Langley Bog Scientific Projects Report
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1.0 INTRODUCTION

Historically, the Langley Bog is estimated to have extended over approximately 500 hectares of land of what is currently the north part of Langley Township, British Columbia.[1] During the 1960s, peat mining operations by the Langley Peat Limited company began taking place in the easterly portion of the bog and continued through the late 1970s.[2] Most of the remaining bog also underwent alteration due to human activity, primarily the conversion into cranberry-growing operations that operate to the present. In 1995, Metro Vancouver (formerly the Greater Vancouver Regional District – GVRD) acquired the land owned by the Langley Peat Limited company as part of the Lower Mainland Nature Legacy Program.[3] This parcel of 89 hectares was annexed to Derby Reach Regional Park in the interest of wildlife conservation. The annexed area has been heavily impacted by peat mining processes but contains some remnants of undisturbed bog forest.

Evident throughout the bog is a dominant pattern of ridges and channels which resulted from peat harvesting operations from 1958 to 1980 (Figure 1). Further remnants of mining can be seen in the presence of several drainage ditches and fill roads consisting of cedar wood chips ("hog-fuel") which run north to south through the middle of the bog and along the southern perimeter. Additionally, along a section of the southern perimeter is a major drainage ditch (Houston) that is still functional. Northern portions of the parcel are bounded by dikes with roadways mainly consisting of mineral fill. On the west side is another major, functional drainage ditch (McQuatt). Hog-fuel appears to comprise a substantial portion of surface material on the bank of the eastern side (bog-side) of McQuatt ditch but some areas seem to have little or no fill, at least under cursory observation.

The original purpose of ditches was to lower the water table in Langley Bog. With drainage, a "dry scratch" method of peat removal (similar to methods tried in other bogs of the Lower Mainland) was attempted in the bog.[4] This method depends on drying the surface layers and subsequently removing the peat of the drier layers. Conditions apparently remained too wet for much success and wet peat extraction methods were then utilized. The wet peat was dug out in trenches involving a floating barge, and water was removed from the peat in a processing

[1] Piteau and Associates, 1994.
[2] Douglas and Chapman, 1995; Piteau and Associates, 1994.
[3] Email communication with staff at Metro Vancouver Parks Office.
[4] Chartbrand, 1995.

plant after removal from the bog; more detailed historical descriptions are available in referenced material.[5] Many ditches, trenches, and channels have in-filled to one degree or another and no longer function in their original capacities of drainage and mining access. However, the resulting pattern of ridges and channels is due to fibrous peat removal in the channels and the ridges seem to be remnant bog and/or additions of debris (such as tree trunks) left behind from the peat removal process.

The study area parcel is located on the south bank of the Fraser River in Derby Reach/Brae Island Regional Park (DRBIRP) in southwestern British Columbia (49°12'02"N, 122°36'26"W). Climate conditions are characterized by a moderate to long growing season (March-October). The number of growing-degree days, used in agriculture as an index of crop growth, is relatively high for Canada at 2104.9.[6] Summers are long and cool with an average annual temperature of 10.0°C (1971-2000) recorded at the nearest meteorological station in Abbotsford, British Columbia (49°01'31"N, 122°21'36"W). The majority of precipitation (70%) occurs as rainfall during the fall and winter (October-March). Average annual precipitation is 1573.2 mm (Figure 1.1).

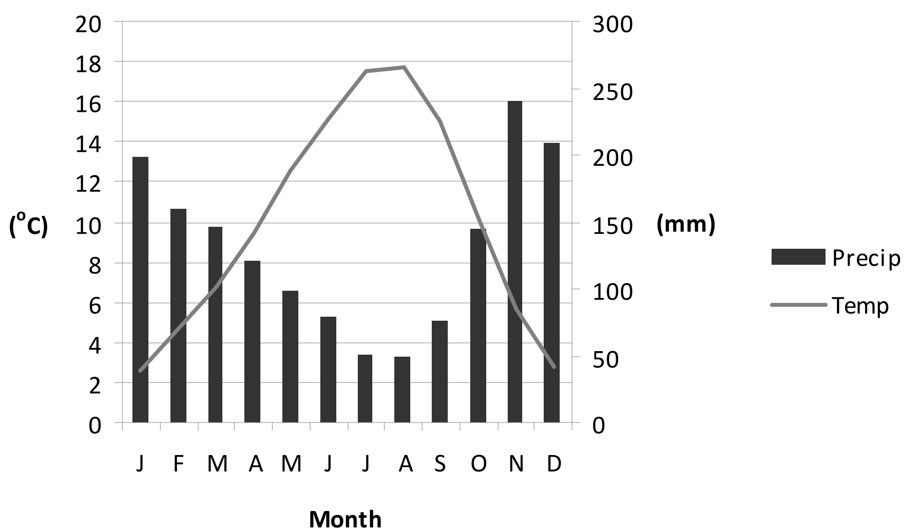

Figure 1.1. Climograph for Abbotsford, British Columbia. Abbotsford is the nearest Environment Canada meteorological station to the Langley Bog study area.

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[5] Luxton and Associates, 2002; Chartbrand, 1995.

[6] Data for this section was compiled from Environment Canada's National Climate Data and Information Archive website.

Basic reports on the characterization of Langley Bog have been conducted previously for various purposes, including the Piteau Associates report, others already cited, and the Derby Reach Biophysical Report Addendum.[7] Our goal is to build on the information in these reports incorporating new data and research with objectives to (1) answer questions regarding whether and how the remaining bog ecosystem may recover, (2) examine the current "natural" bog recovery that seems to be happening to some degree, (3) provide input for management decisions that may enhance recovery, (4) understand Langley Bog natural history, and (5) expand general knowledge of bogs. In short, the purpose of this project is to assess the current physical state of the Langley Bog and work towards implementing restoration with the many partners and volunteers involved in the Langley Bog project. The report is organized into three broad thematic streams focusing on (1) mapping and surveying of basic bog features, (2) studies of soil and water, and (3) studies of vegetation.

Sections 2 – 3 focus on the mapping and surveying of basic bog features. This introductory section (1) provides a brief sketch of historic Langley Bog land use along with a report overview. Section 2, Mapping of Basic Features, and Sections 3, Surface Elevations, focus on the methods and techniques employed in surveying and mapping basic features of the bog, such as the ridge and channel topography and absolute elevations of bog features. Summary results are reported and the important geospatial data acquired are utilized throughout the remainder of this report.

Sections 4 through 6 focus on abiotic studies of soil and water. Section 4, General Characterization of Peatlands and Peat Bog Depth, summarizes current knowledge pertaining to Langley Bog soils, and summarizes and presents results from studies of peat depth in the bog. Section 5, Physical Characteristics of Bog Waters (Hydrology), deals with the hydrology of Langley Bog. Methods and techniques for measuring and mapping surface and groundwater are presented and discussed. Section 6, Chemical Characteristics of Bog Waters, outlines methods and presents results of temperature, dissolved oxygen, pH, nitrates, and calcium observations of both surface and sub-surface bog waters.

Sections 7 through 9 focus on biotic (primarily vegetation) studies conducted in Langley Bog. Section 7, Tree-ring Studies, describes the methods and techniques employed in conducting tree-ring (dendrochronological) research in the bog. Results of tree-ring

[7] Douglas and Chapman, 1995.

chronologies and age determinations for a number of study sites within the bog are presented. Section 8, Native and Non-native Cultivated Cranberry Studies, focuses on the distribution of native and cultivated cranberries throughout the bog and presents the results of reproductive biology and competitive ability experiments for the two species. Section 9, Sphagnum Recovery Test Plots, discusses methods and techniques of sphagnum transplanting studies and summarizes the results of on-going sphagnum transplantation experiments.

The last section (Section 10) provides a series of management recommendations based on the three categories of: Actions, Monitoring, and Maintenance.

Figure 1.2. Two views of the Langley Bog, Fraser River, adjacent cranberry farms, and nearby uplands. The top figure provides a contextual view (Google Maps, 2010) with an inset indicating the original and current bog extent as shown in the lower figure.

2.0 MAPPING OF BASIC FEATURES

Spatial data acquisition and compilation was systematized using Global Positioning Systems (GPS) and Geographic Information Systems (GIS). To establish baseline spatial data, we conducted GPS surveys (summer 2008) to first develop a basemap of Langley Bog showing the channel-ridge structure and outlines of main features. A handheld Garmin 76 GPS unit (UTM 10U NAD 83) was used to capture data points by walking along the boundary of each channel-ridge structure and other features in the bog. Ridges were defined by vegetation type and extent, specifically *sphagnum* and Labrador tea associations at least 15 cm in depth and at least 3 m^2 in area. DNR Garmin software was used to upload the data points from the GPS unit in the Trinity Western University (TWU) Spatial Information Systems Lab, and saved as text files that could be later viewed using ArcMap 9.2.[8]

The basemap from these data is the foundation for various maps that have been created to date. Additional features, such as the locations of shallow monitoring wells (piezometers) were layered over the basemap. The use of GIS in this way allows consistent spatial analysis of data that may reveal patterns, show possible correlations, and otherwise help with data interpretation as well as providing an easily transferable digital record of many variable of the research.

A limited number of areas and features of the bog remain unmapped using the handheld GPS method. For example, the beaver ponds in the eastern portion of the bog limited access to the ridges in that area due to unstable *sphagnum* ground cover. These "trouble-spots" were digitized into the GIS from an orthophoto provided by the Township of Langley's Geomatics Department and verified for ground truth. In addition, "*sphagnum* islands" that were less than 15 cm in height and less than 2 m in diameter were not mapped. One feature was added to the base map in 2009 when an unmapped ridge and adjoining channel were discovered. These features were also digitized from the orthophoto provided by the Township of Langley, and added to the map as an additional layer file (see Figure 2.1). No further changes have been made to the basemap.

[8] Environmental Systems Research Institute (ESRI), 2006.

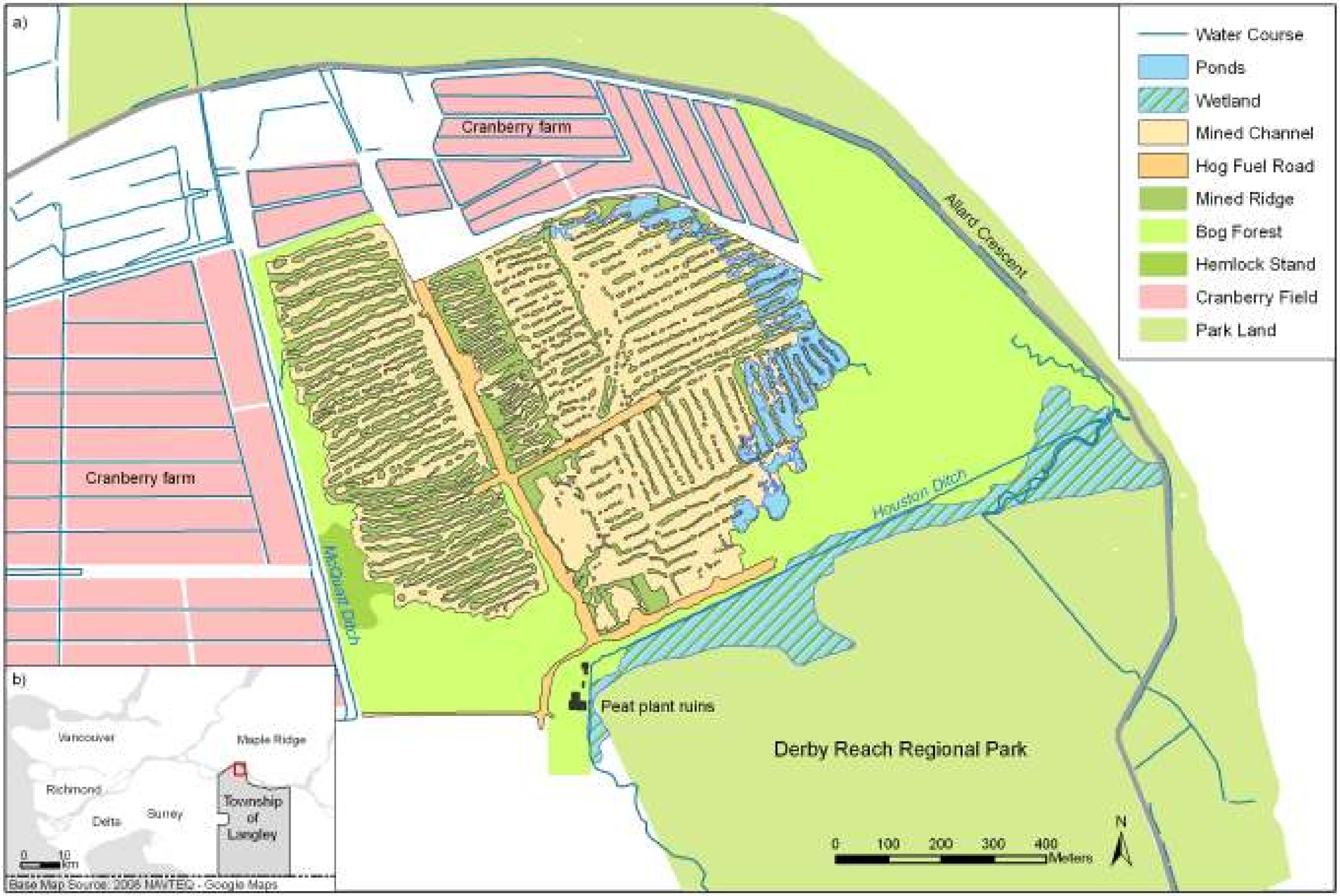

Figure 2.1. (a) Location of Langley Bog study area and (b) regional context.

3.0 SURFACE ELEVATIONS

To gain insight into the current and past "domed" nature of Langley Bog and to better understand water-flow patterns, we determined bog elevation through topographical surveying. Surveying was performed to determine elevations in the bog generally, and specifically at piezometer points (see also Section 5.1), drainage ditches, cranberry fields and standing water locations adjacent to and throughout the bog.

A vertical control surveying technique was performed using a Nikon AC-2s 360° automatic level to obtain the elevation readings across the surface of the bog. For this technique, the measuring rod is first placed on a point of known elevation (Point 1) and a measuring rod height reading is taken through the survey instrument telescope located some distance away along the line of survey. This reading is called the backsight (BS). By adding this reading to the known elevation where the measuring stick is located, the height of the instrument (HI) can be found (HI). The measuring rod is then moved to a new point (Point 2) where the elevation is unknown and a new level reading is taken from the telescope, which remains at the same location as before. This reading is known as the foresight (FS). (In general we attempted to have a similar distance from the instrument to BS and FS, although this was not always possible.) The elevation of Point 2 is found by subtracting the FS from the HI. After the FS reading has been taken for Point 2 (elevation determined), the rod remains at Point 2 while the instrument is then moved to a new location.

Essentially, the process is then iterated until the landscape is fully surveyed: the new BS obtained from this second instrument location can be added to the elevation at this point to obtain a new HI. The new FS measurement establishes the elevation for Point three, and so on. The points where the measuring rods are held to obtain BS and FS measurements are called the turnpoints (TP). Other FS measurements not made to points along the main line are referred to as "sideshots." Piezometer elevations, water level elevations, and other features were made as sideshots off the main lines by shooting down the dikes and hog-fuel roads.

Surveying started at the north-eastern end of the original bog (now in cranberry fields) and proceeded down the hog-fuel roads and across the dikes on adjacent cranberry fields. Benchmarks were created along these causeways by installing a 25.4 cm galvanized steel nail into the ground with a piece of pink flagging tape tied to it. These benchmarks then served as the starting point of subsequent surveying, e.g., such as the elevation of piezometer points in the bog proper.

Two benchmarks from GVRD surveys with known elevations were used to obtain absolute elevations within the bog. The basepoints used were the GVRD benchmarks numbers 81091 and 34256. The elevations and coordinates were gathered from the Crown Registry and Geographic Base Branch's MASCOT website.[9] Benchmark 81091, located on Allard Crescent 890 m east from the intersection with 208th Street, was used as the main point from which absolute elevations within the bog were obtained. Benchmark 34256, located at the Allard – McKinnon intersection, was used as a second point from which to verify absolute elevations within the bog.

Other checks were performed to determine survey accuracy. A surveying loop was closed around the western section of the bog by comparing the elevations of the same point at the beginning and end of the loop. The loop was conducted by starting and ending with the location of piezometer well number 18 (P18). (For discussion of piezometer wells see Section 5.1.) The loop followed the Coast Cranberries Ltd. dike that flanks the northwestern section of the bog and then continued southward alongside McQuatt ditch (on the bog side) until it joined up with the hog-fuel spur road at the southwestern end of the bog linking to P13. Surveying was then conducted eastward along the hog-fuel spur to the main hog-fuel road and then northward to close the loop. The closing of the main loop around the western section of the bog resulted in an error of 11.4 cm. Smaller loops were also checked, typically within a 2 – 3 cm error.

[9] Data was acquired from the MASCOT home page. [online URL: http:://apps.gov.bc.ca/apps/mascotw]

Figure 3.1. Locations of elevation points for piezometer wells, bog features, and survey turnpoints.

Elevation data were imported into ArcGIS 9.3.1 and displayed as x,y events.[10] The data were then converted into shapefiles. Because limited ArcGIS modules are available in the TWU Spatial Information Systems Lab, IDRISI32[11] was used to create masks from the shapefile by generating a triangular irregular network (TIN) on the given data set of points for each time step (in IDRISI, Clark Labs) and rasterizing the TIN. The mask was created to extract only the data that were interpolated (not extrapolated to the resulting rectangular default raster) during the interpolation procedure.

To interpolate a digital elevation model (DEM), the inverse distance weighting (IDW) method was used to determine the estimated elevation (z) between known points. IDW is an exact interpolation method: each point that is used in the interpolation is retained (i.e., not estimated).[12]

The generalized equation for IDW is:

$$z_o = \frac{\sum_{i=1}^{s} z_i \frac{1}{d_i^k}}{\sum_{i=1}^{s} \frac{1}{d_i^k}} \qquad \textit{Equation 3.1}$$

where z_o = the estimated interpolated value at any point on the new raster surface,
z_i = the known z value at point i,
d_i = the distance between point 0 and point 1,
s = the number of points used in the calculation, and
k = the power allotted to the distance (weighting).[13]

For the rasterization of the bog elevation points (z), we set distance power to be 3 (higher than the default of 2 in order that distance between points be more heavily weighted), and the search radius was set as variable with 12 points. The output cell size was set to 1. For displaying the extracted data, a symbology file was created with seven classes. Because the data

[10] ESRI, 1999-2009.
[11] Clark Labs, 1987-2000.
[12] Chang, 2004.
[13] ibid.

were not equally distributed, the data's standard deviation was used as a guide for creating the classes.

Elevations in Langley Bog perimeter areas, including dikes and hog-fuel roads, ranged from about 1.4 m above sea level (asl) in McQuatt ditch at the northwest corner to 6 m asl at the end of the main hog-fuel road on the mid-southern perimeter (Figure 3.1, Figure 3.2) for a total surface relief of 4.6 m. The average elevation of the 168 points was 4.3 m asl. Though the elevation points are not evenly distributed across the bog, and also contain roadway and ditch points, the average height of piezometer well locations was also 4.3 m, suggesting that this is close to the average elevation of the bog itself. In general, higher sections of the bog are located along the southern end, along the dike in the north, and along a "ridge" of higher elevation down the middle, probably associated with the hog-fuel road. The lowest section is located in the extreme northwestern corner of the bog (Figure 3.2). Two low points shown on the north-northeast section of the topographic map are actually in the cranberry fields north of the dike.

Because the bog landscape was not exhaustively sampled, abrupt elevational discontinuities (such as ditches, dikes, roads) are not represented on the DEM (Figure 3.2). More intensive sampling along these discontinuities will improve the topographic surface representation.

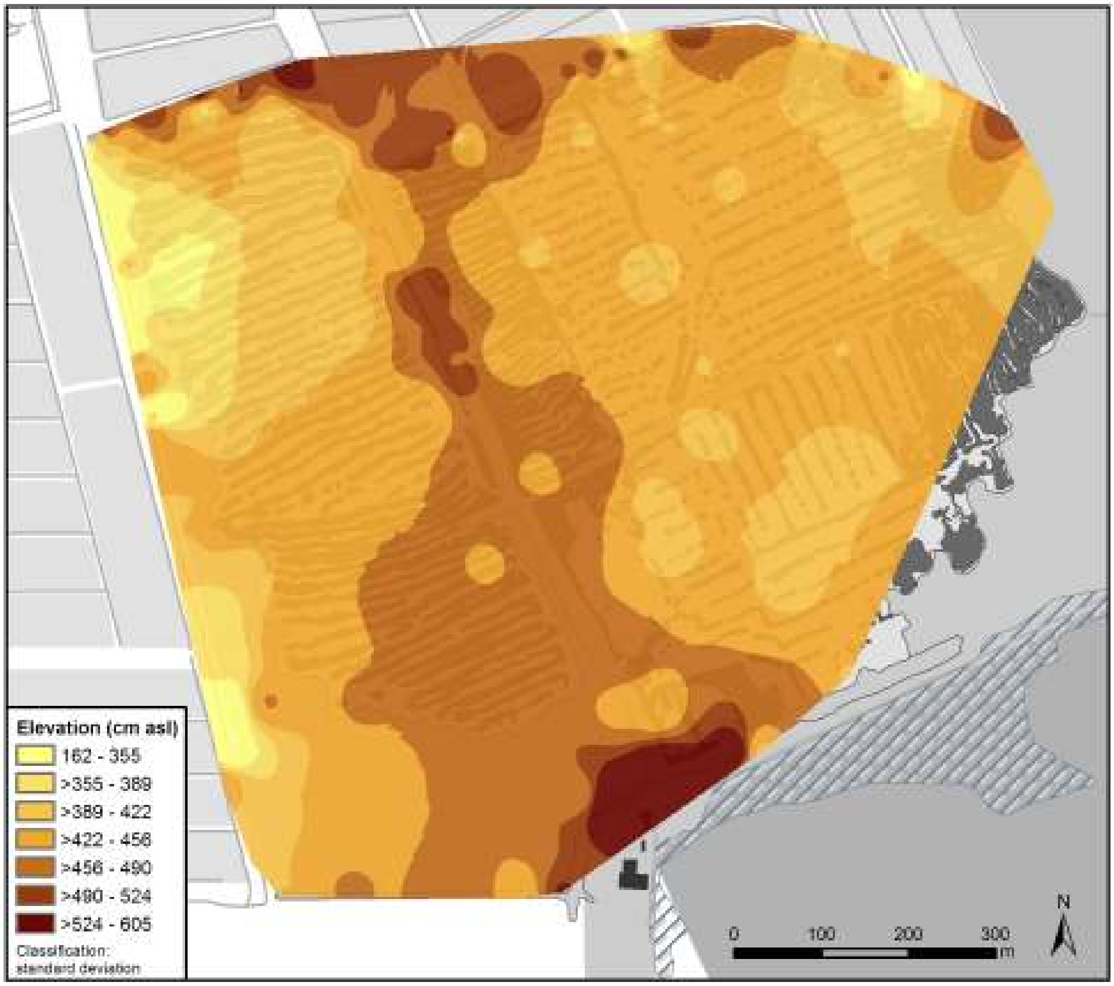

Figure 3.2. Digital elevation model interpolated from survey field work in Langley Bog.

4.0 GENERAL CHARACTERIZATION OF PEATLANDS AND PEAT BOG DEPTH

The Langley area soil survey includes both mineral and organic soil categories, and classifies the main areas of the original Langley Bog, including the mined area, as an organic soil series designated Triggs (TR).[14] Surrounding and associated soils include the Glen Valley (GV), Gibson (GN), Banford (BD), and Hjorth (HJ). Of these, only HJ is a mineral soil (although, there are other more upland surrounding mineral soils). Soil descriptions (i.e., soil below surficial growth, where present) provide some indications of original conditions (Table 4.1). It is important to note that soils have been modified by the peat mining process and do not necessarily reflect past conditions.

Previous records of peat depth in Langley Bog include general descriptions from peat mining and cranberry field operations. A depth of 8 – 10 m of peat is estimated to have been removed during extraction procedures. A 1981 study by the Greater Vancouver Sewerage and Drainage District (GVSDD) reported peat depths of 5 – 7 m existing in cranberry production areas and up to 8 – 10 m in eastern portions of the mined peatlands. In 1988, a Norecol study for Coast Cranberries measured 3.5 – 4 m of peat materials.[15] The latter report also described the peat materials as consisting of 1 – 1.5 m of *Sphagnum* moss underlain by approximately 2.5 m fibrous and amorphous peat, in general agreement with soil survey descriptions.

Table 4.1. Soil survey of Langley Bog.

Predominant Soil Series Type	Organic or Mineral	Brief Description	Geographic Location in Langley Bog
Triggs (TR)	organic	> 1.6 m relatively un-decomposed organic matter, mainly *Sphagnum* mosses	Bog forest just east of mined area; mined area within park boundaries, majority of the original bog area
Glen Valley (GV)	organic	> 1.6 m relatively un-decomposed organic matter, mainly reeds, sedges, and grasses	Westerly portions of the original bog
Gibson (GN)	organic	0.4 - 1.6 m partially decomposed organic matter over floodplain deposits	Bog forest east of mined areas, south and west of Allard Crescent
Banford (BD)	organic	0.4 - 1.6 m well decomposed organic matter over floodplain deposits	Bog forest east of mined area, south and west of Allard Crescent
Hjorth (HJ)	mineral	medium textured laterally accreted floodplain deposits	Forest and low lying areas east of bog

[14] Luttmerding, 1980.
[15] Piteau and Associates, 1994. See also p.3 for GVSDD description, and pp. 3 and 8 for the 8-10 m depth estimates.

The Piteau Associates report includes mapped site locations for five test cores.[16] One is mapped to a GN-BD soil series type located on the northeast edge of the bog, two are mapped to the TR series located just east of the mined portion, and two are mapped to an HJ series located east of the bog closer to Allard Crescent, and in the mined portion of the bog respectively. Using the hardcopy map included in the original report, we have estimated approximate UTM coordinates of the respective soil series types.

We have added a series of test cores to examine depth of peat materials in the bog using a Russian/McCauly style of peat corer with extension rods. Twelve peat cores in 50 cm increments were extracted manually and logged for colour and texture characteristics. Absolute depth of peat core samples was defined as the point below surface elevation when the 50 cm core sample returned primarily mineral material (usually a silt/clay mixture).

Core depths in Langley Bog, including those from previous studies, range from 3.3 m to 5.5 m with an average from of 4.4 m (Table 4.2, Figure 4.1, Table 1A – appendix). In boundary locations such as those described by Banford or Gibson soil classifications, depths are < 1 m. Though it is possible they may exist, no depths have been recorded that match the historical claims of depths > 8 m.

Table 4.2. Peat depths in Langley Bog.

Description	Core	Peat Depth (m)
bog forest west	A	3.34
bog shrub hummock	B	5.5
channel	C	4.5
channel	D / 2	3.5
ridge	E	4.3
ridge	F	4
channel	G	4
channel	H	4.6
channel	1	3.7

Description (con't)	Core	Peat Depth (m)
channel	3	3.75
ridge	4	4
ridge	5	4.7
bog forest east	TH-2	5.2
bog forest east	TH-3	5.2
channel (?)	TH-5	5.5
bog average		**4.39**
northeast forest	TH-1	0.6
southeast forest	TJ-4	0.9

[16] Piteau and Associates, 1994.

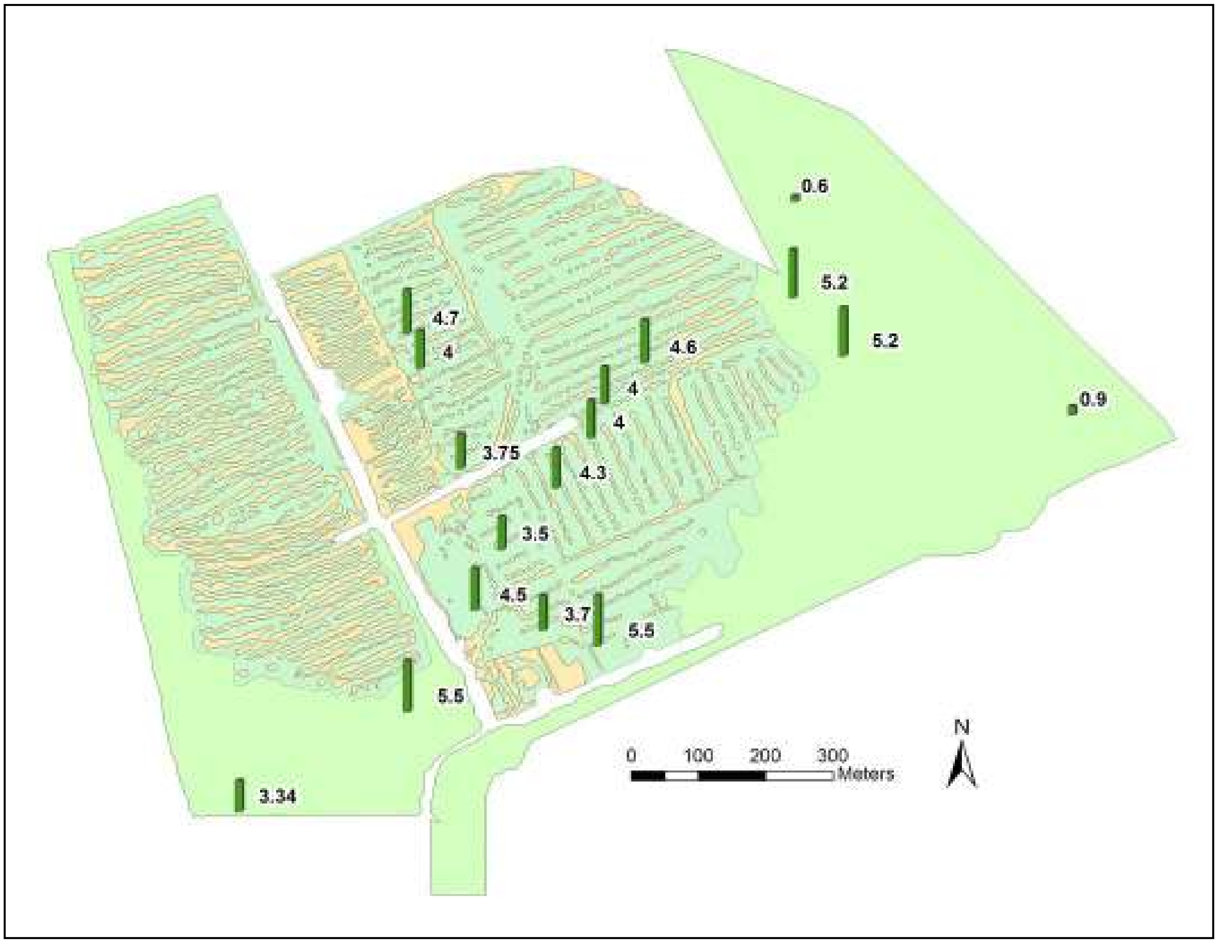

Figure 4.1. Depth (m) of peat core samples extracted from Langley Bog.

The Langley Bog is thought to have been a raised bog or domed bog – one in which the peat materials and ecosystem become elevated over the surroundings in a convex dome, due to accumulation of the peat materials. In such a dome, water is held and even conducted upward through what is described as matrix potential or capillary action; the fibrous partially-decayed peat material acts like a sponge to absorb the water above the level of that expected when the major potential is gravitational. The claimed peat depths of 8 and up to 10 m might be explained by this type of domed structure. Drainage of the bog would lower the water table to a value closer to that determined by gravity potential and surrounding topography – whatever shape and elevation the walls of the trapping basin might be.

Indeed, we suggest peat removal combined with water drainage incurred as a result of mining activity caused the remaining peat materials to slump or collapse. Figure 4.1 shows that most interior locations, apart from locations on the edges, have shallower peat depth measurements than those in remaining unmined bog areas. Collapse occurred because too little surrounding peat material was left to support or maintain free-standing slices of the original domed structure. Compounding the situation was a lack of structure in the remnant peat due to formation of a peat slurry as un-removed peat materials mix with water below the water table. It seems likely that surface levels in mined areas of the bog would have collapsed close to the level of a gravity potential water table, without the sphagnum influences of matrix potential to retain water in higher areas. The depths of peat we see today, in many locations at least, would reflect that removal and surface collapse.

If this assessment is basically correct, there are implications for management. Perimeter bog forest areas that are perhaps deeper in peat and/or higher in surface elevation than the interior (see Section 5), may be subject to water stress with regard to maintaining optimal peat growth. This would be due to altered water table characteristics, lowered as a result of drainage and the centre collapse. Many *sphagnum* hummocks in the southwestern area of remaining bog and bog forest appeared dry enough to be "crispy" in the latter half of summer and also several appeared to be decaying, turning a black color.

On the other hand, collapse towards the existing water table level closer to that defined more by gravitational forces may help favor peat development in the interior, as long as water remains at or near the surface (see Section 5.2). However, both conservation and recovery might be enhanced by maintaining (more or less) as high a water table as possible (see also Section 5.2).

Additional subsurface peat characterization studies have been initiated and/or are under consideration, and include one TWU student thesis. These studies aim to investigate paleoecological and paleoclimatic parameters such as the degree of humification (peat decay), fossil pollen and ancient plant remains, and silt inclusions indicative of ancient Fraser River flood events. Preliminary results indicate that degree of peat humification does vary with depth, suggesting bog peat deposits are a valuable archive of past local/regional climate conditions. Furthermore, marked silt deposits in peat cores suggest that several major Fraser River flood events are recorded in Langley Bog. Given their relatively preliminary nature, further details of these initiatives are not described here but will be reported as those research projects are completed.

5.0 PHYSICAL CHARACTERISTICS OF BOG WATERS (HYDROLOGY)

5.1 Piezometer Network

In the summer of 2008, a piezometer network of 26 wells (shallow groundwater monitoring wells) was added to the network of 13 wells previously installed by Adam Snow (39 wells total). The wells were inserted throughout Langley Bog, roughly 200 m apart. Two more were added in the summer of 2009, for a total of 41 wells (Figure 5.1.1), however, two of the original wells from 2008 (#5 and #28) were lost during 2009. At least one appeared to have been lost during hog-fuel removal because it had been situated near the central road in the bog and the area was noticeably disturbed. Thus, 39 wells were utilized for groundwater observation in 2009 as well as 2008, but 37 of the wells were used in common between the two years, and each year had two wells unique to that year (Figure 5.1.1).

Piezometers were constructed using 3.2 cm diameter PVC pipe cut to one of two lengths, either 152 cm or 213 cm long, a 3.2 cm coupling was glued to one end and closed with a 32 mm screw cap or loose cover which could later be removed in order to take water measurements. A pointed wooden dowel was inserted on the opposite end to allow for easy insertion into the peat. Perforations to allow water inflow into the pipes were drilled quad-directionally 30 cm from the top of the piezometer approximately every 15 cm. Approximately 30 cm of the upper-capped end of the piezometers were left exposed above the bog surface. The piezometer network, along with a number of surface water locations (Figure 5.1.1), was used to monitor several bog water characteristics, including water depth from surface, temperature, and water chemistry.

5.2 Water Depth from Surface

The distance between the piezometer top and the water surface inside the well was determined by observing the “wet” line on a measuring tape when lowered a known length into the well from the top of the well pipe. The height of the piezometer pipe above the ground surface was then subtracted to determine actual water depth below surface.

Figure 5.1.1. Locations of piezometer wells and surface water sampling points in Langley Bog. Data observation dates and data property observed are noted in the figure and in text.

In 2008, the first measurements of water depth were made in mid-July. Water depth was recorded a second time in mid-August using a Solinst electrical water sensor (this was the only time this method was used). As before, piezometer height was recorded and subtracted from the measurements gathered by the electrical water sensor to provide water depth. Water depth measurements were also conducted twice in 2009, during May and July. A total of 39 wells were used in both 2008 and 2009 surveys but, as noted in the previous section, 37 of the 39 were in common between the two years as two were lost from 2008 and two were added in 2009.

In October of 2008, a more limited survey of 20 wells was conducted. Though a smaller subset, the data seem adequately representative of bog conditions as averages of those 20 wells closely matched the average of data from all the wells and the 37 wells in common between 2008-2009 (Table 6.1). Limited collections of water-depth measurements occurred during the winter and early spring of 2009, however much of the ground was frozen during the winter survey and many water measurements were essentially at the surface during these times, probably explainable by the greater precipitation occurring during the winter and spring. However, because actual data sets of observations were not large enough to make valid comparisons, these data were not statistically analyzed, but are reported in Appendix tables for reference.

Table 5.2.1. Comparisons of averages in water depth from the bog surface as measured in piezometer wells.

	Average Water Depth from Surface (cm)				
	July 08	Aug 08	Oct 08	May 09	July 09
Total well average*	-8.4	-12.6	-8.9	-5.4	-16.1
37 well average[a]	-8.8	-13.1	--	-5.2	-15.4
20 well average[b]	-8.8	-13.3	-9.3	-4.9	-16.0
Total well average*	-8.4	-12.6	-8.9	-5.4	-16.1

* 39 wells for all except October, 2008 which was 21,
[a] Average of wells measured in common between 2008 and 2009
[b] Average of the same wells as measured in October of 2008 minus well 5

Subsurface water level maps were created the same way as for the elevation topographic map (Section 4) except that five symbology classes were used for the water levels maps instead of seven classes and new TINs were created for each data set as necessary (Figure 5.2.1).

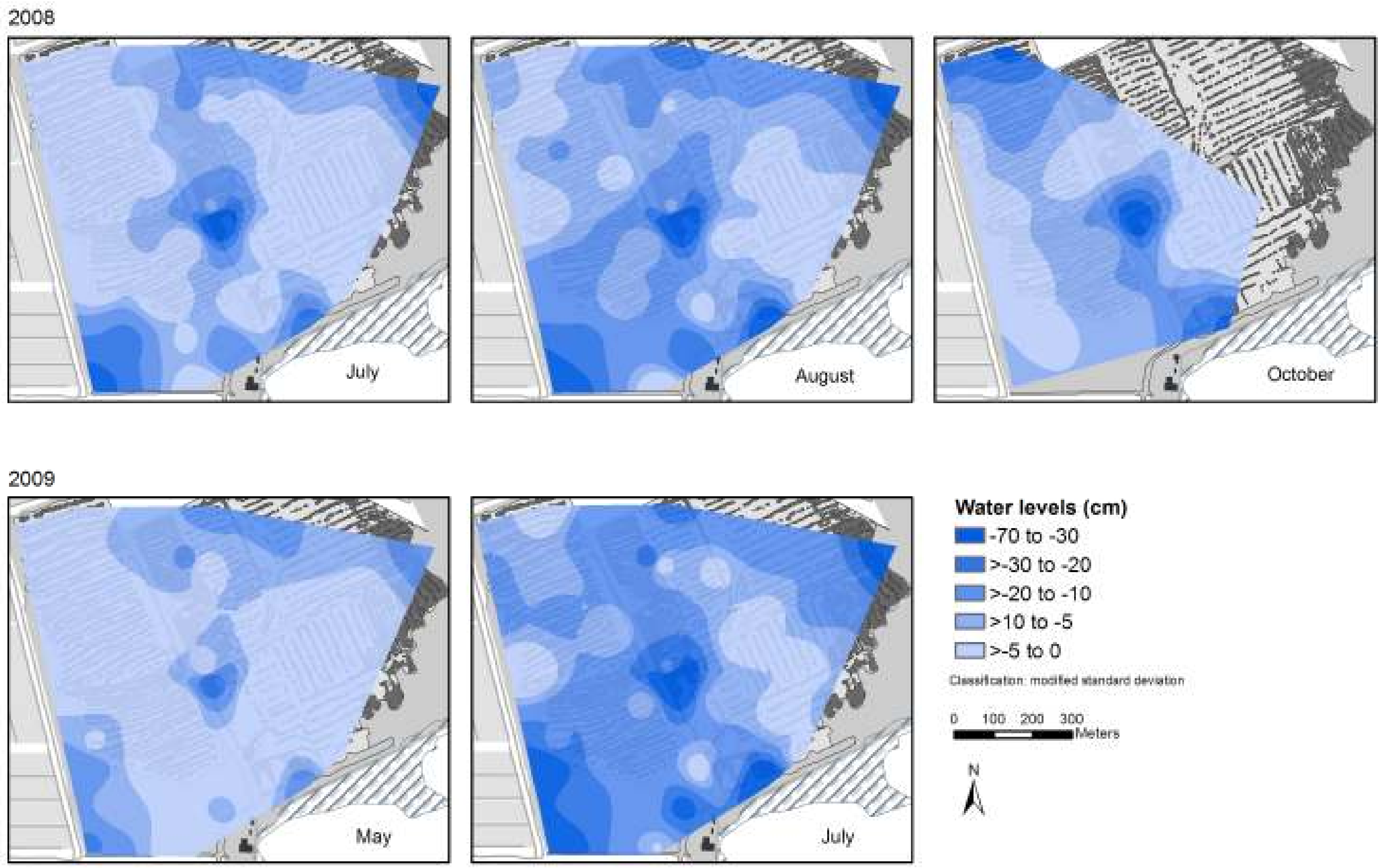

Figure 5.2.1. Subsurface water levels in Langley Bog. Values shown are depth below surface (cm) in 2008 and 2009.

As might be expected, water levels were higher during cooler months and show a definite trend toward lower levels below the surface during the summer months (Figure 5.2.1). There was a pronounced lowering in water levels between July and August of 2008 as well as May and July in 2009, though 2009 was a wetter but warmer year than 2008 (Table 5.2.1, Figure 5.2.2).

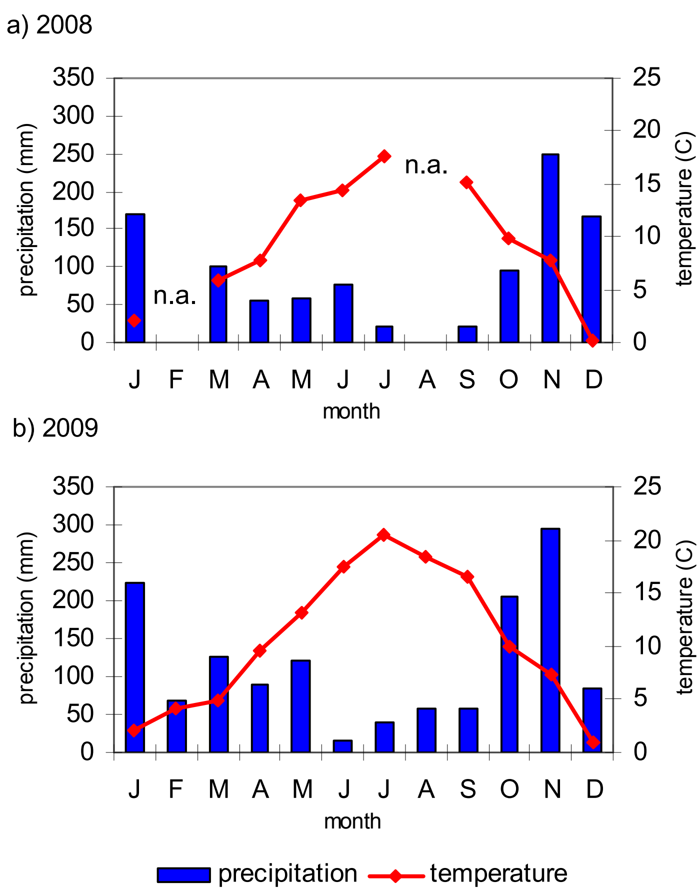

Figure 5.2.2. Climograph for Abbotsford, British Columbia. This climograph shows average monthly temperature and total monthly precipitation for (a) 2008 and (b) 2009. Note two missing values for February and August temperature in 2008.

Total precipitation from March – July of 2008 was 310.5 mm and average temperature for those months was 11.82°C, and these values for the same time period in 2009 were 392.4 mm and 13.08 °C, respectively indicating that the early half 2009 was wetter and warmer. However, the June values for these years indicate that June 2009 was drier and hotter. In fact, June 2008 had a mean monthly temperature of 14.4°C and a total monthly precipitation of 77.1 mm while for June 2009, these values were 17.5 °C and 14.5 mm respectively.[17] The 2008 and 2009 July water level maps show marked differences in water levels, reflecting the low precipitation and higher evaporation potential during the preceding month of June. Presumably, August 2009 would have had a lower average depth below surface than July. Individual water level measurements were both lower and higher in October than in August depending on location (data in Appendix), but the October average was higher than August suggesting recharge was occurring.

If all water measurements within -2 cm of the surface are defined as "water at or near the surface," July 2008 measurements indicated that 19 of 39 sites fulfilled that description, while in August only nine were at or near the surface. In May of 2009, 19 sites were within 2 cm while in July of that year only five were at the surface (see data in Appendix). As with the average water depth below surface, it seems likely that even fewer sites would have been at the surface in August of 2009.

Water level drops are important factors in re-establishment strategies, particularly on mined peat areas relatively devoid of vegetation. *Sphagnum* establishment is correlated to humidity at the surface,[18] and seems to require humidity of at least 80%,[19] supplied by the moisture near the surface in the matrix (in this case, decayed peaty materials) on which the *Sphagnum* attempts to grow.

Such requirements raise the question of how high does the water table need to be maintained? Greenhouse regeneration simulations using *Sphagnum* fragments (diaspores) on a peat substrate grew best when water-tables were maintained at -5 cm, somewhat less when water tables were maintained at -15 cm, and considerably less when water tables were at -25 cm.[20] Similarly, field re-establishment patterns studied on 207 plots in a mined bog of northern Japan suggest that extended dry periods (one month or more) with average water levels lower than about -20 cm are not likely to re-establish *Sphagnum* cover, at least within the parameters of the study plots, aged nine to 30 years post-mining.[21] However, sites that maintained levels at -15 cm

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[17] Data for this section was compiled from Environment Canada's National Climate Data and Information Archive website.
[18] Campeau and Rocherfort, 1996; Ferland and Rochefort, 1997.
[19] Rochefort, 2010.
[20] Campeau and Rocherfort, 1996.
[21] Nishimura et al., 2009.

and above seemed to re-establish *Sphagnum* species through a gradual succession of plant cover types and age (some were too young for peat re-establishment). Similar conclusions were reached in a Quebec bog study where greatest *Sphagnum* recovery occurred when water levels averaged -5 cm but re-colonization did not occur in another area averaging closer to -20 cm.[22] Although higher water table plots from the study in northern Japan did show significant *Sphagnum* regeneration, none of the mined plots had plant cover that matched the control (unmined) plots,[23] indicating that full recovery, if possible, would take longer than 30 years.

In the Langley Bog, we have only worked with averages at this point. A cursory comparison of channel areas with areas having *Sphagnum* cover and/or hummocks suggests that water is often closer to the surface in the channel areas (which are lower in elevation) than the average water level. However, other studies have looked at average characteristics as well so it seems that some generalizations are possible. Though individual locations will vary, for the Langley Bog in a season similar to 2008 where the average depth below surface in August was -13.3 cm, it seems likely that general moisture conditions across the bog favour both natural and enhanced strategies for recovery of *Sphagnum*. On the other hand, in 2009, average water levels were lower than -16 cm in July, and would likely be lower still in August. Such conditions are likely putting *Sphagnum* re-establishment at risk.

Minimizing fluctuations and maintaining consistent hydrological conditions in a disturbed bog is a challenge. It is known that water table fluctuations in mined bogs are greater than in natural bogs.[24] Large areas of *Sphagnum* cover at least 19 cm thick are estimated as necessary in restoration settings to overcome the effects of the abnormal fluctuations.[25] However, in the interim, what strategies should be used for *Sphagnum* to re-establish? Because a consistent water table within -15 cm or so of the surface seems to be required for recovery over large areas in a reasonable amount of time, establishing an average minimum fluctuation range within -15 cm of the surface seems like a functional goal.

Given the mined nature of Langley Bog, *Sphagnum* recolonization is a major concern but maintenance of existing *sphagnum* hummocks is important as well. Water at or near the surface may not be as critical in all stages of *Sphagnum* growth and some species can be relatively

[22] Price and Whitehead, 2004.
[23] Nishimura et al., 2009.
[24] Rochefort et al., 2002.
[25] Lucchese et al., 2010.

tolerant of intermittent drops in water tables. However, as noted in Sections 3 and 4, perimeter bog forest areas, such as in the southwestern portion of the bog, may be higher in elevation than the interior and, consequently existing *Sphagnum* in these locations may be subject to water stress due to lowered overall water table characteristics. Depth-from-surface measurements are consistent with this idea. Extended periods of water tables well below -20 cm (-20 to -70 cm range) are evident (Figure 5.2.1).

Bogs may form under varying conditions but one hypothesized pathway of peat bog genesis is by ecological succession in shallow lakes, that is, the gradual infilling of a lake.[26] The bowl-like character of the underlying surface suggested by peat coring would also seem to indicate that this type of description applies to the Langley Bog. It is possible that too much water (flooding) of *Sphagnum* areas can have mixed results regarding re-establishment, but research indicates that *Sphagnum* recovery is more often enhanced by temporary periods of flooding and even continuous flooding.[27] In addition, non-bog invasive species such as birch trees are more likely to be hindered by such conditions (see section seven). While water levels in much of the Langley Bog appear within range to encourage *Sphagnum* recolonization, we are also inclined to suggest that establishing a water table that is "too high" is unlikely to be a problem, particularly where both maintenance of remnant stands and recolonization are a concern. Standing open water in some locations is better than a water table that is too low. It may therefore not be enough simply to prevent excessive drainage to enhance recovery, but maintaining a water-table as high as possible might be the best strategy for maintaining existing peat, reducing the effects of water table fluctuations, and encouraging rapid overall re-establishment.

5.3 Water Elevations

The bog was surveyed (see Section 4) to provide surface spot elevations, but also to enable the determination of water table elevations in addition to "depth from surface" measurements (Section 5.2). Water table heights were interpolated using the same methods as described earlier (Sections 4 and 5.2) to show potentials for accumulation and loss, and potential

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[26] Wheeler and Proctor, 2000.

[27] Rochefort et al., 2002; Some bogs are considered "floating mat" *Sphagnum* bogs. The bogs have formed in lakes or ponds and appear to have been formed by encroachment of *Sphagnum* and other bog species into the wetland. Such bogs would form under "flooded" conditions but the *Sphagnum* surface remains mostly above water (floating). See for example: Riggs, 1925; McKnight et al., 1985; Tsujino et al., 2010.

directions of flow. Water level depth measurements at each piezometer location were subtracted from the corresponding elevation measurement at each piezometer to obtain water elevations in wells for all 2008-2009 measurements. In addition, elevations of some surface waters for July 2009 were directly surveyed as part of the water table description. The data were used to make subsurface maps of the water table (Figure 5.3.1).

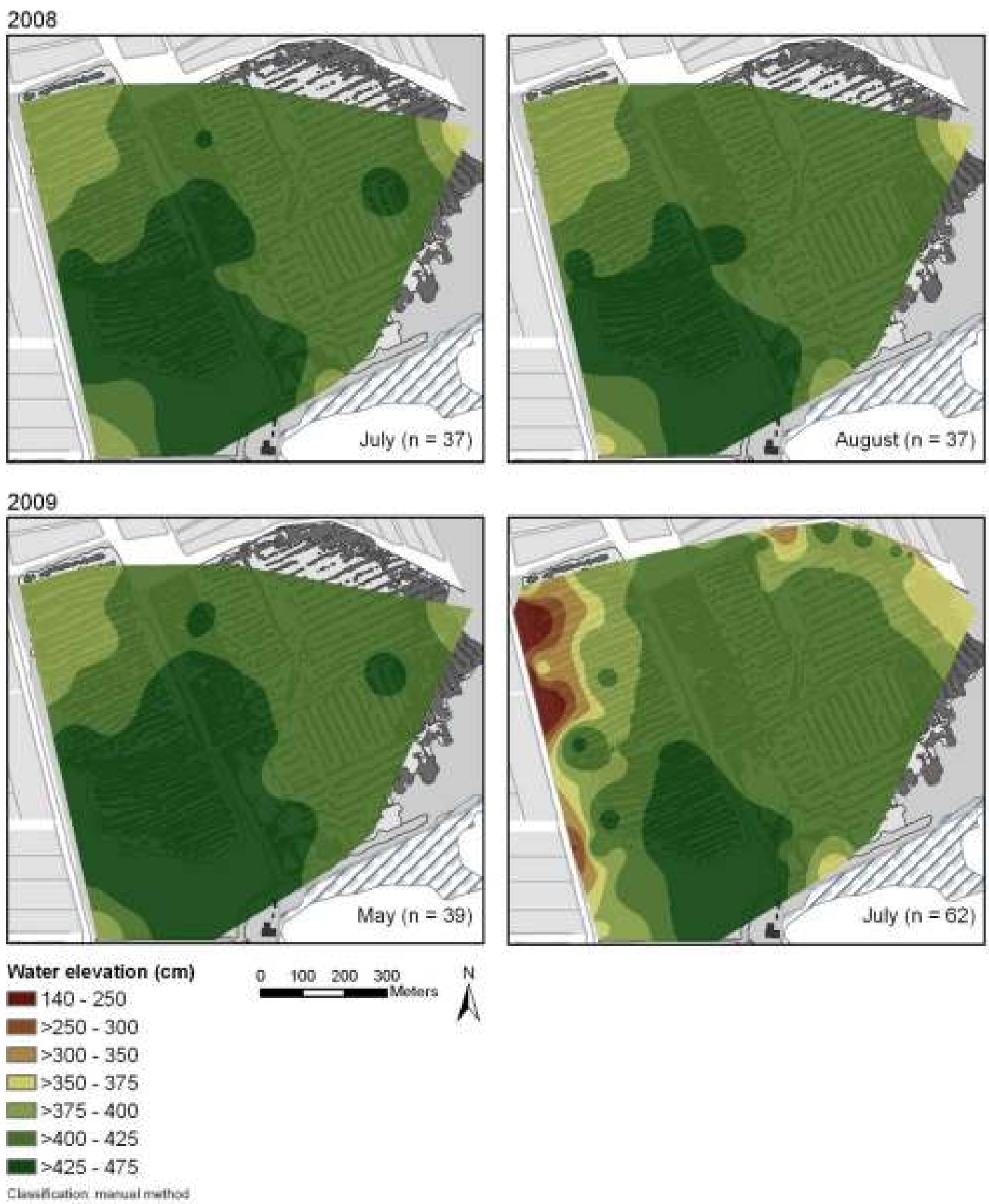


Figure 5.3.1. Subsurface water table elevation. Elevation in this figure is measured from a standard (sea level) in contrast to depth from surface (see Fig. 5.2.1). July 2009 also includes several direct surface water elevation measurements.

The subsurface water table elevation maps of Langley Bog show some similarities to the DEM of absolute elevation indicating that the elevation of the bog surface plays some role in water table height. Water table elevations across sampling times are most often lowest in the northwest region, a pocket of the southwestern corner, and the far eastern portion of the measured area. Highest elevations are in the mid-southern/southwestern area. The combined elevation data suggest that general flow patterns of water could be divided by the "ridge" of higher elevation down the middle of the bog, flowing east and west from the ridge (Figure 4.2, Figure 5.3.2). On the east side, flow might occur toward a central east location, though some drainage might be toward small pockets on the far north and south, or accumulate in the middle. On the west side, flow would tend to occur from some point in the mid-south toward the northwest corner. This is consistent with the water table being closer to the surface in the northwest region (Figure 5.2.1), explainable in terms of water flow and elevation. There also seems to be a pocket of drainage toward the southwest corner (Figure 5.3.2) where a visible outlet into the upper McQuatt ditch occurs.

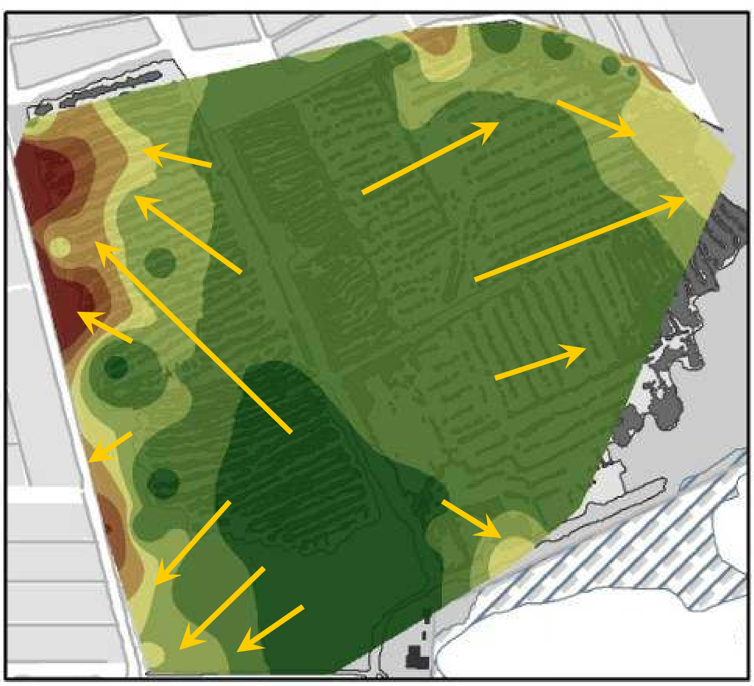


Figure 5.3.2. Possible sub-surface water flow scenario. The scenario is based on water table elevations in July 2009, elevations of McQuatt ditch, surface and pooled water locations, and water outlet points. See also Figure 5.3.1.
General flow pattern is northwest, southwest and east.

Given the water flow scenario proposed above, water is likely to accumulate in lower areas of the bog, resulting in standing water in these locations. The dikes, roads, and surrounding elevations (as discussed below) may contribute to, and alter, water flow direction. Permanent pools exist in and along the eastern bog boundary, however this may be due in large part to the presence of beaver dams.

The weirs installed by bog restoration volunteer, Adam Snow, are located in low-point/outlet areas, and are helping to manage extreme fluctuations in bog water levels. Furthermore, the southwest corner seems to be a drainage point, but much of that region can have large depth-from-surface water deficits as well. This again suggests the need for careful water management to maintain existing bog *Sphagnum*. Because the northwest corner seems to have the lowest points both in the bog and in McQuatt ditch, controlling flow out of that area may be particularly important. Also, it might be worthwhile to look for outlets in the eastern bog forest as possible hydrology control points.

One interesting finding emerging as a result of surveying surface elevations is that the cranberry fields on the northern perimeter are terraced. Figure 5.3.3 shows four transects running from the water level in the bog, across the dike/road, the water level in the ditch between the dike and the cranberry field, and the cranberry fields. Note that the bog water level is the same in all four, but the water level in the ditch and elevation of the cranberry field is higher in the fourth transect (farthest west of the four). We did not take actual survey points in the Coast Cranberry Ltd. field, but visibly, when continuing along from the Raine Cranberry Ltd. fields to Coast Cranberry Ltd. fields, the latter field was higher yet and even higher than the level of the bog.

Where bog water is higher than the water table in the cranberry fields, net outward water flow is expected. Similarly, where the field is higher than the bog, net water movement is expected to flow the other way, into the northwest corner of the bog where bog elevations are generally among the lowest. It is currently unknown how much water exchange may actually take place.

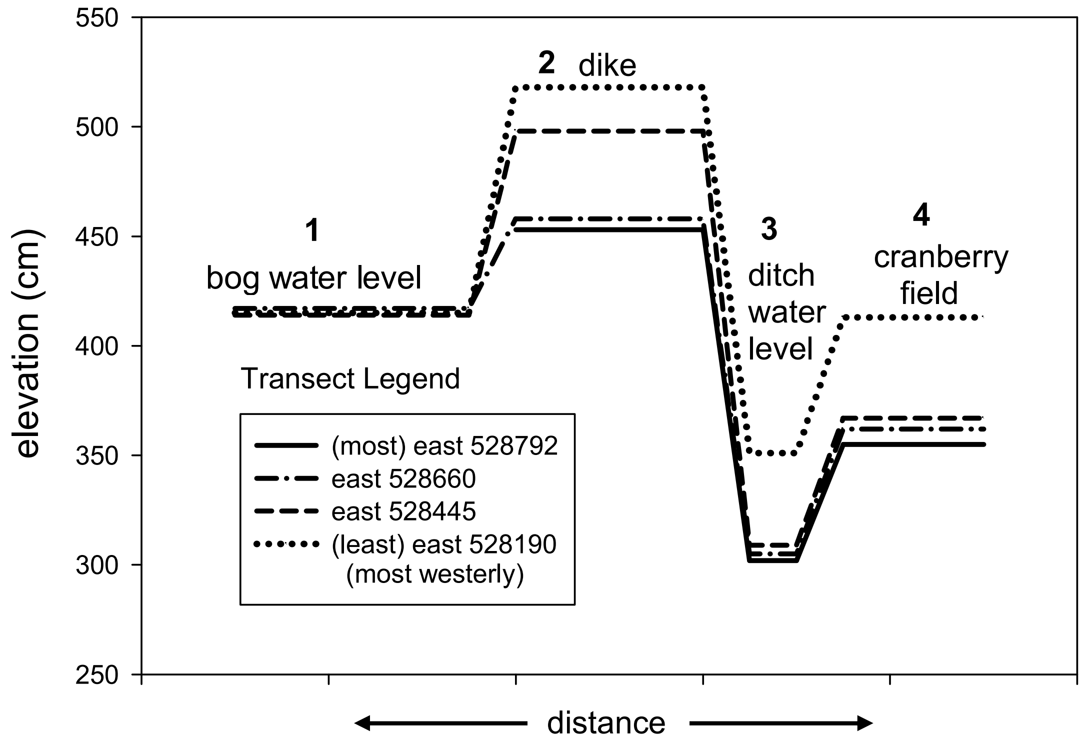


Figure 5.3.3. Four water level transects. The water level transects run from the bog across the mineral dike into the cranberry field (Raine Cranberriey Ltd.) showing the elevations of four features in each transect: (1) bog standing water level, (2) the mineral dike/perimeter road height, (3) the water level in the cranberry field ditch, and (4) the level of the cranberry fields. Transects (UTM easting) are approximate – actual easting measurements varied somewhat. The water-ditch level in 528660 is estimated. The x-axis is not to scale. Water levels are from July, 2009.

6.0 CHEMICAL CHARACTERISTICS OF BOG WATERS

A series of water chemistry measurements were collected at various times during 2008-2009 and included temperature, pH, dissolved oxygen, calcium concentration, and nitrate concentration. Water samples were acquired from around the perimeter of Langley Bog at 16 sites during 2008 and 18 sites in 2009. Within the bog, water was sampled from piezometers P1-P39 in 2008 for a total of 55 sites (Figure 5.1.1). In 2009 samples were taken from wells P1-P41 but minus wells P5 and P28 (see Section 5.2). The total number of sites for 2009 was therefore 57 (Figure 5.1.1). Major collection periods occurred in July and August of 2008, and May 2009 to obtain different seasonal variations. In addition, smaller sets of water samples were collected at various times for other measurements, such as a comprehensive metal analysis analyzed by inductively coupled plasma (ICP). We have also included in this report select measurements from earlier studies where applicable.

6.1 Temperature and Dissolved Oxygen

A handheld dissolved oxygen (DO) and temperature meter (YSI model 55) were used to measure both dissolved oxygen and temperature. In all sample situations, the probe was inserted directly into the water and rapidly agitated beneath the water surface to a depth of approximately 35 cm, until reasonably consistent and stable readings were noted. As measurement teams went out in pairs, two replicate readings at each site for both temperature and DO were taken, one by each team member. Three collections of temperature data were collected.

Table 6.1.1. Water temperatures in Langley Bog for 2008-2009.

	Temp ^{o}C July 2008	sdev	Temp ^{o}C August 2008	sdev	Temp ^{o}C May 2009	sdev
Total Bog Avg	15.5	2.9	16.5	2.1	10.7	1.8
Well Avg	14.6	2.4	16.1	2.2	10.2	1.7
Surface Water Avg	17.8	2.9	17.4	1.9	11.8	1.5

sdev = 1 standard deviation among averaged (2 replicate) points (±)

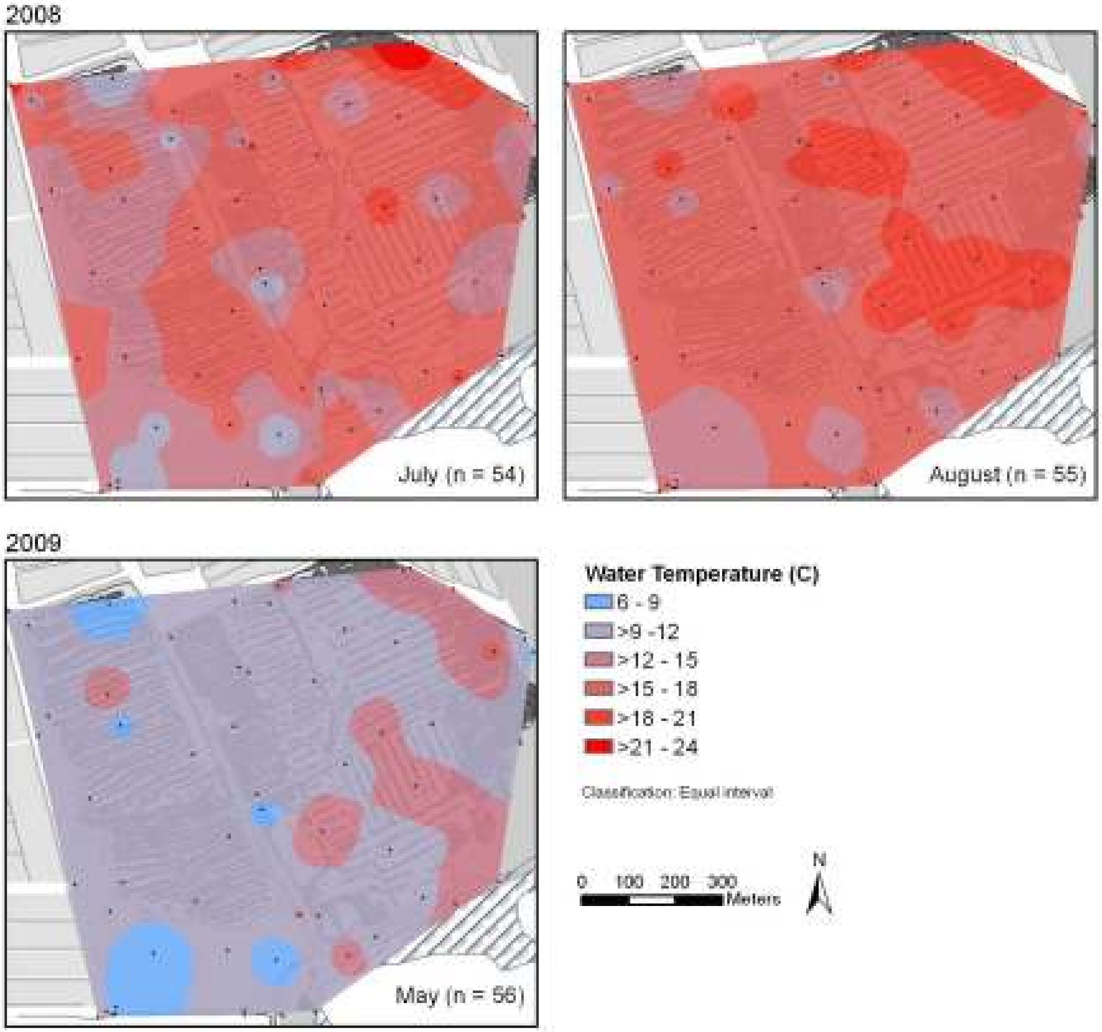


Figure 6.1.1. Interpolated surface and sub-surface average water temperature observations in Langley Bog for 2008-2009.

Averaged water temperatures reflected seasonal effects (Table 6.1.1, Figure 6.1.1). May 2009 was coolest overall, July 2008 considerably warmer, and August 2008 warmest of the three. Surface waters tended to be somewhat warmer than well waters. Lower temperatures were observed in natural bog or bog forest areas and western areas of the Bog that were mined earlier, where more regrowth of *Sphagnum* has occurred (Figure 6.1). These locations also have more tree growth on the ridges, increasing the amount of shade and the potential for evapotranspiration. Higher temperatures occur in the heavily mined area of the bog, as well as in open water. In open mined areas of the bog, relatively little vegetation and more exposed peat allow the surface and ground water to warm.

Based on solubility, temperature, and atmospheric pressure, concentrations of oxygen in water at equilibrium can be calculated. At 25 ^{o}C this value works out to be approximately 8.5 mg/L. Counter to what might be our intuition in this case, more oxygen can dissolve at lower temperatures so at 10 ^{o}C this works out to be closer to 11 mg/L. Such calculated values should represent upper values – maximums under normal conditions.

By comparison, DO readings are generally low within the bog (Table 6.1.2, Figure 6.1.2). Dissolved oxygen values in bog wells for the two data collection periods ranged from less than 0.1 to 4.7 mg/L, though averages were weighted toward the lower end. Open water sites seem to contain the highest DO values, in the northeast corner of the bog and along McQuatt and Houston ditches, ranging from 0.5 to 5.9 mg/L. These generally are still not high. There was little or no movement in the surface waters during measuring times, meaning little potential for aeration other than atmospheric diffusion. Less oxygen was found with warmer temperatures, as might be expected.

Table 6.1.2. Water dissolved oxygen values in Langley Bog for 2008-2009.

	DO mg/L		DO mg/L	
	July 2008	sdev	May 2009	sdev
Total Bog Avg	1.05	0.77	1.94	1.57
Well Avg	0.83	0.59	1.28	1.07

sdev = 1 standard deviation among averaged (2 replicate) points (±)

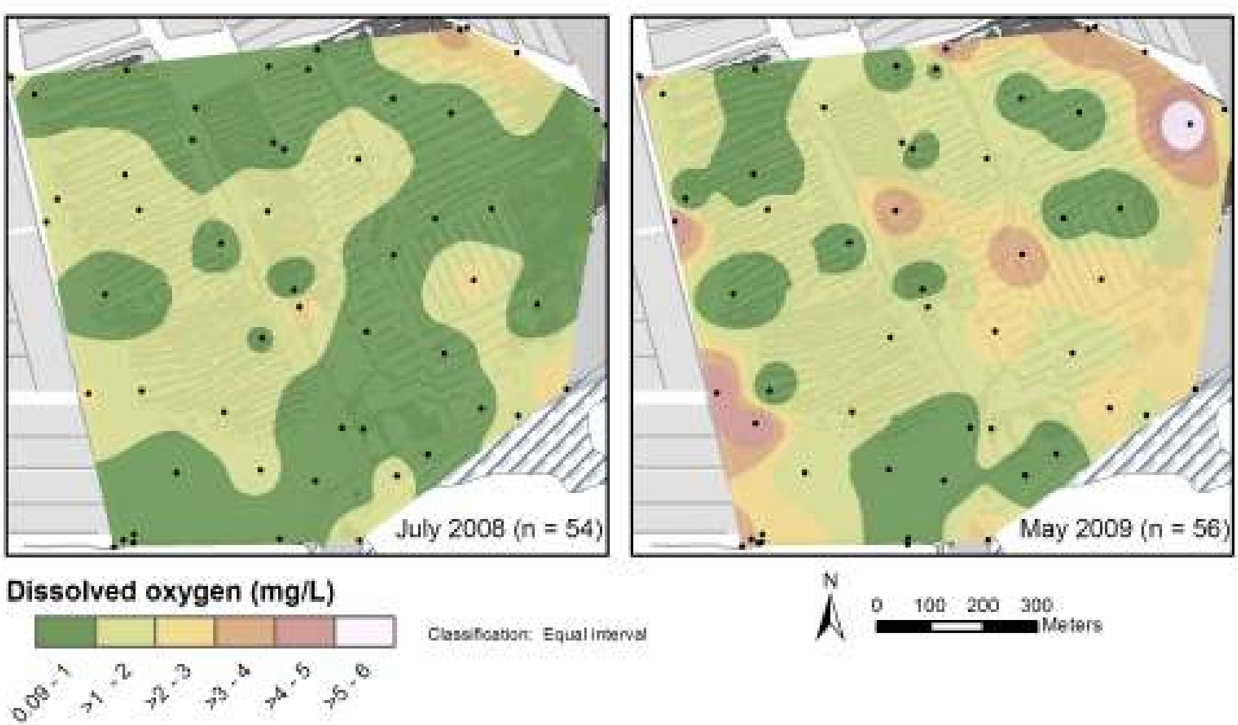


Figure 6.1.2. Interpolated dissolved oxygen values in Langley Bog for 2008-2009.

Low dissolved oxygen levels are consistent with expectations of bog conditions because of high organic matter content, limited oxygen diffusion and slow replenishment of oxygenated water through water flow. Under conditions of high carbon loading in the environment, or more specifically, a high carbon to nitrogen (C:N) ratio, microbial populations may consume available oxygen fairly rapidly, a process sometimes called biological oxygen demand (BOD). The decomposition of peat in limited oxygen-transport, wet environments, provides ideal conditions to create a low oxygen environment, which once established, slows further decomposition. However, bare peat surfaces with no plant cover are susceptible to degradation as oxygen is present at the surface. The warm temperatures seen in summer months increase metabolic processes and would thus also enhance degradation. One rationale for intervention in restoration is to enhance *Sphagnum* cover to help prevent further eroding of existing peat through such degradation processes.

It should be noted that our measurements were generally about 35 cm from the surface. Deeper waters could have lower temperatures and less oxygen due to slow diffusion rates coupled with distance from surface.

6.2 pH

pH measurements were taken using a Hach Sension1 handheld (water-resistant) meter and gel-filled combination electrode. At surface locations, pH measurements were taken directly in the water at the site. Water samples were collected from well sites by using a 60 mL syringe connected to a length of plastic tubing which was lowered into the well. Water was drawn up into the syringe and the first draw was expelled. The second draw was collected in a beaker and measured for pH. The process was then repeated by the second team member to collect two replicate measurements for each sampling time and location. Measurements were averaged.

pH values in wells ranged from a low of 3.2 (P22 May 2009) to a high of 5.8 (P41 May 2009). Surface waters averaged higher overall values, from a low of 3.5 (A13 May 2009) to a high of 6.3 (A2 May 2009). In a similar vein, 15 of 77 well readings were over pH 5 whereas 22 of 33 surface readings were over pH 5. Bog pH values in general seem within limits reported for *Sphagnum* influenced, largely ombrotrophic bogs (Table 6.2.1) but some values may be considered slightly high. Testing and interpolation mapping revealed a general pattern of higher pH around the periphery and lower pH in the middle of the bog (Figure 6.2.1).

Table 6.2.1 Averaged pH measurements in Langley Bog and surrounding waters for 2008-2009.

	pH		pH	
	July 2008	sdev	May 2009	sdev
Total Bog Area Avg	4.79	0.75	4.41	0.84
Well Avg	4.54	0.63	4.05	0.49

sdev = 1 standard deviation among averaged (2 replicate) points (±)

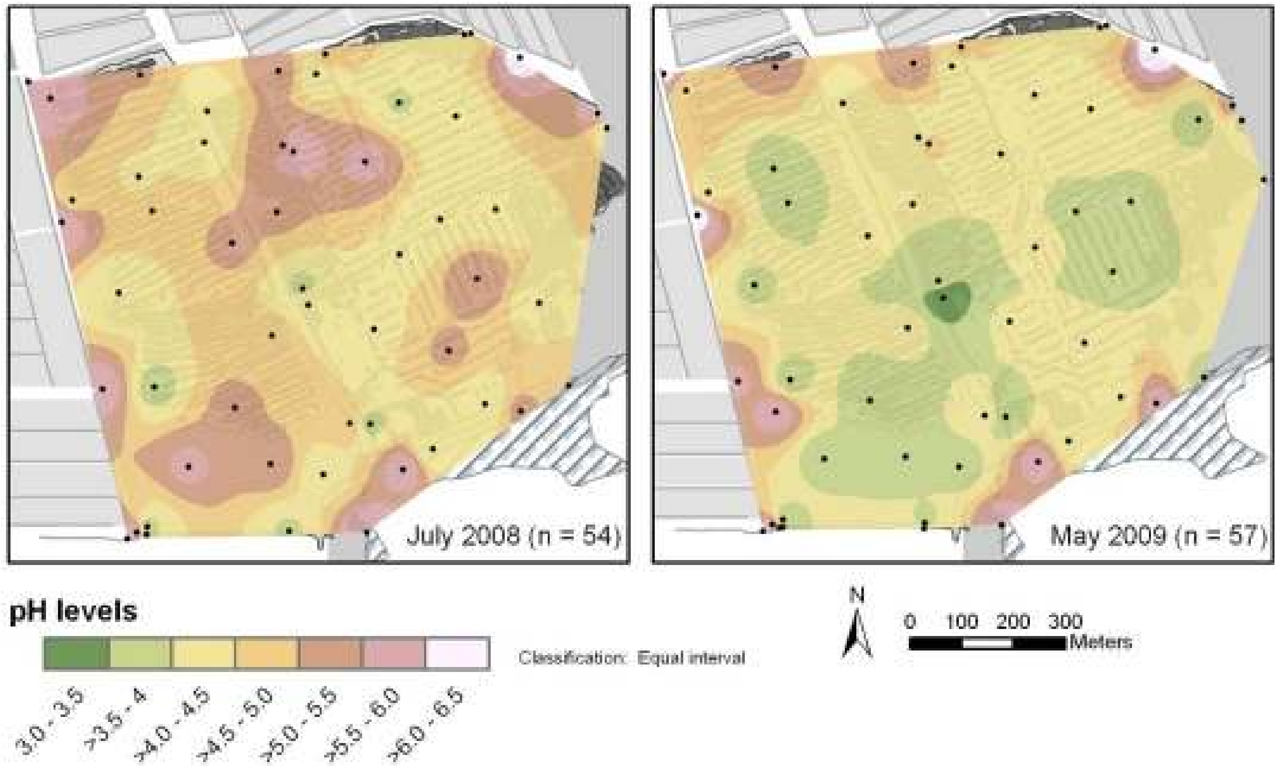


Figure 6.2.1. Interpolated pH values in Langley Bog for 2008-2009. Values represent observations from both piezometer wells and surface water.

The change in pH values seem related to moisture content (pH instruments are temperature corrected). Some swings appear fairly dramatic, as in the southwest quadrant of the bog. Further research questions include explaining why such a magnitude of change occurred.

6.3 Nitrate and Calcium

Samples for nitrate and calcium analysis were collected in a manner similar to that of pH. Field measurements were attempted initially but it seemed more effective to simply collect water samples in the field and then transport them the same day to the TWU Chemistry Lab for testing, which also resulted in less impact on the surrounding vegetation. Normally, field collecting occurred in the morning and analysis occurred in the afternoon. Collections were made in early August of 2008, and during the first three weeks of May 2009.

Four 35 mL samples were drawn from each site and placed in 40 mL plastic vials for transport to the lab. To each sample was added 0.8 ml of ionic strength adjuster, 4 M potassium chloride (KCl) in two samples for calcium analysis and 2 M ammonium sulphate ($(NH_4)SO_4$) for two nitrate samples. Each of the sample replicates were measured twice, once directly using a Hach meter with either an attached calcium or nitrate ion-selective electrode (Orion-Thermo) as appropriate. The second reading involved a "standard addition" of a known amount of calcium or nitrate solution to the corresponding sample type as a check and in some cases to improve sensitivity. Standard addition values could be determined by addition of laboratory de-ionized water. Standard addition amounts could then be subtracted from the total to obtain the sample value. Readings were recorded in mV, requiring that a standard curve be constructed of known concentrations to enable conversion calculations from mV values to concentration values – mg/L which equals parts per million (ppm).

The nitrate nitrogen composition within the Bog generally shows a small range of values from less than 0.05 (limit of detection) to 0.35 mg/L nitrogen as nitrate (Figure 6.3.1). Three exceptions occurred in 2008 measurements – two surface sites had values over 0.9 and one well (P39) had a value of 2.21 mg/L. In May 2008 the latter well measured 0.13, so we are unsure as to the reliability of this measurement and it was thus left out of the average calculation (Table 6.3.1) but its location was mapped (Figure 6.3.1).

Table 6.3.1. Averaged nitrate measurements in Langley Bog and surrounding waters for 2008-2009.

	(NO_3^-) N[a] mg/L[b]		(NO_3^-) N mg/L	
	August 2008	sdev	May 2009	sdev
Total Bog Area Avg	0.18	0.20	0.12	0.07
Well Avg	0.11	0.08	0.11	0.06

[a] the measured form is nitrate but concentration is expressed as the amount of nitrogen
[b] mg/L = ppm (parts per million)
sdev = 1 standard deviation among averaged (4 replicate) points (±)

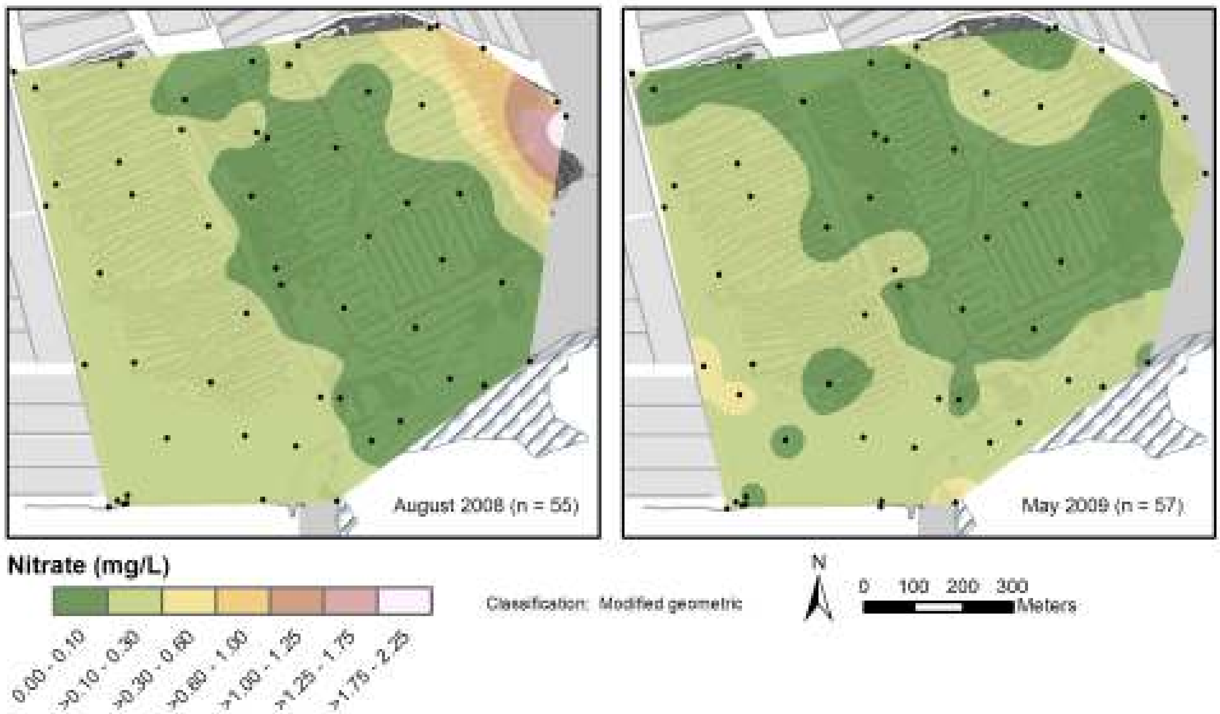


Figure 6.3.1. Interpolated nitrates values in Langley Bog for 2008-2009.

Nitrate concentration within the heavily mined areas of the bog are low and are within parameters of literature values for *Sphagnum*-dominated bogs. Values in the western portion of the bog tend to be higher than the eastern portion. The open water sites in Houston ditch and McQuatt ditch had higher nitrate concentrations as did sites inside the bog along these ditches. Values in general are lower in May when water levels are higher and thus seem related to the amount of moisture.

The calcium concentrations demonstrate similar trends to nitrates, except that concentrations are higher and have a broader range (Figure 6.3.2, Table 6.3.2). Calcium values in and among the hemlock stand, and a portion of the open water sites along Raine Cranberry Ltd. have high calcium concentrations. The highest values occur in the southwestern quadrant of bog forest. The lowest values occur in the eastern and northwest portions of the bog. Similar to nitrate, calcium concentrations seem related to the amount of moisture present, with lower concentrations corresponding to higher water levels.

Table 6.3.2. Averaged calcium measurements in Langley Bog and surrounding waters for 2008-2009.

	Ca^{2+} mg/L[a]		Ca^{2+} mg/L	
	August 2008	sdev	May 2009	sdev
Total Bog Area Avg	4.41	6.45	1.91	2.5
Well Avg	3.31	5.37	1.61	2.64

[a] mg/L = ppm (parts per million)
sdev = 1 standard deviation among averaged (4 replicate) points (±)

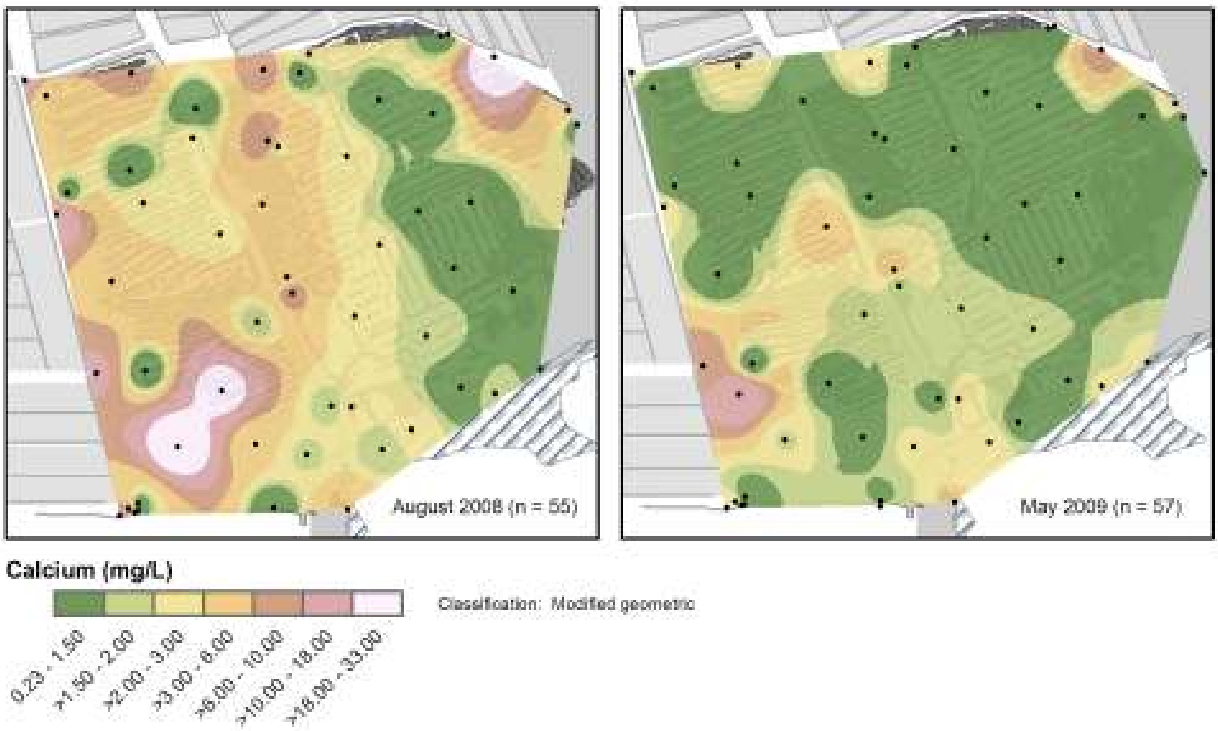


Figure 6.3.2 Interpolated calcium values in Langley Bog for 2008-2009.

Relationships of calcium to pH have long been noted as indicators consistent with other features of mire wetlands that can be used to classify the wetland.[28] Though such characteristics can occur in gradients across a spectrum, they tend toward a bi-modal distribution with fen conditions at one end, more ombrotrophic bog conditions at the other, and nutrient poor, low pH

[28] Gorham, 1956; Siegel and Glaser, 1987; Glaser, 1992.

“poor fen” often falling out with other types of bogs on the bog side as well, but closer to the centre.[29] The calcium pH relationship is probably most easily seen when $\log_{10}$ Ca is plotted vs pH (pH = $-\log_{10} [H^+]$) (Figure 6.3.3). Values from piezometer wells in Langley Bog cluster toward the bog side with a large number of points falling where ombrotrophic character is observed – consistent also with much of the vegetation present in the Langley Bog.

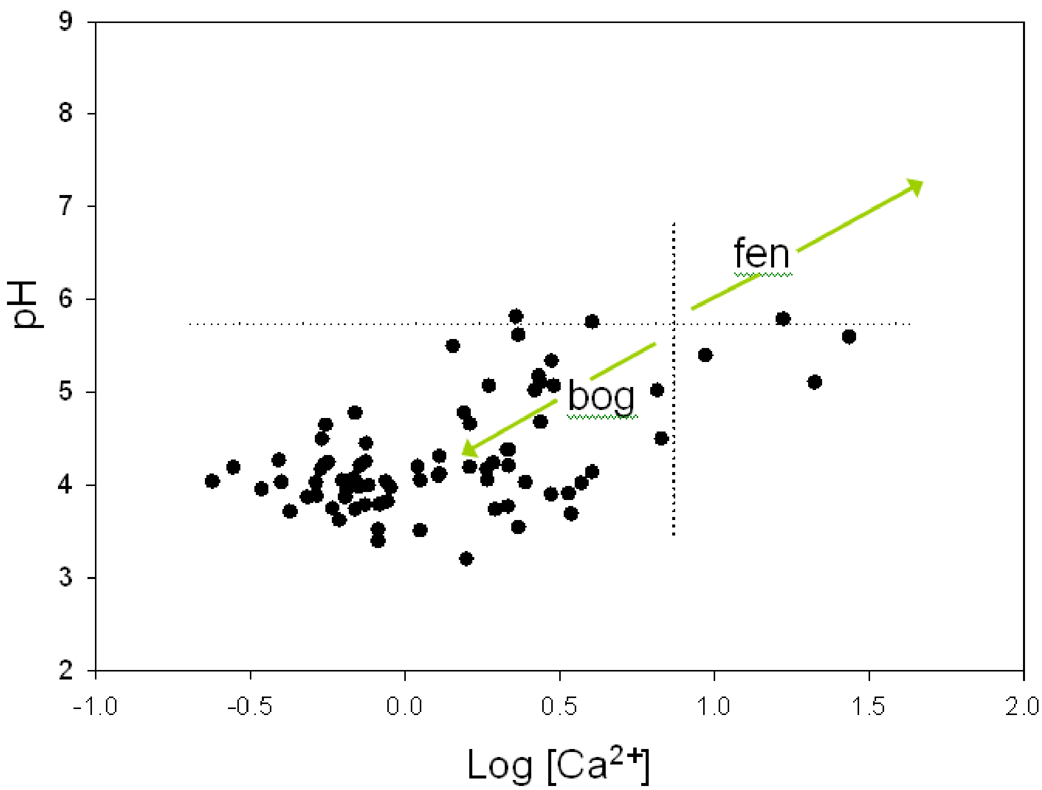


Figure 6.3.3. Log Ca2+ distribution vs. pH values in Langley Bog for 2008-2009. Fens tend to localize more in an upper right quadrant while nutrient poor fens and bogs localize in the bottom left quadrant. Dotted lines are for convenience in identifying approximate boundaries and are estimated from data in Wheeler and Proctor, 2000. Ombrotrophic bog characteristics are more evident as the ratio moves toward the bottom left.

Other bog mineral measurements were taken from seven locations during 2009. Inductively coupled plasma (ICP) analysis was performed for a wide range of metals and common elements. These results are summarized, together with results from a similar test out of

[29] Wheeler and Proctor, 2000.

two wells in the Piteau report, and atomic absorption (AA) analysis for three elements (calcium, iron, and zinc) by a TWU student, in the Appendix. These analyses confirm a generally low nutrient status consistent with ombrotrophic bog character.

There are individual locations that might give cause for concern, but in general, much of the bog seems reasonably healthy from the points of view of water chemistry. It is interesting to note the locations of some values that might be anomalous compared to expectations. Often these occur on the west side of the bog. At one time during our field work, we noticed what appeared to be aerial fertilization of the cranberry fields by helicopter in fields to the west. Dust from the hanging bucket was drifting over into the western bog lands. In addition, the western perimeter seems subject to drying, connected at least in part by proximity to McQuatt ditch. Such factors may suggest a practical step of leaving a perimeter border of developing forest, and focusing restoration efforts (other than hydrology control) on the rest of the bog east of that perimeter.

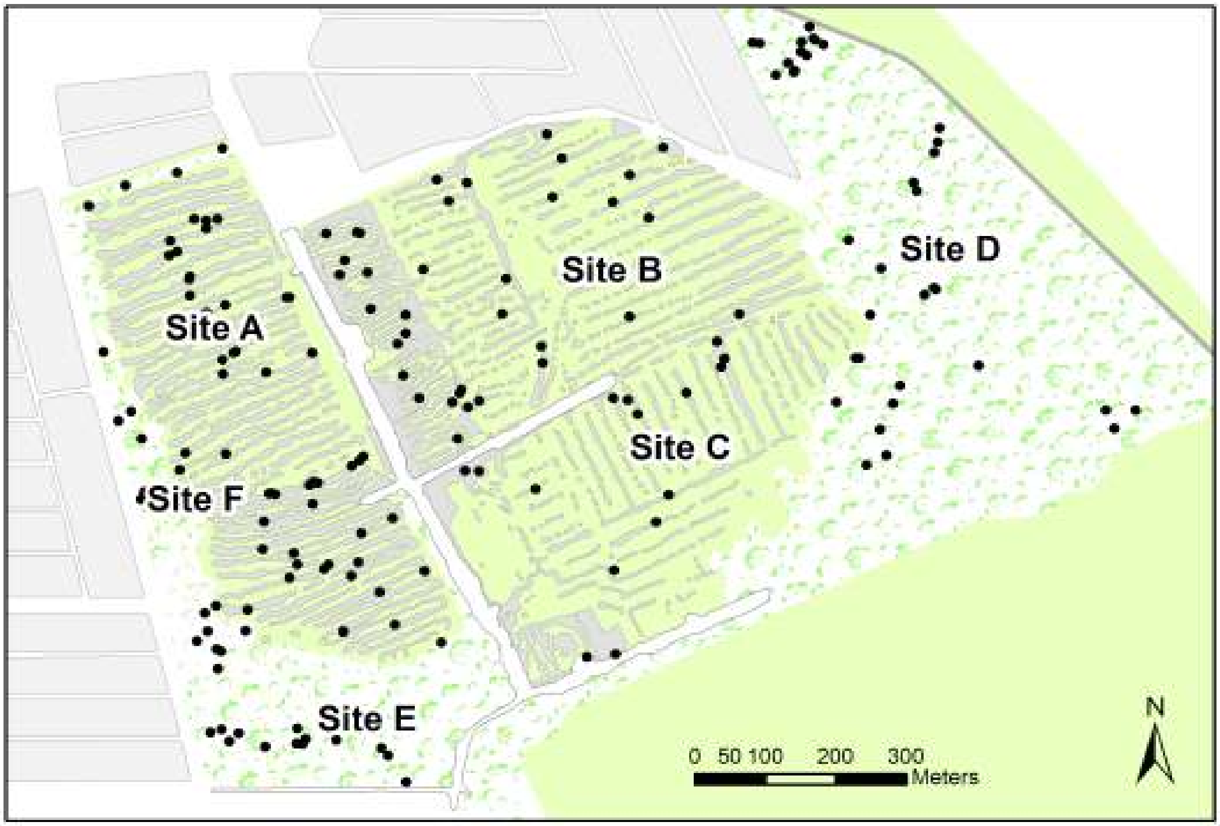
7.0 TREE-RING STUDIES

Dendrochronology is the science of tree time: *dendro* from the Greek word meaning "tree" and *chronology* referring to the study of time. Dendrochronology uses tree rings dated to their exact year of formation to study patterns and processes in the physical and cultural environment. Since its development in the early 1900s dendrochronology has been used in applications ranging from dating ruins of ancient Native American settlements, detecting historic natural hazard events such as floods and rock slides, reconstructing forest fire history using fire scars on tree rings, and reconstructing long-term climate variability.[30] To date, no dendrochronological studies have been undertaken in the Langley Bog.

We employed dendrochronological techniques in this study to accomplish the following objectives: 1) to develop temporally deep, site-specific ring-width chronologies of shore pine (*Pinus contorta var. contorta* Dougl. ex. Loudon) in the Langley Bog and, 2) to determine accurate age estimates of shore pine, western hemlock (*Tsuga heterophylla* Sarg.) and white birch (*Betula papyrifera* Marsh.) by analyzing stand structure and dates of establishment in the bog. Development of site-specific ring-width chronologies and accurate age estimates will help answer questions regarding past bog disturbance, current growth conditions and future restoration and recovery efforts.

During the summers of 2008 and 2009, undergraduate research assistants from Trinity Western University Geography and Environmental Studies programs were hired. Two students were employed in 2008 and three students in 2009. Field work consisted of extracting increment cores, measuring diameter at breast height (dbh) of all sampled trees, recording GPS coordinates, and cutting and sectioning a limited number of tree seedlings. The entire study area was stratified into six sites based on field observations of perceived differences in vegetation form and structure (Figure 7.1).

[30] Fritts and Swetnam, 1989.



7.1. Location of dendrochronological study sites in Langley Bog. Points on the figure represent the locations of individual trees sampled.

Three sites were highly disturbed, previously mined bog surfaces (Figure 7.2a), while the other three sites consisted of partially disturbed to relatively undisturbed remnant bog forest (Figure 7.2b).

Figure 7.2. Field site examples of (a) highly disturbed, previously mined bog site and (b) relatively undisturbed remnant bog forest.

Shore pine, western hemlock and white birch trees > 10 cm dbh were randomly selected and two cores at least 90^{o} apart were extracted using a Haglof 5.15 mm increment borer. We tried to core trees as close to the ground as possible in order to obtain the maximum number of growth rings. Coring near the ground surface proved challenging because of the depth of sphagnum hummocks surrounding the base of most trees (Figure 7.3). We established a standard coring height of 40 cm above ground to facilitate corrections for tree growth to coring height. Increment cores were placed in sealed plastic straws and labeled for transportation back to the lab. The condition of each tree was noted, dbh was measured, and GPS coordinates were obtained (Figure 7.4). Destructive samples of 8 shore pine and 10 hemlock trees were obtained using a hand-held manual cross-cut saw. Seedlings selected for sampling were cut at ground level to intercept the root/shoot interface in order to maximize the number of annual growth rings being sampled. Trees were de-limbed and basal discs were cut at 10 cm intervals. To prevent bark loss necessary for outer ring determination, samples were wrapped in duct tape and subsequently labeled. The procedure for sample selection was repeated in each site with the exception of the destructive sampling.

Figure 7.3. Extracting tree core from base of shore pine in deep sphagnum/Labrador tea hummocks.

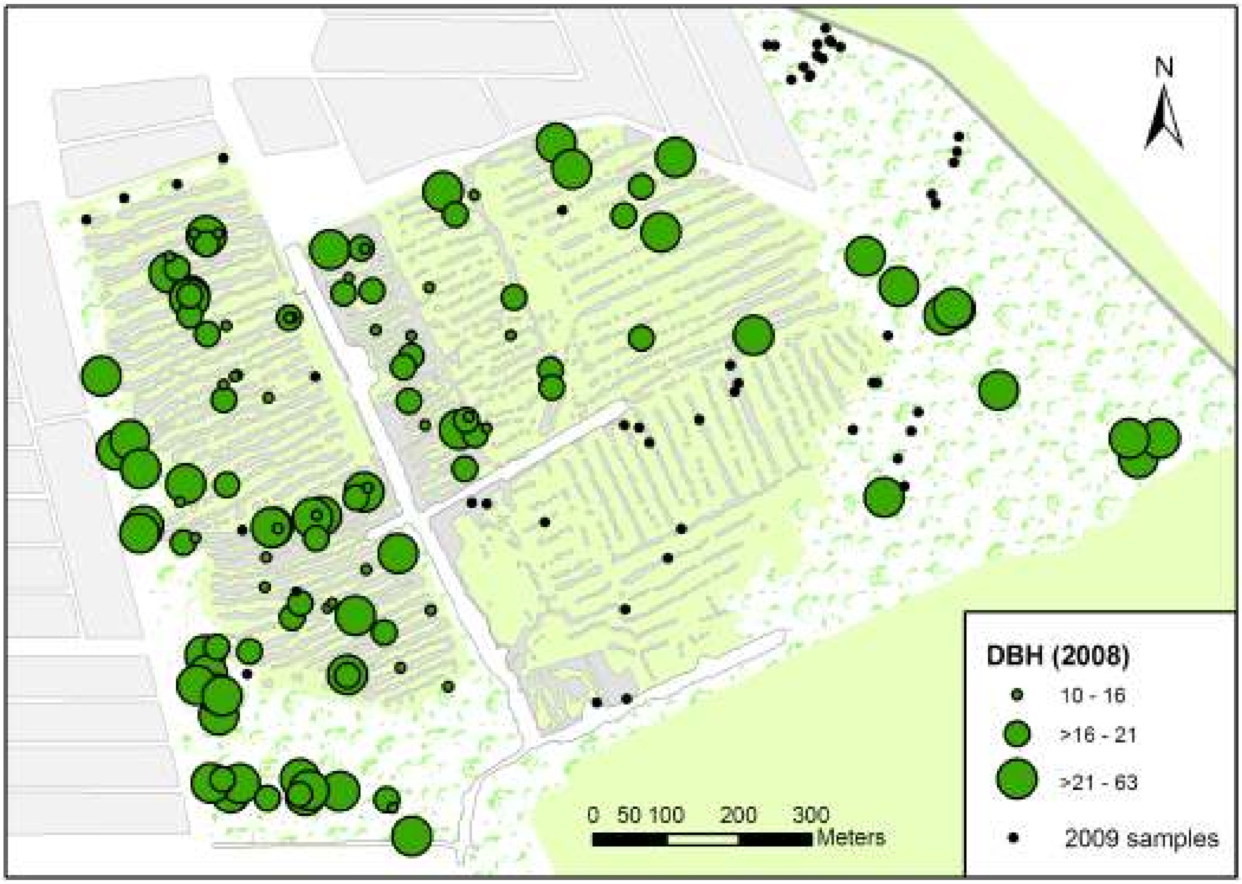


Figure 7.4. Diameter at breast height measurements for sampled trees in Langley Bog for 2008. Locations for 2009 samples also shown.

In total 311 increment cores were collected as part of this study. One hundred and fifty one shore pine cores were sampled in five areas of Langley Bog for ring-width chronologies; 83 cores were sampled from dominant shore pine, western hemlock, and white birch trees for age determination; and 90 basal discs were collected from 8 shore-pine and 10 western hemlock to determine age-to-height growth rates. All cores and sections were returned to the Trinity Western University Tree-ring Lab (TWUTRL) for drying and sample preparation. The majority of cores were air-dried inside the open-ended plastic straws. Excessive moisture levels in the cores however, lead to the growth of mould on some cores inside the straws. All cores were immediately removed from the straws and allowed to dry fully, preventing mould growth and core discoloration. We mounted the dried cores in slotted wooden boards and surfaced cores and sections using a combination of belt-sanding and hand sanding with progressively finer sand papers following standard dendrochronological procedures.[31] Cores and sections were measured to 0.001mm using a Velmex high precision measuring stage coupled to a Quick-Chek QC-10 and a Meiji 40x stereomicroscope. Ring-width values were recorded using Measure J2x software.

Crossdating multiple ring-width samples is one of the fundamental principles behind the science of dendrochronology. Crossdating involves both visual and statistical matching of common growth ring patterns among many samples. By correctly identifying the underlying pattern in a series of growth rings, dendrochronologists can determine the exact year of ring formation. The principle of crossdating ultimately provides researchers with a high degree of accuracy that is used to fix both natural and human events in time. Samples from the bog were crossdated visually using the LIST method.[32] To ensure measuring and crossdating accuracy, the resulting individual ring-width series were verified using the computer program COFECHA.[33] Properly crossdated individual ring-width series are then combined in master ring-width chronologies to represent average tree growth at each sample site throughout the bog. Series showing anomalous radial growth trends, which were most commonly related to recent establishment dates, were excluded from further analysis. One hundred and fourteen ring-width series were ultimately included in the five site-specific shore pine chronologies.

7.1 Chronology Development

According to the principal of aggregate tree growth,[34] the annual radial growth in a given year (G_t) is the result of complex interactions between a number of factors:

$$G_t = A_t + C_t + gD_1 + gD_2 + E_t \qquad \textit{Equation 7.1.1}$$

where: G_t = annual radial growth in a given year,

A_t = age related growth trend (young trees growing in non-competitive environments typically show high initial growth rates, as tree ages growth slows)

[31] Stokes and Smiley, 1968.
[32] Yamaguchi, 1991.
[33] Grissino-Mayer, 2001; Holmes, 1983.
[34] Cook, 1987.

C_t = climatic conditions in a given year (temperature and precipitation),

gD_1 = endogenous disturbance (individual impacts such as competition between trees and disease),

gD_2 = exogenous disturbance (stand level impacts such as forest fire, or insect outbreak),

E_t = error (growth not attributable to other factors).

In order to analyze climatic, ecological or other disturbance signals that may adversely affect tree growth, extracting the age-related decline in ring-width from the pith to the bark of a tree is necessary. The computer program ARSTAN for Windows[35] was used to correct for this age-related trend by standardizing (or detrending) the growth-ring series from individual trees by fitting either a modified negative exponential curve, a linear regression line with positive or negative slope, or a horizontal line through the mean of the raw ring-width measurements. All series from a site are then divided by the value of the curve and averaged together to produce a mean indexed chronology for each site.[36] Resulting growth index values can range from zero to infinity, where values below one represent below average annual growth and values above one represent above average growth in a given year. ARSTAN calculates the average site chronology using a biweight mean, which discounts the influence of outliers caused by non-synchronous disturbances.[37]

Because no known published shore pine chronologies exist for this region, a common set of marker rings was first developed without the aid of other regional tree-ring chronologies. Marker rings, defined as significantly narrower or significantly larger annual growth rings, are important annual rings used to pinpoint a given calendar year. Furthermore, because of generally favourable growing conditions, i.e., moderate average annual temperature and high moisture availability, the growth rings were somewhat complacent. Complacent rings are characterized by moderate to rapid growth and low interannual variability. Such rings hinder the crossdating process by obfuscating pattern recognition.

We have developed five new site-specific ring-width chronologies for shore pine in Langley Bog. Table 7.1.1 presents results in terms of summary statistics and characteristics for

[35] Cook and Krusic, 2005; Cook, 1985.
[36] Grissino-Mayer et al., 1996.
[37] Cook et al., 1990.

the new chronologies. Overall interseries correlation, an important measure of how well each series crossdates with an average master chronology, range in correlation value from 0.391 in Site F to 0.513 in Site B (Pearson's correlation coefficents; $p < 0.001$) (Table 7.1.1). The shore pine chronologies range in age from 39 years at Site A (mean length = 33.7 years) to 127 years at Site D (mean length = 73.8 years). Generally, chronology length seems to support assumptions regarding bog disturbance history. Site A and Site B (mean length = 34.5 years) consist of ridge and channel topography consistent with past peat mining activity. Site D (mean length = 93.8 years) is the longest chronology. Indeed, Site D forms the eastern border of Langley Bog, and consists of mature bog forest with little evidence of recent disturbance. Site E (mean length = 64.1 years) and Site F (mean length = 63.0 years) are slightly more difficult to interpret. Site E, which transitions into the southern boundary of Langley Bog, consists of open bog forest

Table 7.1.1. Crossdating statistics for five site-specific shore pine chronologies in Langley Bog.

	Site A	Site B	Site D	Site E	Site F
Number of dated series	28	29	26	18	13
Total rings in all series	943	1000	2439	1154	819
Master series	39 years 1968-2007	42 years 1965-2007	127 years 1880-2007	77 years 1930-2007	70 years 1937-2007
Mean length of series	33.7 years	34.5 years	93.8 years	64.1 years	63.0 years
Marker rings (narrow)	1993, 1972, 1971	1993	1993, 1969, 1958, 1957, 1956, 1937, 1910, 1909, 1893	1985, 1982, 1958, 1938, 1937	1969, 1938, 1937
Marker rings (wide)	2007, 1997, 1991	2007, 1997, 1981	1997, 1983, 1972, 1946	1997	1997, 1983, 1960
Series intercorrelation	0.457	0.513	0.503	0.465	0.391
Average mean sensitivity	0.195	0.216	0.286	0.270	0.249
Mean measurement (mm)	2.45	2.75	2.23	1.69	2.20

interspersed by peat meadows. Site F forms the western boundary of Langley Bog and is similar to the remnant bog forest to the east, although chronology length is significantly shorter.

Despite the dominance of complacent rings, several marker rings indicating reasonably strong common growth patterns were observed on nearly all cores. The most significant marker rings used to crossdate our samples were 1997, 1993, 1969, 1957, 1956 and 1937 (Table 7.1.1). In nearly all cases marker ring variation was greater/lesser than 1.5 standard deviations above/below the master chronology mean. In addition to aiding the crossdating process, marker rings often reflect a significant short-term change in growth conditions e.g., drought, frost, or disturbance. Although it appears there is an association between narrow marker rings in 1993 with below normal annual precipitation and wide marker rings in 1997 with above average annual precipitation investigating climate-growth relationships was beyond the scope of our analysis.

Mean sensitivity measures the year to year variability in ring-width. High values are desirable because they indicate trees are more responsive to changes in growth signals such as climate and disturbance. Values between 0.10-0.19 are considered low, values between 0.20-0.29 are considered intermediate, while values greater than 0.30 are considered high.[38] Our results range in mean sensitivity value from 0.195 in Site A to 0.286 in Site D. Site A (mean sens. = 0.195) and Site B (mean sens. = 0.216) exhibit the lowest mean sensitivity of the five sites; these low values reflect the sites' short establishment history (Table 7.1.1). Trees began growing on the open sites and were relatively free of competition, having ample access to light, water, and nutrients. This lack of competition is also partially reflected in Site A and B's slightly greater average annual radial growth measurements, 2.45 mm and 2.75 mm, respectively. Sites D (mean sens. = 0.286), E (mean sens. = 0.270), and F (mean sens. = 0.249) are all considered moderately sensitive, with Site D approaching high sensitivity.

Analysis of the time series plots (Figures 7.1.1-7.1.7) reveal both distinct patterns and similarities of radial growth in each of the five sampling sites. Site A showed a fairly constant but gradual decline in mean annual ring-width from 1980 to 2007, with the exception of the period 1968 to 1971. This declining trend in absolute ring-width is a product of the biologically related growth trend; as trees age their absolute annual growth decreases. The standardized chronology, which removes the age-related growth trend, showed only slight fluctuations above and below the expected average growth rate (ring-width index = 1.0, Figure 7.1.1) from 1974 to 1997. Commencing in 1998 a prolonged period of below average radial growth to 2007 was observed. Some caution must be applied in interpreting the results for 1968 to 1971 as the sample depth (number of samples) was much lower. However, from 1968 to 1971 the sampled trees showed significantly lower radial growth rates. Their low growth rate was likely a result of two possibilities: (1) these trees had established prior to the clearing of this section of the Bog for

[38] Grissino-Mayer, 2001a.

peat mining and their slow growth was more reflective of microsite conditions reflecting sphagnum cover and other pine competitors and (2) lowering of the bog water table relative to the trees establishment date was responsible for inhibited growth.

The raw ring-width and standardized chronologies of Site B are similar in most respects to the chronologies of Site A (Figure 7.1.2 and Figure 7.1.3) for the period 1974 to 2007. Statistical analysis shows the Site A and Site B chronologies are significantly correlated. The Pearson's correlation coefficient, which measures the degree of linear association between the two time series is strong and positive, (Pearson's r = 0.637; $p = 0.30$) indicating the two series were responding to a common growth signal (Figure 7.1.3). However, a distinct difference between the two sites existed prior to 1974. In Site B the initial pulse of rapid radial growth commenced in 1965, six years prior to a similar growth pulse in Site A. The significant increase in radial growth suggests the clearing of bog vegetation in this area and regrowth of pine occurred free of competing vegetation.

Site D provided the longest and most variable of the five shore pine chronologies (Figure 7.1.4). Mean annual ring-width was fairly consistent between 2-4 mm/year from 1880 to 1968; after 1968 typical values ranged between 1-2 mm/year. Periods of prolonged above-average growth occurred in the late 1890s to early 1900s, 1940s to mid-1950s, and 1960s. A prolonged period of below average growth occurred from 1983-2002, with the exception of the year 1997. Figure 7.1.4 also shows a number of abrupt decreases in the ring-width index commencing in 1891, 1906, 1954, 1967, and 1983. These abrupt changes in radial growth may signal significant natural and/or anthropogenic disturbances. In fact, the major Fraser River flood of 1948 is recorded in the tree-rings of Site D as a noticeable decrease in growth index for that year. Additionally a number of Site D series show damage in the earlywood portion of the annual growth-ring.

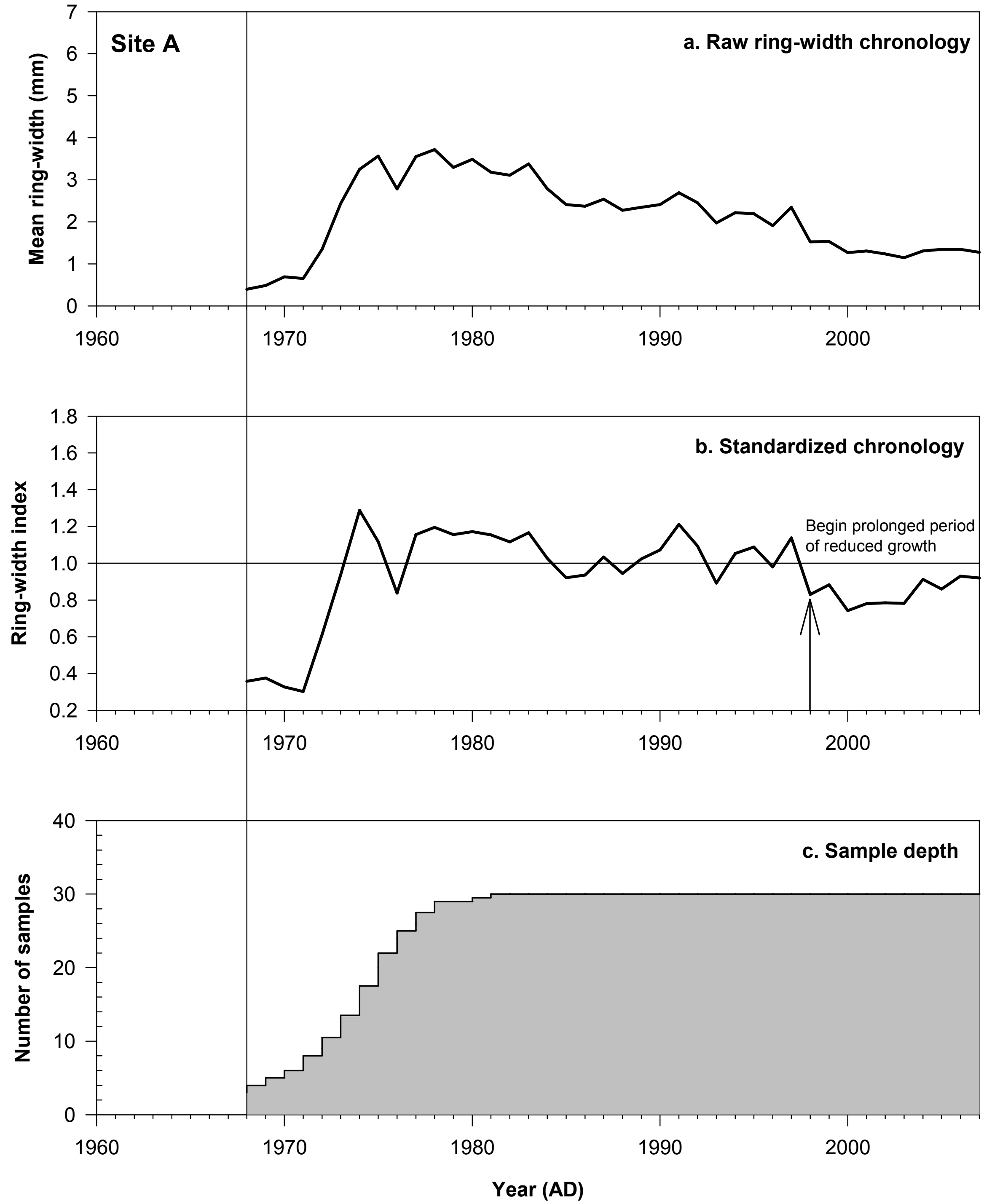


Figure 7.1.1. Raw ring-width chronology, standardized chronology and sample depth of shore pine at Site A.

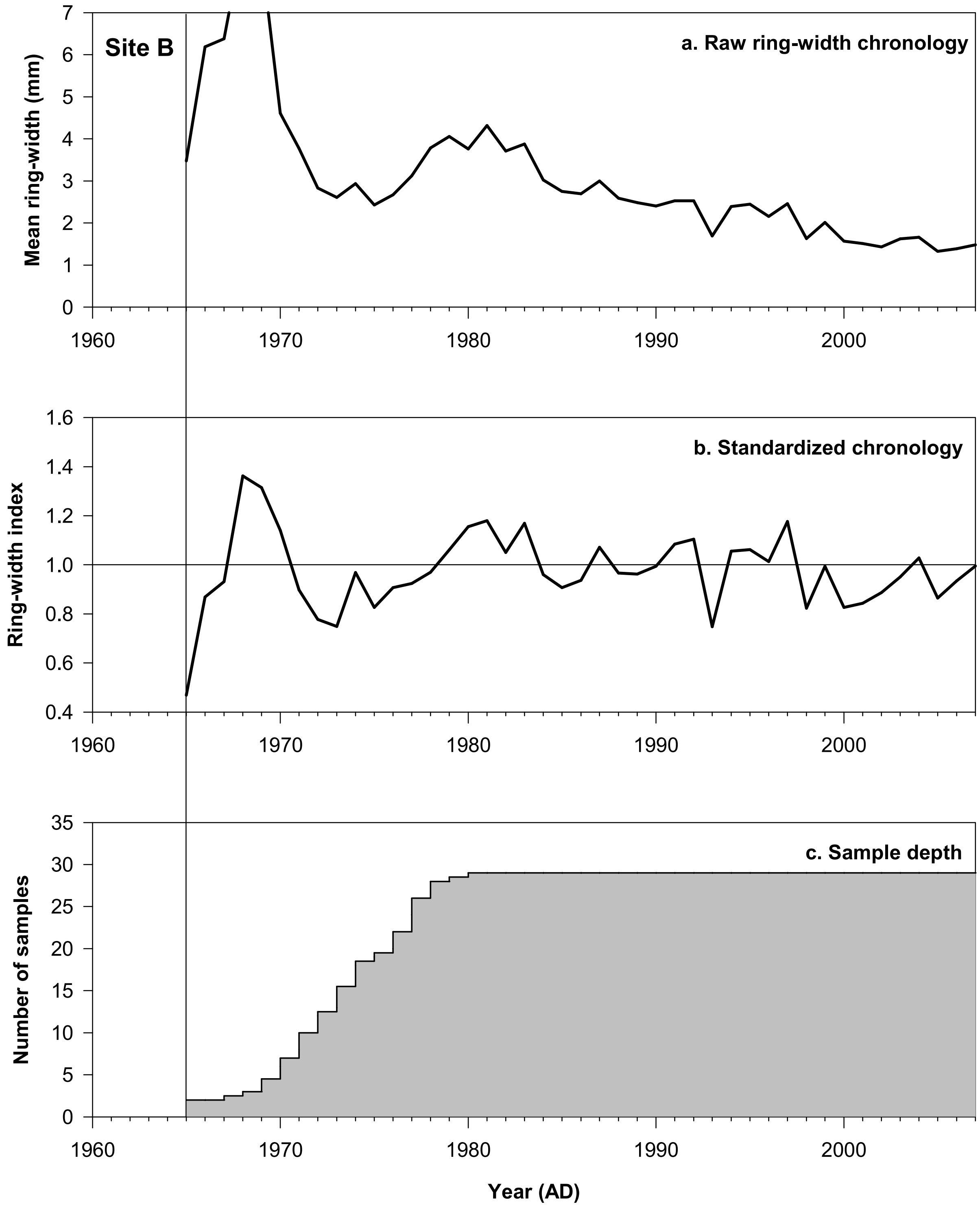


Figure 7.1.2. Raw ring-width chronology, standardized chronology and sample depth of shore pine at Site B.

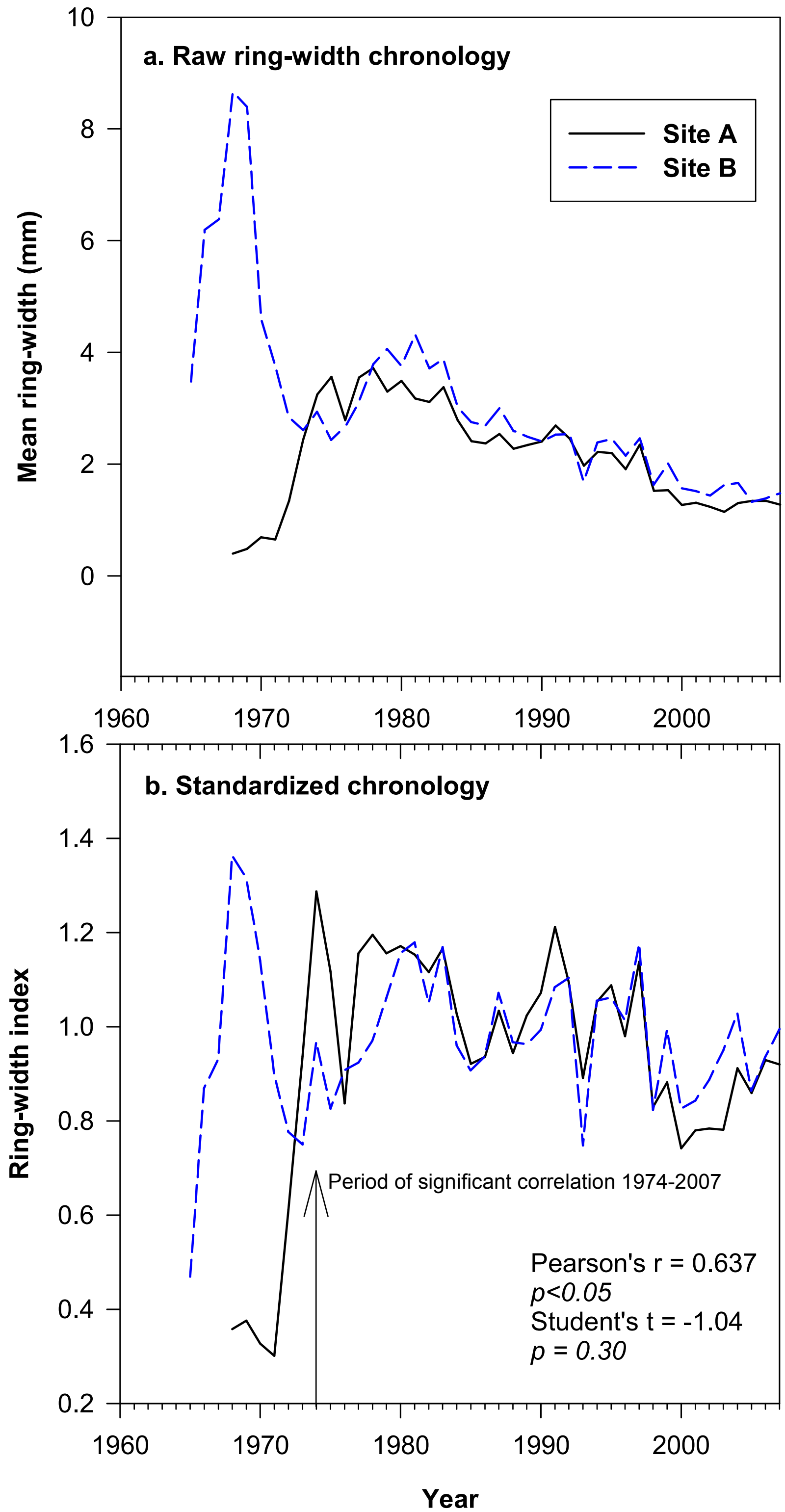


Figure 7.1.3. Comparison of raw ring-width and standardized chronologies for Sites A and B.

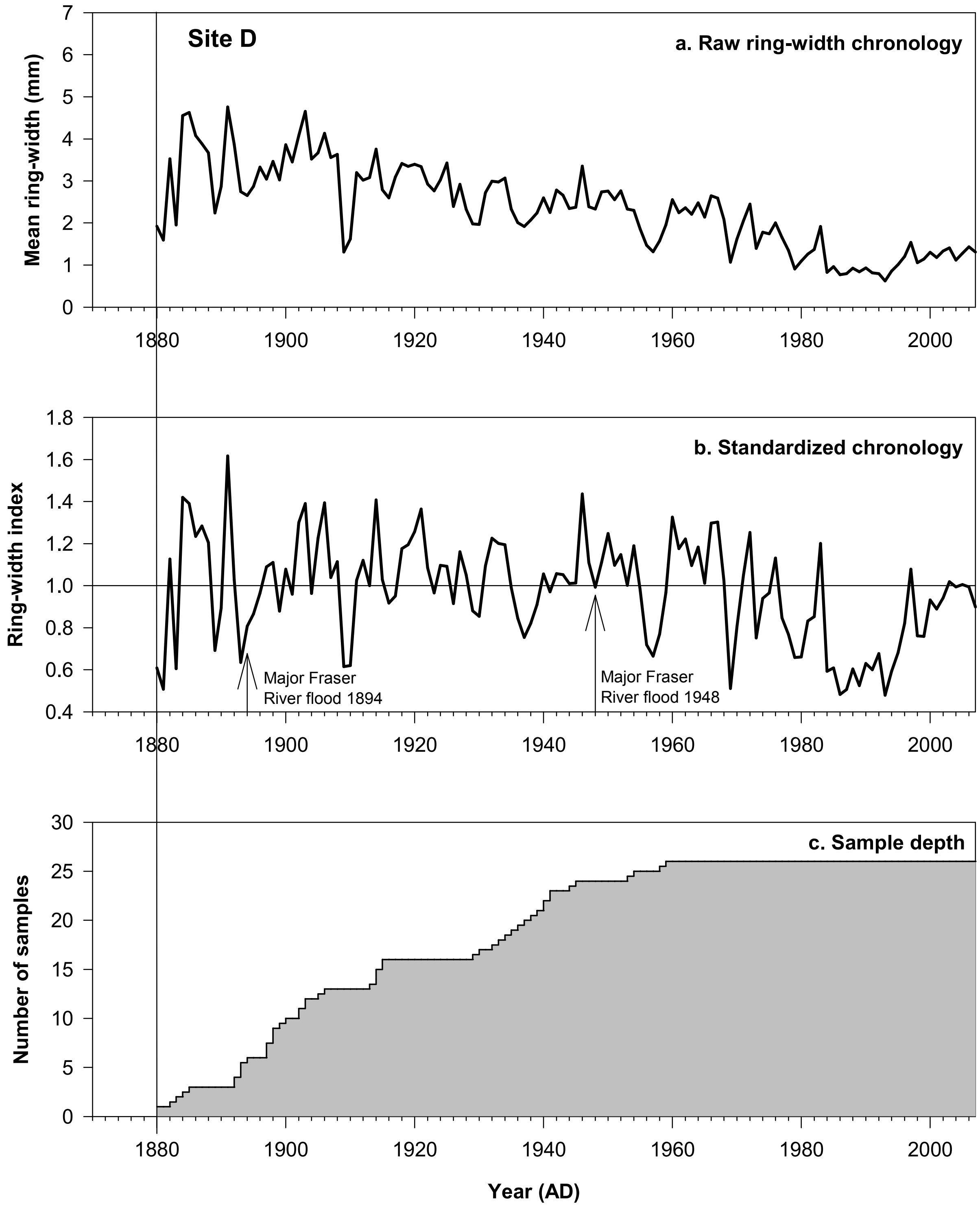


Figure 7.1.4. Raw ring-width chronology, standardized chronology and sample depth of shore pine at Site D.

Site E is the second longest chronology developed from Langley Bog, appearing to share some characteristics with the undisturbed bog forest of Site D, and other characteristics with the highly disturbed sites A and B (Figure 7.1.5). Mean annual ring-width declined fairly constantly from 1943 to 1980 until growth was approximately 0.5 mm/year in 1984, remaining at this level until 2007. The standardized ring-width index shows a prolonged period of above-average growth from the early 1940s to mid 1950s (Figure 7.1.6). Another shorter period of enhanced growth occurred during the early to mid-1960s. A significant spike in above-average growth in the early 1970s mirrored a similar trend in Site A (Figure 7.1.1). Moreover, a prolonged period of reduced growth from the early 1980s to 1997, then again from 1998 to 2007 was observed. Statistical analysis shows the Site D and Site E chronologies were in fact responding to a common growth signal (Figure 7.1.5). The correlation coefficient is moderately strong and positive (Pearson's r = 0.642, $p < 0.05$) once again indicating temporal synchronicity

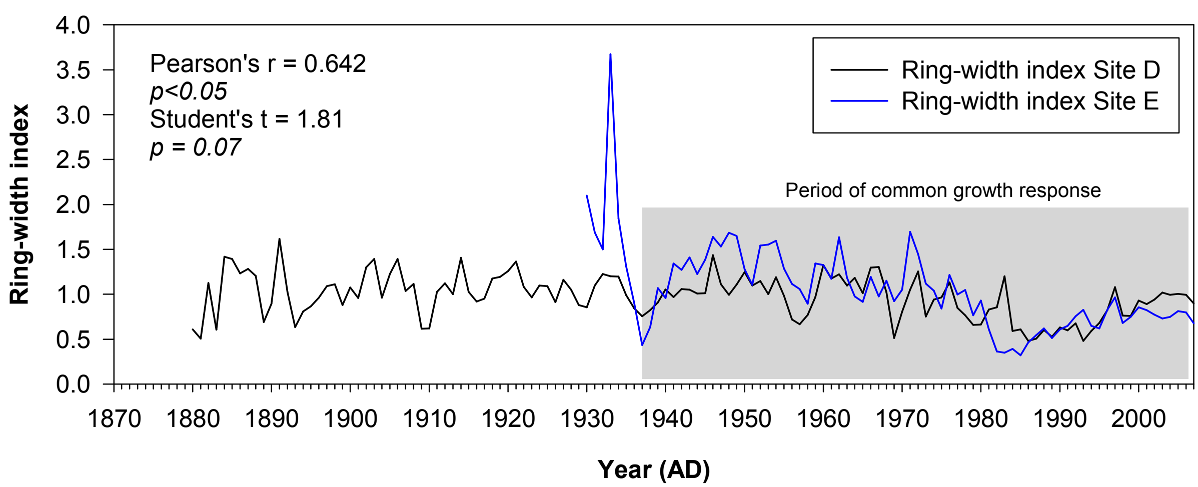


Figure 7.1.5. Comparison of standardized ring-width chronologies of Sites D and E.

in the two series. One notable departure from this pattern occurred in the early 1980s when radial growth decreased significantly in Site E and increased in Site D. This point in time corresponds to the end of hydraulic peat mining activity which significantly altered the local water table, leading to potential moisture stress of Site E trees.

Field observations conducted in Site F suggest the bog forest bordering the west side of Langley Bog might share similar traits to the undisturbed bog forest to the east. However, the overall length of chronology at Site F (70 years) is significantly shorter than Site D (127 years) (Figure 7.1.7). Furthermore, trees in Site F did not crossdate particularly well. Interseries correlation values in Site F (0.391) are significantly lower than in Site D (0.503). Approximately 50% of the shore pine trees at Site F showed significant growth suppression during the last 20 years. Growth suppression is clearly evident on the ring-width index which shows growth well below average since 1980 and a marked decrease in radial growth in the early 1990s. Prior to the mid 1960s however, growth was well above average. In addition, the absolute ring-width values averaged between 4-6 mm for approximately 10 years. During sampling in Site F a number of tree stumps showing evidence of mechanical removal were also noted. This combined evidence suggests an open environment free from competition during establishment of the forest stand, followed by increasing competition and crowding as time progressed. Further sampling in future studies of Site F will allow us to make more definitive conclusions regarding establishment, radial-growth and disturbance history in this important bog forest-cranberry farm boundary area.

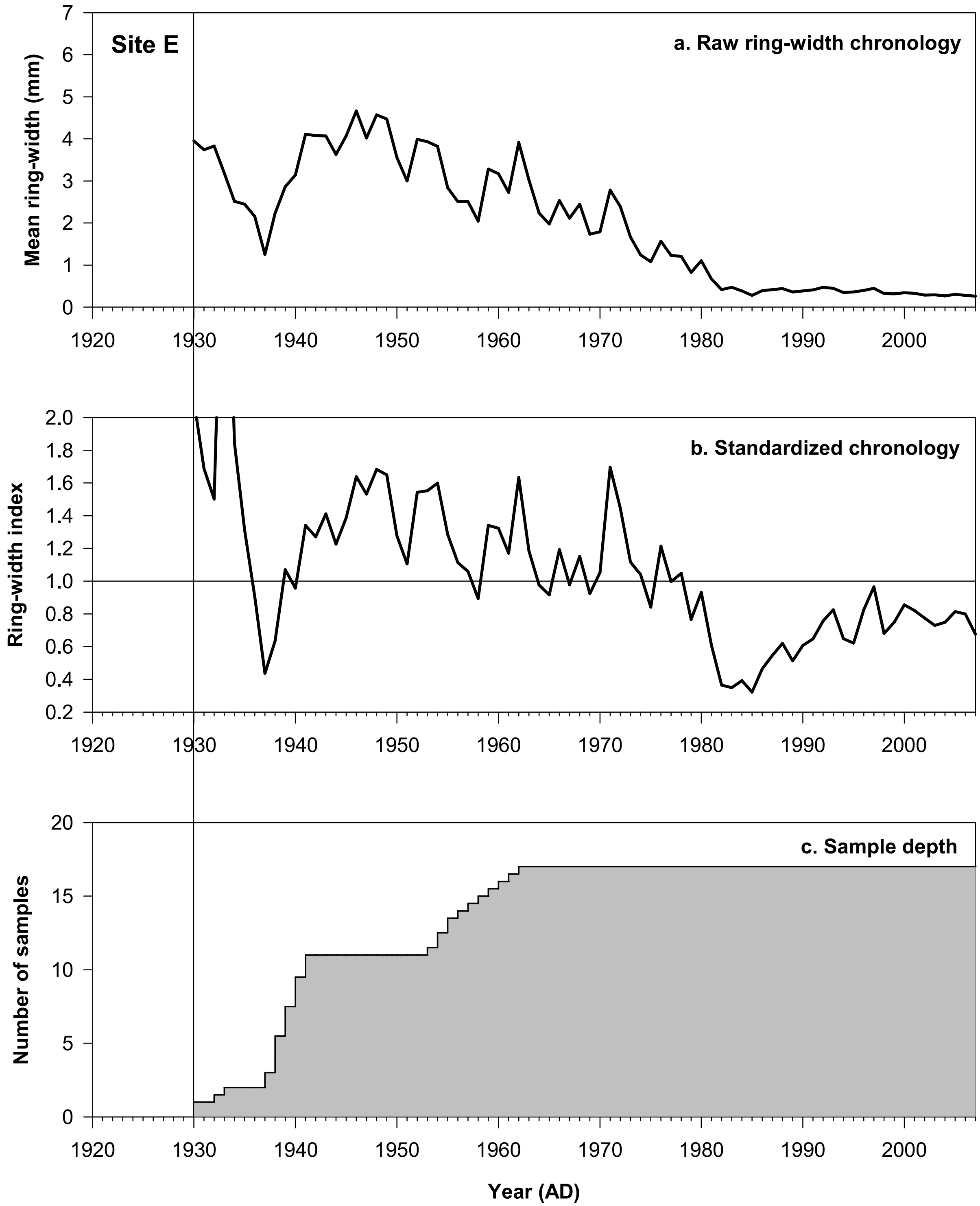


Figure 7.1.6. Raw ring-width chronology, standardized chronology and sample depth of shore pine at Site E.

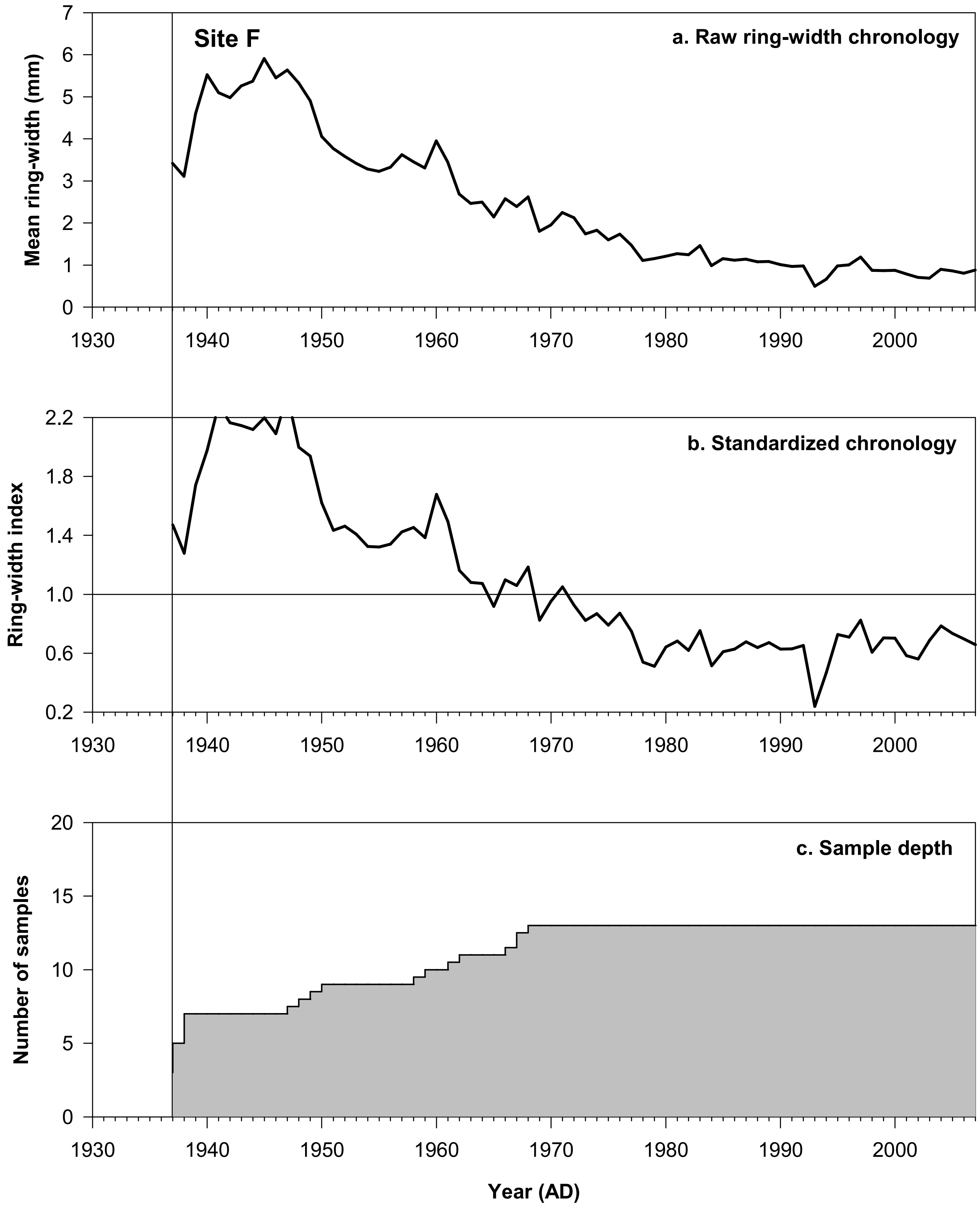


Figure 7.1.7. Raw ring-width chronology, standardized chronology and sample depth of shore pine at Site F.

7.2 Age Determination

Accurate age estimates are required for studying tree population dynamics, determining the date of past disturbances, and investigating anthropogenic influences on forest stands.[39] Typically age estimates are derived by using increment cores or stem cross-sections extracted from a sample of trees. In theory, the inner most growth ring, referred to as pith, should reflect a tree's establishment date and the outermost growth ring should yield the tree's current age. However, research has shown limitations exist with respect to the use of increment cores and stem cross sections to determine tree age.[40] In order to address these limitations for this study we adopted the following three step process to accurately estimate tree age:[41]

1. Increment cores and stem cross sections were visually and statistically crossdated to identify false or missing rings and to assign the proper calendar year to each growth ring.[42]

2. In many cases core samples and cross sections are missing pith due to assymetrical growth, heartwood decay or simply, large tree size. Where no pith is present, estimating the number of rings to pith is possible by using a mathematical correction.[43] In order to calculate the number of missing rings we measured the geometric dimensions of the three growth rings closest to pith to calculate the number of missing rings.

3. Ideally, increment cores are extracted at the root/shoot interface, near ground level, on the tree stem. However, due to increment borer design and thick understory vegetation, in the case of Langley Bog, sphagnum hummocks surrounding tree stems, it was not possible to extract increment cores at ground level. A standard coring height of 40 cm was adopted and a stem height to coring height growth relationship calculated.[44] Eight shore pine and 10 western hemlock seedlings were destructively sampled using a manual cross-cut saw. Stem discs were cut at 10 cm intervals beginning at the ground to a height of 40 cm. Rings were counted on each disc and a linear regression of age to height for

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[39] Lorimer, 1985; Veblen, 1992.
[40] Wong and Lertzman, 2001; Norton and Ogden, 1990.
[41] Daniels and Watson, 2003.
[42] Holmes, 1986; Yamaguchi, 1991; Fritts, 2001.
[43] Duncan, 1989.
[44] Wong and Lertzmann, 2001.

each species was used to calculate the number of years required for each species to grow to coring height.

Thus, the age assigned to each tree was calculated as follows:

Age = (2007/2008) – pith year +1) + (corrections for rings to pith) + (corrections for sample height)

As discussed in Section 7.1, all cores were accurately dated by matching important marker rings and using statistical crossdating. This first step of the age determination process assigned the correct calendar year to the pith or inner-most growth ring if the core did not contain pith. The second step, geometric correction, added a mathematically calculated number of years to cores with missing pith. Table 7.2.1 shows a summary of the geometric correction process per species in the respective sample areas. Applying geometric age correction on at least

Table 7.2.1. Average number of growth-rings (years) added to shore pine, western hemlock, and white birch tree cores as a result of geometric correction (Duncan Method).

	Site A	Site B	Site C	Site D	Site E	Site F
Shore pine	3.8	5.5	1.3	9.6	7.3	4.4
Percent of samples corrected	47.3%	41.6%	16.6%	71.8%	41.6%	42.8%
Western hemlock	1.0	11.8	3.5	n.a.	6.7	6.7
Percent of samples corrected	30.0%	28.5%	42.8%	n.a.	66.7%	37.5%
White birch	2.67	*	0	0	0	0
Percent of samples corrected	30.0%	n.a.	0.0%	0.0%	0.0%	0.0%

* Geometric correction was not possible on two of the three white birch trees sampled in Site B due to the insertion of branch whorl's at the three inner-most growth rings.

40% of the shore pine series was necessary in most sample areas. Correction rates for western hemlock series and white birch series were slightly lower and much lower respectively. Shore pine in Site D (71.8%) and western hemlock in Site E (66.7%) required significantly higher rates of correction because of their larger diameter stems; thus making it more difficult to estimate the direction of pith when extracting cores. Growth geometry of white birch stems was much straighter resulting in the interception of pith on nearly all cores. Considering the asymmetric nature of the bog trees and the difficult sampling conditions, it is somewhat surprising that these correction rates are not higher.

The third and final step of the age determination process was the establishment of an age to coring height relationship. Results of the regression analysis of age against height are shown in Figure 7.2.1. For shore pine, the number of years estimated for seedlings to grow to 40 cm (standard coring height) is 7.5 years. The number of years for western hemlock to grow to 40 cm

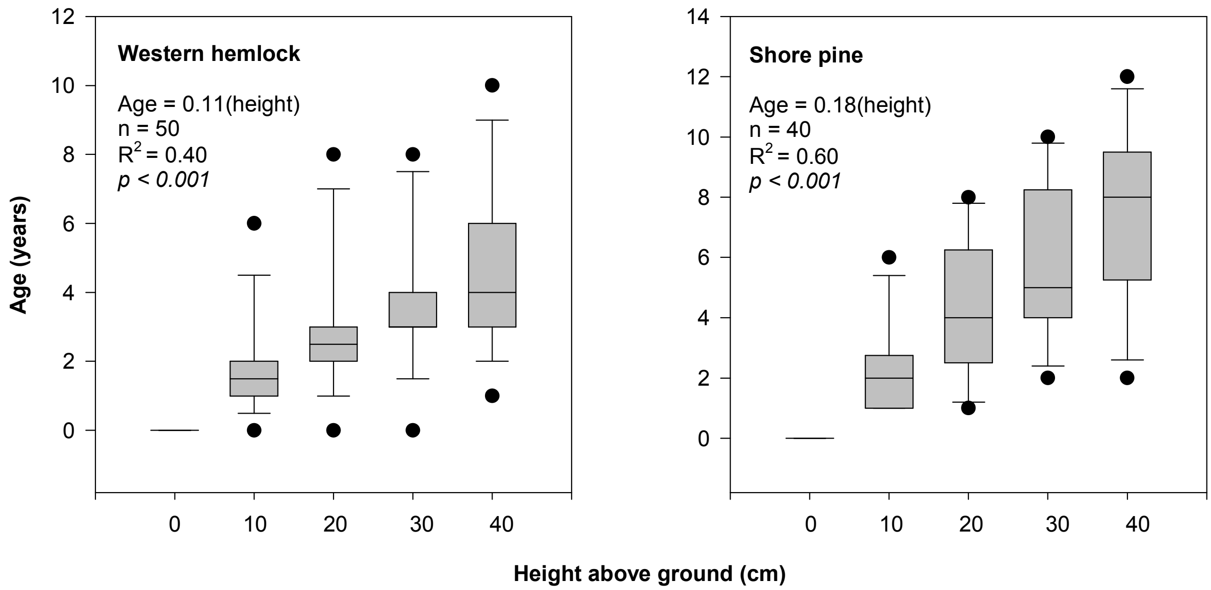

Figure 7.2.1. Species-specific corrections for age to coring height. Median age is indicated by the horizontal line in each box; the box represents the 25th to 75th percentiles; bars represent the 10th and 90th percentiles. Note the different scale on the y-axes.

is 4.9 years. The regression approach assumes that contemporary seedlings and saplings are growing at a similar rate to those in the past. We did not test the assumption in this study, however, other research shows further corrections are sometimes necessary to increase accuracy of age estimates due to changes in initial growth rates over time.[45] The oldest shore pine and western hemlock trees were 158 years (established 1850) and 165 years (established 1843) respectively. The youngest shore pine and western hemlock trees in the sample sites were 28 and 24 years establishing in the 1980s. The number of birch trees inhabiting the bog is much lower than the other two bog tree species; consequently the number of samples was much lower. Of the 24 birch trees sampled the oldest is 39 years (established 1970) and the youngest is 20 years (established 1989). Seedling and sapling ages for all species were not included in the age class distributions because we only aged trees >10 cm d.b.h.

[45] Daniels and Watson, 2003.

Age class distributions for shore pine, western hemlock and birch were created for each of the six sampled sites (Figures 7.2.2 and 7.2.3). The age class plots show four general patterns. For all plots, white birch occupies the three youngest age classes, never exceeding 39 years of age. In the three sites disturbed by past peat mining activities (A, B and C), white birch is the most recent inhabitant of the three bog tree species (shore pine, western hemlock and white birch). Western hemlock ages are more evenly distributed with the exception of site C, where a cohort of trees in the 40-49.9 year age class exists. In contrast, shore pine forms distinct even-aged stands at previously mined Sites A, B and C (Figure 7.2.2). However, at unmined sites D, E and F, shore pine tends towards forming more uneven-aged stands (Figures 7.2.3). Because of the dominance of shore pine throughout Langley Bog the remainder of the discussion focuses on that species.

Age values for dominant shore pine (greater than 10 cm dbh), in formerly mined areas of the Bog show relatively low variation; ranging from a low of 35 years in Site B and C to a high

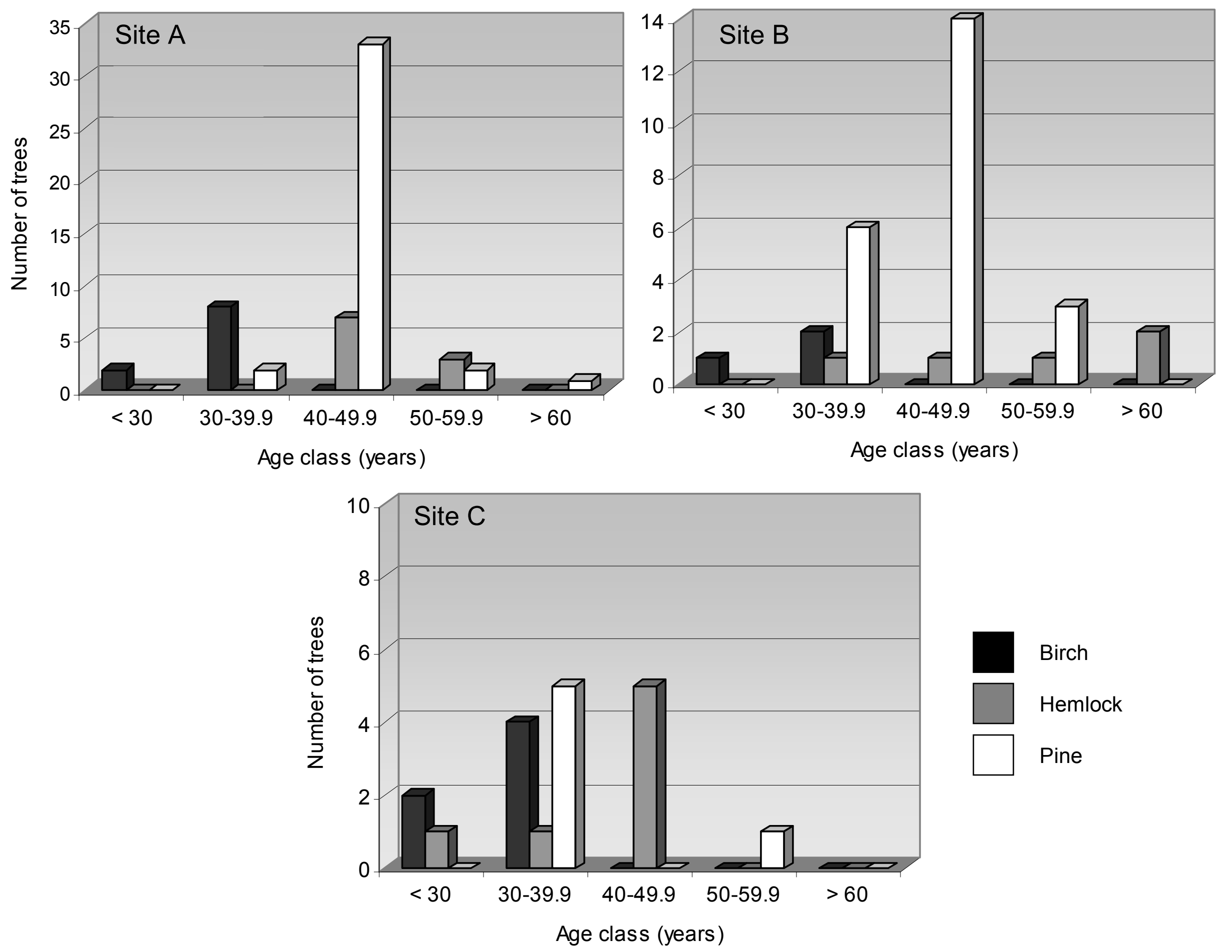

Figure 7.2.2. Age-class plots for Sites A, B and C.

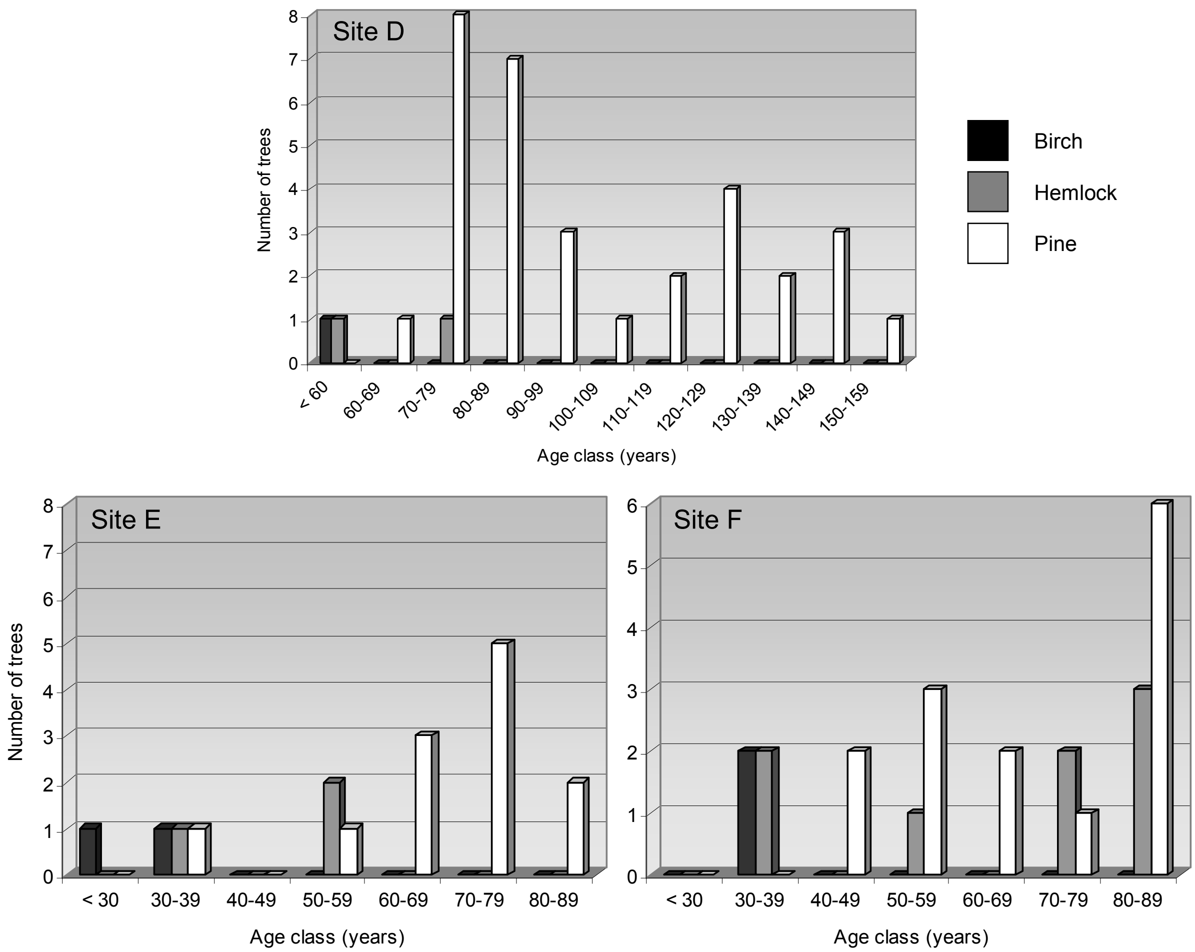

Figure 7.2.3. Age-class plots for Sites D, E and F. Note the different scales on the x-axes for Sites D, E, and F.

of 69 years in Site A (Table 7.2.2). The median ages of shore pine in Site A (43.5 years) and Site B (44.0 years) are nearly identical suggesting very similar establishment histories. The distinct shore pine cohorts of Sites A, B, and C (Figure 7.2.2.) are clearly the result of anthropogenic disturbance processes. Strip mining of sphagnum for peat harvesting removed vast quantities of original bog vegetation including pre-existing trees. The mechanical removal of competing vegetation resulted in the establishment of distinct even-aged cohorts seen in sites A and C and to a lesser extent in Site B.

Table 7.2.2. Descriptive statistics for age-class analysis of five study sites; data for shore pine only (values in years).

	Site A	Site B	Site C	Site D	Site E	Site F
Mean	44.5	43.4	40	101	69.3	69.3
Median	43.5	44	40	88	74.5	72
Standard deviation	± 5.5	± 4.9	± 6.6	± 26.6	± 15.3	± 15.6
Maximum	69	53	53	158	89	87
Minimum	39	35	35	64	36	43

In contrast to the previously mined sites, age characteristics of shore pine in unmined bog forest show much greater variation and a tendency towards uneven-aged stands. Age value ranges are much higher in undisturbed sites; from a low of 36 years in Site E to a high of 158 years in Site D (Table 7.2.2). Site D has the greatest range in age values in any one site; from 64 years to 158 years. Median ages of shore pine are 88 years, 74.5 years and 72 years for Sites D, E, and F respectively. All three sites exhibit a general tendency towards uneven-aged stands suggesting natural disturbance processes are mostly responsible for tree establishment. We noted with interest the distinct cohorts of shore pine in the 70-79 and 80-89 year age classes in unmined sections of the bog. A cursory examination of regional precipitation data shows significantly lower precipitation values from 1925 to 1931 and again from 1935 to 1938. Increases in the establishment of shore pine may be tied to a lowering of the Bog water table brought on by short-term drought. Further research is needed in this area.

Multiple species date of establishment plots were also constructed for the three previously mined sites in the bog (A, B, and C); to provide insights into the processes of forest succession and bog recovery. The data in Figures 7.2.4, 7.2.5 and 7.2.6 suggest the existence of a common pattern of tree establishment throughout the previously mined bog. Shore pine and hemlock established almost simultaneously once initial clearing of the bog was complete. Indeed, the median age of establishment for both shore pine and western hemlock in Site A is 1965. The results for Site B are similar for shore pine (median = 1964), but the number of hemlock samples at this site is too low for summary statements. However, Site B is home to two of the oldest known living trees in the bog. Two western hemlocks were discovered growing just north of the east-west hog-fuel road; one established in 1843 the other in 1852. Median establishment dates for shore pine (1970) and western hemlock (1969) in Site C are more recent than Sites A and B and confirm interpretations regarding the location and timing of historic peat mining operations.[46]

[46] Douglas and Chapman, 1995.

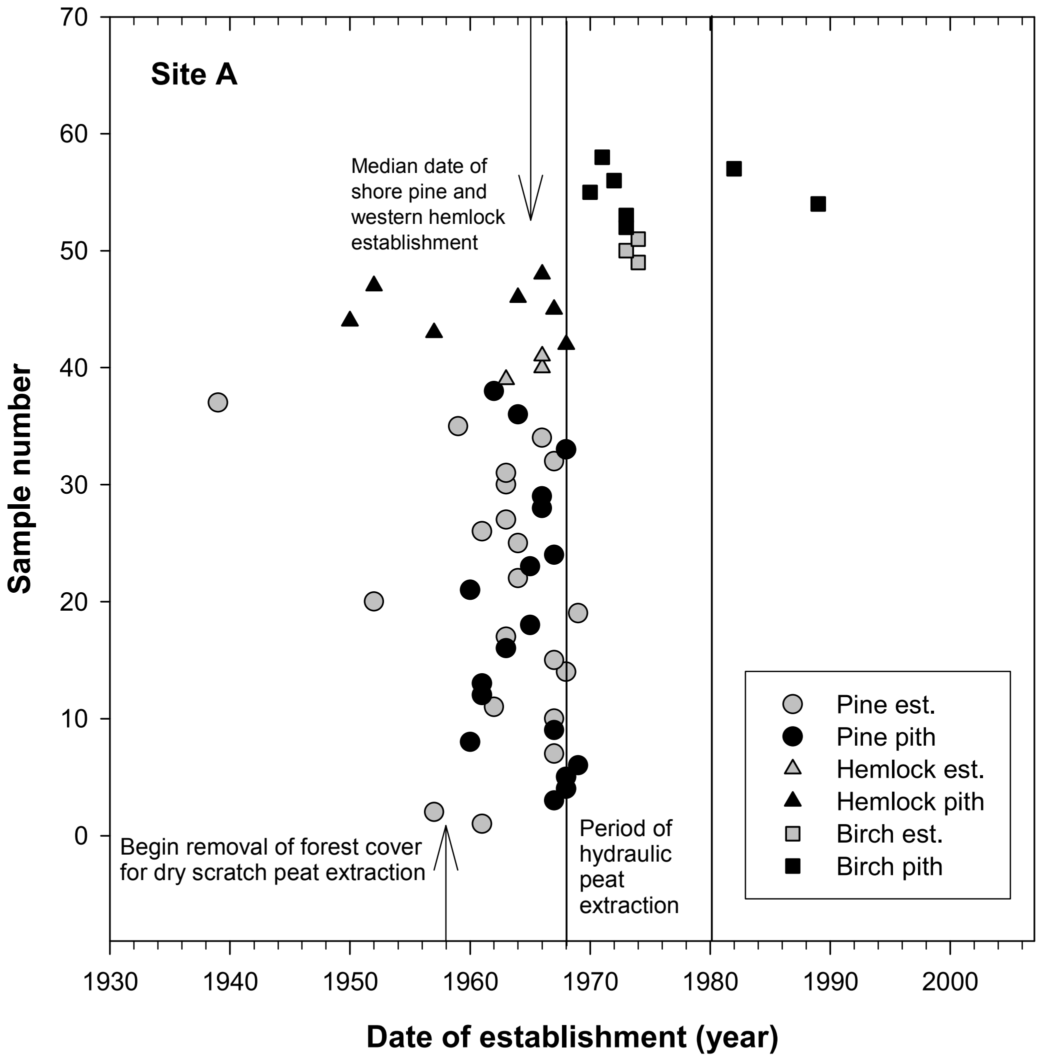

Figure 7.2.4. Date of establishment plot for Site A. Each tree species has two distinct symbols representing the correction method used to determine the exact date of establishment. For example, pine est. (estimated) refers to shore pine ages determined using the Duncan method of correction. Pine pith refers to shore pine ages determined directly from the pith (first ring of seedling growth). Notation is similar for other species.

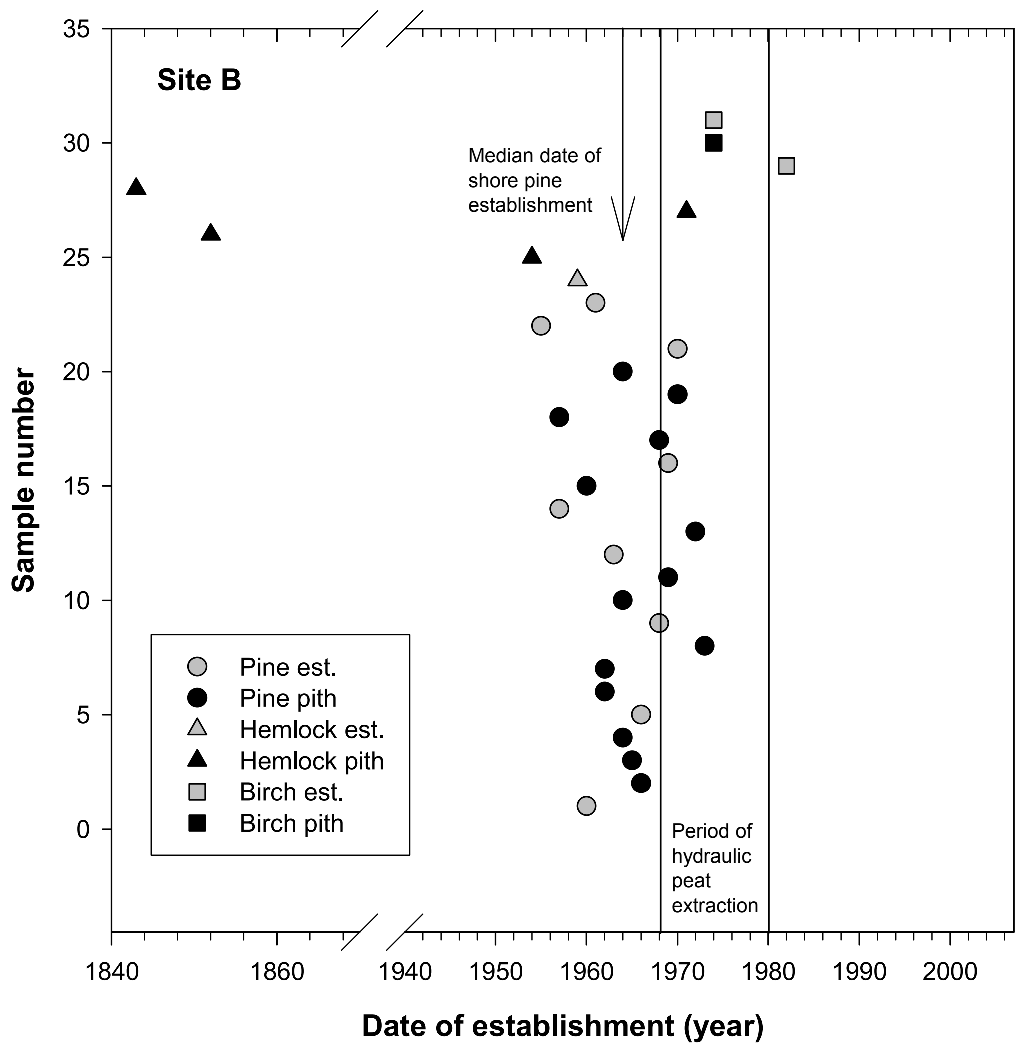

Figure 7.2.5. Date of establishment plot for Site B.

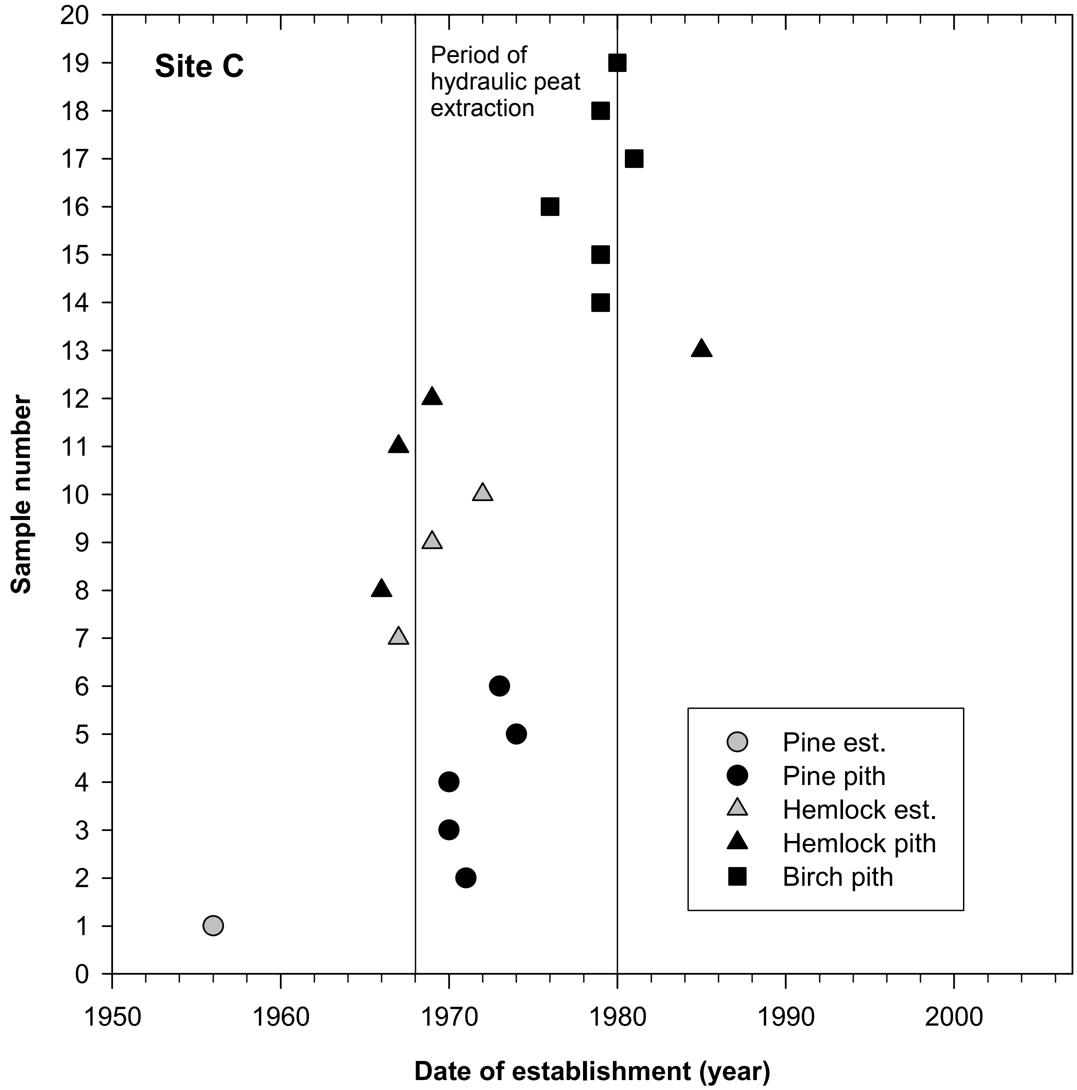

Figure 7.2.6. Date of establishment plot for Site C.

The pattern of white birch establishment mirrors that of shore pine and western hemlock in the three sites; however it is offset by approximately 8-10 years. Establishment dates for white birch range from 1970 in Site A (median = 1973) to 1982 in Site B (median = 1974). Site C has the most recent median establishment date of 1979. Although trees less than 10 cm were not included in the present study there appears to be many white birch seedlings and saplings establishing continuously since 1982. This is potentially problematic with respect to bog restoration as birch is known to significantly draw down bog groundwater reserves.[47] What did tree growth look like prior to peat mining? Preliminary analysis of a limited number of sub-fossil wood samples opportunistically collected in 2009 suggests some trees with diameters as small as 6 cm contain over 200 annual growth-rings. These tentative results are more typical of pristine bog environments, with their low nutrient, high acid soils which lead to very slow tree-ring growth.

[47] Rochefort, 2010.

8.0 NATIVE AND CULTIVATED CRANBERRY STUDIES

Langley Bog assumed its current size of 96 hectares when it was reduced from its original 500 hectare size following the development of cranberry fields around the north and west perimeter beginning in 1981.[48] Meanwhile, disturbance from the mining of the current bog from 1958-1980 created a vast network of mined channels and reduced moisture levels which allowed many exotic plant species to establish in the bog. One of the invading exotics is the cultivated cranberry species from the nearby cranberry fields. Native cranberries already existed in the bog, but the advent of cranberry cultivation introduced the non-native species.

In the southwest corner of the present Langley Bog is a relatively undisturbed bog ecosystem. Although there are some select exotic species encroaching on the area, it serves as a useful reference point for restoration work within the bog. The area is home to the native bog cranberry, but the non-native cultivated cranberry species is absent. Non-native cultivated cranberry is typically found only in areas previously harvested for peat. In the summer of 2009, we conducted an extensive investigation into the distribution of both cranberry species in the Langley Bog and the competitive relationship between them.

Native bog cranberry (*Vaccinium oxycoccus* also *Oxycoccus oxycoccus*), is an evergreen shrub with alternate lance shaped leaf tips. The flowers bloom from early June to July and are pink with reverse curved petals. The fruit that sets ripens in October, and its berry is smaller than non-native cultivated cranberry fruit. Non-native cultivated cranberry (*Vaccinium macrocarpon*) is very similar to native cranberry but does have distinct identifying features. The leaves are also alternate on the stem, however they possess an even, oval shape. Cultivated cranberry flowers are white and bloom during June and July in the Langley Bog. The larger red fruit of cultivated cranberry ripens in October and is typically harvested at this time. The easiest way to differentiate between species is by the pink and white colors of their flowers. They can also be distinguished through leaf color and shape; native cranberry leaves are darker in colour and lance shaped while cultivated cranberry posses light green oval shaped leaves (Figure 8.1).

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[48] Golinski, 2000; Piteau and Associates, 1994.

Figure 8.1. Leaves of cultivated cranberry, *Vaccinium macrocarpon* (left) versus leaves of native cranberry, *Vacinnium oxycoccus* (right).

8.1 Distribution of Cranberry Species in the Bog

In order to determine the approximate distribution of native and non-native cranberry species in Langley Bog vegetation surveys were conducted in 100 randomly selected locations using a 1 m^2 quadrat. GPS coordinates were recorded for each location for future reference and spatial analysis. Quadrat observations were stratified based on previously mined or un-mined areas of the bog. Eighty vegetative quadrat observations were conducted in the east and west sections of previously mined bog; half of which were conducted in the channels and the other half in the ridges. Sixteen quadrats were observed in the southwest portion of the un-mined bog, and four quadrats were observed in a mined channel located in the south central portion of the bog. Percent cover of all living vascular plants was recorded within each of four 0.25 m^2 squares that subdivided the 1 m^2 quadrat, and then averaged. Because Labrador tea and bog laurel often grew above dense stands of native cranberry or other species in the ridges, percent cover did occasionally exceed 100%.

In terms of cranberry species composition, the relatively undisturbed southwest portion of Langley Bog exhibited 28% cover of native cranberry, and no cultivated cranberry plants (Table 8.1.1). Within the western channels, native cranberry averaged 28% cover and cultivated cranberry just 7%; in western ridges, it was 20% for native plants versus close to 0% for cultivated plants. The cultivated cranberry was more abundant on the mined eastern side of the bog. In eastern channels, cultivated cranberries averaged 16% versus 12% for native cranberries. On eastern ridges percent cover for native cranberries still exceeded that of cultivated cranberries: 13% for native plants versus 7% for cultivated plants. We also observed that the eastern mined bog included some significant areas of dense cultivated cranberry stands. Similarly thick stands of cultivated cranberries occurred in the west mined bog, but were more sporadic. Neither cranberry species was ever observed in either the east or west bog forest.

Table 8.1.1. Distribution of two cranberry species in Langley Bog. Observations from the summer of 2009, show average % cover of native and non-native cultivated cranberry.

Cranberry Species	Unmined Bog	Western Bog		Eastern Bog	
		Ridges	Channels	Ridges	Channels
Native	28%	20%	28%	13%	12%
Cultivated	0%	0%	7%	7%	16%

The results clearly show that the channels support a higher proportion of cultivated cranberries than ridges. It appears that the highly disturbed substrates of the channels are most vulnerable to invasion and proliferation of cultivated cranberries. The greater populations of cultivated cranberries in the eastern channels may have resulted from the more recent mining activity there. The beginnings of recovery of natural vegetation in the western mined portion may help resist invasion by cultivated cranberries or at least reduce their rate of proliferation. Still, it is difficult to project the long-term growth and establishment of cultivated cranberry in either location without more information on the interaction between the cranberry plants and *Sphagnum* substrates.

8.2 Reproductive Biology and Competitive Ability

In order to understand the growth and development of the fruit of both native and non-non-native cultivated cranberries, we observed uprights from the flowering stage up until complete fruit set. Thirty uprights of each species were tagged and numbered in the northwest portion of the bog. Initial tagging was carried out on selected uprights bearing flowers because, "individual uprights in cranberry beds tend to produce flowers and fruit in alternate years".[49] The tagged cranberry plants were observed twice per week and number of flowers, intermediates, berries, and/or dead origins were counted. After a flower had been pollinated, and the flower petals fell, it was deemed to be in the intermediate stage (between flower and fruit). The transition from the intermediate to berry stage occurs at the disappearance of the style and the formation of a complete round fruit structure. Dead/aborted fruit was determined when an intermediate became withered and dried up, or when a berry died very early before reaching a mature size.

For both species, all flowers initially entered an intermediate stage (Figure 8.2.1). The number of intermediates slowly declined as berries began to form. The major difference observed between the two species of cranberry was the greater number of aborted fruit produced by cultivated cranberry. Although the cultivated cranberry began with approximately three

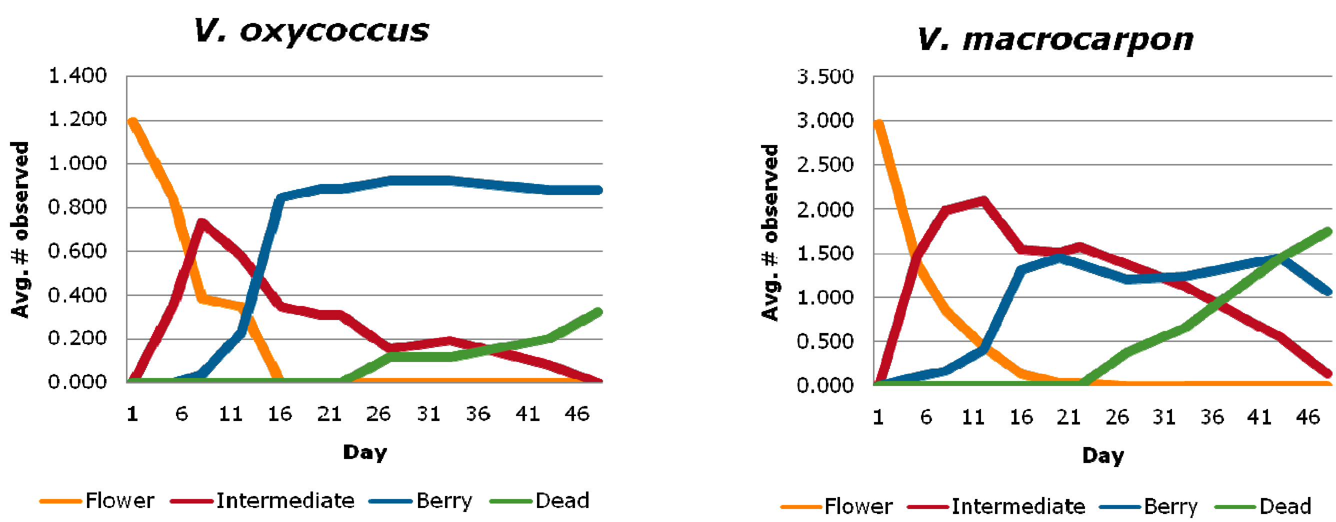

Figure 8.2.1. Fruit development observed in native and cultivated cranberries in Langley Bog (summer 2009).

[49] Wisconsin Cranberry Crop Management Library, 2006.

flowers per upright and the native had only 1.2, the number of filled berries produced per upright was very similar in the end – approximately one per upright (actual number of fruit per upright: 1.1 for cultivated, and 0.9 for native).

In May and June 2009, cranberries produced during the previous season (2008) were collected from both species in the Langley Bog. Intact berries were collected from multiple plants and locations of the bog to maximize diversity and consistency in results. Whole, ripe berries were harvested while still attached to the plant via its stem, to ensure proper species identification of the fruit. The cranberries were taken back to the lab and dissected with microspatulas and tweezers. In total 100 cultivated and 86 native berries were dissected. Seeds appearing flat were eliminated from germination experiments and not counted because the endosperm was likely absent.

In general, all cranberries from the previous season were withered, desiccated and/or fermented inside. The fruit of the cultivated cranberries appeared much larger, about twice the size of the native cranberry fruit. The cultivated cranberries also had twice as many seeds per fruit: 14 per fruit for cultivated versus seven per fruit for native cranberries.

For the germination test, seeds collected from the fruit were rinsed to remove any organic material. Paper towel was folded four times and positioned on the bottom of petri dishes and saturated with 4 mL of distilled water. Twenty-five seeds of a given cranberry species were placed in each dish, which were then sealed using parafilm. Germination tests were run for three weeks. Germination tests were also run on seeds scarified with a razor. The criterion for successful germination was emergence of the radicle through the seed coat. The germination rate for cultivated cranberry seeds was 58% while that for native cranberries was only 35%. Scarification increased the rate of germination of cultivated cranberry seeds slightly to 64%, whereas scarified native cranberries exhibited a lower percentage (28%). In the case of cultivated cranberries 8.3 of 14 seeds per fruit germinated, whereas for native cranberries only 2.4 of 7 seeds per fruit germinated.

A competition experiment was initiated on June 15, 2009, to observe how the two species grew either alone or in the presence of the other species. Seeds that had successfully germinated in the germination chamber were used. The seedlings for each pot were chosen based on their size; large and developed seedlings were potted together, whereas small immature seedlings were planted together. Twenty 10 cm diameter pots were filled with sphagnum saturated with water. Seedlings were sown deep enough to ensure the developing root system was below the surface. The additive series experiment included 5 pots of each treatment ranging from: 0 native uprights/4 cultivated uprights, 1 native upright/3 cultivated uprights, all the way to 4 native uprights/0 cultivated uprights.

The seedlings initially grew at very similar rates. After about two months of seedling development, cultivated cranberry seedlings possessed larger leaves than those of the native cranberry seedlings. This is not unexpected because the leaves of cultivated cranberries are likewise larger in the field. Once the seedlings had grown upwards significantly, they collapsed and became prostrate, much like runners. The cultivated seedlings grew longer stems, reaching an average of 24.3 cm as compared to 18.0 cm for native cranberry plants seven months after planting. The cultivated cranberry plants also produced about twice as many leaves per cm of stem (4.05 leaves per cm for cultivated cranberry, and 2.09 leaves per cm for native cranberry).

After analyzing the reproductive potential of native and non-native cultivated cranberries, it is evident that the reproductive potential of cultivated cranberry was higher on a per plant or per area basis than that of the native cranberry. Among three parameters we evaluated: fruit per upright, seeds per fruit and seed germination, cultivated cranberry possesses an edge over the native cranberry. If these three parameters are combined to form a single index, the reproductive capacity of cultivated cranberry is rated at more than four times that of the native species (Table 8.2.1).

Table 8.2.1. Comparison of reproductive parameters between native cranberry (*V. oxycoccus*) and non-native cultivated cranberry (*V. macrocarpon*). Reproductive rating is the product of fruit per upright, seeds per fruit and percent germination (expressed as a decimal).

	Fruit per upright	Seeds per fruit	% Germination	**Reproductive Rating**
Vaccinium oxycoccus	0.88	6.90	35.00	**2.12**
Vaccinium macrocarpon	1.07	14.40	58.00	**8.94**

Although the density of uprights for either species has not been determined for Langley Bog, the percent coverage is helpful in determining the impact of cranberry reproduction. In the western section of the bog, cultivated cranberry comprises 20% of the cranberry coverage found in the channels, and less than 1% of cranberry plants found in the ridges. Yet because it has a higher reproductive capacity it is probably more of a threat to native cranberry than the densities suggest. In the eastern part of the bog, cultivated cranberry makes up 56% of the cranberry composition in the channels and 33% in the ridges. Thus in the eastern channels, native cranberry is no longer the dominant species; furthermore, the ridges in this area appear very susceptible to further invasion.

Further studies on cranberry dispersal would be helpful in determining invasion pathways. It is clear that germination does not occur when seeds are within the berry.[50] Therefore, determining the source of seed removal from the fruit – whether birds, decomposition, etc., could provide more understanding on reproductive success.

The fact that the uprights of cultivated cranberry have about twice as many leaves per cm in comparison to native cranberry should provide an edge to cultivated cranberry in competition. Along with a larger sized leaf, there are more leaves which increase the surface area for photosynthesis significantly. The increased surface area of leaves for cultivated plants also effectively shields other plant species such as native cranberry. The longer stems of cultivated cranberry are an indicator of greater early growth, allowing it to establish prior to native cranberry.

It is clear that the ecological balance is slowly shifting in favour of the introduced cultivated cranberry (Fig. 8.2.2). Although the native cranberry is still the predominant species throughout much of the bog, and is the only species found in un-mined habitats, the more rapid growth and reproduction by cultivated cranberries calls for management of these non-native plants in order to protect native cranberries and other native plant species.

Potential restoration strategies include transplanting sphagnum plugs into channels to favour native over non-native cranberries or removing cultivated cranberry plants in channels with rakes. Damage to native bog species due to raking would be limited because vegetation is scarce in channels. On one hand, the relatively large area of the bog invaded by non-native cranberries makes the task seem daunting, yet on the other hand, it is a small area relative to the bog as a whole, and the sooner some management action is taken, the less opportunity there is for the cultivated cranberries established in the bog to spread.

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[50] Hill and Vander Kloet, 2000.

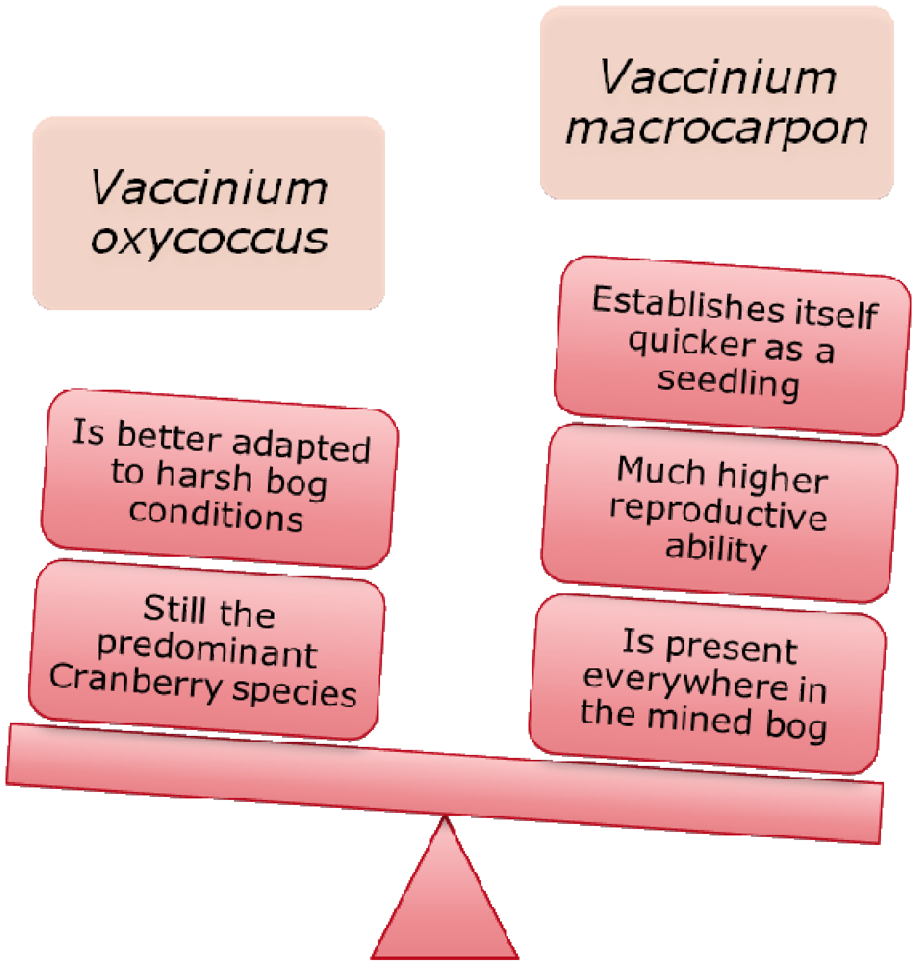

Figure 8.2.2. Comparison of native and non-native cultivated cranberry properties. Studies conducted in Langley Bog suggest the balance is shifting in favour of cultivated cranberry.

9.0 SPHAGNUM RECOVERY TEST PLOTS

Ten *Sphagnum* restoration test plots were established to monitor natural succession and investigate how restoration might be enhanced by "planting" *Sphagnum* plugs. Two plots were established in the spring of 2006 in a channel south of the hog-fuel road spur off the main central road. In the summer of 2008, eight more plots were added. Plot locations were randomized by throwing a stake in the air in the general direction of what seemed representative areas of the channel. The plots are 2 m x 2 m and are divided into four 1 m x 1m subplots. Subplots were randomized by coin toss as to whether they would contain a *Sphagnum* mat (plug) or not. Decayed peat blocks with existing plants in channel sites were cut out with a shovel. *Sphagnum* plugs ranging from approximately 30 cm^2 to 50 cm^2 were cut with a saw from established hummocks in nearby ridges. The removed materials from each site were exchanged – *Sphagnum* plugs were transplanted into selected subplots and peat blocks went back into the hummocks. Precise rasterization technique (see below) was not applied to determine initial area but we estimate a rough average starting area of around 1350 cm^2 or 37 x 37 cm.

A numbering scheme was assigned to the plots and each subplot to allow tracking - each plot was assigned a number from 1 to 10, (Figure 9.1) and each of the four subplots that made up each plot were given a letter from "a" to "d," with the western-most subplot being assigned "a," the northern-most assigned "b," the eastern-most assigned "d," and the southern-most assigned "c."

The percent cover of each plant species, excluding the different species of *Sphagnum* which were counted as one plant type, was estimated in each subplot by placing a 1m x 1m quadrat frame over each of the four sub plots. Two methods for measuring the size of *Sphagnum* plugs were compared: the circumference of each plug was measured with a measuring tape and the area was calculated by using the formulas:

$$\text{diamter} = \frac{\text{circumference}}{\pi} \qquad \textit{Equation 9.1}$$

$$\text{Area} = \pi\, r^2 \qquad \textit{Equation 9.2}$$

where r = the radius.

Moreover, a second method of calculating a "raster" area with the use of the photo editing software *Corel Draw X4*[51] was used. The circumference method proved to be very inaccurate as it assumed that each plug was circular or close to a circular shape, which was not the case. However, the raster method proved to work quite well.

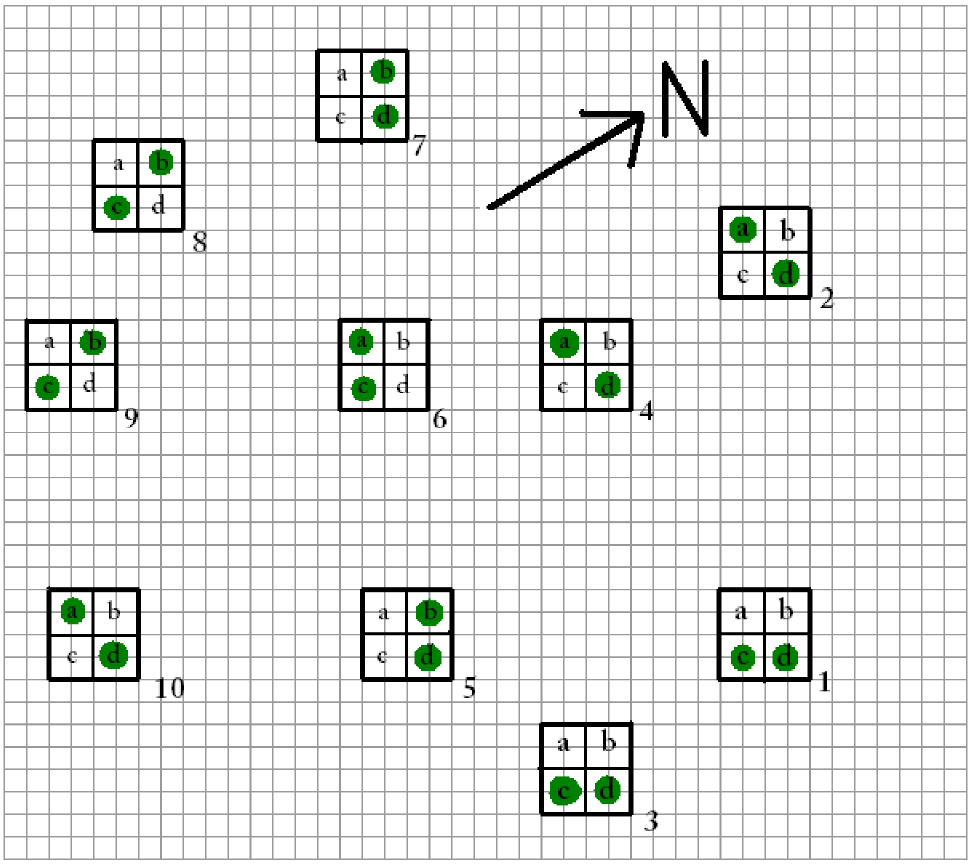

Figure 9.1. Identification scheme for *Sphagnum* plug recovery test plots. Numbers identify each major plot and letters individual subplots. Green circles indicate where Sphagnum plugs were planted.

The raster method involved taking a digital photograph of each of the *Sphagnum* plugs in the centre of a $1m^2$ quadrat with a tape measure outlining the perimeter (Figure 9.2). Then using *Corel Draw X4*, a 50 square x 50 square grid was superimposed on the digital image in line with the 1m x 1m quadrat to create 2500 squares of 4 cm^2 each. The squares that overlaid the sphagnum plug (including the estimation of partial squares) were filled in (Figure 9.2) and the area of each plug was calculated by multiplying the area of each square with the number of squares (i.e. 289 squares x 4 cm^2 / square = 1156 cm^2).

[51] Corel Corporation, 2008.

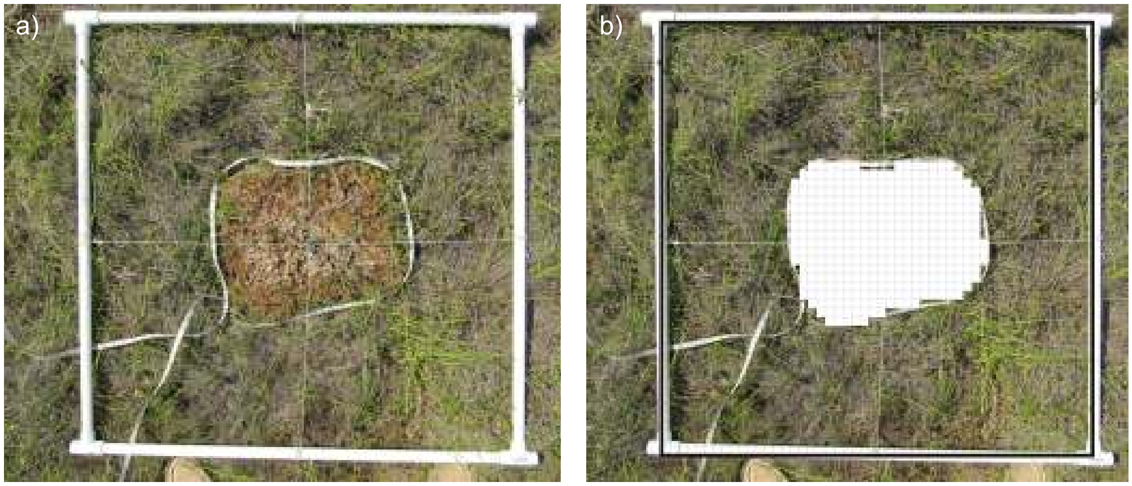

Figure 9.2 Illustration of (a) a typical 1 x 1 m quadrat subplot with *Sphagnum* plug, and (b) rasterization technique.

A large portion of the cover was not identified but appeared to be a sedge species tentatively labeled as *Scirpus*. This plant had an average 21.6 % cover for each plot, and accounted for as much as 48.3 % vegetative cover in Plot 1, and as low as 4 % cover in Plot 8. The second-most abundant plant species was the white-beaked sedge (*Rhynchospora alba*), which had an average of 18.7 % vegetative cover for each plot and accounted for a maximum of 42.5 % cover in Plot 6, and a minimum of 3.3 % cover in Plot 8. The next most abundant species was the cultivated cranberry (*Vaccinium macrocarpon*), with an average percent cover of 15.9 %. Very little native cranberry existed – on average 3.1 % cover – which was only present in the transplanted *Sphagnum* plugs. *Sphagnum* itself accounted for only 3% vegetative cover in just two subplots, 1A and 9D. One club moss species was identified in subplot 7C.

The average plug was 1395 cm^2 for plugs installed in 2008, while the 2006 plots averaged 3072 cm^2, approximately double the 2008 areas. Plots 5 and 6 are the 2006 plots, and Plugs 5b and 5d were by far the largest. The smallest plugs were in Plots 4a and 4d, which had areas of 864 cm^2 and 856 cm^2, respectively. Growth had obviously occurred in the 2006 plots. While several of the 2008 plots showed evidence of growth, in several other plots little or no growth, or die-back, seemed to have occurred. Plots from 2006 were planted in March and Plot 5 is located in a relatively moist area, whereas plots in 2008 were planted in August. It seems reasonably apparent that available water may have played large roles in initial success, in addition to the time difference for growth. A major positive point is that *Sphagnum* did indeed establish and in most cases appears to be growing.

The literature and personal communication with experts suggests another approach that has proved more efficient and effective in restoration than transplanting *Sphagnum* plugs – spreading fairly small cut/shredded pieces of *Sphagnum* (called "diaspores") in sufficient density across a larger area.[52] We suggest this technique be tested in Langley Bog.

[52] Ferland and Rochefort, 1997; Rochefort, 2010; Chirino et al., 2006; Sotocornola et al., 2007.

10.0 RECOMMENDATIONS

Managing the Langley Bog requires continuing scientific assessment of its ecological services and resources. Based on the research we have presented, we make the following recommendations based on action, monitoring and maintenance.

Actions:

- **Devise water management strategy** to maintain water levels at or near the surface (no lower than -15 cm below surface) over as much of the bog as possible.
- Prioritize the **mechanical removal of *Birch spp.***
- **Test diaspore method of S*phagnum* regeneration** over large areas of previously mined bog.
- **Transplant *Sphagnum*** into channels to favour native over non-native cranberries and **remove cultivated cranberry plants** in channels with rakes.
- **Continue research on subsurface peat characteristics** to better understand paleoecological and paleoclimatic conditions of Langley Bog.

Monitoring:

- **Monitor peat depths and the condition of peat health** in both surrounding bog forest and mined sections of the bog.
- Continue to carefully **monitor water levels** in the bog at regular intervals especially during summer months.
- Periodically **monitor bog water chemistry**, in particular those variables which are key indicators of bog health (e.g., water temperature, dissolved oxygen, pH, nitrates and calcium concentrations).
- Periodically **monitor tree growth** using dendrochronological methods and investigate climate-growth relationships.

Maintenance:

- **Maintain currency of GIS database** in order that it may be used as a primary, integral tool to guide all future management decisions (e.g., regrowth of peat ridges).

- **Maintain western bog forest** as perimeter buffer to process excess nutrient load (e.g., nitrates, fertilizers, etc.) from adjacent cranberry operations.

These management actions we recommend are required to initiate bog restoration. Each one of the actions should be carefully designed to be experiments in themselves and thus lead to adaptive management strategies.[53] Monitoring is required to not only assess the ramifications of the actions, but also to determine long-term trends in the ecological health of the bog. Maintenance is required both of the data collection methods in order to access standardized, spatially-explicit geomatics data which is paramount for informed, timely decision-making.

[53] Holling, 1978.

11.0 CONCLUSION

In this report we have presented the results of two years of intense research activities focusing on three important streams: (1) mapping and surveying of basic bog features (Sections 1 – 3), (2) abiotic studies of soil and water (Sections 4 – 6), and (3) biotic studies of vegetation focusing on tree growth, cranberry characteristics, and sphagnum regeneration (Sections 7 – 9).

Given the results of our initial research and the set of recommendations above, the scientific study of the Langley Bog is nascent. Many of the projects presented here have undeniably prompted further questions regarding the ecological components and interrelationships in the bog. Further research following the lines of inquiry which have been spawned by our scientific studies will allow for a more complete understanding of the Langley Bog and will favour its transition to fully restored ecological function.

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