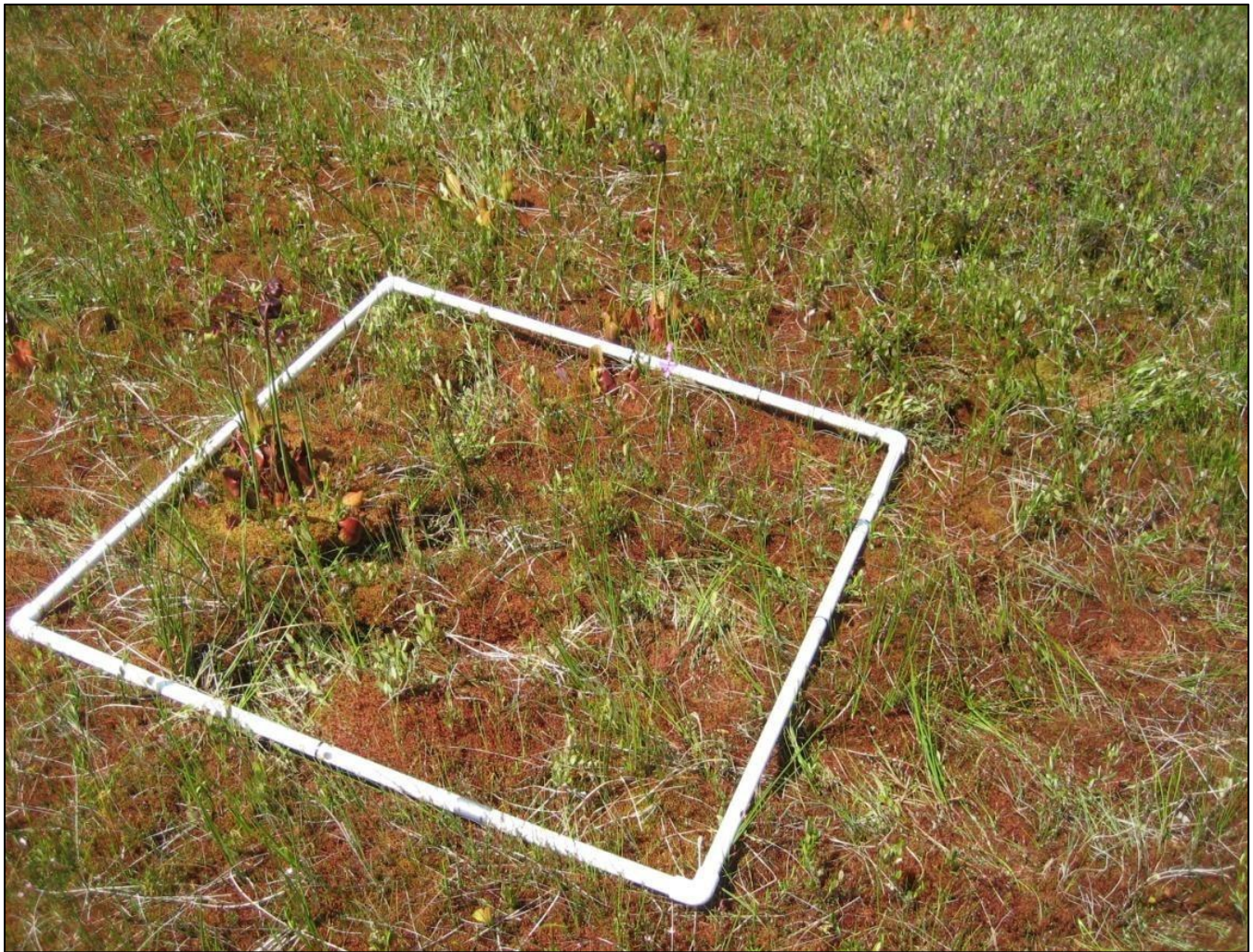




Assessment of Decadal Vegetation Changes in Select Wetlands at Apostle Islands National Lakeshore

Natural Resource Report NPS/APIS/NRR—2019/1954



ON THE COVER

Sphagnum “lawn” on Michigan Island coastal peatland, July 2010. Photograph © James E. Meeker

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Natural Resource Report NPS/APIS/NRR—2019/1954

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Abstract

This report describes the vegetation changes observed at select wetlands within Apostle Island National Lakeshore from the period 1998–2002 to 2010. Sampling in 2010 focused on vegetation changes in both coastal wetlands and island interior marshes and bogs in light of lake level changes (a potential climate related impact), as well as invasion by aggressive plant species. Sites included an interior open peatland on Stockton Island; additional interior peatlands on Devils and Sand Islands; the lagoons of Stockton, Outer, Michigan Islands; the Sand River estuary on the mainland; and seven wetlands on Long Island. Permanently marked transects using 1 m × 1 m quadrats were established in 1998–2002 that summarized the different cover-types, but through re-sampling in 2010 were used to monitor changes.

Of particular interest in this study was to demonstrate whether vegetation in these wetlands tracked changes in water levels by behaving in the manner suggested by the “pulse stable” concept. Pulse stability would be supported if vegetation changes were cyclic, that is constantly changing in species abundances in the short-term, but over longer time scales remaining stable as specific wetland types. Alternatively, wetlands could be undergoing the beginnings of directional change to generally different wetland types.

The results reported here demonstrate that there have been increases in woody and semi-woody plant taxa along with concomitant decreases in more obligate wetland taxa, as Lake Superior levels have dropped over the last 15 years. Over the 8- to 11-year sampling period 21 of the 24 woody taxa increased in abundance, while all of the 13 “aquatic” taxa lost ground. These were predictable results, as the two extreme ends of the water level gradient (the aquatics on the wet end) and the woody plants on the dry end should respond quickly to decadal changes in water levels. In addition, the non-*Sphagnum* wetlands (sedge meadows, shore fens) have changed more over the sampling period in comparison to the *Sphagnum* dominated (bog) sites.

However, the results of this monitoring—following only one half of a full high-water to low-water back to high-water cycle—falls short in demonstrating that the natural cycle of wetland vegetation change (pulse stability) is still operating. Lake Superior has not experienced a return of high water to re-sample, during which we might expect an increase in abundance of the aquatic taxa (that is, a return to the original abundance). It will take another high-water period to determine if we are experiencing a period of directional change or cyclic change, and the water levels on the big lake just have not cooperated. If climate is indeed changing, resulting in a long-term period of lower water levels, we may be observing the beginnings of directional change.

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Introduction

This report assesses approximately a decade of vegetation change at select wetlands within Apostle Island National Lakeshore (APIS). The project goals and objectives in the first phase of this study (1998–2002) were to describe wetlands through mapping cover-types, describe species composition, and establish long-term vegetation monitoring plots in the same wetlands. Specifically, during this first sampling phase we:

1. Mapped vegetation types in the wetlands using aerial photography and then conducted site visits for ground truthing,
2. Characterized species composition in cover-types, and
3. Established, sampled, and geo-referenced long-term monitoring transects.

The results of these earlier studies (Meeker 2000, 2002) are available as PDF files from the APIS Planning and Resource Management Division.

During the second phase of the study (in 2010), we sampled in the same locations as in 1998–2002. During this second sampling phase, we focused on vegetation changes in both coastal wetlands and island interior marshes and bogs in light of lake level changes (a potential climate related impact), as well as invasion by aggressive plant species. This second phase of the study took place in July and August 2010, and the results were compared to those from the first stage of sampling in order to measure vegetative change over time.

Methods

Islands Studied

The wetland transects re-sampled in 2010 were first characterized during the period 1998–2002, (Meeker 2000, 2002) and are listed in Table 1. They include an interior open peatland on Stockton Island (often referred to as Brander Bog); additional interior peatlands on Devils and Sand Islands; the lagoons of Stockton, Outer, and Michigan Islands; and the Sand River estuary on the mainland. In addition, seven wetlands on Long Island were also re-sampled.

Mapping Wetland Cover-Types

We have previously characterized these wetlands' dominant species and cover-types through photo-interpretation and field reconnaissance conducted July through August 1998–2002 (Meeker 2000, 2002). Each wetland was visited at least once during this time period. Mapping of vegetation types for each of the above mentioned wetlands was accomplished by 1) delineating type boundaries on both false color (1988) and monochromatic images (1993–1997), then digitizing these maps in ARCVIEW onto digital ortho-photo quadrangle base maps derived from 1992 aerial photography, and 2) by using a Trimble Pro XL global positioning unit to delineate boundaries in the field and import into ARCVIEW. Layout and printing was also done in ARCVIEW.

Permanent Transects

Permanent transects were established (1998–2002) to summarize the different cover-types, but they were primarily designed to monitor areas (2010) that could describe the successional pathways within each wetland.

Quadrat sampling

Percent-cover for all vascular plant species and *Sphagnum* moss was assessed in 1 m × 1 m quadrats placed along 26 re-locatable transects, first in 1998–2002 and again in 2010 (Table 1). Transects varied in length from 5 to 100 meters depending on the variability of the site (short transects were used where variation was low and/or patch size was small). On several of the longer transects on Long Island, quadrats were selected in segments along transects. For example, along the 100-meter-long Transect 1 of Long Island, a quadrat was randomly selected in each of the 20, 5-meter-long segments, and on Transects 6–8, a quadrat was randomly selected in each of the 20, 3-meter segments of the 60-meter-long transects. Every meter of each transect was sampled in all other sites.

At each quadrat, we listed all taxa and estimated their percent-cover. Taxa covering less than 1% of a quadrat were systematically recorded as 0.1%. Since plants may occupy space at different strata, the sum of individual cover estimates could exceed 100%. Nomenclature for all plant taxa is according to Gleason and Cronquist (1991). Starting and ending points for each transect were marked in the field using white PVC stakes and were geo-referenced using a Trimble Pro XL global positioning unit (Table 1). All sampling took place on the left side of the reference line as one looks from the starting point to the finishing point.

Table 1. Length, years sampled, and UTM coordinates of wetland transects at Apostle Islands National Lakeshore, 2010. Beginning and end-point coordinates are listed using UTM Zone 15, NAD 27 Datum. NS = not sampled.

Location	Transect #	Transect Length (m)	# Quadrats Sampled	Years		Beginning Point		End Point	
				Time 1	Time 2	X	Y	X	Y
Devils Island	1	5	5	1998	2010	672492	5215507	672487	5215510
	2	5	5	1998	2010	672509	5215537	672503	5215535
	3	5	5	1998	2010	672489	5215507	672482	5215516
Michigan Island	1	10	10	1998	2010	689649	5194363	689652	5194374
	2	15	15	1998	2010	689710	5194264	689695	5194261
	3	10	10	1998	2010	689726	5194200	689724	5194210
Outer Island inland bog	1	10	10	1999	NS	695226	5211062	695221	5211070
Outer Island lagoon	1	50	50	1998	2010	693247	5208836	693256	5208842
	2	10	10	1998	2010	693104	5208763	693072	5208723
Sand Island North bog	1	10	10	2001	2010	656912	5205477	656922	5205480
Sand River Lagoon	1	10	10	2001	2010	657214	5199550	657214	5199517
	2	10	10	2001	2010	657214	5199550	657225	5199548
	3	25	25	2001	2010	657112	5199743	657134	5199729
Stockton Island Interior Bog	1	20	10	2001	2010	686985	5202774	686984	5202795
	2	20	10	2001	2010	686985	5202774	686999	5202761
	3	20	10	2001	2010	687418	5202596	687435	5202580
	4	20	10	2001	2010	687418	5202596	687437	5202604
Stockton Island Lagoon	1	10	10	1999	2010	686709	5198490	686707	5198500
	2	10	10	1999	2010	686709	5198490	686719	5198494

Table 1 (continued). Length, years sampled, and UTM coordinates of wetland transects at Apostle Islands National Lakeshore, 2010. Beginning and end-point coordinates are listed using UTM Zone 15, NAD 27 Datum. NS = not sampled.

Location	Transect #	Transect Length (m)	# Quadrats Sampled	Years		Beginning Point		End Point	
				<i>Time 1</i>	<i>Time 2</i>	<i>X</i>	<i>Y</i>	<i>X</i>	<i>Y</i>
Stockton Island Lagoon (continued)	3	10	10	1999	2010	686719	5198494	686728	5198490
Long Island	1	100	20	2002	2010	667788	5177357	667695	5177317
	2	15	15	2002	2010	669412	5176873	669425	5176871
	3	15	15	2002	2010	669412	5176873	669409	5176860
	4	15	15	2002	2010	669735	5176692	669724	5176680
	5	15	15	NS	2010	669718	5176688	669730	5176678
	6	60	20	2002	2010	670479	5175638	670518	5175593
	7	60	20	2002	2010	670621	5175404	670589	5175441
	8	60	20	2002	2010	670914	5174962	670953	5174918

Belt transects for conifer bog assessment

Sampling of species and size for all living and dead trees in forested bogs was conducted in 2001 along two 4 m × 300 m belt transects, one in each of the Sand Island bogs (Sand Island North and Sand Island South). Trees were placed in 5-cm (2-inch) size categories by diameter at breast height (DBH; 1.37 m/4.5 ft. above the ground). The species were able to be determined for most of the dead trees, but some were placed in an unknown category. Belts were delineated with tapes ahead of sampling for each of six consecutive 50-meter segments that made up the 300 m length.

These same belt transects were re-sampled in 2010. Again, for each of these two wetlands (north and south), six consecutive 50-meter segments comprised the 300-meter-long transect. Each 4 × 300 m transect's starting point was marked in the field using PVC stakes in the center of the belt, and was geo-referenced using a Trimble Pro XL global positioning unit. Both transects' (north and south) starting and ending coordinates are listed in Appendix 1.

Analyses of increment cores

In 2010, in addition to re-sampling the 4 m × 300 m tree density transects at Sand Island North, we sampled select trees to measure growth rates and observe trends in forested bogs. Thirty trees—equally distributed between black spruce (*Picea mariana*) and tamarack (*Larix laricina*)—were cored to assess growth patterns over time, resulting in 24 trees that provided cores sound enough to analyze. We endeavored to core trees equally representing the 2-4, 4-6, and the 6-8 inch DBH size categories. Cores were extracted by an increment borer and analyzed under a 25-power dissecting microscope.

Lines of advance and select stem densities measures

In addition to the above mentioned means of monitoring vegetative change over time, we in some cases sampled the lines of advance for beaked sedge (the combined *Carex rostrata* and *C. utriculata*), common reed grass (*Phragmites australis*), and cattail (*Typha* spp.). These lines of advance (LOAs) marked the boundaries between where these potentially dominant taxa occurred and where they had not yet moved into at the time of sampling. LOAs were first sampled during the 1998–2002 period at different years across the islands.

LOAs were delineated using the Trimble Pro XL global positioning unit. Lines of advance indicate where the extreme edges of vegetative clones existed at the time of sampling; that is, the lines of advance delineated the farthest advance made by the species in question into the dominant community type. We only established these lines of advance in cases where the boundaries or leading edges of the species in question were unambiguous, that is dense and not represented by single or a few scattered stems per m². Starting and ending coordinates for lines of advance are listed in Appendix 1.

We also counted stem densities (in addition to percent-cover) in a number of the quadrat-based sampling transects where these aggressive taxa occurred as another measure of change in abundance over time. Sites where lines of advance and/or stem densities were assessed included the interior bog on Stockton Island (Brander Bog), the mouth of Sand River, Outer Island, Michigan Island Lagoon, and Long Island.

Metric Development

Analyses of change using relative importance value from quadrat data

Twenty-six transects were first sampled in 1998–2002 and re-sampled in 2010. By design, each transect was treated as an experimental unit, with the quadrats as subsamples of the transects. Even though we were able to re-locate most of the PVC pipe and re-establish the transect lines with a meter tape, we believed that it was more appropriate to compare transects over time rather than individual quadrats.

Three main metrics were calculated from the quadrat data for the transects; these include **percent-cover**, **frequency of occurrence**, and **relative importance value (RIV)** for all taxa in each transect. **Percent-cover** was the total cover over all the quadrats for each taxon at each transect. Each taxon also had a **frequency of occurrence**. For example, a particular taxon had a frequency of 5 if it was found in 5 of the 10 quadrats along a transect at a particular site. (It is also reported as a percent, as $5/10 = 50\%$). Two other metrics were calculated as intermediate steps in calculating **relative importance value (RIV)**, a composite of cover and frequency): *relative cover* and *relative frequency*. Relative cover was calculated for each taxon as its percent-cover divided by (or relative to) the sum of all other taxa found *in that transect*. Relative frequency was calculated for each taxon as its frequency of occurrence relative to the total frequency of all taxa *at a given transect*. Since each of these metrics is a measure of an individual taxon's abundance relative to all other taxa, the sum of all taxa's relative cover for each transect was 100% and the sum of all taxa's relative frequency for each transect was 100%. Finally, to calculate RIV, each taxon's relative cover and relative frequency was averaged, and it too resulted in a total of 100% for all taxa at each transect. Since we sampled at 26 transects at each of two times, the total RIV for all taxa at each time was 2600% ($100\% \times 26$ transects).

In the analyses of change described below, we used relative importance value as the metric to note changes over time because it encompasses both forms of abundance that a particular plant may have. For example, a species may be distributed as a re-occurring scattering of individuals, that is, very low cover per quadrat but very frequently found, or conversely, much clumped (high cover) but found very infrequently. Since relative importance value is an average of relative frequency and relative cover, it reflects both of these forms of abundance. Additionally, the relativization of these metrics allows one to compare species abundance between a transect of 10 quadrats and a transect of 20 quadrats, whereas if one used raw cover or raw frequency it would likely result in the longer transect (with more quadrats) erroneously showing a greater abundance for a particular species.

Comparing plant community composition among transects and over time through multivariate ordination techniques

To summarize the floristic differences among the 26 transects and to investigate their changes over time, we created taxa $\times$ transect matrices and calculated non-metric multidimensional scaling (NMS) ordinations. These calculations were performed in PCORD (McCune and Mefford 1999) using relative importance value (RIV) on all taxa occurring in three or more transects across the sites. The rare taxa (i.e., seen in less than three transects across all 26 sites) were eliminated for the NMS

calculations as a means of reducing noise in the dataset and increasing the chance of detecting relationships between community composition and environmental factors (McCune and Grace 2002).

We utilized two different ordinations for these analyses. First, a non-metric multidimensional scaling (NMS) ordination was conducted using relative importance values for all twenty-six transects over each of two time periods. Hence fifty-two transects/time are plotted (26 transects $\times$ 2 times). In addition, environmental matrix factors were plotted as vectors in this ordination showing these factors' correlation to the ordination axes scores with $r^2 > 0.250$. (See PCORD, McCune and Mefford 1999, for a description of environmental matrices). Second, all transects with *Sphagnum* as an important component were separated and a second NMS ordination was calculated for just those 34 transects (17 transects $\times$ 2 times) where *Sphagnum* was observed.

Results

Wetland Descriptions and Transect Summaries

Prior wetland descriptions (Meeker 2000, 2002) for all the wetlands first sampled in 1998–2002 and re-sampled in 2010 are available as PDF files from the APIS Planning and Resource Management Division. In addition, Judziewicz and Koch (1993) provide an excellent summary of island wetlands.

First Multivariate Analysis (NMS Ordination On All 26 Transects Over Two Times)

The first NMS ordination (Figure 1) indicates a clear differentiation between those transects with and without *Sphagnum* moss, as the *Sphagnum* “bog” dominated sites plotted closely together (i.e., had more similar vegetation) and lower on axis 1 and low on axis 2, while the non-*Sphagnum* habitats—generally referred to as sedge meadows or shore fens—plotted high on both axes. The *Sphagnum* sites included Devils Island (3 transects × 2 times), Long Island bogs (3 transects × 2 times), Michigan Island (3 transects × 2 times), Sand Island (1 transect × 2 times), Stockton Island bog (4 transects × 2 times), and Stockton Island lagoon (3 transects × 2 times). The non-*Sphagnum* sites included the Long Island sedge meadows (4 transects × 2 times), Outer Island (2 transects × 2 times), and Sand River (3 transects × 2 times).

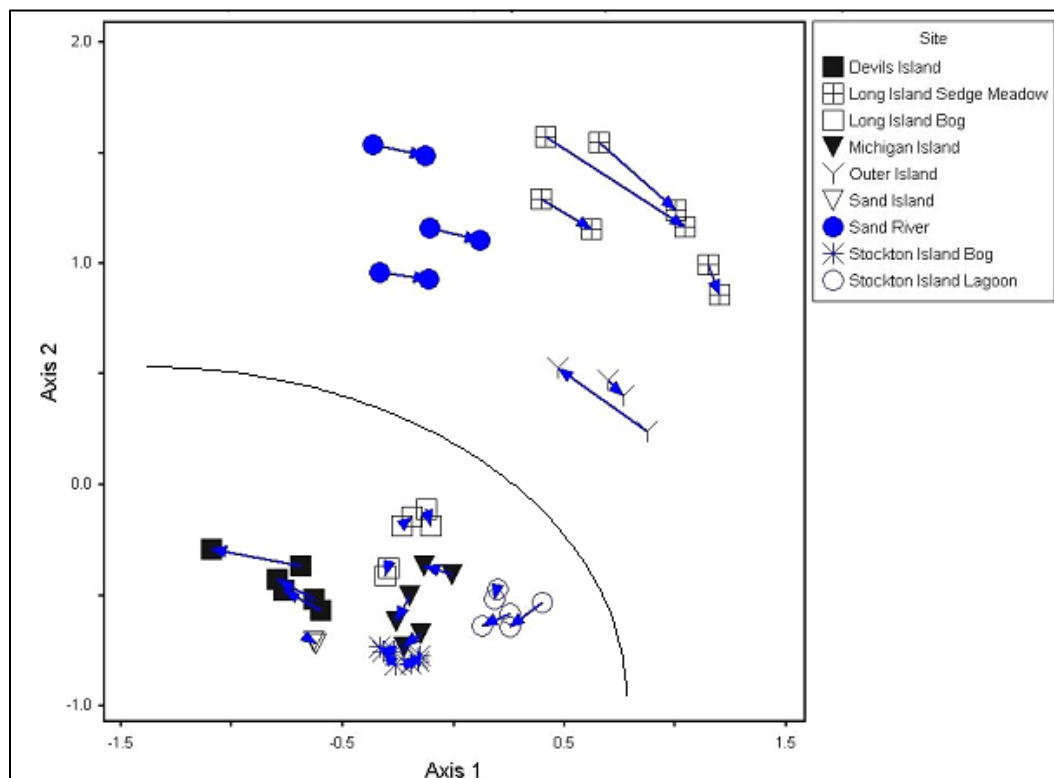


Figure 1. Non-metric multidimensional scaling (NMS) ordination of all 26 transects (each at two times) multiplied by 84 taxa, using relative importance value. Arc shows separation of transects with *Sphagnum* spp. from those without. Arrows connect transect pairs over time and indicate changes in plant community composition.

Additionally, “successional” vectors were plotted to suggest how individual transects may have changed over time (these are shown as arrows plotted for each transect pair connecting Time 1 to Time 2 for a given transect). With the possible exception of one Devils Island transect, it appears that there was more change in vegetative composition (i.e., the vector arrows were longer) from Time 1 to Time 2 at the non-*Sphagnum* sites when compared to the *Sphagnum* dominated sites. We tested this observation by comparing the length of the arrows between the nine non-*Sphagnum* pairs and the 17 *Sphagnum* pairs. (Vector length was calculated using the NMS x, y coordinates for each transect pair over time where:

$$\text{Hypotenuse, or Vector Length} = \sqrt{([x_1 - x_2]^2 + [y_1 - y_2]^2)}$$

A two-sample t-test supported this observation and the mean successional vector length for the nine *Sphagnum* sites was significantly greater when compared to the *Sphagnum* sites (0.3223 vs. 0.0964, at $p = 0.011$).

Taxonomic Differences Between *Sphagnum* and Non-*Sphagnum* Transects

Of the 26 total transects 17 represented “bog” habitat and were dominated by the *Sphagnum* mosses, which had an average relative importance value of 31.4% (Table 2), whereas nine represented sedge meadow habitat. Sixty-one taxa were recorded in the bog transects, while there were 98 taxa recorded in the nine sedge meadow habitat transects. In general, the *Sphagnum* habitats were dominated by fewer taxa, as only three taxa comprised 51.8% of all RIV, while it took eight taxa to comprise 51.8% of the importance for the non-*Sphagnum* habitats. The bog habitats (Table 2) were dominated by the *Sphagnum* mosses and short stature ericads including leatherleaf (*Chamaedaphne calyculata*, 12.0%), cranberry (*Vaccinium oxycoccos* and *Vaccinium macrocarpon*, 8.5%), Labrador tea (*Ledum groenlandicum*, 3.9%), and bog laurel (*Kalmia polifolia*, 2.8%). The only herbaceous taxon approaching 5% RIV was three-leaf Solomon’s seal (*Smilicina trifolia*, 4.6%), while other less abundant herbaceous taxa included pitcher plant (*Sarracenia purpurea*, 2.8%), sundews (*Drosera rotundifolia* and *D. intermedia*, 1.9%), and bog bean (*Menyanthes trifoliata*, 1.4%).

The non-*Sphagnum* sedge-meadow habitat transects (Table 2) were dominated by sweet gale (*Myrica gale*, 16.3%), woolly sedge (*Carex lasiocarpa*, 9.9%), blue-joint grass (*Calamagrostis canadensis*, 8.2%), lake sedge (*Carex lacustris*, 3.9%), swamp candles (*Lysimachia* spp., 3.6%), leatherleaf (3.4%), and willows (*Salix* spp., 3.3%).

Table 2. Dominant taxa (top 20) for 17 transects with *Sphagnum* compared to the nine transects without *Sphagnum*, each sampled twice, at Apostle Islands National Lakeshore. Taxa are ordered by average relative importance value (RIV) per transect. Transect frequency is also listed, where the maximum number for the *Sphagnum* transects = 34 (17 transects × 2 times), and 18 for the non-*Sphagnum* transects (9 transects × 2 times). Cumulative RIV is also listed.

With Sphagnum/ Without Sphagnum	Taxa	Avg. RIV	Freq.	Cum. RIV
With Sphagnum	<i>Sphagnum</i> spp.	31.35	34	31.35
	<i>Chamaedaphne calyculata</i>	12.01	34	43.35
	<i>Vaccinium</i> spp. (cranberry)	8.48	32	51.84
	<i>Smilacina trifolia</i>	4.56	18	56.40
	<i>Ledum groenlandicum</i>	3.94	12	60.33
	<i>Kalmia polifolia</i>	2.80	20	63.13
	<i>Sarracenia purpurea</i>	2.77	22	65.91
	<i>Cladium mariscoides</i>	2.33	9	68.24
	<i>Rhynchospora alba</i>	2.28	15	70.52
	<i>Myrica gale</i>	1.99	10	72.51
	<i>Drosera</i> spp.	1.92	19	74.43
	<i>Picea mariana</i>	1.71	10	76.14
	<i>Scheuchzeria palustris</i>	1.58	12	77.72
	<i>Carex utriculata</i>	1.44	7	79.16
	<i>Menyanthes trifoliata</i>	1.43	10	80.58
	<i>Carex exilis</i>	1.34	6	81.92
	<i>Carex trisperma</i>	1.33	8	83.25
	<i>Larix laricina</i>	1.09	13	84.34
	<i>Rhynchospora fusca</i>	1.06	7	85.40
	<i>Carex paupercula</i>	1.05	5	86.46
Without Sphagnum	<i>Myrica gale</i>	16.34	17	16.34
	<i>Carex lasiocarpa</i>	9.91	15	26.24
	<i>Calamagrostis Canadensis</i>	8.15	10	34.40
	<i>Carex lacustris</i>	3.93	10	38.33
	<i>Lysimachia</i> spp.	3.63	15	41.96
	<i>Chamaedaphne calyculata</i>	3.38	8	45.34

Table 2 (continued). Dominant taxa (top 20) for 17 transects with *Sphagnum* compared to the nine transects without *Sphagnum*, each sampled twice, at Apostle Islands National Lakeshore. Taxa are ordered by average relative importance value (RIV) per transect. Transect frequency is also listed, where the maximum number for the *Sphagnum* transects = 34 (17 transects × 2 times), and 18 for the non-*Sphagnum* transects (9 transects × 2 times). Cumulative RIV is also listed.

With <i>Sphagnum</i> / Without <i>Sphagnum</i>	Taxa	Avg. RIV	Freq.	Cum. RIV
Without <i>Sphagnum</i> (continued)	<i>Salix</i> spp.	3.34	10	48.68
	<i>Rubus</i> spp.	3.14	7	51.82
	<i>Equisetum fluviatile</i>	3.06	8	54.88
	<i>Potentilla palustris</i>	3.02	10	57.89
	<i>Ilex verticillata</i>	2.56	2	60.45
	<i>Campanula aparinoides</i>	2.55	10	63.00
	<i>Carex stricta</i>	2.35	9	65.35
	<i>Vaccinium</i> spp. (cranberry)	2.04	3	67.40
	<i>Carex</i> spp. (ovales grp)	1.79	6	69.19
	<i>Cladium mariscoides</i>	1.78	3	70.96
	<i>Calla palustris</i>	1.62	6	72.58
	<i>Iris versicolor</i>	1.40	9	73.98
	<i>Scirpus cyperinus</i>	1.36	6	75.34
	<i>Utricularia</i> spp.	1.29	4	76.62

Taxonomic Differences Among the Non-*Sphagnum* Sites

Although the nine non-*Sphagnum* transects plotted apart from the *Sphagnum* transects in Figure 1, they also appeared to separate somewhat from each other, with the Sand River transects lower on axis 1 and Outer Island lower on axis 2. Tables 3 and 4 indicate that all three sites (Long Island sedge meadows, Outer Island, and the Sand River estuary) shared an abundance of woolly sedge and sweet gale, but differed somewhat in vegetative composition overall. For example, Sand River (Table 3) had significant amounts of lake sedge, water horsetail (*Equisetum fluviatile*), and marsh five-finger (*Potentilla palustris*), unlike the other two sites. Long Island (Table 4) was dominated by blue-joint grass, found only sparingly at Sand River and absent at Outer Island, and Outer Island (Table 4) had an abundance of winterberry holly (*Ilex verticillata*) and common reed grass, not noted in the transects of the other two sites.

Table 3. Average Relative Importance Value (RIV) for the 15 most abundant taxa occurring in Sand River sedge meadow transects (three transects each sampled twice), along with the increasing cumulative RIV as taxa are added.

Location	Taxa	Average RIV	Cumulative Average RIV
Sand River Sedge Meadow (32 Taxa Total)	<i>Carex lasiocarpa</i>	13.90	13.90
	<i>Myrica gale</i>	10.66	24.56
	<i>Carex lacustris</i>	10.13	34.68
	<i>Equisetum fluviatile</i>	9.04	43.73
	<i>Potentilla palustris</i>	7.62	51.34
	<i>Lysimachia</i> spp.	6.51	57.85
	<i>Salix</i> spp.	5.95	63.80
	<i>Campanula aparinoides</i>	5.83	69.63
	<i>Chamaedaphne calyculata</i>	5.11	74.74
	<i>Calla palustris</i>	4.85	79.59
	<i>Iris versicolor</i>	3.50	83.09
	<i>Sagittaria latifolia</i>	3.41	86.50
	<i>Acorus calamus</i>	2.17	88.67
	<i>Typha latifolia</i>	2.08	90.74
	<i>Cicuta bulbifera</i>	1.99	92.73

Table 4. Average Relative Importance Value (RIV) for the 15 most abundant taxa occurring in Long Island Sedge Meadow transects (four transects each sampled twice) and Outer Island transects (two transects each sampled twice), along with the increasing cumulative RIV as taxa are added.

Location	Taxa	Average RIV	Cumulative Average RIV
Long Island Sedge Meadow (77 Taxa Total)	<i>Calamagrostis canadensis</i>	17.89	17.89
	<i>Myrica gale</i>	14.97	32.87
	<i>Carex lasiocarpa</i>	7.26	40.13
	<i>Rubus</i> spp.	5.49	45.62
	<i>Carex stricta</i>	4.42	50.04
	<i>Carex</i> spp. (ovales grp)	4.03	54.07
	<i>Lysimachia</i> spp.	3.24	57.30
	<i>Scirpus cyperinus</i>	3.06	60.36
	<i>Salix</i> spp.	3.05	63.41
	<i>Juncus arcticus</i>	2.86	66.27
	<i>Utricularia</i> spp.	2.67	68.95
	<i>Lythrum salicaria</i>	2.20	71.15
	<i>Carex utriculata</i>	2.13	73.28
	<i>Euthamia graminifolia</i>	1.86	75.15
	<i>Solidago</i> spp.	1.40	76.54
Outer Island (27 Taxa Total)	<i>Myrica gale</i>	27.59	27.59
	<i>Ilex verticillata</i>	11.51	39.10
	<i>Carex lasiocarpa</i>	9.22	48.31
	<i>Vaccinium</i> spp. (cranberry)	9.07	57.38
	<i>Cladium mariscoides</i>	7.82	65.20
	<i>Chamaedaphne calyculata</i>	7.54	72.74
	<i>Phragmites australis</i>	4.41	77.15
	<i>Carex rostrate</i>	4.27	81.42
	<i>Eleocharis smallii</i>	3.14	84.57
	<i>Rubus</i> spp.	3.14	87.70
	<i>Juncus Canadensis</i>	2.37	90.07
	<i>Dulichium arundinaceae</i>	2.30	92.37
	<i>Carex interior</i>	1.63	94.00

Table 4 (continued). Average Relative Importance Value (RIV) for the 15 most abundant taxa occurring in Long Island Sedge Meadow transects (four transects each sampled twice) and Outer Island transects (two transects each sampled twice), along with the increasing cumulative RIV as taxa are added.

Location	Taxa	Average RIV	Cumulative Average RIV
Outer Island	<i>Carex oligosperma</i>	1.22	95.21
(27 Taxa Total) (continued)	<i>Carex stricta</i>	1.04	96.25

Taxonomic Differences Among the *Sphagnum* “Bog” Sites

The second ordination (Figure 2), included only the 17 transects dominated by *Sphagnum*. Their RIV ranged from an average of 19.9% at Devils Island to 40.8% at Michigan Island (Tables 5–7). There appeared to be four general groupings (note the arcs in Figure 2 for suggested groupings), mostly among different island sites. They were: 1) Devils and Sand Islands that were low on axis 1 and high on axis 2; 2) Long Island, high on axis 1 and midway on axis 2; 3) Stockton Lagoon (with one Michigan Island transect), high on axis 1 and low on axis 2; and 4) Stockton Interior Bog (with the other two Michigan Lagoon transects) low on both axes.

In general, these groupings appear to be influenced by the relative importance values of three different species groups (Figure 2) included in the secondary (or environmental) matrix. There were more “obligate” wetland plants including white water lily (*Nymphaea odorata*), sundew (*Drosera* spp.), and bladderwort (*Utricularia* spp.) in the Stockton Island Lagoon group (Table 6); more short-statured shrubs such as leatherleaf, Labrador tea, and sweet gale on the Devils and Long Island sites (Tables 5 and 6); and more small trees and tall shrubs including black spruce, tamarack, and mountain holly (*Nemopanthus mucronatus*) at the Stockton bog site (Table 7).

Changes in Abundance Over Time by Individual Taxa

In addition to gauging vegetative compositional change over time by vector length through ordination analyses, we calculated an “index of change” for each individual taxon, which measured each taxon’s increase or decrease over the 8–11 year monitoring period. In this analysis all 26

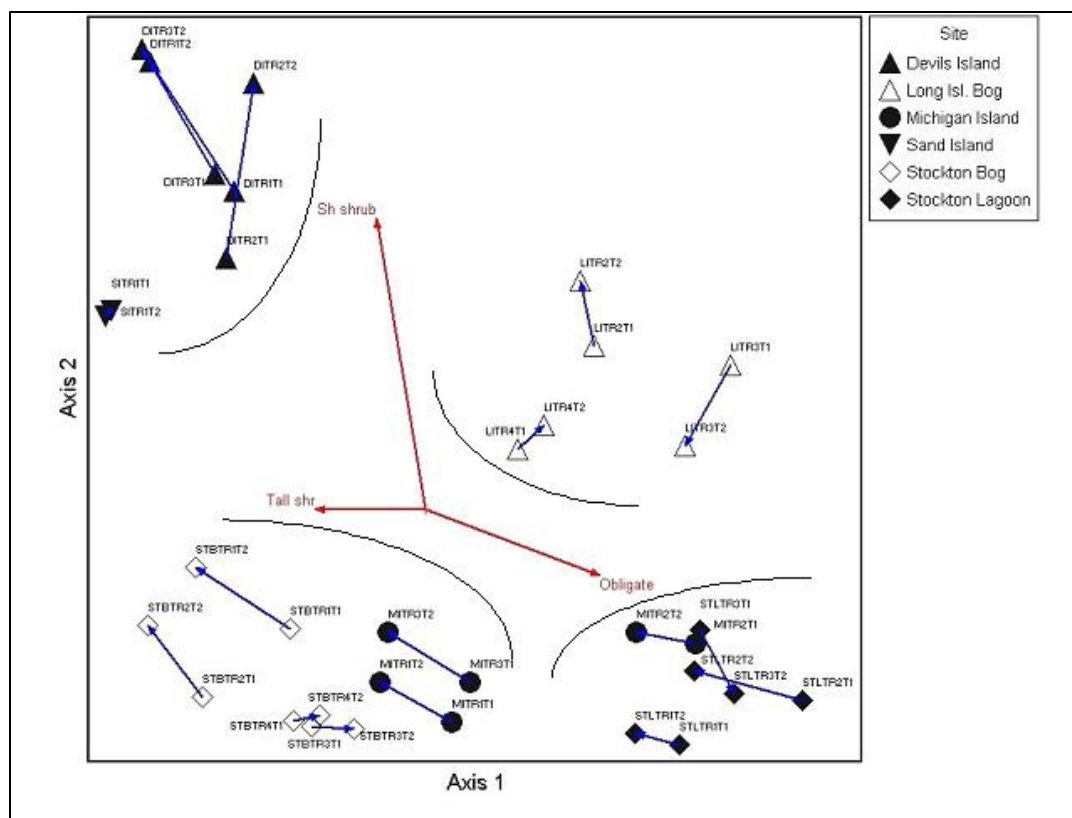


Figure 2. Non-metric multidimensional scaling (NMS) ordination of the 17 transects with *Sphagnum* spp. present (each at two times), using relative importance value. Arcs generally show separation among island sites. Arrows connect transect pairs over time and indicate changes in plant community composition.

Table 5. Average Relative Importance Value (RIV) for the 15 most abundant taxa occurring in Sand Island transects (one transect sampled twice) and Devils Bog transects (three transects each sampled twice), along with the increasing cumulative RIV as taxa are added.

Location	Taxa	Average RIV	Cumulative Average RIV
Devils Island Bog (18 Taxa Total)	<i>Sphagnum</i> spp.	19.85	19.85
	<i>Vaccinium</i> spp. (cranberry)	17.63	37.49
	<i>Ledum groenlandicum</i>	15.01	52.50
	<i>Chamaedaphne calyculata</i>	12.67	65.17
	<i>Smilacina trifolia</i>	10.28	75.45
	<i>Carex paupercula</i>	5.98	81.42
	<i>Carex trisperma</i>	4.46	85.88
	Moss non- <i>Sphagnum</i>	3.27	89.15

Table 5 (continued). Average Relative Importance Value (RIV) for the 15 most abundant taxa occurring in Sand Island transects (one transect sampled twice) and Devils Bog transects (three transects each sampled twice), along with the increasing cumulative RIV as taxa are added.

Location	Taxa	Average RIV	Cumulative Average RIV
Devils Island Bog (18 Taxa Total) (continued)	<i>Gaultheria procumbens</i>	2.21	91.35
	<i>Vaccinium</i> spp. (blueberry)	1.91	93.26
	<i>Pinus strobus</i>	1.72	94.98
	<i>Osmunda regalis</i>	0.96	95.94
	<i>Eriophorum virginicum</i>	0.92	96.86
	<i>Betula papyrifera</i>	0.92	97.78
	<i>Iris versicolor</i>	0.64	98.43
Sand Island Bog (12 Taxa Total)	<i>Sphagnum</i> spp.	27.93	27.93
	<i>Ledum groenlandicum</i>	19.74	47.66
	<i>Smilacina trifolia</i>	16.65	64.32
	<i>Vaccinium</i> spp. (cranberry)	12.13	76.44
	<i>Carex trisperma</i>	9.31	85.75
	<i>Picea mariana</i>	6.18	91.93
	<i>Drosera</i> spp.	1.96	93.89
	<i>Chamaedaphne calyculata</i>	1.89	95.78
	<i>Eriophorum gracile</i>	1.60	97.38
	<i>Larix laricina</i>	1.59	98.97
	<i>Betula papyrifera</i>	0.54	99.51
	<i>Thelypteris palustris</i>	0.49	100.00

Table 6. Average Relative Importance Value (RIV) for taxa occurring in Stockton Lagoon transects (three transects sampled twice each) and Long Island bog transects (three transects sampled twice each). The 15 most abundant taxa are listed for each site along with the increasing cumulative RIV as taxa are added.

Location	Taxa	Average RIV	Cumulative Average RIV
Stockton Island Lagoon (25 Taxa Total)	<i>Sphagnum</i> spp.	27.67	27.67
	<i>Cladium mariscoides</i>	10.50	38.17
	<i>Carex exilis</i>	7.58	45.75
	<i>Nymphaea odorata</i>	5.96	51.70
	<i>Rhynchospora fusca</i>	5.72	57.43
	<i>Myrica gale</i>	5.26	62.69
	<i>Vaccinium</i> spp. (cranberry)	5.23	67.92
	<i>Drosera</i> spp.	4.94	72.86
	<i>Rhynchospora alba</i>	4.65	77.51
	<i>Sarracenia purpurea</i>	4.45	81.96
	<i>Chamaedaphne calyculata</i>	3.57	85.53
	<i>Menyanthes trifoliata</i>	3.41	88.94
	<i>Pogonia ophioglossoides</i>	3.39	92.34
	<i>Utricularia</i> spp.	3.37	95.71
	<i>Eriocaulon aquaticum</i>	0.89	96.59
Long Island Bog (19 Taxa Total)	<i>Sphagnum</i> spp.	33.94	33.94
	<i>Chamaedaphne calyculata</i>	29.38	63.32
	<i>Myrica gale</i>	6.02	69.33
	<i>Carex utriculata</i>	4.99	74.33
	<i>Vaccinium</i> spp. (cranberry)	4.80	79.13
	<i>Alnus incana</i>	4.69	83.82
	<i>Glyceria</i> spp.	3.40	87.23
	<i>Smilacina trifolia</i>	2.79	90.01
	<i>Typha latifolia</i>	2.20	92.21
	<i>Carex lasiocarpa</i>	1.96	94.17
	<i>Calla palustris</i>	1.92	96.09
	<i>Kalmia polifolia</i>	1.68	97.77

Table 6 (continued). Average Relative Importance Value (RIV) for taxa occurring in Stockton Lagoon transects (three transects sampled twice each) and Long Island bog transects (three transects sampled twice each). The 15 most abundant taxa are listed for each site along with the increasing cumulative RIV as taxa are added.

Location	Taxa	Average RIV	Cumulative Average RIV
Long Island Bog (19 Taxa Total) (continued)	<i>Drosera</i> spp.	0.70	98.47
	<i>Sarracenia purpurea</i>	0.51	98.98
	<i>Larix laricina</i>	0.48	99.45

Table 7. Average Relative Importance Value (RIV) for taxa occurring in Stockton Island Bog transects (four transects sampled twice each) and Michigan Island Lagoon transects (three transects sampled twice each). The 15 most abundant taxa are listed for each site along with the increasing cumulative RIV as taxa are added.

Location	Taxa	Average RIV	Cumulative Average RIV
Stockton Island Bog (31 Taxa Total)	<i>Sphagnum</i> spp.	34.55	34.55
	<i>Chamaedaphne calyculata</i>	8.94	43.49
	<i>Kalmia polifolia</i>	7.04	50.52
	<i>Picea mariana</i>	5.73	56.25
	<i>Vaccinium</i> spp. (cranberry)	5.71	61.96
	<i>Smilacina trifolia</i>	5.42	67.38
	<i>Rhynchospora alba</i>	5.28	72.66
	<i>Sarracenia purpurea</i>	4.71	77.37
	<i>Carex oligocarpa</i>	4.32	81.69
	<i>Larix laricina</i>	3.68	85.37
	<i>Scheuchzeria palustris</i>	3.12	88.49
	<i>Carex rostrate</i>	2.25	90.74
	<i>Carex pauciflora</i>	2.19	92.93
	<i>Drosera</i> spp.	2.00	94.93
	<i>Nemopanthus mucronatus</i>	1.76	96.70
Michigan Island Lagoon (23 Taxa Total)	<i>Sphagnum</i> spp.	40.80	40.80
	<i>Chamaedaphne calyculata</i>	9.86	50.66
	<i>Vaccinium</i> spp. (cranberry)	8.75	59.42

Table 7 (continued). Average Relative Importance Value (RIV) for taxa occurring in Stockton Island Bog transects (four transects sampled twice each) and Michigan Island Lagoon transects (three transects sampled twice each). The 15 most abundant taxa are listed for each site along with the increasing cumulative RIV as taxa are added.

Location	Taxa	Average RIV	Cumulative Average RIV
Michigan Island Lagoon (23 Taxa Total) (continued)	<i>Menyanthes trifoliata</i>	4.67	64.09
	<i>Scheuchzeria palustris</i>	4.66	68.75
	<i>Kalmia polifolia</i>	4.59	73.34
	<i>Sarracenia purpurea</i>	4.48	77.82
	<i>Carex lasiocarpa</i>	3.50	81.32
	<i>Carex utriculata</i>	3.16	84.48
	<i>Cladium mariscoides</i>	2.71	87.19
	<i>Eriophorum virginicum</i>	2.68	89.87
	<i>Carex pauciflora</i>	2.28	92.15
	<i>Drosera</i> spp.	1.51	93.66
	<i>Carex</i> spp.	1.48	95.14
	<i>Rhynchospora alba</i>	1.26	96.40

transects at both times ($26 \times 2 = 52$ possible occurrences) were looked at regardless of whether the transects were with or without *Sphagnum*. The index was derived from the change in total relative importance values from Time 1 to Time 2 for each taxon, adjusted by each taxon's frequency of occurrence and its total RIV (across both observation times). This index varied (Table 8) from a high of +6.77 for *Rubus* spp., indicating a major increase over time, to a value of -5.61 for *Typha latifolia*, which indicated a major decrease over time. This index was calculated for all taxa found to have a total RIV greater than 35% that occurred more than six times (of the 52 possible). As measured by this index, the top seven “increasers” were woody or semi-woody taxa (e.g., brambles, *Rubus* spp.), while the “decreasers” included those taxa that are generally favored by wetter conditions, including wetland obligates such as wide-leaf cattail (*Typha latifolia*), bladderwort (*Utricularia* spp.), water arum (*Calla palustris*), and a number of the sedges (*Cladium*, *Rhynchospora*, and *Carex* spp.).

We used this index because a simple listing of the raw RIV change from Time 1 to Time 2 may have been misleading. *Sphagnum*, for example, had the greatest raw RIV change (-80.6), but this was certainly due to occurring often (found in 34 of 52 transects over time) and having the highest total RIV across both times (1065.8) (Table 8). On the other hand, *Calla* occurred only nine times and had a total RIV of only 40.6, but most of that RIV was at Time 1 (resulting in a raw change in RIV of -20.4). Hence, *Calla* had a greater decrease compared to *Sphagnum* as measured by this index (-4.53 vs. -2.57).

Changes in Abundance Over Time by Grouping Taxa

Another analysis of change over time was assessed by categorizing taxa into functional groups and looking at their differences over time. Tables 9 and 10 list all taxa (excepting the ferns and mosses) grouped into four different categories including woody taxa (24 taxa with a mean RIV change of +14.46), aquatic taxa (13 taxa with a mean RIV change of -8.26), forbs (45 taxa with a mean RIV change of -0.68), and graminoids (45 grass-like taxa with a mean RIV change of -3.04). In general, the results of this categorization approach were consistent with the individual taxa assessments for woody and aquatic taxa, in that woody taxa increased and aquatics decreased, while individual forbs and graminoids may have changed but showed no trend as groups.

Changes Over Time in Forested Wetlands

Sand Island

Two separate bogs, Sand Island North and Sand Island South, were first sampled in 2001 and re-sampled in 2010, each including a 300 m belt transect for tree assessment.

Sand Island North

Sand Island North was delineated into three cover-types (Figure 2 in Meeker 2002), including an alder (*Alnus incana*) fringe and areas dominated by either tamarack (*Larix laricina*) or black spruce (*Picea mariana*), respectively. The black spruce dominated areas comprised about two-thirds of the 44.79-hectare conifer area (Table 4 in Meeker 2002). The north/south oriented transect was mostly located within the black spruce cover-type, except for segments 3 and 5.

Table 8. Indices of change for all taxa with total relative importance values (RIV) greater than 35% and occurring on more than six transects. Index was calculated by dividing raw change in RIV from Time 1 to Time 2 by the ratio of total RIV/frequency of occurrence. Negative index values indicate decreases in abundance.

Increasers/Decreasers	Taxa	Raw RIV change	Freq.	Total RIV	Change Index
Increasers	<i>Rubus</i> spp.	54.60	7	56.50	6.77
	<i>Chamaedaphne calyculata</i>	70.95	42	468.99	6.35
	<i>Myrica gale</i>	84.22	27	361.74	6.29
	<i>Larix laricina</i>	11.97	13	36.94	4.21
	<i>Vaccinium</i> spp. (cranberry)	31.47	35	325.18	3.39
	<i>Alnus incana</i>	10.66	13	41.82	3.31
	<i>Kalmia polifolia</i>	14.00	20	95.16	2.94
	<i>Sarracenia purpurea</i>	11.03	22	94.33	2.57
	<i>Picea mariana</i>	13.29	10	58.18	2.28
	<i>Equisetum fluviatile</i>	14.41	8	55.10	2.09

Table 8 (continued). Indices of change for all taxa with total relative importance values (RIV) greater than 35% and occurring on more than six transects. Index was calculated by dividing raw change in RIV from Time 1 to Time 2 by the ratio of total RIV/frequency of occurrence. Negative index values indicate decreases in abundance.

Increasers/Decreasers	Taxa	Raw RIV change	Freq.	Total RIV	Change Index
Increasers (continued)	<i>Potentilla palustris</i>	8.46	10	54.29	1.56
	<i>Salix</i> spp.	9.27	10	60.10	1.54
	<i>Rhynchospora fusca</i>	6.89	7	36.07	1.34
	<i>Carex utriculata</i>	5.41	11	65.97	0.90
	<i>Calamagrostis canadensis</i>	4.84	11	150.07	0.35
Decreasers	<i>Typha latifolia</i>	-16.33	13	37.80	-5.61
	<i>Utricularia</i> spp.	-20.97	11	48.26	-4.78
	<i>Calla palustris</i>	-20.39	9	40.64	-4.52
	<i>Campanula aparinoides</i>	-16.34	10	45.93	-3.56
	<i>Smilacina trifolia</i>	-26.79	18	155.05	-3.11
	<i>Cladium mariscoides</i>	-26.49	12	111.23	-2.86
	<i>Drosera</i> spp.	-9.49	20	68.67	-2.76
	<i>Sphagnum</i> spp.	-80.60	34	1065.82	-2.57
	<i>Rhynchospora alba</i>	-13.21	15	77.67	-2.55
	<i>Carex trisperma</i>	-13.94	8	45.36	-2.46
	<i>Carex lasiocarpa</i>	-18.31	22	211.08	-1.91
	<i>Carex lacustris</i>	-13.25	10	70.79	-1.87
	<i>Lysimachia</i> spp.	-6.73	15	65.41	-1.54
	<i>Carex rostrate</i>	-2.10	11	36.10	-0.64
	<i>Carex stricta</i>	-2.83	9	42.30	-0.60
	<i>Scheuchzeria palustris</i>	-1.93	12	53.56	-0.43
	<i>Ledum groenlandicum</i>	-3.62	12	133.83	-0.32
	<i>Menyanthes trifoliata</i>	-1.52	10	48.50	-0.31

Table 9. Change in Relative Importance Value (RIV) for all woody and aquatic taxa between Time 1 and Time 2 for all 26 transects. The mean change per group is shown.

Woody/ Aquatic	Taxa	Change in RIV
Woody Taxa (24 Taxa Total)	<i>Acer rubrum</i>	3.23
	<i>Alnus incana</i>	10.66
	<i>Andromeda glaucophylla</i>	2.31
	<i>Betula papyrifera</i>	-2.13
	<i>Chamaedaphne calyculata</i>	70.95
	<i>Ilex verticillata</i>	30.47
	<i>Juniperus communis</i>	0.69
	<i>Kalmia polifolia</i>	14.00
	<i>Larix laricina</i>	11.97
	<i>Ledum groenlandicum</i>	-3.62
	<i>Myrica gale</i>	84.22
	<i>Nemopanthus mucronatus</i>	4.38
	<i>Picea mariana</i>	13.29
	<i>Pinus banksiana</i>	1.47
	<i>Pinus strobus</i>	3.11
	<i>Populus tremuloides</i>	5.71
	<i>Quercus rubra</i>	0.74
	<i>Rosa</i> spp.	0.26
	<i>Rubus</i> spp.	54.60
	<i>Salix</i> spp.	9.27
	<i>Spiraea alba</i>	3.26
	<i>Thuja occidentalis</i>	0.16
	<i>Vaccinium</i> spp. (blueberry)	-3.55
	<i>Vaccinium</i> spp. (cranberry)	31.47
	Sum RIV Change	346.93
	Mean RIV Change	14.46

Table 9 (continued). Change in Relative Importance Value (RIV) for all woody and aquatic taxa between Time 1 and Time 2 for all 26 transects. The mean change per group is shown.

Woody/ Aquatic	Taxa	Change in RIV
Aquatic Taxa (13 Taxa Total)	<i>Acorus calamus</i>	-1.16
	<i>Brasenia schreberi</i>	-3.62
	<i>Calla palustris</i>	-20.39
	<i>Drosera</i> spp.	-9.49
	<i>Eriocaulon aquaticum</i>	-4.12
	<i>Iris versicolor</i>	-3.13
	<i>Littorella uniflora</i>	-0.39
	<i>Nymphaea odorata</i>	-6.11
	<i>Potamogeton gramineus</i>	-1.84
	<i>Sagittaria latifolia</i>	-15.58
	<i>Sparganium</i> spp.	-4.30
	<i>Typha latifolia</i>	-16.33
	<i>Utricularia</i> spp.	-20.97
	Sum RIV Change	-107.44
	Mean RIV Change	-8.26

Table 10. Change in Relative Importance Value (RIV) for all taxa of forbs and graminoids between Time 1 and Time 2 for all 26 transects. The mean change per group is shown.

Forbs/Graminoids	Taxa	Change in RIV
Forbs (45 Taxa Total)	<i>Achillea millefolium</i>	-0.40
	<i>Asclepias syriaca</i>	0.57
	<i>Aster</i> spp.	-0.02
	<i>Bidens connate</i>	-0.51
	<i>Calopogon tuberosus</i>	-0.22
	<i>Campanula aparinoides</i>	-16.34
	<i>Cicuta bulbifera</i>	-2.45
	<i>Cirsium</i> spp.	-0.76
	<i>Cornus Canadensis</i>	0.24

Table 10 (continued). Change in Relative Importance Value (RIV) for all taxa of forbs and graminoids between Time 1 and Time 2 for all 26 transects. The mean change per group is shown.

Forbs/Graminoids	Taxa	Change in RIV
Forbs (45 Taxa Total) (continued)	<i>Eupatorium perfoliatum</i>	-0.83
	<i>Euthamia graminifolia</i>	5.28
	<i>Galium labradoricum</i>	-2.42
	<i>Gaultheria procumbens</i>	10.79
	<i>Habenaria clavellata</i>	-0.78
	<i>Hieracium</i> spp.	0.25
	<i>Hypericum</i> spp.	-1.44
	<i>Impatiens capensis</i>	-0.18
	<i>Lactuca</i> spp.	-1.24
	<i>Lycopus</i> spp.	-4.86
	<i>Lysimachia</i> spp.	-6.73
	<i>Lythrum salicaria</i>	-15.01
	<i>Melampyrum lineare</i>	4.38
	<i>Mentha arvensis</i>	-1.23
	<i>Menyanthes trifoliata</i>	-1.52
	<i>Oenothera biennis</i>	-0.40
	<i>Ophioglossum vulgatum</i>	-0.54
	<i>Pogonia ophioglossoides</i>	1.52
	<i>Polygonum punctatum</i>	-3.50
	<i>Polygonum scandens</i>	-0.91
	<i>Polygonum</i> spp.	0.64
	<i>Potentilla norvegica</i>	-2.90
	<i>Potentilla palustris</i>	8.46
	<i>Potentilla</i> spp.	0.99
	<i>Primula mistassinica</i>	1.74
	<i>Sarracenia purpurea</i>	11.03
	<i>Scutellaria galericulata</i>	3.43
	<i>Sium suave</i>	-0.95
	<i>Smilacina trifolia</i>	-26.79

Table 10 (continued). Change in Relative Importance Value (RIV) for all taxa of forbs and graminoids between Time 1 and Time 2 for all 26 transects. The mean change per group is shown.

Forbs/Graminoids	Taxa	Change in RIV
Forbs (45 Taxa Total) (continued)	<i>Solidago</i> spp.	9.47
	<i>Sonchus</i> spp.	1.43
	<i>Spiranthes cernua</i>	-0.51
	<i>Stachys palustris</i>	-0.67
	<i>Taraxacum officinale</i>	0.57
	<i>Triadenum fraseri</i>	2.82
	<i>Tridentalis borealis</i>	0.07
	Sum RIV Change	-30.47
	Mean RIV Change	-0.68
Graminoids (45 Taxa Total)	<i>Agrostis hyemalis</i>	-8.21
	<i>Calamagrostis canadensis</i>	4.84
	<i>Carex canescens</i>	-0.44
	<i>Carex chordorrhiza</i>	-0.22
	<i>Carex diandra</i>	1.04
	<i>Carex exilis</i>	-3.14
	<i>Carex interior</i>	8.54
	<i>Carex lacustris</i>	-13.25
	<i>Carex lasiocarpa</i>	-18.31
	<i>Carex limosa</i>	-8.11
	<i>Carex oligocarpa</i>	0.55
	<i>Carex oligosperma</i>	4.87
	<i>Carex paupercula</i>	-6.27
	<i>Carex rostrate</i>	-2.10
	<i>Carex</i> spp.	7.76
	<i>Carex scoparia</i>	-0.77
	<i>Carex</i> spp. (ovales grp)	-10.13
	<i>Carex stricta</i>	-2.83
	<i>Carex trisperma</i>	-13.94
	<i>Carex utriculata</i>	5.41

Table 10 (continued). Change in Relative Importance Value (RIV) for all taxa of forbs and graminoids between Time 1 and Time 2 for all 26 transects. The mean change per group is shown.

Forbs/Graminoids	Taxa	Change in RIV
Graminoids (45 Taxa Total) (continued)	<i>Carex viridula</i>	-0.26
	<i>Carex pauciflora</i>	-6.17
	<i>Cladium mariscoides</i>	-26.49
	<i>Dulichium arundinaceae</i>	-3.35
	<i>Eleocharis smallii</i>	-12.05
	<i>Eriophorum gracile</i>	3.20
	<i>Eriophorum polystachion</i>	-0.49
	<i>Eriophorum virginicum</i>	-4.75
	<i>Glyceria</i> spp.	1.08
	<i>Juncus arcticus</i>	-9.56
	<i>Juncus brevicaudatus</i>	-0.73
	<i>Juncus canadensis</i>	-3.26
	<i>Juncus effuses</i>	-0.76
	<i>Juncus pelocarpus</i>	-1.70
	<i>Leersia oryzoides</i>	-0.44
	<i>Lolium perenne</i>	0.57
	<i>Panicum</i> spp.	-4.37
	<i>Phalaris arundinacea</i>	2.24
	<i>Phragmites australis</i>	5.74
	<i>Rhynchospora alba</i>	-13.21
	<i>Rhynchospora fusca</i>	6.89
	<i>Scheuchzeria palustris</i>	-1.93
	<i>Scirpus acutus</i>	-2.72
	<i>Scirpus cyperinus</i>	-8.17
	<i>Scirpus subterminalis</i>	-1.41
	Sum RIV Change	-136.83
	Mean RIV Change	-3.04

The count data from this transect in 2001 (Table 11) indicated that small black spruce dominated the transect, predominantly in the 2–4-inch DBH range (84 trees). Notably, in 2001 there were 223 dead trees in this bog, or 51% of all live and dead trees.

Sampling in the same general area in 2010 showed an overall increase from 2001 of 126 live trees, mainly due to a recruitment of black spruce individuals less than 1-inch DBH and less than 6 feet tall (Table 11). Additionally white birch (*Betula papyrifera*) and tamarack all generally increased during the 10-year period. However, 2–4, 4–6, and 6–8-inch DBH black spruce all decreased over the same sampling time. The number of dead trees (standing dead) along these transects also decreased from 223 in 2001 to 106 in 2010. The greatest decrease in the dead tree count was in the 2–4-inch DBH range (a decrease from 102 in 2001 to 26 in 2010; Table 11).

Although we sampled in the same general area, we cannot be assured that we sampled exactly the same 300 m × 4 m belt transect, as a slight deviation in the placement of the transect could result in 2–3 m differences over a span of 300 m. Alternatively, it could be that the recruitment of young black spruce and the reduction of dead trees were real, the former due to improved conditions (less water saturation?) and the latter resulting from the fact that most of standing dead trees counted in 2001 had fallen and were not counted in 2010.

Table 11. Sand Island North bog tree transect data.

Species	Live/Dead	Size	Totals		Sub-totals		Change Over Time	
			2001	2010	2001	2010	Increase	Decrease
<i>Betula papyrifera</i>	Live	<1"dbh /<6' tall	0	4	–	–	4	–
	Live	<1"dbh />6' tall	1	7	–	–	6	–
	Live	1"–2"	0	1	–	–	1	–
	Live	2"–4"	0	1	1	13	1	–
<i>Larix laricina</i>	Live	<1"dbh /<6' tall	0	10	–	–	10	–
	Live	<1"dbh />6' tall	0	0	–	–	–	–
	Live	1"–2"	1	1	–	–	–	–
	Live	2"–4"	12	12	–	–	–	–
	Live	4"–6"	16	27	–	–	11	–
	Live	6"–8"	6	13	–	–	7	–
	Live	8"–10"	1	3	36	66	2	–
<i>Picea mariana</i>	Live	<1"dbh /<6' tall	8	134	–	–	126	–
	Live	<1"dbh />6' tall	3	17	–	–	14	–
	Live	1"–2"	18	23	–	–	5	–

Table 11 (continued). Sand Island North bog tree transect data.

Species	Live/Dead	Size	Totals		Sub-totals		Change Over Time	
			2001	2010	2001	2010	Increase	Decrease
<i>Picea mariana</i> (continued)	Live	2"–4"	84	42	–	–	–	–42
	Live	4"–6"	59	45	–	–	–	–14
	Live	6"–8"	6	1	178	262	–	–5
<i>Betula papyrifera</i>	Dead	<1"dbh />6' tall	0	1	–	–	1	–
<i>Larix laricina</i>	Dead	<1"dbh /<6' tall	1	0	–	–	–	–
	Dead	<1"dbh />6' tall	0	1	–	–	1	–
	Dead	1"–2"	7	1	–	–	–	–
	Dead	2"–4"	10	6	–	–	–	–
	Dead	4"–6"	3	4	–	–	1	–
	Dead	6"–8"	0	0	–	–	–	–
<i>Picea mariana</i>	Dead	<1"dbh /<6' tall	7	1	–	–	–	–
	Dead	<1"dbh />6' tall	12	1	–	–	–	–
	Dead	1"–2"	45	7	–	–	–	–
	Dead	2"–4"	102	26	–	–	–	–
	Dead	4"–6"	22	13	–	–	–	–
	Dead	6"–8"	2	1	–	–	–	–
Unknown	Dead	<1"dbh /<6' tall	1	1	–	–	–	–
	Dead	<1"dbh />6' tall	1	0	–	–	–	–
	Dead	1"–2"	1	9	–	–	8	–
	Dead	2"–4"	9	25	–	–	16	–
Unknown (Conifer)	Dead	4"–6"	0	7	–	–	7	–
	Dead	6"–8"	0	2	–	–	2	–
Total live trees	–	–	215	341	–	–	126	–
Total dead trees	–	–	223	106	–	–	–	–
% Dead	–	–	0.51	0.24	–	–	–	–

Sand Island South

In 2001, Sand Island South was delineated into just two cover-types, including an alder fringe and a mixed conifer swamp of equal abundances of tamarack and black spruce (Figure 3 in Meeker 2002). The count data from the 300-meter transect in 2001 and again in 2010 (Table 12) indicated these

conifer species were represented by small trees mostly in the 1–6-inch DBH range. There was little difference in total tree counts noted between the 2001 (230 trees) and the 2010 (223 trees) sampling. However, some of the 46, 2–4-inch DBH black spruce individuals may have grown into the next size category by 2010 (noting the increase from 21 to 40 in the 4–6-inch category, Table 12). In 2001 and again in 2010 there was only one tree (tamarack) greater than 8 inches in diameter in this transect, and this transect appeared representative of the wetland as a whole. Notably there were very few dead trees in this south bog, ranging from 7% to 9% of the total tree count over the two samplings.

The sampling caveat also applies here. That is, although we sampled in the same general area, we cannot be sure that we sampled exactly the same 300 m × 4 m belt transect over the whole span of 300 m. In this case, it would appear that the general area changed little over the 10-year span.

Table 12. Sand Island South bog tree transect data.

Species	Live/Dead	Size	Totals		Sub-Totals		Change Over Time	
			2001	2010	2001	2010	Increase	Decrease
<i>Abies balsamea</i>	Live	1"–2"	4	2	4	2	0	2
<i>Alnus rugosa</i>	Live	1"–2"	2	1	2	1	0	1
<i>Betula papyrifera</i>	Live	1"–2"	6	0	0	0	0	6
	Live	2"–4"	2	0	0	0	0	2
	Live	4"–6"	1	0	9	0	0	1
<i>Larix laricina</i>	Live	1"–2"	10	10	0	0	0	0
	Live	2"–4"	61	72	0	0	11	0
	Live	4"–6"	22	16	0	0	0	6
	Live	6"–8"	2	0	0	0	0	2
	Live	8"–10"	1	1	96	99	0	0
<i>Picea mariana</i>	Live	1"–2"	46	48	0	0	2	0
	Live	2"–4"	46	33	0	0	0	13
	Live	4"–6"	21	40	0	0	19	0
	Live	6"–8"	3	0	116	121	0	3
<i>Pinus strobus</i>	Live	1"–2"	1	0	0	0	0	1
	Live	2"–4"	0	0	0	0	0	0
<i>Pinus strobus</i>	Live	4"–6"	2	0	3	0	0	2
<i>Betula papyrifera</i>	Dead	1"–2"	1	1	0	0	0	0
	Dead	2"–4"	1	0	0	0	0	0
	Dead	4"–6"	1	0	0	0	0	0

Table 12 (continued). Sand Island South bog tree transect data.

Species	Live/Dead	Size	Totals		Sub-Totals		Change Over Time	
			2001	2010	2001	2010	Increase	Decrease
<i>Betula papyrifera</i> (continued)	Dead	6"–8"	0	0	0	0	0	0
<i>Larix laricina</i>	Dead	1"–2"	2	4	0	0	0	0
	Dead	2"–4"	0	0	0	0	0	0
	Dead	4"–6"	0	0	0	0	0	0
	Dead	6"–8"	0	0	0	0	0	0
<i>Picea mariana</i>	Dead	1"–2"	0	0	0	0	0	0
	Dead	2"–4"	5	8	0	0	0	0
	Dead	4"–6"	2	2	0	0	0	0
	Dead	6"–8"	2	3	0	0	0	0
Unknown	Dead	4"–6"	1	2	0	0	0	0
Total live trees	–	–	230	223	–	–	–	7
Total dead trees	–	–	15	20	–	–	–	–
% Dead	–	–	0.07	0.09	–	–	–	–

Analyses of Increment Cores

In 2010, thirty trees were cored in the sampled area of the north forested bog of Sand Island to assess growth patterns over time, resulting in 24 trees that provided sound enough cores to analyze, equally distributed between black spruce and tamarack. In addition, we cored trees equally representing the 2–4, 4–6, and the 6–8-inch DBH size categories. Cores were extracted by an increment borer and analyzed under 25-power dissecting microscope.

With a few outliers there was a moderate linear relationship ($R^2 = 50\%$) between age and size (DBH in mm) (Figure 3). The six oldest trees (as cored and measured at 4.5 feet high), were four tamaracks and two black spruces that originated between 1920 and 1929 (Figure 4).

The majority of the trees cored (10 of the 24) originated between 1935 and 1939, and the youngest tree's year of origin was 1966. It should be noted that as we cored at 4.5 feet height, the actual ages would be 8–10 years older—the time it is estimated for the individual trees to reach the 4.5-foot height.

The patterns of growth (annual increments) were plotted from the 1920s through 2010 for select groups of trees. Figure 5 indicates that the oldest six trees (four tamaracks and two black spruces, recruited between 1920 and 1930) had similar growth spurts. There was a general increase in growth

from the late 1930s through the 1950s, followed by decreases beginning about 1960 through 1985. From 1985 to present, most of the six trees experienced increases in growth. Figure 6 shows patterns of annual increment for a cohort of five tamaracks that originated between 1935 and 1939, while Figure 7 follows a cohort of four black spruce of the same age. In both cases, the overall pattern is similar to the oldest trees, having several periods of good growth with decreases in the late 1960s through the 1970s.

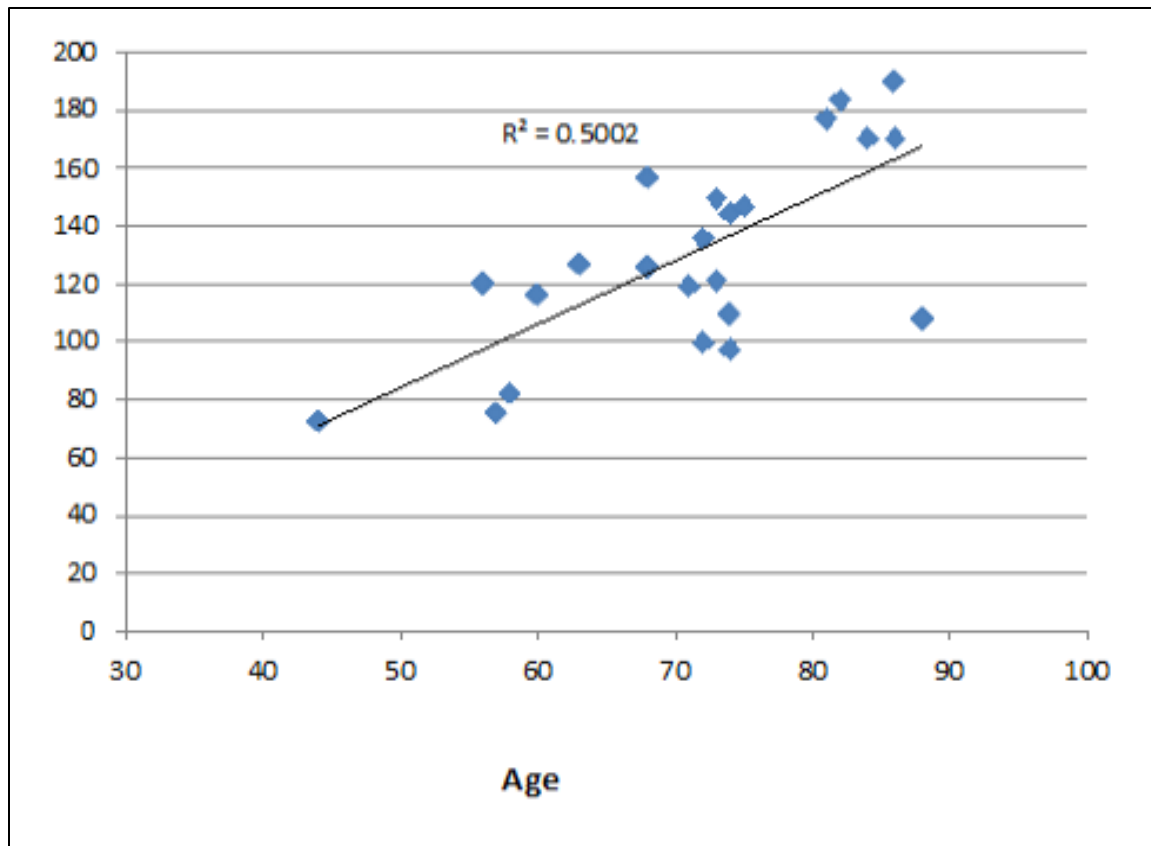


Figure 3. Relationship between age and size of 24 tamarack and black spruce trees cored from Sand Island forested bog (north) in 2010.

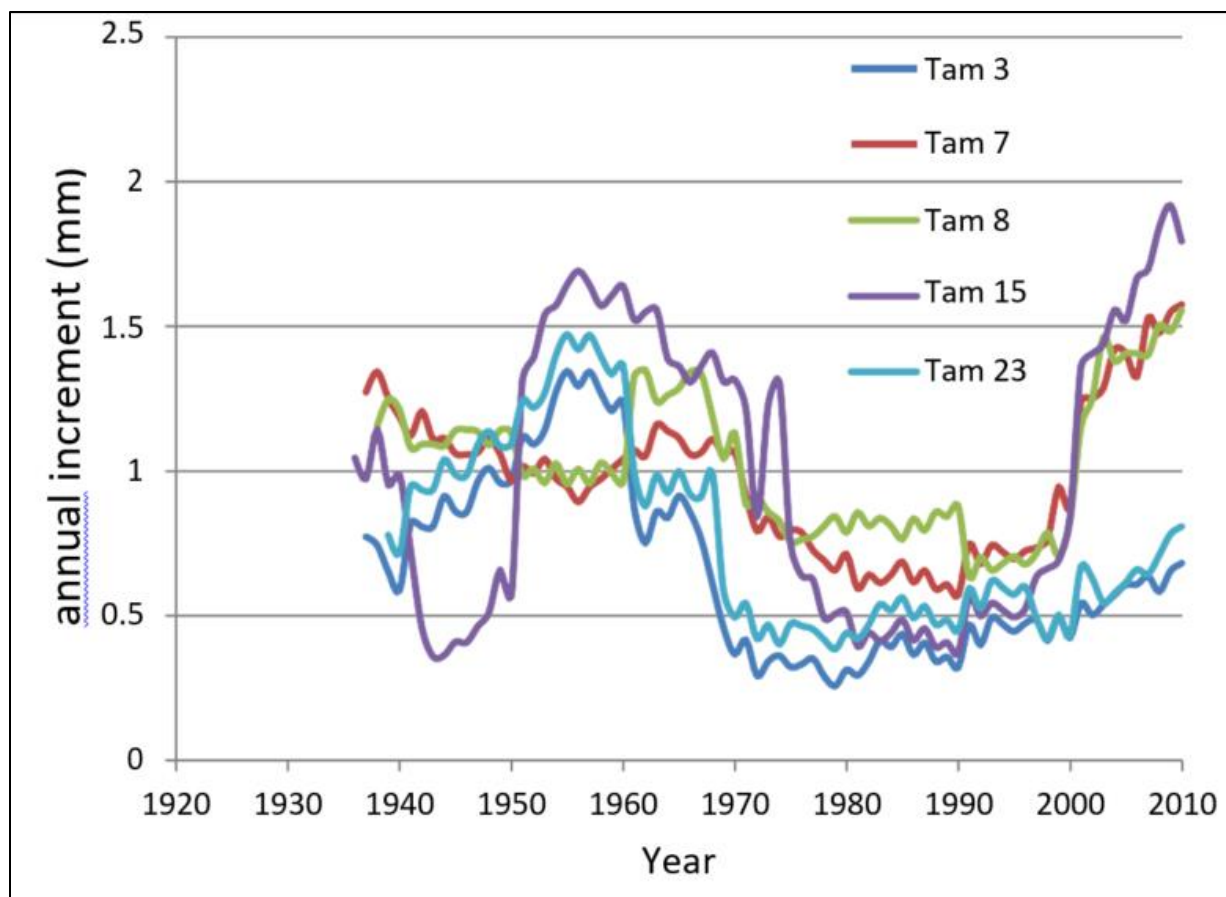


Figure 4. Frequency distribution of the years of origin for 24 tamarack and black spruce trees cored in 2010 from the Sand Island forested peatland (north). Trees were cored at 4.5 feet above the ground; hence, true originating year is 8–10 years earlier.

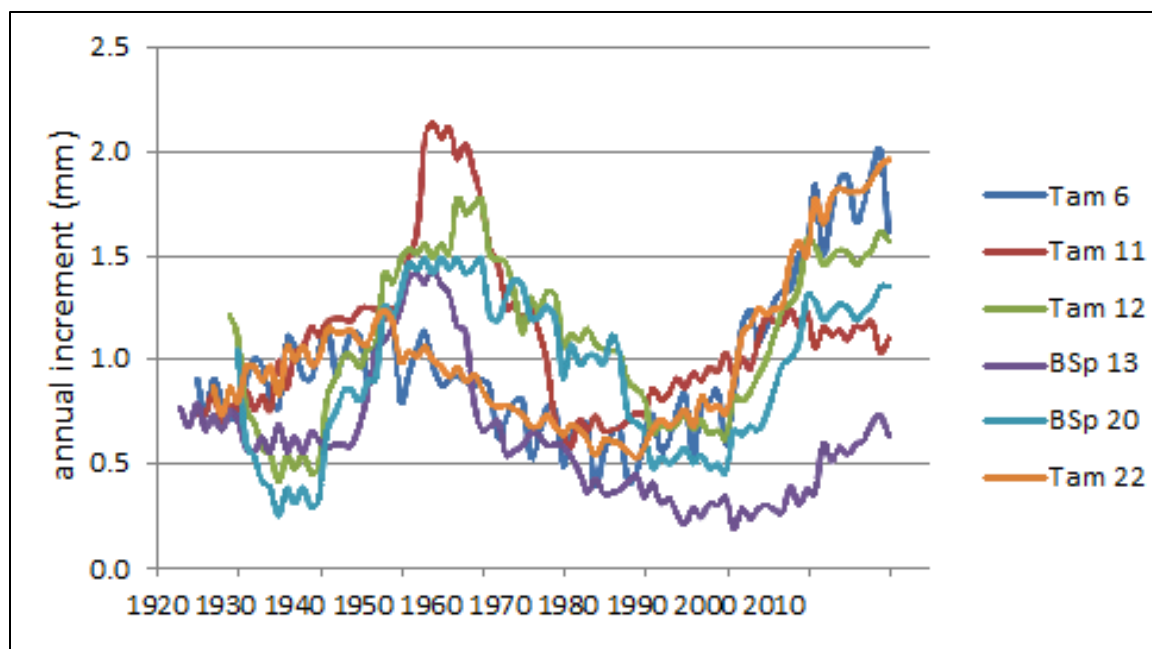


Figure 5. Plots of annual increment width (diameter at breast height, DBH) for the six oldest trees cored in the Sand Island forested peatland (north) in 2010.

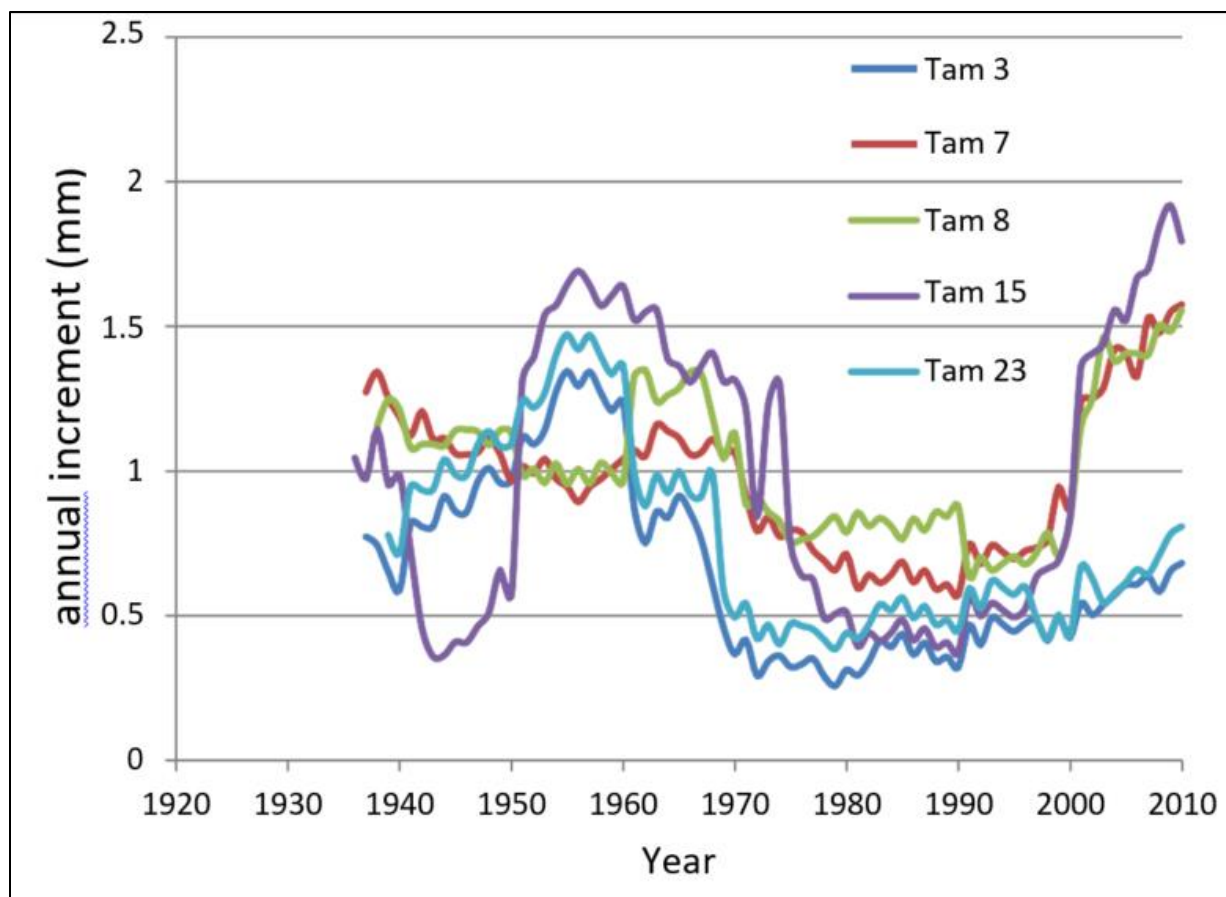


Figure 6. Plots of annual increment width (diameter at breast height, DBH) for a cohort of five tamarack trees originating in the late 1930s in the Sand Island forested peatland (north) cored in 2010.

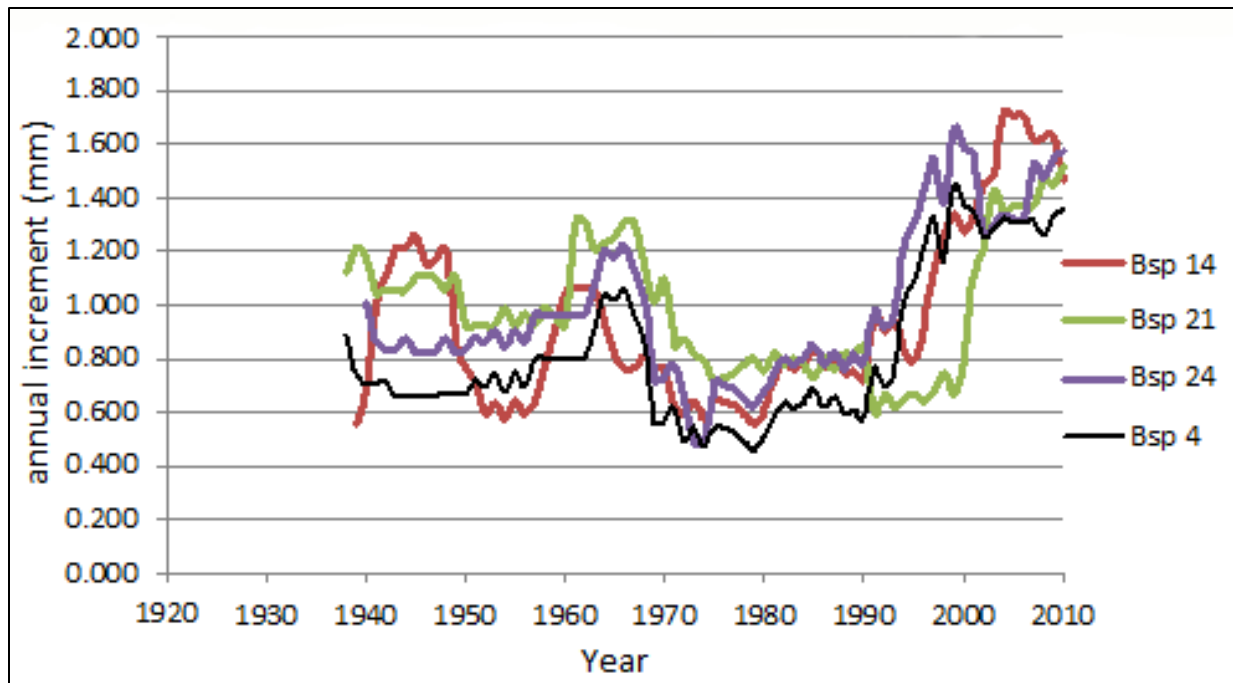


Figure 7. Plots of annual increment width (diameter at breast height, DBH) for a cohort of four black spruce trees originating in the late 1930s in the Sand Island forested peatland (north) cored in 2010.

Lines of Advance and Select Stem Density Measures

Selected wetlands were chosen to monitor vegetative changes over time through an assessment of what we termed lines of advance (LOAs), or the boundaries at the time of sampling where potentially dominant taxa occurred and to where they had not yet moved. Figure 8, for example, indicated three LOAs in 2001 for *Carex rostrata*/*C. utriculata* (combined) on the interior bog at Stockton Island, two near Transects 1 and 2, and another near Transects 3 and 4. In 2001, all of the LOAs were longer and only portions of the two LOAs near Transects 1 and 2 were defined well enough in 2010 to be re-sampled. The assumption with these LOAs is that the taxon in question likely decreased from 2001 to 2010 if it was not abundant enough to follow in Time 2.

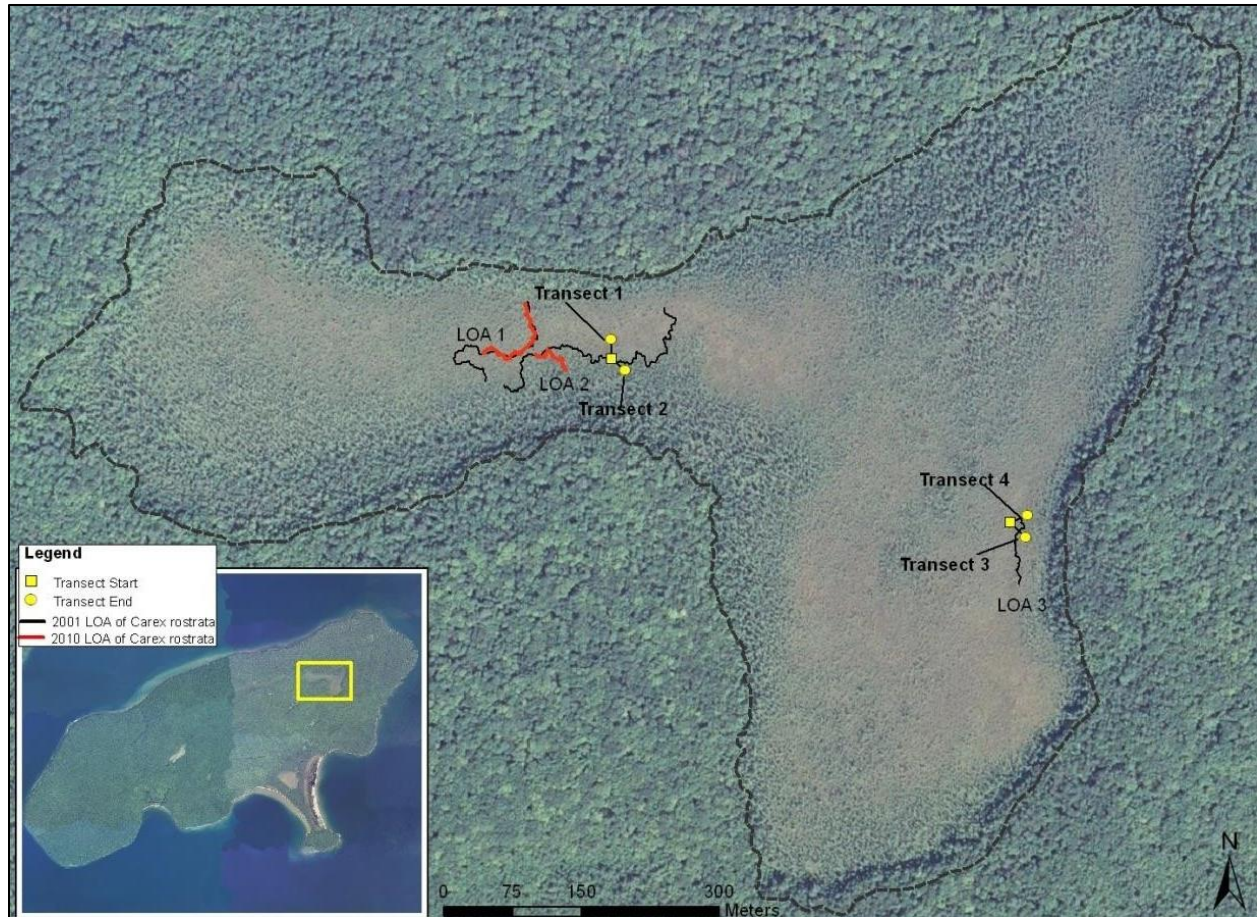


Figure 8. Placement of four transects re-sampled in 2010 for all taxa present and three lines of advance (LOAs) of select taxa in an interior bog (Brander Bog) on Stockton Island.

In a number of cases the same taxa were also assessed for stem density changes over time in the re-sampled transects (in addition to cover). In the case of the Stockton Island interior bog, the stem density measure decreased from 83 stems in 2001 to 11 stems in 2010 (Table 13). Hence, both the stem density and the LOA metrics suggest that *Carex rostrata*/*C. utriculata* decreased considerably in abundance over time.

Re-assessment of the Michigan Island transects suggested that *Typha* decreased (Transects 1 and 2), while *Carex rostrata*/*C. utriculata* increased (Transect 3) (Table 13). The lines of advance (LOAs) support this inference (Figure 9), as one LOA for *Carex rostrata*/*C. utriculata* expanded 6–10 m west near Transect 3, and another east of Transect 2 appeared and presumably was not present in 1998. The *Typha* LOA near Transect 2 that was apparent in 1998 was not observable in 2010. Similarly the *Typha* LOA near Transect 1 shrunk back (moved north) from its 1998 line by 2010. Another *Typha* LOA apparent in 1998 as a dense patch near the wash-over zone (seen in Figure 9), was not apparent in 2010, and only existed as a few scattered stems.

Table 13. Changes in stem density (per 1 m × 1 m quadrat) and percent-frequency of occurrence over time for select aggressive taxa at Stockton interior bog, Sand River mouth, Michigan Island, and Outer Island. Assessment was along the same transects that percent-cover was recorded.

Location	Taxa	Transect	1998 Stem Density	2001 Stem Density	2001 Quadrat Frequency (%)	2010 Stem Density	2010 Quadrat Frequency (%)
Stockton Island Interior Bog	<i>Carex rostrata/uticulata</i>	1	–	5	0	0	0
	<i>Carex rostrata/uticulata</i>	2	–	64	30	3	30
	<i>Carex rostrata/uticulata</i>	3	–	9	60	6	50
	<i>Carex rostrata/uticulata</i>	4	–	5	20	2	10
	Totals	–	–	83	–	11	–
Sand River Mouth	<i>Typha</i> spp.	1	–	5	20	1	10
	<i>Typha</i> spp.	2	–	12	60	3	20
	<i>Typha</i> spp.	3	–	18	28	5	20
	Totals	–	–	35	–	9	–
Michigan Island	<i>Typha</i> spp.	1	4	–	40	0	0
	<i>Typha</i> spp.	2	27	–	33	0	0
	<i>Carex rostrata/uticulata</i>	3	26	–	80	55	100
	Totals (<i>Typha</i>)	–	31	–	–	0	–
Outer Island	<i>Phragmites australis</i>	2	52	–	70	18	40



Figure 9. Placement of three transects re-sampled in 2010 for all taxa present and four lines of advance (LOAs) of select taxa on Michigan Island.

The assessment for Devils Island (Figure 10) suggests that the clear lines of demarcation observed in 1998 between Labrador tea (*Ledum groenlandicum*) and leatherleaf (*Chamaedaphne calyculata*) had shifted to the northwest for LOA1, while faded somewhat at LOA2 and LOA3 by 2010. In addition, the delineation of leatherleaf clones in 1998 and 2010 appeared to also indicate a shift northwest by 2010.

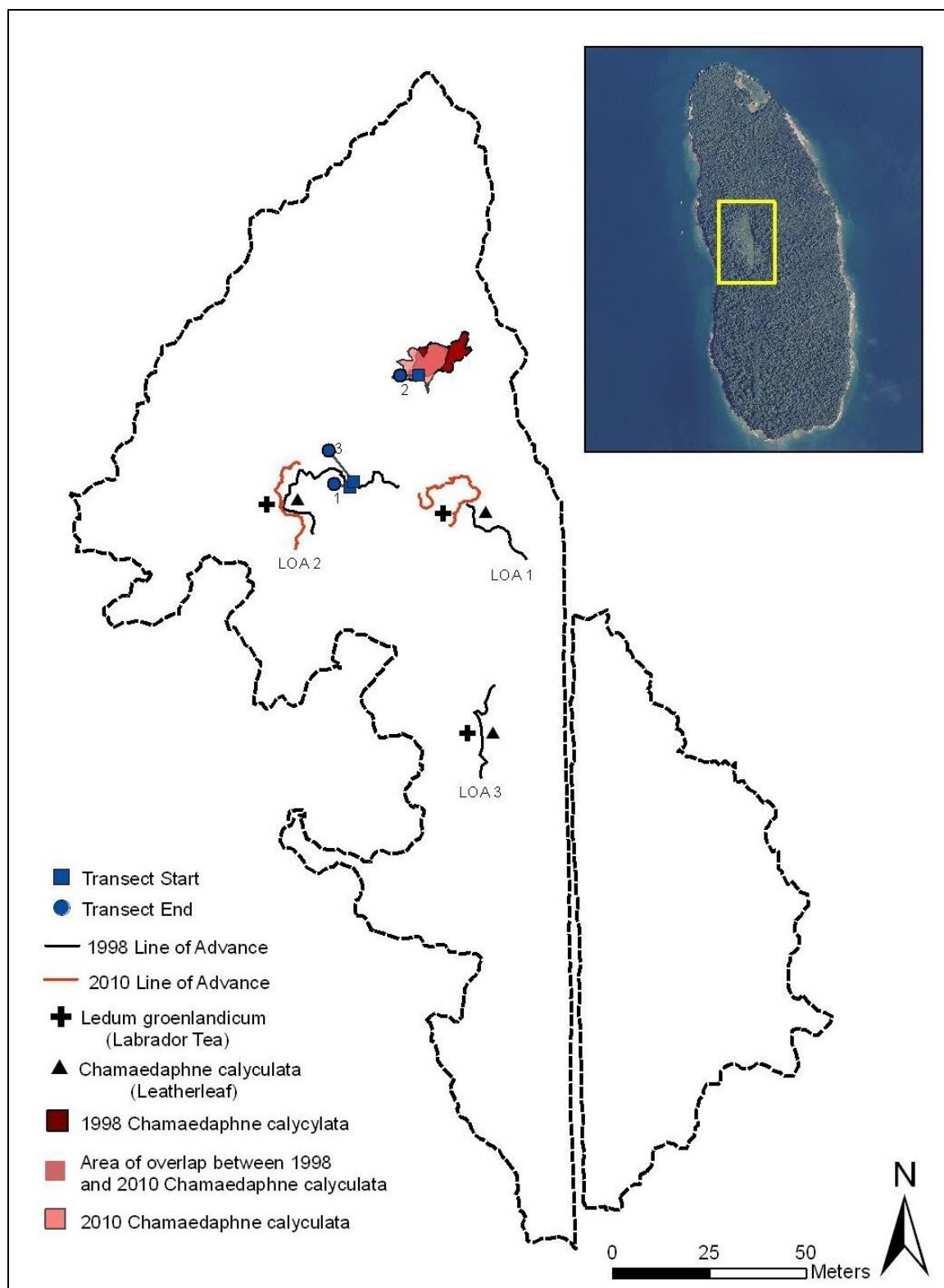


Figure 10. Placement of three transects on Devils Island re-sampled in 2010 for all taxa present, and three lines of advance (LOAs) of select taxa.

The assessment for Outer Island was modified from the above-mentioned LOA approach. On Outer Island *Phragmites australis* was assessed as a 554-m, linear shoreline feature, along which is indicated whether *Phragmites* occurred or not (Figure 11). In 2010, *Phragmites* occurred along 64% of this shoreline, but there was still a small peninsula essentially *Phragmites*-free except for a very small section. This peninsular distribution of *Phragmites* is very similar to the 1998 assessment (Figure 5 of Meeker 2000), but overall it appears that *Phragmites* has coalesced into a solid band line of presence both north and south of this peninsula. This shoreline approach indicates the presence or absence of *Phragmites*, not necessarily its density, which we observed to have declined in the small area covered in Transect 2 (see Table 13). It is very possible that a taxon such as *Phragmites* could decrease in density per square meter, while advancing as scattered stems into an area where it did not occur previously.

Assessment of change at the Sand River site (Figure 12) suggests that cattail (*Typha* spp.) declined in both stem density and frequency over time in each of the three transects, from a total of 35 stems in 15 of 45 quadrats in 2001 to 9 stems in 8 of 45 quadrats in 2010 (see Table 13).

The placement of the three transects in the Stockton Island lagoon (Figure 13) indicates they were distributed over areas with scattered *Sphagnum* hummocks. These hummocks were distributed much as they were mapped in 2001, suggesting little change in vegetation community boundaries (Figure 7 in Meeker 2002).



Figure 11. Placement of two transects on Outer Island, re-sampled in 2010 for all taxa present, and one line of advance (LOA) for *Myrica gale*. *Phragmites* was sampled for presence and absence in a linear assessment.



Figure 12. Placement of three transects at the Sand River estuary, re-sampled in 2010 for all taxa present.



Figure 13. Placement of three transects at Stockton Island lagoon, re-sampled in 2010 for all taxa present. Location of *Sphagnum* clones were delineated in 2010.

On Long Island, of eight transects established (Figure 14), seven were sampled for all taxa in both 2002 and 2010. Due to logistic constraints, Transect 5 was only sampled for stem density of *Carex rostrata*/*C. utriculata* in 2002 and 2010. *Typha*—occurring in four transects—has apparently declined in abundance over the time period. In 2002, there were 47 stems that occurred in 20 of the 70 total quadrats, while in 2010 there were 19 stems occurring in 8 of the 70 quadrats (Table 14).

The combination of *Carex utriculata*/*C. rostrata* occurred in two Long Island transects. It increased over time from 197 stems in 25 of the 30 quadrats in 2002 to 280 stems in 29 of the 30 quadrats in 2010 (Table 14).

Three additional taxa were tracked by stem density along Long Island transects including common reed (*Phragmites australis*), woolgrass (*Scirpus cyperinus*), and purple loosestrife (*Lythrum salicaria*), all apparently declining over time (Table 14). Figures 15–18 show the location of the eight transects relative to surrounding vegetation.

Table 14. Changes in stem density (per 1 m × 1 m quadrat) and percent frequency of occurrence over time for select aggressive taxa at transects on Long Island. Assessment was along the same transects that percent-cover was recorded.

Long Island	Transect	Stem Density 2002	Quadrat Frequency (%) 2002	# of Quadrats (2002 and 2010)	Stem Density 2010	Quadrat Frequency (%) 2010
<i>Typha latifolia</i>	1	13	20	20	10	15
	2	6	27	15	0	0
	3	24	53	15	9	33
	6	4	20	20	0	0
	Totals	47	—	—	19	—
<i>Carex utriculata</i>	4	109	93	15	134	100
	5	88	73	15	146	93
	Totals	197	—	—	280	—
<i>Phragmites australis</i>	6	10	20	20	0	0
<i>Scirpus cyperinus</i>	7	65	60	20	35	50
<i>Lythrum salicaria</i>	8	37	50	20	1	5

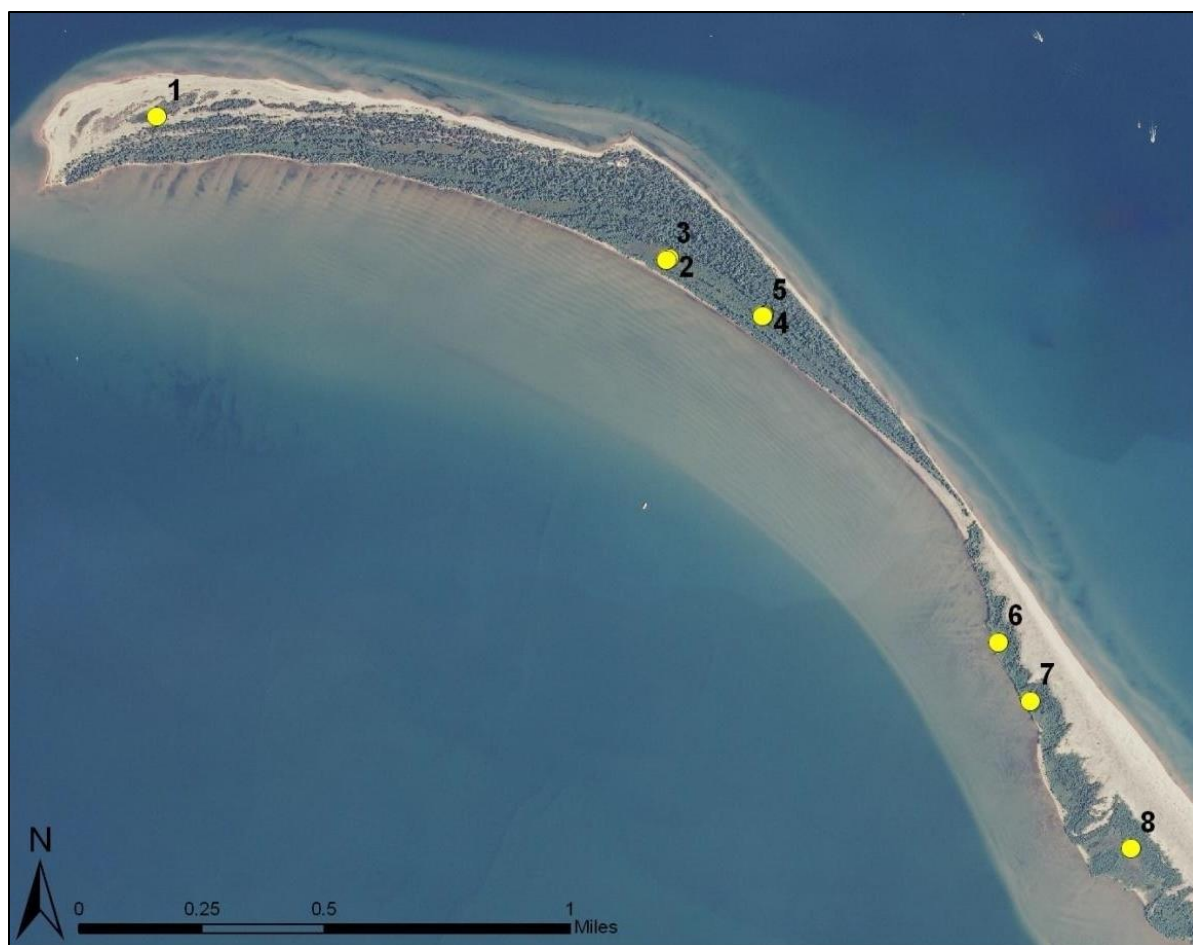


Figure 14. Placement of seven transects on Long Island, re-sampled in 2010 for all taxa present. Transect 5 was not sampled in 2001 and not included in the analyses.

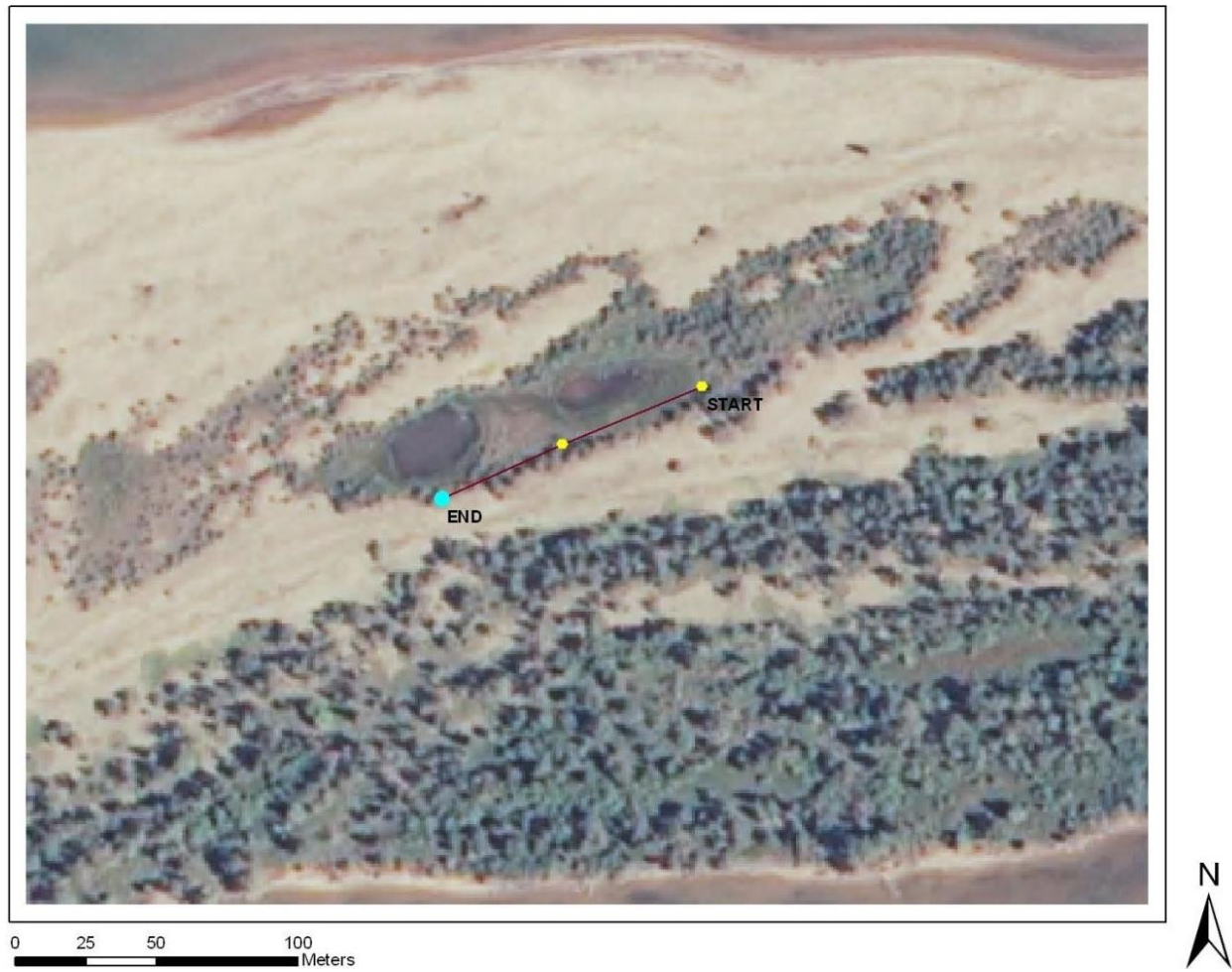


Figure 15. Placement of Transect 1 on Long Island, re-sampled in 2010 for all taxa present.



Figure 16. Placement of Transects 2 through 4 on Long Island, re-sampled in 2010 for all taxa present. Transect 5 was not sampled in 2001 and not included in the analyses.

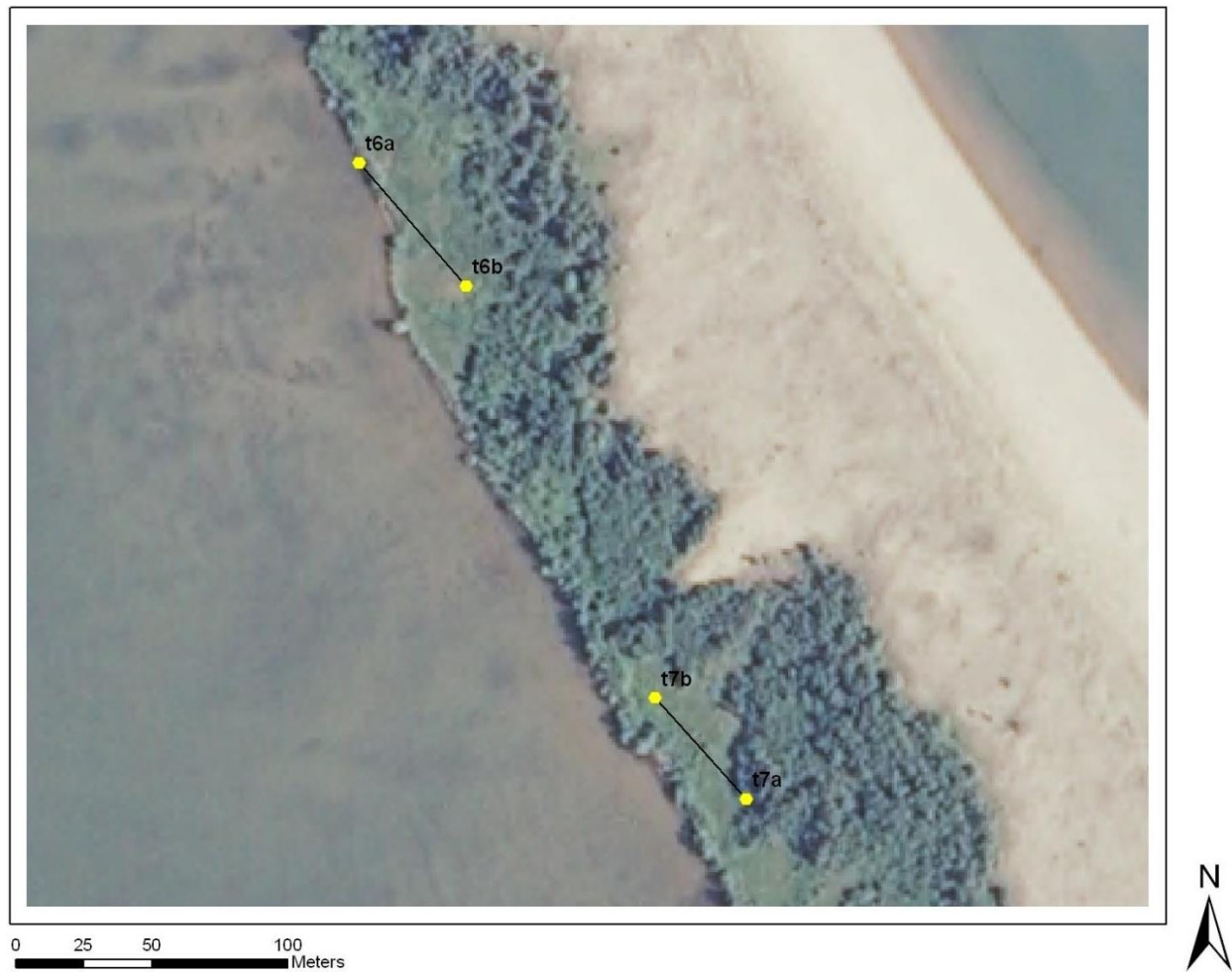


Figure 17. Placement of Transects 6 and 7 on Long Island, re-sampled in 2010 for all taxa present.

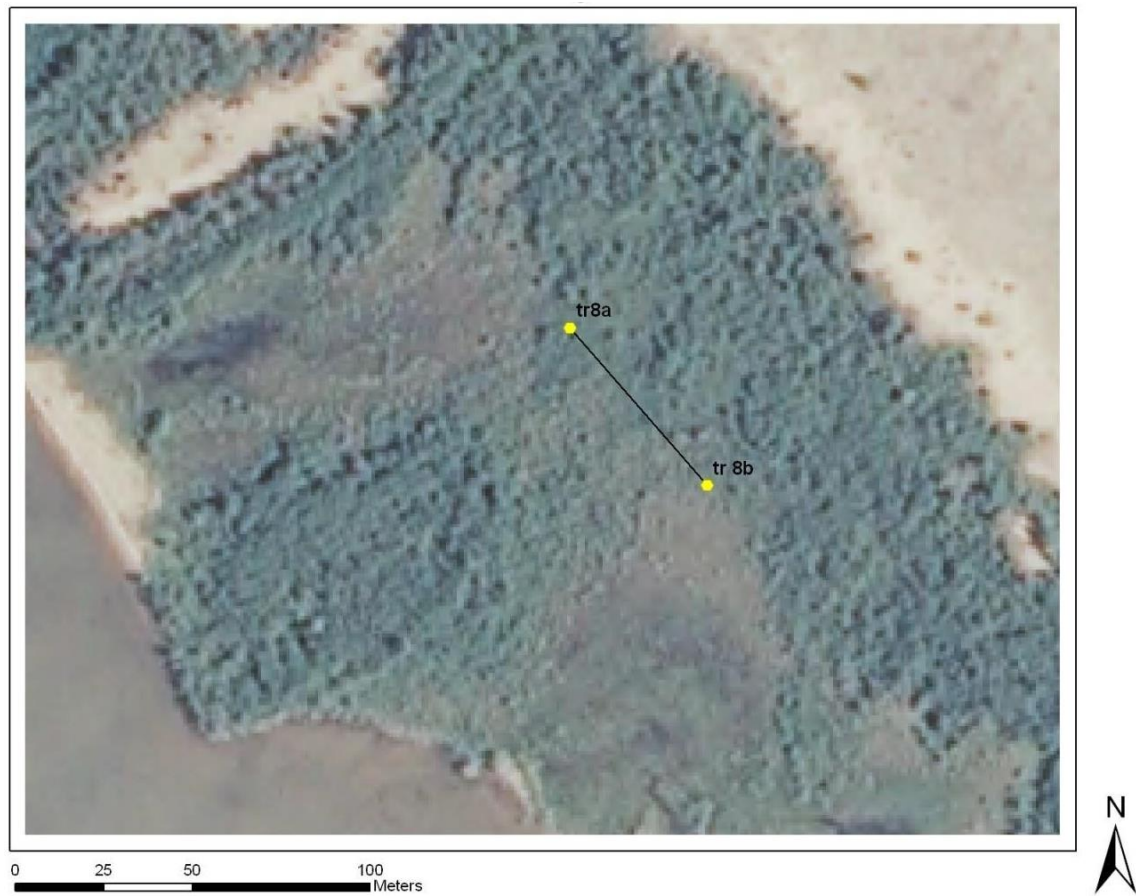


Figure 18. Placement of Transect 8 on Long Island, re-sampled in 2010 for all taxa present.

Discussion

The Pulse Stable Concept

Lake Superior coastal wetlands, including those of the Apostle Islands, often are ecologically different from mainland marshes and bogs in part because they are subject to quasi-periodic year-to-year water level fluctuations. It is thought that these water level changes affect wetlands through a process that ecologists term “pulse stability” (Environment Canada 2002). Both flooding and dewatering provide the important pulses that drive shifts in vegetation, maintain the health and viability of these coastal wetlands by flushing them of accumulated detritus, expose and oxidize sediments from time to time, and prevent dominance by any one species. So, even as the wetlands constantly change in species abundances in the short term, over longer time scales they remain stable as specific wetland types (hence the term “pulse stability”). This process is thought to exist as long as the climate remains relatively constant and exotic species are not a major factor.

However, we do know that in many Great Lakes wetlands (Tulbure et al. 2007), and in large lakes in general (Meeker and Harris 2009), a number of aggressive exotic plants, including species such as narrow-leaf cattail, common reed grass, purple loosestrife, and, at higher elevations, reed canary grass have invaded. The changes in these cases do not appear to be cyclic (or pulse stable), but directional, with richness of smaller plant species eventually being reduced. This peatland-to-marsh transition, already complete in many Lake Ontario wetlands (Wilcox et al. 2008), is progressing in several Lake Superior coastal wetlands outside the Apostles. One of the main objectives of this monitoring project was to determine if these APIS wetlands are indeed behaving in the manner suggested by the pulse stable concept, or whether we are seeing the beginnings of directional change.

Water level changes from high to low have historically occurred numerous times on Lake Superior, and have averaged about 0.7 m (Figure 19). Ideally then, we would have wished to monitor these wetlands over a cycle of high water through low water and back to high to see if the wetland vegetation also behaved cyclically. Unfortunately, the water level fluctuations have not offered us this opportunity. Instead, as we see in the plot of a 20-year, summer-month, three-year running average, we began our first sampling in 1998–2002, the start of a decade of generally low water (Figure 20). So rather than monitoring over an entire high-to-high cycle, we observed a high-to-low event, and the following review of our results should bear this in mind. In this case, the predicted change would be a loss of wetter habitat due to invasion from higher elevations by shrub taxa.

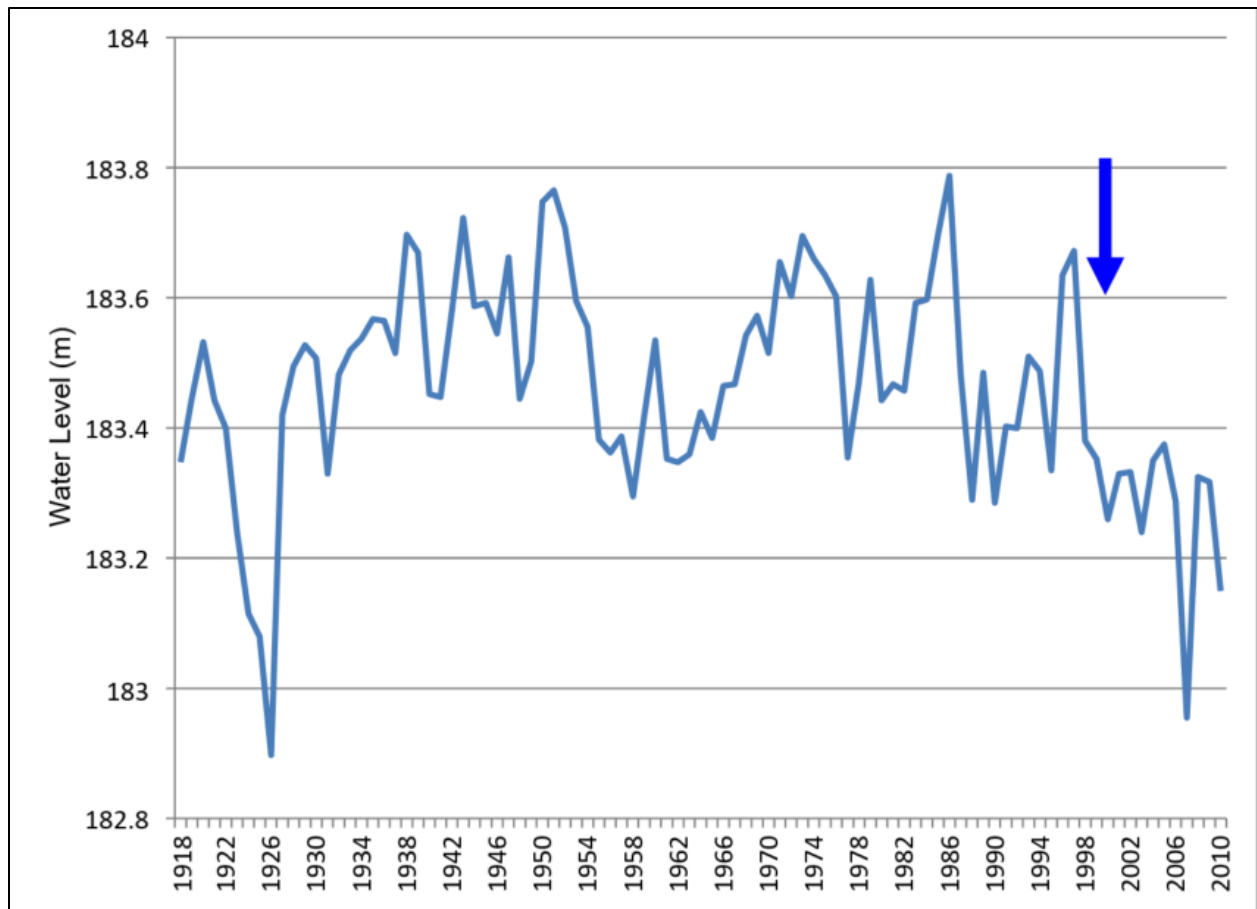


Figure 19. Average summer (May–August) water levels in Lake Superior 1918–2010, in meters. Arrow indicates start of wetland monitoring.

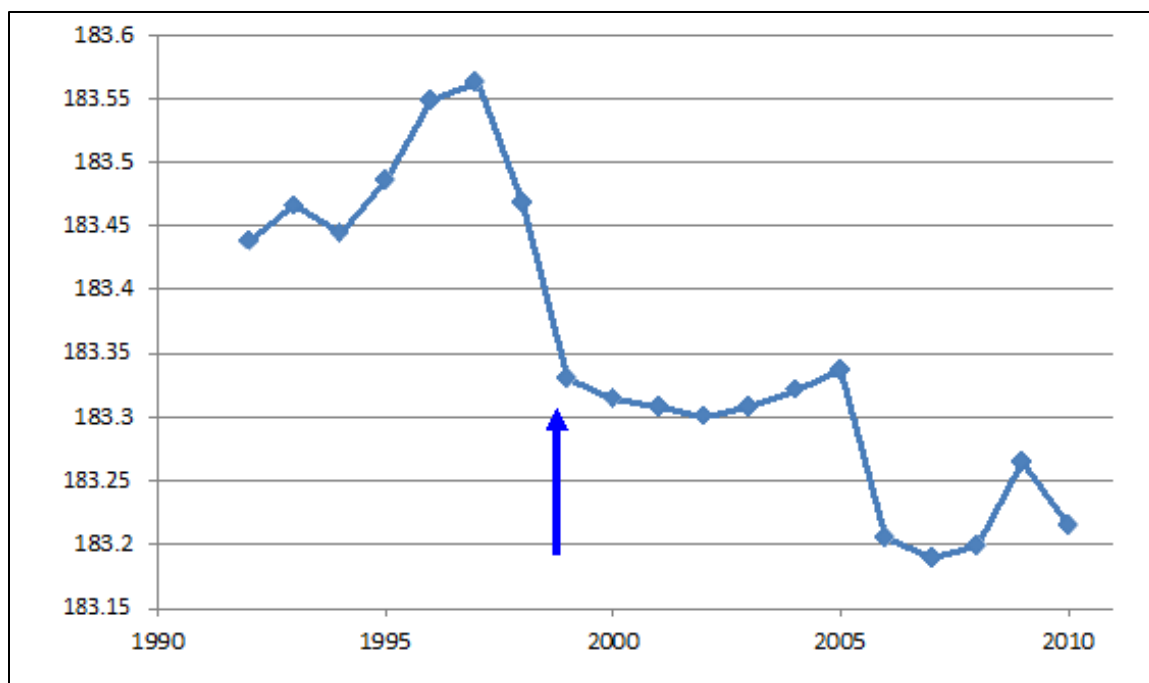


Figure 20. Three-year running average of summer water levels (May–August) on Lake Superior, 1991–2010. Arrow indicates start of wetland monitoring.

Summary of Results

The ordination plot (see Figure 1) and the analysis of the vector length both indicate that the *Sphagnum*-dominated community type changed little over the decadal drying cycle when compared to the sedge-meadow community type. In addition, the differences between these two community types were much greater than any changes in vegetation over time; that is, they plotted apart at both times.

It should be noted that we lumped all *Sphagnum* species (there were likely 5–6 different species), and may have missed shifts in *Sphagnum* species composition over time that would suggest that the bog communities changed more than we report. However, *Sphagnum* species identification coupled with an accurate estimate of their covers was not attempted.

The second ordination (see Figure 2), which included only those transects dominated by *Sphagnum*, suggests that most bog transects changed about the same from Time 1 to Time 2 (the successional arrows were of the same length).

Taxa that were noted to have increased substantially over time include a number of woody taxa such as brambles (*Rubus* spp.), leatherleaf (*Chamaedaphne calyculata*), sweet gale (*Myrica gale*), tamarack (*Larix laricina*), cranberry (*Vaccinium* spp.), bog laurel (*Kalmia polifolia*), and black spruce (*Picea mariana*) (see Table 8). This is consistent with what one may expect during a drying period. The “decreasers” also fit the predicted pattern of loss, that is, the decline of more obligate wetland taxa such as wide-leaf cattail (*Typha latifolia*), bladderwort (*Utricularia* spp.), water arum (*Calla palustris*), and a number of the sedge family (*Cladium*, *Rhynchospora*, and *Carex* spp.).

A more generalized approach of noting change in abundance over time included the lumping of taxa into life from categories (see Tables 9 and 10). Again, as expected, 21 of the 24 woody taxa increased in RIV over the 8 to 11 year period, while all of the 13 “aquatic” taxa lost ground. It was a mixed result for the forb and the graminoid groups, with 18 of the 45 forbs taxa increasing, and 13 of the 45 graminoids increasing (see Table 10). These results were also expected, as one would predict that the two extreme ends of the water level gradient (the aquatics on the wet end and the woody plants on the dry end) would respond more quickly to decadal changes in water levels. In addition, many of the forb taxa appear to be weedy colonizers such as sticktights (*Bidens* spp.), thistles (*Cirsium* spp.), hawkweeds (*Hieracium* spp.), dandelions (*Taraxacum* spp.), sow thistle (*Sonchus* spp.), and smartweeds (*Polygonum* spp.).

Another potential indicator of a general drying trend would be the increased growth rates of tree species such as black spruce and tamarack that we noted in bog forest communities. In all cases, the overall pattern was a period of good growth early on with decreases in the late 1950s through the 1970s, followed by increased growth beginning in the early 1990s. It is interesting to note that this increased growth rate, which may have been due to a reduction of the extremely saturated soils, could eventually result in another decline of tree growth rate if the soils dry out too much.

Conclusion

It appears that the results of this monitoring, following only one half of a full high water to low back to high water cycle, falls short in demonstrating that the natural cycle of wetland vegetation change (pulse stability) is still operating. That is, we have not experienced a return of high water to re-sample. However, we have demonstrated that the drawdown portion is as would be predicted, with a loss of aquatic taxa and an increase in woody taxa. In addition, the general decadal drying may have halted the advance of some of aggressive taxa. For example, the decline of cattail was also seen in the changes in stem densities over time (see Tables 13–14), as well as the RIV analysis (see Table 8). Of note, in addition to the decline in cattail abundance, was the general decline in purple loosestrife (*Lythrum salicaria*) stem densities at Long Island Transect 8, suggesting that a combination of drying habitat and herbicide application have helped slow the advance of this normally aggressive taxon. Other taxa assessed for stem densities (in addition to cover) showed declines, including bulrush (*Scirpus cyperinus*) and common reed (*Phragmites australis*), while the combination of beaked sedges (*Carex utriculata* and *C. rostrata*) declined at some sites but increased at others (see Tables 12–14). It will take another high water period to determine if we are experiencing a directional change or cyclic change, and the water levels on the big lake just have not cooperated. If climate is indeed changing, resulting in a long-term period of lower water levels, we may be observing the beginnings of directional change.

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Appendix 1. Year sampled and UTM coordinates for the beginnings and ends of the Lines of Advance (LOAs) on select Islands (UTM Zone 15, NAD 27 Datum).

Location	LOA #	Year	Beginning		End	
			X	Y	X	Y
Devils Island	1	1998	672478	5215494	672500	5215507
	2	1998	672517	5215502	672533	5215488
	3	1998	672525	5215455	672521	5215431
	1	2010	672513	5215496	672505	5215505
	2	2010	672474	5215512	672473	5215490
Michigan Island	1	1998	689671	5194388	689653	5194380
	2	1998	689699	5194275	689690	5194250
	3	1998	689742	5194186	689721	5194248
	4	1998	689484	5194285	689515	5194293
	1	2010	689654	5194395	689645	5194383
	2	2010	689729	5194261	689716	5194285
	3	2010	689741	5194187	689721	5194278
Stockton Island Interior Bog	1	2001	686848	5202749	686893	5202837
	2	2001	686867	5202745	687043	5202829
	3	2001	687432	5202599	687428	5202529
	1	2010	686891	5202834	686835	5202781
	2	2010	686902	5202778	686936	5202761
Outer Island lagoon (<i>Phragmites</i> assessment)	–	2010	693049	5209153	693228	5209472
Sand Island North (tree transect)	–	2010	656903	5205292	656912	5205590

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