probes (20 cm wave-guides), inserted horizontally into the peat through drilled holes in the tub wall. Water was sprinkled onto the peat over a 48-hour period until the sample reached saturation. The peat was allowed to dry, then θ and Ψ in the block were measured at 3-day intervals.

A *Sphagnum* survey of the trench was conducted in 1998 using the point sampling method (Floyd and Anderson 1987, Bonham 1989). *Sphagnum* cushions touching an upright metal rod (1 cm diameter) were recorded at every 0.5 m along six longitudinal transects corresponding to the morphology of the trench, including D, LS, and MS both sides of the centerline. *Sphagnum* species were not identified.

RESULTS

Water Inputs and Outputs

Total precipitation (P) recorded during the 1997 and 1998 study periods was 118 mm and 218 mm, respectively (Figure 2). Precipitation for June and July 1997 and 1998 was 68% and 109% of the long-term means (Environment Canada 1993). Rainfall totals measured in the tipping bucket and manual rain gauges were within 3% of each other.

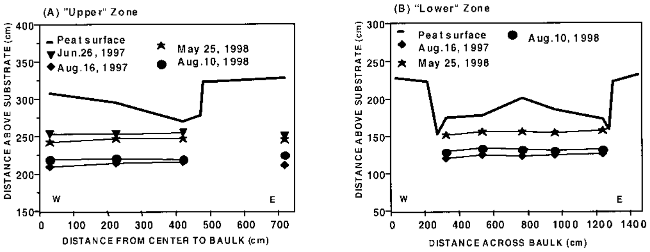

Figure 3. Transverse topographic and water-table-position profiles for the trench from 18 June to 9 August 9 1997 and 9 May to 14 August 1998.

Daily evapotranspiration ranged from 1.9 to 3.8 mm d^{-1} for both years (Figure 2) and varied depending on antecedent soil moisture conditions and surface cover type. Average evapotranspiration in the trench was 2.8 (±1.1) mm d^{-1}. Total evaporative water loss (E) was 167 and 285 mm for the 1997 (59 days) and 1998 (97 days) study periods, resulting in a net water deficit (P-E) of 49 and 65 mm, respectively. The drier conditions in 1997 caused a steady decline of the water table, whereas in 1998, water-table levels remained fairly steady until mid-July, largely because of water inputs from major precipitation events on 14 June (26.2 mm) and 10 July (35.6 mm).

In general, the water table was closest to the surface at the south (101–180 m) end of the trench (Figure 3). Mean water-table depth (± standard deviation) in this ''lower'' section of the trench for 1997 and 1998 was −34.0 (± 15.6) and −25.8 (± 13.5) cm, respectively. In contrast, the ''upper'' zone of the trench (0–100 m) for both study periods was −51.2 (± 18.0) and −44.8 (± 17.1) cm. Water table was deepest under the baulks. These have virtually no *Sphagnum* recolonization, so little further consideration was given to them in this study. Water-table position varied throughout the trenches depending on the local morphology associated with the upwardly convex profile caused by the moderately decomposed skag deposits. The water table remained relatively flat under the peat surface and, therefore, was typically deepest at the CS, followed by the MS, LS, and D. Duration analysis indicated that the water table resided closer to the peat surface in the ''lower'' trench zone for a greater period of time over the summer than in the ''upper'' zone (Figure 4) and for longer in the LS/D (>80% of time above 40 cm) compared to the CS and MS (>40% and 70% of time above 40 cm, respectively). The water table at locations where *Sphagnum* had recolonized (lower trench) had a mean water-table depth similar to a nearby natural bog and was lowest where there was

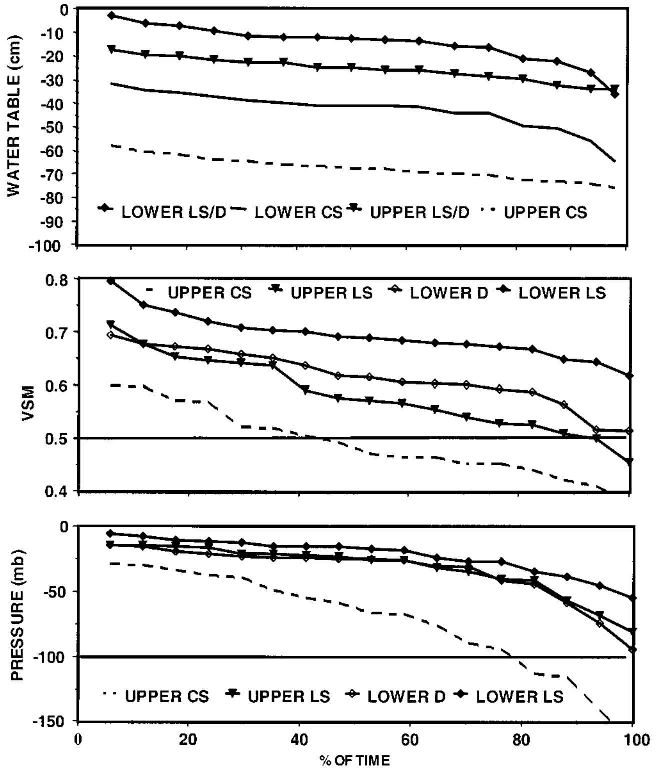

Figure 4. Duration of time that water table (top), volumetric soil moisture (middle), and soil-water pressure (bottom) exceeded respective y-axis values. Water table is from wells along M1 and M4; soil moisture and pressure data were from M1 (Upper CS), M2 (Upper LS), M3 (Lower D), and M4 (Lower LS under Sphagnum).

bare cutover peat (Table 1). There was much less variability at the natural bog.

The geometric mean hydraulic conductivity at all depths of the trench (n = 37) was 1.0 × 10^{-5} (± 3.1 × 10^{-5}) cm s^{-1}. At a hydraulic gradient of 0.01 for the trench, the seepage rate through trench peat was calculated to be 8.6 × 10^{-3} m d^{-1}. This is too slow for a significant transfer of water from ''upper'' to ''lower'' parts of the trench. However, spatially discontinuous seepage of water along the ditch-edge (D) was visible during wet conditions. Exchanges between bog ground water and the regional aquifer were also limited because of the low hydraulic conductivity of the underlying clay substrate (Ks = 5 × 10^{-8} cm s^{-1}). Peat showed little variation in ρ_B and S_y in the vertical profile below the cutover surface. The baulk had mean ρ_B of 0.14 g cm^{-3} compared to trench peat at 0.12 g cm^{-3}. There was no significant difference between ρ_B between CS, MS, LS, or D.

Spatial and Temporal Trends in Volumetric Soil Moisture

Soil moisture (θ) at 2-cm depth (average of 0–4 cm zone) sampled along the length of the trench varied considerably in its spatial distribution throughout the study period, averaging 55.4±11.5% and 49.3±14.8% in July and August 1998, respectively. The soil moisture was much more closely related to the local morphology (CS, MS, LS, and D) compared to its variation along the trench (i.e., upper vs. lower). Both LS and D, however, regularly had higher θ compared to the CS and MS (Figure 5). The LS and D mean θ did not drop below 50% throughout the study period, whereas the CS and MS fell below 40% by early August. Additional variation was associated with microtopography superimposed onto the general profile, although this was hard to quantify. The most variable θ was always at the CS and the least along D. Soil moisture and water-table elevation followed a weak linear relationship (Figure 6). The linear relationship was strongest during wetter months as opposed to drier months.

Spatial and Temporal Trends in Soil-Water Pressure

Soil-water pressure (Ψ) measured 2 cm below the surface became lower (more negative) as the season progressed (Figure 7). The downward trend was punctuated by fluctuations in Ψ caused by rain events. Pressure head fluctuations were most pronounced within the ''upper'' zones of the trench (e.g., ''upper'' CS), whereas wetter sites held steadier Ψ levels over the study period (e.g., ''lower'' CS, D). The ''upper'' zone tensiometers (except LS) dropped below −100 cm during the summer, whereas at ''lower'' zone sites, it remained above −100 cm (see also Figure 4). The

Table 1. Comparison of water table fluctuations between a recolonized *Sphagnum* cushion and bare cutover peat from the harvested Cacouna bog with an intact acrotelm from the adjacent St. Arsène bog, 1998.

	Natural Bog Acrotelm	Recolonized *Sphagnum* Cushions	Bare Cutover Peat
Sample size	90	71	89
Mean water table (cm)	−25.5 (± 5.4)	−24.9 (± 14.3)	−45.1 (± 20.3)
Maximum water table (cm)	−38.5	−63.4	−94.7
Minimum water table (cm)	−13.3	−4.9	−9.0

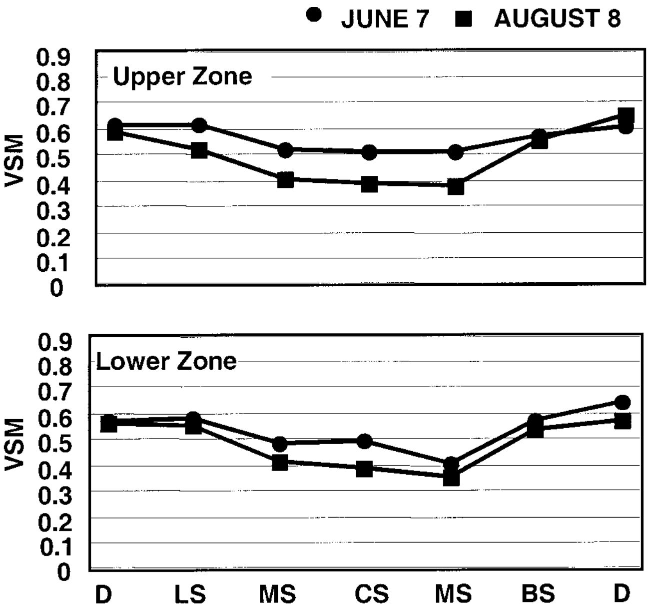

Figure 5. Trench cross-sectional profiles of mean volumetric soil moisture for surface peat (0–4 cm depth) at the ditch (D), bottom-skag (BS), mid-skag (MS), and center-skag (CS) June and August, 1998. Left to right represents west to east in the trench.

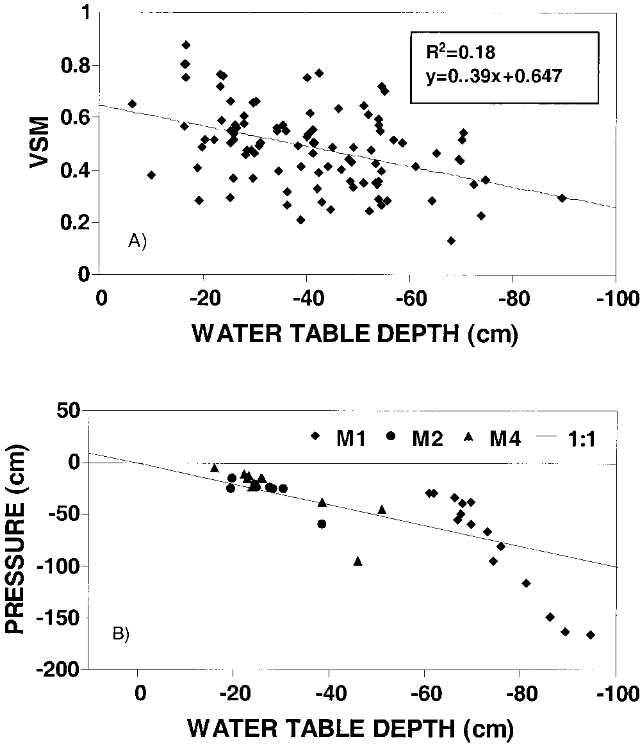

Figure 6. Linear relationship of (A) volumetric soil moisture (0–4 cm) with water-table position and (B) soil-water pressure head (-2 cm) with water table position from 7 June to 8 August 1998.

relationship between water-table position and Ψ were much stronger than with θ (Figure 6), although there was a notable departure from the 1:1 line during the driest conditions, where Ψ fell and the water table remained relatively steady.

Recolonization Patterns of *Sphagnum* and Other Vegetation

The recolonization of *Sphagnum* at Cacouna is < 10% of the total area. In the trench, its distribution corresponds well with observed spatial patterns of volumetric soil moisture (θ) and soil-water pressure (Ψ). Approximately 83% of *Sphagnum* that has recolonized the trench has done so on LS or D (Figure 8), where Ψ and θ remained predominantly above −100 cm (Figure 7) and 50% (Figure 5), respectively. A large proportion (92.2%) of total *Sphagnum* recolonization occurred within the ''lower'' zone, although total coverage there was only 38%. Almost no *Sphagnum* was found in the ''upper'' zone of the trench, except for a few small isolated cushions in the LS and D. Again, during the summer, θ and Ψ within the ''lower'' trench zones were mainly above 50% and −100 cm, respectively.

DISCUSSION

Data collected at another trench in this peatland (with baulks removed just prior to abandonment) showed similar relationships as noted for this study trench (Whitehead 1999). Because of its position in the peatland, this ''baulkless'' trench had a lower longitudinal slope and, thus, was wetter (Whitehead 1999). There are fewer data for this ''baulkless'' trench, but the trends observed there are essentially the same as reported here.

In this study, the water table across the trench was essentially flat and fluctuated uniformly in response to atmospheric fluxes. Water-table depth, therefore, was mainly a function of the topographic variation found throughout the trench-baulk landscape. The water table was shallower in the lower part of the trench and in areas of negative topographic relief (e.g., LS and D) (Figure 3). Ground-water flow along the trench was restricted because of the large distance relative to the flow rate. However, vertical flow to the water table and transverse to the long axis of the trench was adequate to render a flat water table. Seepage along the shallow ditch (D) from the ''upper'' zone, however, contributed to a higher water table in the ''lower'' trench zone. Mean water-table depth and fluctuations were greatest under bare, cutover peat (Table 1). These areas are less favorable for *Sphagnum* in the first place, and to a certain extent, the presence of *Sphagnum* re-

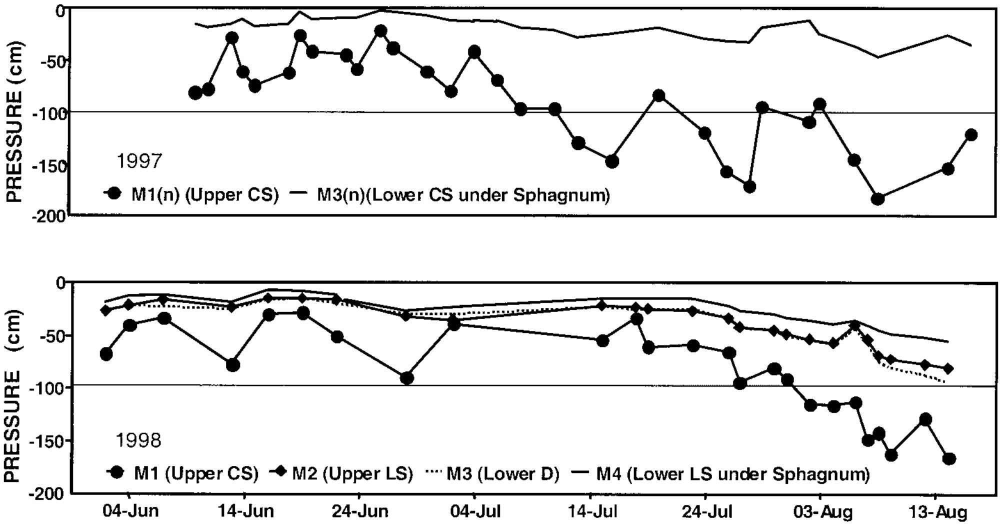

Figure 7. Soil-water pressure head measured at −2 cm from the peat surface from 10 June to 16 August 16 1997 and 2 June to 14 August 1998. Tensiometer site locations are illustrated in Figure 1.

duces the water flux by evaporation, as they can limit water fluxes when dry (Ingram 1983).

Coupled with a partly regenerated moss layer, the water storage characteristics were better at the lower end of the trench. Sy in recolonized *Sphagnum* cushions was similar to the intact acrotelm of the nearby undisturbed St. Arsène bog (Van Seters and Price 2000), but the acrotelm in the natural bog was much thicker. Although both natural and regenerated *Sphagnum* layers had similar mean water-table depths, the ranges in water-table fluctuations differed considerably (Table 1), suggesting that the storage function at Cacouna is not yet restored. At Cacouna, *Sphagnum* is discontinuous and covers a small part of the peatland, so even when the water table is high, it has only a limited effect on storage. At mean water-table levels (and lower), however, the water table at Cacouna is within the former catotelm peat, and the presence of high Sy *Sphagnum* cushions is of little consequence.

At locations where there was a high and stable water table, θ near the peat surface was correspondingly greater and more constant. The LS and D not only had higher mean θ (Figure 5) but also maintained these values for longer periods of time during the summer compared to the CS (Figure 4) and MS because of the proximity of the water table. The CS and MS generally occupied higher points of elevation within the trenches. As the water table fell, capillary flow to the surface became disconnected from the phreatic zone, and soil moisture in the CS and MS dropped to values as low as 13%.

Declines in θ were also accompanied by a lowering of Ψ at the peat surface. In the LS and D, where θ generally did not drop below 50%, Ψ was relatively

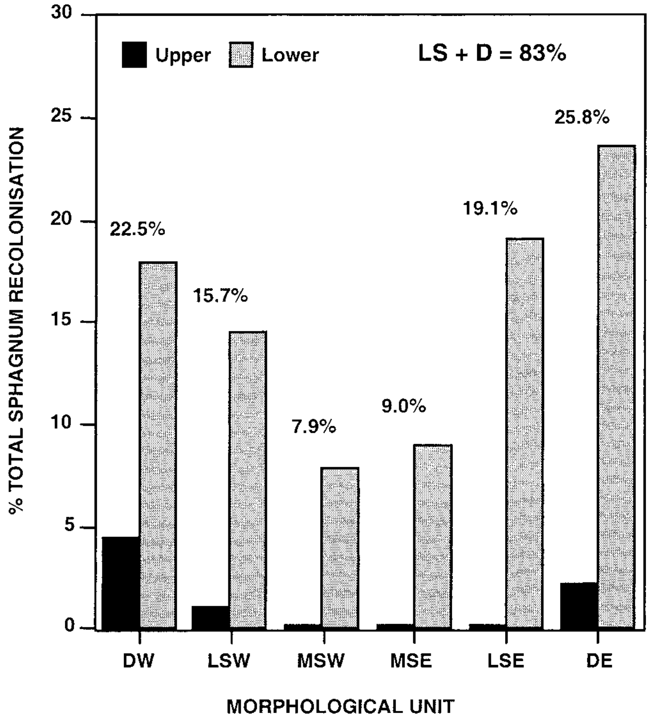

Figure 8. Patterns of *Sphagnum* recolonization characterized by morphology in the ''upper'' and ''lower'' zones of the trench. Note that the CS was not included in the vegetation survey by Girard (1999). MS and CS volumetric soil moisture and soil-water pressure head patterns were very similar, and therefore, MS trends were assumed to best approximate the CS. Total *Sphagnum* coverage (i.e., all transects in both zones) was 16.3%.

steady and remained above −100 cm (Figure 7). By the late summer, however, CS Ψ fell lower than −100 cm (above −100 cm for only 75% of the time) because of the limited upward transport of moisture to the peat surface, as described above. It is probable that *Sphagnum* can tolerate conditions more severe than $\theta_{50\%}$ and $\Psi_{-100\text{cm}}$ for short periods, although the critical duration period for which they remain viable is unknown. Overall, the majority of *Sphagnum* recolonization occurred in the LS and D (Figure 8), when θ (Figure 5) and Ψ (Figure 7) remained predominantly above 50% and −100 cm, respectively. The highest values of Ψ in cutover peat were found under *Sphagnum* cushions. Nearby areas with a similar water table were relatively dry; thus, it is probable that the presence of *Sphagnum* has increased Ψ, because of improved water storage and reduced evaporation losses, as noted above.

The relationship between water-table position and Ψ in this study was complex but was more systematic than the relationship between water table and θ (Figure 6). This pattern of variability has been observed in other studies (Päivänen 1973, Ahti 1974, Mannerkoski 1985, Price 1997, Schlotzhauer and Price 1999). At higher pressures (closer to zero), the pressure change occurred along the 1:1 line with water table. At the drier site (M1), the pressure decreased more than would be approximated by the 1:1 line. A similar finding was reported by Price (1997). Compared to θ, the variability of Ψ with water table was dampened because of volume changes that occurred within the highly deformable peat matrix (Price and Schlotzhauer 1999). During extended dry periods, peat will shrink as a result of lowering Ψ (increased suction) within pores (Hobbs 1986). The θ within pores may remain similar after the removal of water due to a decrease in peat volume, whereas Ψ will continue to decrease (coinciding with a falling water table) as moisture is held more tightly within the smaller pores. Therefore, Ψ is a better indicator of moisture availability than θ or water table, as it is the most sensitive, as well as exerting direct hydraulic control on the plant water supply.

CONCLUSION

While commercial manual block-cutting of peat is no longer occurring in Canada, the legacy of past cutting will remain far into the future. At the Cacouna bog, most cutting activity ended over 30 years ago, yet less than 10% of the area has regenerated a cover of *Sphagnum,* the dominant peat-forming vegetation in bogs. In some measure, this is because the artificial drainage system is still at least partly active (Van Seters and Price 2000). Within the trench and baulk landscape, however, there are some locations, generally where the slope is very small, or at the downslope end of trenches, where *Sphagnum* has begun to regenerate. The hydrologic characteristics of these locations provide a clue to the threshold conditions required for their establishment. *Sphagnum* recolonized where there was a high water table (mean −24.9±14.3 cm) and where soil moisture and soil-water pressure were greater than 50% and −100 cm for the whole season, mostly in shallow ditches and the lower part of the skag. The threshold pressure (−100 mb) seems to confirm the suggestion of Price (1997) that *Sphagnum* is unable to extract water from cutover peat unless soil-water pressure in the peat is greater than −100 cm, which for this peat corresponds with a soil-moisture of at least 50%. Areas where the duration of these threshold conditions was not met generally did not support *Sphagnum.* Even short periods in excess of these thresholds have apparently been detrimental to *Sphagnum* moss reestablishment, although the duration of individual dry periods, rather than the total period, is still unknown. From a management perspective, the use of soil-water pressure (Ψ) as an indicator of site soil suitability is recommended. Soil moisture (θ) is dependent on peat type and state of decomposition, and water tables deeper than 40 cm are imperfectly related to Ψ.

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