



Forest Health Monitoring in the Northeast Temperate Network

2011 Summary Report

Natural Resource Report NPS/NETN/NRTR—2012/604



ON THE COVER

Forest plot in a mature forest stand in Morristown National Historic Park
Photograph by: Caitlin White, NPS

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Kate M. Miller

Northeast Temperate Network
Acadia National Park
Bar Harbor, ME 04609

Brian R. Mitchell

Northeast Temperate Network
54 Elm Street
Woodstock, VT 05091

Jesse S. Wheeler

Northeast Temperate Network
Acadia National Park
Bar Harbor, ME 04609

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Executive Summary

The 2011 field season marked the Northeast Temperate Network (NETN) Inventory and Monitoring Program's second year of repeat sampling in forest monitoring plots, and now half of all forest plots have been sampled twice. This report contains an ecological integrity scorecard for parks that were sampled in 2011 that include Acadia National Park (ACAD), Morristown National Historical Site (MORR), Roosevelt-Vanderbilt National Historic Sites (ROVA), and Weir Farm National Historic Site (WEFA). Additional sections cover all NETN parks monitored for forest health, including an analysis of forest soil chemistry and a power analysis of key forest metrics.

Ecological Integrity

Acadia National Park

Ecological integrity metrics suggest that forests in ACAD are approaching mature stages of forest succession, but late-successional structure, such as medium to large snags, is still lacking on Mount Desert Island and Schoodic Peninsula. ACAD continues to be the least invaded NETN park, with only three out of 176 plots containing indicator invasive exotic species. Damage from beech bark disease and balsam woolly adelgid (*Adelges piceae*) were the only major tree condition issues reported in 2011. Tree regeneration appears to be adequate, and impacts from deer browse are minimal.

Tree growth rates are lower than the regional growth rates calculated from the U.S. Forest Service Forest Inventory and Analysis (FIA) program. Lower growth rates are likely due, in part, to the higher proportion of late successional plots in ACAD. While overall tree mortality is at accepted levels, balsam fir (*Abies balsamea*) and big tooth aspen (*Populus grandidentata*) both have elevated mortality rates. Higher mortality rates for balsam fir are likely influenced by the presence of balsam woolly adelgid. Big tooth aspen mortality is likely the result of forest succession, and is not a forest health concern.

Morristown National Historical Park

An overabundance of white-tailed deer and invasive exotic species continue to significantly impact forest health in MORR, with the most extreme impacts in successional forest stands. Tree regeneration is well below levels required to restock the future forest, and is especially low in successional stands. Invasive exotic species are pervasive throughout MORR, averaging over five indicator invasive exotic species per plot and comprising most of the plant cover in the understory of successional forests. Coarse woody debris (CWD) and large snags are also lacking in MORR forests. Tree condition was good, with only a few cases of elevated insect herbivory and minor beech bark disease reported.

Tree growth rates are lower than the regional growth rates calculated from the FIA program, but the higher proportion of late successional stands in MORR may be influencing the lower growth rates in the park. Overall tree mortality is within accepted ranges, and is lowest for oak species (*Quercus* spp.). The mortality rate for white ash (*Fraxinus americana*) may be of concern if this high rate is maintained over multiple sample periods.

Roosevelt-Vanderbilt National Historic Sites

Eleanor Roosevelt National Historic Site & Home of Franklin D. Roosevelt National Historic Site

While CWD is at expected levels in ELRO/HOFR, snags are lacking both in overall abundance and in abundance of medium to large diameter snags. Tree regeneration and deer browse indicator species metrics both suggest moderate deer browse impacts. Although average percent cover of invasive exotic species is low, indicator invasive exotics occur in 21 out of 24 plots, and plots have an average of three indicator invasive exotic species. Hemlock woolly adelgid (HWA: *Adelgis tsugae*) and Elongate Hemlock Scale (EHS: *Fiorinia externa*) continue to be observed on most eastern hemlocks (*Tsuga canadensis*) in ELRO/HOFR, although hemlock mortality has not been observed since sampling was initiated in 2007. While no other major tree conditions have been reported for ELRO/HOFR, several plots had slightly elevated levels of leaf loss, necrotic leaves, and insect herbivory. Tree growth rates are below regional FIA rates, but are likely due to differences in structural stage between ELRO/HOFR and FIA plots. Tree mortality rates are at expected levels for all tree species in ELRO/HOFR.

Vanderbilt Mansion National Historic Site

VAMA has the highest CWD volume and CWD ratio of any park in the network. Overall snag abundance is also relatively high, although medium to large snags are slightly below expected levels. With the highest average seedling density in NETN, tree regeneration in VAMA appears adequate. HWA and EHS were observed on one plot in VAMA. While no other major tree conditions were reported for VAMA, several plots had elevated insect herbivory and leaf loss. Tree growth and mortality rates were both within accepted ranges.

Weir Farm National Historic Site

Forest health appears to be impacted by a number of factors in WEFA. CWD and abundance of snags are both below expected levels. Tree regeneration and deer herbivory indicator species metrics suggest relatively high deer browse impacts. Invasive exotic species are also a concern in WEFA, with Japanese barberry (*Berberis thunbergii*) occurring in nine out of 10 plots, and an average of over three indicator invasive exotic species per plot. Tree condition was influenced by hemlock woolly adelgid in one plot, and by elevated levels of insect herbivory and necrotic leaves in remaining plots. Tree growth rates were the lowest of NETN parks, and below the regional FIA average. However, these growth rates should be interpreted as preliminary due to the small sample size. The overall mortality rate is within the expected range, although the mortality rate for sugar maple (*Acer saccharum*) is slightly elevated.

Ecological Integrity Scorecard

Park	CWD Ratio	Snag Abundance	Invasive Exotic Plants	Tree Condition/ Forest Pests*	Tree Regeneration*	Deer Browse Indicator Species	Tree Growth & Mortality
ACAD	Good	Caution	Good			Good	Caution
ELRO/HOFR	Good	Caution	Caution			Caution	Caution
MORR	Caution	Sign. Conc.	Sign. Conc.			Caution	Caution
VAMA	Good	Caution	Sign. Conc.			Caution	Good
WEFA	Caution	Caution	Sign. Conc.			Caution	Caution

*Pie charts represent the proportion of plots in each ecological integrity rating category.

Forest Soil Chemistry

Results from the ordination of soil A horizon samples suggest that vulnerability to acidification and N saturation varies across the network and within parks. Forest soils in ACAD, which have high organic content, low pH, and low base saturation, are most vulnerable to acidification in NETN, despite receiving the lowest annual acid deposition rates in the network. Acidification risk is low in the well-buffered soils in MABI, MORR and SARA and varies in the remaining parks. Some plots in SAGA, MIMA and ROVA are comprised of acidic, poorly-buffered soils, and other plots appear to be well-buffered. Forest soils in ACAD are least vulnerable to N saturation and NO_3^- export due in part to high organic content. Parks with a history of agriculture, especially SARA, may be most vulnerable to N saturation.

Power Analysis

Results of power analyses indicate that, for most key forest metrics, the monitoring program meets the target of detecting a 40% change in a metric with 80% power and a Type I error rate (alpha) of 0.10. In other words, if there truly was a 40% change in one of the monitoring metrics, that change would be detected 80% of the time, and if there was not a 40% change, there would be a 10% chance of falsely claiming that there was a change. For each metric, we tested the ability of the monitoring program to detect a trend across the entire network and at each park independently. Native species richness and live-tree basal area consistently had the lowest detectable effect sizes across all NETN parks, and in all parks a 40% change was detectable with 80% power and $\alpha = 0.05$. Conversely, coarse woody debris, regeneration stocking index, and snag abundance metrics had multiple parks that did not meet the detection target of 40% change, even when α was 0.10.

Metrics for the entire network and ACAD performed very well, with a minimum detectable effect size of 10% or smaller for every metric at 80% power and $\alpha = 0.05$. This is primarily due to the large sample size. In contrast, metrics in WEFA consistently did not meet the target to detect a 40% effect size, even at $\alpha = 0.10$. Poor trend detection in WEFA is mostly due to low sample size ($n = 10$). If power continues to be low over multiple survey cycles, NETN may consider adding more plots at WEFA. The remaining parks had varied results, and metrics containing a high proportion of zeros and low values were the most common cause of poor trend detection. Poor trend detection in this case is not a big concern, because a 40% change in a metric with low values is of relatively small magnitude in reality. However, several cases of poor change detection were the result of high metric variability (e.g., average indicator invasive exotic % cover in MIMA and MORR, average herb % cover in SARA). This is of greater concern, because only large changes in a metric can be detected, even if metric values are high to begin with. Post-stratifying plots based on land use history, forest type, or sub unit may improve power to detect change, and power is also expected to improve over time.

Using a Type 1 error rate (alpha) of 0.10 improves the power to detect change over the “standard” value of 0.05. This standard value is the convention for manipulative experiments, and represents the likelihood of failing to accept a null hypothesis when it is true. In this case, that corresponds to claiming a 40% change occurred when in fact the change was less. For NETN’s forest monitoring, we feel that it is appropriate to accept a higher risk of falsely claiming that a change occurred in order to provide a greater chance of detecting important ecological changes. Therefore, the default alpha for future trend analyses will remain $\alpha = 0.10$.

Conclusions

Forest condition in NETN parks is threatened by a range of stressors, including invasive exotic plants, exotic pests and pathogens, high numbers of deer, acid deposition, and lack of late-successional structure. Current indicators suggest that most parks could benefit from less herbivory by white-tailed deer and heightened invasive species control, and that vulnerability to acid deposition impacts varies across the network. Power analysis results indicate that existing sampling techniques are adequate to detect major changes in key metrics of forest condition, structure and function, and that trend detection is expected to improve over time.

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Introduction

The Northeast Temperate Network (NETN) of the National Park Service (NPS) Inventory and Monitoring Program developed a long-term monitoring program for forest resources in response to the identification of Forest Vegetation as a high-priority vital sign for the network (Mitchell et al. 2006). This program also provides data for three additional high-priority vital signs: Forest Soil Condition, White-tailed Deer Herbivory, and Landscape Context. The overall goal of the forest monitoring program is to assess status and trends in the composition, structure, and function of NETN forested ecosystems.

Adapted from the U.S. Forest Service Forest Inventory and Analysis Program, the NETN forest protocol monitors a representative suite of site and vegetation measures in an extensive network of randomly located permanent plots (Tierney et al. 2011). The following parks are monitored in this program: Acadia National Park (ACAD), Marsh-Billings-Rockefeller National Historical Park (MABI), Minute Man National Historical Park (MIMA), Morristown National Historical Park (MORR), Roosevelt-Vanderbilt National Historic Sites (ROVA), Saint-Gaudens National Historic Site (SAGA), Saratoga National Historical Park (SARA), and Weir Farm National Historic Site (WEFA). Roosevelt-Vanderbilt National Historic Sites includes Eleanor Roosevelt National Historic Site (ELRO), Home of Franklin D. Roosevelt National Historic Site (HOFR), and Vanderbilt Mansion National Historic Site (VAMA). Currently NETN has resurveyed half of the plots that have been established throughout the network.

An Ecological Integrity Scorecard is used to facilitate reporting and interpretation of forest condition in NETN parks. The Ecological Integrity Scorecard examines a suite of compositional, structural, and functional metrics in relation to their natural or historical range of variation (Tierney et al. 2009). NETN recognizes that “ecological integrity” may not be the primary goal of park resource management, particularly at historical parks and historic sites where cultural resource management may take precedence. Nevertheless, being able to compare the condition of park resources to ecological integrity benchmarks is valuable because it provides a deeper understanding of park condition, as well as a consistent baseline for assessment of management goals. NETN has started working with several parks to develop scorecards that track progress towards park management goals, and is open to working with other interested parks.

This report includes a section on ecological integrity calculated from data representing the most recent full cycle of plots (2008 to 2011) for ACAD, MORR, ROVA (ELRO/HOFR and VAMA), and WEFA. The second section examines patterns in forest soil chemistry across the network. Results from power analyses on key forest metrics are covered in the third section. Finally, Quality Assurance/ Quality Control results and issues related to the 2011 field season are summarized in Appendix A.

Methods

Permanent forest plots have been installed and each plot is being sampled every 4 years using a rotating four-panel design (Table 1). One panel is sampled each year at ACAD (one-fourth of the plots during each of the four sampling panels) and in alternate years at the nine national historical parks and historic sites (one-half of the plots during each of two sampling panels per park). Because ELRO and HOFR are adjacent park units, the sampling design treats them as a single unit. It is not possible to report on these parks individually because there is not a sufficient sample size at ELRO to support a stand-alone analysis.

Plots were randomly located within each park using generalized random tessellation stratified sampling (GRTS; McDonald 2004). GRTS points that were primarily forested or succeeding to forest were established as forest plots, as long as they were ≥ 15 m from a road (including a carriage road), a perennial stream or water body large enough to create a canopy opening, a mowed area, or the park boundary. Plots in areas receiving management, such as logging and invasive species removal, are included in the target population as long as plots are not being targeted for the management. In one case, a GRTS point was located in a 4 ha deer enclosure in MORR. Because this point was part of the random GRTS sample and met the pre-defined target population guidelines, it was not excluded from analyses. However, major differences between this plot and those outside of exclosures will be noted in ecological integrity metrics and trend analyses.

The permanent plot design is illustrated in Figure 1. Tree and stand measurements are made within fixed-area, square plots ($15 \times 15 \text{ m}^2$ at ACAD; $20 \times 20 \text{ m}^2$ at the other parks). Tree regeneration is measured within three 2-m radius circular microplots embedded within each square plot. Coarse woody debris (CWD) is assessed using line intersect sampling along three 15-m transects originating at plot center. Understory diversity is monitored within eight 1-m^2 quadrats, and soil samples are obtained from a location adjacent to the plot. For a more detailed description of the forest protocol, including background information, field methods, and sample design, refer to Tierney et al. (2011).

Table 1. Northeast Temperate Network forest monitoring panel design. Panel numbers are listed in the table. One-fourth of the plots in ACAD are sampled every year. One-half of the plots in MABI, MIMA, SAGA and SARA are sampled in panels 1 and 3. One-half of the plots in MORR, ROVA (HOFR, ELRO, VAMA), and WEFA are sampled in panels 2 and 4.

Park	Year								
	2006	2007	2008	2009	2010	2011	2012	2013	2014
ACAD	1	2	3	4	1	2	3	4	1
MABI	1		3		1		3		1
MIMA	1		3		1		3		1
MORR		2		4		2		4	
ROVA		2		4		2		4	
SAGA	1		3		1		3		1
SARA	1		3		1		3		1
WEFA		2		4		2		4	

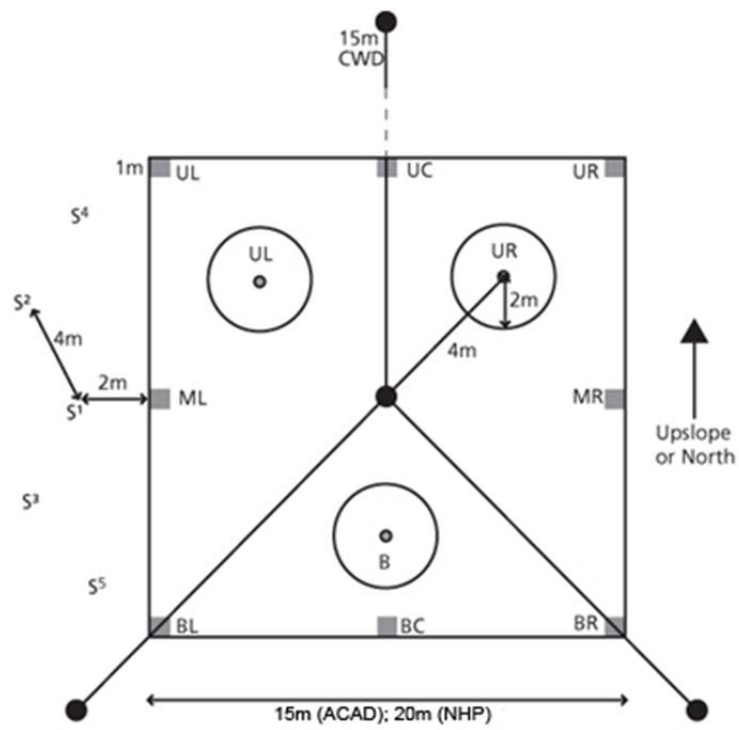


Figure 1. Plot layout showing square tree plot with three nested 2-m radius regeneration microplots, eight 1 m² vegetation quadrats, and three 15 m coarse woody debris (CWD) transects. S^x is location of soil sample.

Ecological Integrity Scorecard

The Ecological Integrity (EI) scorecard uses the concept of “ecological integrity” to interpret the condition of forested ecosystems by assessing a suite of compositional, structural, and functional metrics in relation to their natural or historical range of variation (Tierney et al., 2009). For each metric, assessment points are defined that distinguish acceptable or expected conditions from undesired conditions based on current scientific understanding of their natural or historic range of variation (Bennetts et al. 2007). Integrity is interpreted for a broad audience using three categories: Good, Caution, and Significant Concern. “Good” represents acceptable or expected conditions; “Caution” indicates a problem may exist; and “Significant Concern” indicates undesired conditions that may need management action. For some metrics, NETN does not define conditions that merit Significant Concern because current knowledge is insufficient to justify this rating. Ecological integrity assessment points are summarized in Table 2. For a more detailed discussion of a metric’s justification, calculation and confidence, refer to the Ecological Integrity Reporting SOP in Tierney et al. (2011).

Metric calculations are based on the most recent full cycle (four panels) of data collected from all plots sampled in a given park. Thus, most metrics in ACAD are calculated every year. Due to our alternating sampling schedule in national historical parks (NHP) and national historic sites (NHS), calculations for those parks are calculated every 2 years. Tree condition is the only exception to this approach, as annual changes in tree condition may reflect a pest or disease outbreak. Therefore, the tree condition metric will consider both the 4-year average and the most recent year of plot data.

The following metrics are reported for parks sampled in 2011 (ACAD, MORR, ELRO/HOFR, VAMA, and WEFA): coarse woody debris, snag abundance, tree condition and forest pests, tree regeneration, deer browse indicator species, and invasive exotic plant indicator species. In addition to reporting metrics at the park-level, metrics were rated for groups within parks where sample size was sufficient (i.e., at least 10 plots per group). In ACAD, metrics were calculated overall, and by park subunit. In MORR metrics were rated overall, and by mature and successional stand types. Mature stands were defined as second growth stands that originated from areas cleared by General Washington’s forces around 1788 to 1789. While these stands may have been repeatedly or selectively logged, they have never been plowed or cultivated, and are thought to have returned directly to forest after the end of the encampment (Ehrenfeld 1982, Shaw and Patterson 2005). The successional category represents younger stands that originated on abandoned field or pasture around 1927 or later. Soils in successional stands have likely been plowed, and forests are mostly even-aged (Shaw and Patterson 2005).

The tree growth and mortality metric will be reported for the first time in a NETN summary report, and therefore includes results for all parks that are monitored by this protocol. Forest soil chemistry was analyzed in more depth than in previous reports, and will be covered in a separate section that also includes all parks. Structural stage distribution was not included in the EI scorecard, as this is slow to change and has already been reported in Miller et al. (2010) for all plots in ACAD, MORR, ROVA, and WEFA. Ecological Integrity ratings for these metrics are included in the Executive Summary.

Table 2. Metrics and ratings for evaluating the ecological integrity of forest ecosystems.

Metric type	Metric	Metric Rating		
		Good	Caution	Significant Concern
Landscape structure	Forest patch size	> 50 ha	10-50 ha	0.5 to < 10 ha
	Anthropogenic land use	< 10%	10 - 40%	> 40%
Structure	Structural stage	≥ 70% (MABI, SAGA), ≥ 50% (ACAD), and ≥ 25% (MIMA, MORR, ROVA, SARA and WEFA) late-successional structure	< 70% (MABI, SAGA), < 50% (ACAD), and < 25% (MIMA, MORR, ROVA, SARA and WEFA) late-successional structure	< 70% (MABI, SAGA), < 50% (ACAD), and < 25% (MIMA, MORR, ROVA, SARA and WEFA) combined mature <i>and</i> late-successional structure
	Snag abundance	> = 10% standing trees are snags and > = 10% med-lg trees are snags ¹	< 10% standing trees are snags or < 10% med-lg trees are snags	< 5 med-lg snags/ha
	Coarse woody debris ratio ²	> 15% live tree volume	5 - 15% live tree volume	< 5% live tree volume
Composition	Tree regeneration	Seedling ratio > = 0	Seedling ratio < 0	Stocking index outside acceptable range ³
	Tree condition and forest pests	Foliage problem < 10% <i>and</i> no Priority 1 or Priority 2 pests ⁴ <i>and</i> BBD ⁴ ≤ 2	Foliage problem 10 - 50% <i>or</i> Priority 2 pest present <i>or</i> BBD > 2	Foliage problem > 50% <i>or</i> Priority 1 pest present
	Biotic homogenization	No change	Increasing homogenization ⁵	
	Indicator species: invasive exotic plants	< 0.5 indicator species per plot	0.5 to < 3.5 indicator species per plot	3.5 or more indicator species per plot
	Indicator species: deer browse	No decrease in frequency of most browse-sensitive species	Decrease in frequency of most browsed species <i>or</i> increase in frequency of browse-avoided species	Decrease in frequency of most browsed species <i>and</i> increase in frequency of browse-avoided species
Function	Tree growth and mortality rates	Growth ≥ 60% mean <i>and</i> Mort ≤ 1.6%	Growth < 60% mean <i>or</i> Mort > 1.6% ⁵	
	Soil chemistry: acid stress	Soil Ca:Al ratio > 4	Soil Ca:Al ratio 1 - 4	Soil Ca:Al ratio < 1
	Soil chemistry: nitrogen saturation	Soil C:N ratio > 25	Soil C:N ratio 20 - 25	Soil C:N ratio < 20

¹ Med-lg trees are ≥ 30 cm diameter-at-breast-height.² CWD metric ratings were developed for forested habitats, and do not include plots in woodland habitats in ACAD.³ Tree regeneration stocking index is only applicable to MORR, ROVA and WEFA.⁴ Priority 1 pests are Asian longhorned beetle, emerald ash borer, hemlock woolly adelgid, and sudden oak death. Priority 2 pests are balsam woolly adelgid, butternut canker, elongate hemlock scale, and beech bark disease (BBD).⁵ Significant Concern rating has not been defined for these metrics.

Coarse Woody Debris and Snag Abundance

Dead wood, in the form of fallen coarse woody debris (CWD) and standing dead trees (snags), is an important structural feature of forests that provides habitat for many taxa. Silviculture, land management, and hazard tree removal can reduce the quantity or quality of these features. However, thoughtful land management can maintain or enhance snags and CWD (Keeton 2006).

Density of snags and volume of CWD in mature and late-successional stands vary substantially across ecosystems and with site conditions (Tyrrell et al. 1998). However, positive relationships between live and dead tree density can be used to indicate expected snag levels, and positive relationships between live tree volume and volume of CWD can be used to indicate expected CWD levels (Tierney et al. 2010). In addition, large-diameter snags provide habitat for a greater number of vertebrate species (Cline et al. 1980, DeGraaf and Shigo 1985) and persist longer than smaller-diameter snags (Morrison and Raphael 1993, Garber 2005). Therefore density of large-diameter snags is also an important indicator of habitat quality and availability. These metrics assess the density of snags and volume of CWD in relation to live tree density and volume. CWD metric ratings are based on CWD ratio, which is the ratio of CWD volume to live tree volume and is expressed as a percent. The CWD metric calculation requires a stand height measurement for each plot to calculate live tree volume. Therefore, early successional plots, which do not have a stand height measurement, and plots missing stand height measurements are excluded from this metric calculation. Plots in woodland habitats (ACAD only) are also excluded from the CWD metric, as expected levels of CWD volume to live tree volume are unknown. Snag abundance metric ratings are based on the percent of standing trees that are snags and are calculated on all plots. Since NETN plots are not large enough to accurately estimate rare features such as snags, snag abundance is evaluated at the scale of the park or park subunit, and requires at least 10 plots to be adequately estimated. To facilitate comparisons of our CWD metric calculations with other studies, we also report volume of CWD using both metric and English units.

With the highest ratio of CWD volume to live tree volume, ELRO/HOFR and VAMA received a Good rating for CWD (Table 3). CWD ratios were well below the expected 15% level in MORR and WEFA, and both parks were rated Caution for this metric. CWD ratings varied across ACAD subunits. Isle au Haut (IAH) and the eastern section of Mount Desert Island (MDI) were rated Caution for CWD, and ACAD overall was rated Good. The western section of MDI had the highest CWD ratio reported in ACAD, and was rated Good for CWD.

Ratings for snag abundance were more variable across NETN parks, and IAH was the only park unit to receive a Good rating (Table 4). While all subunits of ACAD met the expected proportion of trees as snags, snags over 30 cm diameter at breast height (DBH) were scarce on eastern MDI and Schoodic, and these two units were rated Significant Concern. For ACAD overall, western MDI and VAMA, % of trees over 30 cm DBH that are snags was just under the expected 10% level, and these units narrowly missed a Good rating. ELRO/HOFR and WEFA were rated Caution due to lower than expected proportion of snags of all sizes and lack of medium to large snags.

Forested systems in most NETN parks are relatively young, and are likely to fall short of desired late-successional levels of CWD and snags for some time. As long as forests are left to mature

Table 3. Coarse woody debris (CWD) metric ratings, ratios, and volume calculations for NETN parks based on data collected from 2008 to 2011. Metric ratings are based on CWD ratio, which is the ratio of coarse woody debris volume to live tree volume and are expressed as a percent. Only plots with complete stand height data are included in the analysis. Groups with fewer than 10 plots were not rated for CWD, and woodland plots are not included in the ACAD ratings. SE refers to 1 standard error around the mean.

Park	Group	# Plots	Rating	CWD Ratio (%)		Metric CWD Volume (m ³ /ha)		English CWD Volume (ft ³ /acre)	
				Mean	SE	Mean	SE	Mean	SE
ACAD	Overall	156	Good	16.04%	3.71%	23.98	2.54	342.66	36.24
	IAH	16	Caution	12.13%	2.87%	23.68	5.57	338.48	79.63
	MDI East	75	Caution	10.89%	2.14%	14.99	2.84	214.22	40.59
	MDI West	59	Good	24.21%	9.35%	35.69	5.05	509.99	72.22
	Schoodic	6	---	10.59%	3.18%	21.96	7.53	313.85	107.57
MORR	Overall	28	Caution	6.66%	1.67%	23.38	5.14	334.08	73.46
	Mature	19	Caution	6.82%	2.00%	25.41	6.80	363.17	97.11
	Successional	9	---	6.33%	3.18%	19.08	7.40	272.67	105.70
ROVA	ELRO/HOFR	24	Good	25.09%	13.05%	45.13	13.62	644.94	194.72
	VAMA	16	Good	27.05%	7.88%	76.12	23.88	1087.90	341.26
WEFA		10	Caution	6.35%	3.78%	21.43	12.29	306.28	175.65

Table 4. Snag abundance ratings and calculations for NETN parks based on data collected from 2008 to 2011. Metric ratings are based on the percent of standing trees (i.e., ≥ 10 cm diameter at breast height) that are snags. M-L Snags refers to medium to large (≥ 30 cm diameter at breast height) diameter snags. Groups with fewer than 10 plots were not rated for this metric. SE refers to 1 standard error around the mean.

Park	Group	# Plots	Rating	# of Snags/ha		# of M-L Snags/ha		% of Trees as Snags	
				Mean	SE	Mean	SE	All Sizes	M-L Snags
ACAD	Overall	177	Caution	177.52	11.51	7.28	1.43	16.67%	9.01%
	IAH	20	Good	122.22	17.62	13.33	5.68	13.25%	15.00%
	MDI East	82	Sign. Conc.	155.01	16.31	4.88	1.73	15.48%	7.26%
	MDI West	65	Caution	208.54	20.76	9.57	2.67	17.67%	9.72%
	Schoodic	10	Sign. Conc.	271.11	47.06	0	0	24.21%	0%
MORR	Overall	28	Sign. Conc.	32.14	6.15	1.79	1.24	11.08%	1.41%
	Mature	19	Sign. Conc.	25.00	7.15	1.32	1.32	8.56%	1.03%
	Successional	9	---	47.22	10.58	2.78	2.78	16.50%	2.22%
ROVA	ELRO/HOFR	24	Caution	38.54	9.03	10.42	4.74	8.15%	7.19%
	VAMA	16	Caution	40.63	12.88	9.38	3.87	10.36%	8.96%
WEFA		10	Caution	35.00	12.47	5.00	3.33	7.78%	3.17%

and management activities do not reduce the potential for development of CWD and large diameter snags, we expect these metrics to improve with time.

Tree Regeneration

This metric assesses the quantity and composition of tree regeneration in the forest understory, which will impact future canopy structure and composition. Regeneration can be affected by a variety of stressors, including invasive species, acid deposition, and climate change. Most notably, sustained, selective browsing by a historically high population of white-tailed deer is currently impacting seedling establishment, growth, and composition in parts of the Midwest and Northeast U.S. (Cote et al. 2004). Significant impacts on forest tree regeneration are associated with deer densities ≥ 8.5 per km², well above pre-settlement estimates of 3-4 deer per km² in the northeastern U.S. (Russell et al. 2001, Augustine and deCalesta 2003).

This metric is rated using a seedling ratio and stocking index. However, due to the regionally limited application of the stocking index, assessment points have only been defined for MORR, ROVA and WEFA. To better assess condition of the tree regeneration metric for all parks, we also present seedling/sapling distributions and deer browse index results. NETN is in the process of developing a tree regeneration metric for ACAD using data collected in late-successional forests and deer exclosures in the park, and this will be incorporated in future reports. As data become available, we also plan to examine how deer densities in network parks relate to these indicators to further refine this metric.

The seedling ratio considers preferential browse of deer on particular seedling species and size classes (Cornett et al. 2000), and uses a ratio developed by Sweetapple and Nugent (2004) that calculates the ratio of seedling species richness in browsed versus unbrowsed size classes of preferred species (Appendix B). While this ratio is useful in detecting moderate impacts of deer browse, it is less effective in systems that lack browse-preferred species for reasons other than deer browse (e.g., spruce-fir forests in ACAD), and may be less effective in systems with relatively low tree diversity (e.g., northern hardwood forests in MABI, MIMA, and SAGA).

The stocking index developed by McWilliams et al. (2005) quantifies whether current seedling numbers are sufficient to restock a mid-Atlantic hardwood forest stand. This index awards and sums points for native tree seedlings by size class within 2-m radius circular microplots as follows: one point for each seedling 15-30 cm, two points for each seedling 30-100 cm, 20 points for each seedling 100-150 cm, and 50 points for each seedling or sapling > 150 cm tall but less than 10 cm DBH. The stocking index in NETN plots is averaged over three 2-m radius microplots. A stocking index less than 25 is considered inadequate for mid-Atlantic hardwood stands, and is the assessment point that distinguishes Caution from Significant Concern for MORR, ELRO/HOFR, VAMA and WEFA. While this stocking index is a useful baseline for the remaining parks, it may need to be refined for northern hardwood and spruce-fir forest systems.

The deer browse index is a qualitative assessment of deer browse impact at each plot based on the presence of browse-preferred and non-preferred woody and herbaceous species (Table 5). This method was adapted from Brose et al. (2008), and Perles et al. (2010), and was initially implemented in 2009. Starting in 2010, the browse index was modified for ACAD to account for the absence of browse-preferred species for reasons other than deer browse, and relies more on signs of deer (e.g., scat, deer trails, browse, etc.) than presence of browse-preferred species. The

deer browse index in this report only includes 2010 and 2011 data, and has not been incorporated into regeneration metric calculations. As more data are collected and deer density data are available, we will assess if the deer browse index is appropriate to incorporate into the tree regeneration metric.

Currently tree regeneration appears to be adequate in all subunits of ACAD; stocking index averages are all well over 100, all seedling size classes are represented, and average deer browse indexes are below 3 (Figure 2 and Table 6). Regeneration in VAMA also appears to be adequate, with 75% of plots rated Good or Caution, the highest density of seedlings across all height classes in NETN, and an average deer browse index well below 3. Regeneration in ELRO/HOFR is less abundant; more plots are rated Significant Concern than Good or Caution, and the average deer browse index indicates moderate browse impacts (Figure 2, Figure 3, and Table 6). These results suggest that ELRO/HOFR regeneration may be experiencing moderate impacts from deer browse.

Results for MORR and WEFA indicate more extensive browse impacts. The average deer browse index in WEFA was 3.8 (Table 6), and 60% of the plots were rated Significant Concern due to low stocking index values (Figure 3). Only two of 28 plots were rated Good in MORR for regeneration, and one of these plots is located in a deer exclosure. While seedling densities are higher in the mature stands in MORR, regeneration is still at extremely low levels (Figure 2). Additionally, both mature and successional stands in MORR average over 4 on the deer browse index (Table 6), which means that browse lines are present in many of the plots, and high impacts are evident in nearly all of the plots.

Table 5. Index of deer browse impacts assessed for each plot in national historical parks and historic sites (NHPs) and ACAD (adapted from Brose et al. 2008 and Perles et al. 2010).

Parks	Level	Browse Impact	Description
NHPs	1	None	Plot located inside deer exclosure, and no browse.
	2	Low	No observed browse; browse-preferred species present.
	3	Moderate	Evidence of browse; browse-preferred regeneration present but with little height variability; non-preferred and browse-resistant species common.
	4	High	Browse evidence common; browse-preferred species rare to absent; non-preferred or browse-resistant vegetation limited in height by browsing.
	5	Very High	Browse evidence omnipresent; browse-preferred species absent; browse-resistant plants show signs of heavy browsing and browse line evident.
ACAD	1	None	Plot located inside deer exclosure, and no browse.
	2	Low	No observed browse or sign of deer activity on plot
	3	Moderate	Evidence of browse and signs of deer activity on the plot
	4	High	Browse evidence common; and non-preferred species show signs of browse
	5	Very High	Browse evidence omnipresent; browse-resistant and non-preferred species show signs of heavy browsing and browse line evident.

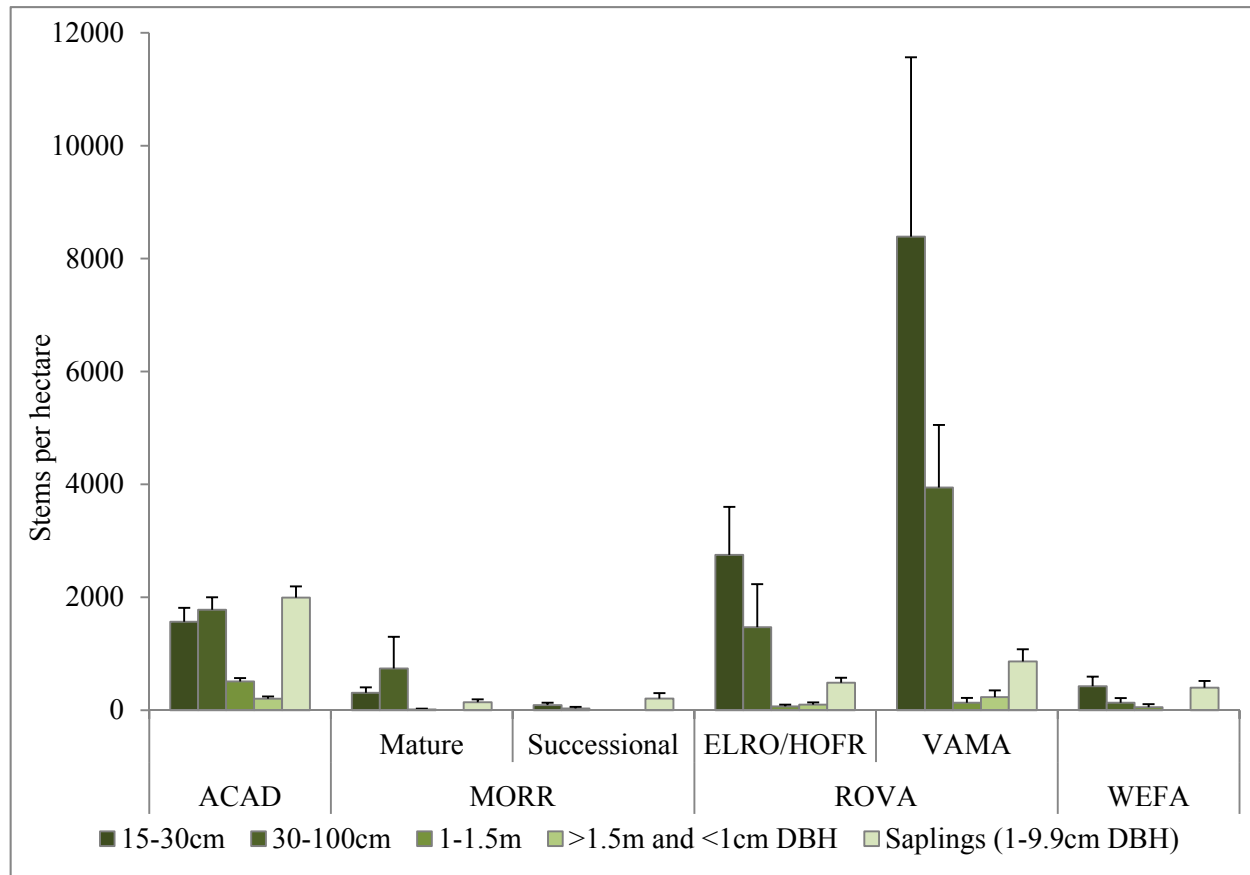


Figure 2. Mean seedling and sapling density (stems/ha) based on data collected from 2008-2011. Error bars denote +1 SE around the mean.

Table 6. Mean stocking index and seedling ratio averaged over three 2 m radius microplots, and based on data collected from 2008-2011. The deer browse index was adopted in 2009, and is based on 2009-2011 data. Summaries do not include woodland plots in ACAD. Plots without browse preferred species are not included in the seedling ratio summaries.

Park	Group	Stocking Index			Seedling Ratio			Deer Browse Index		
		Mean	SE	N	Mean	SE	N	Mean	SE	N
ACAD	Overall	147.45	15.56	155	-0.16	0.07	99	2.57	0.05	114
	IAH	169.13	39.62	15	-1.00	---	1	2.73	0.19	11
	MDI East	118.12	14.89	75	-0.17	0.08	53	2.53	0.07	53
	MDI West	179.91	34.32	59	-0.11	0.11	39	2.57	0.09	44
	Schoodic	140.72	42.72	6	-0.17	0.40	6	2.67	0.21	6
MORR	Overall	11.94	3.15	28	-0.61	0.19	12	4.39	0.12	28
	Mature	11.37	3.75	19	-0.53	0.22	10	4.42	0.16	19
	Successional	13.15	6.06	9	-1.00	0.00	2	4.33	0.17	9
ROVA	ELRO/HOFR	38.56	8.14	24	-0.56	0.10	19	3.08	0.15	24
	VAMA	73.17	16.76	16	-0.23	0.11	15	2.31	0.15	16
WEFA		25.50	7.19	10	-0.83	0.17	4	3.80	0.20	10

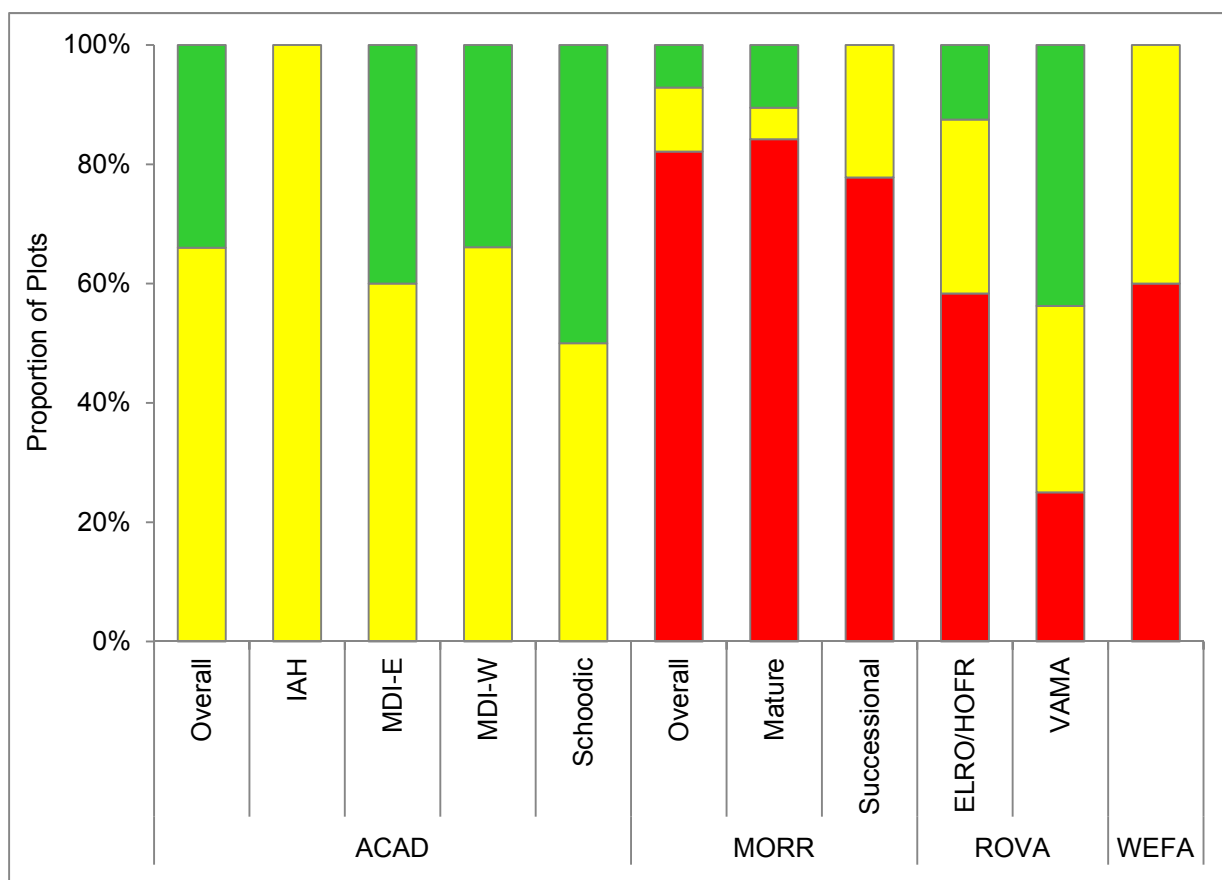


Figure 3. Proportion of plots receiving Good (green), Caution (yellow), and Significant Concern (red) ratings for tree regeneration.

Tree Condition and Forest Pests

This metric assesses tree condition based on qualitative observations of specific tree health problems and canopy foliage condition. As the season progresses, most trees develop minor foliage problems. However, more extensive damage to canopy foliage may be indicative of tree health problems within a species or across a region, and could be related to any combination of soil chemistry, climate stress, pathogens, or other stressors. In particular, exotic pests and pathogens have the potential to severely impact forest tree composition as well as structure and function. Several species of exotic pests pose serious threats to northeastern forests if they advance into the region; these NETN “Priority 1” pests are Asian longhorned beetle (ALB), emerald ash borer (EAB), hemlock woolly adelgid (HWA), and sudden oak death (SOD). Other forest pests can cause problems that are not quite as severe, and/or may already be widespread in the NETN region. These NETN “Priority 2” pests are balsam woolly adelgid (BWA), beech bark disease (BBD), butternut canker (BC), and elongate hemlock scale (EHS).

To calculate this metric, specific tree health problems are tallied per plot, and average percent foliage condition is calculated for the plot and for each tree species represented by two or more individuals. Good condition is defined as minor foliage problems ($< 10\%$) averaged across a plot and within individual species, minor damage from BBD ($BBD \leq 2$), and no evidence of damage

by Priority 1 or other Priority 2 pests and pathogens. More extensive foliage problems (10-50%), more extensive BBD damage (BBD > 2), or evidence of damage by one of the other Priority 2 pests and pathogens indicate cause for concern. Foliage damage above 50% averaged across a stand or within an individual species (represented by at least two individuals) indicates a more serious problem. Likewise, evidence that Priority 1 pests have reached NETN forests indicates a significant concern which might still be controlled by management action.

It is important to note that after the last reporting cycle, HWA was changed from a Priority 2 pest to a Priority 1 pest. While HWA has been in the southern region of NETN for over a decade, hemlock remains a significant component of forests in ROVA and northern NETN parks. The loss of hemlock due to HWA can result in cascading effects throughout the ecosystem, and is a major threat to the more northern parks in the network (Orwig and Foster 1998, Jenkins et al. 1999, Eschtruth et al. 2006). Therefore, we felt it was more appropriate to treat HWA as a Priority 1 pest. This change means that plots where HWA is detected are automatically rated Significant Concern.

Tree condition in ACAD and MORR in 2011 was slightly better than or similar to the 4-year tree condition average, and no plots were rated Significant Concern for the year (Figure 4). Plots rated Caution for tree and foliage condition in ACAD were mostly due to the presence of balsam woolly adelgid, major damage from beech bark disease, isolated pockets of elevated insect herbivory on hardwoods, and/or chlorosis of trees in marginal (e.g., forested swamp) habitats. Plots rated Caution in MORR were mostly the result of slightly elevated insect herbivory or leaf loss, or presence of minor beech bark disease impacts (i.e., BBD index = 2).

The Significant Concern ratings for plots in ROVA are all the result of HWA detections. HWA and EHS were both more common in ELRO/HOFR sites than VAMA because hemlock is more common in ELRO/HOFR. Had HWA and EHS not been detected in ROVA plots, most of these plots would have been rated Good, as only minor tree conditions were recorded for other tree species in these plots. Plots rated Caution in ELRO/HOFR and VAMA were mostly due to elevated levels of insect herbivory, necrotic leaves, and leaf loss. In WEFA only one of the plots that was rated Significant Concern was due to HWA. The other two plots were the result of elevated insect herbivory and multiple trees with necrotic leaves.

While HWA was the only Priority 1 pest detected by the NETN forest crew in 2011, the known range of the emerald ash borer (EAB; *Agrilus planipennis*) continues to expand in the eastern US. Along with the recent detections near ROVA in Ulster, Greene and Orange counties, EAB was detected in a single prism trap in Selkirk, NY, which is approximately 40 miles south of SARA. In response to the EAB infestation near ROVA, ash trees that were encountered by the NETN forest crew in plots or on the way to/from plots in ROVA were examined closely for signs of EAB. No trees were suspected of EAB. However EAB is very difficult to detect in forests during early stages of infestation. Continued vigilance by park staff, cooperators and volunteers is important to slow the spread of EAB. For more information on EAB in New York State, and strategies for slowing the spread of EAB, check the NY Department of Environmental Conservation's EAB website (<http://www.dec.ny.gov/animals/7253.html>).

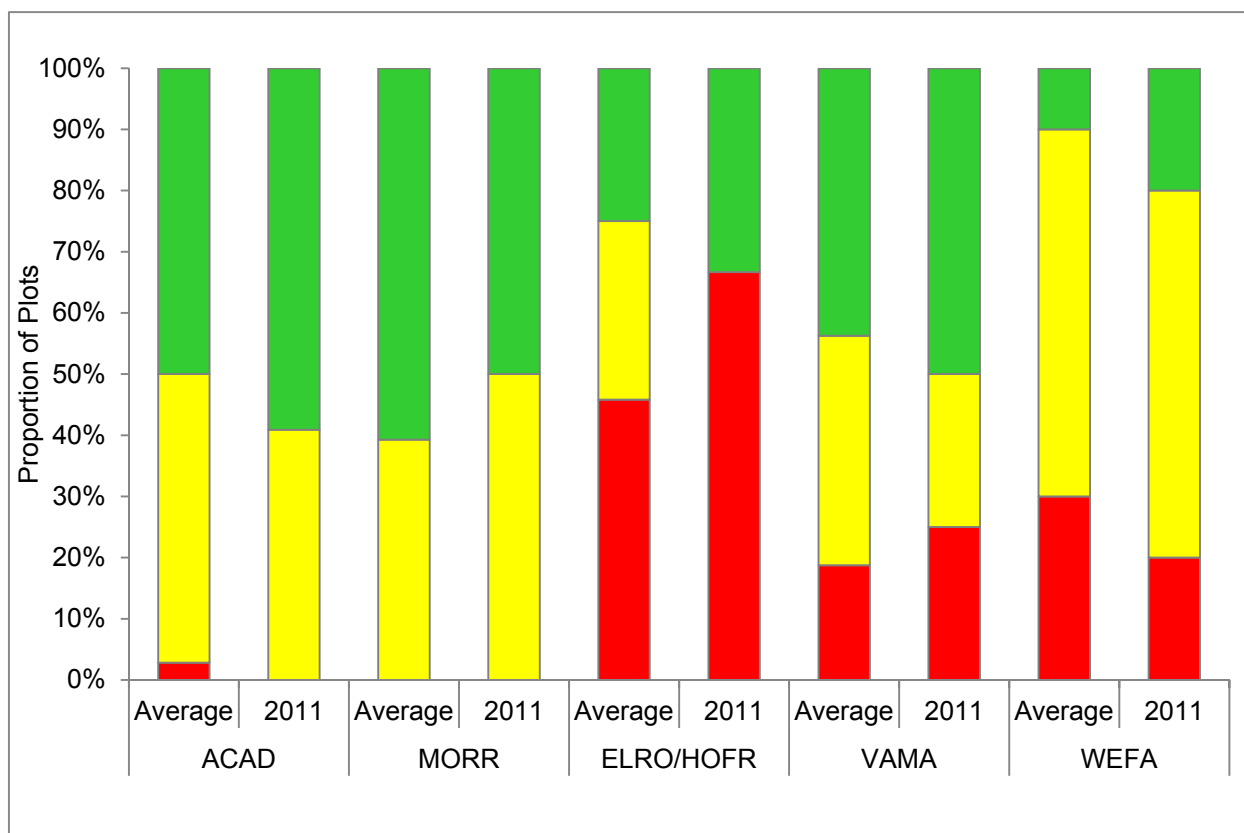


Figure 4. Proportion of plots receiving Good (green), Caution (yellow), and Significant Concern (red) ratings for tree condition for each park sampled in 2011. Average bars include 4 years (2008 – 2011) of data for ACAD, and 2009 and 2011 data for remaining parks. 2011 bars only include data collected in 2011.

Invasive Exotic Plant Indicator Species

Invasive exotic species have the potential to impact structure, composition, and function of forested ecosystems, and are one of the leading threats to biodiversity and ecological integrity of ecosystems worldwide (Mooney et al. 2005). Early detection of invasive exotic plants is an important NETN vital sign that has been incorporated into several long-term monitoring protocols. Status and trends of invasive exotic species are monitored on NETN forest plots, and the Eastern Rivers and Mountains Network (ERMN) and NETN are implementing a separate protocol for early detection of invasive exotic species and forest pests.

To better understand the threat posed by invasive exotic plants, we developed a list of 22 indicator plant species that are highly invasive in northeastern forest, woodland, and successional habitats (Appendix C). Included species are those that may dominate and/or persist under shaded conditions (i.e., in forest or woodland), or that may disrupt succession to forest or woodland. Several exotic species such as knapweeds (*Centaurea* spp.) and celandine (*Chelidonium majus*) were not used as indicator species, despite being present in several parks, because they are not capable of suppressing forest succession and/or do not dominate under a shaded canopy. Therefore, total abundance of exotic species may be higher than reported here for indicator species.

With indicator invasive exotics occurring in only three out of 176 plots, ACAD was the only park sampled in 2011 that was rated Good for this metric (Table 7). Indicator invasive exotic species are more pervasive throughout the southern NETN parks, with every park averaging over three indicator invasive exotic species per plot. While indicator invasive exotics are a widespread problem in ROVA and WEFA, percent cover and diversity of indicator invasive exotics is still much lower than that of native species (Table 7). Indicator invasive exotics are considerably more abundant in MORR, and are likely causing greater impacts to forest condition. However, there is a sizeable difference between mature and successional forests in MORR, with successional stands having significantly higher cover of indicator invasive exotics (F-test p-value <0.001, df =1, 26). Invasive plant management in MORR will require considerably more effort in successional stands, but may be necessary to prevent further invasion into the mature stands.

The list of the top five most frequent indicator invasive exotics for each park demonstrates that NETN parks have a lot of invasive exotic species in common (Table 8). Japanese barberry (*Berberis thunbergii*) is the most frequent indicator invasive exotic across all of the parks sampled in 2011 (Table 8). Excluding ACAD, Japanese barberry occurs in over 40% of plots sampled in each park. Oriental bittersweet (*Celastrus orbiculatus*), Japanese and exotic bush honeysuckles (*Lonicera* spp.), multiflora rose (*Rosa multiflora*) and Japanese stiltgrass (*Microstegium vimineum*), are also common throughout southern NETN parks. These species represent some of the most invasive species in the northeast, and it is critical that park managers continue to eradicate and prevent the spread of these species in their parks.

Table 7. Indicator invasive exotic plant species ratings for NETN parks. Metric ratings are based on the mean number of indicator species found per plot from 2008 to 2011. Average indicator invasive exotic percent cover and mean number of indicator invasive exotic species per quadrat were used to interpret this metric, but were not involved in the metric rating.

Park	Group	# of Plots	Mean #/ Plot	Ave. % Cover/ Quad	Mean #/ Quad	Rating
ACAD	Overall	176	0.03	<0.01	<0.01	Good
	IAH	20	0.00	0	0	Good
	MDI East	82	0.06	0.01	<0.01	Good
	MDI West	65	0.00	0	0	Good
	Schoodic	10	0.00	0	0	Good
MORR	Overall	28	5.54	25.87	1.97	Sign. Conc.
	Mature	19	4.05	11.98	1.22	Sign. Conc.
	Successional	9	8.67	55.19	3.57	Sign. Conc.
ROVA	ELRO/HOFR	24	3.17	2.65	0.56	Caution
	VAMA	16	4.81	3.20	1.27	Sign. Conc.
WEFA		10	3.80	2.34	0.61	Sign. Conc.

Table 8. Most frequent indicator invasive exotic species in NETN forest plots by park from 2008 to 2011.

Park	Group	Latin Name	Common Name	# Plot Occurrences	% Frequency
ACAD		<i>Berberis thunbergii</i>	Japanese barberry	1	0.6
		<i>Frangula alnus</i>	glossy buckthorn	2	1.1
		<i>Lonicera</i> spp.	exotic bush honeysuckle	1	0.6
		<i>Rosa multiflora</i>	multiflora rose	1	0.6
MORR	Mature	<i>Berberis thunbergii</i>	Japanese barberry	15	78.9
		<i>Cardamine impatiens</i>	narrowleaf bittercress	10	52.6
		<i>Celastrus orbiculatus</i>	oriental bittersweet	9	47.4
		<i>Microstegium vimineum</i>	Japanese stiltgrass	10	52.6
		<i>Rubus phoenicolasius</i>	wineberry	9	47.4
	Successional	<i>Berberis thunbergii</i>	Japanese barberry	9	100
		<i>Cardamine impatiens</i>	narrowleaf bittercress	8	88.9
		<i>Celastrus orbiculatus</i>	oriental bittersweet	8	88.9
		<i>Lonicera japonica</i>	Japanese honeysuckle	8	88.9
		<i>Microstegium vimineum</i>	Japanese stiltgrass	9	100
		<i>Rosa multiflora</i>	multiflora rose	9	100
		<i>Rubus phoenicolasius</i>	wineberry	8	88.9
		<i>Acer platanoides</i>	Norway maple	8	33.3
		<i>Ailanthus altissima</i>	tree of heaven	12	50.0
		<i>Alliaria petiolata</i>	garlic mustard	14	58.3
		<i>Berberis thunbergii</i>	Japanese barberry	10	41.7
		<i>Lonicera</i> spp.	exotic bush honeysuckle	9	37.5
		<i>Microstegium vimineum</i>	Japanese stiltgrass	7	29.2
ROVA	ELRO/HOFR	<i>Acer platanoides</i>	Norway maple	11	68.8
		<i>Ailanthus altissima</i>	tree of heaven	13	81.3
		<i>Alliaria petiolata</i>	garlic mustard	15	93.8
		<i>Berberis thunbergii</i>	Japanese barberry	7	43.8
		<i>Euonymus alata</i>	winged burning bush	7	43.8
		<i>Berberis thunbergii</i>	Japanese barberry	9	90.0
	VAMA	<i>Celastrus orbiculatus</i>	oriental bittersweet	4	40.0
		<i>Euonymus alata</i>	winged burning bush	6	60.0
		<i>Lonicera japonica</i>	Japanese honeysuckle	4	40.0
		<i>Rosa multiflora</i>	multiflora rose	5	50.0
WEFA		<i>Berberis thunbergii</i>	Japanese barberry	9	90.0
		<i>Celastrus orbiculatus</i>	oriental bittersweet	4	40.0
		<i>Euonymus alata</i>	winged burning bush	6	60.0
		<i>Lonicera japonica</i>	Japanese honeysuckle	4	40.0
		<i>Rosa multiflora</i>	multiflora rose	5	50.0

Deer Browse Indicator Species

A recurring trend that has been observed throughout eastern U.S. forests is a compositional shift in forest understories in response to sustained high deer densities (Horsley et al. 2003, Rooney et al. 2004, Wiegmann and Waller 2006, Thiemann et al. 2009, Mudrak et al. 2009). This shift is characterized by losses in deer-preferred species such as native perennial forbs and increases in browse-resistant or non-preferred species such as grasses and sedges, ferns, and exotic species (Rooney 2009). Negative browse impacts have been documented where deer densities are as low as 8 per km² for 10 or more years, and severe impacts have been observed with deer densities $\geq$ 20 per km² (Horsley et al. 2003, Augustine and deCalesta 2003).

This metric monitors the change in frequency of indicator herbaceous species over time. The indicator list of species includes fifteen common, highly-visible herbaceous species that are preferred by deer, and/or have been shown or predicted to be intolerant of deer browsing due to life history traits (Augustine and deCalesta 2003). Also included on the list are three species and one genus considered unpalatable to deer, and that have been shown to increase in abundance under heavy deer browse pressure. Frequency is calculated for each indicator species, based on presence or absence in eight herbaceous quadrats per plot, and is summarized at the park unit or group level for each survey cycle. Note that this metric relies on change in species frequency, and therefore has limited value for sites already highly impacted by deer browse.

Indicator species are listed in Appendix D. Metric ratings are based on the change in frequency of indicator species between time periods, and therefore only include data from plots that have been sampled more than once. Only plots sampled in 2007 and 2011 were included in this metric because of quadrat sampling inconsistencies between 2006 and 2010 (i.e., parks were sampled in reverse order in 2006 from all following years, and phenological differences may bias analyses). Therefore, with only one panel of plots to rate this metric, results are preliminary.

VAMA is the only park unit where more than half of browse-preferred species decreased in frequency and more than half of browse-avoided species increased in frequency between survey cycles (Table 9). These results would put VAMA in the Significant Concern category for this metric, but since they are based on only one panel of data, we will not assign a Significant Concern rating until our dataset is more robust. MORR, ELRO/HOFR and WEFA all showed a slight increase in quadrat frequency of browse-avoided species, and a slight decrease in quadrat frequency of at least one browse-preferred species. ACAD was the only park with no change in indicator species frequency, and was rated Good for this metric.

Table 9. Deer browse indicator species ratings for plots sampled in 2011. % Decrease Browse-Preferred is the proportion of browse-preferred species that declined in frequency between survey cycles. % Increase Browse-Avoided is the proportion of browse-avoided species that increased in quadrat frequency between survey cycles.

Park	Group	# Plots	% Decrease Browse-Preferred Species	% Increase Browse-Avoided Species	Rating
ACAD		44	0	0	Good
MORR		14	33	100	Caution
ROVA	ELRO/HOFR	12	67	25	Caution
	VAMA	8	67	100	Caution
WEFA		5	50	100	Caution

Tree Growth and Mortality Rates

Background

Tree growth and mortality rates are important indicators of tree health and vitality. Tree growth rates can decline in response to environmental factors or anthropogenic stress, and tree mortality is often preceded by some years of reduced tree growth (Ward and Stephens 1997, Pedersen 1998, Dobbertin 2005). Decreased growth or elevated mortality rate in trees of a particular species can indicate a particular health problem for that species (Duchesne et al. 2003, Hyink and Zedeker 1987); while altered vital rates for multiple species across a region may indicate a regional environmental stress, such as acid deposition (Steinman 2004, Dobbertin 2005).

To account for differences in growth and mortality rates due to site characteristics, stand structural stage, and by tree species and size and crown class (i.e., tree position in canopy), both rates will be calculated for canopy trees (i.e., dominant, co-dominant, or intermediate crown classes) in stands that have succeeded to a mature or late-successional stage (based on the structural stage metric). To examine patterns of tree growth, we use relative basal area growth (% basal area / year), which is calculated as the percent change in basal area from successive diameter at breast height (DBH) measurements on individual trees, converted to an annual rate. Relative basal area growth rate is then averaged for canopy trees across the plot, and also by species within the plot. Metric ratings are based on regional growth rates, and are derived from U.S. Forest Service Forest Inventory and Analysis (FIA) data collected from plots in the same Ecological Subsection of each NETN park.

Annual mortality rate is calculated from successive observations as the percent of stems that died between sample events (not including trees that were cut) and is converted to an annual basis. Annual mortality rate is calculated for each plot and for individual species within a plot, and then averaged by park or group of plots. Assessment points for this metric are based on annual mortality rates that have been documented in old-growth forests, which range from 0.3 to 1.6% (Busing 2005, Runkle 2000, Woods 2000).

Growth and mortality rates presented in this section only represent half of the monitoring plots in each park, and should be considered preliminary due to insufficient sample size. Species growth and mortality rates were only calculated for species with five or more individuals in a park, and overall growth and mortality rates include all species. As more panels are sampled, we will explore group patterns within parks and by species in more detail. It is also important to note that DBH measurements were Quality Control checked for potential errors that could skew growth rate calculations. Trees that differed more than 6 cm between surveys were very likely the result of a data entry error, and were omitted from the analysis. While an increase of more than 4 cm, or a decrease of more than 2 cm in diameter between surveys is possible, these are more likely errors due to inconsistent location of tree DBH measurements. These errors are easy to spot when the result is a negative growth rate, but are more difficult to detect on the positive growth side. Assuming measurement errors are normally distributed around zero, removing only negative growth rates could bias our estimates. Therefore, these trees were flagged for further examination during the third survey cycle, but were not removed from current analyses.

Results

Average growth rates were lower for all NETN parks than FIA average growth rates (Table 10), and only MIMA, SARA, and VAMA had growth rates that were within 60% of the FIA growth

rate (Table 11). Average mortality rates tended to be slightly higher in NETN parks than FIA plots (Table 12). A closer look at the distribution of plots across structural stages suggests that growth rates in NETN parks are based on a higher proportion of late-successional stands (Figure 5). Trees in late-successional stands tend to have slower growth rates and slightly higher mortality rates than trees in mature stands, and this may explain at least some of the differences in growth and mortality rates. Species composition may also explain some of the differences, and may be examined in future reports as more data are available.

The species with the highest growth rate was white ash (*Fraxinus americana*) in SARA. White ash can occupy early-successional habitats as a pioneer species, and is a gap exploiter in late successional stands. Therefore, the relatively high growth rate isn't surprising. It will be important to track white ash growth rates over time, as a reduction in growth rate could indicate the introduction of emerald ash borer, and a change in growth rate may be observed before mortality increases.

Table 10. Average growth rates (% basal area / year) for the most common tree species in each park and all species combined. The growth rate calculation includes canopy trees (i.e., dominant, co-dominant, or intermediate crown classes) in stands that have succeeded to a mature or late-successional stage (based on the structural stage metric). U.S. Forest Inventory and Analysis (FIA) data were derived from plots located within the same Ecological Subsection as each park. Common names of tree species are listed in Appendix E.

Species	ACAD	MABI	MIMA	MORR	ROVA		SAGA	SARA	WEFA
					ELRO/ HOFR	VAMA			
<i>Abies balsamea</i>	2.24	---	---	---	---	---	---	---	---
<i>Acer platanoides</i>	---	---	1.71	---	---	---	---	---	---
<i>Acer rubrum</i>	1.34	---	1.60	---	---	---	1.08	2.00	0.79
<i>Acer saccharum</i> / <i>A. nigrum</i>	---	1.26	---	---	1.37	3.44	---	---	---
<i>Betula alleghaniensis</i>	1.19	---	---	---	---	---	---	---	---
<i>Betula lenta</i>	---	---	---	0.33	---	---	1.19	---	1.35
<i>Betula papyrifera</i>	1.75	---	---	---	---	---	---	---	---
<i>Fagus grandifolia</i>	---	---	---	1.04	---	---	1.62	---	---
<i>Fraxinus americana</i>	---	1.49	1.38	0.85	---	---	---	5.60	---
<i>Larix decidua</i>	---	1.42	---	---	---	---	---	---	---
<i>Liriodendron tulipifera</i>	---	---	---	1.98	---	---	---	---	---
<i>Picea mariana</i>	0.73	---	---	---	---	---	---	---	---
<i>Picea rubens</i>	1.69	---	---	---	---	---	---	---	---
<i>Pinus strobus</i>	2.38	1.30	1.90	---	---	---	0.40	2.04	---
<i>Pinus sylvestris</i>	---	0.20	---	---	---	---	---	---	---
<i>Populus grandidentata</i>	2.65	---	---	---	---	---	---	---	---
<i>Quercus rubra</i>	2.07	---	3.13	---	2.27	1.63	1.96	---	---
<i>Quercus velutina</i>	---	---	1.56	0.97	---	---	---	---	---
<i>Thuja occidentalis</i>	0.88	---	---	---	---	---	---	---	---
<i>Tsuga canadensis</i>	---	0.54	---	---	0.61	---	0.71	---	---
Park Overall	1.57	1.15	1.80	1.12	1.14	2.41	1.03	2.64	0.74
FIA	5.05	3.74	3.16	4.34	3.62		3.74	3.92	2.87

Table 11. Growth and mortality rate summaries and metric rating for each park. Growth rates that are less than 60% of the regional mean are labeled as "-". Growth and mortality rates that are within the ranges established by NETN are labeled "()". Mortality rates that are greater than 1.6% are labeled "+".

Park	Group	Growth Rate	Mortality Rate	Rating
ACAD	Overall	-	()	Caution
MABI		-	+	Caution
MIMA		()	()	Good
MORR		-	()	Caution
ROVA	ELRO/HOFR	-	()	Caution
	VAMA	()	()	Good
SAGA		-	()	Caution
SARA		()	+	Caution
WEFA		-	()	Caution

Table 12. Average annual percent mortality rate for dominant species in each park. The mortality rate calculation includes only plots in mature and late-successional stands, and only canopy trees (i.e., dominant, co-dominant and intermediate crown class). U.S. Forest Service Forest Inventory and Analysis (FIA) data were derived from plots located in the same Ecological Subsection as each park. Common names of tree species are listed in Appendix E.

Species	ACAD	MABI	MIMA	MORR	ROVA		SAGA	SARA	WEFA
					ELRO/ HOFR	VAMA			
<i>Abies balsamea</i>	4.46	---	---	---	---	---	---	---	---
<i>Acer platanoides</i>	---	---	0.00	---	---	---	---	---	---
<i>Acer rubrum</i>	0.41	---	0.00	0.00	---	---	0.00	0.00	1.56
<i>Acer saccharum/ A. nigrum</i>	---	1.30	---	---	0.00	0.00	0.00	0.00	5.00
<i>Betula alleghaniensis</i>	0.00	---	---	---	---	---	---	---	---
<i>Betula lenta</i>	---	---	0.00	1.85	---	---	0.00	---	0.00
<i>Betula papyrifera</i>	0.00	---	---	---	---	---	---	---	---
<i>Fagus grandifolia</i>	---	---	---	0.00	---	---	3.13	---	---
<i>Fraxinus americana</i>	---	1.25	2.50	5.00	0.00	---	---	0.00	---
<i>Larix decidua</i>	---	0.00	---	---	---	---	---	---	---
<i>Liriodendron tulipifera</i>	---	---	---	1.79	---	---	---	---	---
<i>Picea mariana</i>	1.00	---	---	---	---	---	---	---	---
<i>Picea rubens</i>	1.43	---	---	---	---	---	---	---	---
<i>Pinus strobus</i>	0.00	5.36	0.00	---	---	---	0.98	4.58	---
<i>Pinus sylvestris</i>	---	4.55	---	---	---	---	---	---	---
<i>Populus grandidentata</i>	5.00	---	---	---	---	---	---	---	---
<i>Quercus alba</i>	---	---	0.00	0.00	0.00	---	---	---	---
<i>Quercus rubra</i>	0.00	---	0.00	0.00	0.00	0.00	0.00	---	---
<i>Quercus velutina</i>	---	---	2.08	0.00	---	---	---	---	---
<i>Thuja occidentalis</i>	0.00	---	---	---	---	---	---	---	---
<i>Tsuga canadensis</i>	---	0.00	---	---	0.00	---	2.08	---	---
<i>Ulmus americana</i>	---	---	---	---	---	---	---	12.50	---
Overall	1.11	1.91	0.63	1.50	0.25	1.00	0.92	3.43	1.19
FIA	2.20	0.75	0.96	1.05	0.95	0.75	0.75	1.07	0.63

WEFA had the lowest overall growth rate. However, the growth rate was based on only five plots, and can be influenced by just a few measurement errors. If WEFA continues to have a low growth rate after multiple sample cycles, then there may be a forest health issue that will require further investigation. MABI and SARA were the only parks with mortality rates that exceeded the 1.6% assessment point. The high mortality rate in SARA was influenced by two species that had elevated mortality rates. First, a substantial die-off of pole-size American elm (*Ulmus americana*) occurred between 2006 and 2010, and this was likely the result of Dutch elm disease (*Ophiostoma novo-ulmi*). The mortality rate of white pine (*Pinus strobus*) in SARA was elevated in the areas that regenerated as monotypic white pine stands after agricultural abandonment. These stands are still in the stem-exclusion phase of forest succession, and this likely explains the higher white pine mortality rate. Several other species that are near the 5% mortality range include bigtooth aspen (*Populus grandidentata*) in ACAD, white pine in MABI, white ash in MORR, and sugar maple (*Acer saccharum*) in WEFA. Big tooth aspen mortality is likely the result of succession, and not of concern. If, over time, rates are consistently high for the remaining species, there may be a problem beyond normal stand dynamics.

With the combined results of tree growth and mortality rates, MIMA and VAMA were the only parks that received a Good rating. All other parks received a Caution rating because at least one of the rates was outside of the range established for NETN ecological integrity reporting. It is important to note that these ratings are tentative until more plots and multiple surveys have been sampled, and there are no criteria for a rating of Significant Concern.

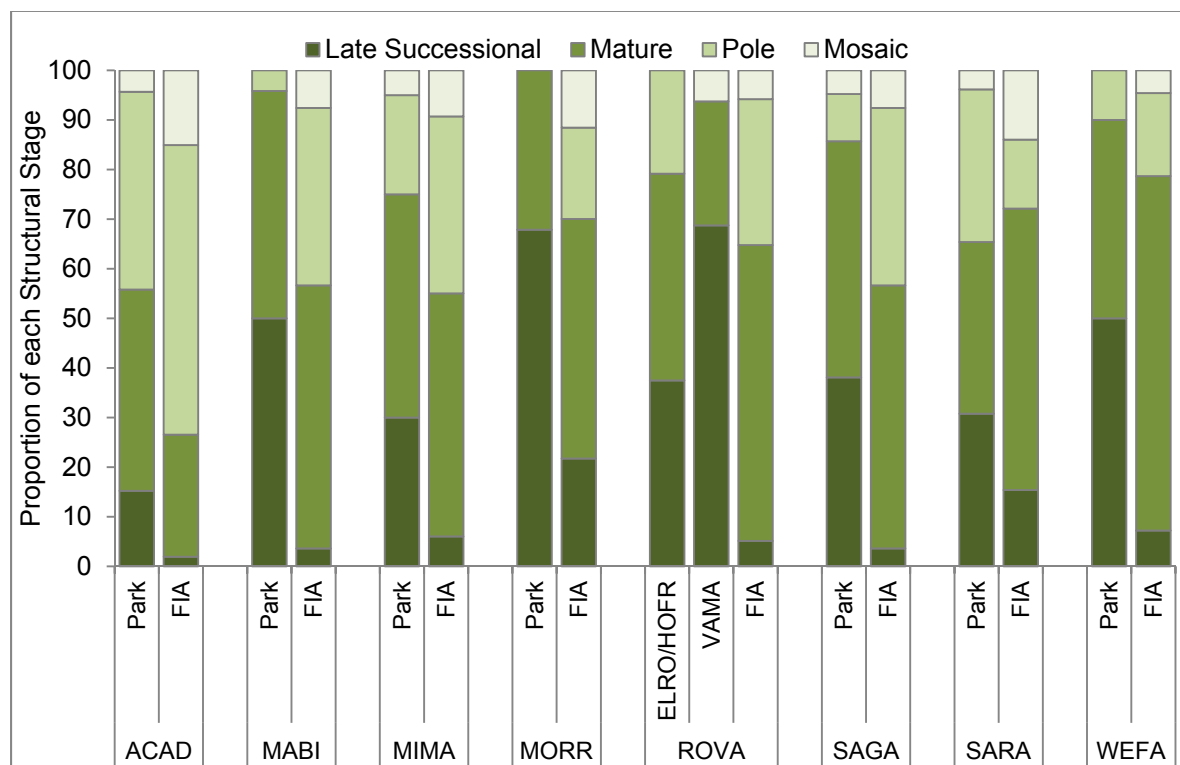


Figure 5. Proportion of plots in each structural stage. Park structural stages are based on data collected between 2008 and 2011. FIA structural stages are based on plots within the Ecological Subsection where each park is located.

Management Implications

Acadia National Park

Ecological integrity metrics related to forest structure (e.g., coarse woody debris and snag abundance) suggest that forests in ACAD are beginning to reach mature stages, but still lack late-successional structure such as medium to large snags. As long as forest composition metrics remain stable (e.g., no new invasive species, stable tree condition/forest pests, and continued regeneration), late-successional structure is expected to develop over time. Invasive species and forest pests are the major controllable threats to forest health in ACAD. Continued vigilance and outreach are vital to preventing the spread of forest pests such as hemlock woolly adelgid, emerald ash borer, and Asian longhorned beetle. Ongoing exotic plant management and early detection efforts are equally important to maintain forest health in ACAD.

Morristown National Historic Park

A high density of white-tailed deer and invasive exotic species are significantly impacting forest health in MORR and management action will be necessary to improve forest condition. Invasive exotic species are pervasive throughout MORR and especially abundant in successional stands. Regeneration densities are well below levels required to restock the future forest, and have been for some time as evidenced by the lower than expected density of trees in the 10-30 cm size classes. It is important that MORR continue to move forward on its white-tailed deer management plan, which also includes plans for invasive species control. In areas where seed sources are absent, planting of native herbaceous and shrub species may be necessary to restore diversity in the understory.

Roosevelt-Vanderbilt National Historic Sites

Forest condition, composition, and structure vary considerably between ELRO/HOFR and VAMA. VAMA has the highest average density of seedlings in NETN and deer browse impacts were minimal. In contrast, the majority of plots in ELRO/HOFR were rated as Significant Concern for regeneration, and moderate deer browse impacts were observed. The deer browse indicator species metric tentatively detected browse impacts for both ELRO/HOFR and VAMA. If these trends worsen in ELRO/HOFR, managers may need to consider deer management. Invasive exotic species and forest pests are a concern in both ELRO/HOFR and VAMA, and control and early detection should be a high priority for all ROVA units. This is especially important, considering the moderate deer impacts observed in ELRO/HOFR, as high densities of deer largely favors invasive exotic species. Emerald ash borer (EAB) continues to pose a threat to forests in ROVA, although EAB signs and impacts have not yet been observed in ROVA. Continued early detection and outreach efforts to prevent the spread of EAB throughout the park, New York, and the Northeast are extremely important.

Weir Farm National Historic Site

Forest health appears to be impacted by a number of factors, including white-tailed deer herbivory, forest pests, invasive exotic species, and lack of dead wood in the form of snags and coarse woody debris. Coarse woody debris and snag abundance are expected to increase over time as WEFA's second-growth forests mature. Management efforts to improve forest health in WEFA should focus on controlling invasive species and reducing deer densities. Early detection of new invasive species and forest pests should also be a priority in the park.

Forest Soil Chemistry

Background

NETN monitors soil chemistry to understand the effects of atmospheric deposition on forest health, which is a special concern for forests in the northeast that tend to have thin soils with low soil buffering capacity. Acid deposition occurs when emissions derived from the combustion of fossil fuels and industrial processes react with water and oxygen in the atmosphere to produce acidic anions of sulfur (S) and nitrogen (N), and then fall to earth in dry or wet form (Connolly et al. 2007). Impacts of atmospheric deposition include soil acidification, base cation leaching, increased availability of toxic aluminum (Al), and altered N cycling (Bailey et al. 2005, Connolly et al. 2007). Acid deposition has also dramatically increased inputs of N and S to forested ecosystems in the northeast, and concern has arisen that excess N may “saturate” forest soils, causing excess nitrification and N leaching and exacerbating the effects of acidification (Aber et al. 1998). All of these impacts can reduce plant growth and increase susceptibility of trees to other stresses (Bullen and Bailey 2005).

At each plot, NETN collects a composite of soil samples from each O and A horizon, because these upper soil layers are where the bulk of fine roots are located and nutrient uptake occurs. In most cases, the composited sample for each layer is composed of three replicate samples. However in extremely rocky or root-laden habitats, there are occasions where only one or two samples can be collected. If no soil horizons are apparent, NETN collects a composite of the upper soil containing fine roots to a maximum depth of 10 cm. The thickness of each horizon is recorded for each sample, and the presence or absence of earthworms is recorded for each plot.

Post collection, soil samples are oven dried, and then sent to the Analytical Laboratory at the University of Maine for chemical analysis. Soil pH is measured in distilled water. Organic matter is measured by loss on ignition at 550 °C. % total N (TN) and % total C (TC) are measured by combustion analysis at 1350 °C. Exchangeable acidity is extracted in potassium chloride and measured by titration. Exchangeable cations are extracted in ammonium chloride and measured by inductively coupled plasma optical emission spectrometry (ICP-OES). Effective cation exchange capacity is calculated by summation of milliequivalent levels of Ca, K, Mg, and Sodium (Na), and acidity. From the chemical analysis results provided by the University of Maine Analytical Laboratory, several additional variables are calculated, including the soil quality index developed by Amacher et al. (2007; Table 13).

Data Analysis

Non-metric Multidimensional Scaling (NMDS) ordinations were used to examine major gradients in forest soil chemistry across network parks, and to relate these gradients to stressors (e.g., acid deposition, N saturation, and invasive species), land-use history, environmental gradients, and forest condition. To examine potential relationships between soil chemistry and other gradients, a matrix of environmental variables was assembled to include values derived for each permanent monitoring plot or park, depending on the data source.

For each plot, elevation, aspect, topographic position, slope, location (X and Y coordinates), vegetation type, bedrock geology, native plant species richness, regeneration stocking index (McWilliams et al. 2005), and average cover of indicator invasive exotic plant species were

Table 13. Soil chemistry variables used in Non-metric Multidimensional Scaling ordinations, and codes used for each soil variable on ordination figures.

Soil Chemistry Variable	Code	Soil Chemistry Variable	Code
Soil pH	soil pH	Carbon: Nitrogen ratio	C:N
Effective cation exchange capacity	ECEC	Nitrogen: Phosphorus ratio	N:P
% Base Saturation	BaseSat	% Total Carbon	TC
Calcium: Aluminum Ratio	Ca:Al	% Total Nitrogen	TN
Calcium % Saturation	Ca%Sat	% Loss of Ignition	LOI
Aluminum % Saturation	Al%Sat	Phosphorus (mg/kg)	P
Calcium (mg/kg)	Ca	Exchangeable acidity (meq/100g)	acidity
Aluminum (mg/kg)	Al	Iron (mg/kg)	Fe
Magnesium (mg/kg)	Mg	Manganese (mg/kg)	Mn
Potassium (mg/kg)	K	Zinc (mg/kg)	Zn
Sodium (mg/kg)	Na	Soil Quality Index	SQL

compiled. Total N and S deposition rates for each park were extracted from Sullivan et al. (2011). Water quality parameters collected from park waterbodies were averaged across each park, including pH, acid neutralizing capacity (meq/L), and nitrate concentrations ($\mu\text{eq/L}$). In all but WEFA, water quality data were collected from park streams. WEFA water data were taken from Weir Pond because there are no streams within the park.

Prior to each ordination, soil chemistry variables were standardized to remove the influence of different scales and units. Ordinations were performed using the metaMDS function in the R vegan package (Oksanen et al. 2011, R Development Core Team 2011). After experimenting with multiple combinations of distance matrices (Euclidean, Bray-Curtis, Manhattan, and Kulczynski), dimensions ($k=1-3$), and transformations, we found the settings that resulted in the best (i.e., low stress, converged model) and most interpretable models were with $k=2$ dimensions, Bray-Curtis distance matrix, and manual standardization: $(x_i - \min_x) / (\max_x - \min_x)$. NMDS ordinations were performed on 1) the full soil community dataset, 2) the A horizon for all NETN parks, and 3) the O horizon for ACAD. All analyses are based on data collected between 2007 and 2010.

NMDS results are displayed in 2-dimensional ordination plots to aid interpretation of patterns. Forest plots that are close together in the ordination plot have similar soil chemistry, and forest plots that are far apart have dissimilar soil chemistry. The location of soil chemistry variables in the ordination plot were calculated using weighted averages of the plot scores for each variable. In other words, plots near the soil pH variable in an ordination plot all tend to have relatively high soil pH, and plots that are far away from the soil pH variable tend to have relatively low soil pH. In addition, soil chemistry variables that are close together in the ordination plot tend to be positively correlated, and variables far apart tend to be negatively correlated.

To assess associations between the ordinations and environmental variables and factors, multiple additional functions were used from the vegan package in R. The envfit function was used to test the significance of environmental variables and groups in the ordination. Because many of the environmental variables did not have a linear response in the ordination, the ordisurf function was also used. The function ordisurf uses thinplate splines in a generalized additive model

(GAM) to predict and plot the surface of each variable in the 2-D ordination space, and therefore does not rely on a linear response. To assess distinct park groupings we used the ordiellipse function which plotted 95% confidence regions for the standard error of the centroid of each group. The ordisurf, ordiellipse, and envfit functions do not influence the ordination results, but provide a visual reference for how environmental variables and factors relate to the ordination. Soil ordination interpretations are based on dozens of ordisurf, ordiellipse, and envfit operations on multiple environmental and soil variables. However, to save space, we only present the most relevant or illustrative ordination plots. The full suite of ordination plots, R code, and data are available upon request.

Results presented here focus on relationships between soil chemistry and impacts from atmospheric deposition. This is part of a larger project that is examining patterns in soil chemistry across multiple Inventory and Monitoring Networks, and a more detailed report will be available in the near future. In addition, boxplot summaries of individual soil chemistry variables by park and horizon are included in Appendix E.

Results and Discussion

NMDS ordinations were successfully performed on the full soil community dataset (stress = 0.063), A horizon samples for all parks (stress = 0.077), and O horizon samples from ACAD (stress = 0.152); stress values below 0.3 indicate a successful ordination. The first major gradient in the ordination of the full soil community dataset related to soil horizon (Figure 6). The

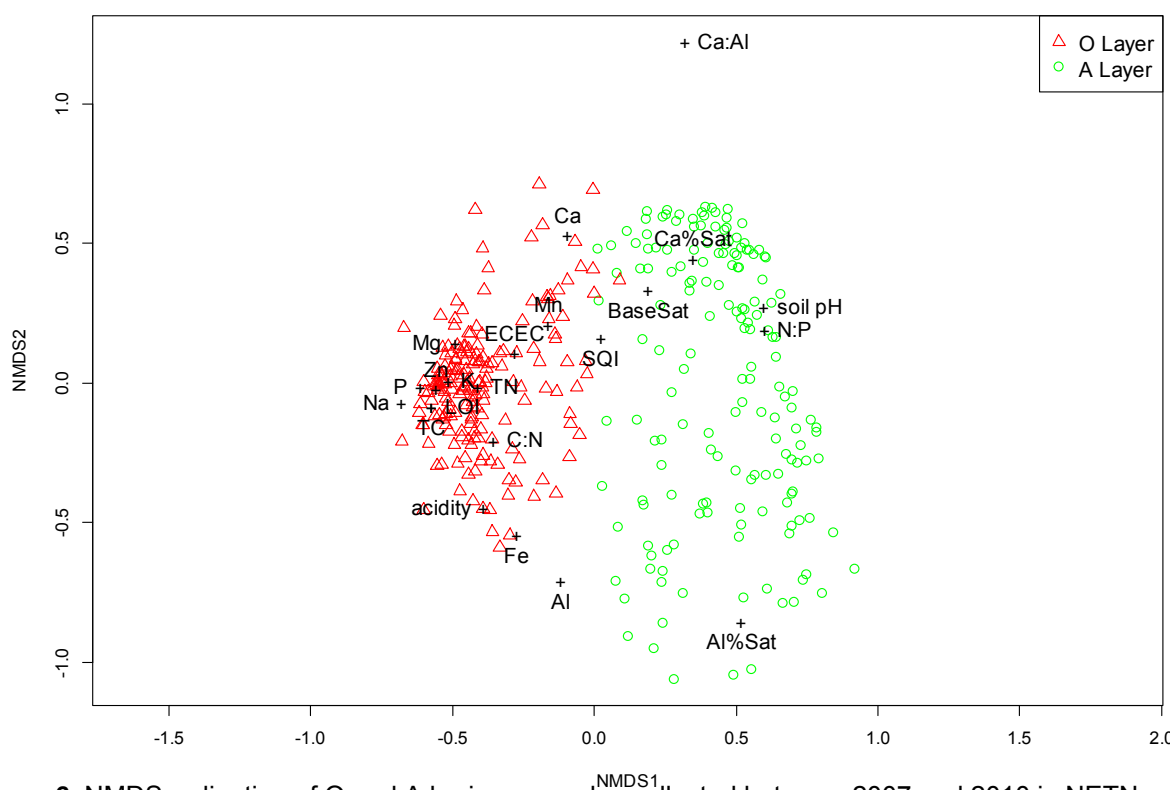


Figure 6. NMDS ordination of O and A horizon samples collected between 2007 and 2010 in NETN parks. Red and green symbols represent plots. The weighted average score for each soil chemistry variable is plotted as a black “+”.

centroids of the O and A horizon were significantly different in the ordination space (envfit $p = 0.001$), and there was very little overlap between O and A horizon samples. This is expected, as chemical properties of the O and A horizons are determined by different soil processes. With such a distinct separation in horizons, and with numerous plots represented twice on opposite ends of the ordination, assessing environmental variables at this level of ordination is not ideal. Therefore, assessment of environmental gradients focused on individual soil horizons. A horizons were the focus of the network-wide analysis because there were considerably more A horizon samples per park (except at ACAD). Environmental gradients were also not as strong in the O horizon ordinations, and may be due to the strong influence of plant species-specific leaf litter and other micro-site conditions on the O horizon that may obscure the environmental gradients. We did, however, examine patterns in the O horizon for ACAD, because there are more O horizon samples in ACAD, and the vegetation in the park is more homogenous.

Analysis of A horizon samples for all NETN parks

Ordination results indicate that A horizon soil chemistry varies considerably across (and sometimes within) NETN parks, and follows two major gradients (Figure 7) reflected in the NMDS axes. The gradient in NMDS Axis 1 relates to the coupled negative relationship between Ca and Al. Plots on the negative (left) side of Axis 1 have A horizons with lower pH, higher Al and Fe concentrations, and higher Al % saturation (Appendix G: Figure G-1). Alternatively, plots on the positive (right) side of Axis 1 have richer A horizons with higher soil pH, higher base cation concentrations, and higher base cation % saturation. Average quadrat species richness is also correlated with Axis 1, with greater diversity associated with richer soils ($r^2 = 0.122$, $p < 0.001$). The second major gradient in the A horizon follows NMDS Axis 2. Plots on the negative (bottom) end of Axis 2 have high % Total C, organic C (LOI), % Total N and P, and a lower pH than plots on the positive (high) end of Axis 2 (Appendix G: Figure G-3). Relating these patterns to each park, we find that soils in ACAD are acidic with relatively high Al, Fe and organic matter. On the other extreme, soils in SARA have high base saturation and base concentration, higher pH and lower C and N content. Soils in MABI and MORR also appear to be relatively rich, although C content is higher in MORR. Soil chemistry in remaining parks is more variable with plots represented across each gradient.

The gradients in Axis 1 and Axis 2 can also be related to risk of impacts from atmospheric deposition. Axis 1 provides information about the relative risk of each park to soil acidification, such that soils on the positive side of Axis 1 are well buffered and resistant to acidification and soils on the negative end of Axis 1 have lower buffering capacity and are more vulnerable to acidification. The Ca:Al ratio and acid neutralizing capacity (ANC) of park streams provide further evidence of acidification vulnerability along Axis 1. Low values of the Ca:Al ratio (i.e., $\text{Ca:Al} < 4$) have been used as an indicator of acid stress for trees (Cronan and Grigal 1995, and Fenn et al. 2011), and this ratio increases from left to right on Axis 1. ANC also increases from left to right on Axis 1. To relate these results to each park, Axis 1 was divided into five categories (bins) of vulnerability. Bins were chosen based on ranges of the Ca:Al ratio that have been linked to levels of acidification risk, and natural breaks in % base saturation and Al concentration (Appendix G: Figure G-2). Distribution of plots along the acidification gradient were then summarized as pie charts, and overlaid on a map of 2010 wet deposition of S (Figure 8).

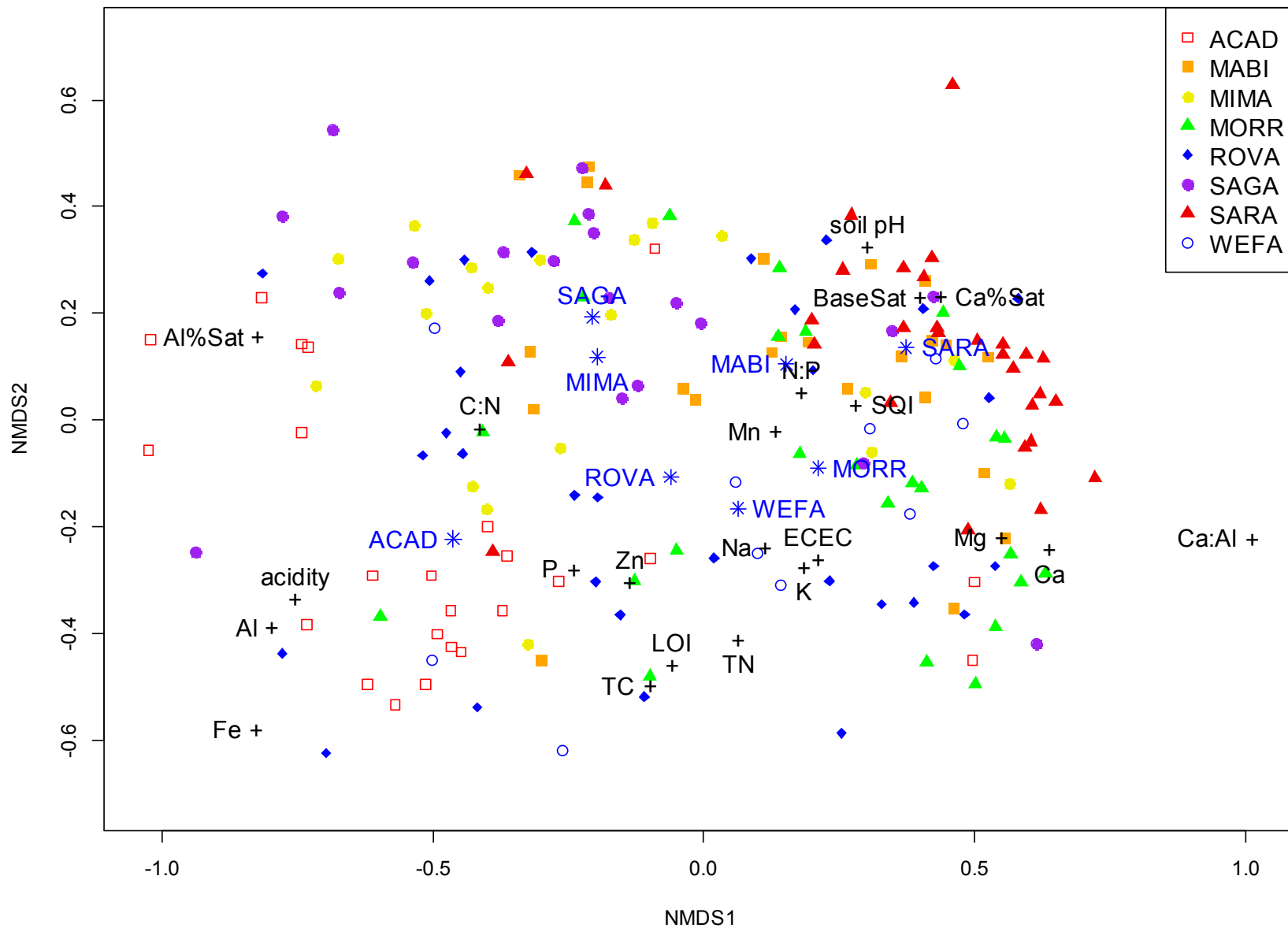


Figure 7. NMDS ordination on A horizon samples collected between 2007 and 2010 in NETN parks. Colored symbols represent plots. The weighted average score for each soil chemistry variables is plotted as a black "+".

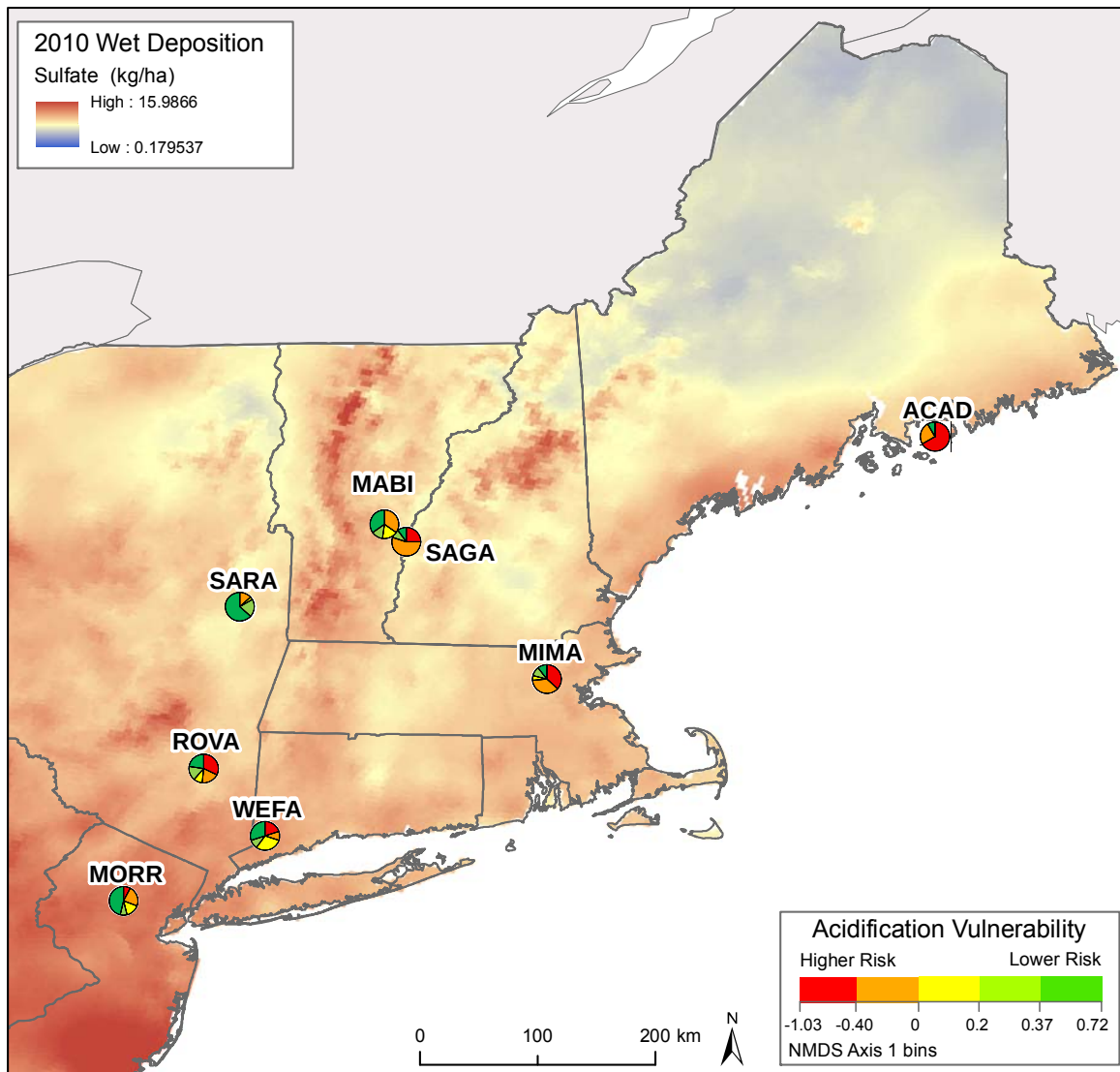


Figure 8. Relative vulnerability of A horizon soils to acidification based on A horizon NMDS Axis 1. NMDS Axis 1 was divided into five bins, with the most negative bin representing highest risk (red), and the most positive bin representing lowest risk (green). Pie charts represent the proportion of plots in each NMDS Axis 1 bin. Background map displays 2010 sulfate deposition rates for the eastern U.S. (National Atmospheric Deposition Program 2011).

Despite receiving the highest S and N deposition rates, the majority of plots in MORR are at low risk of acidification. The soils in SARA and MABI appear most resistant to acidification. ACAD soils are most vulnerable, with over 90% of plots falling in the two higher risk categories. Over 70% of plots in MIMA, and 80% of plots in SAGA also fell in the two higher risk categories of acidification vulnerability. Plots in ROVA and WEFA were relatively evenly spread across Axis 1.

The patterns in Axis 2 describe a positive association of total C, total N and P and organic C. This association isn't surprising, as they are all products of the decomposition of organic material. Interestingly, parks with a more recent history of agriculture or timber harvesting (e.g.,

MABI, MIMA, SAGA and SARA) fall almost exclusively on the positive end of Axis 2 suggesting A horizons in these parks have low organic content and lower N and P. Parks with a less intensive history of disturbance, including MORR, ROVA and WEFA, have plots scattered across Axis 2.

While the patterns in Axis 2 are informative, relating these patterns to risk of acid deposition impacts is more complicated than with the first axis. To help interpret the results in Axis 2, we rely on two indicators of N saturation risk, including soil C:N ratio (Aber et al. 2003, MacDonald et al. 2002), and stream NO_3^- concentration (Fenn et al. 2011). The C:N ratio indicates N status of forest soils such that ratios below 20 are at risk of increased nitrification and NO_3^- export. Fenn et al. (2011) suggest that stream NO_3^- concentrations above 20 $\mu\text{eq/L}$ indicate sites where N saturation and NO_3^- export may be occurring (assuming N inputs from other sources in the stream are minimal).

Based on A horizon C:N ratios, stream NO_3^- concentrations, and deposition rates, ACAD appears to be the least at risk of N saturation (Figure 9). SARA is on the other extreme with the lowest average C:N ratio, and the only average stream NO_3^- concentration above the 20 $\mu\text{eq/L}$ threshold. This suggests that soils in SARA are most vulnerable to N saturation, and it is possible

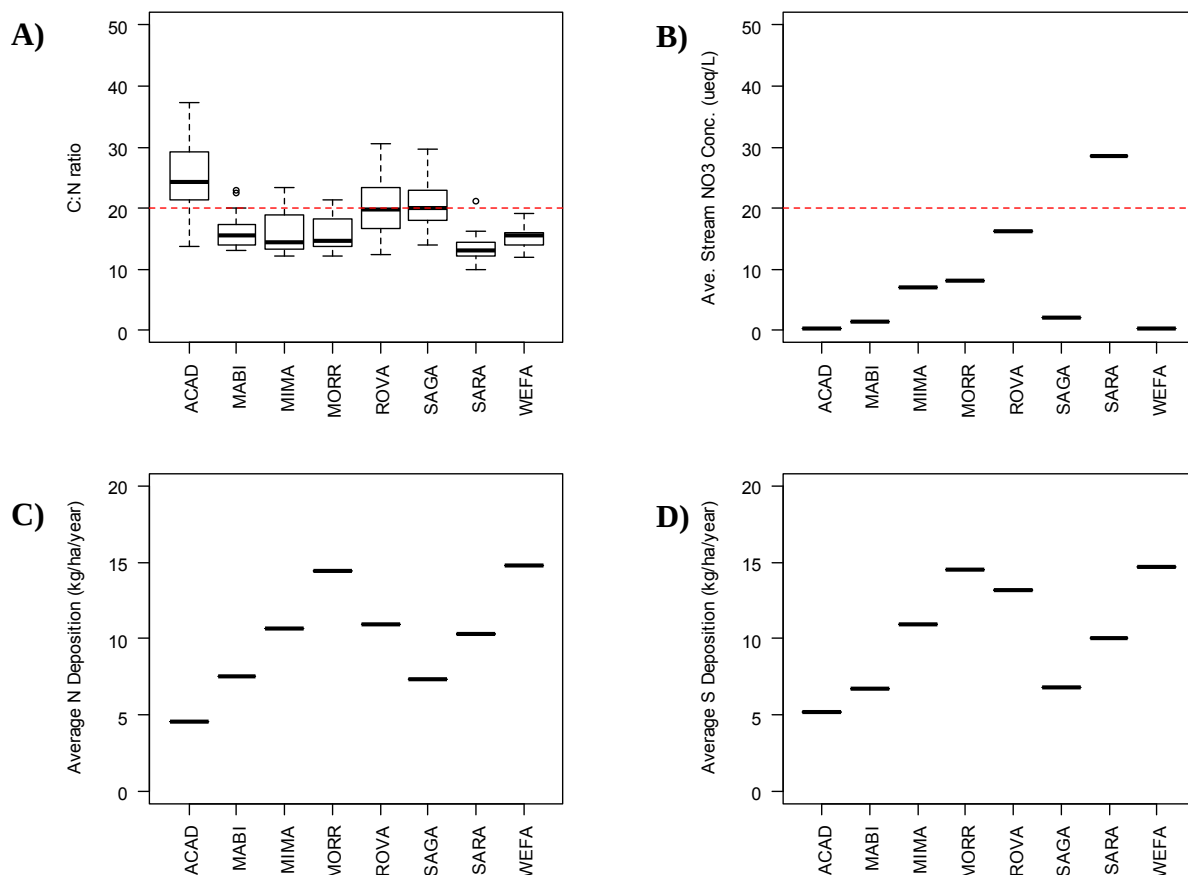


Figure 9. Boxplots of A) C:N ratios of A horizons by park, B) Average stream nitrate concentrations ($\mu\text{eq/L}$), C) Average annual N deposition (kg/ha), and D) Average annual S deposition (kg/ha). Red lines represent thresholds proposed in Fenn et al. (2011) such that C:N ratios below 20 indicate risk of nitrification, and stream nitrate values above 20 indicate possible nitrate leaching.

that N saturation and NO_3^- leaching are occurring in SARA. However, SARA is surrounded by agricultural lands, and NO_3^- inputs from agriculture cannot easily be separated from those of soil leaching. ROVA also has a fairly high stream NO_3^- concentration, and as with SARA surrounding land-use may be a contributing factor.

A horizons in MABI, MIMA and SAGA also tend to have low C and C:N ratios at or below 20 (Figure 9), indicating park-wide vulnerability to N saturation. Plots in MORR, ROVA and WEFA vary in their vulnerability to N saturation, and C:N ratios in these parks may be related to forest type and landform. With low stream NO_3^- concentrations, N saturation and NO_3^- export does not appear to be an issue in most NETN parks. However, if N deposition rates were to increase, the low C:N ratios for most NETN parks suggests N saturation may occur. These results serve as an important baseline that, over time, will allow us to understand relationships between soil chemistry, acid deposition, and stream chemistry and to relate these trends with indicators of forest health (e.g., tree growth and mortality rates).

Analysis of Acadia National Park soil chemistry

There were no distinct groupings by vegetation type, park subunit, or fire history in the NMDS ordination of O horizon samples (Figure 10). While plots burned in the 1947 fire tended to have slightly lower organic C (LOI) and total C than plots on eastern MDI that didn't burn, there were few other differences in soil chemistry between burned and unburned plots. Soils do appear to be more homogenous and similar to each other on Isle au Haut (IAH) and Schoodic Peninsula (Schoodic) than on Mount Desert Island (MDI). While larger sample size may partially explain the greater variability in soil chemistry on MDI, greater diversity of habitats and broader range of elevations on MDI is also likely a factor.

Patterns in the first axis of the ordination on ACAD O horizon samples are similar to the A horizon analysis of all NETN parks. Plots on the negative (left) side of Axis 1 are more acidic with greater Al concentration and Al % saturation. These plots also tend to have a Ca:Al ratio below 1, indicating elevated risk of acid stress. Plots on the positive (right) side of Axis 1 tend to have O horizons with greater soil fertility and Ca:Al ratios above 5.

To examine how patterns in Axis 1 relate to topography and geographic location in ACAD, NMDS Axis 1 was broken into five categories of vulnerability to acidification. Vulnerability categories were based on ranges of the Ca:Al ratio that have been linked to levels of acidification risk and natural breaks in % base saturation and Al concentration (Appendix G: Figure G-2). Each plot was assigned a risk based on its Axis 1 score, and was mapped over a bare ground LiDAR digital elevation model. Acidification vulnerability assignments for each plot from the network-wide analysis of A horizon samples were also plotted on these maps. It is important to note that the acidification vulnerability assignments on O and A horizons are based on different analyses and therefore not directly relatable. However vulnerability categories were based on similar ranges of the Ca:Al ratio, % base saturation and Al concentration in both horizon analyses and should be roughly comparable.

Maps of acidification vulnerability indicate soils in each subunit run the full range of acidification risk in the O horizon, and tend to have higher vulnerability assignments in the A horizon (Figures 11-14). Acidification vulnerability does not appear to differ between areas in the park that burned in 1947 and areas that did not burn (Figure 12). Higher elevation plots tend

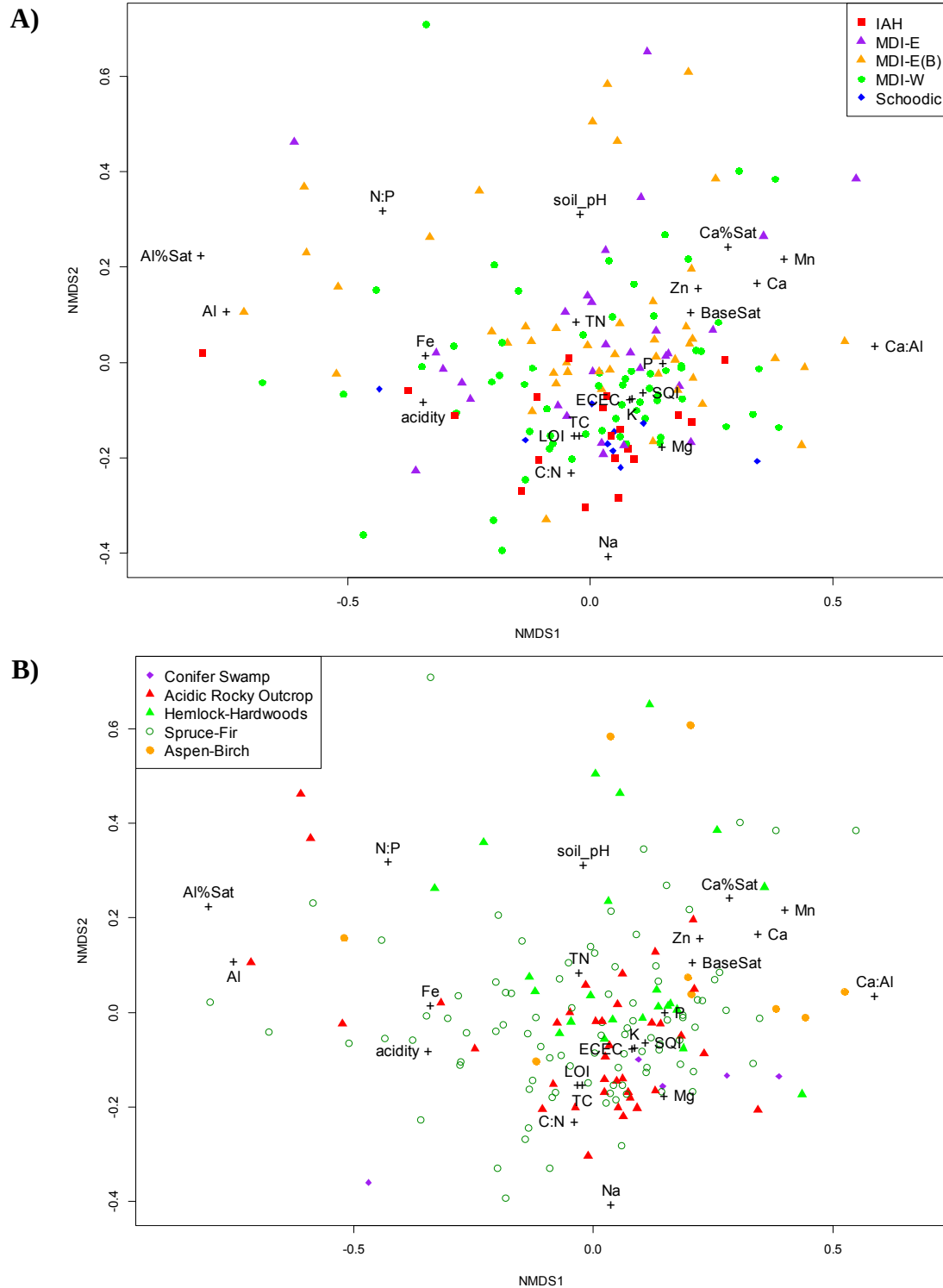


Figure 10. NMDS ordination on O horizon samples collected in ACAD between 2007 and 2010 grouped by A) Park subunit, and B) Forest type. Park subunit abbreviations are IAH for Isle au Haut, MDI-E for plots on the eastern side of Mount Desert Island (MDI), MDI-E (B) for plots on MDI-E that were burned in 1947, MDI-W for plots on western MDI, and Schoodic for plots on the Schoodic Peninsula. Colored symbols represent plots. The weighted average score for each soil chemistry variables is plotted as a black “+”.

to be more vulnerable to acidification ($r^2 = -0.215$, $p < 0.005$) in the O horizon, and this is most evident on eastern MDI where most of the high elevation sites occur in ACAD. However, the negative correlation between elevation and Axis 1 is weak. The weak correlation is due to numerous plots at lower elevations that are also high risk, including a cluster of plots with relatively high acidification vulnerability on the northern end of the western MDI section. It is unclear why so many plots in this area are vulnerable, but may relate to forest type, stand age, and/or land use history.

These results serve as a valuable baseline for forest soil chemistry in ACAD, and it will be important to continue tracking trends in soil chemistry to see if our current understanding is correct and to better understand how soil chemistry relates to indicators of forest health, such as tree condition, growth, and mortality.

Conclusions

NETN is still in the early stages of forest soil monitoring, and our analyses are limited by the lack of temporal data. After multiple rounds of plot surveys are completed, it will be important to compare tree growth and mortality rates to our assessments of acidification vulnerability and risk of N saturation to validate and refine our conclusions. It will also be useful to examine potential relationships between atmospheric deposition and indicators of forest health, and determine how these variables respond to changes in deposition rates and climate.

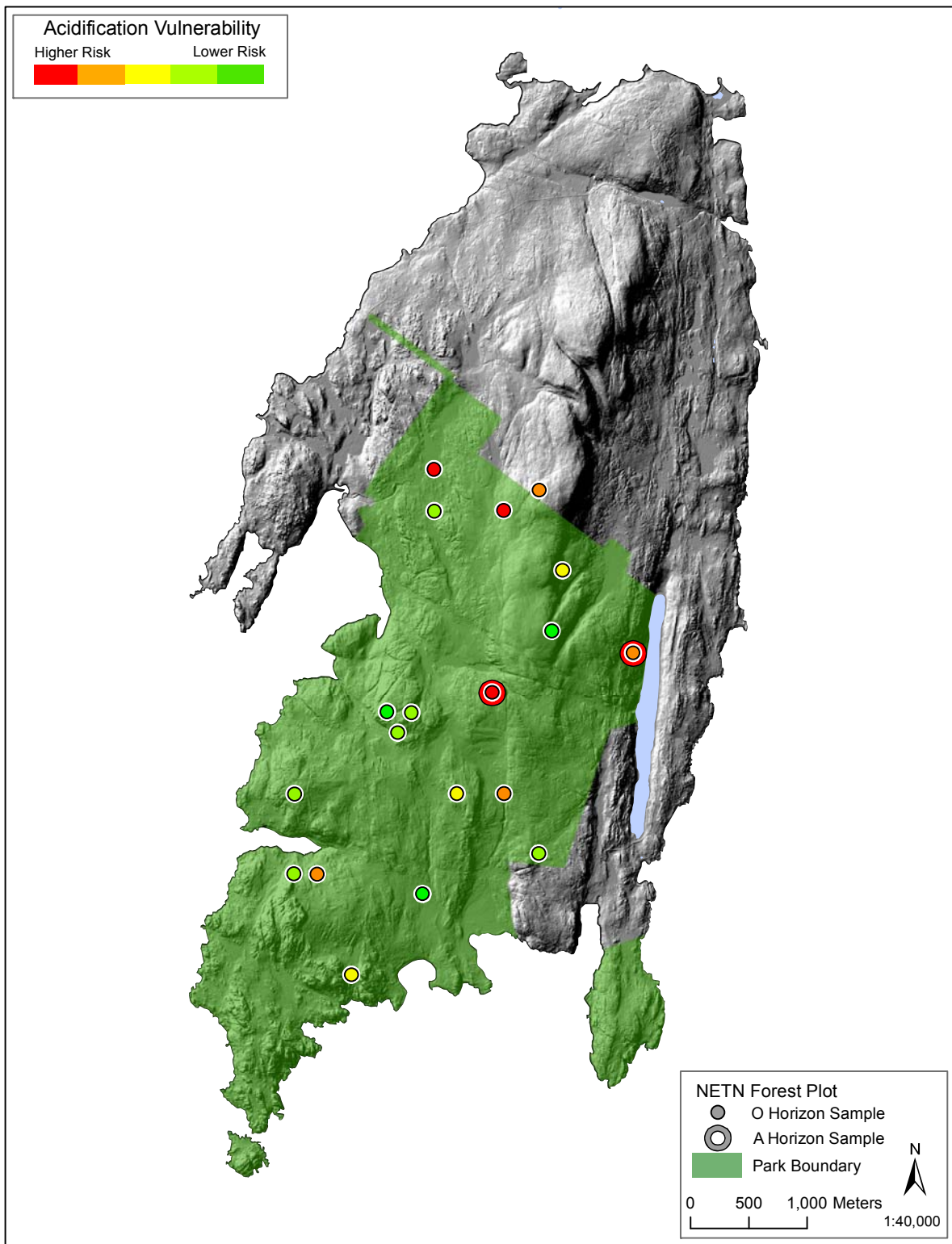


Figure 11. Acidification vulnerability of O and A horizons by forest plot on Isle au Haut.

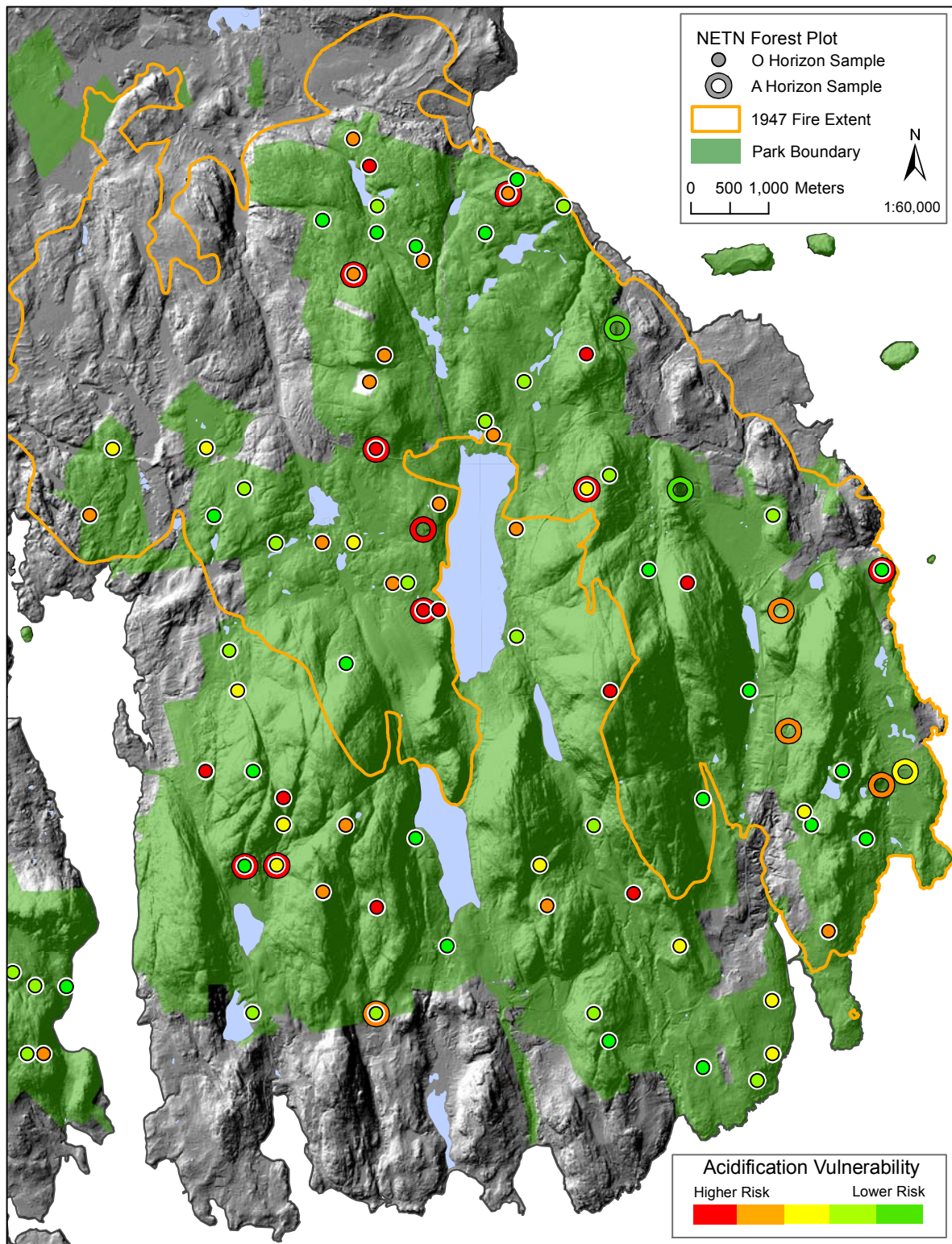


Figure 12. Acidification vulnerability of O and A horizons by forest plot on eastern Mount Desert Island.

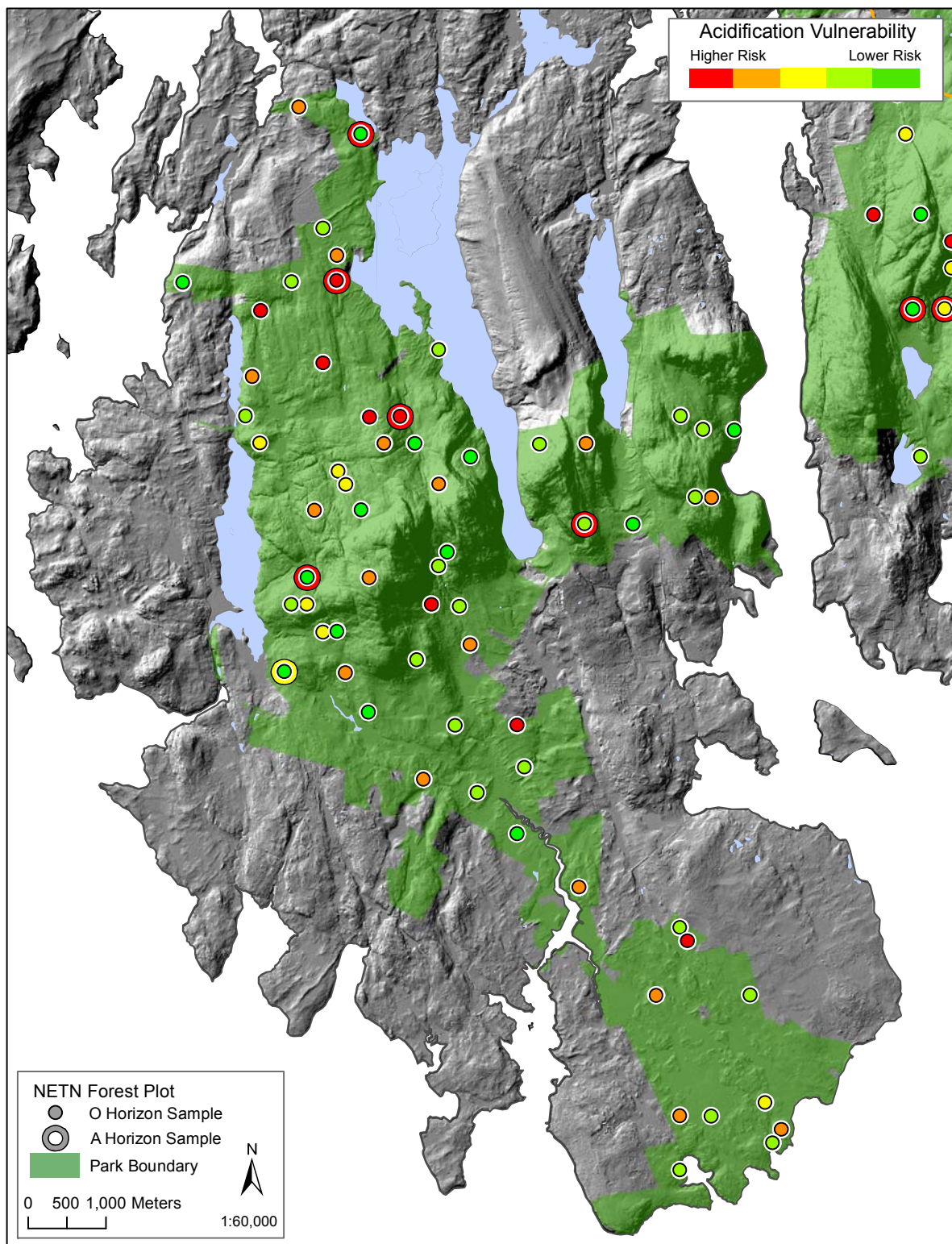


Figure 13. Acidification vulnerability of O and A horizons by forest plot on western Mount Desert Island.

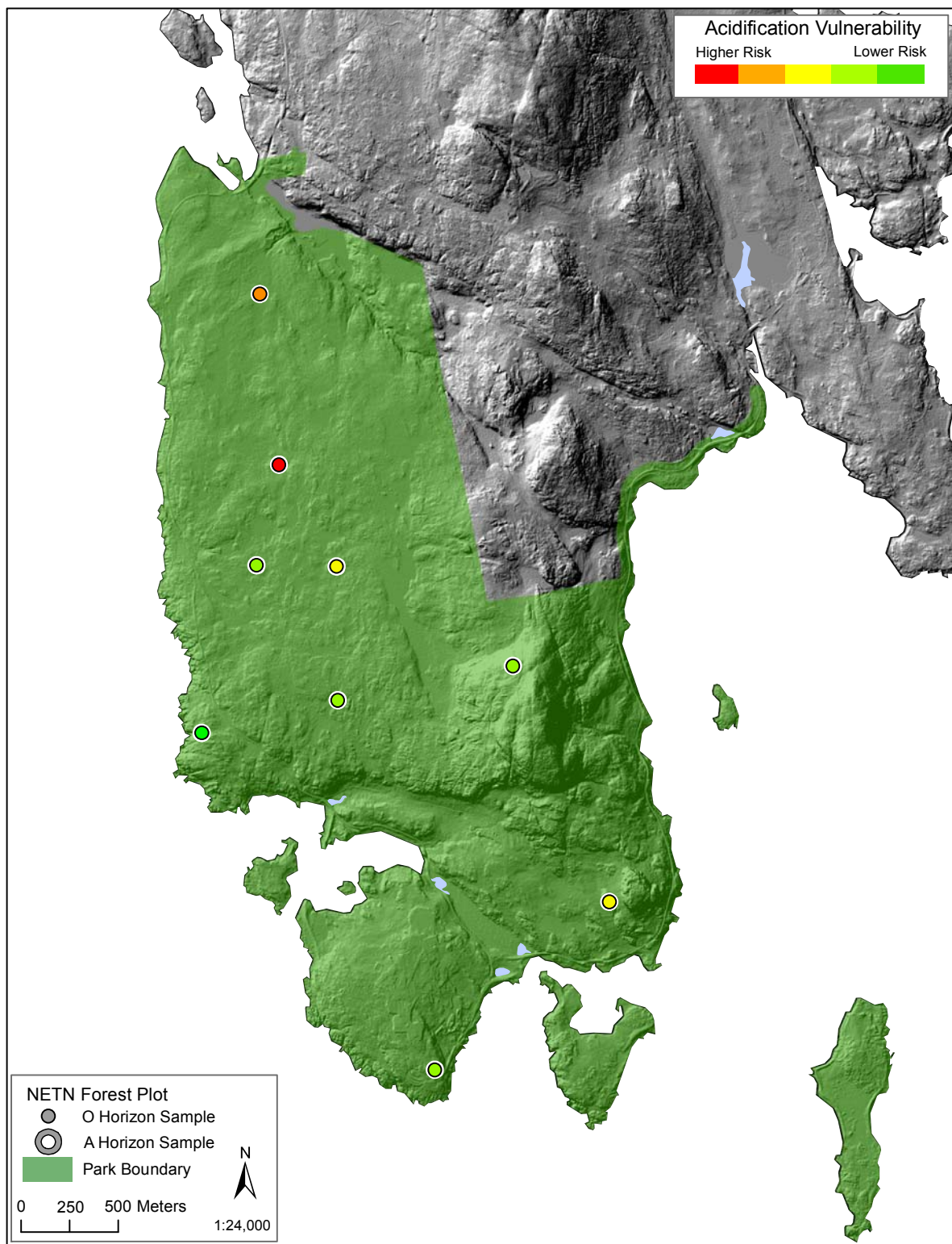


Figure 14. Acidification vulnerability of O horizon by forest plot on Schoodic Peninsula.

Power Analysis

Background

The overall goal of the Northeast Temperate Network (NETN) long-term forest monitoring program is to monitor status and trends in the structure, function, and condition of NETN forested ecosystems in order to inform management decisions affecting those systems (Tierney et al. 2011). For this program to be effective, it must be capable of detecting change in key metrics of forest condition with sufficient statistical power. Given that a change has occurred, power is the probability of correctly rejecting the null hypothesis of “no change”, and is influenced by sample size, variability of the metric, effect size, and the Type I error rate (probability of rejecting the null hypothesis when it is true; Cohen 1988).

Knowing the power to detect a specific effect size for each metric provides important information about the strength of evidence when no change is detected, and also shows where improvements can be made in the monitoring program. That is, when the power to detect change in a metric is low, monitoring staff should consider improving measurement precision, increasing sample size, increasing the Type I error rate, or removing that metric from the monitoring protocol. Ideally, power analyses are performed during the initial stages of program development to ensure that sampling efforts are worthwhile from the beginning (DiStefano 2001). However, this approach requires pre-existing data that are compatible with proposed methods and planned data analyses and include spatial and temporal variability. Pre-existing data of this nature were not available to perform power analyses during the development stage of the NETN forest protocol. Now that two rounds of forest data have been collected in half of the permanent plots established across NETN, data are now available to analyze the power of key metrics.

The overall goal set for the forest monitoring program was to have (at a minimum) 80% power to detect a 40% change (effect size) over a 10 year period while controlling both Type I (alpha) and Type II (beta) error at 20% (Tierney et al. 2011). However, it was recognized that specific objectives and appropriate error rates for each measure may vary (Di Stefano 2003). Type I error is the probability of erroneously rejecting the null hypothesis (when no change has occurred), and Type II error (one minus power) is the probability of failing to detect a true change. For the purposes of this analysis, we started with a stricter Type I error rate of 0.05 and power of 80% (Type II error of 20%) to assess which metrics performed the best. Metrics that failed to detect a 40% change at $\alpha = 0.05$ and 80% power for one or more parks were also analyzed using $\alpha = 0.10$.

Power analyses were performed on the following key forest metrics: average herb % cover, average fern % cover, average indicator invasive exotic % cover, native species plot richness, coarse woody debris (CWD) volume, regeneration stocking index, snag abundance, and live tree basal area.

Methods

Bootstrap power analysis simulations were performed using mixed effect models on key forest metrics of NETN forest health data that represented two survey cycles and 10 park units. A bootstrapped data set is a plausible data set produced by randomly selecting data from a pilot or sample data set until a desired sample size is reached. For a single simulation, many hundreds of bootstrapped data sets are created and analyzed in order to produce a distribution of potential

results for a range of effect sizes. We chose to use mixed effects models for our simulations because this type of model allows estimation of certain “fixed” or “treatment” effects (like park unit or trend over time) while accounting for “random” effects (like randomly located plots). Mixed effects modeling was performed using the nlme package in R (Pinheiro et al. 2012, R Development Core Team 2011). In the mixed effects models plot was the random effect, time and park were fixed effects, and the varIdent function was used to model different variances for each park. The only exception to this model is when the varIdent function caused singularity issues due to an overparameterized model. This only occurred with the regeneration stocking index metric, and the default variance structure was used for this metric.

Prior to bootstrapping, data transformations were performed to prevent simulations from using impossible values (e.g., negative counts, proportions below zero or above one, etc.). Metrics that could not be negative (i.e., live tree basal area, snags per hectare) were log transformed. Metrics that ranged between 0 and 1 (e.g., percent cover data) were transformed using a modified logit following Warton and Hui (2011). The modified logit transformation adds a small fixed constant (ϵ) to the logit numerator and denominator to solve the issue with sample proportions that equal 0 and 1, which otherwise result in undefined values. The constant ϵ is defined as the smallest non-zero number in the dataset, or the smallest difference between 1 and the largest number less than 1, whichever is smaller. In a few cases, bootstrapped datasets had a tendency to result in all 0's for a park, which resulted in no variance and crashed the simulation (e.g., average indicator invasive exotic % cover in ACAD). To resolve this issue, data were "jittered" by adding small non-zero values to 10 percent of the plots in the park with the problem.

Bootstrapped data sets were generated based on randomly selecting values from the first sampling cycle (actual NETN data) to generate initial data values. Data for the second occasion were created by applying an effect (between -50% and 50%, see below) to the initial data values, and then adding a randomly selected difference between the first and second sampling cycle (again from actual NETN data). To prevent a trend in the NETN data from biasing the bootstrap, the sign (positive or negative) of the actual differences was randomized for each bootstrap data set.

Statistical power was determined by repeatedly generating data sets with a specified percent change between sampling cycles in the value of each metric, and then testing whether the mixed-effects model could detect the change (modeled as a linear trend). Simulations were run for effect sizes ranging from a 50% decline to a 50% increase in 5% increments, and were run across all parks (additive model with no interaction) and for each park (model with interaction effect). The interaction model was used to assess power for each park, given the worst-case scenario of a change only occurring in one network park. Note that in the situation where there is no effect (0% change), the analysis does not assess power. In this case, the percentage of times when a trend is detected should equal alpha. If it does not the simulation may be biased, or based on too few bootstrapped data sets.

For each iteration of the simulated data, additive and interaction mixed effects models were fit based on two sample cycles, and confidence intervals were calculated using the parameter estimate for time (i.e., change between cycles) and its standard error. Confidence intervals that did not contain 0 were considered significant, and the results of each significance test were

stored by effect size, park, and simulation. Power was calculated as the proportion of simulations where a trend was detected, and was calculated for each effect size across the network and within each park. A total of 250 simulations were performed on each metric, at each of 11 effect sizes and nine scenarios (network-wide change or change at one specific park).

Results

Average Herb Percent Cover

Power analyses for this metric were based on average quadrat percent cover of native herbaceous species per plot. Minimum detectable effect size at 80% power was at or below 20% for MORR, ROVA, and WEFA, and 5% for ACAD and NETN (Table 14). SARA was the only park that failed to detect 40% change at $\alpha = 0.05$, and this was likely due to the large variability of herb cover (Figure 15). At $\alpha = 0.10$, minimum detectable effect size improved for all parks except SARA (Table 15). SARA was still outside of the 40% target at $\alpha = 0.10$, and was slightly worse than at $\alpha = 0.05$ (Table 15). The decrease in trend detection at $\alpha = 0.10$ for SARA was likely due to the random nature of these simulations, and is not a meaningful result. These results suggest that moderate changes in herb percent cover will likely be detected in all parks except SARA. Trend detection may be improved by analyzing percent cover of only

Table 14. Minimum detectable positive and negative effect size for each metric by park at 80% power and $\alpha = 0.05$. Metrics that did not reach 80% power by 50% effect size are recorded as "---".

	<u>Ave. Herb % Cover</u>		<u>Ave. Fern % Cover</u>		<u>Ave. Indicator Invasive Exotic % Cover</u>		<u>Native Species Plot Richness</u>	
	Decrease	Increase	Decrease	Increase	Decrease	Increase	Decrease	Increase
NETN	-5	5	-5	5	-5	5	-5	5
ACAD	-5	10	-10	5	-5	5	-5	5
MABI	-25	20	-20	20	-10	15	-5	5
MIMA	-35	30	-15	15	-40	45	-10	10
MORR	-15	15	-10	10	---	---	-5	5
ROVA	-20	15	-10	10	-30	35	-5	5
SAGA	-25	25	-25	25	-20	25	-5	5
SARA	-45	40	-40	35	-30	35	-5	5
WEFA	-20	20	-15	10	-35	45	-10	10

	<u>Coarse Woody Debris Volume</u>		<u>Regeneration Stocking Index</u>		<u>Snag Abundance</u>		<u>Live Tree Basal Area</u>	
	Decrease	Increase	Decrease	Increase	Decrease	Increase	Decrease	Increase
NETN	-10	10	-10	10	-5	5	-5	5
ACAD	-10	10	-10	10	-10	10	-5	5
MABI	-35	35	---	---	-45	40	-5	5
MIMA	-50	50	-45	45	-35	35	-5	5
MORR	-25	25	-40	40	-35	35	-5	5
ROVA	-20	20	-20	20	-30	25	-5	5
SAGA	-30	25	-30	30	-10	10	-5	5
SARA	-30	25	-40	40	-20	20	-10	10
WEFA	---	45	---	---	---	---	-5	5

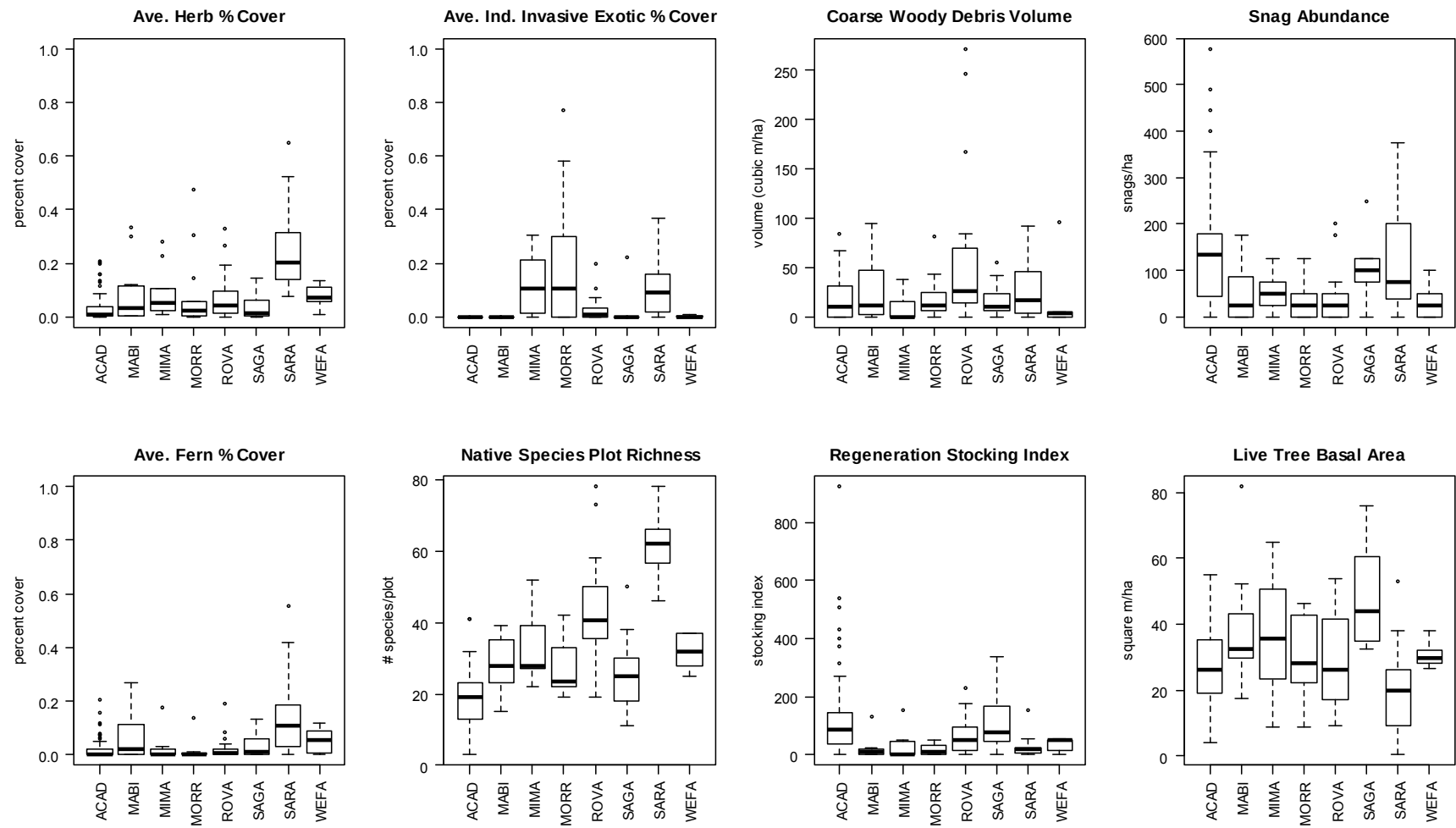


Figure 15. Boxplots of 2006 metric values by park.

common herb species in a park. Trend detection in SARA may be improved by post-stratifying plots by forest type or land-use history and should improve over repeated surveys. However, only very large changes in herb cover may be detectable in SARA for some time.

Average Fern Percent Cover

Power analyses for this metric were based on average quadrat percent cover of fern species per plot with 80% power and $\alpha = 0.05$. Overall, the ability to detect both positive and negative changes in fern percent cover was very good (Table 14). All parks met the target to detect a 40% change with 80% power at $\alpha = 0.05$. All but SAGA and SARA were able to detect changes at or below 20%, and minimum detectable change tended to be smaller than for average herb % cover. This is useful information, as ferns are often the group that replaces herbaceous cover when moderate deer browse impacts occur (De La Cretaz and Kelty 2002, Wiegmann and Waller 2006). Therefore, changes in the understory may be identified by a significant increase in fern cover before a decrease in herbaceous cover is detected, especially because a significant increase tends to be easier to detect statistically than a significant decrease.

Average Indicator Invasive Exotic Percent Cover

Power analyses for this metric examined average quadrat percent cover of indicator invasive exotic species per plot (see Appendix B for a list of indicator invasive exotic species). MIMA and MORR were the only parks that did not meet the target of 80% power to detect 40% change at $\alpha = 0.05$, and this was due to the large variability of invasive exotic cover in both parks (Figure 15). In WEFA, simulations indicated that a 35% decline in invasive exotic cover could be detected. However, simulations failed to detect a 40% increase in invasive exotic cover. The low sample size and high proportion of plots with no invasive exotic cover are the main reasons for the inability to detect the target level of change in WEFA. Because invasive exotic cover is so low in WEFA, a 40% increase only translates to a small amount of actual cover in quadrats. Therefore, failing to detect a 40% change in WEFA is not a big concern. The inability to detect changes in invasive exotic cover in MIMA and MORR is more of an issue because invasive exotic cover is higher in these parks.

At $\alpha = 0.10$, MIMA reached the 40% effect size target, and the minimum detectable effect sizes improved for all parks except MORR, which failed to detect even a 50% change due to high metric variability (Figure 15). Indicator invasive exotic cover varies by successional stage (i.e., mature and successional), and post-stratifying MORR by successional stages may improve trend detection. Trend detection is also expected to improve over time for all parks. Considering the improvement in change detection that occurred for most parks when the Type I error rate was increased, and the ecological importance of detecting a change in invasive exotic plant cover, $\alpha = 0.10$ will be used for trend analyses of this metric. Additional metrics to understand indicator invasive exotic species dynamics may also be examined, such as number of species per plot, quadrat frequency within a plot, and percent cover change within plots where indicator invasive species occur.

Native Species Plot Richness

Analyses of this metric examined ability to detect a change in the number of native species per plot at 80% power and $\alpha = 0.05$. This metric performed very well, with all parks detecting changes at or below 10% while maintaining 80% power at $\alpha = 0.05$. This suggests that even

Table 15. Minimum detectable positive and negative effect size for select metrics by park at 80% power and alpha =0.10. Metrics that did not reach 80% power by 50% effect size are recorded as "---".

	Ave. Herb % Cover		Ave. Indicator Invasive Exotic % Cover		Coarse Woody Debris Volume		Regeneration Stocking Index		Snag Abundance	
	Decrease	Increase	Decrease	Increase	Decrease	Increase	Decrease	Increase	Decrease	Increase
NETN	-5	5	-5	5	-5	5	-10	10	-5	5
ACAD	-5	5	-5	5	-10	10	-10	10	-10	10
MABI	-20	20	-10	10	-30	30	-50	---	-40	40
MIMA	-30	25	-35	40	-45	40	-45	45	-35	35
MORR	-15	15	---	---	-25	25	-35	35	-30	35
ROVA	-15	15	-25	30	-15	15	-15	15	-30	25
SAGA	-20	20	-20	20	-25	25	-25	25	-10	10
SARA	---	---	-25	30	-25	25	-35	35	-20	20
WEFA	-20	15	-30	40	-45	40	-50	45	---	---

small changes in native species richness are likely to be detected in all NETN parks, making this a reliable metric for examining trends in species composition and understory dynamics.

Coarse Woody Debris Volume

Coarse woody debris (CWD) power analyses were based on CWD volume (m^3/ha). Minimum detectable effect size at 80% power and $\alpha = 0.05$ varied across network parks, with NETN and ACAD having the lowest detectable effect size of $\pm 10\%$ (Table 14). MABI, MORR, ROVA, SAGA and SARA reached the 40% effect size target, and MIMA and WEFA did not reach the 40% effect size target. The low power in MIMA and WEFA can be explained by a combination of low sample size and numerous plots without CWD. At $\alpha = 0.10$, MIMA and WEFA still did not reach the 40% effect size target, but the minimum detectable effect sizes improved in the remaining parks. The inability of this metric to detect a 40% effect size in MIMA and WEFA is not a big concern. CWD volume in MIMA and WEFA is fairly low, and a 40% increase in this metric does not translate to a lot of CWD volume. Considering the improvement in change detection that occurred in most parks when the Type I error rate was increased, $\alpha = 0.10$ will be used to detect change for this metric.

Regeneration Stocking Index

Tree regeneration power analyses were based on the stocking index which was designed by McWilliams et al. (2005), and is used for the tree regeneration metric in the NETN Ecological Integrity Scorecard (Tierney et al. 2011). The stocking index assigns a weight to each seedling based on its height class, with higher weights for larger height classes. The stocking index is calculated as the sum of the weights across all height classes, and averaged over three 2-m radius microplots in each plot.

At 80% power and Type I error rate of 0.05, MABI, MIMA, and WEFA failed to detect a 40% effect size (Table 14). All three parks have relatively high standard deviations in relation to the mean value for this metric (Table 16). This results in low power both because the magnitude of a 40% effect size is still pretty small, and the high standard deviation means that a large change must happen to be significant. While increasing the Type 1 error rate to $\alpha = 0.10$ improved the minimum detectable effect size for some parks, MABI, MIMA and WEFA still failed to detect the target effect size. Considering the poor change detection at $\alpha = 0.05$ for most parks, this metric will be analyzed using an $\alpha = 0.10$. We may also consider using additional metrics to examine trends in tree regeneration, such as seedling density by height class.

Snag Abundance

Power analysis for this metric was based on the number of snags in each plot converted to number of snags per ha. MABI narrowly missed the 40% change detection target at 80% power and $\alpha = 0.05$, and WEFA widely missed this target (Table 14). Both MABI and WEFA have relatively high standard deviations in relation to the mean value for this metric, and have a high proportion of plots with 0 (Table 16). This results in low power both because the magnitude of a 40% effect size is still relatively small, and the high standard deviation means that a large change must happen to be significant. At $\alpha = 0.10$, MABI reached the 40% effect size target. However, WEFA still failed to detect the target effect size. Because several parks were not able to detect a 40% effect size at 80% power and $\alpha = 0.05$, an alpha rate of 0.10 will be used in future analyses of this metric.

Live Tree Basal Area

Analyses for this metric examined the ability to detect a change in live tree basal area (m^3/ha) per plot. This metric performed very well, with all parks detecting changes at or below 10% while maintaining 80% power at $\alpha = 0.05$. This suggests that even small changes in live tree basal area are likely to be detected in all NETN parks, making this a reliable metric for examining patterns in forest stand dynamics.

Discussion

Results of the power analyses indicate that most metrics meet the target of detecting a 40% effect size while maintaining 80% power at a Type I error rate of 0.05. Native species richness and live tree basal area consistently performed well, and all parks were able to detect a 40% effect size or better at 80% power and $\alpha = 0.05$. In contrast, coarse woody debris, regeneration stocking index and snag abundance metrics had multiple parks that did not meet the detection target of 40%, although this improved slightly with increasing the Type I error rate to 0.10. However, even at $\alpha = 0.10$, metrics in WEFA consistently did not meet the target to detect 40% effect size while maintaining 80% power. This isn't surprising, as WEFA has the smallest sample size ($n = 10$) of the NETN parks. Power is expected to improve as plots are repeatedly sampled over time. If, after three survey cycles, power continues to be low for most WEFA metrics, NETN may consider adding more permanent plots.

Metrics for NETN overall and ACAD performed very well, with a minimum detectable effect size of $\pm 10\%$ or better for every metric. This is expected, as ACAD has the highest number of forest plots ($n = 176$) in the network. Remaining parks varied in change detection, and metrics containing a high proportion of zeros and low values were the most common cause for poor change detection. Poor trend detection in this case is not a big concern, because a 40% change in a metric with low values is of relatively small magnitude in reality. In contrast, several cases of poor change detection were the result of high metric variability (e.g., average indicator invasive exotic % cover in MIMA and MORR, average herb % cover in SARA). This is of greater concern, because only large changes in a metric can be detected, even if metric values are high to begin with. Post-stratifying plots based on land use history, forest type, or management unit may improve power to detect change, especially if metric variability differs between groups. However, testing this hypothesis is beyond the scope of this analysis.

Increasing the Type I error to $\alpha = 0.10$ improved the power to detect change for many metrics. Additionally, the risk of missing an important ecological change is just as important for many of the key forest metrics as the risk of erroneously detecting a trend. Therefore, the default Type I error rate for future trend analyses will be $\alpha = 0.10$.

Table 16. Table of summary statistics of 2006-2007 data for each metric by park. Mean is the average value, including 0. SD is the standard deviation. The % 0's column represents the proportion of plots in the dataset where the metric value is 0 for each park.

Ave. Herb % Cover			Ave. Fern % Cover			Ave. Indicator Invasive Exotic % Cover			Native Species Plot Richness			
	Mean	SD	% 0's	Mean	SD	% 0's	Mean	SD	% 0's	Mean	SD	% 0's
ACAD	0.03	0.05	11.69	0.02	0.04	53.25	<0.01*	<0.01*	51.95*	16.61	5.79	0.00
MABI	0.09	0.13	8.33	0.08	0.11	16.67	<0.01	<0.01	91.67	27.42	8.63	0.00
MIMA	0.08	0.10	0.00	0.03	0.04	40.00	0.06	0.07	0.00	24.80	7.51	0.00
MORR	0.09	0.14	0.00	0.01	0.04	64.29	0.24	0.30	14.29	29.57	7.82	0.00
ROVA	0.11	0.11	5.00	0.03	0.10	40.00	0.05	0.08	20.00	37.05	14.53	0.00
SAGA	0.04	0.05	0.00	0.03	0.05	0.00	0.01	0.04	90.00	28.60	9.61	0.00
SARA	0.29	0.15	0.00	0.13	0.15	7.14	0.03	0.04	7.14	44.80	6.88	0.00
WEFA	0.10	0.07	0.00	0.06	0.06	20.00	0.00	0.00	40.00	34.60	7.23	0.00

Coarse Woody Debris Volume			Regeneration Stocking Index			Snag Abundance			Live Tree Basal Area			
	Mean	SD	% 0's	Mean	SD	% 0's	Mean	SD	% 0's	Mean	SD	% 0's
ACAD	17.27	21.25	24.68	135.43	157.34	9.09	170.85	161.39	14.29	26.13	12.01	0.00
MABI	26.19	28.94	16.67	20.08	36.32	41.67	45.83	54.18	41.67	39.32	17.07	0.00
MIMA	10.77	11.20	30.00	37.50	66.15	20.00	42.50	33.44	10.00	37.37	15.58	0.00
MORR	25.86	32.78	7.14	13.91	15.85	28.57	33.93	27.05	21.43	28.70	10.71	0.00
ROVA	60.37	61.21	5.00	101.57	104.36	0.00	53.75	61.38	20.00	28.47	13.06	0.00
SAGA	17.58	16.75	30.00	155.30	148.55	10.00	117.50	99.34	10.00	52.88	16.89	0.00
SARA	27.65	28.94	35.71	36.87	41.41	35.71	103.33	100.39	7.14	21.39	15.45	0.00
WEFA	22.98	47.51	60.00	41.47	34.45	20.00	25.00	30.62	40.00	30.53	4.65	0.00

*Invasive exotic plant cover statistics are based on jittered dataset.

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Appendix A. Protocol implementation for the 2011 field season.

2011 Sampling Inconsistencies and Data Issues

Overall data quality for the 2011 field season was very good. The 2011 dataset had fewer data errors and missing records than any previous year. While an exceptional forest crew is a major reason for this improvement in data quality, another important contributor is the data checker that NETN Data Manager Adam Kozlowski built into the forest database. There were only a few minor recurring errors in the dataset, such as neglecting to record witness trees, and most of these were the result of not being part of data checker. All known issues have since been built into the data checker so that these errors will be detected in the future.

Quality Control and Quality Assurance (QA/QC)

To verify data quality and quantify sampling error, we resample 5% (four plots) of the forest plots that crews sample every year. Plots are randomly selected for QA/QC, with two plots located in ACAD and two plots located in a randomly selected national historical park or national historic site. ROVA plots 004 and 011, and ACAD plots 057 and 074 were sampled for QA/QC in 2011.

Data comparisons between the forest crew and the QA/QC crew were very close for tree diameter at breast height (DBH) measurements, quadrat species and percent cover, and microplot data. Coarse woody debris (CWD) measurements did not correspond as closely as we would like on two plots that had numerous pieces and multiple crossings of CWD. Because we keep track of pieces that cross CWD transects multiple times, and our current CWD volume calculations do not include the multiple crossings, this issue will not impact our assessment of the CWD ecological integrity metric. However, we will use this example to further stress the importance of accurate CWD measurements during crew training.

Resampling and Protocol Revision

Over the last 2 years of plot resampling, it has become increasingly clear that fiberglass stakes are not an ideal plot marker. At a large majority of plots, we encounter at least one missing fiberglass stake, and often several. Most of the data collected on the plot is unaffected by a missing stake or two. However, the data collected in quadrats are greatly compromised because the fiberglass stakes are important markers for determining quadrat locations. To resolve this issue, we plan to adopt the Mid-Atlantic Network's (MIDN) approach to forest plot marking (with permission from our parks). MIDN uses bent pieces of rebar flush with the ground for plot corners, and rebar with a permanently attached and labeled survey cap at plot center. 2011 was the first year of repeat sampling in MIDN, and crews encountered very few plots with missing rebar. The added benefit with rebar is they can be flush with the ground (i.e., inconspicuous to visitors) and still easily relocated with a metal detector.

In the process of analyzing diameter at breast height (DBH) data for the tree growth metric, we encountered issues with data quality that need to be addressed. Two types of errors were apparent in our DBH dataset: transcription errors, and errors due to misplacement of DBH on the tree. Transcription errors are the result of incorrectly recording the DBH data, and often result in values that differ ± 6 cm DBH between years. These errors are easy to spot, and can be removed from tree growth analyses. We are also building checks into the database to detect large differences in DBH between survey cycles. Errors due to inconsistent location of DBH, which

Appendix A. Protocol implementation for the 2011 field season (continued)

often result in a negative growth rate, are more difficult to detect on the positive growth side because they may appear to be within normal range. Assuming measurement errors are normally distributed around zero, removing only negative growth rates could bias our estimates. However, allowing these errors to continue reduces our ability to make sound predictions on tree growth rates. Our best solution to resolve this issue is to begin marking DBH on all trees, instead of only marking trees where the DBH location had to be changed due to an obstacle at the default location. MIDN marks DBH of all trees with green spray paint, and has had good success with the approach. The green paint is rather inconspicuous from a distance, especially as it fades over time. Enough paint remains after 4 years that DBH can be easily spotted when a technician is standing next to the tree.

Appendix B. Indicator species used for seedling ratio.

Species	Common Name	Potential Deer Impact	Cite ¹	Note
<i>Acer rubrum</i>	red maple	High	2	
<i>Acer saccharum</i>	sugar maple	High	2	
<i>Cornus florida</i>	flowering dogwood	High	1	
<i>Liriodendron tulipifera</i>	tulip poplar	High	2	
<i>Magnolia acuminata</i>	cucumber tree	High	2	
<i>Prunus pensylvanica</i>	pin cherry	High	2	
<i>Sassafras albidum</i>	sassafras	High	1	
<i>Sorbus americana</i>	mountain ash	High	1	
<i>Thuja occidentalis</i>	northern white cedar	High	1	
<i>Tilia americana</i>	basswood	High	1	
<i>Tsuga canadensis</i>	eastern hemlock	High	2	
<i>Betula alleghaniensis</i>	yellow birch	Medium	2	High preference but medium browse tolerance
<i>Betula lenta</i>	black birch	Medium	2	High preference but medium browse tolerance
<i>Carya</i> spp.	hickories	Medium	2	High preference but medium browse tolerance
<i>Fraxinus</i> spp.	ashes	Medium	2	High preference but medium browse tolerance
<i>Hamamelis virginiana</i>	witch hazel	Medium	1	
<i>Juglans cinerea</i>	butternut	Medium	1	
<i>Juglans nigra</i>	black walnut	Medium	1	
<i>Nyssa sylvatica</i>	black gum	Medium	3	Sprouts have medium to high palatibility
<i>Quercus</i> spp.	oaks	Medium	2	High preference but medium browse tolerance
<i>Ulmus</i> spp.	elm	Medium	1	
<i>Abies balsamea</i>	balsam fir	Medium/Low	1	Low choice but heavily browsed if needed
<i>Acer pensylvanicum</i>	striped maple	Medium/Low	2	Medium preference but high browse tolerance
<i>Fagus grandifolia</i>	American beech	Medium/Low	2	Medium preference but high browse tolerance
<i>Pinus resinosa</i>	red pine	Medium/Low	1	Low choice but heavily browsed if needed
<i>Pinus rigida</i>	pitch pine	Medium/Low	1	Low choice but heavily browsed if needed
<i>Pinus strobus</i>	white pine	Medium/Low	1	Low choice but heavily browsed if needed
<i>Pinus sylvestris</i>	Scotch pine	Medium/Low	1	Low choice but heavily browsed if needed
<i>Alnus</i> spp.	alder	Low	1	
<i>Betula papyrifera</i>	paper birch	Low	1	
<i>Betula populifolia</i>	gray birch	Low	1	
<i>Carpinus caroliniana</i>	musclewood	Low	1	
<i>Crataegus</i> spp.	hawthorn	Low	1	
<i>Juniperus virginiana</i>	red cedar	Low	1	

Appendix B. Indicator species used for seedling ratio (continued).

Species	Common Name	Potential		Note
		Deer Impact	Cite ¹	
<i>Larix laricina</i>	tamarack	Low	1	
<i>Ostrya virginiana</i>	hop hornbeam	Low	1	
<i>Picea</i> spp.	spruces	Low	1	
<i>Populus</i> spp.	aspens	Low	1	
<i>Prunus serotina</i>	black cherry	Low	2	
<i>Rhamnus cathartica</i>	buckthorn	Low	1	
<i>Robinia pseudoacacia</i>	black locust	Low	1	

¹1 — New York State Department of Environmental Conservation (NYS DEC). A Preference List of Winter Deer Foods (www.dec.state.ny.us/website/dfwmr/wildlife/deer/foodlist.html); 2 — USFS 2003. Forest Inventory and Analysis. Northeast Field Guide, Version 1.7, App. 12; 3 — USFS Fire Effects Information System tree description. (www.fs.fed.us/database/feis/plants/index.html).

Appendix C. Key indicator invasive exotic plant species of forest, woodland and successional ecosystems in the northeastern U.S. that were used in the NETN Ecological Integrity Scorecard.

Latin name	Common name	Habitat
<i>Acer platanoides</i>	Norway maple	Open & forest habitats
<i>Ailanthus altissima</i>	tree-of-heaven	Edges & successional habitats
<i>Alliaria petiolata</i>	garlic mustard	Open & forest habitats
<i>Berberis thunbergii</i>	Japanese barberry	Open & forest habitats
<i>Berberis vulgaris</i>	European barberry	Open & wooded habitats
<i>Cardamine impatiens</i>	narrowleaf bittercress	Open & wooded habitats
<i>Celastrus orbiculatus</i>	oriental bittersweet	Edges & successional habitats
<i>Cynanchum louiseae</i>	black swallow-wort	Open, successional & wooded habitats
<i>Cynanchum rossicum</i>	European swallow-wort	Open, successional & wooded habitats
<i>Euonymus alata</i>	winged burning bush	Open, successional & wooded habitats
<i>Frangula alnus</i>	glossy buckthorn	Wetland & successional habitats
<i>Ligustrum</i> spp. (<i>obtusifolium</i> , <i>vulgare</i>)	privet	Successional & forest habitats
<i>Lonicera japonica</i>	Japanese honeysuckle	Edges & successional habitats
<i>Lonicera</i> spp. (<i>morrowii</i> , <i>tatarica</i> , x <i>bella</i>)	exotic honeysuckles	Open & successional habitats
<i>Luzula luzuloides</i>	forest woodrush	Open & wooded habitats
<i>Microstegium vimineum</i>	Japanese stiltgrass	Open & forest habitats
<i>Polygonum caespitosum</i>	oriental ladythumb	Open & successional habitats
<i>Polygonum cuspidatum</i>	Japanese knotweed	Riparian, open & successional habitats
<i>Rhamnus cathartica</i>	common buckthorn	Riparian, open & successional habitats
<i>Rhodotypos scandens</i>	black jetbead	Open, successional & wooded habitats
<i>Rosa multiflora</i>	multiflora rose	Open & successional habitats
<i>Rubus phoenicolasius</i>	wineberry	Open, successional & wooded habitats

Appendix D. Herbaceous indicator species of deer browse pressure in northeastern U.S. forests.

Latin name	Common Name	Deer Preference	Citations
<i>Ageratina altissima</i> var. <i>altissima</i> (formerly <i>Eupatorium rugosum</i>)	white snakeroot	Avoided	Augustine and Jordan 1998
<i>Aralia nudicaulis</i>	wild sarsaparilla	Browsed	Balگوoyen and Waller 1995
<i>Eurybia divaricata</i>	white wood aster	Browsed	Williams et al. 2000
<i>Carex</i> spp.	sedge	Avoided	Williams et al. 2000, Augustine and deCalesta 2003, Horsley et al. 2003
<i>Clintonia borealis</i>	blue bead lily	Browsed	Balگوoyen and Waller 1995
<i>Dennstaedtia punctilobula</i>	hayscented fern	Avoided	Horsley et al. 2003
<i>Maianthemum (Smilacina)</i> spp. (<i>racemosum</i> , <i>stellatum</i>)	Canada mayflower and false Solomon's seal	Browsed	Fletcher et al. 2001, Augustine and deCalesta 2003
<i>Polygonatum</i> spp. (<i>biflorum</i> , <i>pubescens</i>)	smooth Solomon's seal	Browsed	Augustine and deCalesta 2003, Webster et al. 2005, Kraft et al. 2004
<i>Sanguinaria canadensis</i>	bloodroot	Browsed	Augustine and deCalesta 2003
<i>Thelypteris noveboracensis</i>	New York fern	Avoided	Williams et al. 2000, Horsley et al. 2003
<i>Trillium</i> spp. (<i>cernum</i> , <i>erectum</i> , <i>grandiflorum</i> , <i>undulatum</i>)	trillium	Browsed	Anderson 1994, Augustine and Frelich 1998, Rooney 2001, Augustine and deCalesta 2003, Webster et al. 2005
<i>Uvularia</i> spp. (<i>grandiflora</i> , <i>perfoliata</i> , <i>sessifolia</i>)	bellwort	Browsed	Fletcher et al. 2001, Augustine and deCalesta 2003, Webster et al. 2005

Appendix E. Scientific and common names of tree species mentioned in the Tree Growth and Mortality metric.

Scientific Name	Common Name
<i>Abies balsamea</i>	balsam fir
<i>Acer platanoides</i>	Norway maple
<i>Acer rubrum</i>	red maple
<i>Acer nigrum</i>	black maple
<i>Acer saccharum</i>	sugar maple
<i>Betula alleghaniensis</i>	yellow birch
<i>Betula lenta</i>	sweet birch
<i>Betula papyrifera</i>	paper birch
<i>Fagus grandifolia</i>	American beech
<i>Fraxinus americana</i>	white ash
<i>Larix decidua</i>	European larch
<i>Liriodendron tulipifera</i>	tulip poplar
<i>Picea mariana</i>	black spruce
<i>Picea rubens</i>	red spruce
<i>Pinus strobus</i>	eastern white pine
<i>Pinus sylvestris</i>	Scots pine
<i>Populus grandidentata</i>	bigtooth aspen
<i>Quercus alba</i>	white oak
<i>Quercus rubra</i>	northern red oak
<i>Quercus velutina</i>	black oak
<i>Thuja occidentalis</i>	northern white cedar
<i>Tsuga canadensis</i>	eastern hemlock
<i>Ulmus americana</i>	American elm

Appendix F. Soil chemistry boxplots of NETN parks.

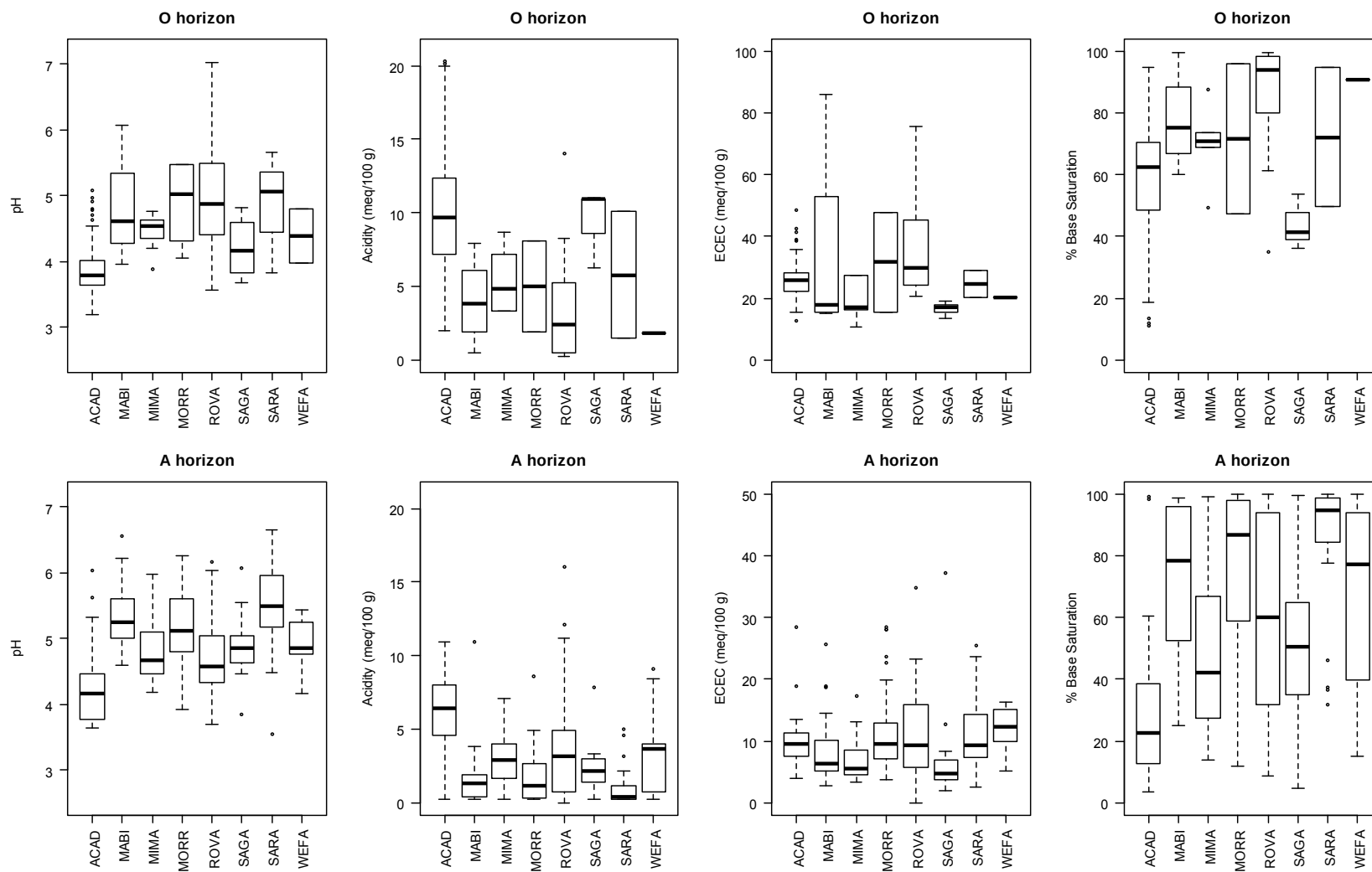


Figure F-1. Soil parameters for each park by horizon.

Appendix F. Soil chemistry boxplots of NETN parks (continued).

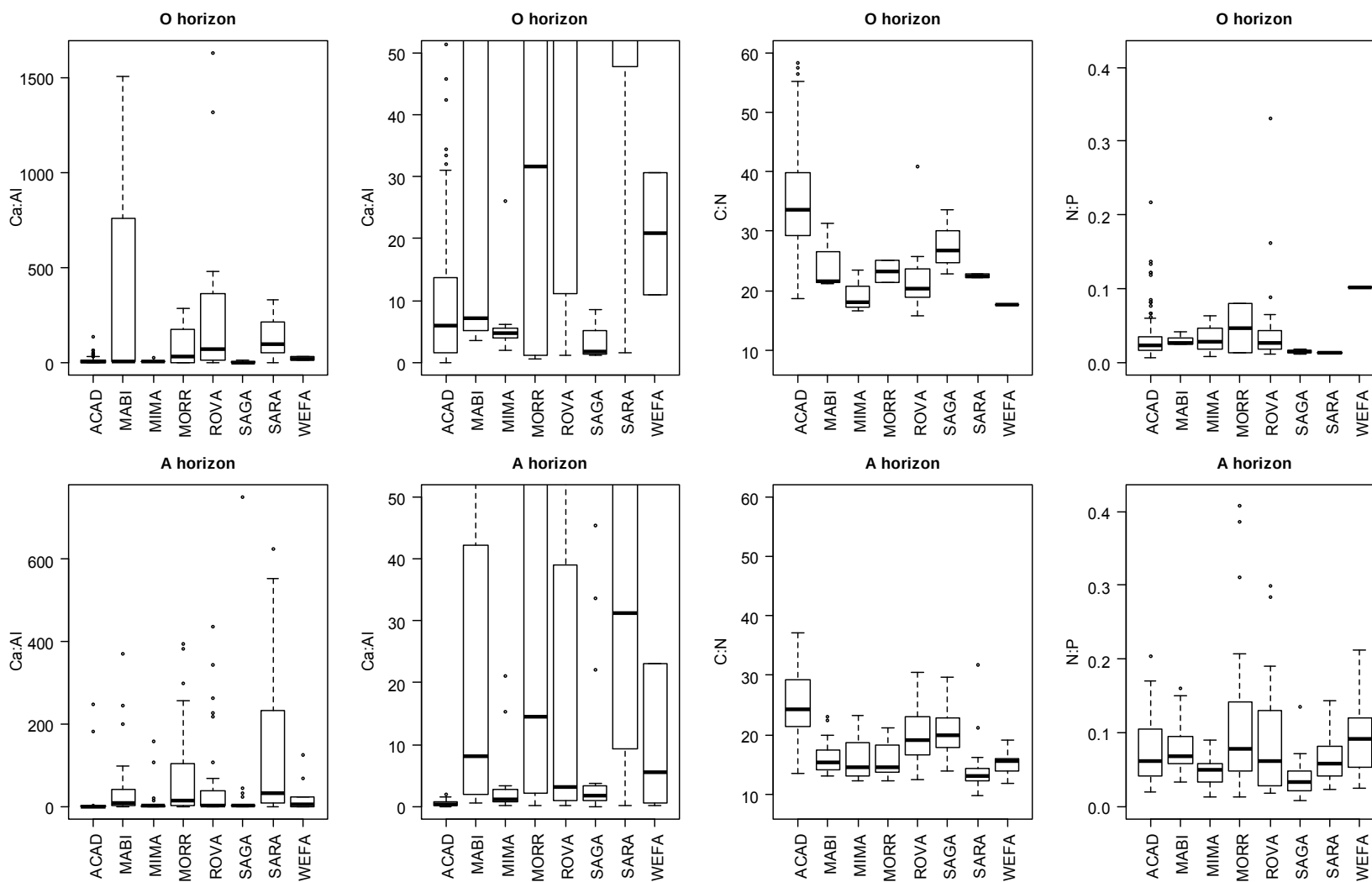


Figure F- 2. Ca:Al, C:N, and N:P ratios for each park unit by horizon. The second column of Ca:Al shows the lower range of ratio values for the parks.

Appendix F. Soil chemistry boxplots of NETN parks (continued).

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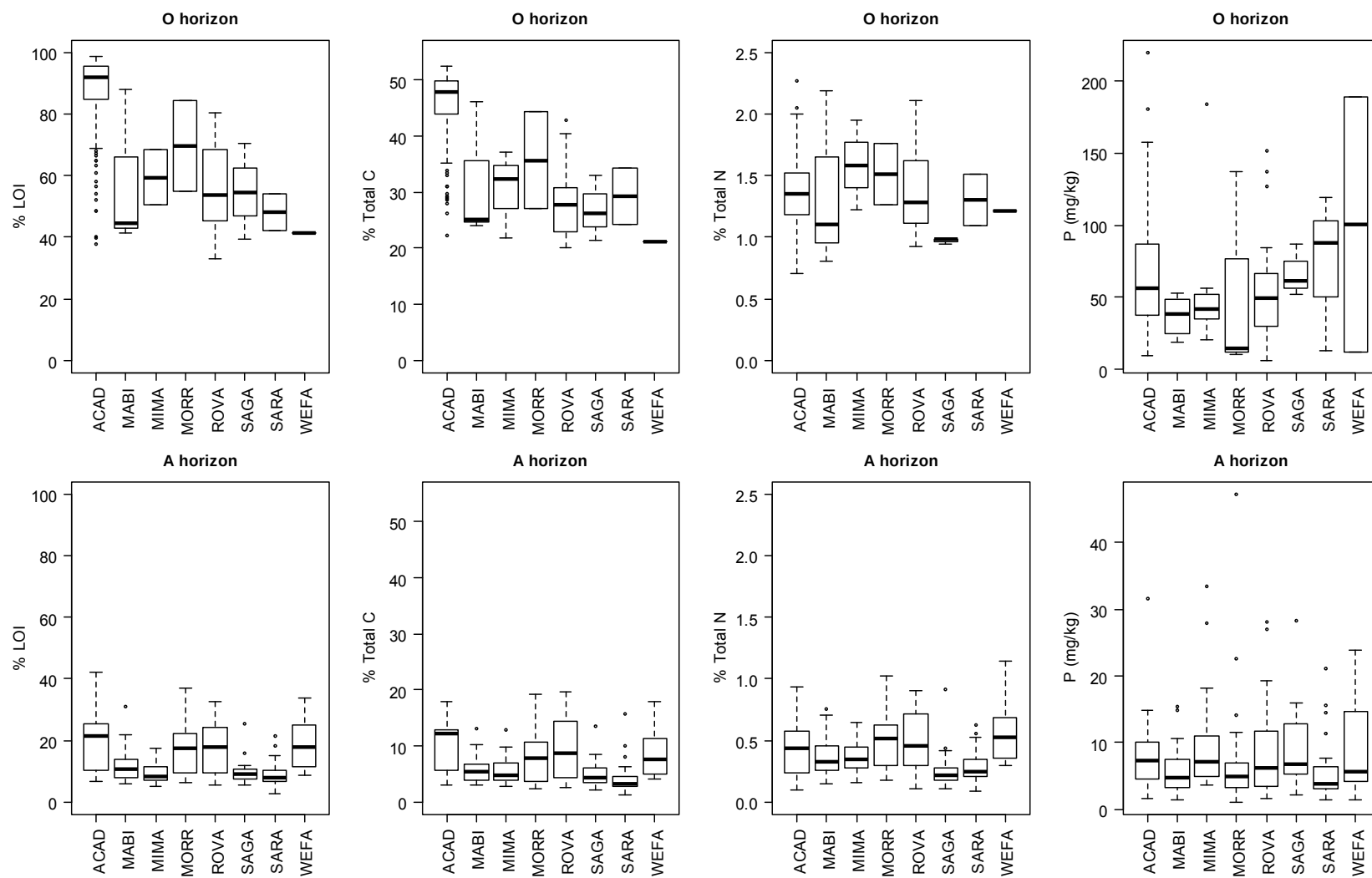


Figure F-3. C, N and P parameters for each park unit by horizon.

Appendix F. Soil chemistry boxplots of NETN parks (continued).

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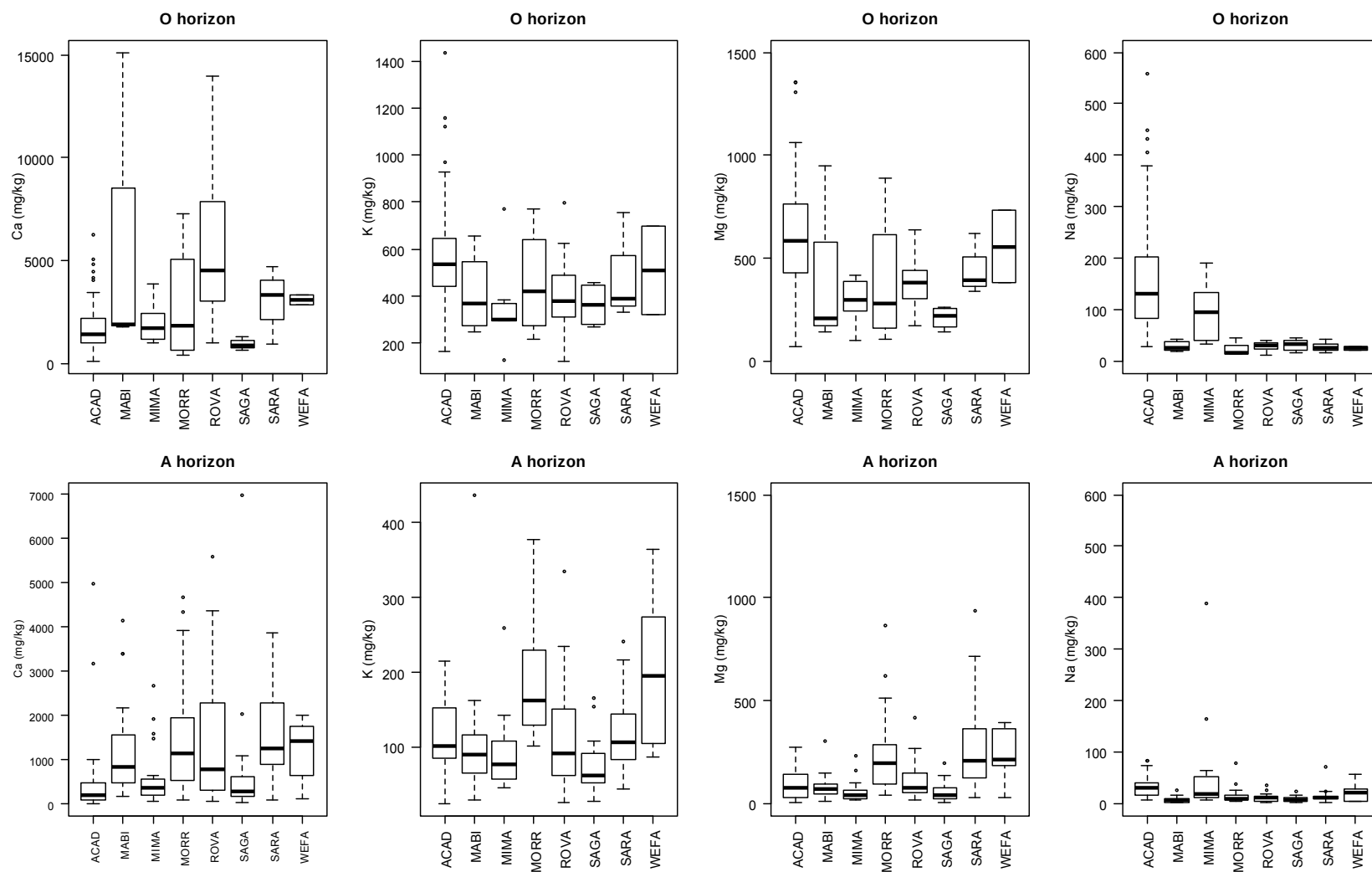


Figure F-4. Base cations for each park unit by horizon

Appendix F. Soil chemistry boxplots of NETN parks (continued).

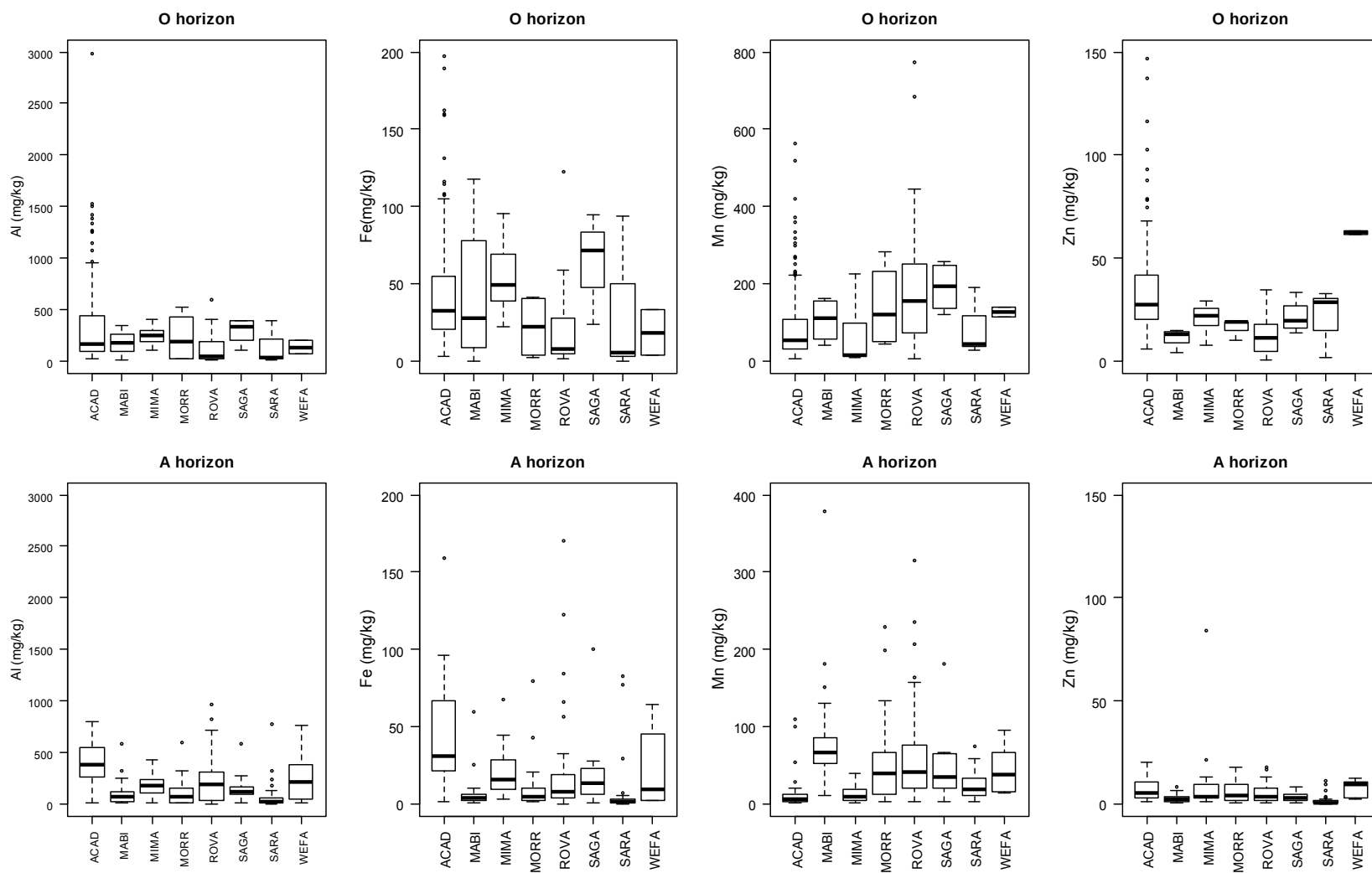


Figure F-5. Acid cations for each park unit by horizon.

Appendix G. Supplemental ordination plots and figures used to interpret A horizon NMDS results.

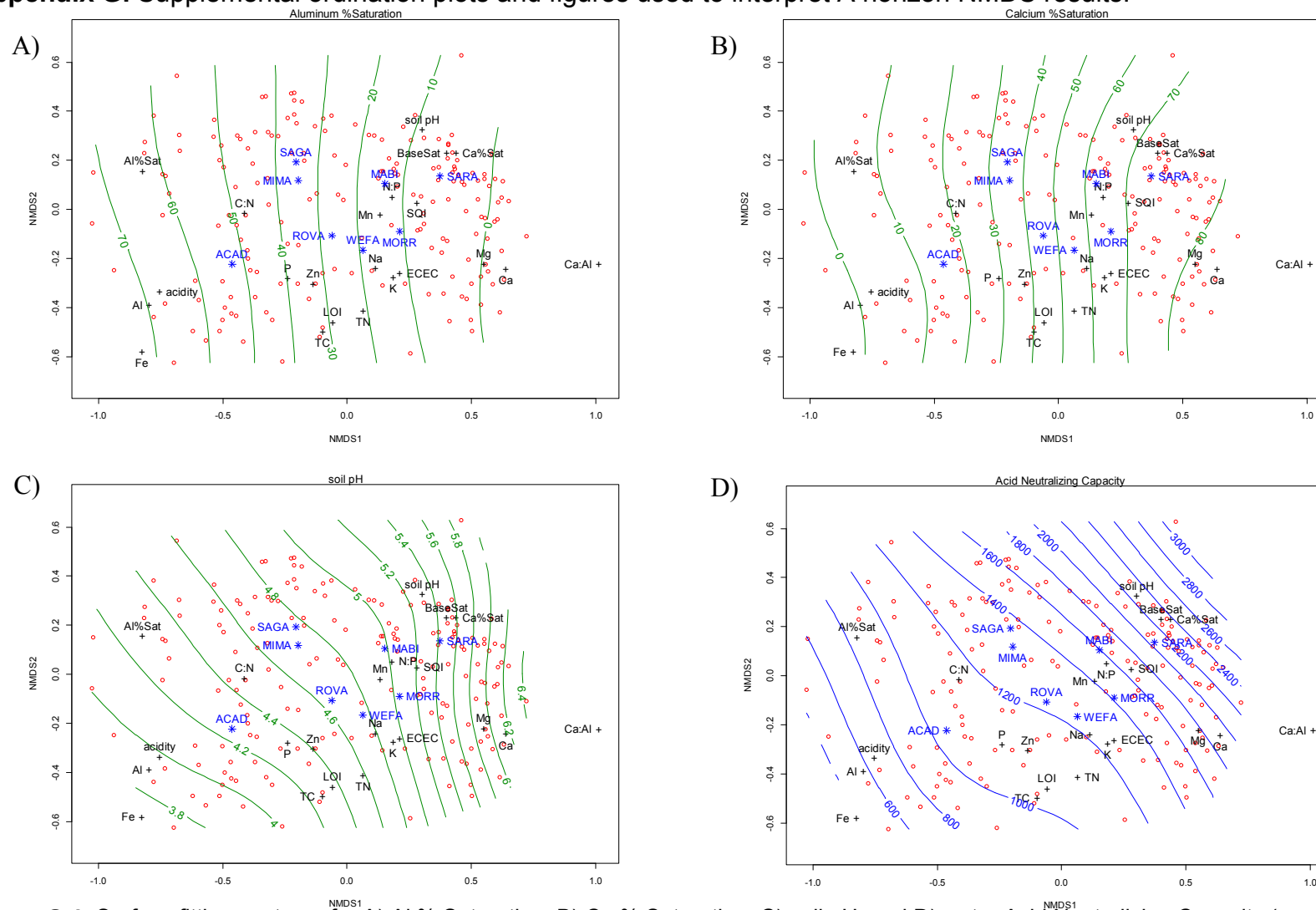


Figure G-1. Surface fitting contours for A) Al % Saturation, B) Ca % Saturation, C) soil pH, and D) water Acid Neutralizing Capacity (meq/L). Green contours are variables that were part of the soil chemical dataset for the NMDS ordination, and are expressed in their original units. Blue contours are environmental variables that did not influence the NMDS ordination.

Appendix G. Supplemental ordination plots and figures used to interpret A horizon NMDS results (continued).

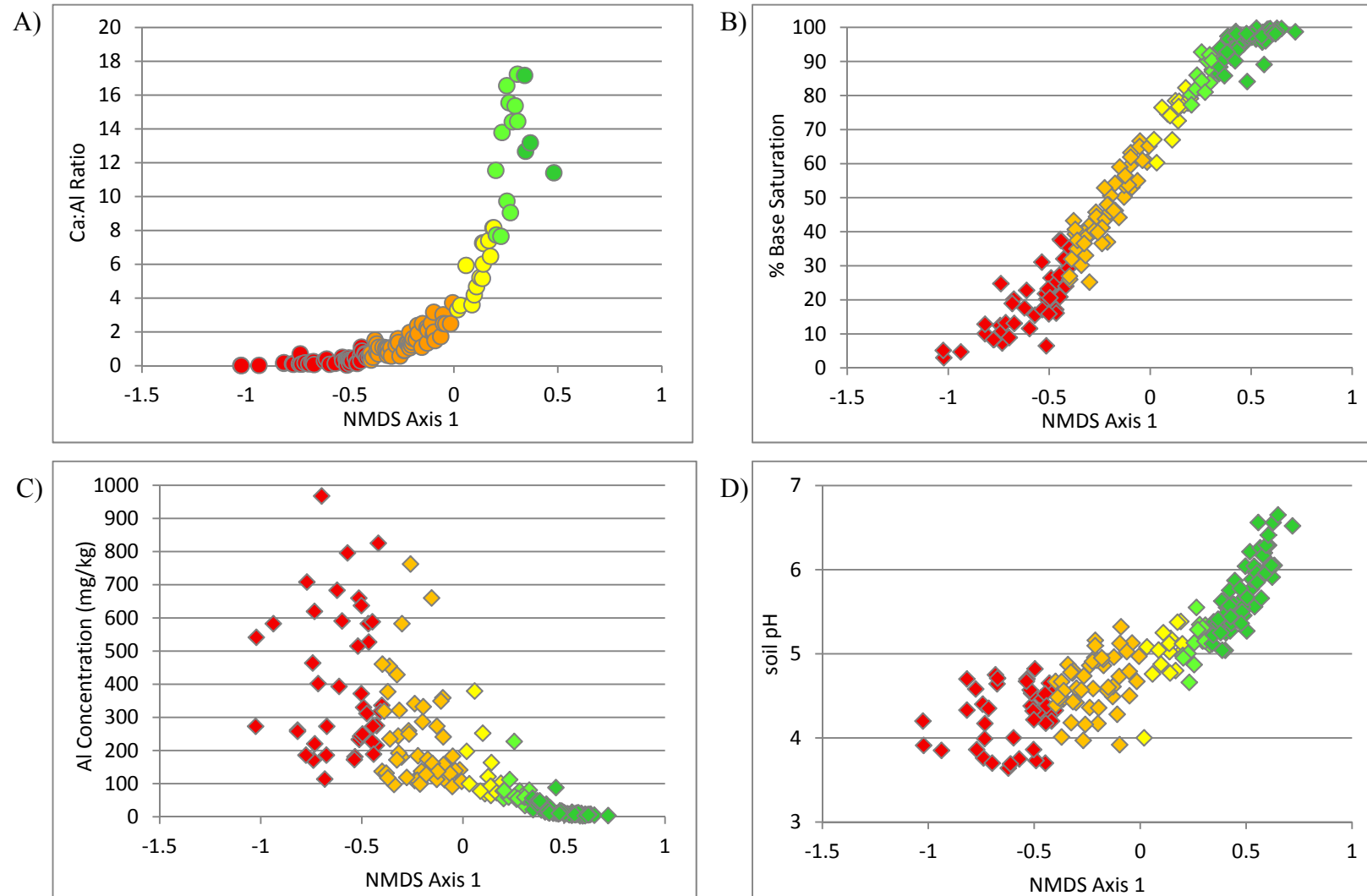


Figure G-2. Scatterplots of NMDS Axis 1 scores versus A) Ca:Al ratio, B) % Base Saturation, C) Al concentration (mg/kg), and D) soil pH. Point colors represent the bins used to assign relative acidification risk of plots in ACAD based on O horizon samples. Note that the Y axis in Figure A was cut off at 20 to view patterns in the lower range of this ratio.

Appendix G. Supplemental ordination plots and figures used to interpret A horizon NMDS results (continued).

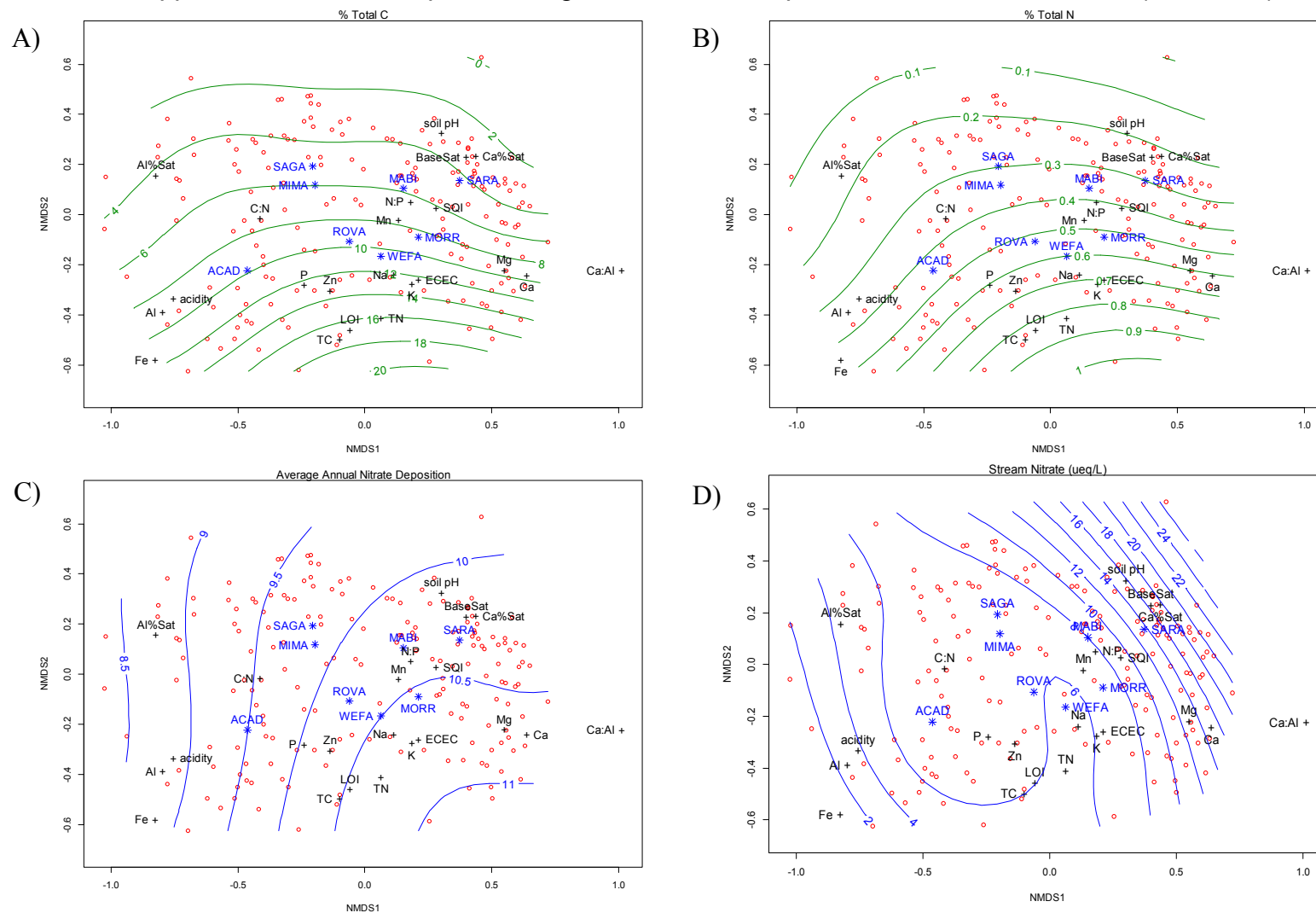


Figure G-3. Surface fitting contours for A) % Total C, B) % Total N, C) Average Annual N deposition, and D) Stream NO_3^- concentration ($\mu\text{eq/L}$). Green contours are variables that were part of the soil chemical dataset for the NMDS ordination, and are expressed in their original units. Blue contours are environmental variables that did not influence the NMDS ordination.

Appendix G. Supplemental ordination plots and figures used to interpret A horizon NMDS results (continued).

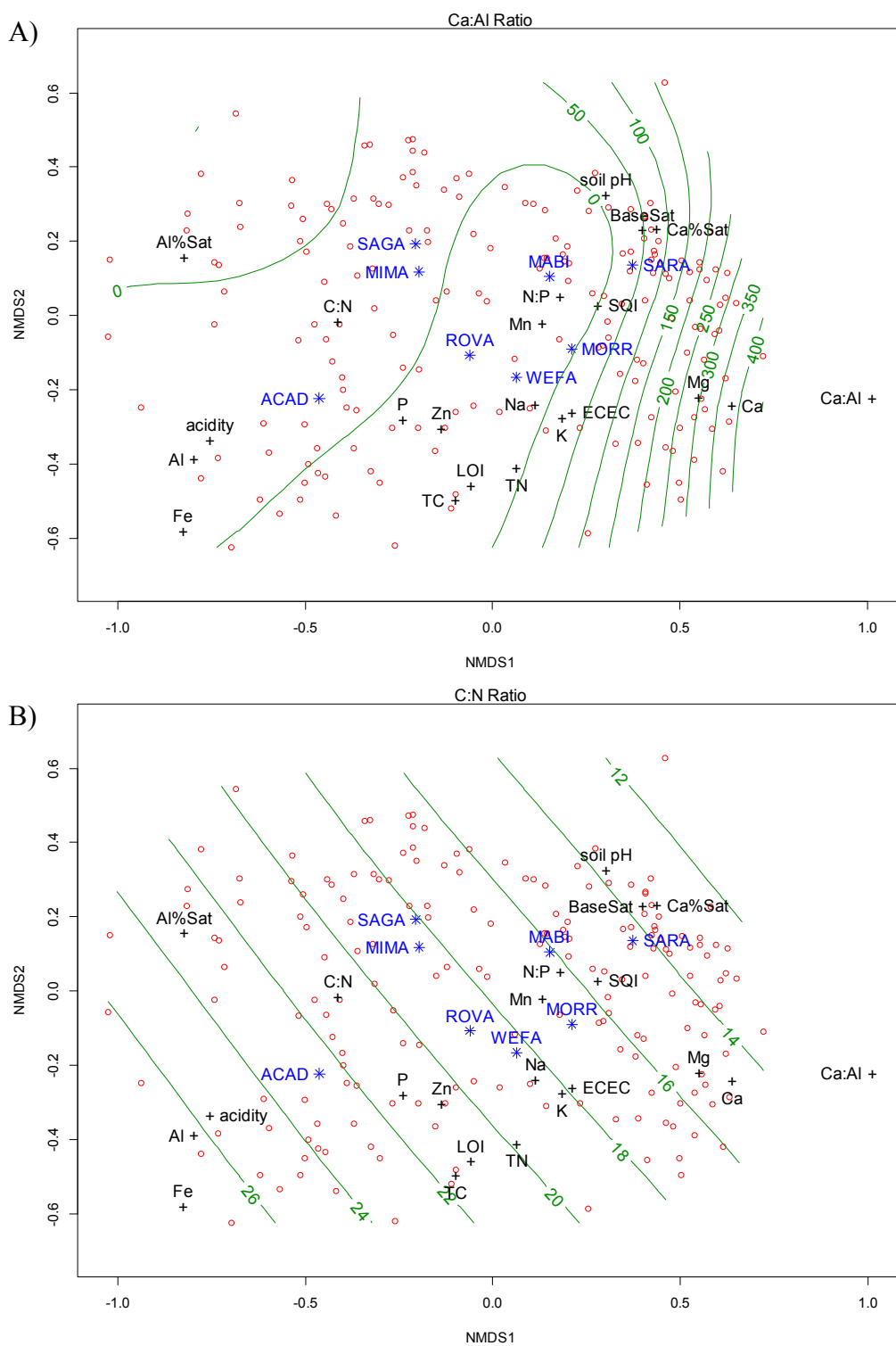


Figure G-4. Surface fitting contours for A) Ca:Al ratio and B) C:N ratio.

Appendix H. Ordination plots and figures used to interpret NMDS results for O horizon analyses in ACAD.

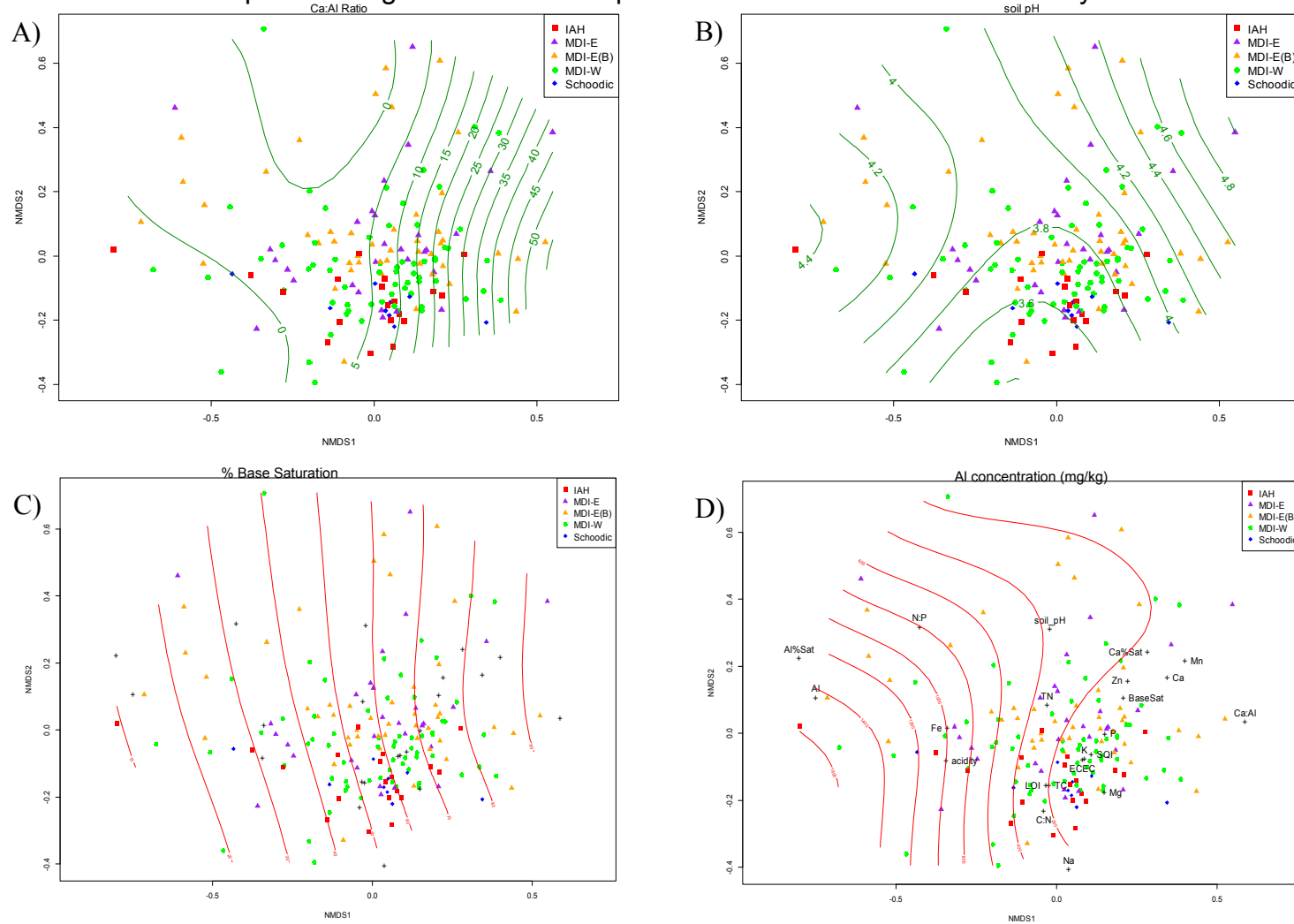


Figure H-1. Surface fitting contours for A) Ca:Al ratio, B) soil pH, C) % Base Saturation, and D) Al concentration (mg/kg). Green contours are variables that were part of the soil chemical dataset for the NMDS ordination, and are expressed in their original units. Red contours represent environmental variables that did not influence the NMDS ordination.

Appendix H. Ordination plots and figures used to interpret NMDS results for O horizon analyses in ACAD (continued).

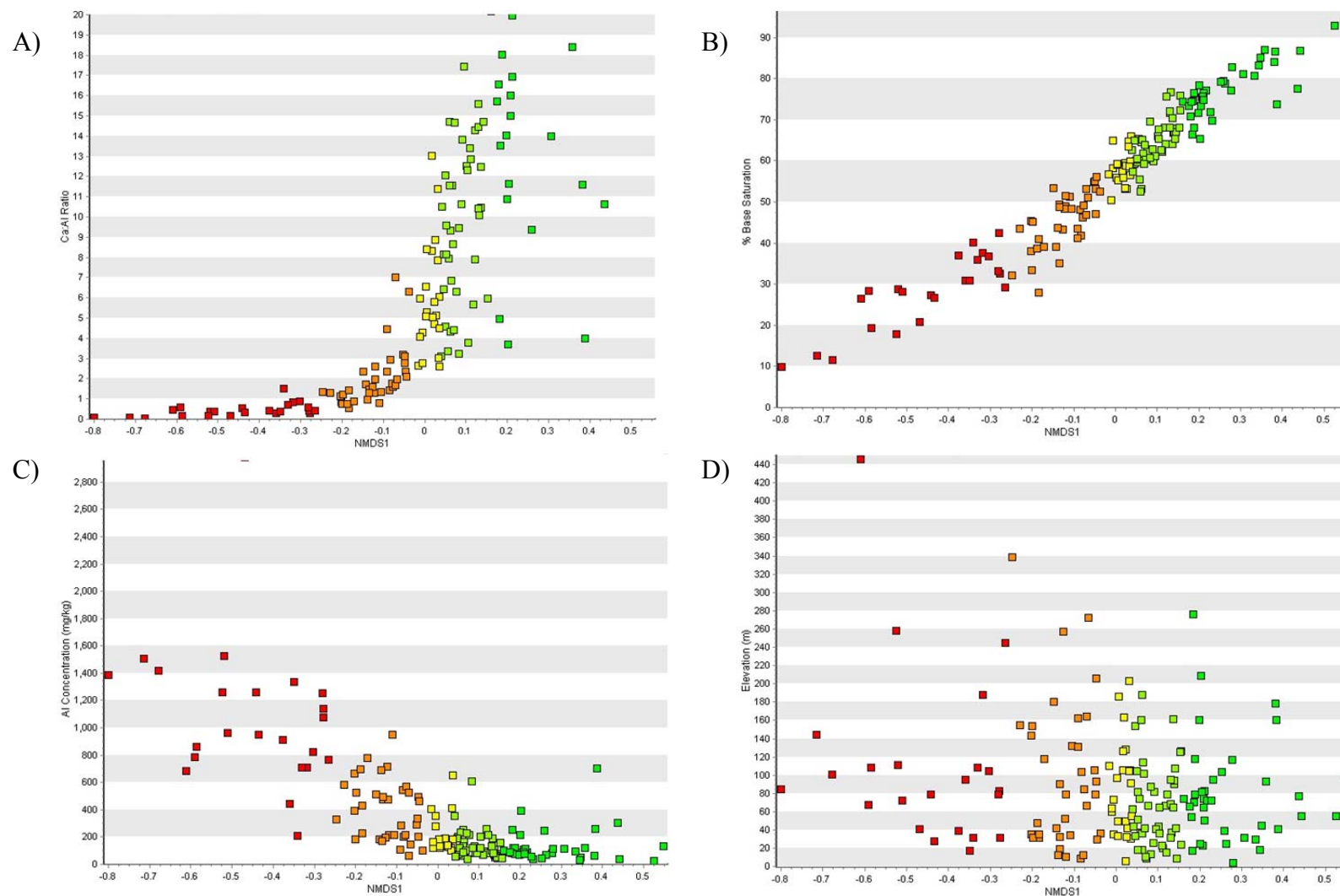


Figure H-2. Scatterplots of NMDS Axis 1 scores versus A) Ca:Al ratio, B) % Base Saturation, C) Al concentration (mg/kg), and D) Elevation. Point colors represent the bins used to assign relative acidification risk of plots in ACAD based on O horizon samples. Note that the Y axis in Figure A was cut off at 20 to view patterns in the lower range of this ratio.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

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