

INTRODUCTION

In preparing the 5-year Forest Inventory and Analysis (FIA) report for Vermont in 2007–08, analyses showed an increase in tree mortality since the previous inventory of 1996–97. Adjacent States had a similar spike in mortality. Further evaluation of FIA plot data helped focus the investigation. Some general characteristics of the mortality included: (1) distribution in both northern and southern Vermont, (2) high-elevation forests and timberland forests were affected, and (3) mortality was not related to stocking levels. Several species seemed to be affected, including red spruce (*Picea rubens*), paper birch (*Betula papyrifera*), balsam fir (*Abies balsamea*), red maple (*Acer rubrum*), and American beech (*Fagus grandifolia*). Local concern about white ash (*Fraxinus americana*) decline led to its inclusion in this investigation even though FIA data did not show significant mortality.

Our major goals were to:

- Investigate potential causes of tree mortality detected in recent FIA data for Vermont.
- Identify site conditions that contributed to tree mortality in order to inform forest management strategies to maintain future forest health.

METHODS, RESULTS, AND DISCUSSION

The investigation results are grouped into three sections:

- (1) Existing forest health data on forest disturbance factors;
- (2) Spatial analyses of FIA data and potential inciting and contributing factors; and
- (3) Field assessments of sites with high mortality.

Summary of Forest Disturbance Factors

Existing data from Vermont forest health monitoring programs were used to identify stress events that had occurred since the last FIA inventory. Data sources included those from the national Insect and Disease Survey (IDS), tree health plots visited annually since 1988 as part of the North American Maple Project (30 sites), Vermont Monitoring Cooperative forest health plots (19 sites), and pest survey plots. Analysis of the most likely stress agents involved focused on:

- ice storm in 1998
- droughts in 1999 and 2001–02
- birch decline agents
- spruce winter injury

CHAPTER 9.

Investigating Causes of Mortality in Vermont

(Project NE–EM–B–10–01)

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- forest tent caterpillar (*Malacosoma disstria*) defoliation
- beech bark disease
- stand-replacing windstorms
- balsam woolly adelgid (*Adelges piceae*) damage
- air pollution effects (acid deposition and ozone)

The 1998 ice storm was initially thought to be a major factor in the observed mortality spike because it caused an increase in dead and dying trees for several years following the event. However, the initial effects from the ice storm were resurveyed in 1998, and the 1997 FIA data were adjusted in a subsequent analysis to account for ice storm mortality and tree volume reductions. In addition, follow-up crown health monitoring showed that most species recovered well from the ice storm (Kelley and others 2002).

However, lingering effects from the ice storm were later shown to be a significant contributor to birch decline. Studies of white birch (*Betula papyrifera*) declines identified the 1998 ice storm as the inciting factor, with tree recovery influenced by drought and soil nutrition (Halman and others 2011).

Significant winter injury on red spruce was reported across the Northeast in 2003. This event was extensively studied, and published articles indicated this event was responsible for red spruce mortality (Schaberg and others 2011). Due to results from these studies on birch and red spruce declines, these species were not included in our investigation.

Spatial Analysis

Aerial survey maps of forest disturbances were intersected with FIA plots to compare known locations of disturbance history and incidence of mortality on ground plots. Aerial survey maps showed that approximately 45 percent of Vermont's forest land received damage between 1997 and 2005. Data from FIA plots within mapped disturbance polygons indicated that tree growth was slower where disturbances occurred than on undamaged plots for all forest type groups, but no statistically significant differences were detected. Similarly, the spruce/fir, oak/hickory, and aspen/birch forest type groups showed more standing dead trees per acre where disturbances occurred than on the undamaged plots, but no statistically significant differences were found. Additional spatial data layers were used to assess site conditions in relation to aerial survey maps. Soil moisture and water availability were site factors of importance, and several datasets were used to evaluate these.

Soil moisture and site characteristics—

A soil drainage index (DI) (Schaetzl 1986), also referred to as the soil dryness index, is designed to represent the amount of water that a soil potentially contains and makes available to plants under normal climatic conditions. This index was used to characterize aerial survey damage polygons and FIA plots. A high DI corresponds to sites with high water-holding capacity. A low DI corresponds to sites with low water-holding capacity. The main factors that influence the DI are the depth to the water table and the soil volume available for rooting. In

addition, a depth-to-bedrock map was created for Vermont that included finer scale data than the DI map. We used shallow-to-bedrock polygons from this map as another means of addressing potential drought susceptibility of FIA sites.

The DI and shallow-to-bedrock maps were compared to aerial survey damage maps and FIA plots. Results indicated that:

- Significantly more acres with damage were mapped on sites shallow to bedrock.
- FIA plots on shallow soils were more likely to have 1 or more years of damage.
- The greatest relationship between sites with shallow soils and standing dead trees per acre was found in the aspen/birch forest type group.
- Greater mortality was reported on sites that were either dry or wet (from DI) when combined with shallow soils.

Long-term (30-year) average growing-season precipitation maps were used with FIA plots to compare average precipitation with forest land in each forest type group. General relationships between precipitation and forest type groups were assessed. Several growth and mortality trends were found in relation to the average growing-season precipitation. The white/red/jack pine forest type group grew more often in areas of relatively low average precipitation, and the maple/beech/birch group grew more often in areas of relatively high average precipitation. The oak/hickory type group had higher net

growth per acre per year on sites with moderate precipitation. The spruce/fir type group was more prevalent in areas with higher average precipitation.

Specific years when precipitation was below normal (1999, 2001, and 2002) were also compared to FIA plots. It should be noted that nearly the entire State was under drought conditions during these years. The only specific mortality relationship that was statistically significant was that the spruce/fir forest type group had the highest number of standing dead trees per acre at sites that experienced drought during the 1999 growing season. No other statistically significant relationships were found between precipitation deficits, dryness index, and tree mortality.

The spatial distribution of standing dead basal area (DBA) was assessed using Global Moran's I spatial autocorrelation statistic, a tool used to evaluate whether the pattern of mortality is clustered, dispersed, or random. DBA showed patterns of spatial autocorrelation for all species, and individually for red maple, balsam fir, and American beech (fig. 9.1). Spatial analysis of DBA of all species showed positive correlations with stand age and elevation. A northern cluster of declining plots was positively correlated with elevation. A southern cluster was positively correlated with stand age. A central cluster was positively correlated with both elevation and stand age. On a species level, high red maple DBA was most prevalent on FIA plots in southern Vermont. High balsam fir DBA was concentrated in two separate clusters, one in the

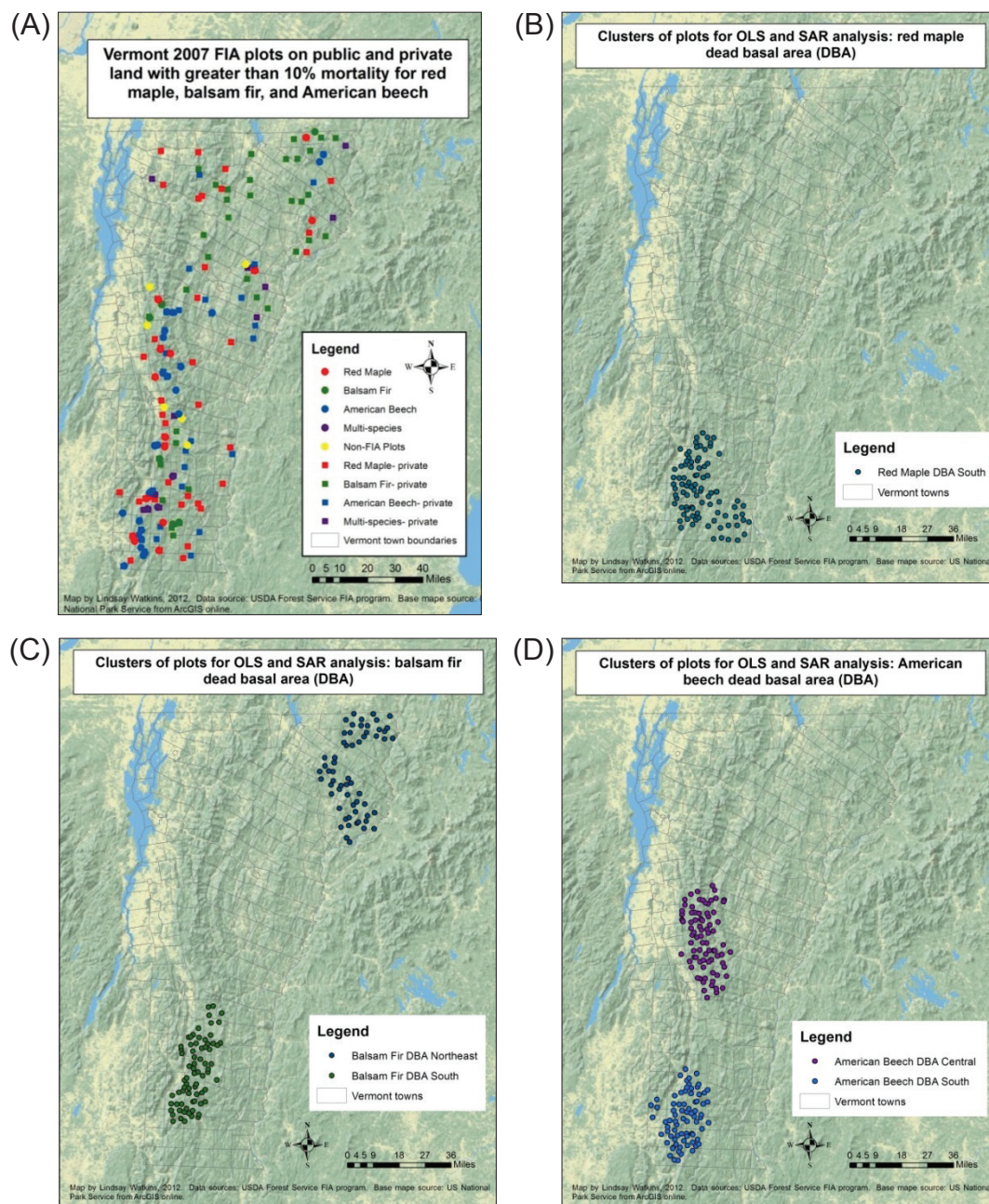


Figure 9.1—(A) High mortality FIA plots in Vermont in 2007 identifying the tree species involved; cluster analysis identifying geographic groupings of dead basal area for (B) red maple, (C) balsam fir, and (D) American beech. Plot locations are approximate.

Green Mountains of southern Vermont and a second cluster in the Northeast Kingdom. High beech DBA was clustered in central Vermont in the Green Mountains, with a separate cluster in the southern Vermont Green Mountains.

Spatial analysis of DBA for each species cluster was compared to site features. For total balsam fir DBA, slope was negatively correlated with dead basal area. In the northeast, elevation was positively correlated with DBA, and 30-year average growing-season precipitation was negatively correlated with DBA. In the south, slope and soil dryness index were both negatively correlated with DBA. For total American beech DBA, stand age and elevation were positively correlated with DBA, and 30-year average growing-season precipitation was negatively correlated with DBA. For the central cluster, stand age and elevation were again positively correlated with DBA, and 30-year average growing-season precipitation was negatively correlated with DBA. In the southern cluster, only stand age was positively correlated with DBA. Stand age, elevation, and precipitation deficit were the factors most associated with DBA for beech plot clusters. No significant relationships were found between red maple DBA and stand or site factors.

Ozone and ozone bioindicator plant trends—During the interval between FIA samplings, ozone concentration dropped, and the severity of ozone symptoms on bioindicator plants was reduced (Smith and others 2012, Vermont Monitoring Cooperative 2009). While it is possible that previously high ozone levels

affected long-term tree health, the absence of ozone symptoms observed in forests over the previous decade does not support any long-term ozone effects.

Acid deposition effects on tree health—

Previous work developing critical load and exceedance maps for nitrogen and sulfur have been used successfully to demonstrate relationships between forest decline and areas exceeding critical load (Pardo and others 2010, Schaberg and others 2010, Sullivan and others 2013). Our analysis using FIA plots with varying mortality levels did not find any relationships between mortality and acid deposition indicators.

Field Assessments

Field assessments were used to find on-the-ground evidence for the timing of mortality events, site characteristics contributing to mortality, and any inciting factors still in evidence at high mortality sites. Sites with more than 10-percent mortality were identified through FIA plot data (15 sites on public lands) and using aerial survey records or through referrals from foresters (16 sites). Field assessments focused on sites and tree variables for four species: red maple, balsam fir, American beech, and white ash. Thirty-one mortality sites were visited, but only 15 sites met our criteria for sampling. At sampled sites, data were collected on past disturbances, physiography, soil type and drainage, ground cover species, and regeneration. In addition, 20 trees were measured for diameter, height, crown class, dieback, defoliation, vigor, seed, bole damage, presence of standing water,

and other potential damage agents. Tree cores were collected on a subset of trees. It was our intent to collect cores from live, declining, and dead trees, but this was not possible due to limited numbers of sample trees in each class for each species and a high amount of internal decay, especially on declining trees. As mentioned previously, research on paper birch and red spruce mortality was conducted by others.

Red Maple is susceptible to mechanical injury, defects, diseases, and sapsucker damage (Burns and Honkala 1990b). Fungal diseases often attack the stem through branch stubs and wounds and then advance quickly. Red maple can be found in early-, mid-, and late-successional forests. It can be a pioneer species, though it is more shade tolerant than other pioneers. While it can also be considered a climax species in some forest types (usually on wet sites), in the Northern Hardwood Forest it is usually replaced by more shade-tolerant species. Depending on growing conditions, trees can reach maturity at 70 to 80 years and rarely live past 150 years.

Field results showed that trees were on average more than 80 years of age at seven of the nine declining sites visited. Three of the sites had trees that were 100 to 125 years old. Also present at most sites was evidence of past logging (93 percent of sites) in the form of basal bole wounds. At one site, 70 percent of the trees were either wounded or dead. Red maple is particularly susceptible to wound-induced decay. Although

dead basal area was not significantly related to stand age (see above), the combination of aging trees and wound-induced decay seems likely to have contributed to some, if not most, of the red maple mortality observed.

White ash crown assessments were measured on 45 FIA phase 3 plots. White ash had the second highest incidence of poor crown condition, with 25 percent of the live basal area displaying poor crowns. Poor crowns were defined by dieback >20 percent, crown density <35 percent, or foliage transparency >35 percent (Morin and others 2011). Crown health was especially poor on plots in southern Vermont.

Field assessments included observations of symptoms of ash yellows disease. These symptoms include tufted foliage due to slow twig growth and short internodes, small leaf size, deliquescent branching or loss of apical growth dominance that resulted in lateral branching, presence of witches' brooms at the trunk base, and vertical cracks on the trunk near the ground. Very few of these symptoms were observed at the sites visited. Root collar samples were collected from declining ash trees and analyzed for ash yellows disease. Tests were negative in all cases except one site in southeastern Vermont. Site characteristics in declining ash stands indicated that the sites were prone to water deficits. As a ring-porous species, white ash is susceptible to decline following drought years. This was likely involved as a contributing factor to ash declines.

Balsam fir grows at upper elevations along the spine of the Green Mountains as well as

in lowland spruce/fir forests and several of Vermont's swamp communities (Thompson and Sorenson 2000). Maximum size and age vary with climate, soil, and biotic conditions, but trees can grow to 40 to 60 feet and 12 to 18 inches in diameter and reach a maximum age of 200 years (Burns and Honkala 1990a). Balsam fir has several important insect pests, including spruce budworm (Rose and Lindquist 1994), which defoliates trees and causes extensive root damage, and the balsam woolly adelgid, an introduced species that attacks tree stems, twigs, and buds and can kill trees within 3 years (Quiring and others 2008). Spruce budworm populations have been at low levels in Vermont since the 1980s, but mortality from balsam woolly adelgid was mapped during aerial surveys on nearly 11,000 acres in 2004, when it was confined to central and southern Vermont (Vermont Department of Forests, Parks, and Recreation 1997–2011).

Several fungal pathogens can cause decay in the trunk, branches, and roots of balsam fir. These pathogens can affect trees without any visible external symptoms and may be more severe on drier sites. Unfortunately, tree cores from balsam fir did not remain intact when extracted from trees, so they were unavailable for assessment of tree age, and we were unable to ascertain the timing of mortality. The presence of balsam woolly adelgid in southern Vermont will remain a strong candidate as an inciting factor for mortality. In northern Vermont, precipitation

deficit seems likely to be the inciting factor for mortality.

American beech in Vermont has experienced decades of injury from beech bark disease (BBD), a nonnative pathogen vectored by beech scale insects (Vermont Department of Forests, Parks, and Recreation 1997–2011). Diseased trees tend to decline when water availability is reduced, such as during the recent droughts of 1999 and 2001–02. Field assessments at one location showed that 95 percent of sample trees were infested with BBD or were dead.

CONCLUSIONS

Determining causes for mortality after the fact is a challenge, and thus they are difficult to assign with certainty. Thankfully, our annual detection surveys and periodic ground plot measurements allowed us to get a head start in this investigation.

Our findings point to the following inciting and contributing factors for species and locations involved in this mortality study:

- Balsam fir trees in southern Vermont experienced mortality because of balsam woolly adelgid damage, with drought being a likely contributor to mortality.
- Balsam fir trees in northern Vermont likely experienced water fluctuations during drought years, resulting in decline and mortality.
- Beech trees showed reduced growth and poor crown condition due to beech bark disease

and stand age; elevation and precipitation deficit were contributing factors in increased mortality.

- Red maple mortality was likely related to internal decay from past logging wounds that reduced tree vigor, but did not cause mortality until other compounding factors reached critical levels. Aging trees and multiple years of drought may have been contributing factors.
- White ash decline was likely initiated by water fluctuations at well-drained sites brought on by recent drought events. Ash yellows disease was confirmed at only one location in southeastern Vermont.

The role of soil nutrition in this mortality event could not be fully explored. Initial results from other research on red spruce and paper birch declines revealed a role for calcium in stress recovery (Halman and others 2011, Schaberg and others 2011). Paper birch initially damaged by the 1998 ice storm varied in recovery success depending on site levels of available calcium. Mortality was greater on low-calcium sites. Similar results were reported for red spruce following damage from winter injury. Site levels of calcium were correlated with recovery and subsequent growth.

CONTACT INFORMATION

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