



# Ecological Integrity of Tree Regeneration in Acadia National Park Spruce-fir Forests

Natural Resource Report NPS/ACAD/NRR—2013/660



**ON THE COVER**

Late-successional forest on Beech Hill in Acadia National Park  
Photograph by: Evan Heck, NPS

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# **Ecological Integrity of Tree Regeneration in Acadia National Park Spruce-fir Forests**

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## Executive Summary

The Northeast Temperate Network (NETN) has been monitoring forest health using permanent plots in Acadia National Park (ACAD) since 2006. The overall goal of the NETN long-term forest monitoring program is to monitor status and trends in the structure, function, and composition of NETN forested ecosystems in order to inform management decisions affecting those systems. To facilitate reporting and interpretation of forest condition, we developed an Ecological Integrity Scorecard, which examines a suite of compositional, structural, and functional metrics. For each metric, assessment points were defined that distinguish acceptable or expected conditions from undesired conditions based on current scientific understanding of their natural or historic range of variation. Ecological integrity is interpreted using three categories for each metric: 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.

At the time of scorecard development, baseline data were insufficient to define undisturbed or impacted condition for the spruce-fir forests that dominate ACAD and that are classified as the Red Spruce – Fir Forest Group and the Northern Hardwood - Hemlock - White Pine Forest Group by the U.S. National Vegetation Classification (USNVC). The currently used regeneration metric focuses on impacts of deer browse on hardwood forest regeneration, and it has proven to be inadequate for ACAD. To bridge the information gap, we collected regeneration data in minimally-disturbed, late-successional stands of spruce-fir forest in coastal Maine to define reference condition (NPS Reference). Regeneration data collected by the Maine Natural Areas Program (MNAP) from late-successional stands in Ecological Reserves were also used to examine reference condition for spruce-fir forests (MNAP Reference). We use late-successional stands as our benchmark because pre-settlement spruce-fir forests in Maine were primarily composed of late-successional forest (Lorimer and White 2003). ACAD forests are relatively young (i.e., primarily composed of pole and mature stands) due to historic land uses such as logging and agriculture, and much of the eastern section of Mount Desert Island (MDI) was burned in 1947. Today, the forests in ACAD are protected from timber harvesting and are primarily under natural disturbance regimes. We therefore expect ACAD spruce-fir forests to move into later successional stages over time, and base many of our ecological integrity metrics on characteristics of a late-successional forest.

The two main goals for the regeneration metric in ACAD are to assess 1) whether regeneration abundance is adequate to replace the canopy, and 2) whether regeneration patterns in spruce-fir forests are consistent with those expected in late-successional forests. We calculated multiple common measures of regeneration (e.g., seedling distribution by size class, stem density, stocking index, and ratio of sapling density to small seedling density) to compare reference stands to the various successional forest stages (pole, mature, and late-successional) represented by the ACAD forest plots. We also included woodlands, which are forests with open canopies (less than 60% canopy cover) due to harsh growing conditions, in the initial analyses to see how regeneration patterns compared between forests with closed canopies and woodland stand types. We assessed each measure based on how easy it was to analyze and interpret, how well it incorporated expected differences in regeneration by successional stage, and the amount of variability in reference stands and ACAD forest plots.

We selected the stocking index to assess abundance of regeneration for all successional closed-canopy forest stages and woodlands. We chose a ratio of sapling density to small seedling density to evaluate patterns of regeneration in spruce-fir forests. Assessment points were based on confidence intervals around the mean for each measure. Due to issues of non-normality and high variance, confidence intervals were derived from bootstrapping (DiCiccio and Efron 1996) many datasets containing 10 reference plots per sample. This approach allowed us to account for the natural variability of regeneration in the reference stands, but requires sampling of at least 10 plots to rate this metric.

Assessment points were defined for the overall regeneration metric to distinguish among plots that follow regeneration patterns and abundance expected in late-successional spruce-fir forests (Good), plots that have adequate regeneration but follow patterns that differ from late-successional spruce-fir forests (Caution), and plots lacking in regeneration (Significant Concern).

The assessment points that define ecological integrity of regeneration in ACAD are as follows:

**Good:** stocking index  $\geq 20$ , and sapling:small seedling density ratio  $\leq 0.11$ .

**Caution:** stocking index  $\geq 20$ , and sapling:small seedling density ratio  $> 0.11$ .

**Significant Concern:** stocking index  $< 20$ .

This metric requires a minimum of 10 plots to rate regeneration in ACAD, and should not be applied to individual plots. Because the stocking index did not vary significantly among NPS reference stands, successional closed-canopy forest stages, and woodlands, the stocking index can be applied to both closed-canopy forests and woodlands. The sapling:small seedling density ratio can only be applied to forest plots in the Red Spruce – Fir Forest Group or the Northern Hardwood – Hemlock – White Pine Forest Group (e.g., forested swamps and woodlands are excluded), as these are the habitats expected to follow the stages of spruce-fir stand development that were described by Davis (1961) and further characterized by the NPS and MNAP reference stands.

Applying the new metric to ACAD forest plots, we find sufficient abundance of regeneration across all subunits, stand types (woodlands and three closed-canopy forest successional stages), but patterns of regeneration in spruce-fir forests reflect those of earlier stages of succession (i.e., high abundance of saplings). Based on this new metric, ACAD spruce-fir forests were rated Good for abundance and Caution for regeneration patterns, with an overall rating of Caution. As spruce-fir forests mature and develop into more uneven-aged stands, we expect the sapling:seedling density ratio in ACAD to approach the ratio observed in NPS reference stands and eventually move into the Good category.



## **Acknowledgments**

We are grateful for the efforts of numerous individuals who have contributed to the overall success of the forest health monitoring program and have made this report possible. We are indebted to Geri Tierney for developing the forest Ecological Integrity Scorecard and the NETN long-term forest monitoring protocol, and for her continued input. We would like to thank Andrew Cutko from Maine Natural Areas Program for providing regeneration data from sites sampled in Maine Ecological Reserves, and for providing valuable feedback on the manuscript. We are also grateful for Holly Gorton, Bob Paul, and Yi-Tak (Megan) Lai of St. Mary's College for their help with Evan's senior thesis, from which this report was derived. We thank Camilla Seirup for her help sampling the Pemetic Mountain site. Finally, thanks to John Karish, John Paul Schmit, and Jill Weber for reviewing the manuscript.



## Introduction

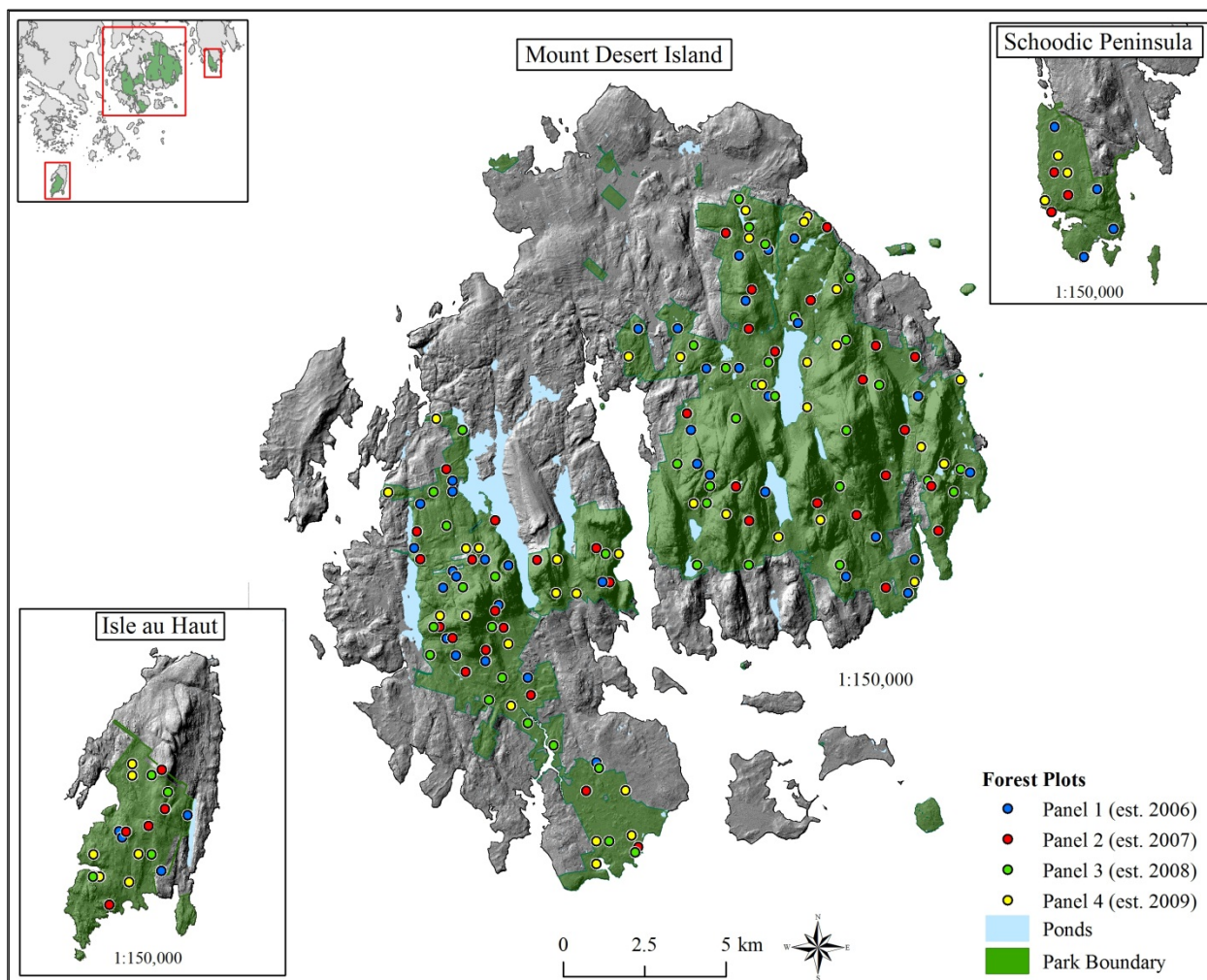
Since 2006, the Northeast Temperate Network (NETN) has been monitoring forest vegetation in an extensive network of randomly located permanent plots in 10 national parks in the northeastern U.S. (Tierney et al. 2012). The overall goal of the NETN long-term forest monitoring program is to monitor status and trends in the structure, function, and composition of NETN forested ecosystems in order to inform management decisions affecting those systems (Tierney et al. 2012).

In Acadia National Park (ACAD) 176 forest plots have been established, a quarter of which are sampled each year (Figure 1). Based on the park vegetation map, forest plots in ACAD represent six U.S. National Vegetation Classification (USNVC) Groups, with the majority of plots located in the Red Spruce – Fir Forest Group (Lubinski et al. 2003; Table 1). The Red Spruce – Fir Forest Group is a transition zone between northern hardwood forest to the south and boreal forest to the north, and is comprised of species found in both northern hardwood and boreal forests (NatureServe 2012). The Red Spruce – Fir Forest is composed of at least 50% conifer cover in the canopy, with red spruce (*Picea rubens*) as the dominant tree species. Other diagnostic species include balsam fir (*Abies balsamea*), yellow birch (*Betula alleghaniensis*), paper birch (*Betula papyrifera*), eastern white pine (*Pinus strobus*), and northern white cedar (*Thuja occidentalis*).

The less common forest types include mixed woodlands (woodlands have less than 60% canopy closure) in three USNVC groups (Great Lakes Pine – Oak Forest and Woodland, North – Central Appalachian & Laurentian Rocky Outcrop, and Pitch Pine Barrens), and a mixed conifer – hardwood forest (the USNVC Northern Hardwood – Hemlock – White Pine Forest Group) all of which also contain varying amounts of red spruce (NatureServe 2012). Collectively, the Red Spruce – Fir Forest Group and the Northern Hardwood - Hemlock - White Pine Forest Group are referred to as Acadian spruce-fir forests (Ricketts 1999, Mosseler et al. 2003), or simply as spruce-fir forests. These forests are found in the region containing ACAD and extending into higher elevations of Vermont, New Hampshire, and the Adirondacks of New York, along with the Canadian provinces of New Brunswick, Nova Scotia, and southern Quebec.

To facilitate reporting and interpretation of forest condition in NETN parks, we developed an Ecological Integrity Scorecard, which examines a suite of compositional, structural, and functional metrics (Tierney et al. 2009). For each metric, assessment points were defined that distinguish acceptable or expected conditions from undesired conditions based on current scientific understanding of their natural or historic range of variation (Parrish et al. 2003, Bennetts et al. 2007). Ecological integrity is interpreted using three categories for each metric: 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 (Tierney et al. 2009).

In some cases, existing datasets and/or scientific literature are not available that characterize natural variability or historic condition sufficient to define assessment points for all of the forest types in NETN. For example, very little is known or has been documented on expected levels of coarse woody debris in woodland habitats in ACAD. Therefore plots located in woodlands are not included in coarse woody debris metric calculations and ratings for ACAD.



**Figure 1.** Map of forest plots in Acadia National Park overlaid on 2010 LiDAR bare earth imagery.

**Table 1.** Forest plots by park subunit in each U.S. National Vegetation Classification (USNVC) Group. IAH is Isle au Haut. MDI-E is eastern section of Mount Desert Island. MDI-W is the western section of MDI. Schoodic is the Schoodic Peninsula.

USNVC Group	IAH	MDI-E	MDI-W	Schoodic	<b>Total</b>
Great Lakes Pine - Oak Forest and Woodland <sup>1</sup>	---	---	---	1	<b>1</b>
North - Central Appalachian & Laurentian Rocky Outcrop	---	14	6	2	<b>22</b>
Northern and Central Conifer & Hardwood Acidic Swamp	---	---	5	---	<b>5</b>
Northern Hardwood - Hemlock - White Pine Forest	---	23	1	---	<b>24</b>
Pitch Pine Barrens <sup>1</sup>	4	3	---	---	<b>7</b>
Red Spruce - Fir Forest	15	42	53	7	<b>117</b>
<b>Total</b>	<b>19</b>	<b>82</b>	<b>65</b>	<b>10</b>	<b>176</b>

<sup>1</sup>Jack pine woodlands and pitch pine woodlands were assigned to a different Group than mixed conifer and hardwood woodlands in the latest USNVC (Federal Geographic Data Committee 2008).

A more significant gap in the Ecological Integrity Scorecard is the tree regeneration metric for spruce-fir forests in ACAD. The current metric uses a seedling ratio developed by Sweetapple and Nugent (2004), and a stocking index developed by McWilliams et al. (2002) to rate ecological integrity of tree regeneration. The seedling ratio considers preferential browse of deer on particular seedling species and size classes (Cornett et al. 2000). It calculates the ratio of browse-preferred species richness in highly browsed (30-100 cm) versus less browsed (15-30 cm) size classes (Sweetapple and Nugent 2004).

The stocking index developed by McWilliams et al. (2002) quantifies whether current seedling levels are sufficient to restock a mid-Atlantic hardwood forest stand. This index sums points for native tree seedlings by height 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 12.5 cm DBH. We revised the stocking index size range in the highest category to > 150 cm tall and less than 10 cm DBH to be consistent with our protocol (stems  $\geq 10$  cm are considered trees).

A stocking index less than 25 is considered inadequate for mid-Atlantic hardwood stands with low deer densities and an index less than 100 is inadequate for stands with high deer densities. While the current regeneration metric provides a useful baseline for most NETN parks, both the seedling ratio and the stocking index have limited application in ACAD. The seedling ratio requires a relatively diverse regeneration layer, and assumes lack of browse-preferred species or size class is the result of deer browse. In ACAD, the regeneration layer is naturally low in species diversity, and site and climatic conditions, rather than deer browse, are the primary reasons. The stocking index is more useful as a metric to track change over time, but the stocking targets (i.e., 25 and 100) are based on experimental data collected in oak-hickory forests in Pennsylvania, and it is unknown whether these numbers are appropriate for the spruce-fir forests that dominate ACAD.

Part of the difficulty behind developing a regeneration metric appropriate for ACAD relates to where and why regeneration research has been conducted in the eastern US. The majority of relevant research has taken place in northern hardwood forests (Cornett et al. 2000, Rooney 2001, Rooney and Waller 2003) and mid-Atlantic oak/ hickory forests (McWilliams et al. 2002, Liang and Seagle 2002, Horsley et al. 2003), where impacts from deer overabundance are the major concern. While deer are a major stressor in eastern U.S. forests, current levels in ACAD appear to be within the carrying capacity of the park (Saeki 1991, Miller et al. 2012), and other stressors, such as acid deposition, climate change, invasive plants, and forest pests are of equal or greater concern in ACAD forests.

Complex patterns of regeneration in spruce-fir forests, which vary by successional stage and disturbance history (Davis 1961, Mosseler et al. 2003), add to the difficulty of developing the regeneration metric for ACAD. Davis (1961) describes seven stages of spruce-fir forest succession starting after a stand-replacing disturbance (Table 2). In the initial stage, paper birch regeneration is abundant. This stage is followed by slow replacement by spruce (primarily red spruce) and balsam fir advanced regeneration as paper birch die off (stages 2 & 3). As spruce and balsam fir seedlings are released by paper birch die-back, they form a dense conifer thicket and undergo a stem exclusion phase. It is at this stage (stage 4) where seedling abundance is expected to be low due to the crowding of conifer saplings and small trees. As forests mature (stage 5),

advanced regeneration of spruce and balsam fir (the climax species) begins to develop again and increases in density and complexity over time (states 6 and 7).

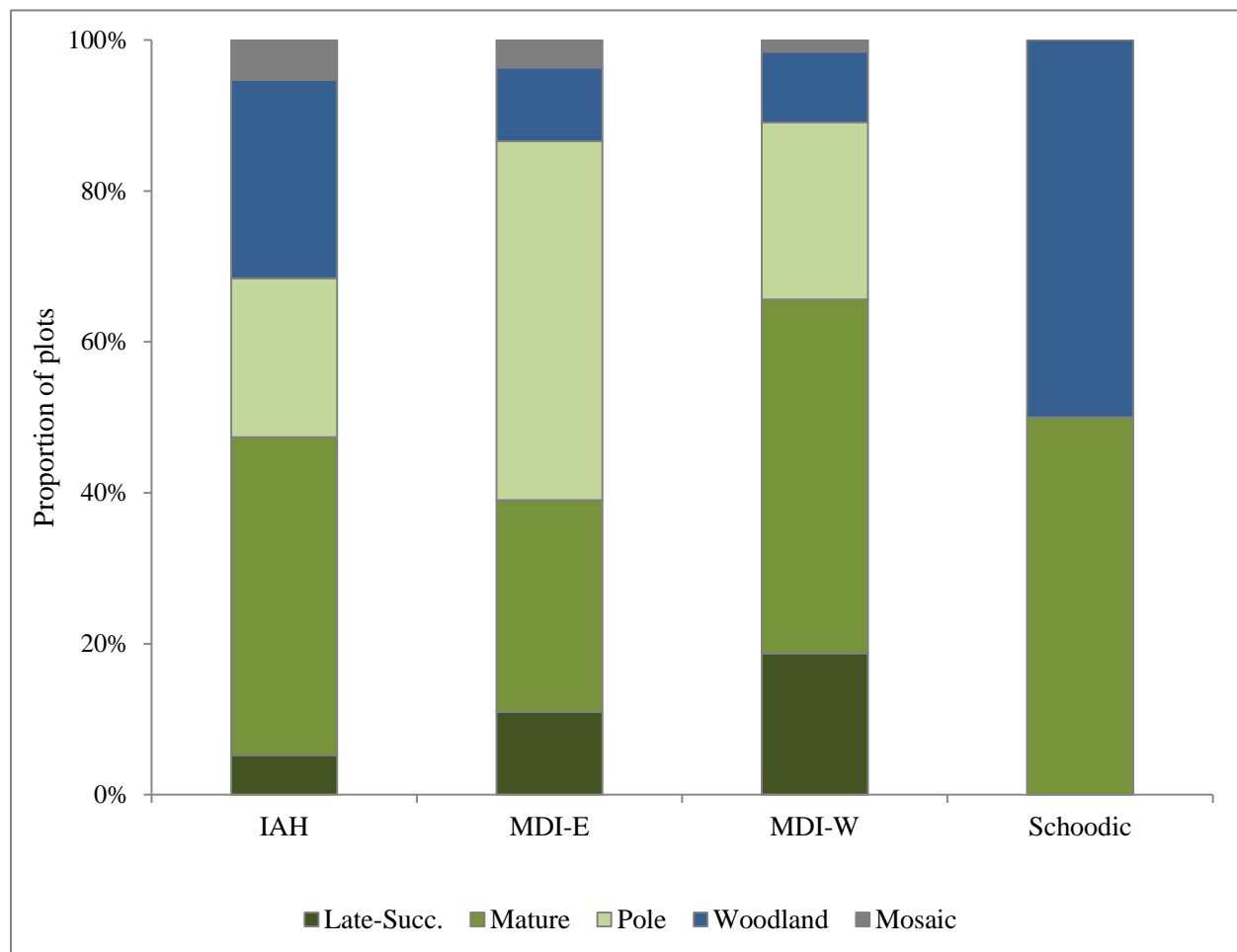
The stages described by Davis (1961) are similar to the assessment points we use to determine pole, mature, and late-successional stages for the structural stage distribution ecological integrity metric, with the exception that Davis stages 3 and 4 are lumped into our pole category (Miller et al. 2010). Based on the structural stage metric, the majority of the forest plots in ACAD are in the pole and mature (Davis stage 5) stages, with a few late-successional (Davis stage 6) plots on Mount Desert Island (MDI; Figure 2). The only known example of old growth spruce-fir forest (Davis stage 7) in ACAD consists of a small stand on Bernard Mtn., but due to the small area of the stand and our random sample design, no forest plots were established in this stand. In the absence of major disturbance, forests are expected to advance into later stages of succession over time. Forested swamps are not included in Davis' successional continuum. Woodlands, which have less than 60% canopy cover, are common to each subunit and occur in areas with thin soils and exposed bedrock. Woodlands represent a relatively stable state due to harsh growing conditions and also do not fall along Davis' successional continuum. We are nevertheless interested in tracking regeneration abundance in woodlands over time, as we expect woodlands to be especially sensitive to stressors due to already harsh growing conditions.

The two main goals for the regeneration metric in ACAD are to assess 1) whether regeneration abundance is adequate to replace the canopy in the event of a disturbance, and 2) whether regeneration patterns in spruce-fir forests are consistent with those expected in late-successional spruce-fir forests. The overall metric must be broad and not focused on one stressor (e.g., deer browse), and be relatively easy to analyze and interpret. A useful metric for regeneration abundance should be easy to calculate, and preference will be for a metric with low spatial variability. An abundance metric should also be applicable across woodlands and successional closed-canopy forest stages, such that all categories are able to receive a Good, Caution, or Significant Concern rating for regeneration abundance. Conversely a metric for assessing regeneration patterns should be distinct for late-successional spruce-fir stands. This will allow us to follow regeneration patterns in younger spruce-fir forests through time and determine if they are following expected trajectories toward late-successional forest. To assess regeneration in ACAD, we also need a good estimate of regeneration patterns and abundance for spruce-fir forests from undisturbed, late-successional stands.

We base many of our ecological integrity metrics in ACAD on characteristics of a late-successional forest because presettlement spruce-fir forests in Maine were primarily composed of late-successional forest (Lorimer and White 2003), and lack of this habitat is an ecological integrity issue. As with most of the northeastern US, forests in ACAD are relatively young (i.e., primarily composed pole and mature stands), due to historic land uses such as logging and agriculture. In addition much of the eastern section of Mount Desert Island (MDI) was burned in 1947, and these forests are composed primarily of early successional hardwoods. Considering the distribution of ACAD forests in younger successional stages, we do not expect to find late-successional patterns of regeneration in the majority of forest plots. However, forests in ACAD are protected from timber harvesting and are primarily under natural disturbance regimes. We therefore expect ACAD spruce-fir forests to move into later successional stages over time, and are interested in tracking whether regeneration is following expected trajectories.

**Table 2.** Stand development stages of spruce-fir forests adapted from Davis 1961.

Stage	Description
1	High proportion of paper birch following a major disturbance
2	Spruce regeneration below paper birch
3	Pole: Spruce gradually replaces birch with rapid spurts of spruce growth as birches die off
4	Pole: Spruce crowding/thicket, slowing of growth, coupled with dying suppressed saplings
5	Mature: Beginnings of moss ground cover, greater tree height (35+ feet), and spruce seedlings (mean stand age: 82 years)
6	Late-succession: Continued tree growth and repeated establishment of new seedlings, openings in canopy caused by death or blow-down of large trees. Development of spruce and fir saplings (mean stand age: 112 years)
7	Old Growth: Subsequent deaths, blow-downs, and replacement by young trees, increase in quantity of small fire, increase in overall diversification of stand age and size structure (mean stand age: 163 years)



**Figure 2.** Proportion of plots by structural stage class (for closed-canopy forest plots) or stand type (woodland or mosaic plots). Mosaic plots are composed of two or more distinct structural classes, each covering at least 25% of the plot. IAH is Isle au Haut. MDI-E is eastern section of Mount Desert Island. MDI-W is the western section of MDI. Schoodic is the Schoodic Peninsula.

Unfortunately, regeneration data from undisturbed spruce-fir forests are not available. To bridge this gap, we searched for the best (i.e., least impacted) examples of late-successional and old growth stands of spruce-fir forest in coastal Maine, and collected new regeneration data. We only used sites that were identified by Davis 1961 or the Maine Natural Areas Program (MNAP) as late-successional or old growth (MNAP, A. Cutko, Ecologist, pers. comm., 27 October 2011). We also acquired regeneration data collected by MNAP in late-successional spruce-fir stands located in Maine Ecological Reserves (MNAP, A. Cutko, Ecologist, pers. comm., 27 October 2011). These data were used as independent comparisons with data collected in ACAD forest plots, and helped guide the development of our metric calculations and assessment points.



# Methods

## Site Selection

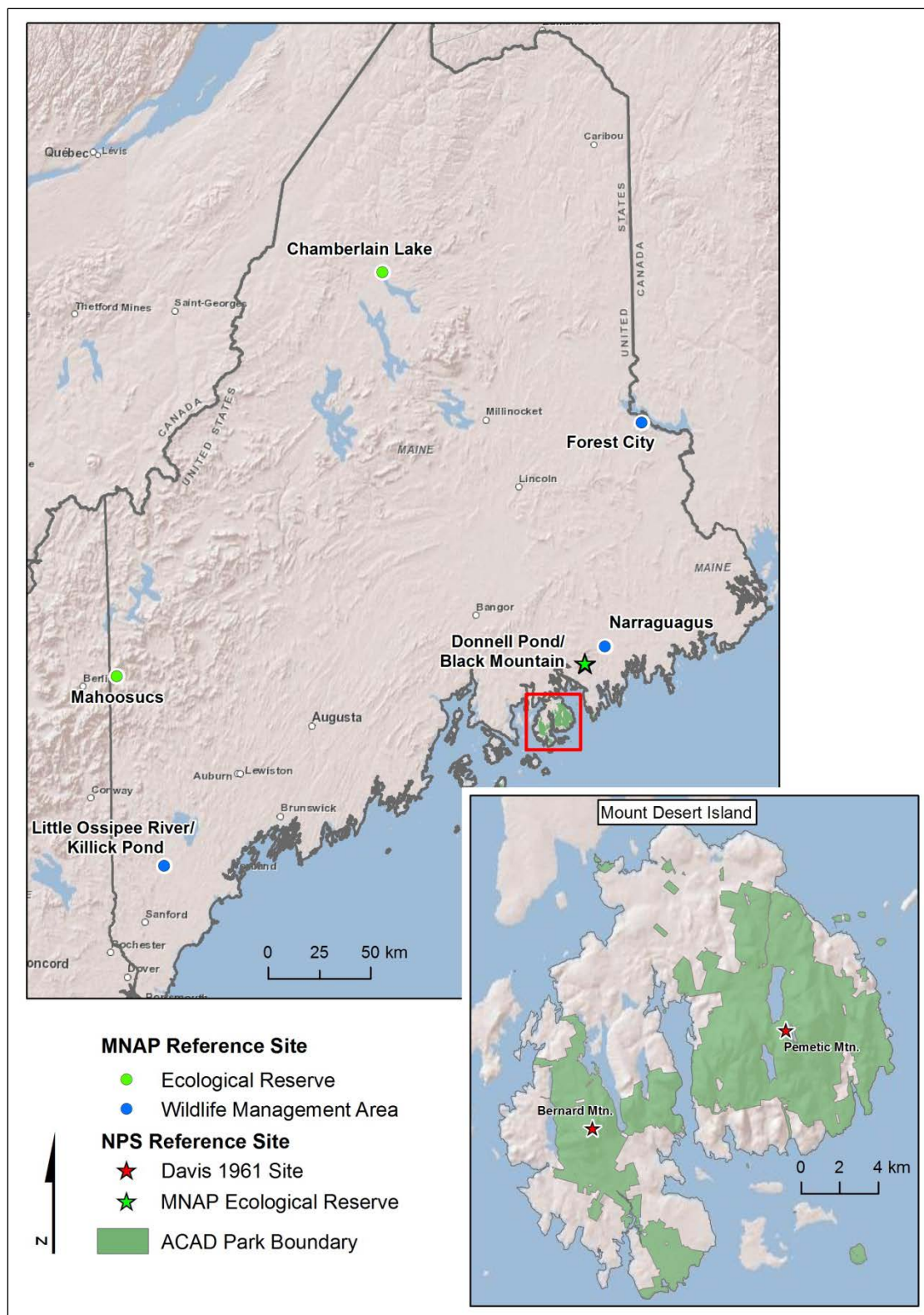
### **ACAD forest plots**

Permanent forest plots were randomly located in ACAD using generalized random tessellation stratified sampling with a 200 m<sup>2</sup> grid (GRTS; Stevens and Olsen 2004). GRTS points that were primarily forested (i.e., had at least 25% cover of tree species) were established as forest plots, as long as they were  $\geq 15$  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 are located across the three major units of ACAD: Mount Desert Island (MDI), Isle au Haut (IAH), and Schoodic Peninsula (Schoodic).

### **NPS reference sites**

The spruce-fir forest type was the focus of this research because spruce-fir forests are the dominant forest type in ACAD. Spruce-fir stands to be used as reference sites were selected based on information in the scientific literature and best professional judgment that they were minimally disturbed (Davis 1961, Davis 1966, MNAP, A. Cutko, Ecologist, pers. comm., 27 October 2011). We sampled two sites in ACAD (on Bernard and Pemetic mountains), and one site on Black Mountain in the Donnell Pond Ecological Preserve that is also monitored by MNAP (Figure 3). Both of the sites in ACAD were sites that were identified and sampled by Davis (1961). The site on Bernard Mountain is the only known old growth stand in ACAD (Davis 1961, Maine Critical Areas Program 1983), and is located on a steep southeast-facing slope. The forest stand on Pemetic Mountain represents a late-successional forest stage (Davis 1961). The stand on Black Mountain is located in a saddle between the two peaks that make up Black Mountain, and is considered late-successional and potentially old growth (MNAP, A. Cutko, Ecologist, pers. comm., 27 October 2011). While MNAP has monitoring plots in the Donnell Pond Ecological Preserve, they have not established plots in this specific stand. These stands will represent reference condition for spruce-fir forests in ACAD because this should be the dominant structural stage in the park.

To determine sampling locations, we first delineated the approximate boundary of each late-successional or old growth stand in a Geographic Information System using all available information, including hand-drawn maps and descriptions from Davis 1961 and descriptions provided by the MNAP (Maine Critical Areas Program 1983, MNAP 2009). After each stand was delineated, we added a 20-m buffer to account for mapping uncertainty, and used this as the stand boundary. Plots were randomly located within each stand boundary using GRTS sampling, and were generated using the *spsurvey* package in R (Kincaid and Olsen 2011, R Core Team 2012). Only plots that met the following criteria for late-successional to old growth spruce-fir forest were sampled:  $\geq 60\%$  canopy cover,  $\geq 40\%$  moss understory, and at least one tree  $\geq 40$  cm diameter at breast height (DBH) within a 9-meter radius of plot center (criteria adapted from Davis [1961,1966], and Whitman and Hagan [2007]). At Black Mountain and Pemetic Mountain, the stand boundary that we delineated to generate the GRTS sample only covered about half of the late-successional stand we observed in the field. The original GRTS sample did not provide a sufficient sample size, which we set as five plots per stand. Rather than leaving the site and generating a new GRTS sample, we sampled the first GRTS plots that met our sampling criteria, and used these plots as random starting points to identify additional plots 30 m away in the four



**Figure 3.** Map displaying sampling locations of late-successional forests overlaid on a World Shaded Relief basemap (ESRI 2009). NPS reference sites were sampled by NETN staff. MNAP reference sites were sampled by MNAP staff.

cardinal directions of each useable GRTS plot. We continued establishing plots 30 m from sampleable plots in the four cardinal directions until we were outside of our target habitat, or within 30 m of another plot. A total of 21 reference plots were sampled, with seven on Bernard Mountain, nine on Black Mountain, and five on Pemetic Mountain.

### ***MNAP reference data***

MNAP monitors forest health in Ecological Reserves and Wildlife Management Areas using a protocol similar to the U.S. Forest Service Forest Inventory and Analysis program. Permanent forest plots have been established throughout the state (MNAP 2003), and MNAP provided regeneration data from twenty-one of these forest plots for our analyses. Plots were chosen based on best professional judgment that they were late-successional forest (e.g., presence of older and large trees, and high basal area), and showed no signs of cutting in the last 20 years (MNAP, A. Cutko, Ecologist, pers. comm., 27 October 2011). After removing four plots in non-target habitats (e.g., hemlock stands and a forested swamp), we ended up with seventeen late-successional spruce-fir forest plots that spanned two Ecological Reserves and three Wildlife Management Areas.

## **Sampling Methods**

### ***ACAD forest plots***

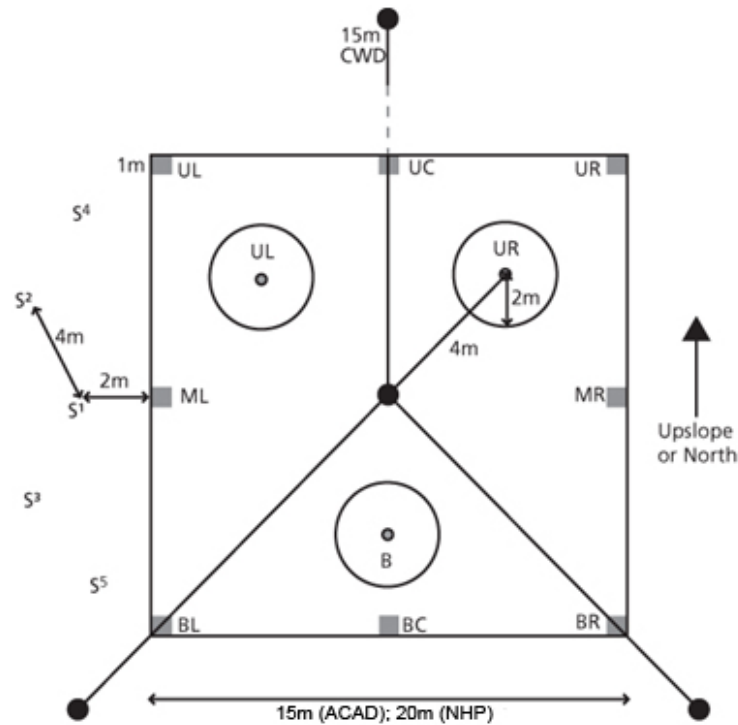
The NETN long-term forest monitoring protocol uses 15 x 15 m square plots that are oriented upslope, or to true north if the plot is flat (Tierney et al. 2012). In each plot, three 2-m radius microplots are located 4 m from plot center at 45, 180, and 315 degrees relative to the plot orientation (Figure 4). In each microplot, we tally the number of tree seedlings by species and height class, measure the DBH and species of saplings, and estimate percent cover of shrub species over 30 cm tall. Seedlings are defined as living, juvenile trees at least 15 cm in height and less than 1 cm DBH, and are tallied in the following height classes: 15-30 cm, 30-100 cm, 1-1.5 m, > 1.5 m and less than 1 cm DBH. Saplings include trees between 1 cm and 10 cm DBH.

### ***NPS reference sites***

Plots were established and the three 2-m radius microplots were sampled according to the NETN long-term forest monitoring protocol (Tierney et al. 2012), with the exception that plot level assessments were conducted in 9-m radius circular plots rather than the entire plot to improve sampling efficiency. These plot level assessments include presence/ absence of microtopography, percent crown closure, percent cover of bare soil, exposed rock, non-vascular vegetation, and lichens and percent cover of vascular vegetation at three heights: < 0.5 m, 0.5-2 m, and 2-5 m. We also estimated the Davis (1961) successional stage of the plot.

### ***MNAP reference data***

MNAP forest monitoring procedures are similar to the U.S. Forest Service Forest Inventory and Analysis program's phase 3 procedures (MNAP 2003). Regeneration data were collected in one 6.8-m radius (13.5 m<sup>2</sup>) plot. Conifer seedlings over 15.24 cm (6 inches) tall and less than 2.54 cm (1 in) DBH were tallied by species. Hardwood seedlings over 30.48 cm (1 ft) tall and less than 2.54 cm (1 in) DBH were tallied by species. Seedlings were not tallied by height class. For more details on sampling methods and plot design, refer to MNAP 2003.



**Figure 4.** Plot layout showing square tree plot with three nested 2-m radius regeneration microplots, eight 1 m<sup>2</sup> vegetation quadrats, and three 15 m coarse woody debris (CWD) transects. S<sup>x</sup> is location of soil sample.

### Data Analysis

Before combining the NPS reference site data to compare with ACAD forest plot data, we tested for site differences in R 2.15.2 using Analysis of Similarities (ANOSIM) in the *vegan* package (Oksanen et al. 2012, R Core Team 2012). Prior to running ANOSIM, regeneration variables were standardized to remove the influence of different scales and units using  $(x_1 - \min_x) / (\max_x - \min_x)$ . We used a Bray-Curtis dissimilarity matrix, 999 permutations, and site was the grouping variable for the test. ANOSIM results were not significant ( $p = 0.15$ ), indicating that regeneration patterns among the three NPS reference sites were not distinct, and it was appropriate to combine these sites for comparisons with regeneration in ACAD forest plots.

To examine patterns in ACAD forest plot and NPS reference plot data, we calculated mean and standard errors for woodland plots and plots in three closed-canopy forest successional stages for the following metrics: overall seedling density, seedling density by height class, sapling density and stocking index. ACAD forest plots containing a mosaic of two or more distinct structural classes or containing forested swamps were excluded from the metrics. We used Analysis of Variance (ANOVA) to determine differences in metrics by plot type, and tested for equal variance between groups using the modified Levene's tests in the *car* package in R 2.15.2 (Fox et al. 2012; R Core Team 2012). When modified Levene's tests were significant, we performed weighted least squares ANOVAs using the *bstats* package (Wang 2012) in R 2.15.2 to account for the unequal variance. Tukey pairwise comparisons were performed using the *multcomp* package to test for significant differences between groups (Hothorn et al. 2008). In most cases,

data were not normally distributed, and while ANOVA is robust to violations of normality, significant results should be treated as suggestive rather than definitive. We also ran these analyses using generalized linear models with a negative binomial distribution. Results were very similar to the ANOVA analyses. For simplicity and ease of interpretation, we will only interpret the ANOVA results in this report.

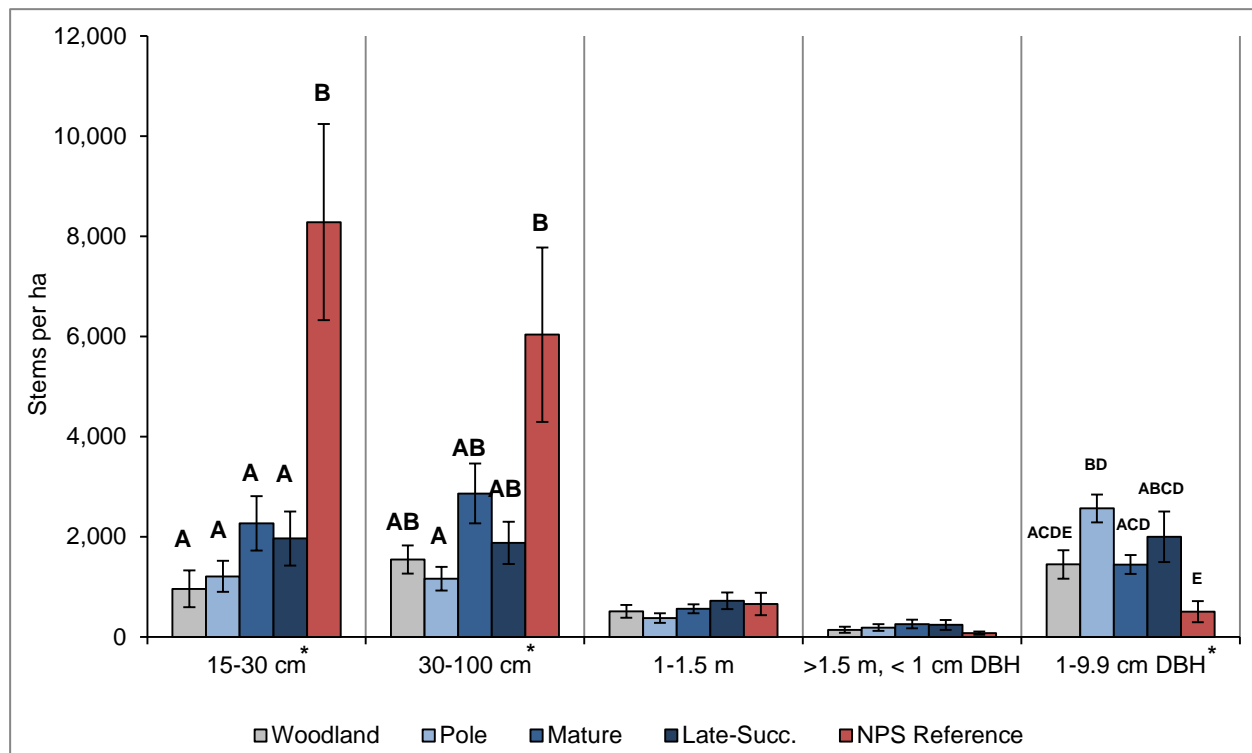
To make comparisons among ACAD forest plot, NPS reference, and MNAP reference data, the ACAD forest plot and NPS reference seedling and sapling data were adjusted to match size classes used by MNAP. Seedlings include conifer seedlings greater than 15 cm tall, and less than 2.54 cm (1 inch) DBH, and hardwood seedlings greater than 30 cm and less than 2.54 cm (1 inch) DBH. Saplings include stems that are  $\geq 2.54$  cm (1 inch) DBH and less than 10 cm DBH. To correct for differences in microplot size, seedling and sapling densities were expressed as number of stems per hectare. Because MNAP seedling and sapling definitions differ from those used by McWilliams et al. 2002, the stocking index metric was not calculated.



## Results

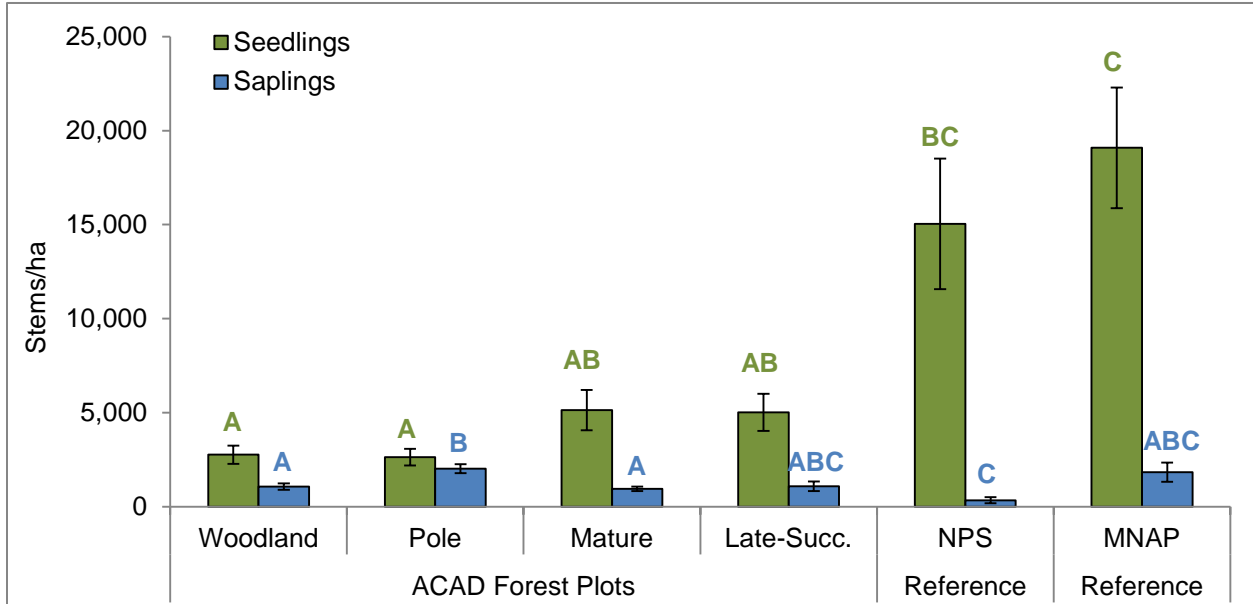
Seedling density varied considerably by size class across woodlands and the three closed-canopy forest successional stages, and density of small seedlings (15-100 cm) was inversely related to sapling density (Figure 5). In NPS reference stands, density of smaller seedlings was high and density of saplings was low. Conversely, pole and late-successional forest stages of ACAD plots had relatively high density of saplings and low density of smaller seedlings. Mature stands had moderate levels of both small seedlings and saplings. These patterns generally follow expectations of spruce-fir regeneration by successional stage, as seedling density was lower and sapling density relatively high in the pole stage. The distribution of seedling density by size class in woodlands was not distinct from successional stages in ACAD closed-canopy forest plots.

Patterns in the overall adjusted seedling density data were less complex, and followed an increasing trend with successional stage. Seedling density was highest in NPS and MNAP reference stands (Figure 6). ACAD closed-canopy forest plots in mature and late-succession stages had intermediate seedling densities, and the pole stage had the lowest seedling density. Variability in seedling density also tended to increase with successional stage. Woodland seedling density was similar to the pole stage. Patterns were less clear with saplings.

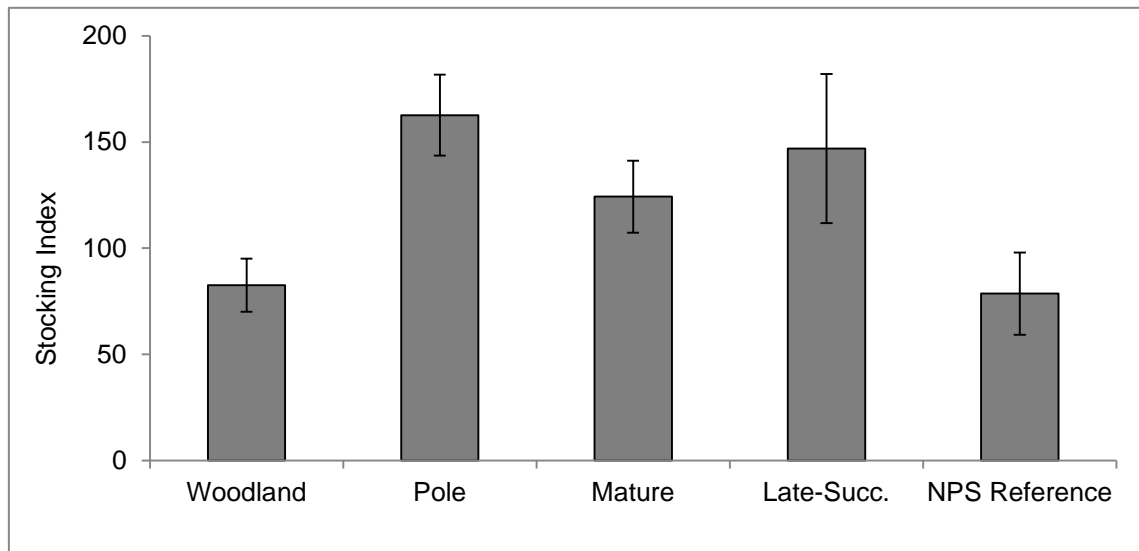


**Figure 5.** Seedling and sapling (1.0-9.9 cm DBH) densities by size class and woodland and closed-canopy forest stage. Stem densities were tested in separate ANOVAs by size class using Tukey's test for within size class pairwise comparisons. An (\*) indicates the ANOVA used weighted least squares. Different letters represent significant differences in mean stem density between groups within each size class. NPS Reference data were collected in late-successional stands; remaining categories contain ACAD forest plot data. Data were not normally distributed, and while ANOVA is robust to violations of normality, significance should be treated as suggestive rather than definitive. Error bars denote 1 standard error around the mean.

Results from stocking index analyses indicated that woodland and closed-canopy forest stages are similarly stocked with regeneration (Figure 7). Based on the modified Levene test, the stocking index had consistent variance between groups ( $p = 0.10$ ). The overall ANOVA test for differences in mean stocking index by group was significant ( $p = 0.04$ ), but Tukey's pairwise comparisons suggested only marginal differences between pole and NPS reference stands ( $p = 0.09$ ), and woodland and pole stands ( $p = 0.09$ ).



**Figure 6.** Adjusted seedling and sapling stem densities by woodland and closed-canopy forest stage. Seedling and sapling data were tested in separate ANOVAs using weighted least squares and Tukey's pairwise comparisons. Different letters represent significant differences in mean stem density between groups. Data were not normally distributed, and significance should be treated as suggestive rather than definitive. Error bars denote 1 standard error around the mean.



**Figure 7.** Average stocking index by woodland and closed-canopy forest stage. Stocking index data were tested for differences between groups using ANOVA. NPS Reference data were collected in late-successional stands; remaining categories contain ACAD forest plot data. No significant differences were detected between groups. Error bars denote 1 standard error around the mean.



## Discussion

Results from our analyses indicate that not all measures will yield a useful ecological integrity metric for regeneration in ACAD. For example, total seedling density is extremely variable in NPS and MNAP reference stands, and is less than ideal because individuals of small seedlings have equal weight as individuals of larger seedlings (> 1 m tall) and saplings. Seedlings have smaller space and resource requirements, and can be extremely abundant in small size classes. Whereas saplings, which occur at lower densities due to greater space and resource requirements, have lower mortality rates than small seedlings (Marquis and Bjorkbom 1982, McWilliams et al. 1995). The stocking index is a better representation of regeneration abundance in ACAD because it gives a higher weight to larger seedlings and saplings (McWilliams et al. 1995), and because it is similar across woodlands and closed-canopy forest successional stages. The stocking index is also easy to analyze and interpret, and is being widely used to assess forest regeneration in the eastern U.S. (NPS 2009, Perles et al. 2010, NPS 2011, Comiskey and Wakamiya 2012), including as part of our regeneration metric for the southern parks in NETN. Therefore the stocking index will be used to assess abundance of regeneration, and will be applied to woodlands and all successional stages of upland closed-canopy forests (i.e., excluding wetland forests).

Seedling density by size class is another highly variable measure that is difficult to analyze and interpret, and is not suitable for the regeneration metric. However, our results suggested an inverse relationship between small seedling and sapling abundance that differed between successional stages, and this should be incorporated into the regeneration metric. We will use the ratio of sapling density:small seedling (15-100 cm) density to account for this pattern in the regeneration metric for ACAD, and the expectation will be that as spruce-fir forest stands move into later stages of succession, the ratio will decrease (i.e., there will be an increase in small seedling density relative to sapling density). The sapling:small seedling density ratio can only be applied to upland closed-canopy forests, as these are the habitats expected to follow the stages of spruce-fir stand development that were described by Davis (1961) and further characterized by the NPS and MNAP reference stands.

The final stage of metric development is to define assessment points that can distinguish Good, Caution, and Significant Concern ecological integrity, and to use these assessment points to rate ACAD forest plots. We defined assessment points based on confidence intervals around the mean values observed in reference stands. Because NPS reference stand data had significant issues with normality and high spatial variability, typical methods for calculating confidence intervals were not appropriate. To deal with these issues, we generated many bootstrapped datasets of 10 reference plots per dataset using the sample function in R (R Core Team 2012).

Bootstrapping is a technique that randomly resamples the original data with replacement. After many iterations, the results of each bootstrap are combined to develop an approximation of the sampling distribution for that dataset (DiCiccio and Efron 1996). The approximate sampling distribution can then be used to derive standard error and confidence intervals. We ran the bootstrap simulations separately for the stocking index and sapling:small seedling density ratio. For the stocking index, each bootstrap simulation randomly selected 10 NPS reference plots and calculated the mean stocking index of the 10 plots. For the sapling:small seedling density ratio, each bootstrap simulation randomly selected 10 NPS reference plots and summed the saplings

and seedlings on those 10 plots to calculate a pooled sapling:small seedling density ratio. The sapling:small seedling ratio data are pooled to avoid issues with undefined ratios (i.e., when there are no seedlings on a plot), and to incorporate the inherent spatial variability of regeneration in reference stands. We ran 9,999 simulations to generate approximate sampling distributions for each metric.

The resulting bootstrapped datasets were used to estimate confidence intervals on a ten-plot sample and calculate standard error for the mean stocking index and sapling:small seedling density ratio. Using the percentile method, we generated one-tailed 99% confidence intervals with the *boot.ci* function in the *boot* package (Canty and Ripley 2012). This approach allowed us to account for the natural variability of regeneration in the reference stands, and requires at least 10 plots to rate this metric. We used the sample size of 10 because there are 10 forest plots on Schoodic Peninsula, and this is the minimum number of plots we expect to evaluate for regeneration in ACAD.

The objective of this metric is to distinguish among plots that follow regeneration patterns (i.e., low sapling:small seedling ratio) and abundance expected in late-successional spruce-fir forests (Good), plots that have adequate regeneration but follow patterns that differ from late-successional spruce-fir forests (Caution), and plots lacking in regeneration (Significant Concern). The assessment points are based on an upper one-tailed 99% confidence interval derived from bootstrapping the stocking index data from NPS reference plots, and a lower one-tailed 99% confidence interval derived from bootstrapping the sapling:small seedling density ratio data from NPS reference plots (Table 3). We used 99% confidence intervals, rather than the more common 95% confidence interval to give the assessment point a wider range for the Good category. The assessment points that define ecological integrity of regeneration in ACAD are as follows:

**Good:** stocking index  $\geq 20$ , and sapling:small seedling density ratio  $\leq 0.11$ .

**Caution:** stocking index  $\geq 20$ , and sapling:small seedling density ratio  $> 0.11$ .

**Significant Concern:** stocking index  $< 20$ .

This metric requires a minimum of 10 plots to rate regeneration in ACAD, and should not be applied to individual plots. The stocking index can be applied across woodlands and all closed-canopy upland forest successional stages, but the sapling:small seedling ratio should only be applied to forest plots in the Red Spruce – Fir Forest Group or the Northern Hardwood – Hemlock – White Pine Forest Group. We designed this metric to only require one sampling event to be rated. However, it will also be important to track how the sapling:small seedling ratio changes over time. If the sapling:small seedling ratio does not decrease over time, this may be cause for concern. For example, invasive species or deer browse could be impeding regeneration of seedlings.

For the purpose of reporting ecological integrity in ACAD, this metric will primarily be rated for each park subunit, and we will present the ratings for regeneration abundance and patterns. As long as there are at least 10 upland forest plots in a group, this metric can also be used to rate regeneration in ACAD using other groups such as successional stage. The metric can be applied to coastal Maine spruce-fir forests, assuming regeneration data are compatible (e.g., seedlings are tallied by the same height classes), and sample locations are within the same ecological

subsection as ACAD (Maine Eastern Coastal Subsection- 211Cb; U.S. Forest Service 2007). Application to spruce-fir forests outside of coastal Maine (e.g., southern Appalachian highlands, Adirondacks in NY) may also be possible, but the assessment points will need to be recalibrated for each region.

**Table 3.** Summary statistics based on 9999 bootstrapped datasets of 10 reference plots per sample, and using the percentile method for calculating each confidence interval. SE stands for standard error, and the SE calculation for the density ratio accounts for error propagation due to the estimation of two uncertain numbers.

<b>Metric</b>	<b># Plots</b>	<b>Mean</b>	<b>SE</b>	<b>99% CI</b>
Stocking index	21	78.68	33.43	20.50 (lower)
Sapling: small seedling ratio	21	0.035	0.018	0.110 (upper)



## Conclusions

The two overall goals for an ecological integrity metric on regeneration in ACAD are to assess 1) whether regeneration abundance is adequate to replace the canopy, and 2) whether regeneration patterns are consistent with those expected in late-successional spruce-fir forests. We selected the stocking index to assess abundance of regeneration, and a ratio of sapling density to small seedling density to evaluate patterns of regeneration in spruce-fir forests. Assessment points were derived by generating many bootstrapped datasets of 10 NPS reference plots per sample, and then estimating confidence intervals and standard error on the ten-plot mean for the stocking index and pooled sapling:small seedling ratio. This approach allowed us to account for the natural variability of regeneration in the reference stands, and requires sampling of at least 10 plots to rate the full metric.

Applying this new metric to ACAD, we find that forests plots across all subunits and groups (woodlands and closed-canopy forest successional stages) have sufficient levels of regeneration (Table 4). However, the ratio of sapling:small seedlings is much higher in ACAD spruce-fir forests than the ratio observed in NPS reference stands. Despite adequate levels of regeneration, patterns of regeneration reflect those of earlier stages of forest succession (i.e., high abundance of saplings), and all units (except Schoodic, which was not rated due to insufficient sample size) and spruce-fir forest successional stages in ACAD were rated Caution. As spruce-fir forests succeed and move towards more uneven-aged stands, we expect the sapling:seedling ratios across ACAD subunits to approach the ratio observed in NPS reference stands and to eventually be rated Good.

**Table 4.** Ecological Integrity ratings for forest plot data collected from 2009 to 2012, and based on the new assessment points. The stocking index includes all but mosaic plots. The sapling:small seedling ratio only includes upland forest plots. The sapling: small seedling density ratio defines saplings as having diameter at breast of 1-9.9 cm, and tree seedlings as 15 to 100 cm tall. SE stands for standard error, and the SE calculation for the density ratio accounts for error propagation due to the estimation of two uncertain numbers.

		Stocking Index				Sapling: Small Seedling Ratio				Overall Rating
		N	Mean	SE	Rating	N	Mean	SE	Rating	
ACAD Overall		165	132.22	10.45	Good	140	0.53	0.09	Caution	Caution
<i>Subunit</i>	IAH	18	153.43	32.09	Good	13	1.14	0.53	Caution	Caution
	MDI-E	79	116.01	14.91	Good	70	0.72	0.20	Caution	Caution
	MDI-W	58	148.95	18.60	Good	52	0.39	0.10	Caution	Caution
	Schoodic	10	125.03	29.86	Good	5	0.15	0.07	---	---
<i>Stage</i>	Late-Succ.	22	146.89	35.13	Good	22	0.52	0.20	Caution	Caution
	Mature	64	125.95	17.46	Good	64	0.28	0.07	Caution	Caution
	Pole	55	155.29	18.11	Good	54	1.25	0.25	Caution	Caution
	Woodland	24	82.61	12.47	Good	n/a	---	---	---	---



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## Appendix A. R code used to generate confidence intervals and standard error.

```
# The following code was used to generate standard error and confidence intervals
# on regeneration metrics in reference stands. The process generates a new data
# set for each sample of 10 plots per bootstrap. Because the boot function doesn't
# allow one to specify the sample size, we ran multiple bootstraps with one replicate
# each using the sample function. We then stored the results the same way as the boot
# function, which allowed us to use the boot.ci function to generate confidence
# intervals from the bootstrap results.

setwd("C:/NETN/Monitoring_Projects/Forest_Health/Annual_reports/2012/EI_Regen_Metric_A
CAD/regen_data")
regen<-read.csv("ACAD-REF_Stock_sdlg_size_naomit.csv", header=T, sep=",", row.names=1)
library(boot)
ref.regen<-subset(regen, park=="REF")
ref.regen$park<-ref.regen$park[,drop=T]
ref.regen$unit<-ref.regen$unit[,drop=T]
ref.regen$stage<-ref.regen$stage[,drop=T]
attach(ref.regen)
names(ref.regen)
str(regen)

#-----
# This section handles the data set creation and bootstrap for the sapling:seedling
# density ratio, storing each bootstrap result in temp.t.

num.reps <- 9999
temp.t <- matrix(NA,num.reps,1)
for (N in 1:num.reps) {
  temp.data <- ref.regen[sample(nrow(ref.regen), 10), ]
  boot.ratio <- boot(data = temp.data, function(x, i)(sum(x$sap.ha))/(sum(x$sm_sdlg)), R=1)
  temp.t[N,1] <- boot.ratio$t[1,1]
}

# This section replaces the incorrect objects (based on the last repetition
# of boot) with the correct values.
# t0 = the mean of the original data set
# t = bootstrap replicates, in matrix
# bias = mean(t) - t0
# R = total number of replicates

boot.ratio$t0 <- (sum(ref.regen$sap.ha))/(sum(ref.regen$sm_sdlg))
boot.ratio$t <- temp.t
boot.ratio$R <- num.reps
boot.ratio$data <- ratio
boot.ratio$weights[1:nrow(ref.regen)] <- 1/nrow(ref.regen)
```

**Appendix A.** R code used to generate confidence intervals and standard error (continued).

```
# This section generates confidence intervals

str(boot.ratio)
boot.ratio.ci<-boot.ci(boot.ratio, conf=0.98, type="perc")
boot.ratio.ci
plot(boot.ratio)

#-----
# This section handles the data set creation and bootstrap for the stocking
# index, storing each bootstrap result in temp.t2.

num.reps <- 9999
temp.t2 <- matrix(NA,num.reps,1)
for (N in 1:num.reps) {
  temp.data <- sample(stocking,10)
  boot.SI<-boot(data = temp.data, function(x, i)mean(x[i]) , R=1)
  temp.t2[N,1] <- boot.SI$t[1,1]
}

# This section replaces the incorrect objects (based on the last repetition
# of boot) with the correct values.
# t0 = the mean of the original data set
# t = bootstrap replicates, in matrix
# bias = mean(t) - t0
# R = total number of replicates

boot.SI$t0 <- mean(stocking)
boot.SI$t <- temp.t2
boot.SI$R <- num.reps
boot.SI$data <- stocking
boot.SI$weights[1:nrow(ref.regen)] <- 1/nrow(ref.regen)

# This section generates confidence intervals
str(boot.SI)
boot.SI.ci<-boot.ci(boot.SI, conf=0.98, type="perc")
boot.SI.ci
plot(boot.SI)

#-----
# This section calculates the standard error of the ratio, while correcting
# for estimation of 2 uncertain numbers.
attach(ref.regen)
mean.sap<-mean(sap.ha)
mean.sap
```

**Appendix A.** R code used to generate confidence intervals and standard error (continued).

```
mean.sdlg<-mean(sm_sdlg)
mean.sdlg

mean.ratio <- mean.sap/mean.sdlg
mean.ratio

ratio.c<-subset(ref.regen, select=c("stocking", "sap.ha", "sm_sdlg"))
cor.ratio <- cor(ratio.c$sap.ha, ratio.c$sm_sdlg, method = "pearson")
cor.ratio

sd.sap<-sd(sap.ha)
length(sap.ha) #=21
sd.sap

sd.sdlg<-sd(sm_sdlg)
length(sm_sdlg) #=21
sd.sdlg

# Calculate standard deviation
s.rat2<- (sd.sap/mean.sap)^2+
          (sd.sdlg/mean.sdlg)^2 -
          (2*cor.ratio*sd.sap*sd.sdlg)/(mean.sap*mean.sdlg)
s.rat2
s.rat<-sqrt(s.rat2)
s.rat<- s.rat*mean.ratio
s.rat

se.ratio<-s.rat/(sqrt(length(ref.regen$ratio)))
se.ratio
```



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