

Restoration ecology: aiding and abetting secondary succession on abandoned peat mines in Nova Scotia and New Brunswick, Canada

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SUMMARY

The efficacy of using vegetative clumps derived from seeds with a variety of origins to establish nuclei for regeneration of bog vegetation on abandoned peat mines in Nova Scotia and New Brunswick (Canada) was tested using seeds within scats (excrement) and seeds from berries, various techniques for creating clumps, and different clump sizes. Direct placement of scat pieces on peat in the field did not produce successful colonisation. Vegetative clumps begun in a greenhouse, whether from seeds extracted from scats or berries, were 60–100 % successful when transplanted into abandoned peat mines depending on the initial size of the transplant. Based on annual growth rate, *Vaccinium oxycoccos* has the greatest capacity to quickly colonise abandoned peat mines. Other promising taxa were *Vaccinium vitis-ideae* and the genus *Empetrum*.

KEY WORDS: animal dispersed seeds; berries; bog restoration; dwarf shrubs; peatland regeneration

INTRODUCTION

One of the consequences of peat extraction, especially through vacuum mining methods, is the creation of large areas of unconsolidated and non-vegetated peat. Successful colonisation by naturally-occurring peatland species is hindered by processes such as wind erosion, sheet wash and frost heaving which, according to Quinty & Rochefort (2000), uproot and kill recently established seedlings such as *Eriophorum spissum* L.

It cannot be denied that plant succession will eventually occur on these abandoned peat mines; however, as Graf *et al.* (2008) have shown, it is an exceedingly slow and haphazard process initially restricted to wind-dispersed taxa and rarely involving *Sphagnum* mosses or species that are dispersed by animals (i.e. zoochorous plant species). Indeed, these authors report that the only flowering plants which had successfully established on abandoned peat mines near Rivière-du-Loup (47° 45' N, 69° 30' W) were wind-dispersed Cyperaceae, even though adjacent intact bogs contained 14 zoochorous species (Blouin & Grandtner 1971). Of these, only *Vaccinium angustifolium* Aiton was observed on abandoned peat mines, but whether this had established from rhizome fragments or from seed was not determined. Recruitment from seed on these organic

remnants is not inevitable because *Vaccinium angustifolium*, like all *Vaccinium* species, leaves only a few viable seeds in the soil column (Hill & Vander Kloet 2005), which were probably removed with the extracted peat in this instance. Successful recruitment of these fleshy-fruited taxa can invariably be traced back to seed brought in by animals and deposited in their scats (excrement) (Vander Kloet & Hill 2000, Vander Kloet & McRae 2009). Consequently Graf *et al.* (2008) suggest that, if natural secondary succession does not meet restoration targets in recreating vegetation resembling a natural bog association, then active restoration should be pursued. This recommendation is especially germane for the mined coastal bogs of Nova Scotia and New Brunswick where two of the most abundant naturally occurring species, *Empetrum nigrum* L. and *Vaccinium oxycoccos* L., do not re-invade bogs after vacuum extraction (Campbell *et al.* 2000).

Returning post-vacuum-extracted peatland to a semi-natural state is a subject of ongoing research. With manipulation, considerable success has been achieved in restoring *Sphagnum* communities (Rochefort *et al.* 2003). Subsequent invasions of wind-dispersed bog taxa—especially the Cyperaceae, the Pinaceae and the Amentiferae—have been observed (Graf *et al.* 2008, Rochefort 2010); but not of the dwarf shrubs that bear fleshy

fruits, which are also abundant in natural bogs (Blouin & Grandtner 1971). Transplantation of rhizome or stolon fragments from these fleshy-fruited taxa into abandoned peat mines has met with indifferent success (Noormets *et al.* 2004, Bussi res *et al.* 2008, Bellemare *et al.* 2009). For example, the mortality of *Rubus chamaemorus* L. rhizomes planted in abandoned peat mines near Lameque (New Brunswick) was around 70 % in the first year after transplanting, rising to around 80 % in the third year (Bellemare *et al.* 2009). None of these restoration strategies attempts to use the natural dispersal mechanism of the fleshy-fruited bog shrubs, which involves the fruits being eaten by animals and deposited elsewhere in their scats i.e. endozoochory.

The research reported here aims to characterise and compare different planting methods in terms of which would be more successful for achieving the regeneration of dwarf fleshy-fruited shrubs on abandoned peat mines. Three planting methods were undertaken, namely: a) placing scat fragments on the mire surface in the field, and planting out seedlings as vegetative clumps begun in a greenhouse from b) seeds contained in scat fragments, and c) seeds derived from berries. Success was measured on the basis of survival and growth of vegetative clumps.

METHODS

Site descriptions

The peatland at Fafard near Shippagan, New Brunswick (NB) (47° 41' N, 64° 46' W) is the most northerly of the three experimental sites (Figure 1) and experiences more severe winter conditions than the two sites in Nova Scotia. Located on Crown land, the Fafard site is a coastal bog and is currently under lease to FPM Peat Moss Company Ltd. The peat lease on this 416 ha wetland was issued in 1941 for horticultural extraction operations which continued until 2000 when operations ceased because of problems with salt water intrusions. Manual cutting of blocks was replaced by vacuum extraction in the 1970s (J. Thibault, pers. comm.). A 2004 isopach map shows that residual peat depths in the south-east section range from < 1 m to 3.0 m. The site, still under lease, is currently undergoing restoration to natural wetland and/or peatland in compliance with NB policy (Province of New Brunswick 2010). The experimental site slopes gently downwards towards the north-west, where the peat surface is generally more humid and often

under water for much of the growing period. The peat layer remaining beneath the experimental plot is homogeneous throughout, with a humification value of approximately H4 on the von Post scale of decomposition (McKeague 1981).

The experimental site at Baltzer Bog in Coldbrook, Nova Scotia (NS) (45° 04' N, 64° 35' W) is located on the south-western quadrant of a 28 ha privately owned peatland where front-end loaders were formerly used to extract peat for mixing with sand/silt in a landscaping enterprise. An examination of aerial photography indicates that perimeter ditching associated with agricultural activities was already affecting the western half of the bog in 1967. By 1977, extensive ditching had occurred on the western half, and two large drainage ditches had been cut across the eastern half of the peatland. Although vegetation changes indicative of drainage were evident by 1987, peat excavation occurred in the south-western quadrant only after 1992 and before 2001. Originally, the peat layer was more than two metres thick with alternating layers of wood and moss-rich peat, possibly reflecting historical alternations between swamp and bog systems (I. S. Spooner, pers. comm.). The residual mesic peat (H6 on the von Post scale) in the experimental plot is derived from mosses and woody material, and is shallow (generally less than 30 cm thick). The northerly sloping experimental plot becomes increasingly wet towards the main east–west drainage ditch.

Squinces Bog near Bickerton West, NS (45° 09' N, 61° 43' W) is a 316 ha bog complex located on Crown land along the Atlantic Coast. A lease for horticultural peat extraction was issued in 1991 and subsequently surrendered in 1999 following ditching and removal of the vegetation from a section of the peatland east of Highway 221. The Crown released the lessee from further responsibility for the site in 2000 following blocking of the main ditches to promote rewetting. The experimental site slopes to the west and south, and peat thickness ranges from 4.3 m to approximately 3 m (Anderson & Broughm 1988, Peatland Area Map H39). Vacuum extraction was not successful in removing a significant amount of the surface layer of fibric graminoid peat (H3 or H4 on the von Post scale).

Collection of seeds and scats

Beginning in 1998 and continuing until the autumn of 2007, 113 scats were collected from Canadian sites located in NS (80 sites), NB (eleven sites), and Newfoundland and Labrador (NL) (four sites); and



Figure 1. Map of south-eastern Canada showing locations of the three experimental sites.

from one USA site in New Hampshire (NH). During the same period, the ripe berries used in this study were collected from 89 sites; 71 in NS, four in NB, and 14 in locations ranging from NL to Vermont, USA. Collections were made at the convenience of the senior author during even wider-ranging field excursions (Appendix 1), rather than specifically for this study. Most of the scat fragments and berries that were sown into seedling containers were collected in NS. The scats were fresh enough that seeds contained within them had not yet germinated and were denoted as originating from specific mammalian and avian species including bear (primary mammal), mink, otter, fox, racoon and gull; as generic "scats" (sources unidentified); and as "bird scats" (not assigned to species). They were dried and stored in a refrigerator at Acadia until the experiments began, at which time fragments were placed directly on a mire surface or sown in seedling

containers. Berries were collected as ripe fruit from *Empetrum* spp., *Vaccinium vitis-ideae* and *Vaccinium oxycoccos*; and from three species belonging to *Vaccinium* section *Cyanococcus* (*Vaccinium angustifolium*, *Vaccinium myrtilloides*, *Vaccinium boreale*), with the vast majority being from *Vaccinium angustifolium*. Species within *Vaccinium* section *Cyanococcus* were pooled for starting vegetative clumps and, subsequently, for analyses.

Direct field planting of scats

Scat fragments were randomly selected from available scats. The fragments were around one cm³ in volume and contained 135 seeds on average, and were sown directly into small cracks along transects on moist-to-wet-to-soggy bare peat that ranged from H5 to H8 on the von Post scale, at Fafard and Baltzer Bog only. At Fafard, 87 scat fragments in

total were placed one metre apart along four transect segments; the first tranche ($n = 26$) on 05 July 2004, the second tranche ($n = 30$) on 02 September 2004, and the third tranche ($n = 31$) on 28 June 2005. Twenty-six scat fragments were laid out similarly at Baltzer Bog, but on a single transect, on 20 April 2005. Decomposition of these scats, concomitant seed germination and seedling establishment (if any) was monitored for four years at both sites.

Greenhouse germination

Greenhouse germination produced seedlings from two separate sources, namely ripe fruits (berries) and scat fragments. Seeds taken from berries were washed out from the fruits and carefully dried, then sown in 183 lots of around 50 seeds. Both seeds and scat fragments ($n = 733$) were sown on top of blueberry soil which consisted of a 50:50 sand-peat mixture augmented with small volumes of magnesium sulphate, hydrated ferrous sulphate and MagAmp® K (Sumitomo Corporation of America; 7 % nitrogen, 40 % phosphate, 6 % potassium, 15 % magnesium). This was contained in 10 cm plastic pots ($n = 82$); 67-unit, 3 cm multi-pots (Can-Am Container; $n = 11$); or 28×18 cm plastic trays ($n = 22$), in order to create vegetative clumps of different sizes. The pots and trays were placed in a misting chamber at Acadia University Greenhouse until the first leaves emerged, then transferred to cold frames as stock material for the experimental trials on peatland. Not all seedlings were used in this study, and some that were used were washed away before being assessed for survival or measured for growth. Unless specifically noted, seedlings that washed away were excluded from survival and growth analyses and from summary statistics.

Vegetative clumps were composed of seedlings from a single taxon (*Empetrum*, *Vaccinium oxycoccos*, *Vaccinium vitis-idaea*); from taxa within *Vaccinium* section *Cyanococcus*; or from mixed taxa (hereafter referred to as 'mixed'), with 77 % of clumps being derived from scat fragments. Clumps representing *Vaccinium* section *Cyanococcus* were primarily *Vaccinium angustifolium*, and those consisting of mixed taxa were primarily mixtures of *V. angustifolium*, *Rubus* spp. and *Empetrum*, but also contained other Ericaceae and non-ericaceous taxa in low proportions (Table 1). Vegetative clumps were thus distinguished in analyses on the basis of their primary taxonomic composition (*Empetrum*, *Vaccinium* section *Cyanococcus*, *Vaccinium oxycoccos*, *Vaccinium vitis-idaea*, mixed). Of the vegetative clumps set out that were derived from scat fragments, 82 % originated from NS, 8 % from

NB and 10 % from all other seed sources combined.

Because natural peatland surfaces are mosaics of hummocks and hollows, it was decided to set out the seedlings from each container in the field as vegetative clumps rather than individual seedlings so that, should they survive, they could act as nuclei for hummock formation on cutover peat surfaces. Therefore, at various times during the growing season roughly corresponding to spring, summer and autumn, some of the containers were taken from the cold frames at Acadia University and brought to the abandoned peat mines. The source (scat or berries) of each vegetative clump (container) was recorded. Seedling-root-balls were lifted out of their containers and planted 1 m apart (or 2 m apart if the plants were large) along a series of transects (e.g. Figure 2). Vegetative clumps were selected for location along transects at random, thereby creating a medley of clumps from different containers and of different sizes and taxa. Transect length ranged from about 20 m to more than 50 m depending on the number of seedlings, their spacing, and available space within the transect area.

Measurements and analyses

All clumps were known on the basis of criteria such as provenance and seed source (Table 2), and they were monitored for survival and measured for growth once or twice a year. Greenhouse-grown vegetative clumps were measured at transplanting (initial plant-base size or 'initial diameter') and at various dates up to four years after planting. Growth rate was calculated as the annual change in diameter by measuring radial expansion of the plant base including runners and dividing by fractional years (e.g. 2.5 years). Survival, growth and planting regimes are summarised in this article.

Factors that contributed to growth rate were analysed using one-way, two-way and three-way ANOVA. Some of the more complex ANOVAs were unbalanced in that entire categories within one or more factors lacked data due to the specific assortment of taxon assemblages in the clumps that were initially set out, and subsequent survivorship. For example, for the factor 'seed source', no scats were set out at Squinces Bog; or for factor 'planting season' only spring planting was done in Coldbrook whereas no scat fragments were directly sown in spring at Fafard. Therefore, data were pooled across various factors before analysis (e.g. vegetative clumps derived from scats were combined with those derived from berries) and taxa were pooled accordingly. The sensitivity of pooling data was tested, where possible, to ascertain whether pooling

or additional factors changed trends. Relationships between initial clump diameter and growth rate were determined by least-squares (linear) regression. Log transformed values were used to linearise growth regressions, but actual data were plotted. Analyses (both linear regression and ANOVA) were carried

out using R version 2.15 (R Development Core Team 2008) with a familywise error rate of 0.05. Residuals were analysed graphically to verify the assumptions of ANOVA. Tukey HSD was used to analyse multiple comparisons (simple effects) when more than two factor levels existed.

Table 1. Features recorded from surviving vegetative clumps set out on three formerly mined, and now abandoned, peatlands.

1. Planting site	1) Shippagan, New Brunswick (Fafard) 2) Coldbrook, Nova Scotia (Baltzer Bog) 3) Bickerton West, Nova Scotia (Squinces Bog)
2. Planting period	1) Spring 2) Summer 3) Autumn
3. Provenance of scats or berries	1) Nova Scotia 2) New Brunswick 3) Other
4. Peat texture (von Post humification value)	1) dry for part of the year (H5) 2) wet throughout the year (H6 or H7) 3) soggy and unconsolidated throughout the year (H8)
5. Source of vegetative clump	1) scat 2) berry
6. Vegetative clump composition	1) <i>Empetrum</i> 2) <i>Vaccinium</i> section <i>Cyanococcus</i> 3) <i>Vaccinium vitis-idaea</i> 4) <i>Vaccinium oxycoccos</i> 5) Other taxa (Rosaceae <i>etc.</i>) 6) Mixed taxa



Figure 2. Vegetative clumps in a planted transect at Squinces Bog, Bickerton West, Nova Scotia, July 2007.

Table 2. Taxa observed to germinate from greenhouse-germinated vegetative clumps and their percentage (%) taxon placement for analysis.

Taxon	Greenhouse Germinated Vegetative Clumps				Mixed
	<i>Empetrum</i>	<i>Vaccinium</i> section <i>Cyanococcus</i>	<i>Vaccinium</i> <i>oxycoccus</i>	<i>Vaccinium</i> <i>vitis-ideae</i>	
<u>Ericaceae</u>					
<i>Vaccinium angustifolium</i> Aiton	<2%	99%			42%
<i>V. boreale</i> I.V. Hall & Aalders		<1%			
<i>V. macrocarpon</i> Aiton					<1%
<i>V. myrtilloides</i> Michx.		<1%			
<i>V. oxycoccus</i> L.			100%		<1%
<i>V. uliginosum</i> L.					2%
<i>V. vitis-idaea</i> L.				100%	<1%
<i>Empetrum</i> sp. L.	98%				25%
<i>Gaylussacia baccata</i> (Wang.) K. Koch					1.5%
<u>Non-ericaceous</u>					
<i>Betula</i> L.					<1%
<i>Fragaria vesca</i> L.					1.5%
<i>Juniperus communis</i> L.					<1%
<i>Myrica pensylvanica</i> Loisel					1%
<i>Plantago maritima</i> L.					<1%
<i>Rosaceae</i> (<i>Rubus</i> sp. L.)					21%
<i>Sorbus americana</i> Marsh					<1%

RESULTS

Direct field planting of scats

At Fafard, some seeds germinated every year from the scats so long as they remained more or less intact, i.e. they were not blown or washed away during the winter. On 28 June 2005, five scats had some germination, i.e. some emerging radicles and cotyledons were observed; but 21 of the 56 scats laid out before that date could not be found, having apparently been washed or blown away during the winter. As noted above, a third tranche of 31 scats was laid out at this time. On 03 September 2006, 32 (or 48 %) of the remaining scats had some germination. Although most of the seedlings were

very small, some could be identified as *Vaccinium*, *Empetrum*, *Amelanchier* or *Rubus*, and most of them were *Vaccinium*. On 05 September 2007, 17 (or 26 %) of the scats had small seedlings or germinating seeds, but many of those recorded in 2006 had died and/or been washed away during the winter; only seven *Vaccinium angustifolium* seedlings were identified along with one *Myrica pensylvanica*. On 03 September 2008, all of the scats had disappeared and 18 *Vaccinium angustifolium*, one *Rubus*, three *Gaylussacia* and two *Amelanchier* seedlings were found along the entire length of all transects. Whether these were seedlings that germinated from the planted-out scats or grew from seeds that lodged after the scat

seedlings emerged is unknown; e.g. no *Amelanchier* seedlings were identified in potted vegetative clumps before they were put out (Table 1).

Similar results were obtained at Baltzer Bog. Only five scats had germinating seeds on 12 July 2006, and all of these had died by 10 September 2007. Only one *Gaylussacia* seedling and one *Vaccinium angustifolium* seedling were found whilst walking the transect on this date.

Greenhouse germination of scats

In the greenhouse, germination of seeds from scat fragments was invariably successful. Some, such as *Vaccinium angustifolium* and *Vaccinium myrtilloides*, all germinated together directly from scats, whereas others like *Empetrum* and *Gaylussacia* germinated successfully only if the scats were stratified (seeds separated and mixed with soil). During the six years of this study, nine Ericaceae and seven non-ericaceous species emerged from scat fragments (Table 1).

Vegetative clumps

Of 916 greenhouse-germinated seedlings from scats and berries forming vegetative clumps set out over the three years, 634 were alive at the last observation date (4 September 2008), 185 (20 %) had died after some growth, and 97 (11 % of total) had been washed away. Of those that were washed away, all were placed at Fafard where 21 % were put out in dry, 36 % in wet, and 43 % in soggy soil. The majority of the clumps that were set out were of mixed variety ($n = 311$) followed by *Vaccinium* section *Cyanococcus* ($n = 263$), *Empetrum* ($n = 253$), and *Vaccinium oxycoccus* ($n = 24$). Seven clumps contained only *Vaccinium vitis-idaea*, and 58 clumps were unidentified, but all of these washed away. At Fafard, 34 % of vegetative clumps died after 1.8 ± 1.2 years (range 1–4 years), 27 % at Baltzer Bog after 1.9 ± 0.7 years (range 1–3 years), and 11 % at Squinces Bog after 1.6 ± 0.5 years (range 1–2 years). Vegetative clumps that died were not used in growth analysis because 77 % died before their second year and the remainder, retrospectively, may have been unhealthy or planted in unfavourable microhabitats doomed to seedling failure thus biasing the information gained from growth analysis.

Scats containing seeds of more than one taxon produced mixed vegetative clumps, but the constituents of clumps derived from both berries and scats that were large enough to permit identification were known to species. *Vaccinium oxycoccus* and *Vaccinium vitis-idaea* grew much

more vigorously than *Empetrum* or *Vaccinium* section *Cyanococcus*, so that mixed clumps with growth greater than the 75th percentile were most likely to be composed of *Vaccinium vitis-idaea* or *Vaccinium oxycoccus* (Figure 3). Clumps containing *Vaccinium oxycoccus* were especially noteworthy as their mean growth exceeded that of other taxa (Figures 2 and 3). However, they were planted only in soggy peat and only at Fafard, so that the potential of this species in other habitats could not be assessed. In fact, high growth rates in *Vaccinium oxycoccus* combined with lower growth rates in *Empetrum* increases the distribution of growth rates seen in soggy habitats (Figure 5).

Survival after transplanting into abandoned peat mines was strongly dependent on the initial size of the vegetative clump—the larger the initial transplant, the more likely it was to survive (Table 3). If the transplant was larger than 10 cm in diameter, survival was guaranteed; whereas up to 40 % of transplants < 5 cm in diameter died. Thus, the optimum diameter for transplants in terms of handling time and survival potential is 5–10 cm. Seedlings in clumps belonging to this size class survive almost as well as in larger clumps, but many more of the smaller clumps can be established (in greenhouses) and set out in the field. Thus, they offer the most efficient means for creating numerous hummock nuclei where wind-dispersed diaspores can lodge, germinate and become established (e.g. Figure 6).

If the transplants survived their first year in the field, radial expansion, albeit highly variable, was observed. Of 624 surviving vegetative clumps, the diameters of 22 decreased (range -0.32 to -8.7 cm year⁻¹), whereas 60 clumps showed little (< 2 cm year⁻¹) or no growth; the latter consisting of *Empetrum*, *Vaccinium* section *Cyanococcus*, and mixed; all with various initial diameters. Two clumps had annual growth rates exceeding 100 cm year⁻¹; one *Vaccinium* section *Cyanococcus* clump and the other mixed. These two high growth rates and growth rates less than zero were removed from all analyses because they would overly influence summary statistics and bias ANOVA results. *Vaccinium oxycoccus* had the greatest growth rate ($n = 24$, 50 ± 14 cm year⁻¹) followed by *Vaccinium vitis-idaea* ($n = 5$, 22 ± 14 cm x year⁻¹), mixed ($n = 197$, 8.0 ± 8.2 cm year⁻¹), *Empetrum* ($n = 209$, 7.7 ± 4.8 cm year⁻¹), and *Vaccinium* section *Cyanococcus* ($n = 165$, 7.1 ± 4.0 cm year⁻¹); the latter three being similar. *Vaccinium oxycoccus* also had the greatest mean initial diameter (26 cm) compared with ~5–7 cm for other taxa. Linear

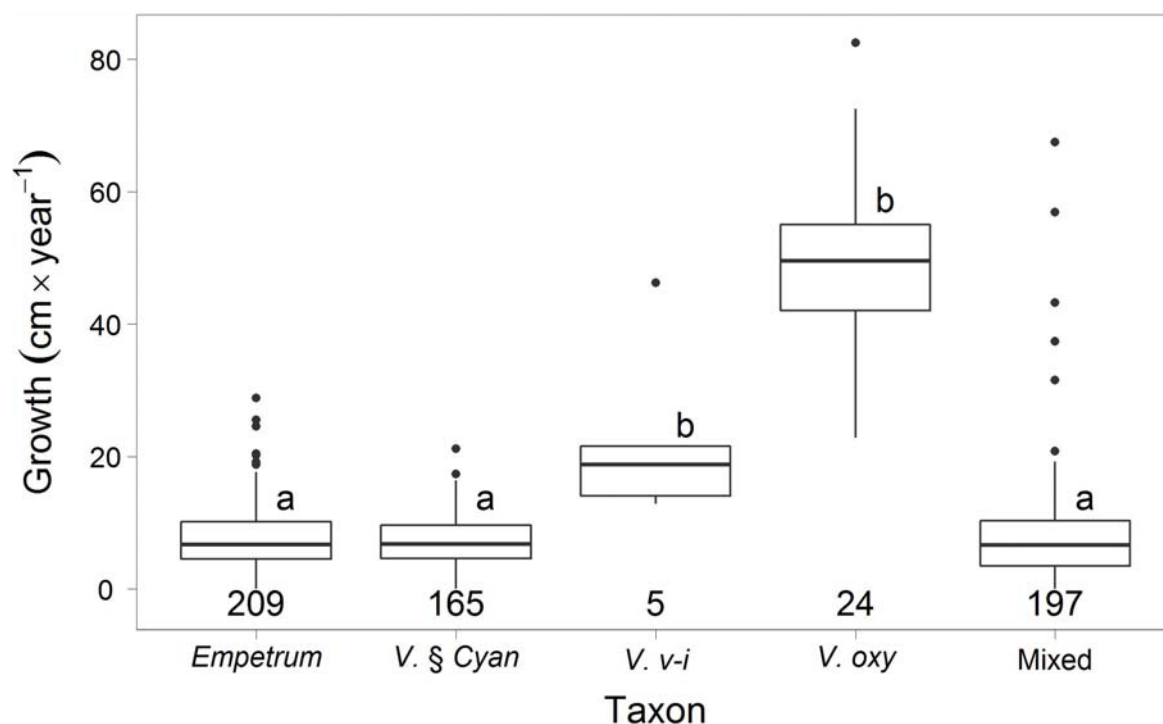


Figure 3. Comparisons of growth measured by changes in annual vegetative clump diameter for five taxa set out in Nova Scotia and New Brunswick, Canada. Taxa were pooled across planting site, planting season, and peat texture. Sample sizes are provided below boxes. *V. § Cyan* = *Vaccinium* section *Cyanococcus*; *V. v-i* = *Vaccinium vitis-idaea*; and *V. oxy* = *Vaccinium oxycoccos*. Significant differences at $\alpha = 0.05$ are indicated by different letters (a, b) and dark lines in boxes are median values. ANOVA table and Tukey HSD values are provided in Appendix 2.

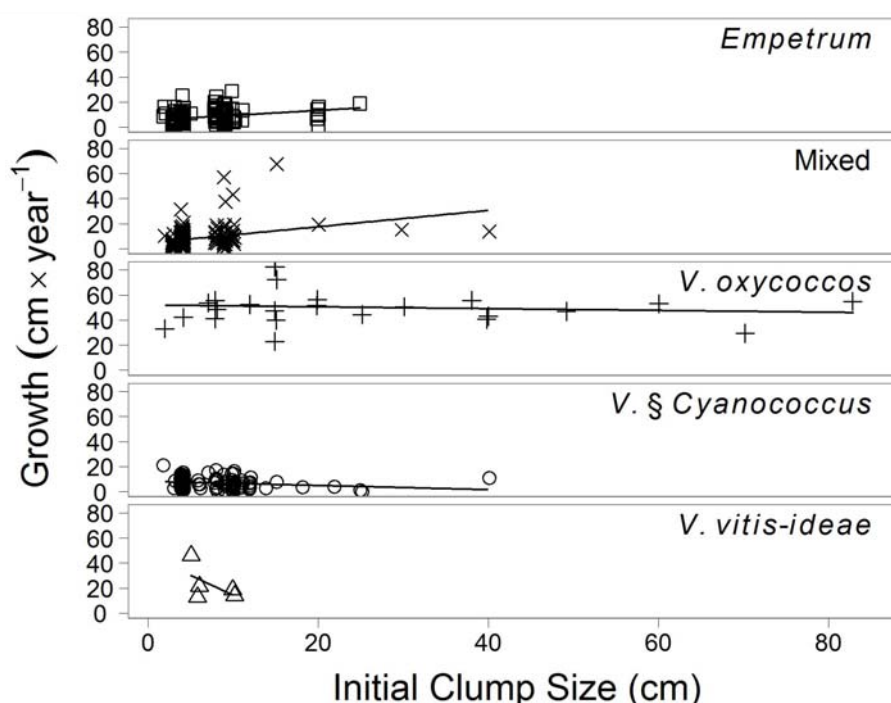


Figure 4. Relationships between initial clump diameter and annual growth rate for five taxa pooled across planting site, planting season, and peat texture.

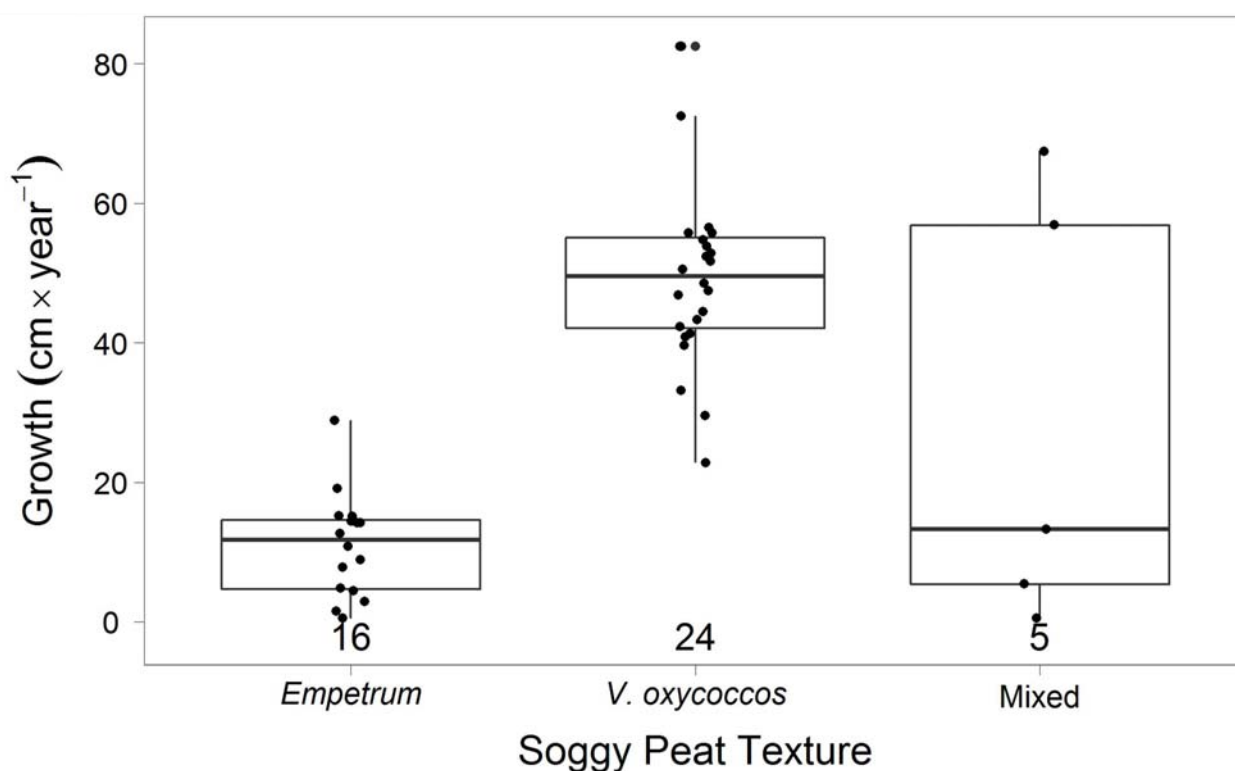


Figure 5. Comparison of the growth rates of vegetative clumps of three taxa set out within soggy peatlands. *V. oxycoccus* = *Vaccinium oxycoccus*. Dots are jittered data points, sample sizes are provided below boxes, and dark lines in boxes are median values.

Table 3. Numbers and percentages of vegetative clumps of different initial diameters that survived to their respective last observation dates on the three Canadian peat mine sites.

Site		Vegetative Clump Diameter (cm)		
		<5	5–10	>10
Fafard, NB	initial polsters	306	44	24
	surviving at final observation	188	36	24
	percent survival	61	82	100
Baltzer Bog, NS	initial polsters	95	59	24
	surviving at final observation	57	49	24
	percent survival	60	83	100
Squinces Bog, NS	initial polsters	10	66	6
	surviving at final observation	10	57	6
	percent survival	100	86	100
Totals	initial polsters	411	169	54
	surviving at final observation	255	142	54
	percent survival	62	84	100



Figure 6. Potential hummock nucleus arising from an *Empetrum* vegetative clump set out on 17 June 2006 in Squinces Bog near Bickerton, Nova Scotia. Photo taken 10 July 2009.

regression shows significant relationships between initial diameter and annual growth for *Empetrum* ($r^2 = 0.04$, $p < 0.002$), *Vaccinium* section *Cyanococcus* ($r^2 = 0.11$, $p < 0.001$) and mixed clumps ($r^2 = 0.07$, $p < 0.001$), with *Vaccinium* section *Cyanococcus* showing decreased, and *Empetrum* and mixed clumps increased annual growth rates (Figure 4). However, all relationships had low r^2 and the regression through *Vaccinium vitis-ideae* was based on five values, so these analyses are uninformative. No relationship between initial diameter and annual growth was found for *Vaccinium oxycoccos* (Figure 4; $p = 0.876$). In the case of mixed clumps, dispersion in residuals was evident and driven by more than one taxon (see Figure 3 for an example) so that any underlying relationship at the species level was obscured. We conclude that, overall, initial diameter has little bearing on annual growth rate and, thus, initial diameter is not accounted for in further analyses.

Overall taxa differences, pooled across all other factors, show that *Vaccinium oxycoccos* and *Vaccinium vitis-ideae* do not have significantly different growth rates (Figure 3; $p = 0.067$);

although low sample size and one extreme value in *Vaccinium vitis-ideae* coupled with high variability in *Vaccinium oxycoccos* is likely to be masking a true difference. Nonetheless, both are significantly greater than all other taxa ($p < 0.003$ for all comparisons) (Figure 3). Conversely, *Empetrum* does not have a significantly greater growth rate than mixed ($p = 0.765$), nor does *Vaccinium* section *Cyanococcus* from *Empetrum* ($p = 0.847$) or mixed ($p = 0.999$).

Low numbers of *Vaccinium vitis-ideae* and *Vaccinium oxycoccos* combined with their inclusion in only one or two habitats prevent their inclusion in a meaningful analysis of growth differences across sites, peat textures and planting season because they would influence only one factor or factor level within the analysis thereby biasing results. In addition to the limited planting of *Vaccinium oxycoccos* noted above, *Vaccinium vitis-ideae* was planted only in dry peat in the spring at Baltzer Bog. Therefore, only *Empetrum*, *Vaccinium* section *Cyanococcus* and mixed taxa have sufficient numbers (pooled or not) of vegetative clumps in factors site, peat texture and planting season to

compare using ANOVA. Furthermore, annual growth was not significantly affected by seed provenance ($p = 0.182$) when using taxon as a blocking factor, so seed provenance was excluded from further ANOVA analyses. Also, taxa differences were not significant when factor 'taxon' was added to any combination of other factors ($p > 0.435$ for all comparisons) and was dropped from subsequent ANOVAs.

No significant difference in annual growth rate was found between Fafard and Squinces Bog ($p = 0.902$), but Baltzer Bog showed significantly lower growth rates ($p < 0.001$) than the other two sites (Figure 7A). Planting in summer provided longer-term gains in mean growth rate than either

spring or autumn planting ($p < 0.001$), with spring and autumn showing no difference ($p = 0.681$) (Figure 7B). Finally, soggy and wet peat texture showed no significant difference ($p = 0.730$), but both had significantly greater growth rates than dry texture ($p < 0.004$) (Figure 7C). Seasonal comparisons were made by pooling data within each season (data collapsed across peat texture and sites) because vegetative clumps were put out in the autumn at Baltzer Bog only, and all within dry peat. These results did not change when peat texture was included as a factor within the ANOVA. For similar reasons, site comparisons were pooled across seasons, and results did not change if peat texture was included as an additional factor.

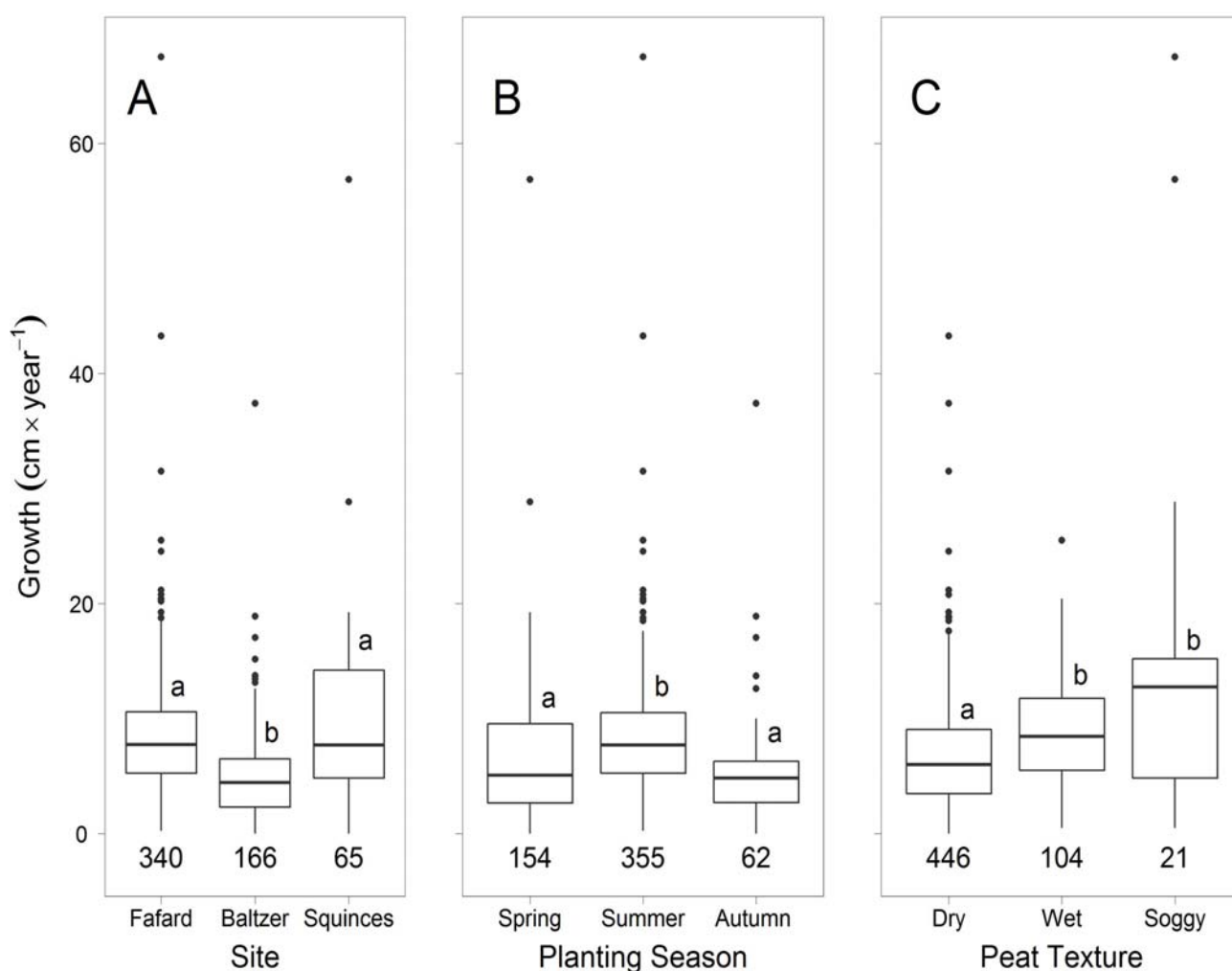


Figure 7. Comparisons of growth rate of vegetative clumps for three taxa set out in various conditions. Taxa were variously pooled because of missing data for some cells of the ANOVA (see text). Sample sizes are provided below boxes. Significant differences at $\alpha = 0.05$ are indicated by different letters within A, B, and C and dark lines in boxes are median values. ANOVA table and Tukey HSD values are provided in Appendix 2.

DISCUSSION

Our results show that, if scats are laid out directly in the field, some of the seeds they contain will germinate over a number of successive years; but very few, if any, of the emerging seedlings will ultimately survive. Thus, even heavy applications of scats to mined peat bogs will not lead to large-scale recruitment of zoochorous species.

Even though it is not always the fastest-growing species, *Vaccinium oxycoccos* can develop new runners up to one metre long during a single growing season resulting in a tangle of woody stems where *Drosera* seeds and *Sphagnum* spores become trapped and establish small communities. Slower-growing taxa such as *Empetrum* (Figure 8) provide similar nuclei for trapping seeds and spores, but some plants may be less than robust (e.g. *Vaccinium angustifolium*; Figure 9) and require several years to establish communities. Furthermore, some stems

from *Vaccinium oxycoccos* may become dislodged in winter and spring and then establish new colonies during the next growing season. Indeed, *Vaccinium oxycoccos* is the ideal candidate, in conjunction with more slowly-spreading taxa, to hasten the process of secondary bog-heath succession after peat mining. In practical terms, given an initial density of one 10 cm vegetative clump per one m² and a rate of expansion of 100 % per annum, each clump should infill the entire m² in about seven years; clumps with diameter larger than 10 cm should infill the same space in about four years; and clumps with an initial diameter of about 5 cm will require about 20 years to occupy the entire m².

The main difference in growth appears to be related to site wetness, as is the case in spring and autumn planting when more rainfall is common. The addition of peat texture as a factor within the analysis did not change the overall trend suggesting that planting season could be important to



Figure 8. Vegetative clump containing *Empetrum* set out at Squinces Bog, Bickerton West, Nova Scotia, July 2007.



Figure 9. Vegetative clump containing *Vaccinium angustifolium* set out at Squinces Bog, Bickerton West, Nova Scotia, July 2007.

establishing hummock nuclei and some site-specific conditions should be tested before any large-scale restoration efforts are undertaken.

In conclusion, if restoration of fleshy-fruited dwarf shrubs is an explicit goal, then using seedling vegetative clumps derived from scats or seeds (from berries) is much more effective than planting scat fragments, not only in terms of survival (60–100 % for vegetative clumps in this field trial), but also in terms of forming hummock nuclei to help stimulate natural bog formation.

ACKNOWLEDGEMENTS

We wish to thank J-Y Daigle (Peat Research Institute), P. Thomas (Mark-Lyn Construction Ltd.) and M. Pulsifer (Nova Scotia Department of Natural Resources) for their comments and encouragement and for providing us with free access to harvested peatland to set out our experiments.

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Submitted 20 Dec 2010, final revision 19 Sep 2012
Editor: Olivia Bragg

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Appendix 1. Global list of collection areas for berries and scats. Collection sites for this study (96 for scats and 89 for berries) lay within CAN and USA collection areas, and in some cases were located at a finer scale.

City/Town, Area	County	Province/Territory/State, Country
Coldbrook	Kings Co.	NS, CAN
Huntington Point to Harbourville, shoreline heath	Kings Co.	NS, CAN
Mechanic seed bank	Kings Co.	NS, CAN
Mud Lake bog	Kings Co.	NS, CAN
Sheffield Mills, Experimental Farm	Kings Co.	NS, CAN
Gore	Hants Co.	NS, CAN
Kennetcook	Hants Co.	NS, CAN
Earlton, Biorachan barrens	Colchester Co.	NS, CAN
West Branch	Pictou Co.	NS, CAN
Diligent River, Department of Natural Resources	Cumberland Co.	NS, CAN
Westchester Mtn.	Cumberland Co.	NS, CAN
Larry's River	Guysborough Co.	NS, CAN
Duncan's Cove	Halifax Co.	NS, CAN
Halifax International Airport Interchange	Halifax Co.	NS, CAN
Junction of Highways 101 & 103	Halifax Co.	NS, CAN
Hubbards	Halifax Co.	NS, CAN
Indian Harbour	Halifax Co.	NS, CAN
Pennant Point	Halifax Co.	NS, CAN
Taylor Head	Halifax Co.	NS, CAN
Gaff Point	Lunenburg Co.	NS, CAN
New Ross	Lunenburg Co.	NS, CAN
Zinck Head	Lunenburg Co.	NS, CAN
Baccaro Point	Shelburne Co.	NS, CAN
Cape Sable Island, Hawk Beach	Shelburne Co.	NS, CAN
Shag Harbour, outcropping Rt. 3	Shelburne Co.	NS, CAN
Digby	Digby Co.	NS, CAN
Long Island	Digby Co.	NS, CAN
South Freeport	Digby Co.	NS, CAN
Fourchu Barrens	Richmond Co.	NS, CAN
Petit-de-Grat	Richmond Co.	NS, CAN
Gooseberry Cove	Cape Breton Co.	NS, CAN

City/Town, Area	County	Province/Territory/State, Country
Cape Breton Highlands National Park, Sky-line Trail	Inverness Co.	NS, CAN
Ingonish, Cape Smokey	Victoria Co.	NS, CAN
Mica Hill	Victoria Co.	NS, CAN
South Point	Victoria Co.	NS, CAN
Jonah Mountain	Albert Co.	NB, CAN
Fafard Peat Mine	Gloucester Co.	NB, CAN
Grand Anse, 6 Rds.	Gloucester Co.	NB, CAN
Miscou Island	Gloucester Co.	NB, CAN
Shippagan	Gloucester Co.	NB, CAN
Kouchibouguac National Park	Kent Co.	NB, CAN
Sackville, Frosty Hollow	Westmoreland Co.	NB, CAN
Dieppe, TCH (Hwy. 2)	Westmoreland Co.	NB, CAN
Mount Stewart, Anderson Rd.	Queens Co.	PE, CAN
North Cape	Prince Co.	PE, CAN
Poverty Beach, Hwy. 17	Kings Co.	PE, CAN
Bristol	Kings Co.	PE, CAN
Parc de la Pointe-Taillon	Lac-Saint-Jean-Est. Cte.	QC, CAN
Peribonka River, St. Monique	Lac-Saint-Jean-Ouest Cte.	QC, CAN
Riviere-du-Loup	Riviere-du-Loup Cte.	QC, CAN
St. John's, Cape Spear	Avalon	NL, CAN
St. John's, Ft. Amherst	Avalon	NL, CAN
Hollyrood, Hawke Hills	Avalon	NL, CAN
Petty Harbour	Avalon	NL, CAN
Frobisher Bay	Baffin Island	NU, CAN
Mt. Clinton	Coos Co.	NH, USA
Paul Smiths, Adirondack Centre	Franklin Co.	NY, USA
Whiteface Mountain at 1237m	Essex Co.	NY, USA
Jay Peak at 965m	Orleans Co.	VT, USA
Vardo	Aland Islands	FIN
Wiesel Weg	Apeldoorn	NLD

KEY. *Countries:* CAN: Canada; FIN: Finland; NLD: The Netherlands; USA: United States of America. *Provinces/Territories/States:* NB: New Brunswick; NH: New Hampshire; NL: Newfoundland and Labrador; NS: Nova Scotia; NU: Nunavut; NY: New York; PE: Prince Edward Island; QC: Québec; VT: Vermont.

Appendix 2. ANOVA tables and Tukey HSD values for the comparisons shown in Figures 3 and 7. *Emp* = *Empetrum*, *V. § Cyan* = *Vaccinium* section *Cyanococcus*, *V. v-I* = *Vaccinium vitis-idaea*, *V. oxy* = *Vaccinium oxycoccus*, *Mix* = Mixed taxa. For each comparison, Tukey HSD p-values are provided in a triangular matrix.

Figure 3 ANOVA					Tukey HSD p-values				
TAXON					Emp	V. v-i	V. oxy	Mix	
					§ Cyan	0.847	0.001	<0.001	0.999
Group	SS	Df	F-value	p-value	Emp		0.003	<0.001	0.765
Taxon	17.5	4	55.1	<0.001	V. v-i			0.067	0.001
Residuals	47.3	595			V. oxy				<0.001

Figure 7 ANOVA						Tukey HSD p-values	
SITE							
Group	SS	Df	F-value	p-value		Baltzer Bog	Squinces Bog
Site	5.49	2	37.7	<0.001	Fafard	<0.001	0.902
Residuals	41.4	568			Squinces Bog	<0.001	
PLANTING SEASON							
Group	SS	Df	F-value	p-value		Autumn	Spring
Season	3.78	2	24.9	<0.001	Summer	<0.001	<0.001
Residuals	43.1	568			Spring	0.681	
PEAT TEXTURE							
Group	SS	Df	F-value	p-value		Dry	Soggy
Texture	2.46	2	15.7	<0.001	Wet	<0.001	0.730
Residuals	44.41	568			Soggy	0.004	

Appendix 3.

Sam P. Vander Kloet

A Tribute to “The Man on the Bicycle”



Sam on a bicycle in The Netherlands, 2006.

Sam was born in It Heidenskip, Friesland (The Netherlands) and immigrated to Canada with his family as a child in 1947. He received a BA in Classics and a PhD in Botany from Queen's University where he also met his wife, Carol. They have a daughter Julie and son Peter (who co-authored this article and worked alongside Sam on many research trips). Sam was a fixture in the Acadia University Department of Biology for 29 years from 1972, particularly during morning and afternoon coffee where his laugh signalled the twice-daily ritual. In between coffee breaks, Sam would ride his bicycle around King's County to check on various blueberry projects, becoming known in the community as “the man on the bicycle”. His penchant for biking and walking is legendary. I recall a long walk from Cape Spear in Newfoundland and Labrador on a cold spring day *ca.* 1998 to check blueberry germination at several plots. The taxi driver was particularly perplexed that we did not require a return trip to St. John's! Sam was elected a Fellow of the Linnean Society, London, UK in the same year. After retirement he became Acadia's University Botanist but never stopped discovering, teaching and mentoring. He helped establish the Harriet Irving Botanical Garden that houses his work on the E.C. Smith Herbarium (ACAD), of which he was curator for many years. Sam had a love for Latin and the Ericaceae,

particularly *Vaccinium*—becoming a well-respected expert on blueberries—and many living plants of his collection remain at Acadia in the K.C. Irving Environmental Science Centre.



Sam with his living plants collection at Acadia.



Acadia Arctic Biological Expeditions, 1973–74.

During his career, Sam travelled extensively to sample plants from the far reaches of Earth and produced 70+ publications including a highly-acclaimed monograph on *Vaccinium* biology and taxonomy. One memorable trip was the Acadia Arctic Biological Expeditions of 1973–74.

Sam died on 21 January 2011 while out on his nightly walk in Wolfville, just a month after our manuscript was submitted to *Mires and Peat*. A legacy garden has been planted in his honour, very close to where his greenhouse sat for around 35 years. The garden will be forever adorned with his last bicycle. It may be that his final words are contained in this article and in a commemorative issue of *Botany* 90(5), but knowing Sam's legacy, I suspect there will be more; there is certainly plenty to remember. Sam was a colleague, mentor, and friend. His laugh will be missed by many.

Mens curiosa numquam cessat

by Trevor Avery

(Thanks to Julie, Melanie and Dan for pictures, and Rodger for spearheading the bike and legacy garden)



Sam's bicycle on its last stand in the legacy blueberry garden at Acadia University.