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# Human-ecosystem interactions in relation to Holocene environmental change in Port Joli Harbour, southwestern Nova Scotia, Canada

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ABSTRACT

A high-resolution pollen record from Path Lake in Port Joli Harbour, Nova Scotia, Canada, provides a paleoecological perspective on Holocene climate and vegetation variability within the context of local archaeological research. Pollen assemblages in the early Holocene reflect a post-glacial forest dominated by *Pinus*, *Tsuga*, *Betula* and *Quercus*. During this time, a lower frequency of radiocarbon dated cultural material suggests lower human settlement intensity. Shallow water aquatic (*Isoetes*) and wetland (*Alnus*, *Sphagnum*) taxa increased after 3400 cal yr BP in response to a transition towards wetter climatic conditions. Culturally significant periods, where settlement intensity increased in the Maritimes and Maine, coincide with maximum values of reconstructed total annual precipitation, suggesting that environmental conditions may have influenced prehistoric human activity. European settlement, after 350 cal yr BP, was marked by a rise in *Ambrosia*. The impact of anthropogenic fire disturbances on the landscape was evidenced by peak charcoal accumulations after European settlement.


## Introduction

Understanding the complex structure of human–ecosystem interactions, both in the past and present, is an important aspect of environmental studies (Briggs et al., 2006). Archaeological and historical records provide evidence of cultural activities, while paleo-environmental records reconstruct past vegetation and climate regimes. The combination of these records allows for a better understanding of how ecosystem structure is related to human land-use, and vice-versa, at a decadal- or century-scale temporal resolution (Briggs et al., 2006, Gajewski et al., 2011). By combining archaeological records with studies of local to regional scale changes in vegetation composition and climate during the mid to late Holocene, inferences can be made regarding cultural development and adaptation of past human populations to environmental changes (Coe and Flannery, 1964).

The paleoecology of coastal ecosystems can be more specifically studied in relation to shell middens, which provide archaeological records of maritime cultures (Graham et al., 2003). Archaeological excavations of shell middens from the Atlantic coast of Nova Scotia indicate the presence of ancient Mi'kmaw occupations between ca. 3000 and 350 cal yr BP (Keenlyside, 1999). This paper uses a paleo-ecological perspective to investigate Holocene vegetation and climate variability, within the context of local archaeological research in Port Joli Harbour, southwestern Nova Scotia.

After local deglaciation, post-glacial climate change began with a warming period (late glacial; 14,000–10,000 cal yr BP), where boreal/woodland forests dominated the landscape (Mott and Stea, 1993; Mayle and Cwynar, 1995). During the late glacial, the Younger Dryas (12,900–11,700 cal yr BP) represented a major reversion to cooler conditions, causing a change in vegetation to shrub and herbaceous tundra (Mayle et al., 1993; Levesque et al., 1994; Walker et al., 2009). Another notable global cooling of 4 °C occurred during the early Holocene '8200 cal yr BP event' (Lennox et al., 2010). Around 3000 cal yr BP, there was a regional transition to relatively wet and cool conditions in Nova Scotia (Railton, 1973; Ogden, 1986; Lennox et al., 2010). Superimposed on broad-scale climate changes during the Holocene were higher frequency variations, the latest of which was a cool period termed the Little Ice Age (LIA), which occurred across North America between 600 and 100 cal yr BP (Wanner et al., 2008).

Relative sea-level changes in Nova Scotia during the Holocene were due to a combination of postglacial isostatic adjustments (Edgecombe et al., 1999), regional crustal subsidence and local sea-level rise (Forbes et al., 2009). Submergence of the coastline and fluctuations in marine productivity associated with rising sea levels during the mid to late Holocene would have had consequences for Mi'kmaw settlements along the coast. The interaction of Mi'kmaw occupations with terrestrial as well as marine ecosystems is an important consideration when developing a detailed environmental history of the region.

Human activities have had profound influences on forest dynamics in eastern North America (Delcourt and Delcourt, 2004; Gajewski et al., 2011). Clear-cutting or controlled burning of forests for agriculture during European settlement in Nova Scotia between 350 and 200 cal yr BP led to major transformations in vegetation distribution and structure (Briggs et al., 2006). The region of Port Mouton, located less than 10 km from Port Joli Harbour, was an encampment of De Monts and Champlain

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around 350 cal yr BP, and a settlement for loyalists after the American Revolution around 170 cal yr BP (Fig. 1; Macgregor, 1832; Dunlop and Scott, 2006). The long history of human occupation extending to the present makes the region surrounding Port Joli Harbour an ideal location for studying human–ecosystem relationships. A high-resolution pollen record of a sediment core from Path Lake (43°52.17′N, 64°55.39′W; Fig. 1) was used to show the evolution of the Acadian Forest Region in southwestern Nova Scotia during the mid- to late-Holocene, at a time when human occupations along the coast were becoming increasingly prominent.

## Study site

Path Lake is located approximately 600 m from the northwestern shoreline of Port Joli Harbour, at an elevation of 15 m above present sea level (Fig. 1). This headwater lake is large (21.9 ha), slightly acidic (pH 6.2), and has an extensive littoral zone (Nova Scotia Department of Fisheries, 1995). Path Lake receives minimal inflow from a small spring at its northwest corner, and an outlet channel flows towards the ocean from the eastern side.

The present vegetation of the Atlantic Maritime Provinces is classified as the Acadian Forest Region (AFR; Mayle and Cwynar, 1995). The high abundance of red spruce (*Picea rubens*) is a distinguishing feature of the AFR, as this shade-tolerant species thrives in high moisture conditions (Mosseler et al., 2003). Other associated species include balsam fir (*Abies balsamea*), eastern hemlock (*Tsuga canadensis*), eastern white pine (*Pinus strobus*), yellow birch (*Betula alleghaniensis*), sugar maple (*Acer saccharum*) and American beech (*Fagus grandifolia*) (Mosseler et al., 2003). Port Joli Harbour is further categorized within the AFR as part of the Atlantic Shore Ecoregion, as a forest type described as Acadian–Boreal Coastal. Wetland environments are common along the coast and include fens, raised or flat bogs, and salt marshes (Webb and Marshall, 1999).

## Methodology

In July 2013, a 4.16 m long sediment sequence was recovered from Path Lake using a modified Livingstone piston corer. The uppermost sediments were collected in a clear plastic tube. Unconsolidated sediments near the water–sediment interface (7 m deep) were extruded at 0.5–1.0 cm intervals, with individual cross-sections stored in zip-lock bags. Remaining sediments were extruded horizontally and intact in the field, and wrapped in plastic-wrap, aluminum foil and PVC tubing for transport to the University of Ottawa. Cores were stored in a refrigerator at 4 °C.

The magnetic susceptibility of the Path Lake sediment core was measured at 1.0 cm intervals using a Bartington™ MS2C meter and loop sensor. Values within 4 cm of core extremities were excluded from analysis as the sensor averages over several cm.

Determination of organic and carbonate content within the sediment cores was assessed using loss-on-Ignition (Dean, 1974). The dry weight was obtained after heating the subsamples to 105 °C for 12–24 h followed by ignition at 550 °C for 4 h to determine the organic carbon content (Heiri et al., 2001). The carbonate content was obtained after igniting the subsamples at 950 °C for 2 h (Dean, 1974), and resultant values were multiplied by 1.36 to compensate for the molar mass of carbon dioxide and carbonate (Heiri et al., 2001).

Accelerator-mass spectrometry (AMS $^{14}C$ dating) was used to obtain the ages of six samples at a series of depths in the Path Lake core. Identifiable pieces of organic matter including fibres, wood and charcoal, were picked from sieved sediment. These samples of organic matter were then submitted to the Beta Analytic Dating Laboratory, and resulting ages were calibrated using the IntCal09 calibration curve (Reimer et al., 2009). An age–depth model was fit to the data in the R software package BACON to establish a chronology (Blauuw and Christen, 2011).

Sediment subsamples of 1 $cm^3$ were extracted for pollen analysis. Non-polliniferous material was removed through chemical treatment, involving 10% hydrochloric acid, 10% potassium hydroxide, hydrofluoric acid, and acetolysis solution. Residual pollen material was preserved and mounted on microscope slides with silicone oil (Faegri et al., 1989). Two *Lycopodium* spore tablets (batch #938934) were added to each sample before processing to enable the calculation of fossil pollen concentration and accumulation rates (Faegri et al., 1989). Pollen grains and spores were counted using a Nikon Eclipse 80i light microscope at 400× magnification, along evenly spaced transects to avoid potential differential sorting during the creation of the slides. Reference material and texts helped with the identification of fossil pollen and spores (Roland and Smith, 1969; McAndrews et al., 1973; Faegri et al., 1989; Moore et al., 1991). An average total pollen sum of 535 was reached for 121 subsamples, excluding all aquatic species.

Micro-charcoal was identified as any black, angular fragments or any opaque fragments where a linear or rectangular wood-like structure was visible (Clark, 1982). Fragments were classified into four categories according to size; 1: $218.75 \leq \times < 437.5$ μm$^2$, 2: $437.5 \leq \times < 875$ μm$^2$, 3: $875 \leq \times < 1750$ μm$^2$ and 4: $\geq 1750$ μm$^2$ (Whitlock and Larsen, 2002; Paquette and Gajewski, 2013). The total area of charcoal for each

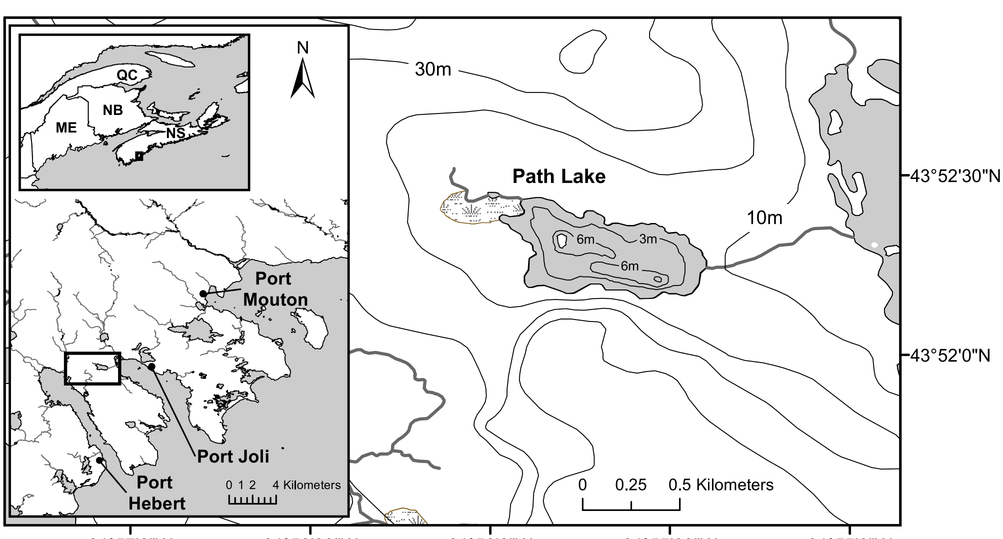


**Figure 1.** Location of Path Lake in relation to Port Joli Harbour, Southwestern Nova Scotia.

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depth interval was calculated by summing the geometric mean of each size class (Whitlock and Larsen, 2002).

The Modern Analogue Technique (MAT) (Sawada, 2006) and version 1.8 of the North American Modern Pollen Database (NAMPD) (Whitmore et al., 2005) were used to reconstruct the mean annual temperature (°C), and mean total annual precipitation (mm/yr). These variables were computed using the average of the three closest analogues and a squared chord distance dissimilarity coefficient (Williams and Shuman, 2008). Modern pollen data between 0 and 100°W longitude and 25 and 85°N latitude were considered as potential candidates for modern analogues. The reconstructions were based on a pollen sum of 16 pollen taxa, including *Pinus*, *Picea*, *Abies*, *Tsuga*, *Larix*, *Cupressaceae*, *Acer*, *Betula*, *Fagus*, *Fraxinus*, *Populus*, *Quercus*, *Ulmus*, *Alnus*, *Ericaceae* and *Sphagnum*.

Radiocarbon dates from archaeological sites were extracted from the CARD database (Gajewski et al., 2011; http://www.canadianarchaeology.ca/) to document human activity in the region. Dates were extracted from the Maritime Provinces (Nova Scotia, New Brunswick, Prince Edward Island) and the state of Maine, and further separated into coastal and interior sites. New radiocarbon dates from a work in progress in the Port Joli region (Betts, 2011) were also separately included.

The evolution of the Port Joli Harbour coastline was mapped using a reconstructed Holocene sea level curve of 14 compiled data points (Ogden, 1986; Scott et al., 1995a, 1995b; Edgecombe et al., 1999) and bathymetric data from the harbour (Surveys, Mapping Branch, Department of Energy, Mines and Resources, 1989).

## Results

### *Sediment*

Organic content (LOI at 550 °C) ranged between 24 and 35%, and the carbonate content (LOI at 950 °C) comprised less than 8% of the sediment (Fig. 2). Organic content decreased until 9150 cal yr BP, and remained stable below 30% before increasing for a short period once at 7200 cal yr BP, and again at 3700 cal yr BP. At 2400 cal yr BP, organic content reached its highest values and only began to decrease again at 2000 cal yr BP. In the last 1700 yr, organic matter increased by 3%. Other than very large values near the base of the core, magnetic susceptibility showed no significant changes throughout the Holocene, as all values remained within the range of instrumental error.

### *Chronology*

All six $^{14}$C-calibrated dates fit in chronological order as a function of depth (Table 1, Fig. 3). Based on the interpolated ages, the basal date of Path Lake was determined to be just over 9600 cal yr BP. The age-depth model for Path Lake produced a relatively linear curve with no visible outliers. The mean sediment accumulation rate, assuming a gamma distribution (shape = 2), was 21.9 yr cm$^{-1}$.

### *Pollen record*

The Path Lake pollen record was dominated by pollen of *Pinus*, *Picea*, *Betula* and several other hardwoods (Fig. 4). Zones were delimited based on a principal component analysis (PCA) ordination of the pollen percentages (below).

Zone P1 (9280–5250 cal yr BP) was dominated by arboreal taxa, which represented over 90% of the total pollen sum. *Pinus haploxylon* and *Betula* maintained relatively high pollen percentages, whereas *Picea* was at its lowest abundance. *Pinus diploxylon* was at its maximum abundance (20%) at 8600 cal yr BP, and decreased to between 1 and 15% in the most recent four zones. In this zone, *Tsuga* began to rise at 6650 cal yr BP, reached maximum abundance (27%), and subsequently declined between 5350 and 5250 cal yr BP. As *Tsuga* increased, there was a corresponding decline in both *Betula* and *Quercus*. *Alnus*

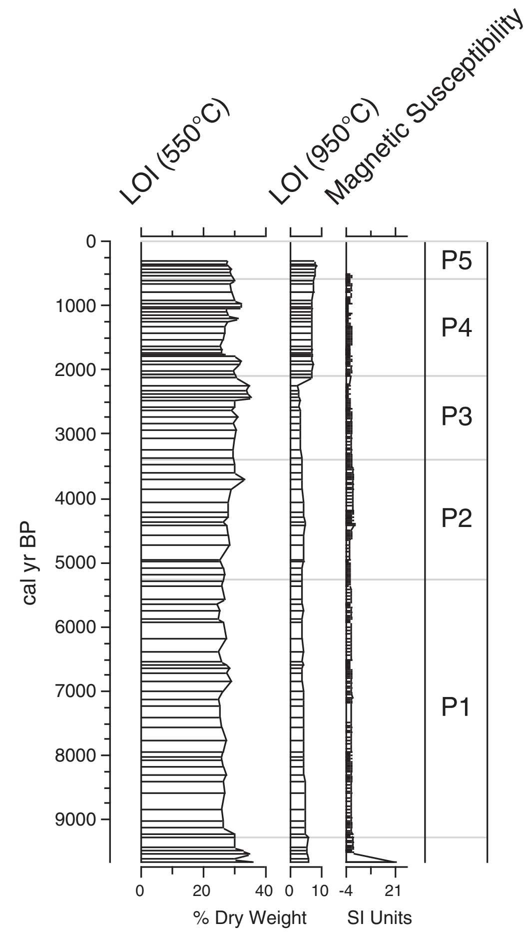


**Figure 2.** Loss on Ignition and magnetic susceptibility for Path Lake, Port Joli, Nova Scotia.

represented less than 4% of the total pollen sum in this zone. Pollen percentages of herbaceous taxa, spores and aquatics were also minimal in this zone.

Zone P2 (5250–3400 cal yr BP) was characterized by a maximum abundance of *P. haploxylon*, which lasted for 220 yr, at the beginning of the zone. Throughout the zone, *P. haploxylon* pollen percentages remained relatively high, ranging between 30 and 40% of the total pollen sum. The rapid decline of *Tsuga* within the previous zone had stabilized by around 5000 cal yr BP, before beginning a more gradual increase. *Picea* and *Abies* pollen percentages steadily increased, and those of the herbaceous taxa, spores and aquatics remained very low.

In Zone P3 (3400–2100 cal yr BP) *P. haploxylon*, as well as *Quercus* gradually decreased, although the latter decrease was far less pronounced. At the beginning of this zone, pollen percentages of shrub taxa (*Alnus*, *Corylus* and *Ericaceae*) began to increase, representing up to 15% of the total pollen sum once they had reached peak abundance at 180 cal yr BP. *Isoetes*, an aquatic plant, also began to increase around 2450 cal yr BP.

In Zone P4 (2100–600 cal yr BP) pollen percentages of *P. haploxylon* stabilized at a range between 15 and 25% of the total pollen sum. *Isoetes* gradually increased and reached a peak at around 1700 cal yr BP before declining again. A similar increase was seen in *Sphagnum*, though this taxon peaked later at 1200 cal yr BP. These two taxa have a negative relation with *Picea*, which decreased slightly in abundance midway through the zone before increasing again. Shrub pollen percentages again continued to steadily increase. Pollen of the shrub *Ilex* increased from minimal percentages at 1700 cal yr BP, and declined abruptly at 900 cal yr BP.

In Zone P5 (600 cal yr BP — present) there was a significant increase in non-arboreal pollen, beginning around 350 cal yr BP (1600 AD). The

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**Table 1**
Conventional radiocarbon ages and calibrated age ranges (CALIB 6.0; Stuiver and Reimer, 1993; Reimer et al., 2009) for Path Lake, Port Joli, Nova Scotia. Samples were comprised of organic material extracted from the sediment core.

| Laboratory no. Beta- | Depth (cm) | $^{13}C/^{12}C$ ratio, ‰ | Conventional radiocarbon age, $^{14}C$ yr BP | Calibrated age ranges, cal yr BP, (probability) | Sigma (σ) |
|---|---|---|---|---|---|
| 343098 | 41–43 | −26.9 | 870 ± 30 | 698–803 (0.757)<br>808–831 (0.059)<br>855–905 (0.184) | 2σ |
| 329631 | 74–75 | −29.0 | 1190 ± 30 | 1006–1029 (0.038)<br>1053–1180 (0.932)<br>1209–1230 (0.03) | 2σ |
| 329632 | 130–131 | −27.2 | 2030 ± 30 | 1898–1914 (0.037)<br>1918–2062 (0.933)<br>2086–2105 (0.03) | 2σ |
| 343099 | 205–207 | −32.8 | 3750 ± 30 | 3987–4048 (0.222)<br>4065–4162 (0.674)<br>4167–4180 (0.021)<br>4198–4230 (0.082) | 2σ |
| 343100 | 301–302 | −26.8 | 5840 ± 30 | 6562–6593 (0.105)<br>6597–6737 (0.895) | 2σ |
| 329633 | 399–400 | −26.3 | 8740 ± 40 | 9560–9574 (0.028)<br>9580–9888 (0.972) | 2σ |

main taxa contributing to this change were *Ambrosia*, *Poaceae* and *Rumex*. Another peak in *Isoetes* was also seen at this time. *Alnus rugosa*, *Ericaceae*, *Picea* and *Abies* reached peak abundance in this zone, while the pollen percentages of hardwood taxa and *Tsuga* gradually decreased until the present. The pollen percentages of *Betula* remained fairly constant throughout the entire sequence.

The total pollen accumulation rate (PAR) for Path Lake was relatively low in Zones P1, P2 and P3 (Fig. 5). In Zone P4, there were two peaks in PAR, firstly between 1900 and 1700 cal yr BP, and again between 1300 and 1000 cal yr BP. The PAR in Zone P5 was characterized by a single large peak at roughly 250 cal yr BP, around the time of the European settlement.

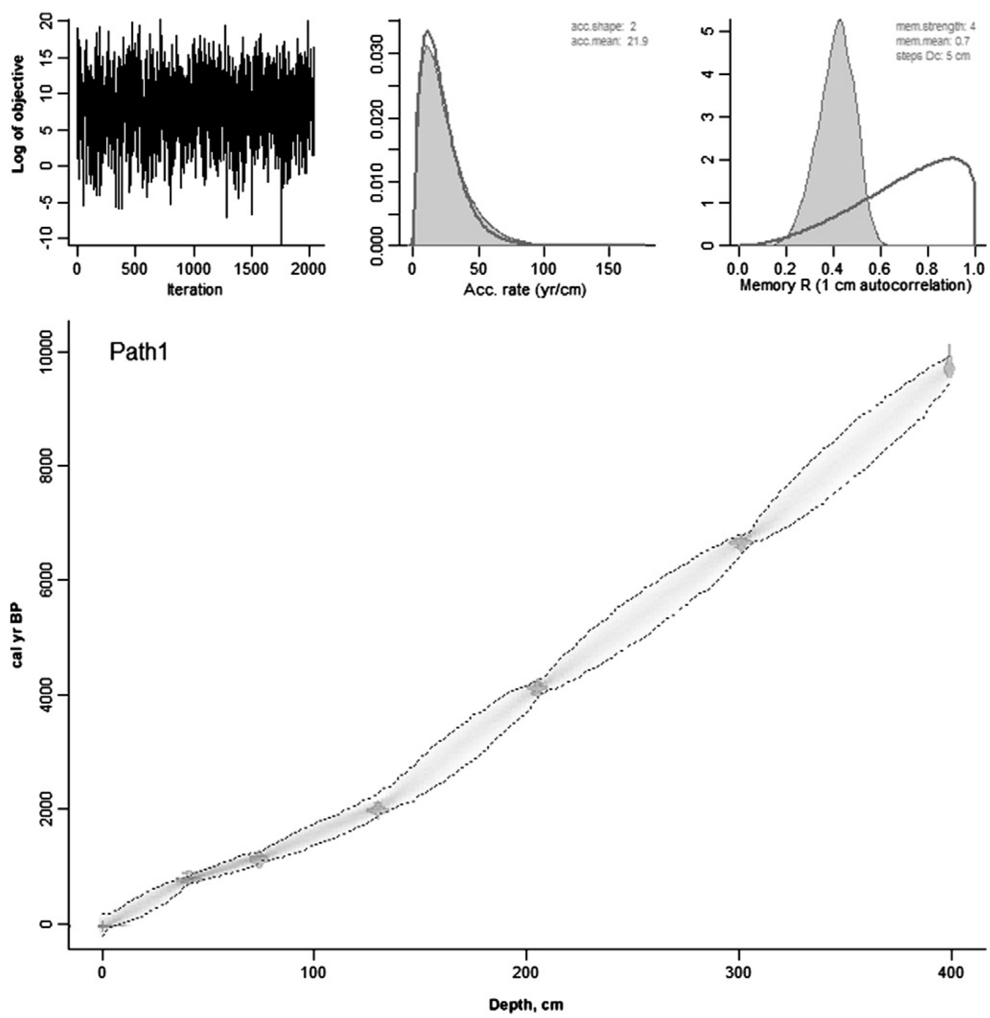


**Figure 3.** The estimated chronology for the Path Lake sediment core using the R software package BACON. The points indicate calibrated $^{14}C$ dates.

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**Table 2**
Taxon loadings and the explained variance (eigenvalues) of a principal component analysis performed on the pollen percentages of a core from Path Lake.

| Taxon | Component 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| *Pinus haploxylon* | −1.56 | 0.97 | 0.45 | −1.06 |
| *Pinus diploxylon* | −0.55 | −0.70 | −0.62 | 2.20 |
| *Picea* (undiff.) | 1.00 | −0.61 | 2.13 | −0.03 |
| *Abies balsamea* | 1.26 | 0.45 | 1.49 | −0.05 |
| *Tsuga canadensis* | −0.83 | 1.22 | −0.79 | 1.73 |
| *Larix* | 1.21 | 0.79 | −1.08 | 0.58 |
| *Juniper* | 0.92 | 1.44 | −0.38 | −0.19 |
| *Acer* (undiff.) | 0.05 | 0.73 | 1.45 | 0.29 |
| *Betula* | −0.43 | −1.48 | −0.73 | −1.20 |
| *Fagus* | 1.09 | 1.46 | −0.61 | −0.36 |
| *Fraxinus* (undiff.) | 0.84 | 1.41 | −0.78 | −0.45 |
| *Populus* | 1.09 | −0.21 | −1.27 | 0.20 |
| *Quercus* | −0.62 | −0.25 | −1.11 | −1.39 |
| *Ulmus* | −0.22 | −0.44 | 0.37 | 1.96 |
| *Alnus* (undiff.) | 1.70 | −0.76 | −0.17 | 0.14 |
| *Ericaceae* | 1.24 | −0.94 | 0.12 | −0.04 |
| *Sphagnum* | 0.75 | −1.50 | −1.05 | −0.05 |
| Eigenvalues | 0.25 | 0.14 | 0.09 | 0.08 |

### *Micro-charcoal*

Charcoal accumulation rates (CAR) were relatively low in Zones P1 and P2 (Fig. 5). Charcoal fragments greater than 1750 μm$^2$ contributed to three peaks above background values across these two zones. Charcoal accumulation rates generally increased at the beginning of Zone P3 with more frequent peaks, though estimates of fire reoccurrence could not be determined due to non-continuous sampling depths. In Zone P4 there were two large periods of charcoal influx at 1700 and 1100 cal yr BP. Charcoal accumulation rates reached a maximum in Zone P5, and were mainly represented by a single large peak between 160 and 180 cal yr BP, which was over 13 times greater than the average CAR of the entire sequence.

### *Numerical analysis*

A principal component analysis (PCA) illustrates the relation among the pollen taxa ( Table 2; Kindt and Coe, 2005). The first four components of the ordination explained 56% of the variance (Component 1: 24.5%; 2: 13.8%; 3: 9.2%; 4: 8.0%). Major changes in the PCA components were used to delineate the zone boundaries of the pollen diagram (Walker and Wilson, 1978).

The first component of the PCA had negative scores in Zones P1 and P2, entered a period of transition in Zone P3, and generally remained positive with fluctuating scores from 1900 cal yr BP (Zone P4) until the present (Fig. 5). *P. haploxylon* was one of the few pollen types that was negatively correlated with this component, while *Abies*, *Larix* and non-arboreal pollen (*Alnus* and *Ericaceae*) were all very positively correlated (not shown).

The second component showed a similar, but reversed, trend to the first component. There was an overall decrease in scores, although the transition zone was more variable in terms of both positive and negative scores, and only reached a constant state of negative scores around 1200 cal yr BP. Many hardwood taxa, including *Juniper*, *Acer*, *Fagus*, and *Fraxinus*, were positively correlated with this component. The correlation between this component and *Sphagnum* was highly negative.

In Zones P1, P2, and P4 the scores for the third component were mostly small and negative, while Zones P3 and P5 consisted of positive scores. *Picea* and *Abies* were both positively correlated with component three, and hardwood taxa were negatively correlated. Component four had positive scores in Zone P1, negative scores in Zone P2, and fluctuated just above and below zero in the three most recent zones. It was highly correlated with *Pinus diploxylon*, *Tsuga* and *Ulmus*, and had a negative correlation with *Quercus*.

### *Climate reconstruction*

The reconstructed mean annual temperature of Path Lake averaged 4.3 °C for the past 9000 yr of the Holocene (Fig. 5). Annual temperature fluctuated within a range of 1 °C below this average, and up to 2 °C above average in Zones P1, P2, and P3. In Zone P4, mean annual temperature became more variable, exceeding a 2 °C range both above and below average. Around 250 cal yr BP (zone P5) there was a significant decrease in mean annual temperature to 1.5 °C, which was 2.8 °C below average.

The Path Lake record had an average total annual precipitation of 984 mm. In Zones P1 and P2 annual precipitation was below average. At the end of Zone P2, at 3400 cal yr BP, total annual precipitation began to increase. Between 3400 and 1600 cal yr BP was a period of variability where precipitation oscillated around the average, although the overall trend was still increasing. At 1400 cal yr BP, total annual precipitation reached its maximum, and gradually declined until present.

### *Human activity in the region*

Recent research has utilized the frequency of aggregated radiocarbon dates from regions as a proxy for human populations (e.g. Briggs et al., 2006; Munoz et al., 2010; Peros et al. 2010). The frequency of cultural radiocarbon dates (FCRD) found across the Maritimes and in Maine was relatively low in Zone P1 (Fig. 5). After 4800 cal yr BP, the FCRD increased mainly in Maritimes and Maine coastal sites, reaching a maximum at around 3600 cal yr BP. In Zone P3, the FCRD of coastal sites decreased until 2800 cal yr BP. At 2800 cal yr BP, while the FCRD of coastal sites was still low, there was an increase in dates from inland sites. The FCRD of coastal sites began to recover mid-way through Zone P3, and the first coastal archaeological sites in Nova Scotia appear in the FCRD record at this time. In Zone P3, there was a single radiocarbon date from Port Joli harbour at 3150 cal yr BP. Several dates were recovered from Port Joli Harbour archaeological sites (Fig. 6; Betts, 2011) beginning at 1600 cal yr BP (Zone P4). In this zone, the FCRD at all scales increased at roughly 1600 cal yr BP, decreased slightly at 1300 cal yr BP, and increased again at 900 cal yr BP. Finally, in Zone P5, the FCRD generally decreased, as artefacts from this time period can be dated using historical records of context.

## Discussion

The high-resolution pollen record for Path Lake shows the postglacial evolution of what is now classified as the Acadian–Boreal Coastal forest of southwestern Nova Scotia. Based on a principal component analysis of Holocene pollen assemblages, five pollen assemblage zones were delineated, but only three major zones could be readily distinguished in the paleoclimate reconstruction. Forests with a significant component of white pine, accompanied by hemlock, birch and oak trees characterized the early to mid-Holocene in Path Lake. Forest succession in response to changes in climate in the later Holocene favoured an increase of species found in more moist environments, as well as an increase in boreal species (spruce and fir).

The sediment sequence obtained from Path Lake had a basal date of 9650 ± 30 cal yr BP (Fig. 3); this overlaid 20 cm of sandy sediment. Other lake sediment sequences from Nova Scotia had basal dates ranging between 10,800 and 12,700 cal yr BP (Green, 1987; Mott and Stea, 1993). In many of these lakes, Mott and Stea (1993) found organic deposits related to the Wisconsinan late-glacial period, buried under a layer of minerogenic deposits. This inorganic layer was interpreted as a product of mass-wasting and solifluction associated with climatic cooling during the Younger Dryas around 11,700 cal yr BP (Mott and Stea, 1993; Walker et al., 2009). Sediment accumulation in Path Lake therefore began at a later date in comparison to the regional record. The main purpose of the study was to provide a paleo-environmental

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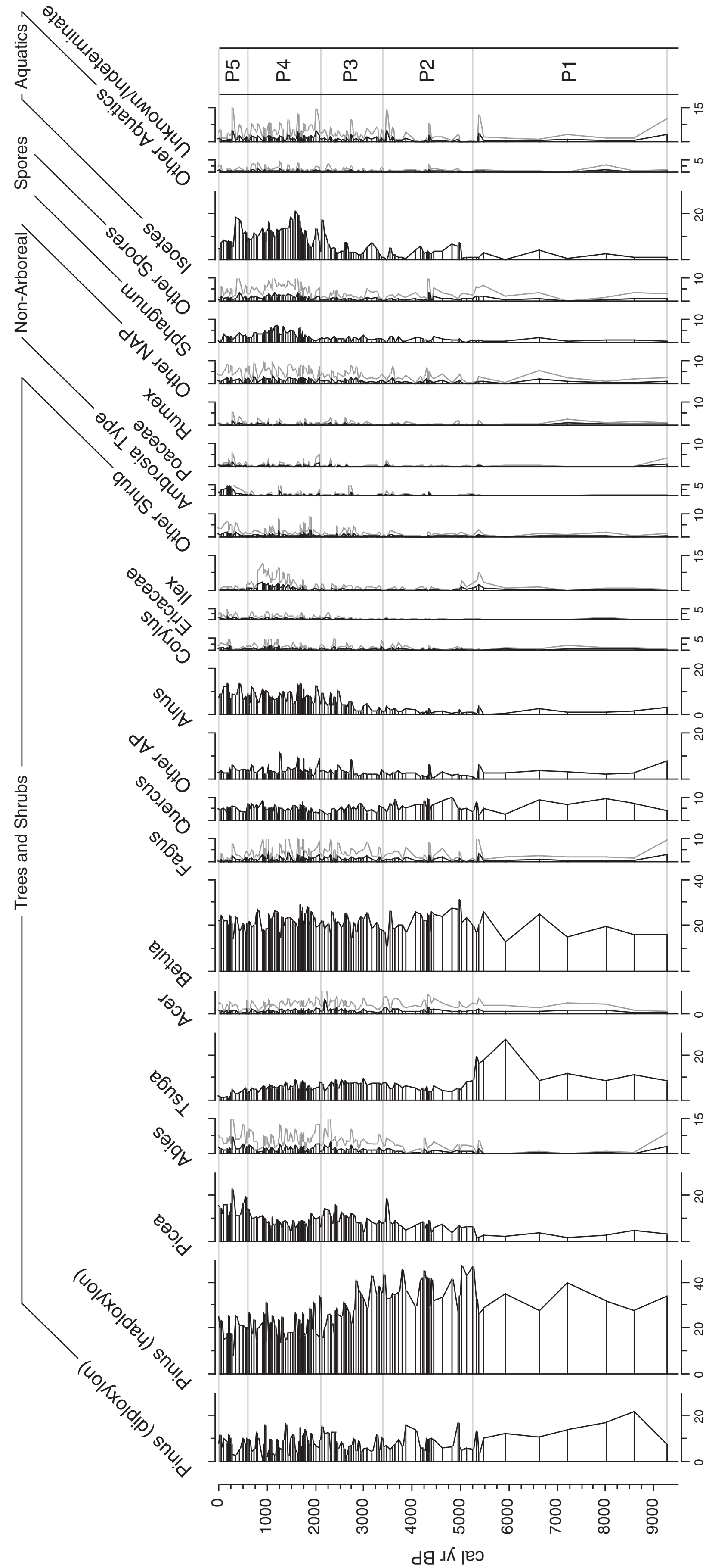


**Figure 4.** Pollen percentage diagram for Path Lake, Port Joli, Nova Scotia. Only major taxa are shown, and a 3× exaggeration is applied to taxa representing a smaller portion of the total pollen record.

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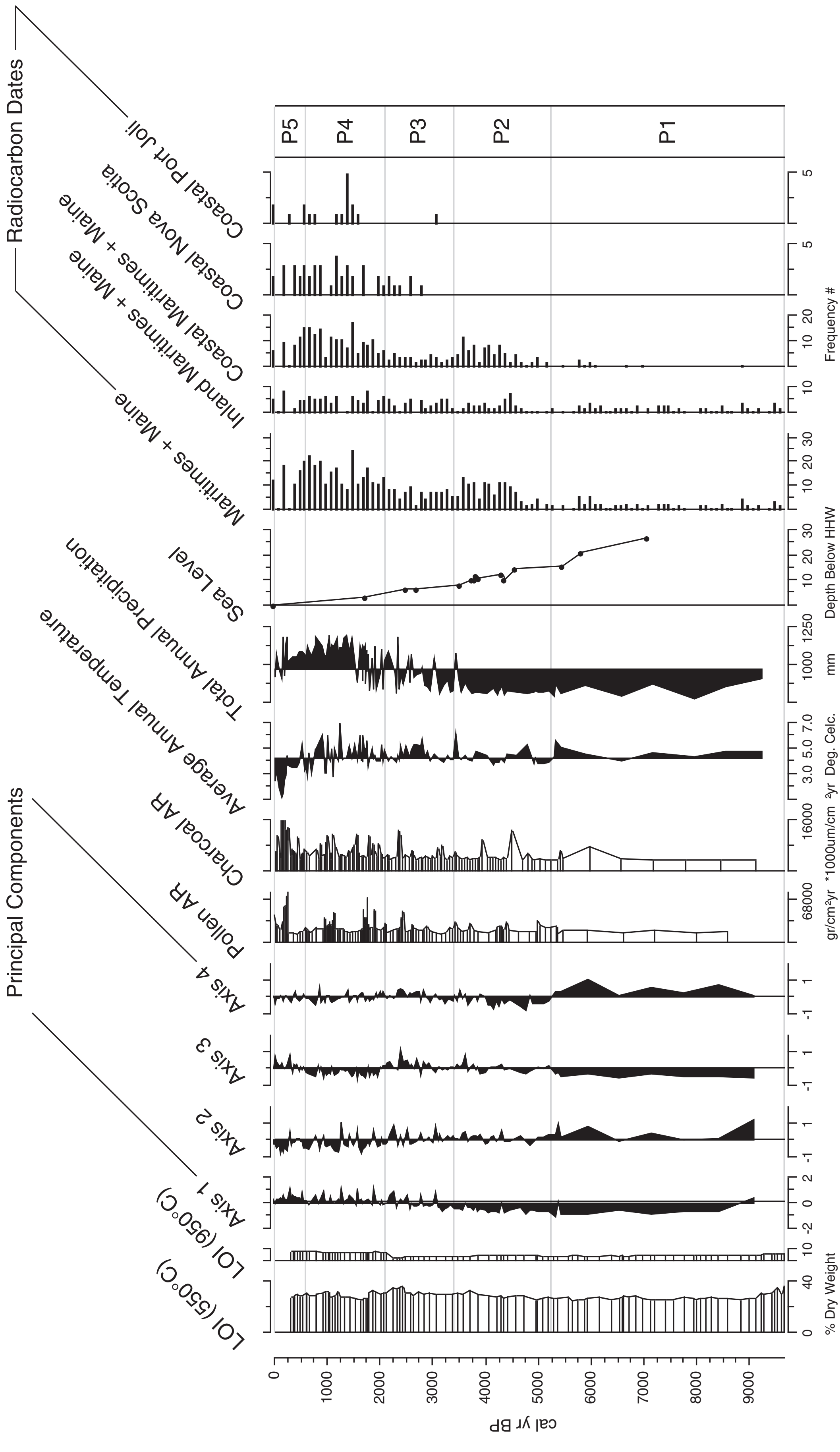


**Figure 5.** Paleo-environmental summary for the Port Joli region, Nova Scotia, including Path Lake organic/carbonate content, principal components, pollen and charcoal accumulation rates, paleoclimate reconstructions, sea level (Ogden, 1986; Scott et al., 1995a, 1995b; Edgecombe et al., 1999) and archaeological radiocarbon dates. Archaeological frequency distributions of $^{14}C$ dates are interpreted as representing cultural activity. The $^{14}C$ dates were obtained from the CARD database (http://www.canadianarchaeology.ca/; Morlan, 2005) and the Canadian Museum of Civilization (Port Joli).

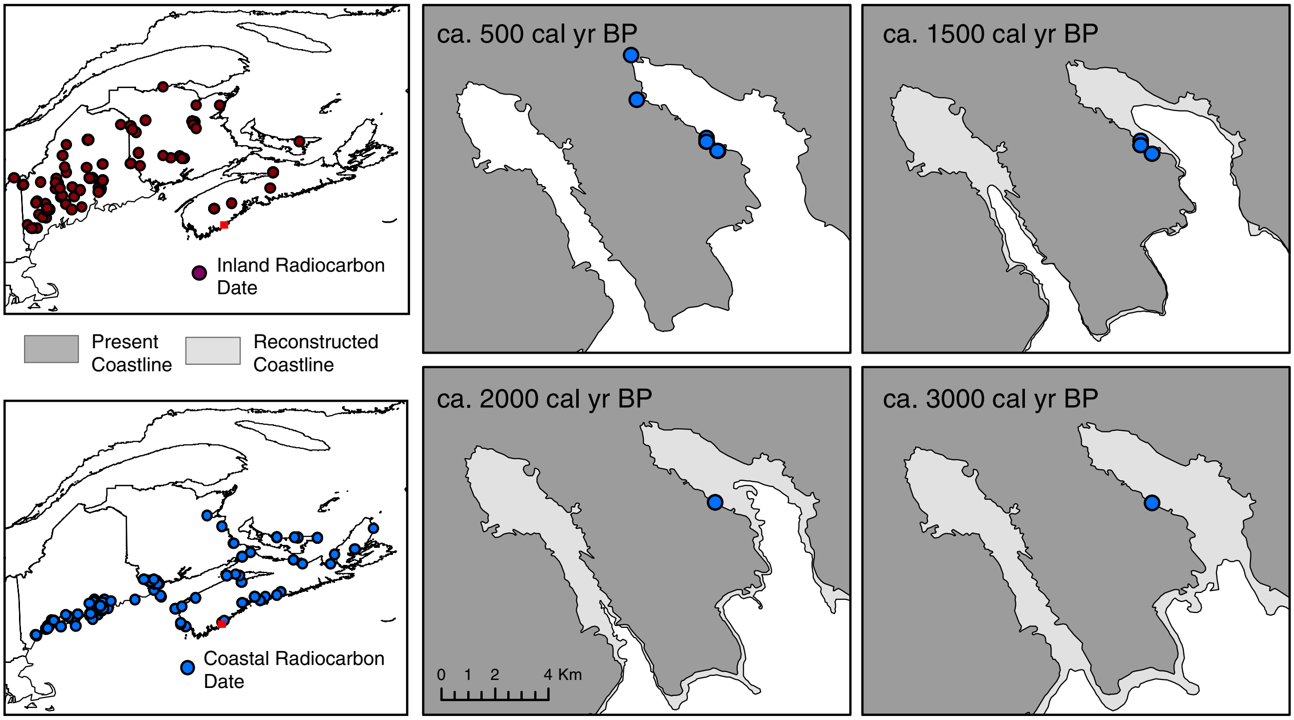


**Figure 6.** Coastline reconstruction of Port Joli Harbour, Nova Scotia, during the mid- to late- Holocene. Previous coastlines were constructed based on sea-level rise and bathymetry data. The plotted $^{14}C$ dates were obtained from the CARD database (http://www.canadianarchaeology.ca/; Morlan, 2005) and the Canadian Museum of Civilization (Port Joli).

record in the context of archaeological findings dating roughly to the past 3000 yr, thus the formation and early history of Path Lake and the surrounding region was not studied further.

*Holocene vegetation and climate variability*

In Nova Scotia, the Younger Dryas cooling event marked a shift in vegetation from predominately boreal/woodland forest (*Picea*, *Pinus*, *Larix*, *Abies* and *Betula*) to shrub-tundra and herbaceous tundra (Mott and Stea, 1993; Levesque et al., 1994). After the Younger Dryas, warming climatic conditions favoured the return of a mixed forest rather than the previously dominant spruce–fir forests (Green, 1981). The early pollen record for Path Lake (Zone P1), which dated to this latter period, had very low abundances of *Picea* and *Abies* (Fig. 4), in concordance with other results from the area. The post-glacial forest was instead comprised primarily of *Pinus* (including both *haploxylon* (white pine) and *diploxylon* (red pines)), with relatively high percentages of *Tsuga*, *Betula* and *Quercus* (Fig. 4). The combination of hardwood and mixed stands would have limited the frequency and intensity of fire disturbances (Green, 1987), and this is reflected in the relatively low charcoal influx rates prior to 5500 cal yr BP.

An increased abundance of *Tsuga* in Path Lake at 6500 cal yr BP, followed by its subsequent decline at 5500 cal yr BP, is also seen in records from other lakes in Nova Scotia (Mott, 1974; Ogden, 1986; Green, 1987; Mott and Stea, 1993; Mott et al., 2009; Lennox et al., 2010). Following the decline in *Tsuga* (and to a lesser extent, hardwood taxa), there was a gradual re-colonization of *Picea* and *Abies*. This increase in boreal species is interpreted as a gradual shift to moister conditions (Green, 1987). Hardwoods and mixed stands are less flammable than conifers (Green, 1987), and the accumulated charcoal in Zone P1 was at its minimum. Alternatively, low-frequency fire disturbances may have helped to promote the eventual succession of *P. haploxylon* stands to spruce–fir forests (Carleton et al., 1996).

The closed-canopy mixed forest persisted until 3400 cal yr BP in the area of Path Lake. After this time, reconstructed total annual precipitation shows a transition towards a wetter regime between 3400 and 1600 cal yr BP (Zone P3; Fig. 5), as do other multi-proxy records from the region (Railton, 1973; Lennox et al., 2010). Increased abundance of quillwort (*Isoetes*) after 3400 cal yr BP indicates rising water tables, as this species colonizes early in shallow water (Railton, 1973). Aquatic species were excluded from the pollen sum used in the paleoclimate reconstruction, meaning that the increase seen in the reconstructed total annual precipitation was not influenced by the corresponding rise in *Isoetes* at the same point in time. Increased shallow water environments favour the development of wetlands (Lennox et al., 2010), and an increase in pollen percentages of *Alnus* and *Sphagnum* at 3400 and 2100 cal yr BP, and a general decline in *P. haploxylon* and hardwood taxa reflect an ecological response to cooler and moister climatic conditions (Green, 1987).

At around 900 cal yr BP, the pollen assemblages showed an increase in boreal species (spruce and fir) that reached their maximum abundances by 260 cal yr BP (Fig. 4). This could potentially be a response to a climatic cooling associated with the Little Ice Age (600–100 cal yr BP; Wanner et al., 2008), where reconstructed annual temperatures were up to 2.8 °C cooler than the Holocene average. However, temperature does not seem to show any significant change associated with known climatic shifts during the Holocene in the region before this time. For this reason, it is more reasonable to believe that the pollen assemblages of Path Lake are reflective of an ecosystem driven by moisture rather than temperature. Increased soil moisture may be explained by several factors, such as an increase in precipitation, and/or a rise in the regional water table associated with an increasing sea level (Fig. 5). In coastal sites, a rise in sea level can induce an equivalent rise in the regional water table in order to maintain a constant rate of freshwater discharge to the ocean (Werner and Simmons, 2009).

*Human–ecosystem dynamics*

Excavated shell middens from archaeological sites in Port Joli show that the ancient Mi'kmaw inhabitants who occupied the Atlantic coast during 3400 cal yr BP to 350 cal yr BP had an important connection to the marine ecosystem (Betts, 2011; Betts et al., 2012). Across Maine and the Atlantic Provinces a significant portion of their diet consisted of fish and shellfish all through the year (Speiss and Lewis, 2001; Black, 2004), thus the proximity of dwellings to the Atlantic coastline would have been essential. The sea level curve shows that between 7000 and 3000 cal yr BP, relative sea level rose by 20 m in Nova Scotia (Fig. 5; Ogden, 1986; Scott et al., 1995a; Scott et al., 1995b; Edgecombe et al., 1999). Submergence of land by rising sea levels after deglaciation may therefore explain the absence of coastal archaeology sites in Nova Scotia during this time (Keenlyside, 1999). Based on the sea level curve and the bathymetry of Atlantic Nova Scotia, Fig. 6 shows that the formation of Port Joli Harbour occurred after 3000 cal yr BP, further indicating the possibility that potential archeological sites dating before this time are submerged due to marine inundation.

Studies often use temporal frequency of archeological radiocarbon dates to infer prehistoric settlement intensity or cultural activity, as larger populations presumably produce more sites and therefore more dated contexts (Rick, 1987; Munoz et al., 2010; Peros et al., 2010). The frequency of cultural $^{14}C$ dates may also be expected to change during periods of climatic discontinuity as humans respond to their environment (Wendland and Bryson, 1974; Munoz et al., 2010). At 4800 cal yr BP, settlement intensity in the Maritimes and in Maine increased, for reasons not well understood. The transition to moister conditions after 3400 cal yr BP, interpreted from the pollen record, was associated first with decreased settlement intensity in the coastal sites of the Maritimes and Maine, followed by a gradual increase as reconstructed precipitation reached consistently above Holocene average values (Fig. 5). The lower settlement intensity at the coast coincided with increasing inland settlement intensity, although the effect of coastal inundation is likely the mitigating factor in this trend.

Settlement intensity was generally highest during the Middle Maritime Woodland Period (1630–1380 cal yr BP) and the later Late Maritime Woodland period (850–660 cal yr BP), a pattern that corresponds well with data from Port Joli Harbour. These culturally significant periods coincide with the highest reconstructed total annual precipitation values for the Holocene in the Path Lake paleoclimate reconstruction. The increased precipitation at these times, or perhaps effective soil moisture in this particular coastal environment, may have led to changes in the ecosystem that would have favoured cultural development. The climatic influence on vegetation may therefore be indicative of optimal conditions for prehistoric settlement. At the beginning of the time of increased cultural activity in Port Joli Harbour (1600 cal yr BP), sea level was less than 3.5 m lower than the present day (Fig. 5). This shows a relative stabilization of coastal submergence in comparison to the earlier sea-level rise, thus archeological sites along what is now the present coastline may have been better preserved. Sea-level rise may also have resulted in the development of foreshore mudflats, as shown in Fig. 6, which were populated by *Mya arenaria* (soft shell clam), and are associated closely with the location of shell midden sites in Port Joli Harbour. The number and size of shell midden sites at 1450 and 700 cal yr BP in Port Joli correspond well with the periods of increased effective moisture recorded in the pollen diagram. *M. arenaria* prefer estuarine environments with relatively low salinity values (Newell and Hidu, 1986); increased effective moisture may be indicative of increased freshwater inputs into the intertidal ecosystem of Port Joli.

The shrub gallberry (*Ilex glabra*) is generally found along the Atlantic and Gulf coastal plains, in swamps, bogs and sandy pinelands (Burrows and Tyrl, 2013); Nova Scotia represents this taxon's northeastern range limit (USDA, 2013). Gallberry is a common understory shrub of frequently burned forests as it responds quickly and prolifically to fire disturbances (Miller and Miller, 2005). Increased *Ilex* abundance coincided with peaks in charcoal influx at 1700 and 1100 cal yr BP (Fig. 4). Gallberry was used by aboriginal inhabitants of North and Central America as an emetic and a mild ceremonial stimulant in herbal teas (Odenwald and Turner, 2006; Burrows and Tyrl, 2013). The maximum prehistoric settlement intensity in Nova Scotia and Port Joli occurred around 1600–600 cal yr BP, when *Ilex* pollen increased in abundance, perhaps suggesting that it may have been related to local cultural activities.

There is little evidence from an archeological perspective to suggest that aboriginal inhabitants of the northeast were deliberately clearing forests for agricultural use (Mosseler et al., 2003). A pollen study by Livingstone (1968) also showed no noticeable changes in forest composition associated with human activity before the European settlement. The European settlement in southwestern Nova Scotia is reported to be between 350 and 200 cal yr BP, although the region only saw a large growth in population after the American Revolution at 170 cal yr BP (Levac, 2001; Miller, 2004; Dunlop and Scott, 2006). The *Ambrosia* rise in Path Lake dates to 350 cal yr BP (1600 AD), although dating in the uppermost part of sediment sequences is difficult due to the lack of compaction of the sediment. A single peak in charcoal influx (over 13 times greater than the Holocene average) between 160 and 180 cal yr BP shows the extent of European disturbances and land clearance in the region at this time.

## Conclusion

The pollen assemblages of Path Lake reflect a coastal ecosystem where precipitation, or potentially effective soil moisture influenced by rising sea levels, was the major influence on the vegetation. Based on the reconstructed total annual precipitation, three distinguishable climate regimes were seen for the Atlantic coastal region during the Holocene. An extended dry period (9280–3400 cal yr BP) was characterized by a mixed forest canopy, primarily comprised of pine and hardwood stands. A transitional period of increasing total annual precipitation or effective moisture (3400–1600 cal yr BP) was associated with increased wetland-type environments, which led to higher abundances of alder, *Sphagnum* and quillwort pollen percentages. A relatively wet period (1600 cal yr BP to present) characterized the late Holocene, where moister environmental conditions promoted the establishment of boreal species (spruce and fir).

The shifting environmental conditions correspond well with important changes in cultural activity during the Holocene at both regional and local scales. Ancient Mi'kmaw populations were likely susceptible to gradual climatic and ecological changes in their environment. Interpreting cultural activities is made difficult due to the potential loss of sites as sea level rose; however, it is reasonable to conclude that the initial establishment or relocation of archeological sites would have been dependent on the evolution of the physical environment over time. After 350 cal yr BP, humans had a significant impact that altered forests in coastal Nova Scotia from their 'presettlement' state.

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