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Research Article

Vegetation Changes in Tree and Shrub Species in Forested Island Communities in Lake Winnipesaukee, New Hampshire, USA

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Abstract

We documented changes in overstory species composition and foliar cover during a 33-year sampling period, compared woody species on three small islands in Lake Winnipesaukee, New Hampshire, and determined changes in dominant plant species over time. Floristic surveys had begun on these islands in 1901, and provided valuable information about earlier vascular plant composition. Woody species were observed and measured in 25 permanent plots that were established on the three islands in 1978. The overstory was measured by frequency, density, and dominance of individual tree and shrub species. Data from the study show that species richness increased significantly from 1978 to 1991 on all three islands but remained relatively constant in 1991, 2001, and 2011. Species evenness on all the islands remained relatively constant in all four years of sampling. The dominant species in the study were *Pinus strobus, Quercus rubra,* and *Tsuga canadensis*.

Keywords: *Acer pensylvanicum*; Freshwater Island Vegetation; Forest Succession; *Hamamelis virginiana*; Long-Term Study; *Pinus strobus*; *Quercus rubra*; Temperate Forests; *Tsuga canadensis*

Introduction

Despite widespread alteration of the New England landscape since European settlement, there have been few major shifts in species distributions, but several notable changes in the relative abundance of tree taxa [1]. Various studies have collected data on the overstory throughout the region [2-4]. In one recent study conducted at the University of New Hampshire by [5], the overstory species reported were similar to those of the three islands of our study [6]. The species included *Acer rubrum, Acer saccharum, Betula alleghaniensis, Betula lenta, Fagus grandifolia, Fraxinus americana, Pinus strobus, Quercus rubra, Tilia americana*, and *Tsuga canadensis*. A few of these species, including *Tsuga canadensis*, have been important in the natural history of New Hampshire [5]. In this study, we continue to assess the influence of environmental variation and land-use history on forest composition and distribution on islands of central New Hampshire [6]. We focused on the vegetation of three of the 253 islands in Lake Winnipesaukee: Blueberry (BI), Hawk's Nest (HNI), and Three Mile (TMI) islands. These three islands are either owned or managed by the Appalachian Mountain Club (AMC), which allowed the senior author, who is a member of the Club, easy access for sampling. Detailed site descriptions of the three islands are available in [6]. Residents of the Lake Winnipesaukee area began tracking "ice-out" on the Lake in 1887. The ice-out date has been observed and recorded for nearly 130 years. The setting of the exact date and time is non-scientific and is now determined by an observer in a small plane that flies over the lake several times a day. Records show the latest date for ice-out on May 12, 1888, while the earliest date occurred on March 18, 2016. Thus, these records provide documentation for an overall warming trend in central New Hampshire.

In 1900, the AMC established a permanent camp on Three Mile Island [7]. TMI soil is strongly acidic, dominated by gravelly sand and gravelly muddy sand, low in essential nutrients and fairly homogenous in terms of moisture and bulk density [8]. This island has an elevation gradient of 50 feet, increasing as one moves to the interior. Shore areas have elevations of 470 feet above sea level, while the island's center is 520 feet above sea level [9]. By the early

1970's the Camp had grown and the managers' realization that certain land uses needed to be restricted led to the implementation of a land use plan [38,39]. Following an adaptation from [12] four types of environments needed by humans, the Camp was divided into Protective, Productive, Urban, and Compromise zones [13]. Protective and Productive zones are exposed to relatively little human use, whereas Urban and Compromise zones support the majority of human activity. Lake islands are not typically considered "closed" ecosystems as compared to oceanic islands [14]. Lake islands, such as those of Lake Winnipesaukee, are generally closer to the mainland than are oceanic islands. As such their floras may be comparable to the surrounding mainland due to their close proximity and lack of definitive physical barriers separating them from the mainland flora. Despite this, they may still be subject to broad ecological principles that apply to oceanic islands [15]. Humans have often endangered certain plant species through different activities such as habitat destruction and unintentional species movement. In particular, these activities often lead to the introduction of nonnative plant species, which sometimes may threaten to outcompete or eliminate native vegetation. The introductions of such exotic species have led to concern about the impact that these nonnative species may have on the native flora and fauna of ecosystems [16,17]. This study was part of a continuing effort to document the flora of three islands which started in 1901 when the camp on TMI was founded, and the earliest floristic survey was made by landscaper [18]. The most extensive early compilation of vascular plant species on the island was made by [19] and included many of the notations and collections made by J.H. Emerton (in May 1906) and R.A. Ware (in July 1906), as well as by Pease. Other collections on the island included those of [20] and [13] undertook an extensive study that compared their collections with those of [18,19,20]. Many of these collections are preserved in two Massachusetts herbaria (NEBC at Harvard University and SCHN at Smith College). Floristic studies were also conducted on other islands in Lake Winnipesaukee, including Rattlesnake [21], Bear [22] and Timber Islands [14,23]. Sizes of these islands and the most recent number of species found on each are compared below (Table 1). We also looked at the relationships between the native and nonnative plant species on the three smallest islands. "Nonnative" species are those that had been introduced to the islands since 1901, even those that are native to the New England area. In 1901 Harlan Kelsey donated 481 plants of 60 different species to the TMI Camp, only 9 of which were native to the island. However, most of these introductions did not survive over the years, and by the mid-1980's only 20% of Kelsey's introductions were observed [13]. Species reported by [13] which had not been recorded on Pease's list include: *Aster nemoralis, Chenopodium album, Festuca elatior, Oxalis europaea, Phalaris arundinacea*, and *Stellaria media*, all of which were found in the Urban Zone. The current investigation looked at the composition and abundance of the native and nonnative plant species historically since 1978 when ecological studies began [39]. Any invasive, nonnative, or threatened species was considered a "species of concern" [24]. This manuscript follows up on previous work described by [18,19] [13] and [6], and underscores the utility of long term studies in identifying trends in vegetation change and dynamics especially in the context of climate change. Distributions of tree and shrub species were generated for each plot in each of the four land-use zones. To provide a manageable dataset, we report here on numbers of adult woody species (trees and shrubs), and will report on seedlings and herbs in a separate manuscript. Each year of measurement used the bootstrap, sampling with replacement [25,26]. The resampling procedure involved pooling the data for each year and zone; for example, one data pool contained data from the protective plots assessed in 1978. Then N samples were randomly selected from and replaced to a given data pool, where N equals the number of circular plots within a given land use zone. The mean of the N samples was then calculated and recorded and the procedure repeated for each measurement year and land-use zone combination through 10,000 iterations using @Risk software (Palisade, Inc., Ithaca, NY), within Excel (Microsoft Inc., Redmond, WA). Distributions of tree and shrub species were modeled by bootstrapping data for each sampling period. The increase in total overstory species in the protective and compromise zones between 1978 and 1991 was significant, and was very likely the result of a major storm in December 1980 which opened up the canopy [6]. No other significant differences in the frequency distribution of total overstory species in any of the other land-use zones, over the periods 1978-1991 and 1991-2001, were observed [11] and 2001-2011 [27]. The 1980 storm affected eight of the sampling plots on the north end of TMI, one plot on the north end of HNI, and one plot on the northeastern end of BI. While individual trees have been struck by lightning or toppled by strong winds, no storm events as massive as the December 1980 storm have been experienced since then.

The following are the "species of concern" on TMI, HNI, and BI. The species listed as invasive in various databases are *Berberis thunbergii* [17], *Poa compressa* [17], and *Robinia hispida* [16]. The species that are not native to the islands but were introduced by Harlan Kelsey in 1901 are *Halesia carolina* and *Rhododendron calendulaceum* [52]. The rare, threatened and endangered species are *Cypripedium arietinum* [28], *Rhododendron maximum* [28], and *Rhododendron viscosum* [52]. The species that are of concern to island campers, but do not fall under the above categories are *Apios americana* and *Desmodium perplexum* [17, 52]. We present results from plot-based ecological studies that quantify the frequency, distribution, density, and dominance of woody species listed in [13] floristic survey. Based on the theory of island biogeography [29, 30, 31] we predicted total species richness would be highest on the largest island (Three Mile), lowest on the smallest (Blueberry), and that species richness would increase over time [32]. Second, we expected to see a decrease over time in the importance of *Fagus grandifolia* and *Tsuga canadensis*, which were threatened in other places by two non-native invasive species: the hemlock wooly adelgid beetle to the south [33, 34,35] and beech bark disease on the mainland [36,37]. Third, we predicted species richness would be higher in the Protective and Productive plots, and lower in the Urban and Compromise plots where most trails are located.

Island	Size (ha)	No. of plant species
Bear	303.5	317
Rattlesnake	161.9	255
Timber	54.6	187
TMI	17.4	80
HNI	0.41	35
BI	0.27	40

Table 1: Lake Winnipesaukee islands where flora was surveyed. This table includes the most recent number of species and sizes of the islands in hectares. Bear, Timber, and Rattlesnake islands' data were summarized from [14]. Three Mile, Hawk's Nest (HNI) and Blueberry Islands (BI) were summarized from the 2011 sampling.

Materials and Methods

This study was a part of a regular ecological sampling of the vascular flora that has occurred on TMI, HNI and BI islands since 1978 [10]. Samplings occurred on the islands at roughly ten year intervals in 1978, 1991, and 2001 [6,32]. The fourth sampling occurred in the summer of 2011 from June 11 to July 2 and followed the protocol of the other samplings. In 1978, 25 permanently marked circular plots were randomly distributed across the three islands, and their numbers were assigned based on coordinates in a number grid [10]. Each circular plot was 34 m (111.5 ft) in diameter and was approximately 908 m^2 [39], and the overstory plants were sampled in the circular plots [10, 11], while 1m x 1m square quadrats nested within each larger plot were used for sampling understory plants [39]. Nomenclature followed [40] and [52]. In the summer of 2011, a team of volunteers was gathered to assist with the sampling. They were campers at TMI and had prior knowledge of the islands' flora because of their experiences as professional foresters or volunteers with the New England Wildflower Society. Sampling consistency since 1978 has been provided by the senior author. The team sampled the understory first and then the overstory for each plot. Then the team surveyed the islands for any plant species of concern, and made notes on abundance and location for each species. Within the 25 larger plots, woody plants over 2.0 m in height were recorded as part of the "overstory," which included both tree and shrub layers [6]. The number of individuals (density), the number of plots (frequency), and the size and/or canopy position (dominance) of each species were recorded [6]. Two different methods were used to calculate relative dominance. The first method used a rating system of canopy position developed by Smith [6,41,42] and the second measured diameter at breast height (dbh) [43]. Individual trees and shrubs were assigned to one of four categories descriptive of their relative vertical position in the forest, including: overtopped (formerly "suppressed" in Smith 1962), intermediate, codominant and dominant, respectively [32,39, 42].

Dominant trees were those having crowns extending above the level of general crown cover receiving full light from above and partly from the sides. Co-dominant trees had medium-sized crowns and received little light from the sides. Intermediate trees were shorter than those in the two preceding classes; receiving a little direct light from above but none from the sides. Overtopped (e.g. short trees, saplings, and tall shrubs) had crowns entirely below the general level of the crown cover [6,42]. From these data, a mean was calculated by dividing the four summed ratings for each species by the number of individuals of the species in each plot. Knowing the mean canopy class has proven to be biologically meaningful in studying natural forests where competition is fierce for trees growing on gravelly sandy substrates such as these islands. For the 2011 sampling, diameter at breast height (dbh) was also recorded for the trees on TMI and HNI that were larger than 2.5 cm dbh. but not at BI due to the presence of bald eagles nesting on the island. After each tree was identified and recorded, a piece of visible tape was placed on the tree to ensure that it was not recorded again. As had been done in the 1978, 1991, and 2001 samplings, importance values were calculated for each species. The importance value of a species is a relative quantitative measurement that combines density, dominance, and frequency. These parameters' influence can vary in calculating importance values, where one parameter such as frequency may be higher than density. Using [44] method, importance values are also influenced by the number of species, so if only one species is present, its importance value would be 300. In general, an importance value represents the prominence of a species in an ecosystem [45]. Importance values of overstory species were based on relative frequency, relative dominance and relative density [44]. Note that in the following formulas, "q" represents one species. Relative dominance was calculated using the following formula: (rating species q/ ratings of all species) x 100 or (basal area of species q/ basal area of all species) x 100. In an effort to obtain the most accurate data for species dominance, the 2011 sampling plan had been to measure the dbh of each woody specimen. However, NH Audubon would only allow us to sample on BI if we agreed to move quickly on and off the island. Thus, in consideration of the bald eagle eaglets, the team agreed to use the faster "rating" approach. Relative density was calculated using the following formula: (number of individual species q)/ (total number of individuals of all species) x 100. Relative frequency was calculated using the following formula: ((number of plots species q was found in/total frequency of all species) * 100). Then, the importance values were calculated from the sum of the relative density, relative dominance and relative frequency. Lastly, the prominent species in the overstory of each island were determined from the importance value data. The dbhs recorded on Three Mile and Hawk's Nest islands were converted into basal areas using the following formula: Basal area = $(DBH^2*0.7458)/10000$ (cm^2/m^2) [43], and the basal areas were then summed for each species in the plots. The dbhs from 2011 were summed for HNI and TMI and these data were used to calculate relative dominance. Each calculation of relative dominance was used to determine a second set of importance values. These importance values were compared with the set of 2011 importance values calculated from ratings to demonstrate any differences in the overstory sampling methods. Shannon's Diversity index was calculated to determine the diversity of the plots and the islands. The Shannon's Diversity index took into account both the species richness and evenness in the sampling year. The index was calculated using the following formula: $H' = -\Sigma^{S}_{i=}1(p_i{*}\ln(p_i))$ where p_i is the proportion of individuals of a species (number of individuals/total # of individuals in the sampling) and S is the total number of species in the sampling. The closer the index is to ln(S), the more even the sampling. Species evenness was calculated using the formula E = H'/ln(S) where H' is the Shannon's Diversity Index and S is the number of species from that sample. From these values, the diversity and evenness were compared across the four years of sampling for the islands' overstory.

Results

Three Mile Island

Since 1978, the species with the highest importance values (IV) on TMI were (Table 3; Figure 1): *Acer pensylvanicum, Acer rubrum, Fagus grandifolia, Hamamelis virginiana, Pinus strobus, Quercus rubra*, and *Tsuga canadensis*. Whether ratings or basal areas were used to calculate dominance in 2011, these same seven species are most important (Table 2). The density of *Acer pensylvanicum, Fagus grandifolia, Hamamelis virginiana*, and *Tsuga canadensis* increased over the 33year sampling (Figure 2). By 2011, *Acer pensylvanicum, Acer rubrum, Pinus strobus, Quercus rubra*, and *Tsuga canadensis* appeared in all 19 plots (Figure 3). In 2011, *Quercus rubra* had the highest canopy position and size in the overstory (Figure 4). Species of concern were only encountered on TMI (Tables 2,3). While *Robinia hispida* has been found in the plots during three samplings, its mean importance value is 4. *Halesia Carolina* was sampled in the overstory in 1991, but not since (Table 3), and *Rhododendron maximum* was only sampled in 2011. The understory species of concern will be discussed in a separate manuscript.

Species	Frequency	Density	Sum of Ratings	Dominance	DBHs	IV
Acer pensylvanicum L.	19	852	1005	1.2	520.918	27
Acer rubrum L.	19	507	892	1.8	1116.152	22
Acer saccharum Marshall	7	52	88	1.7	178.521	8
Alnus incana (L.) ssp. *rugosa* (Du Roi) R.T. Clausen	3	143	151	1.1	48.894	6
Amelanchier laevis Wiegand	4	55	58	1.1	24.66	5
Betula alleghaniensis Britton var. *alleghaniensis*	-	-	-	-	-	-
Betual lenta L.	2	9	13	1.4	40.547	4
Betula papyrifera Marshall	6	30	60	2	226.853	8
Betual populifolia Marshall	3	13	19	1.5	33.635	5
Cephalanthus occidentalis L.	-	-	-	-	-	-
Fagus grandifolia Ehrh.	18	722	1014	1.4	760.555	26
Fraxinus americana L.	1	2	5	2.5	27.182	6
*Gaylussacia baccata (*Wangenh.) K. Koch	1	1	1	1	1.638	3
Halesia carolina L.	-	-	-	-	-	-
Hamamelis virginiana L.	16	1229	1364	1.1	275.129	33
Ilex mucronata (L.) Powell, Savolainen & Andrews	-	-	-	-	-	-
Ilex verticillata (L.) A. Gray	3	67	89	1.3	22.299	6
Lyonia ligustrina (L.) DC.	-	-	-	-	-	-
Nyssa sylvatica Marshall	2	21	28	1.3	40.624	4
Ostrya virginiana (Mill.) K. Koch	7	255	334	1.3	141.595	11
Pinus resinosa Aiton	7	31	67	2.2	302.715	9
Pinus strobus L.	19	330	684	2.1	1694.149	20
Populus grandidentata Michx.	5	16	32	2	136.972	7
Populus tremuloides Michx.	-	-	-	-	-	-
Prunus pensylvanica L. f.	-	-	-	-	-	-
Prunus serotina Ehrh.	2	9	12	1.3	25.277	4
Quercus alba L.	-	-	-	-	-	-

Quercus rubra L.	19	260	783	3	2239.216	21
Rhododendron maximum L.	1	2	3	1.5	7.568	4
Rhus typhina L.	-	-	-	-	-	-
Robinia hispida L.	2	3	4	1.3	1.638	4
Sambucus nigra L. ssp. *canadensis* (L.) R. Bolli	-	-	-	-	-	-
Tilia americana L.	2	4	10	2.5	42.391	7
Tsuga canadensis (L.) Carriere	19	624	947	1.5	1270.158	24
Vaccinium corymbosum L.	4	83	83	1	24.297	6
Vaccinium fuscatum Aiton	6	80	88	1.1	36.351	7
Viburnum acerifolium L.	10	44	44	1	31.657	8
Viburnum lentago L.	2	17	17	1	8.188	4
Viburnum nudum L. var. *cassinoides* (L.) Torr. & A. Gray	-	-	-	-	-	-
Totals	209	5461	7895	43.1	9279.78	300

Table 2: 2011 Sampling Data for trees and shrub species of Three Mile Island.

Species	1978	1991	2001	2011
Acer pensylvanicum L.	27	26	29	27
Acer rubrum L.	25	27	22	22
Acer saccharum Marshall	14	8	9	8
Alnus incana (L.) ssp. *rugosa* (DuRoi) R.T. Clausen	-	6	7	6
Amelanchier laevis Wiegand	-	4	4	5
Betula alleghaniensis Britton var. *alleghaniensis*	-	4	-	-
Betula lenta L.	10	7	7	4
Betula papyrifera Marshall	23	12	12	8
Betula populifolia Marshall	-	3	3	5
Cephalanthus occidentalis L.	-	2	-	-
Fagus grandifolia Ehrh.	29	18	23	26
Fraxinus americana L.	-	6	2	6
Gaylussacia baccata (Wangenh.) K. Koch	-	3	3	3
Halesia carolina L.	-	4	-	-
Hamamelis virginiana L.	21	31	31	33
Ilex mucronata (L.) Powell, Savolainen & Andrews	-	5	5	-
Ilex verticillata (L.) A. Gray	-	-	3	6
Lyonia ligustrina (L.) DC.	-	2	3	-
Nyssa sylvatica Marshall	10	5	5	4
Ostrya virginiana (Mill.) K. Koch	8	9	9	11
Pinus resinosa Aiton	14	8	10	9
Pinus strobus L.	34	21	20	20
Populus grandidentata Michx.	-	7	8	7
Populus tremuloides Michx.	12	5	4	-
Prunus pensylvanica L. f.	-	2	-	-

Prunus serotina Ehrh.	6	4	4	4
Quercus alba L.		6	8	
Quercus rubra L.	34	21	22	21
Rhododendron maximum L.	-	-	-	4
Rhus typhina L.	-	3	-	-
Robinia hispida L.	-	5	3	4
Sambucus nigra L. ssp. *canadensis* (L.) R. Bolli	-	2	-	-
Tilia americana L.	7	4	5	7
Tsuga canadenisis (L.) Carriere	26	15	18	24
Vaccinium corymbosum L.	-	5	7	6
Vaccinium fuscatum Aiton	-	-	-	7
Viburnum acerifolium L.	-	6	6	8
Viburnum lentago L.	-	-	-	4
Viburnum nudum L. *var. cassinoides* (L.) torr. & A. Gray	-	4	4	-
Species Richness	16	35	30	28
Totals	300	300	300	300

Table 3: Importance values (IV) for tree and shrub species on Three Mile Island.

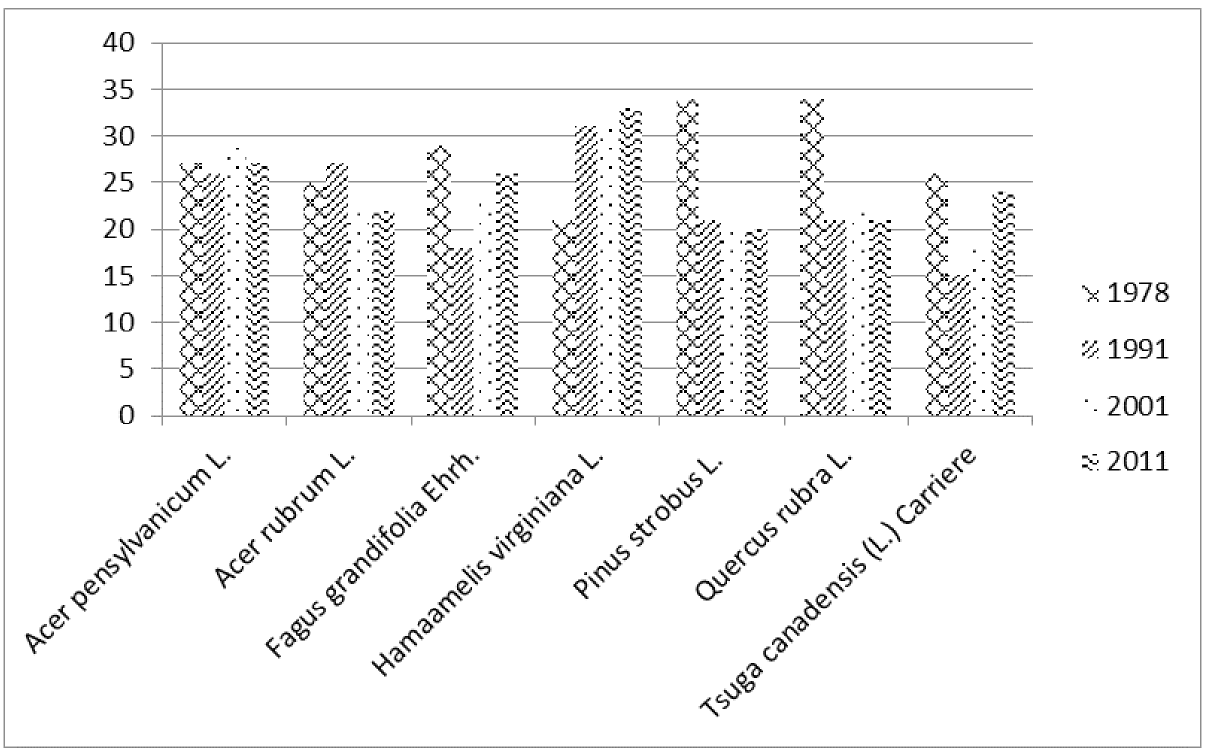

Figure 1: Importance values for seven tree and shrub species on Three Mile Island

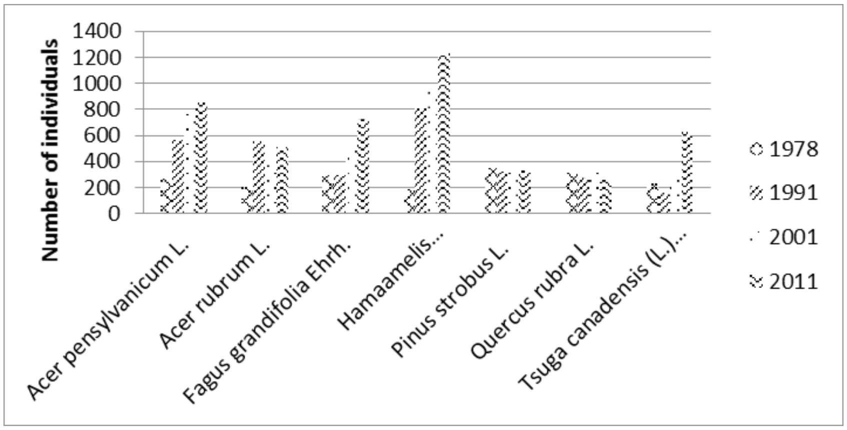

Figure 2: Density for seven tree and shrub species on Three Mile Island.

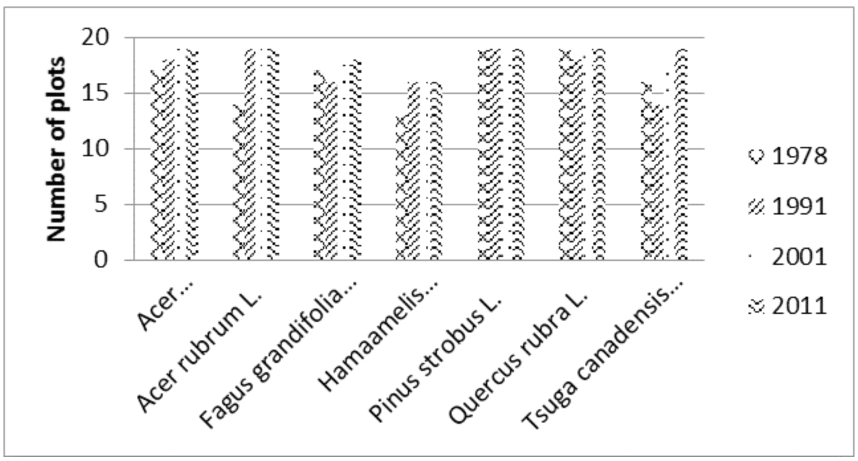

Figure 3: Frequency for tree and shrub species on Three Mile Island

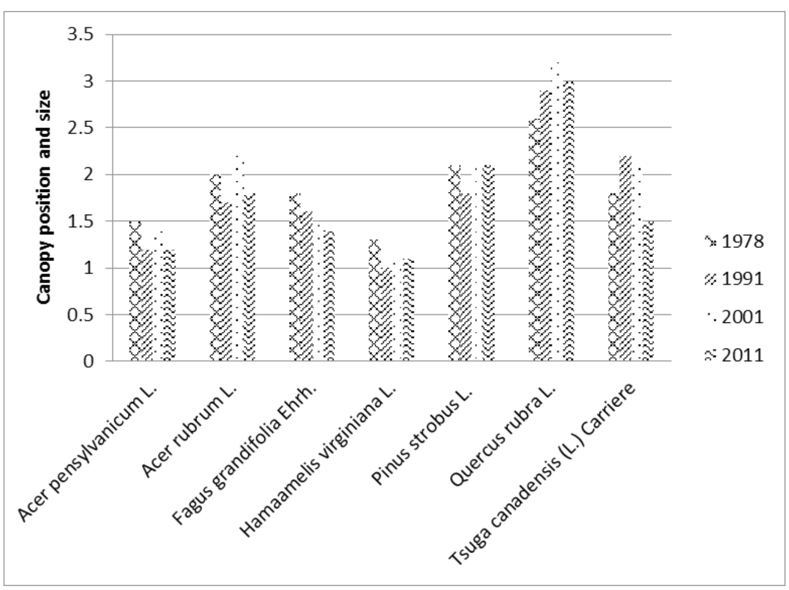

Figure 4: Dominance for tree and shrub species on Three Mile Island.

Hawk's Nest Island

Since 1978, the species with the highest importance values on Hawk's Nest Island were (Table 5; Figure 5): *Alnus incana ssp. rugosa, Betula populifolia, Pinus resinosa, Pinus strobus, Quercus rubra*, and *Tsuga canadensis*. Whether ratings or basal areas were used to calculate dominance in 2011, these same six species are most important (Table 4). The density of *Betula populifolia, Quercus rubra*, and *Tsuga canadensis* increased over the 33year sampling (Figure 6). By 2011, *Pinus resinosa, Pinus strobus, Quercus rubra*, and *Tsuga canadensis* appeared in all three plots (Figure 7). In 2011, the two pines had the highest canopy position and size in the overstory (Figure 8).

Species	Frequency	Density	Sum of Ratings	Dominance	DBHs	IV
Acer pensylvanicum L.	-	-	-	-	-	-
Acer rubrum L.	2	28	43	1.5	81.963	16
Acer saccharum Marshall	-	-	-	-	-	-
Alnus incana (L.) ssp. *rugosa* (Du Roi) R.T. *Clausen*	2	28	146	1.1	31.192	27
Amelanchier laevis Wiegand	2	52	54	1	17.803	17
Betula lenta L.	-	-	-	-	-	-
Betula papyrifera Marshall	1	10	10	1	5.178	8
Betula populifolia Marshall	2	69	85	1.2	22.693	20
Gaylussacia baccata (Wangenh.) K. Koch	-	-	-	-	-	-
Hamamelis virginiana L.	2	59	60	1	18.229	18
Lyonia ligustrina (L.) DC.	1	56	56	1	12.255	14
Nyssa sylvatica Marshall	1	1	1	1	1.638	7
Pinus resinosa Aiton	3	37	98	2.7	268.68	25
Pinus strobus L.	3	50	134	2.7	364.427	26
Populus tremuloides Michx.	-	-	-	-	-	-
Quercus rubra L.	3	52	93	1.8	220.666	23
Rhododendron canadense (L.) Torr.	1	1	1	1	1.638	7
Rosa palustris Marshall	1	2	2	1	2.316	7
Tsuga canadensis (L.) Carriere	3	129	301	2.3	420.13	35
Vaccinium corymbosum L.	1	27	27	1	8.509	10
Vaccinium fuscatum Aiton	1	53	53	1	13.864	14
Viburnum nudum L. var. *cassinoides* (L.) Torr. & A. Gray	2	42	42	1	14.549	15
Viburnum recognitum Fernald	2	6	6	1	5.299	11
Totals	33	702	1212	24.4		300

Table 4: 2011 sampling data for tree and shrub species of Hawk's Nest Island.

Species	1978	1991	2001	2011
Acer pensylvanicum L.	11	7	-	-
Acer rubrum L.	19	15	17	16
Acer saccharum Marshall	16	13	-	-
Alnus incana (L.) ssp. *rugosa* (Du Roi) R.T. Clausen	-	22	23	27
Amelanchier laevis Wiegand	11	17	18	17
Betula lenta L.	14	-	-	-

Betula papyrifera Marshall	15	21	18	8
Betual populifolia Marshall	17	15	17	20
Gaylussacia baccata (Wangenh.) K. Koch	-	-	9	-
Hamamelis virginiana L.	12	13	14	18
Lyonia ligustrina (L.) DC.	-	21	19	14
Nyssa sylvatica Marshall	-	-	-	7
Pinus resinosa Aiton	41	29	29	25
Pinus strobus L.	56	30	29	26
Populus tremuloides Michx.	-	8	-	-
Quercus rubra L.	39	26	26	23
Rhododendron canadense (L.) Torr.	-	-	-	7
Rosa palustris Marshall	-	-	-	7
Tsuga canadense (L.) Carriere	48	47	45	35
Vaaccinium corymbosum L.	-	-	11	10
Vaccinium fuscatum Aiton	-	-	-	14
Viburnum nudum L. var. *cassinoides* (L.) Torr. & A. Gray	-	8	17	15
Viburnum recognitum Fernald	-	8	8	11
Species Richness	12	16	15	18
Totals	300	300	300	300

Table 5: Importance values (IV) for woody tree and shrub species on Hawk's Nest Island.

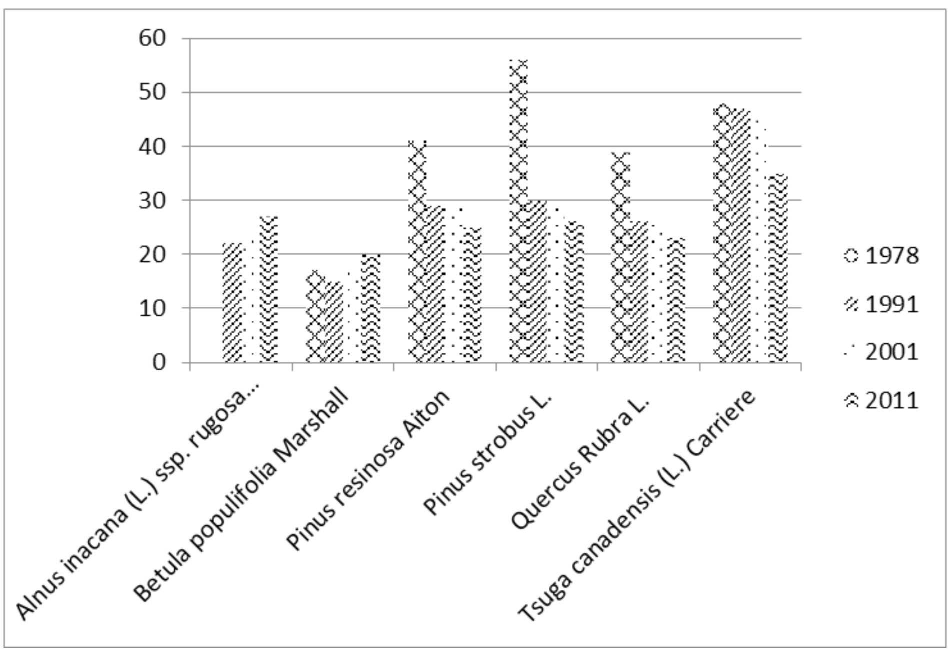

Figure 5: Importance values for six tree and shrub species on Hawk's Nest Island.

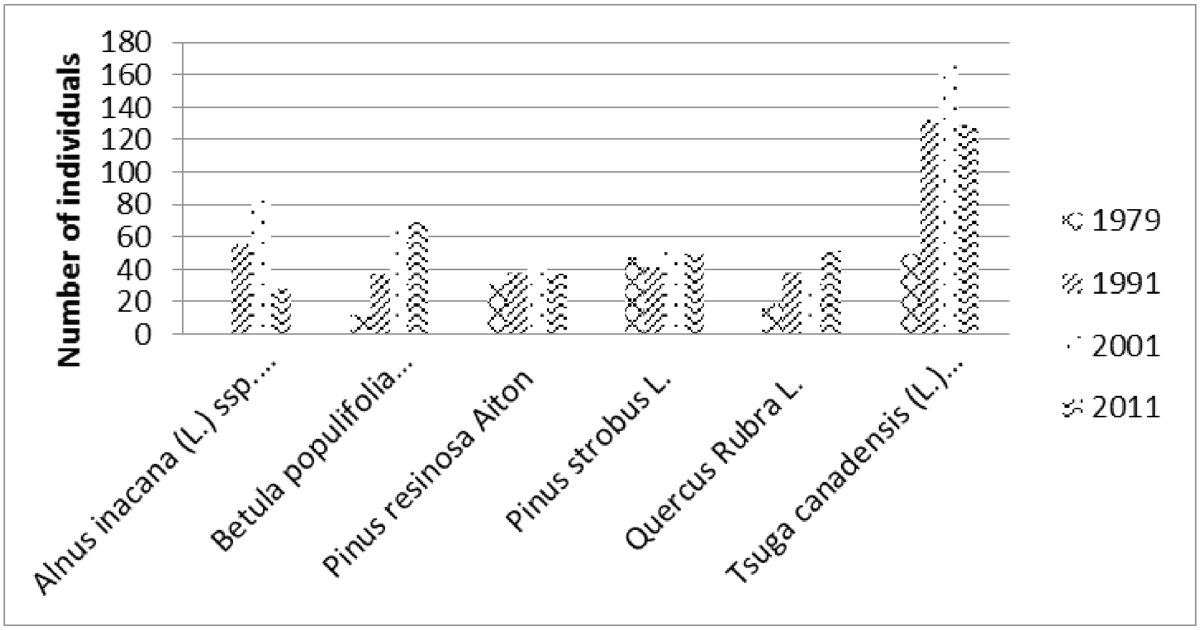

Figure 6: Density for six tree and shrub species on Hawk's Nest Island.

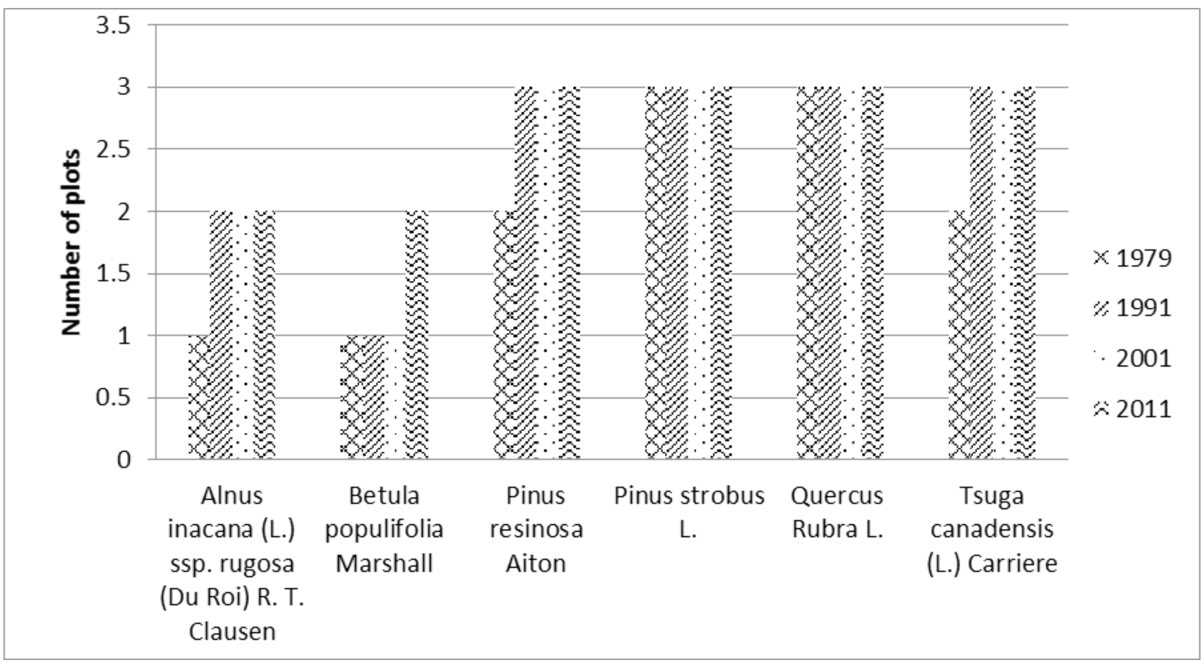

Figure 7: Frequency for tree and shrub species on Hawk's Nest Island.

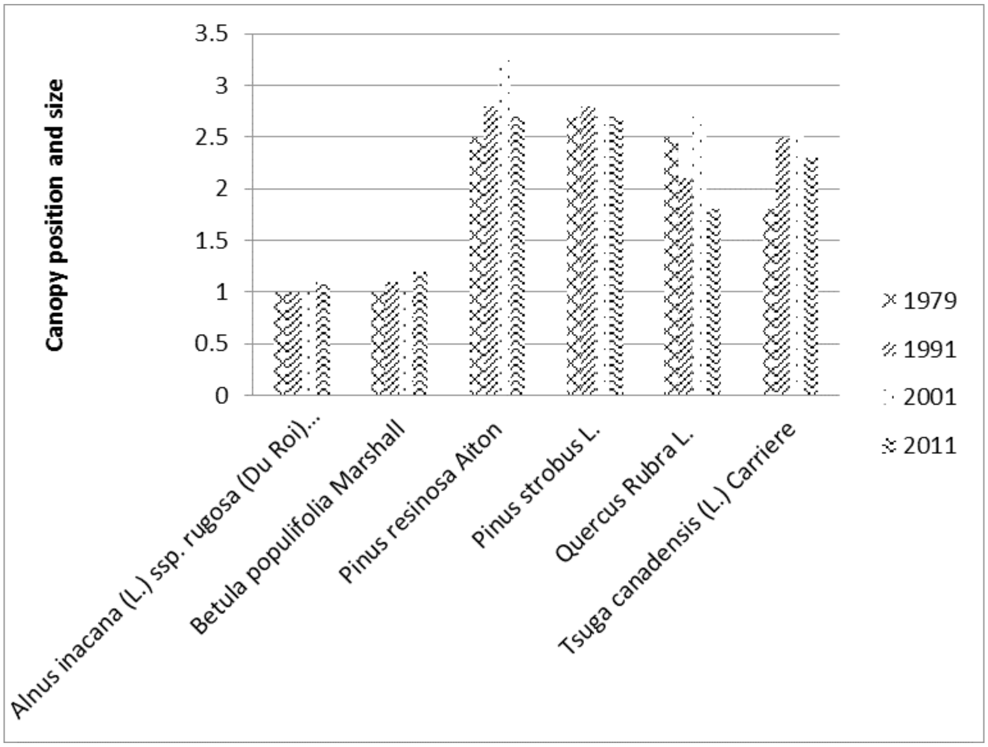

Figure 8: Dominance for tree and shrub species on Hawk's Nest Island.

Blueberry Island

Since 1978, the species with high importance values on BI were (Table 7; Figure 9): *Acer rubrum, Betula papyrifera, Betula populifolia, Ilex mucronata, Nyssa sylvatica, Picea rubens, Pinus strobus, Tsuga canadensis,* and blueberry bushes. Undoubtedly, both species of blueberry found in 2011 (*Vaccinium corymbosum* and *Vaccinium fuscatum*) had been present throughout the 33year sampling, but they had not previously produced flowers and fruits at the same time. In 2011 the most dominant species on BI were *Ilex mucronata, Vaccinium corymbosum,* and *Vaccinium fuscatum* (Table 6). The density of *Ilex mucronata, Vaccinium corymbosum*, and *Vaccinium fuscatum* were each over 800 individuals in 2011 (Figure 10). In 2011, *Acer rubrum, Nyssa sylvatica, Pinus strobus, Tsuga canadensis*, and *Vaccinium fuscatum* appeared in all 3 plots (Figure 11). In 2011, *Picea rubens* had the highest canopy position and size in the overstory (Figure 12).

Species	Frequency	Density	Sum of Ratings	Dominance	IV
Acer rubrum L.	3	32	69	2 2	12
Alnus incana (L) ssp. *Rugosa* (Du Roi) R T. Claus en	2	62	81	1.3	9
Amelanchier laevis Wiegand	2	26	42	1.6	9
Betula pap yrifera Marshall	1	21	31	1.5	6
Betula papulifolia Marshall	2	127	209	1.7	12
Fagus grandifolia Ehrh	1	1	3	3	9
Fraxinus nigra Marshall	1	3	7	2.3	7
Gaylussacia baccata (Wangenh.) K Koch	1	3	3	1	4
Hamamelis virginiana L.	1	5	5	1	5
Ilex Mucronata (L) Powell, Savolainen & Andrews	1	820	820	1	28
Ilex verticillata (L) A. Gray	2	20	20	1	7

Lyonia ligustrina (L.) DC.	3	34	42	1.2	10
Myrica gale L.	_	_	_	_	_
Nyssa sylvatica Marshall	3	48	74	1.5	11
Pinus rubens Sarg.	1	1	4	4	11
Pinus resinosa Aiton	2	13	43	3.3	12
Pinus strobus L.	3	30	106	3.5	15
Populus grandidentata Michx	1	1	4	4	11
Prunus Pensylvanica L. f.	_	_	_	_	_
Prunus serotina Ehrh	_	_	_	_	_
Quercus rubra L.	2	2	5	2.5	10
Rosa palustris Marshall	1	2	2	1	4
Spriraea alba Du Roi var. *latifolia* (Ation) Dippel	1	7	7	1	5
Tsuga canadensis (L.) Carriere	3	44	138	3.1	15
Vaaccinium corymbosum L.	1	1068	1158	1.1	35
Vaccinium fuscatum Aiton	3	1028	1034	1	39
Vibumum lentago L.	2	55	60	1.1	8
Viburnum nudum L. var. *cassinoides* (L.) Torr. & A. Gray	1	5	5	1	5
TOTALS	44	3458	3972	47	300

Table 6: 2011 sampling data for woody tree and shrub species of Blueberry Island.

Species	1978	1991	2001	2011
Acer rubrum L.	39	16	13	12
Alnus incana (L.) ssp. *rugosa* (Du Roi) R.T. Clausen	15	11	13	9
Amelanchier laevis Wiegand	-	11	11	9
Betula papyrifera Marshall	23	12	10	6
Betual populifolia Marshall	42	18	15	12
Fagus grandifolia Ehrh.	13	-	8	9
Fraxinus nigra Marshall	-	-	-	7
Gaylussacia baccata (Wangenh.) K. Koch	-	-	5	4
Hamamelis virginiana L.	14	7	5	5
Ilex mucronata (L.) Powell, Savolainen & Andrews Savolainen&Andrews	-	23	32	28
Ilex verticillata (L.) A. Gray	-	18	32	7
Lyonia Ligustrina (L.) DC.	-	7	14	10
Myrica gale L.	-	25	6	-
Nyssa sylvatica Marshall	25	15	13	11
Picea rubens Sarg.	23	11	12	11
Pinus resinosa Aiton	-	19	13	12
Pinus strobus L.	39	18	14	15
Populus grandidentata Michx.	-	10	6	11
Prunus pensylvanica L.F.	-	10	6	-
Prunus Serotina Ehrh.	-	-	7	-

Quercus rubra L.	-	-	-	10
Rosapalustris Marshall	-	-	-	4
Spiraea aalba Du Roi var . *latifolia* (Aiton) Dippel	-	-	5	5
Tsuga canadensis (L.) Carriere	48	19	15	15
Vaaccinium corymbosum L.	18	50	33	35
Vaccinium fuscatum Aiton	-	-	-	39
Viburnum Lentago L.	-	-	-	8
Viburnum nudum L. var. *cassinoides* (L.) Torr. & A. Gray	-	-	13	5
Species Richness	11	18	23	25
Totals	300	300	300	300

Table 7: Importance values (IV) for woody trees and shrub species on Blueberry Island.

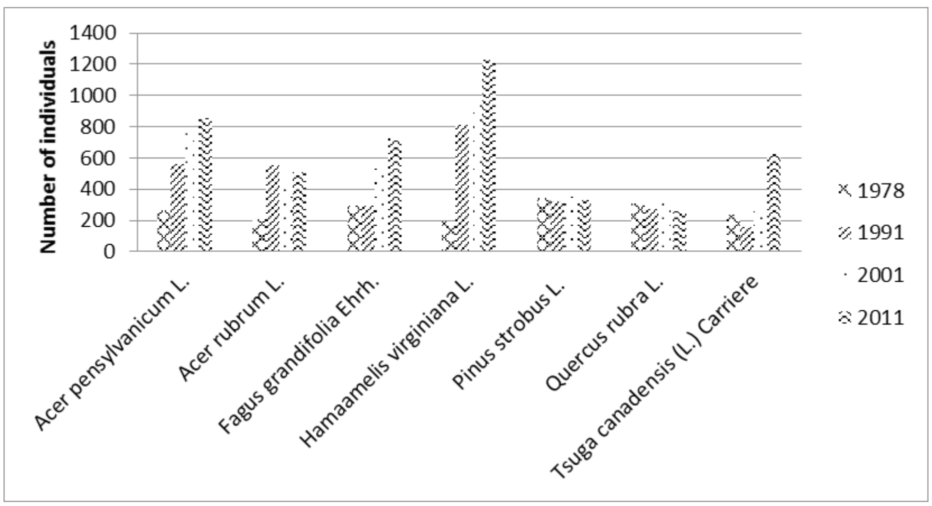

Figure 9: Importance values for ten trees and shrub species on Blueberry Island.

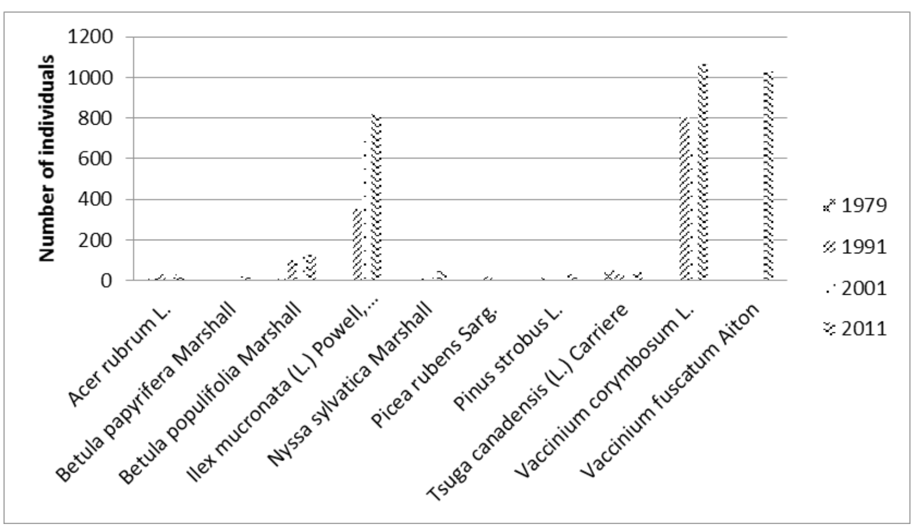

Figure 10: Density for ten trees and shrub species on Blueberry Island.

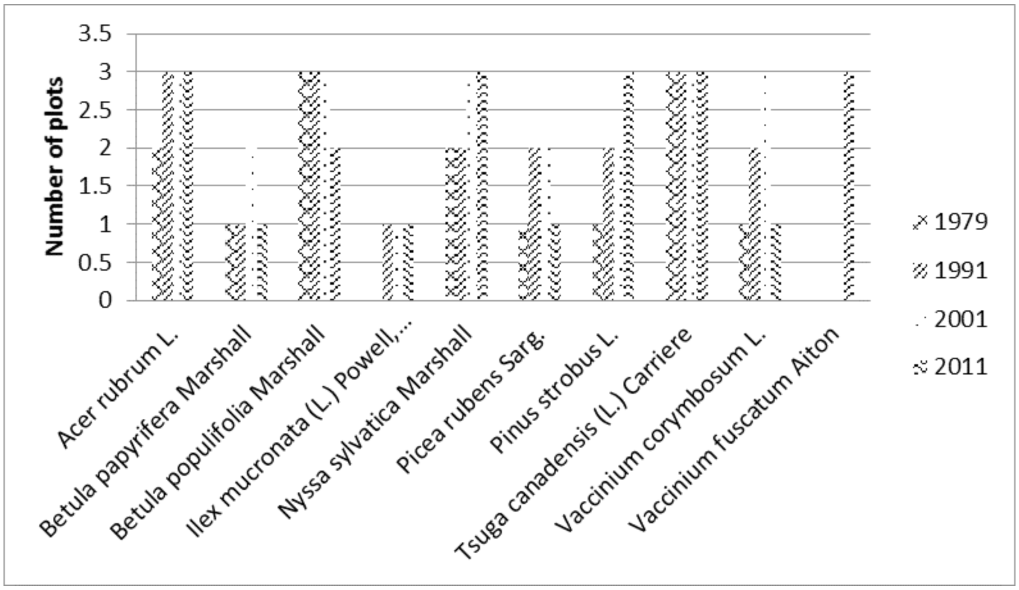

Figure 11: Frequency for trees and shrub species on Blueberry Island.

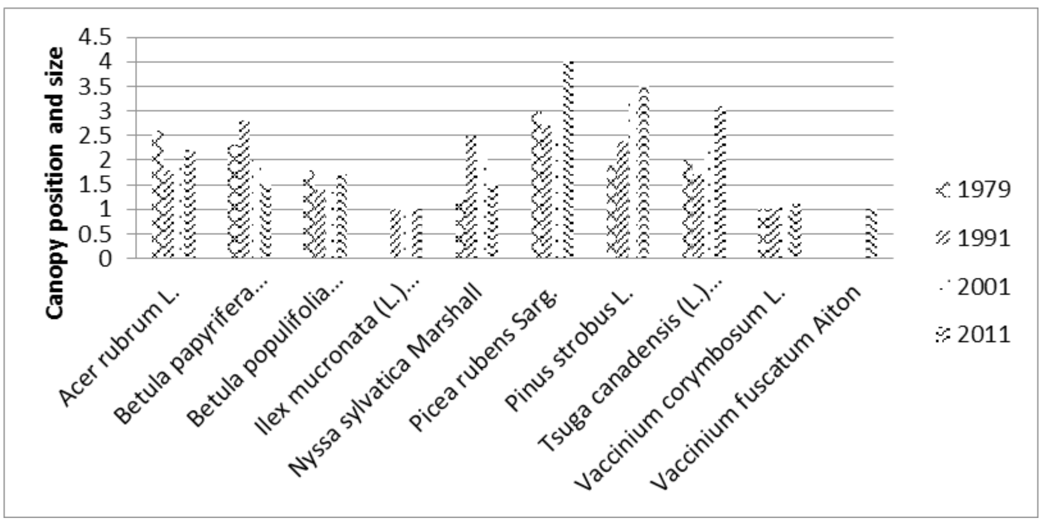

Figure 12: Dominance for trees and shrub species on Blueberry Island.

Richness, Evenness, and Diversity

Over the 33 year sampling period, 39 species were sampled in the overstory (Table 8). Throughout the sampling, evenness and diversity remained relatively constant, while species richness generally increased (Table 8). On TMI, species richness increased significantly from 1978 to 1991 and remained relatively constant in the later samplings (Figure 13). Species evenness decreased from 1978 to 1991 and remained constant in the later samplings (Figure 14). However, the Shannon diversity index remained constant throughout the four samplings (Figure 15). On HNI, species richness increased from 12 species to 18 from 1978 to 2011 (Figure 13). Species evenness and Shannon's diversity index increased through the sampling years (Figures 14,15). On BI, species richness increased through the years (Figure 13). However, species evenness decreased through the sampling years (Figure 14). Similarly to TMI, the BI Shannon diversity index remained relatively constant through the years, but it was highest during the 2001 sampling (Figure 15). Overall, the three islands saw a significant increase in total species richness from 1978 to 1991, though it remained constant in 2001 and 2011 (Figure 13).

When mean species richness is examined by zone, it was highest in the Urban zone in 1978, but increased in all four zones over the 33year sampling period, and was highest in the Protective zone in 2011 (Table 11). Thus, our third hypothesis was not supported. Species evenness did not change much among the four samplings (Figure 14). Lastly, Shannon's diversity on TMI and BI increased from 1978 to 1991 but decreased slightly from 2001 to 2011, while it increased during each sampling on HNI (Figure 15). On TMI, the following species were absent from the plots in 2011 but not 2001: *Ilex mucronata, Lyonia ligustrina, Populus tremuloides, Quercus alba,* and *Viburnum nudum var. cassinoides*. The following species were present in the plots in 2011 but not 2001: *Rhododendron maximum*, *Vaccinium fuscatum*, and *Viburnum lentago*. On HNI, *Gaylussacia baccata* was absent in 2011 but not 2001. The following species were present in 2011 but not 2001: *Nyssa sylvatica, Rhododendron canadense*, *Rosa palustris*, and *Vaccinium corymbosum*. On BI, the following species were absent in 2011 but not 2001: *Myrica gale, Populus grandidentata, Prunus pensylvanica*, and *P. serotina*. The following species were present in 2011 but not 2001: *Fraxinus nigra, Populus tremuloides, Quercus rubra, Rosa palustris, Vaccinium fuscatum*, and *Viburnum lentago*. Even though some species were not located in the plots in 2011, that does not mean that they were not present in other locations on these islands. Throughout the years of sampling, the overstory increased in the number of individuals and in total ratings on all three islands (See Tables 8-10). In particular, the overstory on BI increased significantly from 1978 to 1991 in both the number of individuals and total ratings (Tables 9 and 10). Also, the BI increases in overstory individuals from 1991 to 2001 were relatively the same as from 2001 to 2011 (Table 9). It should be noted that while numbers of species in various plots may have increased over the 33 years of sampling, that no new overstory species have been found since the collections in the early 1900s [18,19].

Island	Year	Species	Evenness	Shannon
All	1978	22	0.782907397	2.42
All	1991	39	0.775201914	2.84
All	2001	36	0.789726537	2.83
All	2011	38	0.747748611	2.72
Three Mile	1978	17	0.836506014	2.37
Three Mile	1991	35	0.705978699	2.51
Three Mile	2001	31	0.728016691	2.5
Three Mile	2011	28	0.717242892	2.39
Hawk's Nest	1978	12	0.75254336	1.87
Hawk's Nest	1991	16	0.807909223	2.24
Hawk's Nest	2001	15	0.867783027	2.35
Hawk's Nest	2011	18	0.878779691	2.54
Blueberry	1978	14	0.70858635	1.87
Blueberry	1991	18	0.646975599	1.87
Blueberry	2001	23	0.641047268	2.01
Blueberry	2011	25	0.543668068	1.75

Table 8: Overstory data compilation including species richness (Species), species evenness, and Shannon's Diversity Index. Data were compiled for all plots found on TMI, HNI and BI. Shannon's Diversity Index was calculated using the EstimateS software package.

	TMI	Hawk	Blue	Overall
1978	2207	176	121	2504
1991	3759	483	2175	6417
2001	4588	656	2764	8008
2011	5459	806	3458	9723

Table 9: Total number of woody individuals sampled in the overstory plots on TMI, HNI and BI by sampling year.

	TMI	Hawk	Blue	Overall
1978	4253	379	229	4861
1991	5683	887	2417	8987
2001	7395	1197	3081	11673
2011	7892	1212	3972	13076

Table 10: Total ratings of individuals sampled in the overstory plots on TMI, HNI and BI in all four sampling years.

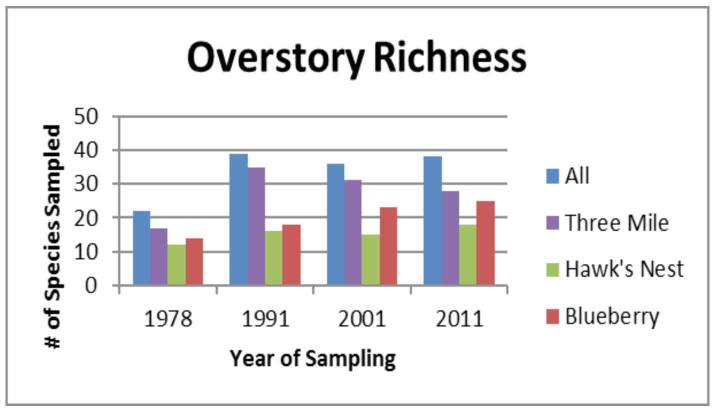

Figure 13: Overstory species richness of TMI, HNI and BI in the four years of sampling. A total of 39 species was found in the plots in the four sampling years.

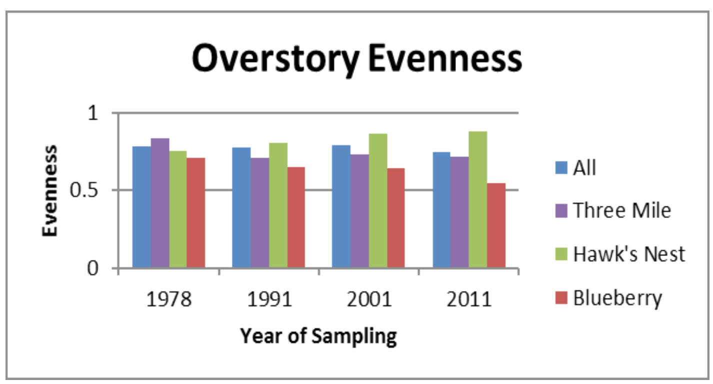

Figure 14: Overstory species evenness of TMI, HNI and BI in the four years of plot sampling.

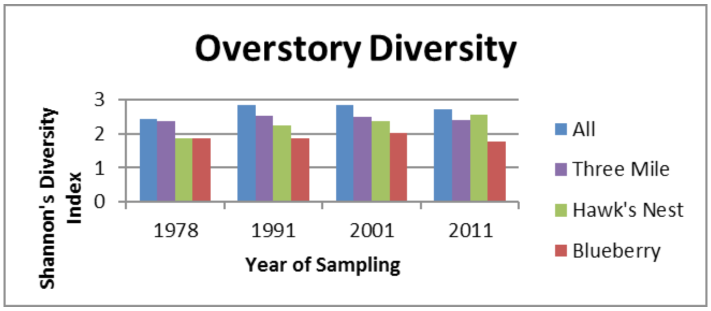

Figure 15: Overstory Shannon's Diversity Index of TMI, HNI and BI in the four years of plot sampling.

Synthesis

Throughout the sampling period, the three islands can be characterized as dominated by red maple (*Acer rubrum),* paper birch (*Betula papyrifera*), American witchhazel *(Hamamelis virginiana*), eastern white pine (*Pinus strobus*), and eastern hemlock (*Tsuga canadensis*). Over time, Hawk's Nest Island increased in species richness, species evenness, and Shannon's Diversity (Tables 8-10), which may be attributed to this island's designation as falling entirely with in a Protective zone. Shrubs in the genera *Gaylussacia* (huckleberry), *Ilex* (holly), *Lyonia* (maleberry), *Vaccinium* (blueberry), and *Viburnum* (arrowwood) have become established along each island's shoreline, exhibiting higher importance values today than at the start of the ecological sampling in 1978.

Discussion

Succession

Since the earliest records for BI, HNI, and TMI date from the 1890s, we assume that the seeds of trees noted [46] in presettlement New Hampshire (*Fagus grandifolia, Tsuga canadensis,* and *Pinus* spp.) may have been moved by wind or mammals onto the islands. Seeds of maple, birch, and conifers are wind dispersed and with the mainland less than 0.5 miles (1 km) away from the islands, the mainland could have provided the seed source for these species. Whereas records from the 1890s [7] indicate that TMI was covered by *Betula* spp. and *Populus* spp., and we assume the same was true for HNI and BI, by the early 2000s the most frequently encountered tree species were *A. rubrum, F. grandifolia, P. strobus, Q. rubra,* and *T. canadensis*. By 2011, both *B. papyrifera* and *B. populifolia* were present on TMI, HNI and BI, but were not as frequent as in the past [6]. The sampling of the three islands on Lake Winnipesaukee is part of ongoing floristic and ecological studies [6,18,19,20,27,39]. As of this writing, healthy populations of *Tsuga canadensis* have been found on all three islands, undoubtedly due to the fact that hemlock wooly adelgid has not moved north to Lake Winnipesaukee. In spite of the infestation of beech bark disease on TMI, density of *Fagus grandifolia* has increased over the study period; *F. grandifolia* has not been found on HNI, but the one lone *F. grandifolia* on BI continues to survive. In 2011, many of TMI's dominant species overlapped with those found in the study of [5]. These species include *Acer rubrum, Fagus grandifolia, Pinus strobus, Quercus rubra* and *Tsuga canadensis.* Only a few dominant species on HNI and BI overlap with the Asahina study. These species are *Pinus strobus, Quercus rubra,* and *Tsuga canadensis*. Similarly, several woody species were found on both TMI and Timber Island [14]. These species include *Acer pensylvanicum, Acer rubrum, Acer saccharum, Betula alleghaniensis, Betula papyrifera, Fagus grandifolia, Gaylussacia baccata, Hamamelis virginiana, Ostrya virginiana, Pinus resinosa, Pinus strobus, Quercus rubra, Tsuga canadensis, Vaccinium angustifolium,* and *Vaccinium corymbosum.*

Role of Large Grazing Herbivores

Application of the Simple Matching Index to the island floras of TMI and Timber Island produced a value of 65.59% [14]. This high similarity value is striking given the difference in human traffic on the two islands. Timber Island (135 acres) is the largest undeveloped island in Lake Winnipesaukee and supports a large deer population, while TMI (43 acres) experiences regular human disturbance from early June through late September when various AMC events are underway. [6] suggested that this heavy human activity had protected TMI from deer grazing throughout the first 23 years of vegetation sampling. However, a pregnant doe and a yearling either walked on the ice or swam over to TMI during winter/spring 2015, and two fawns were sighted with their mother and the yearling throughout that summer. The doe was not threatened by TMI campers, and at least two does were sighted on numerous occasions throughout the Urban and Compromise zones during summer 2016. The role of large grazing herbivores on TMI is already of interest to biologists, staff, and campers at the AMC camp, and the extent of deer browse is being documented.

Role of Shrubs and Short Trees

All three islands had shrubby understory species become more important throughout the course of the study. Five out of the 25 plots sampled on BI, HNI, and TMI are shoreline plots, bordered by the Lake. It is in these plots that woody shrubs have proliferated, and the preponderance of *Gaylussacia baccata, Ilex mucronata, Ilex verticillata, Vaccinium corymbosum,* and *Vaccinium fuscatum* have been documented. Undoubtedly the easy access to sunlight has allowed these shrubs to dominate the shorelines of the three islands. In the center of the island, two TMI "overtopped" tree species, *Acer pensylvanicum* and *Hamamelis virginiana*, increased in importance throughout the study. One explanation is that the lowered density of large woody trees like *Pinus strobus, Quercus rubra*, and *Tsuga canadensis* after the 1980 blowdown opened the canopy for smaller tree and shrub species. As had been predicted [6] the shorter woody species (both trees and shrubs) exhibiting high importance values in 2001 on the islands' edges have continued their importance there.

Land Use on Each Island

This study emphasized the value of an ecological land use plan for monitoring the natural habitats of three small islands. After the extensive floristic survey which occurred in the late

1970s and early to mid1980s [13] the land use plan was made more restrictive with the re-discovery of *Cypripedium arietinum* in the middle of the Productive Zone. When this rediscovery was brought to the attention of the volunteer management committee, the area was designated Protective, a designation which continues today. Unfortunately, *C. arietinum* has not been sighted since 1985. Three TMI plots were established in wetland areas: these support woody hydrophytes such as *Cephalanthus occidentalis* and *Alnus rugosa*. All three of these plots are designated as part of the Protective zone, and have been accumulating organic matter in the three lowest inland areas on TMI over at least the last 100 years. [47] studied over 20 wetlands across the globe and found that most wetlands are net carbon sinks. Thus, Mitsch et al. suggest that humans should endeavor to protect existing wetlands, since the older they become, the more carbon they can sequester. TMI is the only island that is large enough to support all four (Urban, Compromise, Productive, and Protective) land use zones [13]. HNI is completely zoned Protective, while BI is zoned Protective on the north and south ends of the island, but is zoned Compromise in the island's center. Mean overstory species richness in plots of the Protective zone increased by 4.2 species during the 33year sampling period (Table 11). Enacting long-term land use plans may play useful roles in assisting managers to protect natural habitats in other areas throughout the world.

Zone	Protective	Productive	Compromise	Urban
Year				
1978	7.9	7.7	7.8	9.5
1991	10.6	9.7	10.6	12.7
2001	12	10.4	12.4	11.5
2011	12.1	10.3	11.4	12. 0

Table 11: Mean species richness in zones of overstory plots on TMI, HNI, and BI.

Biodiversity

The earth is in the midst of a biodiversity crisis, and projections indicate continuing and accelerating rates of global changes [48]. [49] estimate that land use and related pressures have already reduced local biodiversity intactness across 58.1% of the world's land surface, where 71.4% of the human population live. Many ecosystem services are underpinned by biodiversity, but globally there is currently a lack of coordinated action to halt biodiversity declines [50]. In general, the compositions in the permanent plots of TMI, HNI, and BI demonstrated several changes in vegetation over time. During the 33year sampling period, overstory species richness increased on each island. By 2011, TMI supported more species than BI and HNI probably due to its larger size. However, the small BI supported more species than HNI undoubtedly because the density of shrub growth on each end of BI allowed protection for dense tree growth. At this time, no changes in overstory species can be attributed directly to climate change. However, as temperatures warm, fires associated with lightning strikes may intensify. The three islands studied represent a microcosm of species and natural habitats found in the Lake Winnipesaukee, NH, region. The main difference between the islands and the mainland is the intensity of development on the mainland, especially along the shore. By establishing a camp on TMI in 1900, the AMC demonstrated its continuing commitment to sustaining and protecting the natural vegetation of the Lakes/ White Mountain region. [51] examine global sustainability of marine fisheries, and note the importance of human rewards for maintaining biodiversity. They report that getting incentives right matters, and suggest that the ways in which these incentives can shift specific feedbacks in social ecological systems hold promise for conservation and management efforts in the ocean. A similar examination of incentives for management of northern forested ecosystems could prove beneficial.

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