

**Seeing the Forest and the Trees:
Stand Dynamics of Beech Mountain in Acadia National Park, Maine**
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INTRODUCTION

Trees act as environmental recorders on the landscape. Dendrochronology, the scientific study of tree-ring characteristics through time, can be used to reconstruct past environmental conditions. Dendroecology, a subfield, focuses on reconstructing ecological disturbances that impact trees and forest stands, including fire, insect outbreaks, and meteorological events (Speer 2010). The purpose of this study is to investigate disturbance dynamics in a red spruce (*Picea rubens*) forest in Acadia National Park (ANP), Maine. The Köppen Climate Classification subtype for the Mount Desert Island region is "Dfb" (Warm Summer Continental Climate). Thirty-year mean annual temperature is 8.4°C with January and July being the coldest (-5°C) and warmest (21°C) months, respectively. Mount Desert Island averages 145 cm of precipitation annually, with November being the wettest month and August receiving the lowest amount of rainfall. Spring storms generate the highest mean annual wind speeds (13 km/h) in March and April. Coastal areas of varied topography such as Mount Desert Island also often experience anomalous winds and downdrafts unrelated to the general weather pattern, and hurricane season runs from June through October. According to Keim *et al.* (2007), the return period for tropical cyclones with winds higher than 63 km/h in Bar Harbor, ME is less than once every 100 years. Due to a low number of annual lightning strikes and relatively consistent precipitation, naturally occurring wildfires are rare within coastal Maine forest stands (U.S Fish and Wildlife Service, 2012).

Red spruce is found in cool, moist climates and in soils with a thick mor humus as well as a well-defined A horizon. It often grows in sites unfavorable for competing species, including rocky substrates and steep slopes. Red spruce is shade-tolerant and individuals can persist in the understory for decades.

Common, historical disturbances in red spruce ecosystems include logging, spruce budworm, windthrow, and ice. The most recent spruce budworm outbreaks began in 1709, 1762, 1808, 1914, and 1976 (Fraver *et al.* 2007). Timber harvesting was widespread in the region between 1820 and 1840, suggesting that some stands in the park, including our study site, and may contain single age classes due to harvesting events (NPS 2007).

Reconstructing stand dynamics using tree rings can provide information about past ecological events, which can be used to infer how the forests may respond to future climatic and disturbance events, and associated variability. Stand dynamics reconstructions are also beneficial when approaching concerns in forest management, including appropriate silvicultural treatments, management for natural succession and invasion, and habitat preservation. In coastal regions, ecological reconstructions are also valuable to discerning the effects of coastal climate on forests. Public education and outreach about natural disturbance can also aid the public in understanding the importance of forests and the natural succession of stands.

To better understand the dynamics and drivers behind forest stand structure, we asked the following research questions:

1. What is the disturbance history of this site?
2. What are the disturbance agents affecting this site?
3. What is the stand-age structure?
4. What is the relationship between competition and the growth of trees?

Site Description

This study was conducted on a small ridge of Beech Mountain (44.3124° N, 68.3422° W; elevation: 152m), located in the southwestern portion of Mount Desert Island, in Acadia National Park (Figure 1). Overstory vegetation of the site was composed primarily of mature *P. rubens*, with *Pinus resinosa*, *Pinus strobus*, and *Thuja occidentalis* present in small numbers. Understory vegetation was dominated by *Abies balsamea* and various saplings.

Acadia National Park is classified as a humid continental (Dfb) Koppen climate zone (Peel *et al.* 2007), indicating the site studied here experiences warm, humid summers, and cold, snowy winters. Due to the proximity of the site to the Atlantic Ocean, the climate is considerably more moderate than areas of inland Maine. The site regularly experiences summer fog, winter ice, and year-round rainfall.

Plot Design and Sampling Method

As a preliminary exploration of the dynamics and structure of spruce-dominated forest on Beech Mountain, we created one circular plot with radius 15.96-m for sampling on June 3, 2015 (Fig. 2). All trees within the plot with diameter at breast height (dbh) greater than 10 cm were tagged for coring. Two cores at 90° to one another were taken from each tagged tree (Cook and Kairiukstis; Stokes 1980). Additional data recorded for each tagged tree included dbh, distance and azimuth from plot center, crown class, status (live vs. dead), and notes on the condition of the tree.

Additional cores and dbh measurements were taken from targeted large trees outside of the plot boundary in an effort to extend the chronological record. Targeted sampling resulted in an additional 42 cores consisting of *P. rubens* (n = 35), *P. strobus* (n = 4) and *P. resinosa* (n = 3). Six cross-sections were extracted from downed trees located both inside and outside of the plot boundaries.

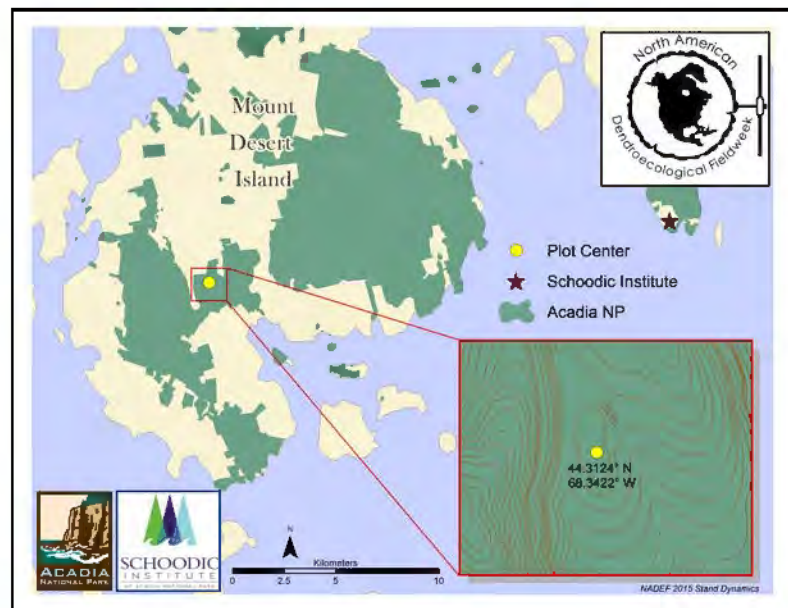


Figure 1. Location of plot in Acadia National Park.

We used the planar intersect technique to quantify the volume of coarse woody debris (CWD) on the plot (Brown 1974). Three 20-m transects extending from plot center were established at 0°, 120°, and 240°. We recorded the diameter at intersection, decay class, and species of all CWD woody greater than 10 cm in diameter.

ANALYSIS

Standardization

Standardization approaches were applied in the dplR package for R (Bunn *et al.* 2015). We developed a master detrended chronology using a horizontal mean value line to maintain variability in the record associated with forest stand dynamic effects (Fig. 3; Bunn *et al.* 2015; Cook and Peters 1981).

Annual ring widths were measured with a Velmex stage micrometer using MeasureJ2X for one of two cores sampled for each tree. Due to time constraints, only one of two cores extracted were measured for each tree. Appropriate cores were determined by the accuracy of initial dating and the physical condition of the sample. For trees that were not cored to pith, a distance to pith (in years) was determined with a pith indicator to estimate establishment dates (Applequist 1958). Series were then statistically crossdated using the program COFECHA to determine the correlation between all years among all trees (Grissino-Mayer 2001; Holmes 1983).

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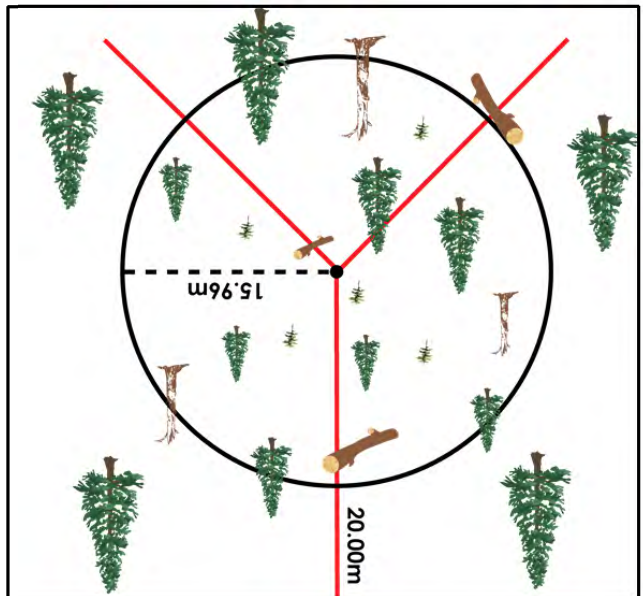
2002). Cross-sections were also carefully sanded. Samples were then dated using the list method, and marker years were recorded and tallied (Douglas 1941; Yamaguchi 1991).

All increment cores collected in the field were dried and mounted on wood mounting blocks, and then sanded using a progression of 120, 220, 320, 400, and 600 grit sandpaper (Orvis and Grissino-Mayer 2002). Cross-sections were also carefully sanded. Samples were then dated using the list method, and marker years were recorded and tallied (Douglas 1941; Yamaguchi 1991).

Laboratory Procedures

woody debris transects.

Figure 2. 15.96-m radius sampling plot with 20-m coarse



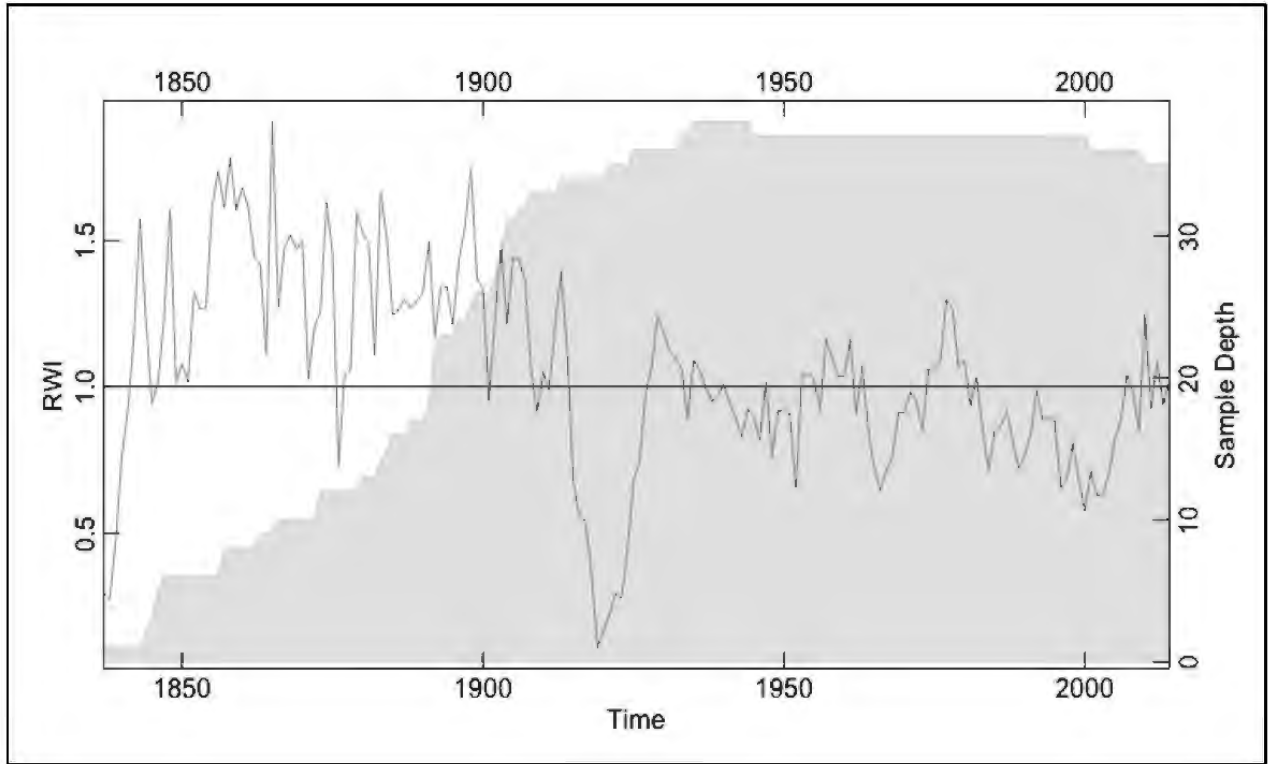


Figure 3. Standardized growth chronology for the Beech Mountain study plot.

Disturbance

We applied the absolute-increase method of disturbance detection in the TRADER package for R to identify occurrence of growth release and open recruitment events within the chronology (Fraver and White 2005; Altman *et al.* 2014). Open recruitment is defined as rapid early growth upon recruitment to dbh, rather than a release following suppression. Growth within a 15-year moving window that exceeded the absolute threshold for *P. rubens* of 0.58 mm (Fraver and White 2005), for a minimum duration of 5 years, was flagged as a true release (Fig. 7). Individual series were further examined visually to verify release events and screen for ‘false positives’. A composite disturbance chronology was then developed for the whole plot. Total volume of CWD by decay class was also calculated to further address historical and spatial patterns in tree loss and disturbance.

Competition

Clustering of trees can decrease growth through competition for resources (D’Amato and Puettmann 2004; Wagner and Radosevich 1998). We sought to quantify this effect and tested for a relationship between competition and observed growth. Competition is quantified through the competition index of Hegyi (1974):

$$CI_f = \sum_{n=1}^N \frac{S_n}{S_f} \cdot \frac{1}{\text{Distance}_{nf}}$$

Where the competition index (CI) is calculated at each focal tree (f) as the sum of the contribution from each neighboring tree (n) within a 6-m radius from the focal tree. Competition scales the ratio of the size of the neighboring tree (S_n) relative to the size of the focal tree (S_f), and is inversely proportional to the distance between the focal and neighboring trees (Distance_{nf}). Size is quantified as the crown volume, and was calculated from dbh using an allometric relationship derived from a collection of 485 spruce trees with dbh and crown dimensions (Fraver 2005). Because calculation of CI requires summing over all trees within a specified radius, trees within 6-m of the plot edge were excluded from the analysis. Clustering

was then compared against the mean annual radial growth rate (GR) of each tree (mean ring width, 1995-2014).

RESULTS AND DISCUSSION

Chronology Characteristics

The size-class and species distribution of all sampled trees within the plot is mapped in Figure 4. A total number of 39 increment cores were crossdated and measured for years 1837-2014.

Individual series ring width and mean value growth chronologies can be viewed in Figure 5. The master chronology identifies a dramatic decrease in growth during the period of 1919-1921 (with a total of 23 locally absent rings), and a period of above average growth in 1850-1900. EPS signal, mean interseries correlation, and mean $\bar{r}$ values are provided in **TABLE 1**.

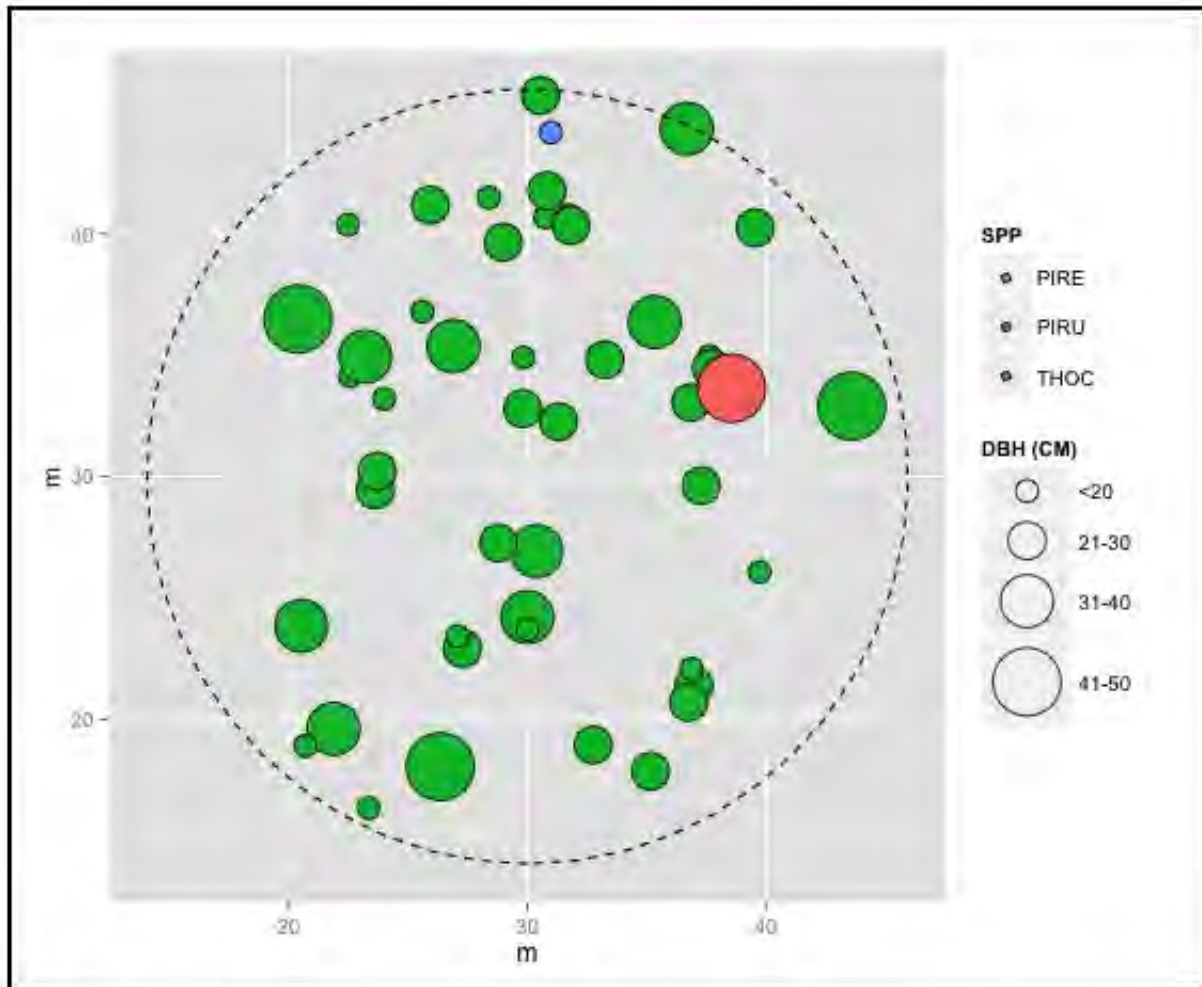


Figure 4. Radial plot of tree distribution. Size of circle corresponds to DBH class, and color of circle identifies species (red for *P. rubens*, green for *P. resinosa*, and blue for *T. occidentalis*).

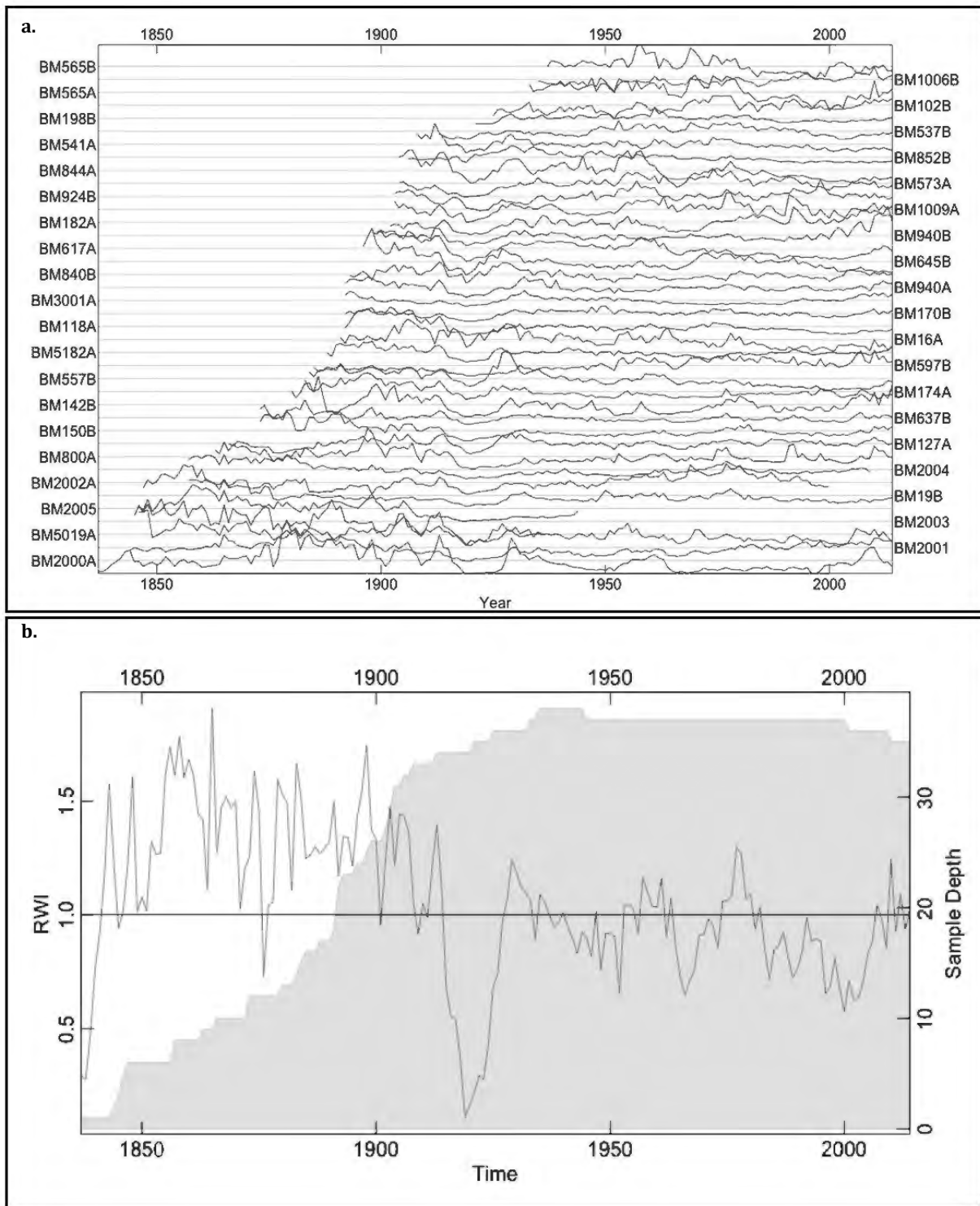


Figure 5. (a) Spaghetti plot of raw ring width for each series, and (b) composite plot-level growth chronology standardized with horizontal line.

Age structure

The age-class distribution in Fig. 6 illustrates the year of recruitment to breast height in *P. rubens*, *P. resinosa*, and *P. strobus* with known or estimated pith dates. The majority of *P. rubens* recruitment occurred prior to 1900, with the two largest peaks occurring in 1845 and 1895; though *P. rubens* continued to establish in small numbers for over seven decades (1835 to 1905). The only periods of *P. resinosa* and *P. strobus* recruitment in this stand occurred between 1845 and 1864.

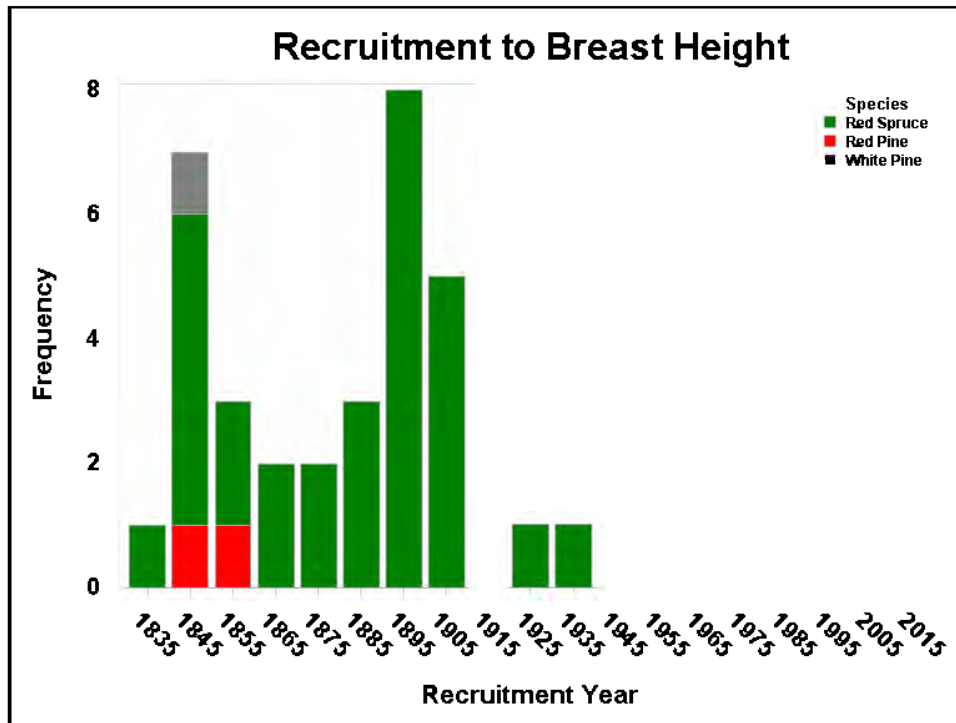


Figure 6. Distribution of time of recruitment to breast height for *P. rubens*, *P. resinosa*, and *P. strobus*.

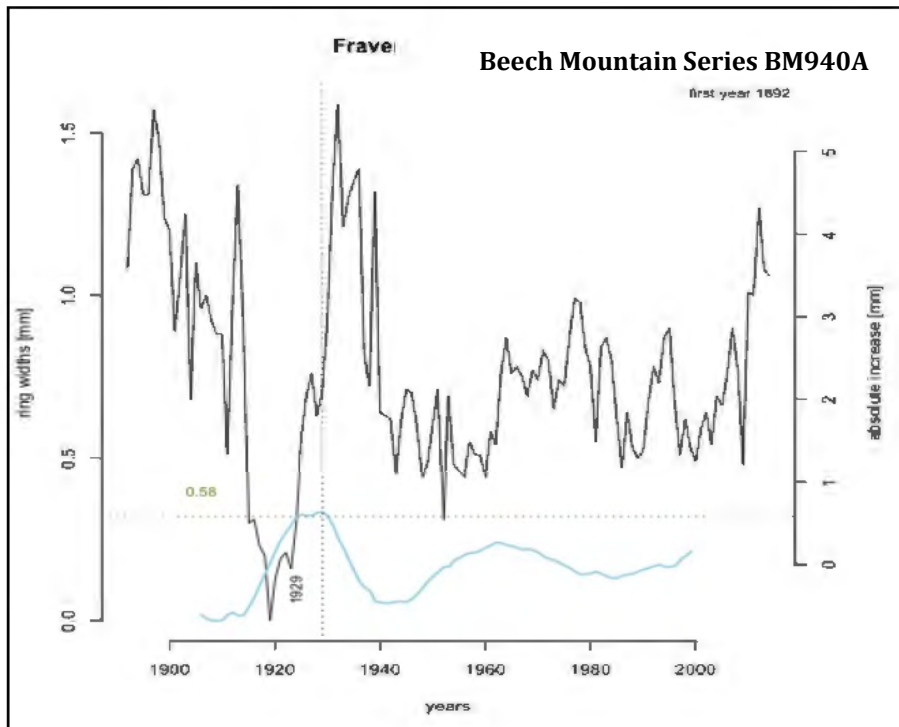


Figure 7. Example of absolute-increase method output for identifying growth release events for one series, based on duration and magnitude of event above 0.58-mm threshold.

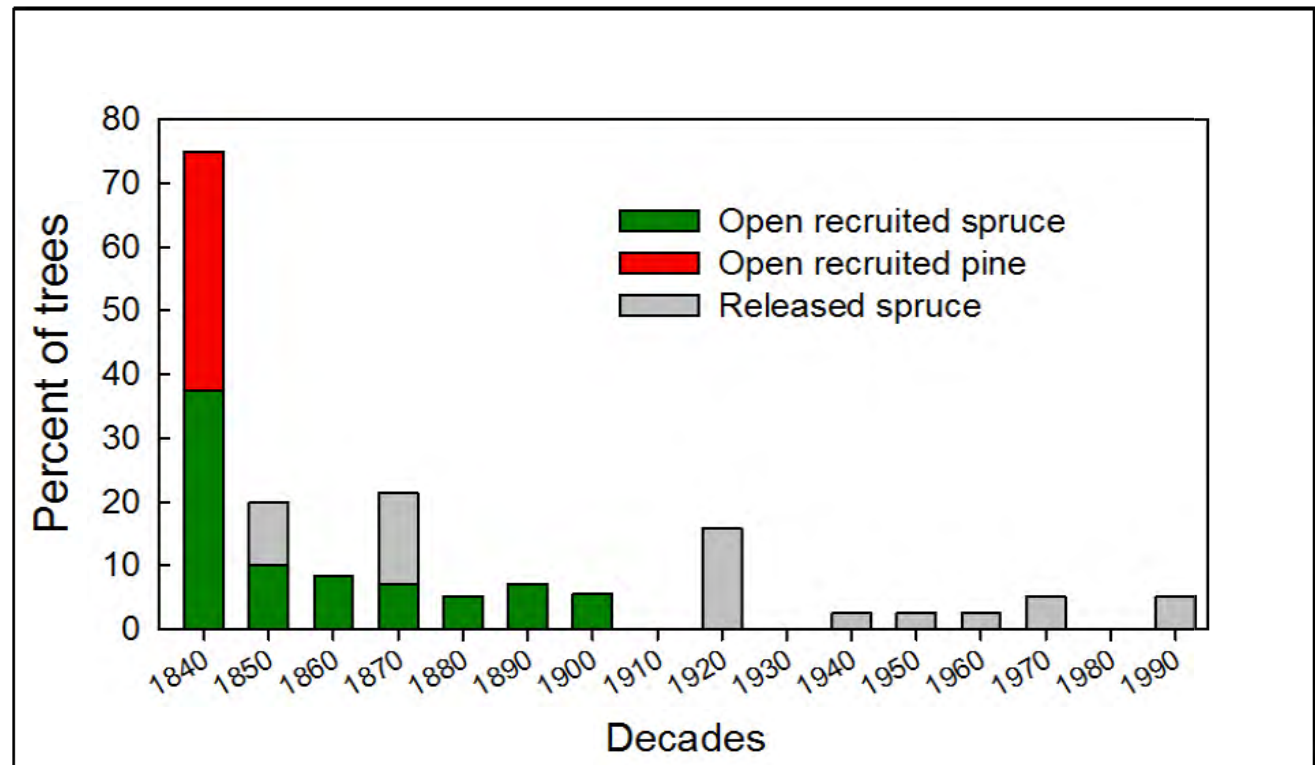


Figure 8. Percent of trees per decade exhibiting open recruitment and release events in study area, 1840-2014.

Disturbance chronology

The site-wide disturbance chronology includes open canopy recruitment to breast height and true growth release events (Fig. 8). The greatest period of open recruitment occurred in 1840, and was high in both *P. rubens* and *P. resinosa*, identifying a time of when an open canopy allowed for rapid growth to breast height indiscriminate to species. This significant period of open recruitment indicates a disturbance event prior to 1840 that significantly thinned or cleared the existing canopy layer. This onset of open recruitment was sustained until 1900. However, the simultaneous gap recruitment of *P. resinosa* and *P. rubens* was only noted at the onset of open recruitment in 1840, and no open recruitment events occurred after 1900.

The largest *P. rubens* release event (including recovery releases) in the chronology occurred in 1920. More *P. rubens* release events occurred between 1920 and 2014 (six release events) than prior to 1920 (two release events).

Competition index

A comparison of the spatial distribution of competition (CI) and mean annual radial growth rate (GR) reveals an apparent relationship between competition and growth, with rapid growth confined exclusively to trees with low CI (Fig. 9). This apparent relationship motivates a quantitative comparison of the CI and GR. We find a strong linear relationship between $\log(\text{CI})$ and $\log(\text{GR})$ (Fig.10).

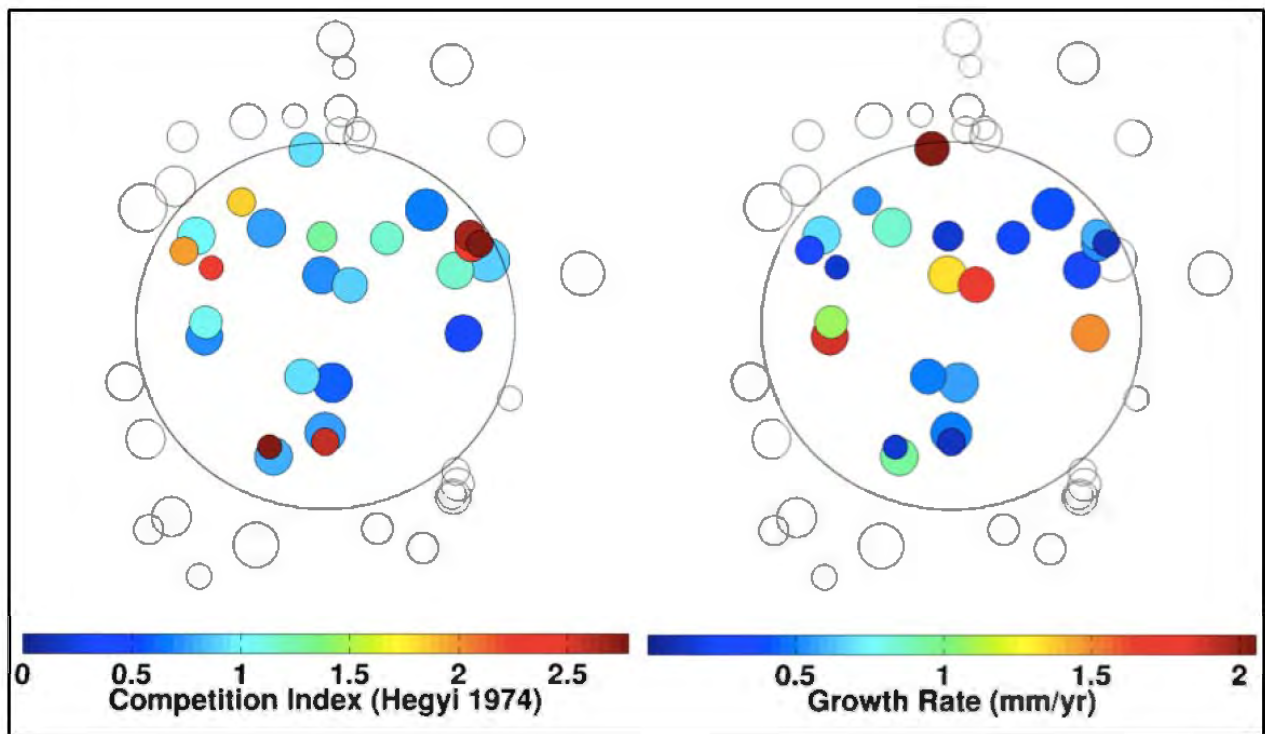


Figure 9. Comparison of spatial variability of competition (CI: left) and mean annual radial growth rate (GR: right). Size of circles scale with dbh. CI and GI are calculated for tree within 10 m of plot center.

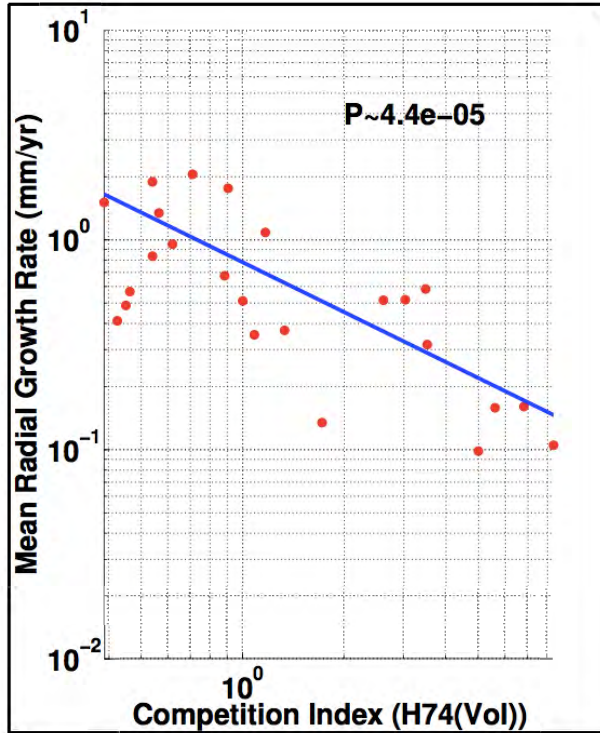


Figure 10. Comparison of variability of competition (CI) and mean annual radial growth rate (GI). $\log(GI)$ decreases approximately with $\log(CI)$.

DISCUSSION AND CONCLUSION

Historical disturbance events in ANP include wind damage, spruce budworm outbreaks, and intensive logging (Seymour 1994). Evidence for three of these disturbances can be seen in the chronology presented here. Logging in ANP began in 1820 and reached its peak production during the mid-1830s (NPS). Removal of trees by logging results in the loss of overstory canopy volume creating significant gaps that shade-tolerant species such as *P. rubens*, that persist after the cessation of logging, can take advantage of and convert increased sunlight to increased growth (Gray and Spies 1996). This phenomenon of rapid, sustained growth following a large-scale loss of canopy volume is referred to as “open recruitment.” The open recruitment episode noted in the 1840s of this record is likely associated with increases in growth following a height in logging which left a large gap in the forest canopy, allowing for the rapid recruitment of trees untouched by logging. Though we believe this to be the most likely explanation for the 1840s open recruitment event, a large, unrecorded windthrow event may have also caused a similar recruitment event.

The second disturbance in this chronology can be seen around 1919 and is characterized by a series of narrow and locally absent rings. Historical widespread spruce budworm outbreaks occurred in Maine in 1709, 1762, 1808, 1914, and 1976 (Fraver et al. 2007), and moved through southern and coastal Maine in 1919 (Maine Forest Service 2014). We suggest that the period of narrow rings around 1919 followed by the release event noted in *P. rubens* during the 1920s indicate the suppressed growth and ultimate recovery of trees affected by a regional spruce budworm outbreak. Further evidence for this interpretation stems from a preliminary host/non-host analysis (Blais 1965). Two other species, which are not affected by spruce budworm, (*P. strobus* and *T. occidentalis*) were analyzed at this site for a separate study, and neither showed suppressions in the 1910s or 20s, suggesting that the 1919 suppression event noted in *P. rubens* was a species-specific event, likely related to a spruce budworm defoliation event.

The final disturbance recorded in this chronology is the 1952 marker year, noted for its narrow width and latewood. Two unusual meteorological events occurred in February 1952 prior to the onset of the growing season: (1) a tropical storm, and (2) a macro-scale nor’easter. High wind speeds, snowpack, and ice associated with winter storms of this magnitude may cause windthrow, canopy loss, and other structural damage, resulting in a low period of growth following the event.

Preliminary analyses conducted at Beech Mountain in Acadia National Park provided some initial insight into cohort establishment, red spruce overall stand structure and neighborhood dynamics, and also the natural and anthropogenic disturbance events and the associated structural and ecological responses. Scaling the sampling methods to forest and regional scales would greatly improve our chronology and our understanding of growth and response trends within Acadia in coastal Maine spruce forests, and ultimately aid in improving management decisions in a changing world.

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