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Forest Vegetation Monitoring and Foliar Chemistry of Red Spruce and Red Maple at Acadia National Park in Maine

G. Bruce Wiersma · Jose Alexander Elvir · Janet D. Eckhoff

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Abstract The USDA Forest Service Forest Health Monitoring (FHM) program indicators, including forest mensuration, crown condition classification, and damage and mortality indicators were used in the Cadillac Brook and Hadlock Brook watershed forests at Acadia National Park (ANP) along coastal Maine. Cadillac Brook watershed burned in a wildfire in 1947. Hadlock Brook watershed, undisturbed for several centuries, serves as the reference site. These two small watersheds have been gauged and monitored at ANP since 1998 as part of the Park Research and Intensive Monitoring of Ecosystems Network (PRIMENet). Forest vegetation at Hadlock Brook was dominated by late successional species such as *Acer saccharum*, *Fagus grandifolia*, *Betula alleghaniensis*, *Acer rubrum* and *Picea rubens*. Forest vegetation at Cadillac Brook, on the other hand, was younger and more diverse and included those species found in Hadlock as well as early successional species such as *Betula papyrifera* and *Populus grandidentata*. Differences in forest species composition and stand structure were attributed to the severe wildfire that affected the Cadillac Brook watershed. Overall, the forests at these ANP watersheds were healthy with a low percentage (≤22%) of trees showing symptoms of damage.

Foliar nitrogen (N) concentrations were higher in *A. rubrum* and *P. rubens* trees growing in Hadlock Brook watershed, but differences were significant only for *P. rubens*. Foliar aluminum (Al) concentrations were also higher in both species growing in Hadlock Brook watershed but differences were significant only for *A. rubrum*. Foliar calcium (Ca) and manganese (Mn) concentrations, on the other hand, were significantly lower in Hadlock Brook watershed for both species. Foliar potassium (K) was significantly higher for *P. rubens* growing in Hadlock Brook. No differences in foliar concentrations of magnesium (Mg), phosphorus (P), boron (B), copper (Cu) and lead (Pb) were found between watersheds. The higher foliar N concentrations as well as higher foliar concentrations of Ca and Al might indicate early stages of N saturation and acidification in Hadlock Brook watershed as also suggested by Hadlock Brook stream N flux data in published PRIMENet studies at ANP.

Keywords Acadia · Foliar chemistry · Forest composition · Forest ecosystem · Mensuration

G. B. Wiersma (✉)
University of Maine, 5755 Nutting Hall,
Orono, Maine 04469, USA
e-mail: Wiersma@maine.edu

J. A. Elvir
Apt. Postal #2. ESNACIFOR,
Siguatepeque, Comayagua, Honduras
e-mail: alexit98@yahoo.com

J. D. Eckhoff
National Natural Landmark Coordinator, Midwest Region,
National Park Service, Wilson's Creek National Battlefield,
6424 W. Farm Road 182,
Republic, MO 65738, USA

1 Introduction

Studies have indicated that airborne pollutants are being transported along the eastern United States coastline and are impacting ecosystems along coastal Maine (National Atmospheric Deposition Program (NADP) 2003; Jagels, Carlisle, Cunningham, Serreze, & Tsai 1989). One of the highlights of coastal Maine is Acadia National Park (ANP) on Mount Desert Island. In 1996, the Park Research and Intensive Monitoring of Ecosystems Network (PRIMENet) was established by the US Environmental Protection Agency (EPA) and the US Department of the Interior, National Park Service (USDOI, NPS) to examine long-term trends and linkages between environmental stressors, such as airbone pollutants, and ecosystem responses (Kahl et al., 2006, this volume; USDOI NPS, 2000). Environmental stressors being monitored in 14 National Parks in the United States include air quality, wet and dry deposition, and toxic contaminants.

The goals for the multidisciplinary PRIMENet research undertaken at Acadia were to examine the ecological consequences of atmospheric nitrogen (N) and mercury (Hg) deposition on surface waters, soils, and vegetation. To achieve those goals, two paired-watersheds, Hadlock Brook and Cadillac Brook, dominated by different forest types as a result of different fire histories, were established as contrasting case studies of forest ecosystem function.

The specific objectives of this study were to provide baseline information on forest vegetation for two watersheds with distinctly different disturbance histories at ANP. These objectives were achieved using the Forest Service's Forest Health Monitoring (FHM) program indicators to compare forest diversity, forest structure, and forest health. The FHM program was developed jointly by the US EPA, USDA Forest Service, and several other agencies to address concerns about potential effects from air pollution, acid rain, global climate change, insects, diseases, and other stressors (Alexander & Palmer, 1999). In addition, foliar chemistry of *Acer rubrum* (red maple) and *Picea rubens* (red spruce) was compared between the two watersheds at ANP and also foliar N concentrations between ANP watersheds and the treated and untreated watersheds at the Bear Brook Watershed in Maine (BBWM).

2 Materials and Methods

2.1 Research site

Acadia National Park (ANP) is located in Hancock County, Maine on Mount Desert Island (MDI), which is situated within the Gulf of Maine (Figure 1). ANP was established in 1916 as the Sieur de Monts National Monument. In 1919, through an act of Congress, the area became Lafayette National Park, and in 1929 the Park name was changed to Acadia. ANP has an area of 14,165 hectares (ha) (National Park Service (NPS), 2001).

In the fall of 1947, following a dry summer, wildfires burned over 6,680 ha on MDI (Schauffler, Nelson, Johnson, Kahl, & Jacobson Jr, 2002; Schauffler, Nelson, Kahl, Jacobson Jr, Haines, & Peterson III, 2006; National Park Service (NPS), 2001). More than 4,000 of those hectares were scattered within ANP boundaries. Following the fires, areas of ANP were logged as timber salvage operations removed trees damaged by fire. Another large-scale disturbance within ANP occurred in January 1998. A severe ice storm, lasting six days, impacted the northeastern and New England states and southeastern Ontario and western Quebec, extending somewhat into New Brunswick and Nova Scotia (Miller-Weeks & Eagar, 1999). Damage to

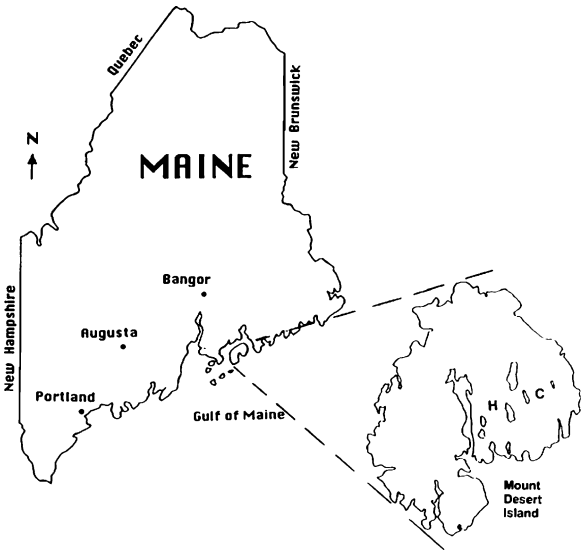

Figure 1 Location of Cadillac Brook watershed (*C*) and Hadlock Brook watershed (*H*) in Acadia National Park on Mount Desert Island, Maine.

the vegetation included broken tops and losses of major limbs.

For this study two first-order stream upland watersheds were selected within ANP. Cadillac Brook watershed, with an area of 31.8 ha, is located on the southeast face of Cadillac Mountain (elevation 470 m); this watershed was burned by the wildfire in 1947. Hadlock Brook watershed, with an area of 42.7 ha, is located on the south slope of Sargent Mountain (elevation 418 m). The vegetation in Hadlock Brook watershed was not directly affected by the wildfire in 1947.

2.2 Plot locations and plot design

Protocols and methods used for plot design and forest measurements were adapted from the FHM program protocols (Tallent-Halsell, 1994). The FHM plot design utilizes a cluster-plot design of four circular plots. This study at ANP did not employ cluster-plots, but used individual FHM subplots. Subplots established in both Cadillac (Figure 2) and Hadlock watersheds (Figure 3) were selected randomly using a grid overlay on the watershed maps.

In 1999, thirty 7.32-m radius (168 m^2) vegetation plots were established in each watershed. Within each plot was a 2.07 m fixed-radius microplot (13 m^2) located at 90° and 3.7 m from the plot center.

Within the 7.32-m radius circular plot, forest mensuration, crown condition classification, and damage and mortality indicators were recorded in all trees with a diameter at breast height (dbh) ≥12.7 cm in summer 2000. Forest mensuration measurements included species name, location from the plot center (horizontal distance and azimuth), dbh, live or snag, and height (using a clinometer). Crown condition measurements included crown class, live crown ratio, vigor, and width. Damage and mortality measurements included the location, damage type, and severity of up to three damage types per tree (Table I).

In the microplots, forest mensuration, crown condition classification, and damage and mortality measurements were recorded for saplings (2.54 cm ≤ dbh <12.7 cm). Measurements recorded for the saplings included species name, location from the plot center, dbh, height (measured with a height pole), crown class, live crown ratio, crown vigor and damage location, damage type, and severity of up to three damage types per sapling. Also in the microplots, mensuration and crown condition data were recorded on tree seedlings (dbh <2.54 cm and

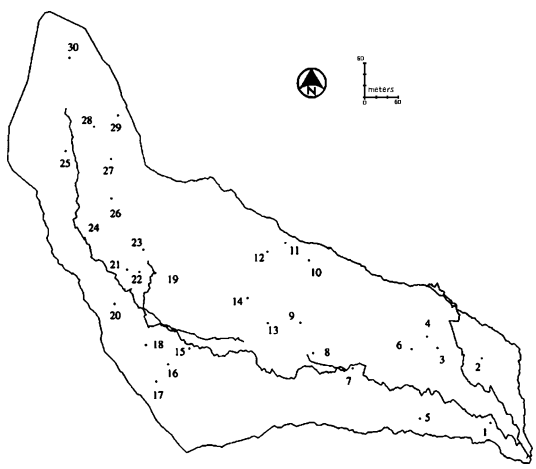

Figure 2 Location of the vegetation monitoring plots in Cadillac Brook watershed in Acadia National Park.

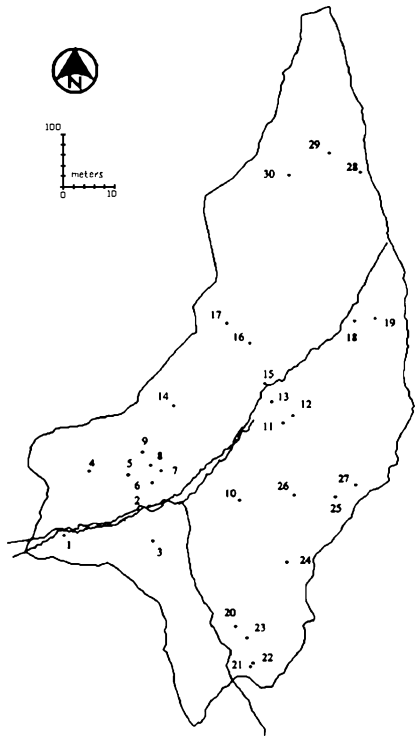

Figure 3 Location of the vegetation monitoring plots in Hadlock Brook watershed in Acadia National Park.

Table I FHM damage and mortality indicator: minimum thresholds for each combination of damage sign and the locations on the tree or sapling (shaded areas indicate that this location and damage sign is not a valid combination)

Damage sign or symptom: listed in decreasing priority (FHM code number)	Location on the tree or sapling (FHM code number): first priority location, last priority location								
	Roots and stump (1)	Roots and lower bole (2)	Lower bole (3)	Lower and upper bole (4)	Upper bole (5)	Crownstem (6)	Branches (7)	Buds and shoots (8)	Foliage (9)
Canker (1)	20% of the circumference affected within a 0.91 m (3 ft) vertical section								
Conks, fruiting bodies, and decay (2)	No minimum threshold								
Open wounds (3)	20% of the circumference affected within a 0.91 m (3 ft) vertical section								
Resinosis or gummosis (4)	20% of the circumference affected within a 0.91 m (3 ft) vertical section								
Broken bole or roots >0.9 m (3′) from bole (11)	No minimum threshold								
Brooms or roots or bole (12)	No minimum threshold								
Broken or dead roots <0.9 m (3′) from bole (13)	<20% affected								
Loss of apical dominance (21)						No minimum threshold			
Broken or dead branches (22)							<20% affected		
Excessive branching or brooms (23)							<20% affected		
Damaged foliage or shoots (24)								≤30% of the buds, shoots or foliage <50% affected	
Discoloration of foliage (25)									≤30% foliage <50% affected
Other (31)	No minimum threshold no minimum threshold			No minimum threshold				No minimum threshold	

Severity codes vary by type of damage; for most damages 20%–29% affected = code 2, 30%–39% affected = code 3, etc.; other damages are ‘0’ regardless of severity. Information adapted from Tallent-Halsell (1994).

<0.3 m tall). Measurements included species name, crown class, crown exposure, crown vigor, and seedling height.

2.3 Foliar analysis

Twenty samples of red maple and red spruce foliage were collected from each watershed at ANP. Foliar chemical analysis procedures used at ANP were similar to those used by White (1996). Samples were collected from codominant trees found in the 7.32-m radius circular plots and/or along a transect between plots.

Foliar samples were collected using a pruning saw at a height no taller than 9 m from lateral sunleaves branches on the south side of the crown during the first week of September for red maple, and during the last week of October for red spruce. Foliar samples

consisted of approximately 30 healthy leaves for red maple and several current year shoots for red spruce. Timing was late enough in the growing season that the leaves or needles were fully developed and functional but early enough so that physiological changes leading to fall senescence or dormancy had not yet occurred.

Foliar samples were not washed prior to analyses, and were dried to constant weight at a temperature of 65°C and ground in a Wiley mill to 40 mesh. The Wiley mill was vacuumed between samples to avoid cross sample contamination. Chemical analyses were performed by the Maine Agricultural and Forest Experiment Station Analytical Laboratory at the University of Maine. Non-volatile nutrients were processed using a dry ash digestion with element analyses by inductively coupled plasma emission (ICP) (Kalra & Maynard, 1991; Moyse & Fernandez 1987). Total N was determined with a LECO CN 2000 total-nitrogen analyzer (United States Department of Agriculture (USDA), 1996).

Statistical analyses were conducted using the Statistical Analysis System (SAS Institute, 1998). For comparing each set of data between Cadillac Brook and Hadlock Brook watersheds, one-way analysis of variance (ANOVA) was used. ANOVA

Table II Species composition of the trees, saplings, and seedlings, within the deciduous and coniferous forest-types in Cadillac Brook and Hadlock Brook watersheds in Acadia National Park in 1999

Latin name	Common name	Cadillac Brook		Hadlock Brook	
		Deciduous Forest types (%)	Coniferous Forest types (%)	Deciduous Forest types (%)	Coniferous Forest types (%)
a) Trees species					
Abies balsamea	Balsam fir	0	19	0	3
Acer pensylvanicum	Striped maple	12	0	0	0
Acer rubrum	Red maple	2	4	8	4
Acer saccharum	Sugar maple	5	0	15	0
Betula alleghaniensis	Yellow birch	2	3	39	11
Betula papyrifera	Paper birch	48	1	0	0
Betula populifolia	Gray birch	0	1	0	0
Fagus grandifolia	American beech	2	0	23	0
Fraxinus americana	White ash	7	0	0	0
Larix laricina	Tamarack	0	0	0	1
Picea rubens	Red spruce	5	24	15	80
Pinus rigida	Pitch pine	0	8	0	0
Pinus strobus	Eastern white pine	0	0	0	1
Populus grandidentata	Bigtooth aspen	17	0	0	0
Thuja occidentalis	Northern white cedar	0	39	0	1
b) Saplings species					
Dacer pensylvanicum	Striped maple	65	(Incomplete information)	0	0
Amelanchier sp.	Serviceberry	0		0	14
Betula alleghaniensis	Yellow birch	0		0	29
Betula papyrifera	Paper birch	24		0	0
Fagus grandifolia	American beech	6		50	0
Fraxinus american	White ash	6		0	0
Picea rubens	Red spruce	0		50	57
c) Seedlings species					
Abies balsamea	Balsam fir	4	(Incomplete information)	2	7
Acer pensylvanicum	Striped maple	81		27	14
Acer rubrum	Red maple	4		0	0
Betula alleghaniensis	Yellow birch	0		0	7
Fagus grandifolia	American beech	11		11	0
Picea rubens	Red spruce	0		59	68
Pinus strobus	Eastern white pine	0		0	4

assumptions were tested using Levene's test for homogeneity of variances and Shapiro–Wilk *W* test for normality. When transformations were necessary to meet ANOVA assumptions, logarithm 10, square root, 1/square root, or reciprocal transformations were used. Raw data were used for boron (B) and log transformed data for manganese (Mn); although the data were homogeneous, the latter could not be normalized. A probability of 0.05 was used to confer significance.

In addition, foliar nitrogen (N) concentrations of *A. rubrum* and *P. rubens* were compared between ANP watersheds and the treated and untreated watersheds at the Bear Brook Watershed in Maine (BBWM). The BBWM is a paired-watershed research area located ~60 km north of ANP. Ambient wet plus dry deposition at the BBWM was estimated to be ~8.4 kg/ha/year for N and ~14.4 kg/ha/year for S. Since 1989, one watershed at BBWM has been manipulated with bimonthly additions of granular, dry ammonium sulfate at the rate of ~20 kg $(NH_4)_2SO_4$ ha^{-1} per application, while the other watershed is used as reference (exposed only to ambient levels of atmospheric deposition). Details on the BBWM site and the chemical treatment are available elsewhere (Kahl, Norton, Fernandez, Rustad, & Handley 1999; Norton et al., 1999; Rustad et al., 1996.

3 Results

3.1 Cadillac brook watershed

Approximately 60% of Cadillac Brook watershed was characterized by open areas (mostly bare rock surfaces) and mixed scrub/shrub communities. Twenty percent of the watershed was covered by deciduous forest and 20% by coniferous forest. There were 13 species recorded in the tree category and four species in each of the sapling and seedling categories (Table II). The dominant tree species were *Betula papyrifera*, *Populus grandidentata*, *Acer pensylvanicum*, *Fraxinus americana*, *P. rubens*, *Thuja occidentalis*, and *Abies balsamea*. Approximately 10% of the trees recorded in this watershed were snags (dead standing trees).

The average tree dbh and height for the live trees in the deciduous forest in Cadillac watershed was 16.8 cm and 14 m, respectively (Table III). The average live crown ratio was ~43%. Ninety percent of the trees in the deciduous forest in Cadillac were in the codominant crown class and 10% in the intermediate crown class. Overall almost two-thirds of the trees had high crown vigor.

Approximately 79% of the trees in the deciduous forest in Cadillac showed no signs or symptoms of damage. The most common damage recorded was the presence of conks followed by fruiting bodies, or other indicators of advanced decay, present on approximately 14% of the trees. Other damages that occurred infrequently included cankers, loss of apical dominance or dead terminal leader, and broken or dead branches within the live crown area.

Within the deciduous forest in Cadillac the dominant sapling species were *A. pensylvanicum* and *B. papyrifera* (Table II). Overall 78% of the saplings had no signs or symptoms of damage. The most common damage recorded on saplings was broken or dead branches followed by open wounds and cankers.

The dominant seedling species were *A. pensylvanicum* and *Fagus grandifolia* (Table II). All tree

Table III Mean, median, range, standard deviation, and standard error (by forest-type) for the tree dbh, height, live crown ratio, and tree crown width (two perpendicular measurements) in Cadillac and Hadlock watersheds at Acadia National Park in 1999

Tree measurements	Cadillac Brook			Hadlock Brook					
	Forest type			Forest types					
	Deciduous			Deciduous			Coniferous		
	N	Mean	SD	N	Mean	SD	N	Mean	SD
Tree dbh (cm)	42	16.8	4.1	13	26.3	11	204	22.9	8.1
Tree height (m)	42	14.1	2.9	12	15	3.4	58	15.9	3.8
Tree live crown ratio (%)	42	43.2	14.7	13	45.8	19.3	58	40.9	20.3
Tree crown width (m)[1]	42	4.3	1.1	13	7.65	3.25	58	4.4	1.35

[1] Two crown widths were measured per tree, the second at a perpendicular (90°) angle to the first.

seedlings were in the overtopped crown class; within this class 56% of the seedlings had high crown vigor, 18% had medium crown vigor, and 26% had low crown vigor. Overall, 7% of the seedlings received direct light from above and from the sides (high light levels). Forty-eight percent of the seedlings were exposed to direct light from above but relatively little from the sides (moderate light levels). Thirty percent of the seedlings received limited direct overhead light and 15% grew in heavily shaded areas (poor light levels).

3.2 Hadlock brook watershed

Approximately 23% of Hadlock Brook watershed was open areas (mostly bare rock surfaces) and mixed scrub/shrub communities. Coniferous forest was the dominant forest type with 70% cover. Only 7% of the watershed was deciduous forest. There were nine species recorded in the tree category and three and six species in the sapling and seedling categories, respectively (Table II). The dominant tree species were *P. rubens*, *F. grandifolia*, *Acer saccharum*, and *Betula alleghaniensis*. About 15% of the trees recorded in this watershed were snags.

In the deciduous forest in Hadlock watershed, the average tree dbh and height for the live trees was 26.3 cm and 15 m, respectively (Table III). The average live crown ratio was approximately 46%. Sixteen percent of the trees in the deciduous forest in Hadlock were in the dominant crown class; the majority (84%) of the trees were in the codominant crown class. One-third of the trees had high crown vigor and more than 1/2 had moderate crown vigor.

In the coniferous forest in Hadlock watershed, the average tree dbh and height was 23 cm and 16 m, respectively (Table III). The average live crown ratio was 41%. Two-thirds of the trees were codominant and around 1/4 were in the intermediate crown class. Thirty-one percent of the trees had high crown vigor and 53% had medium crown vigor.

Approximately 23% of the trees recorded in the deciduous forest in Hadlock showed no signs of damage. The most common damage recorded was the presence of cankers on 31% of the trees. Fifteen percent of the trees had conks, fruiting bodies or other indicators of advanced decay and another 15% had broken or dead branches within the live crown.

Within the coniferous forest, ~53% of the trees recorded had no signs of damage. The most common damage on 20% of the trees was broken or dead branches within the live crown. Other damage signs present included cankers, conks, fruiting bodies and other indicators of advanced decay, open wounds, resinosis or gummosis and loss of apical dominance or terminal leader.

Within the deciduous forest in Hadlock, the dominant sapling species were *P. rubens* and *F. grandifolia* (Table II). Common damage signs on saplings in the deciduous forest were broken or dead branches and cankers. Within the coniferous forest, *P. rubens* and *B. alleghaniensis* were the dominant sapling species (Table II). About 57% of the saplings had no damage signs. Broken or dead branches were the most common damage form of damage on saplings, followed by evidence of conks, fruiting bodies, or decay.

In the deciduous forest, the dominant seedling species were *P. rubens*, *A. pensylvanicum*, and *F. grandifolia* (Table II). In the coniferous forest, the dominant seedling species were *P. rubens* and *A. pensylvanicum*. In the deciduous forest, 23% of the seedlings had high crown vigor, 45% had medium and 32% had low crown vigor. This contrasts with the coniferous forest, in which 46% of the seedlings had high crown vigor, 29% had medium and 25% had low crown vigor. Fifty-two percent of the seedlings in the deciduous forest in Hadlock were growing in poor light levels. The rest of the seedlings were primarily growing in areas exposed to moderate light levels or in limited direct overhead light. Eighty-nine percent of the seedlings in the coniferous forest were exposed to moderate light levels.

3.3 Foliar chemical analyses

Analyses of *A. rubrum* and *P. rubens* foliage showed statistically significant differences in foliar chemistry for some nutrients between Cadillac Brook and Hadlock Brook watersheds. *A. rubrum* trees growing in the Cadillac Brook had significantly higher concentrations of calcium (Ca), copper (Cu), Mn, zinc (Zn), cadmium (Cd), and significantly lower concentrations of aluminum (Al) (Table IV). Analysis of *A. rubrum* foliage indicated no significant differences between Cadillac Brook and Hadlock Brook watersheds for N, potassium (K), magnesium (Mg), B, phosphorus (P), iron (Fe) and lead (Pb). *P. rubens* trees growing in the Cadillac Brook had significantly higher concentrations of Ca, Fe, Mn and Zn and

Table IV Mean and standard deviation of nutrient concentrations in *Acer rubrum* and *Picea rubens* in Cadillac Brook watershed and Hadlock Brook watershed in Acadia National Park in 1999 (n = 20; untransformed data), and in East Bear and West Bear watersheds at the BBWM in 1994

	Acadia National Park (this study)			Bear Brook Watershed in Maine (White, 1996)	
	Cadillac Mean std. deviation	Hadlock Mean std. deviation		East Bear Mean std. deviation	West Bear Mean std. deviation
a) *Acer rubrum*					
N (%)	1.75 ± 0.3	1.80 ± 0.2	**	1.83 ± 0.2	2.14 ± 0.1
*Ca (mg/kg)	6,509.7 ± 2,949.4	4,482.1 ± 1,576.5		5,700.0± 848.0	6,060.0 ± 732.0
K (mg/kg)	6,377.4 ± 1,458.4	7,061.7 ± 2,338.5		7,380.0 ± 4,88.0	6,180.0 ± 2,100.0
Mg (mg/kg)	1,097.7 ± 278.0	1,138.3 ± 443.6		1,250.0 ± 309.0	1,550.0 ± 265.0
P (mg/kg)	937.9 ± 158.0	841.5 ± 143.8		1,090.0± 142.0	1,220.0 ± 76.3
*Al (mg/kg)	8.1 ± 5.0	10.8 ± 5.5	**	10.3 ± 1.0	13.7 ± 3.4
B (mg/kg)	34.5 ± 13.1	28.6 ± 17.8		33.7 ± 6.8	33.8 ± 8.2
*Cu (mg/kg)	7.3 ± 2.5	4.9 ± 2.2		6.4 ± 2.5	5.6 ± 1.2
Fe (mg/kg)	50.1 ± 29.5	49.2 ± 17.4		44.6 ± 10.1	53.6 ± 9.8
*Mn (mg/kg)	362.8 ± 116.0	144.7 ± 160.7	**	386.0 ± 159.0	782.0 ± 232.0
*Zn (mg/kg)	37.8 ± 15.0	27.5 ± 7.8		24.0 ± 7.0	28.5 ± 6.8
*Cd (mg/kg)	0.111 ± 0.08	0.073 ± 0.014			
Pb (mg/kg)	<0.5	<0.5			
b) *Picea rubens*					
*N (%)	1.01 ± 0.1	1.10 ± 0.1	**	1.09 ± 0.1	1.19 ± 0.1
*Ca (mg/kg)	2,352.3 ± 978.5	1,626.4 ± 466.1		1,690.0 ± 504.0	1,780.0 ± 541.0
*K (mg/kg)	5,608.2 ± 944.9	7,221.3 ± 894.3	**	7,710.0 ± 1,260.0	7,050.0 ± 1,450.0
Mg (mg/kg)	1,025.1 ± 169.8	964.3 ± 115.7		704.0 ± 106.0	722.0 ± 136.0
P (mg/kg)	851.8 ± 111.9	875.5 ± 108.3		1,090.0 ± 108.0	1,130.0 ± 165.0
Al (mg/kg)	39.6 ± 15.6	45.3 ± 19.3		56.5 ± 14.4	55.5 ± 18.2
B (mg/kg)	16.3 ± 2.5	15.8 ± 4.5		14.9 ± 3.9	16.5 ± 3.9
Cu (mg/kg)	2.9 ± 0.3	3.1 ± 0.4		3.8 ± 0.8	3.9 ± 0.6
*Fe (mgtkg)	28.9 ± 8.3	22.8 ± 3.3		26.4 ± 4.8	25.6 ± 3.5
*Mn (mg/kg)	380.1 ± 189.7	234.9 ± 54.0		938.0 ± 345.0	936.0 ± 453.0
*Zn (mg/kg)	33.4 ± 28.6	21.5 ± 5.1		17.5 ± 3.6	16.5 ± 4.6
Cd (mg/kg)	<0.052	<0.052			
Pb (mg/kg)	3.1 ± 0.7	2.9 ± 0.6			

*Indicates statistically significant differences between Cadillac Brook and Hadlock Brook watersheds at $P < 0.05$.

**Indicates differences between East Bear Brook and West Bear Brook watersheds.

significantly lower concentrations of N and K (Table IV). No significant differences between watersheds for *P. rubens* were found for Mg, P, Al, B, Cu, Cd and Pb.

4 Discussion

On MDI the extensive wildfire in 1947 impacted the landscape in a patchy manner, affecting Cadillac Brook watershed but not Hadlock Brook watershed. This contrast was reflected in forest differences observed in this study (Table II). The majority of Hadlock Brook watershed (70%) was dominated by *P. rubens* with a relatively small area of deciduous forest. In Cadillac Brook watershed, on the other hand, deciduous and coniferous forest-types were more equally distributed.

The average tree height was similar in both watersheds (Table III). However, trees growing in Cadillac watershed were smaller (16.8-cm dbh), which reflected their post-fire establishment. Forests in Hadlock Brook watershed, which were not exposed to the 1947 fires, had a larger average dbh reflecting older stands.

In the deciduous forest within Cadillac there was a higher percentage (79%) of trees that displayed no

damage signs or symptoms than in either the deciduous (23%) or coniferous (53%) forests in Hadlock. The mature age of the trees in Hadlock may have contributed to the presence of some of the more common damage signs that were recorded.

The understory seedling composition in the deciduous forest at Cadillac reflected a potential long-term species shift away from shade intolerant species like *B. papyrifera* and *P. grandidentata* to more shade tolerant species including *F. grandifolia* and *A. rubrum*. This shift, however, is dependent on reoccurring disturbance events that could reopen the overstory canopy and continue to favor shade intolerant species. In the deciduous forest in Hadlock the understory included a substantial component of *P. rubens*. This also suggests a species shift towards a mixed deciduous/coniferous forest-type.

4.1 Foliar chemical analyses at acadia

The initial effects of fire and harvesting on biogeochemical cycling in forest ecosystems include elevated losses of some nutrients from the system, e.g., N (Clinton, Vose, & Swank 1996), Ca^{2+}, Mg^{2+} and K^{+} (Pardo, Driscoll, & Likeips 1995). The extent of the nutrient loss due to fire varies depending on the intensity of the fires (Vose, Swank, Clinton, Knoepp, & Swift 1999). Gillon, Houssard, Vallete, & Rigolot (1999) and Clinton et al. (1996) found that the effects of fires on foliar N concentrations were short-term; within two years, foliage N concentrations were back to pre-fire levels in several deciduous tree species. Therefore, foliar chemistry at ANP might be more related to deposition of N and other compounds rather than to direct effects from the 1947 wildfire.

Foliar chemical analyses from ANP showed that N concentration for *A. rubrum* did not differ between Cadillac Brook and Hadlock Brook watersheds. Nitrogen concentration for *P. rubens*, on the other hand, was significantly higher in Hadlock Brook watershed than in Cadillac Brook watershed. Differences in foliar N might indicate early stages of N saturation in Hadlock Brook as also suggested by Hadlock Brook stream N flux. Hadlock Brook nitrate flux showed signs of early stages of N loss or N saturation (Kahl et al., 2006, this volume). Nitrogen saturation may be induced at least in part by atmospheric N deposition. Foliar N chemistry and reported stream water chemistry suggest that Hadlock watershed might be under higher atmospheric N deposition rates than Cadillac Brook watershed. Johnson (2002) studied deposition rates at ANP during 1999 and 2000 and showed that deposition at ANP was high for sites with a southwest aspect and under softwoods (conifers), while deposition was low for sites facing southeast and under hardwoods (broadleaf). Hadlock Brook watershed faces southwest and, as discussed above, vegetation is dominated by softwoods while Cadillac Brook watershed faces southeast to east and has a higher percentage of hardwoods.

Foliar Ca concentrations were significantly higher in Cadillac Brook watershed in both *A. rubrum* and *P. rubens*. However, foliar K concentrations were significantly higher in Hadlock Brook watershed in both *A. rubrum* and *P. rubens*. Although differences were significant only for *A. rubrum*, higher foliar Al concentrations in Hadlock Brook watershed for both species suggest that soils in Hadlock Brook watershed might be more acidic than soils in Cadillac Brook watershed.

A comparison of the foliar nutrient concentrations, especially N, between ANP and BBWM indicated that both Cadillac and Hadlock Brook foliar nutrient concentrations were similar to East Bear (the reference watershed) more than West Bear (the manipulated watershed) for both *A. rubrum* and *P. rubens* (Table IV). The higher foliar N concentrations reported in West Bear at BBWM reflect whole watershed chronic N amendments in the form of ammonium sulfate (White, Fernandez, & Wiersma 1999; White 1996). Foliar N concentrations from East Bear, Cadillac and Hadlock watersheds reflect ambient N depositions. Foliar chemistry, soil chemistry, stream water chemistry and forest growth studies at the BBWM are available elsewhere (Elvir, Wiersma, White, & Fernandez 2003; Fernandez, Rustad, David, Nadelhoffer, & Mitchell 1999; Norton et al. 1999; Wang & Fernandez 1999; White et al. 1999).

5 Conclusions

The current heterogeneity of the vegetation in Cadillac and Hadlock watersheds at ANP was attributed to the disturbance history that included the 1947 wildfire, the 1998 ice storm, and the ecology of the different tree species. Hadlock watershed forest cover includes *P. rubens*, *A. balsamea* and late

successional deciduous species such as *A. saccharum*, *F. grandifolia*, and *B. alleghaniensis*. Cadillac watershed is covered by more diverse deciduous and coniferous forest types including the species *T. occidentalis*, *Pinus rigida*, *P. rubens*, *A. balsamea*, *A. rubrum*, and some early successional species such as *B. papyrifera* and *P. grandidentata*.

Foliar nutrient concentrations for *A. rubrum* and *P. rubens* in Cadillac and Hadlock watersheds at ANP may be attributed to atmospheric deposition of N and other compounds as well as biogeochemical cycles of elements rather than to post-effects from the 1947 wildfire. The higher foliar N concentrations for *A. rubrum* and *P. rubens* trees growing in Hadlock watershed indicate a higher soil N availability, which might be induced by higher atmospheric N deposition. The higher foliar Al concentrations and lower foliar Ca concentrations for these tree species might indicate a higher degree of soil acidification in Hadlock Brook watershed compared to Cadillac Brook watershed.

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