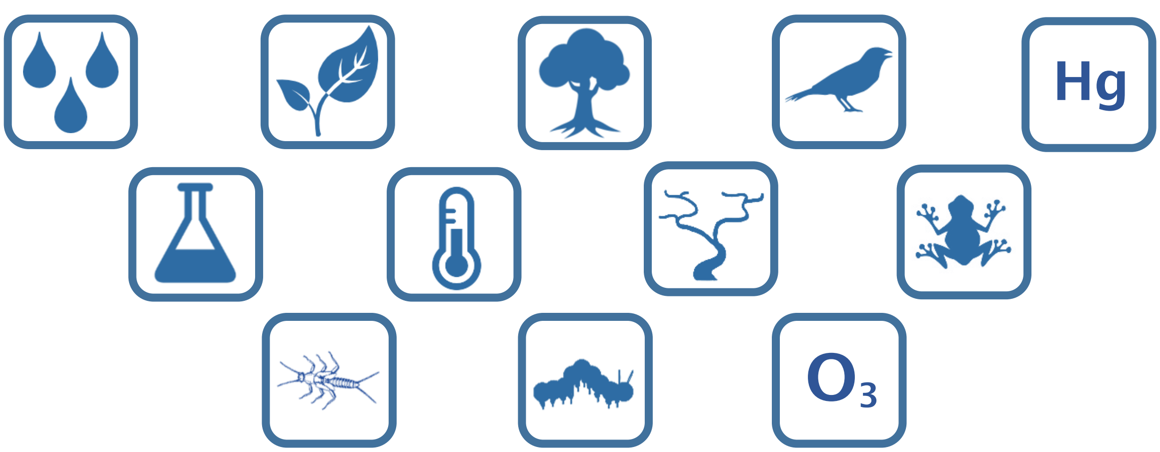
Vermont Monitoring Cooperative

Providing the information needed to understand, manage, and protect Vermont's forested ecosystems in a changing global environment

Long-Term Monitoring Update 2014



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The Vermont Monitoring Cooperative Long-Term Monitoring Update - 2014

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Vermont Monitoring Cooperative, South Burlington, VT, USA

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Acknowledgments

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Introduction

Established in 1990 as a partnership among the USDA Forest Service, the State of Vermont Agency of Natural Resources and The University of Vermont (UVM), the Vermont Monitoring Cooperative (VMC) serves as a hub to facilitate collaboration among federal, state, non-profit, professional and academic institutions toward ongoing monitoring of forested ecosystems across the region and an improved understanding of forested ecosystems in light of the many threats they face. While VMC efforts focus on the health of Vermont's forests, forested ecosystems are complex entities supporting many organisms, proving a wealth of ecosystem services, and whose condition is based on more than just the status of trees. Because a healthy forest system is also dynamic in response to natural climate variability, disturbances and succession, long-term monitoring to quantify year to year variability is essential to identify emergent forest health issues or subtle changes indicative of chronic stress.

Driven by its mission to amass the information necessary to monitor and detect such changes and their impacts on forested ecosystems, the efforts of the VMC network over the past 25 years have resulted in 170 individual research and monitoring projects across the state of Vermont conducted by over 180 collaborators, investigating a range of forest, soil, water, wildlife, pollutant and climate relationships. While this includes many individual investigations relevant to understanding and sustaining healthy forest ecosystems, this report offers a sampling of the extraordinary amount of information that currently contributes to the VMC's long-term archive of ecological data. Our goal is to include both a summary of the latest year's data on key forest, wildlife, water, and air quality metrics, along with an analysis of the long-term patterns and trends in the data in order to provide a relevant and timely source of information on the current state of the region's forested ecosystems.

The information in this report is intended to be a snapshot of the larger body of monitoring and research that has been amassed over time, and which is growing daily. We have tried to include a subset of this work that is representative of the overall health and function of the forested ecosystem. This allows us to quantify forest health in 2014 in the context of long-term monitoring datasets. As an organization, VMC believes that the regular analysis and reporting of such information is critical to identify emerging forest health issues, as well as understand the drivers and impacts of ecosystem change.

Forest Health

Long-Term Canopy Condition and Regeneration Monitoring

Stress and disturbance are natural components of forest ecosystem dynamics, but the severity and frequency of such events may alter competitive regimes.

Forest monitoring plots, such as those measured at the VMC network of sites, provide long term data on forest health trends and responses to disturbances. This includes detailed measurements of decline symptoms, which provide information on subtle changes in forest condition that may not be apparent from aerial detection or citizen reports of declining trees. Monitoring the nature and severity of stress responses is essential to understanding how best to manage forest resources into the future.

The Data

In 1990, a systematic forest health detection program started in New England and grew to become the national Forest Health Monitoring program, aimed at detecting emerging regionally significant forest health problems. We have adopted key ecosystem measurement methods from this program in our permanent forest health monitoring plots, including a full inventory of tree species, canopy characteristics, stress symptoms and damage agents. The VMC plot network provides a unique opportunity to co-locate these forest health measurements with those of atmospheric, weather, wildlife, water, and soils conditions at the Mt. Mansfield and Lye Brook Intensive Research sites. This allows us to examine relationships among environmental changes, forest health, and ecological dynamics. In addition, the VMC monitoring plots are located in forests most sensitive to anthropogenic stressors such as climate change and acid deposition, providing early indications of potential problems that will affect a wider area of Vermont's forests. In 2014, the full network of pre-existing VMC plots were measured in the same year for the first time since 2007, and two additional plots were added in key areas across the state of Vermont to ensure that the long-term monitoring network is representative of forests across the state[1]. The 2014 field season included detailed canopy assessments of over 755 mature trees representing 16 different species.

2014 in Summary

Forest Health: There are many metrics used to assess the condition of tree canopies. The VMC data follows FIA's Forest Health Monitoring (P3) methods for crown health assessments including early symptoms of tree stress such as increases in foliage transparency, as well as more chronic decline metrics such as crown dieback and live crown ratio. Our assessment of 2014 showed that percent dieback was on par with typical measurements for all species except red maple and white ash, which showed slight increases in average percent dieback (Table 1). Similarly, percent transparency increased significantly for white ash, consistent with the 2013 record high for this species. While there is concern that the invasive emerald ash borer may spread into Vermont, there was no evidence of infestation on VMC plots. Change in mean diameter at breast height (DBH) for many species likely results from natural successional processes. And the decrease in mean American beech DBH likely results from mortality of larger stems, combined with an increase in the number of saplings entering the inventory. Beech bark disease is frequently associated with beech decline at these sites.

Table 1. Indicators of tree condition for selected dominant and codominant stems. The long-term and 2014 means are given, along with the magnitude of difference (Dif). Color in the difference column indicates when the change was greater than or equal to one standard deviation above (blue) or below (red) the mean.

	DBH (cm)			% Dieback			Live Crown Ratio			%Transparancy		
Species	*2014 Mean*	*Long-term mean*	*Dif*	*2014 Mean*	*Long-term mean*	*Dif*	*2014 Mean*	*Long-term mean*	*Dif*	*2014 Mean*	*Long-term mean*	*Dif*
Abies balsamea (Balsam fir)	18.0	19.0	-1.0	13	13	0	66	71	-5	22	19	3
Acer rubrum (Red maple)	31.1	29.4	1.7	8	7	2	51	49	1	21	20	1
Acer saccharum (Sugar maple)	27.1	24.5	2.5	6	6	1	55	57	-2	19	17	2
Betula alleghaniensis (Yellow birch)	32.2	33.1	-0.9	7	7	0	54	55	-1	21	19	2
Betula papyrifera (Paper or White birch)	20.1	20.0	0.1	12	11	1	41	44	-3	27	22	5
Fagus grandifolia (American Beech)	25.1	29.2	-4.0	11	11	0	55	58	-3	23	23	-1
Fraxinus americana (White ash)	30.0	28.5	1.5	10	8	2	53	36	17	27	19	8
Picea rubens (Red spruce)	23.6	22.4	1.2	7	7	0	50	54	-4	18	17	1
Quercus rubra (Northern red oak)	20.2	20.8	-0.6	5	5	1	42	32	10	15	17	-2

While the mean dieback (9.6 percent) across all key species in 2014 was not severe, it does represent an increase compared to 2013 (9.1 percent dieback). Over the full historical record, 2014 ranked in the 79th percentile for all dieback measurements (up from the 54th percentile in 2013). This increase in dieback symptoms was particularly notable for American beech (from the 25th percentile in 2013 to the 54th percentile in 2014), red maple (from the 17th percentile in 2013 to the 88th percentile in 2014), and white ash (from the 25th percentile in 2013 to the 75th percentile in 2014).

[1] In 2015, another 20 plots were added to the network

Regeneration: Similar to 2013, red maple regeneration dominated most plots, followed by American beech, and balsam fir (Figure 1). The high degree of variability across plots likely results from the broad geographic and elevational range of plots spanning several forest types. However, since most plots are located on mid-late successional stands the lack of regeneration of shade tolerant species such as sugar maple is concerning. Considering the species composition of mature trees across the VMC long-term monitoring plots (Figure 2) are dominated by red spruce and yellow birch at upper elevations, and sugar maple at mid- lower elevations, our data suggests that red maple and American beech are out-competing other regeneration. Considering the economic and ecological importance of sugar maple to the region continued monitoring of regeneration is warranted to understand the trends and patterns in sugar maple regeneration.

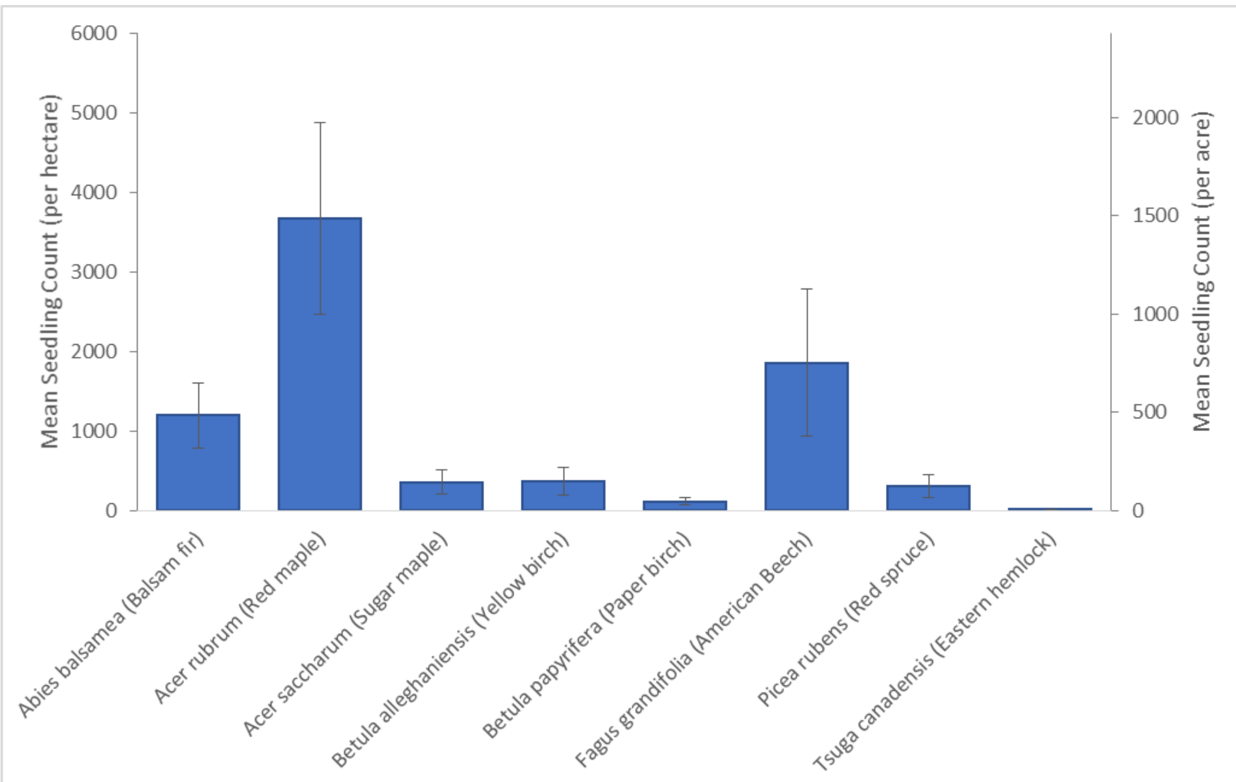

Figure 1. Mean number of seedlings per hectare (left axis) and per acre (right axis) at the VMC forest health monitoring plots in 2014 provide a picture of regeneration success and the potential composition of the future forest. Note the abundance of red maple and beech compared to sugar maple, yellow birch and red spruce, and the near absence of hemlock and paper birch.

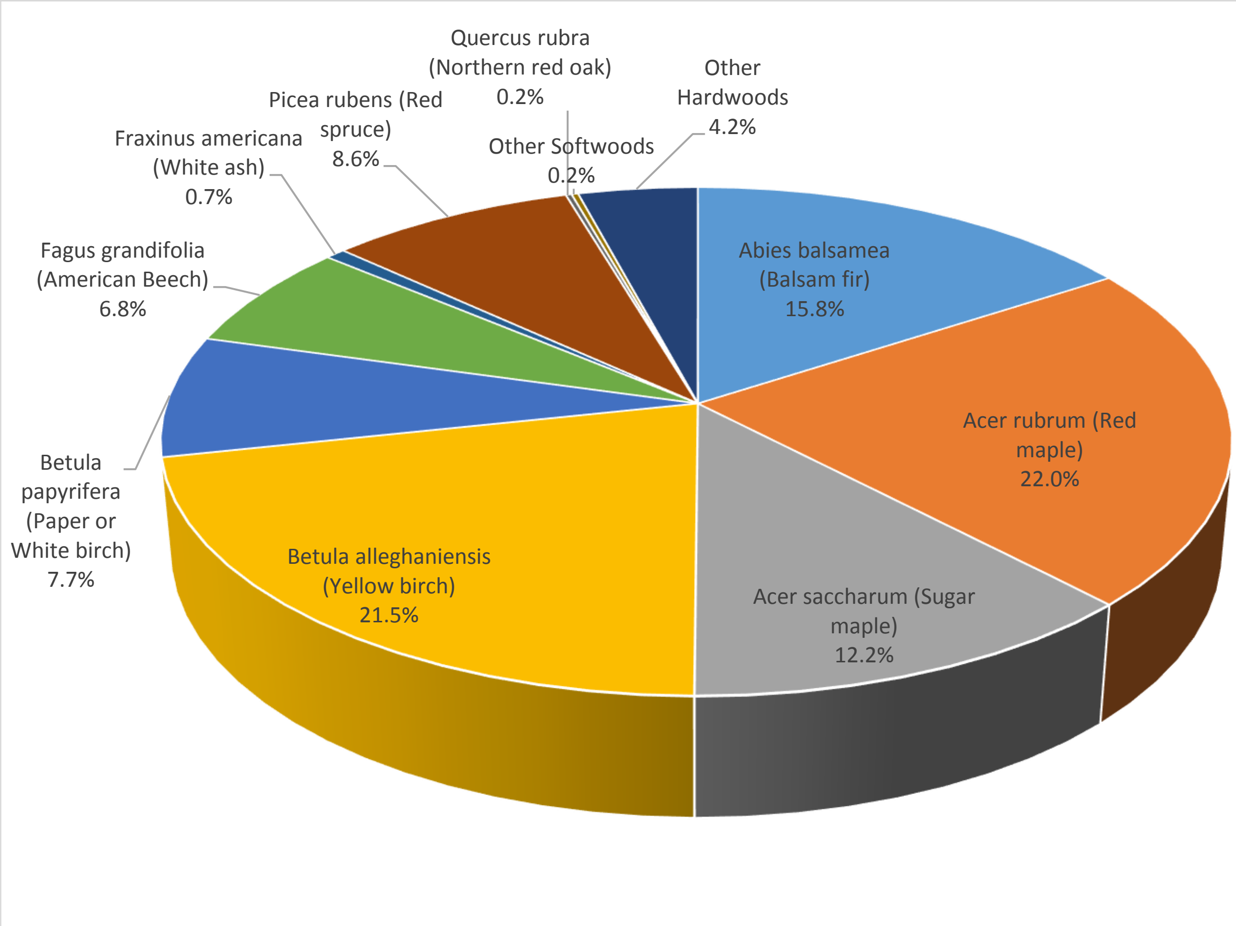

Figure 2. Species composition of all stems greater than 10cm diameter at the VMC long-term monitoring plots.

Long Term Trends

Forest Health: An examination of the full temporal data set allows us to look past the year to year variability to consider species recovery rates and identify more chronic stress conditions. Figure 3 fits a simple spline to the mean transparency and dieback for each species in each year. While there is clearly a large amount of year-to-year variability, the trends include a nearly uniform peak in percent canopy dieback in the late 2000's. Drought in 1999 and again in 2001-2002 were likely involved in these declines.

In contrast, mean transparency values over the past decade are nearly double the mean values in the 1990's for almost all species. This increasing trend may be reversing for most species except for yellow birch, white ash and paper birch. The VMC will continue to monitor these species to understand how changing environmental conditions are altering competitive relationships or altering productivity rates.

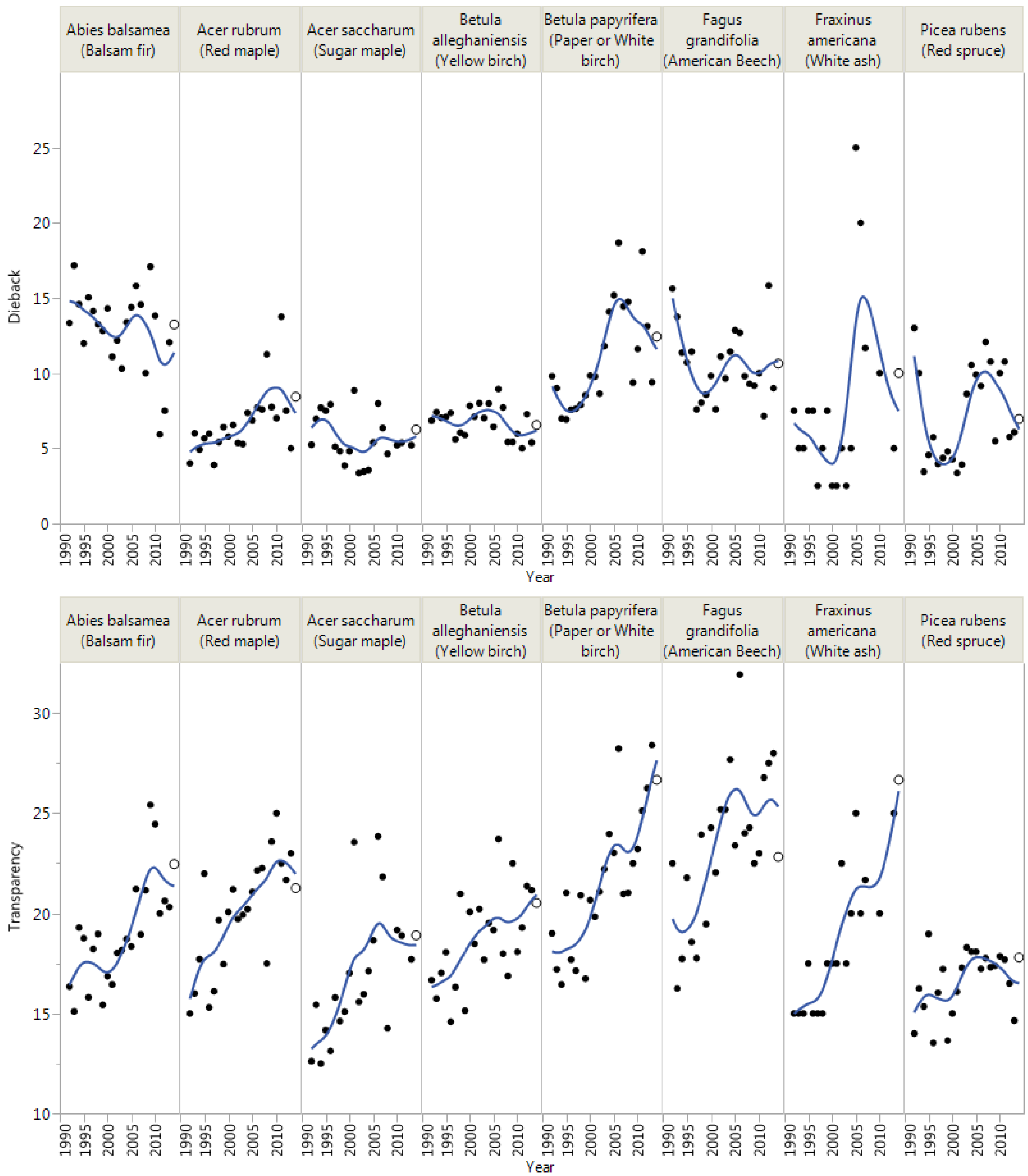

Figure 3. A simple spline fit to the plot mean dieback (top) and transparency (bottom) for each species in each year. Note the high year to year variability, and peak in dieback symptoms between 2007 and 2009 for most species. In contrast, transparency continues on an upward trend for white ash, yellow and paper birch.

Regeneration: While regeneration data is available for the full VMC monitoring network in 2013 and 2014, assessments prior to that time were sporadic. Limiting our analysis only to plots located in the Browns River watershed on Mount Mansfield, (6 total plots measured five times since 1992) we find that 2014 was a boom year for regeneration across all species relative to previous levels (Figure 4). This is likely attributable to the relatively wet spring, when seedlings are most sensitive to drought-induced mortality. The predominance of red maple seedlings is particularly obvious in this watershed.

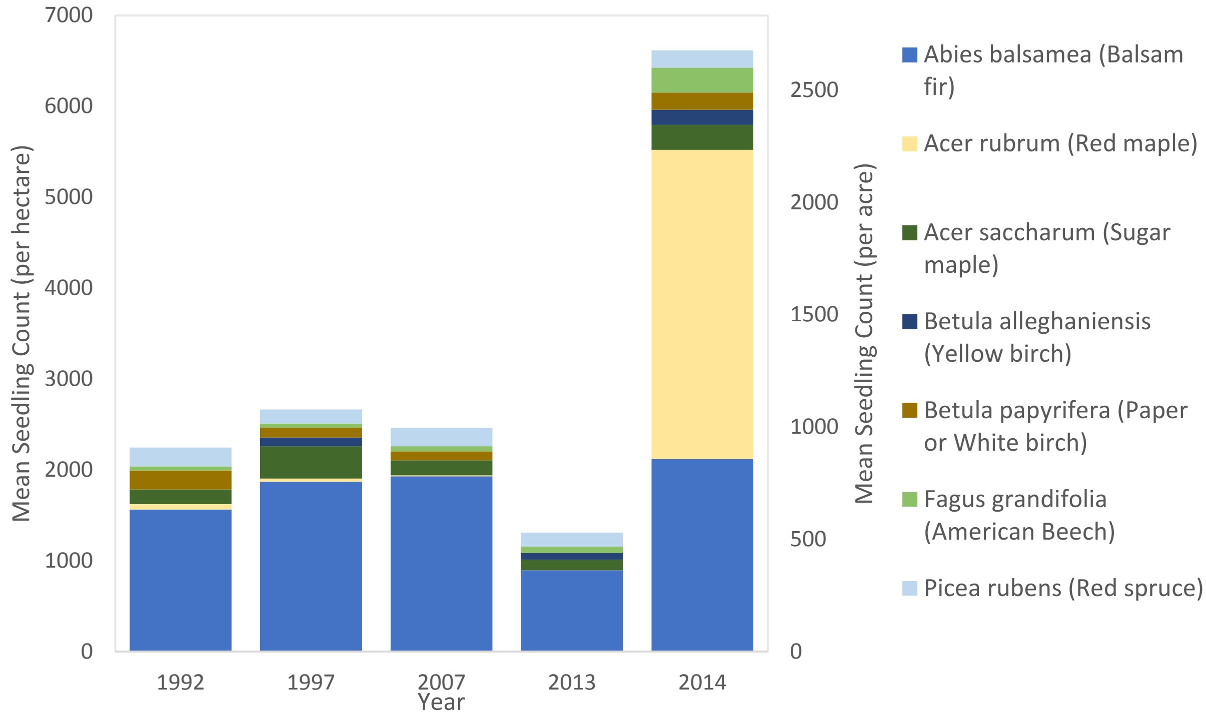

Figure 4. Mean number of seedlings per hectare (left axis) and per acre (right axis) at the six Mount Mansfield plots that were consistently remeasured for regeneration over the course of data collection. At the upper elevation plots regeneration is dominated by balsam fir, while red maple dominates the mid- and lower elevation northern hardwood plots.

Implications

VMC forest health monitoring has been instrumental in determining how trees respond to and recover from stress events. Our monitoring is able to detect subtle but steady changes that may not be captured by VT FPR aerial surveys or highly visible to the public. Overall, 2014 canopy decline symptoms were slightly worse than in previous years. Species that appear to be experiencing continued decline trends include American beech, red maple, and white ash. Species currently dominating regeneration may be creating a different mix for the future forest.

Forested ecosystems provide immeasurable benefits to society; from their aesthetic beauty and recreational opportunities to biomass energy and carbon sequestration. While the composition of forests may change, this ongoing work will inform forest management decisions to maximize the productivity and health of the forested landscape into the future.

Canopy condition has varied over the past decade but the failure of these metrics to return to 1990 levels for many species indicates the need for continued monitoring and research into the drivers of forest productivity and health across the region.

Additional Resources

VT Forests, Parks and Recreation Vermont Forest Health Highlights 2014. Online at http://fpr.vermont.gov/sites/fpr/files/Forest_and_Forestry/Forest_Health/Library/2014%20VT%20Forest%20Health%20Highlights.pdf

Investigating Causes of Mortality in Vermont, IN Forest Health Monitoring: National Status, Trends and Analysis 2014. Online at http://www.srs.fs.usda.gov/pubs/49266

VMC Project Database Link

Forest Health Monitoring: http://www.uvm.edu/vmc/project/forest-health-monitoring

Aerial Detection Surveys

Landscape Scale Forest Injury Assessments

Aerial sketch mapping provides direct recording of sketched disturbance features on a moving map display into a GIS model for data analysis.

The Vermont Department of Forests, Parks, and Recreation (VT FPR) and the US Forest Service conduct aerial surveys annually to map the extent and severity of current year forest injury. This type of landscape scale assessment compliments plot-level field assessments of forest condition and has proven useful in detecting new health issues.

While more complete results of the 2014 Vermont sketch mapping effort can be found in the 2014 report on Forest Insect and Disease Conditions in Vermont (VT FPR 2014), here we provide the long-term context for understanding the severity of forest injury in 2014 and trends worth watching.

The Data

Forest health aerial surveys have been a part of Vermont's overall forest health monitoring program for about fifty years. Statewide data is collected by the VT Department of Forests, Parks, and Recreation, while the US Forest Service collects data over the Green Mountain National Forest and other federal lands.

Surveys are aligned with US Forest Service Forest Health Monitoring Program survey methods and reporting standards. In addition to maps of forest damage, polygonal delineations include information on the cause, extent, severity and type of forest damages. In most years, this includes assessments covering the entire state (over 2.5 million hectares). While aerial detection surveys have been conducted for over 50 years, for this report, we limit the long-term analyses to the period from 1995 to 2014 due to inconsistencies in earlier digital survey data.

Aerial surveys provide the benefit of long-term statewide coverage. However, the user must recognize there are also limitations to the method. All data is acquired at speeds of over 100 mph and sketched onto maps. It is subject to variations due to weather, observers, and program priorities. Because subtle canopy damage is not visible from an airborne platform, it does not capture small scale disturbance or light decline from incipient stress agents.

2014 in Summary

In 2014, 15,463 hectares (38,235 acres) of forest damage were mapped statewide (Figure 5, *VT FPR 2014*). This represents less than 1% of Vermont's forestland, and an 80% decrease from 2013.

The non-native pest complex, beech bark disease, accounted for the most area with 36% of the total area mapped. Major defoliating insects did not reach outbreak levels. Anthracnose on maple, ash, and oak and *Septoria* on birch plummeted from recent years, with 2,489 hectares (6,150 acres) of these diseases mapped, compared to 51,649 hectares (127,628 acres) in 2013. White pine needle diseases did remain widespread in 2014, and the extent of damage was likely much larger than the 2,012 hectares (4,972 acres) that were mapped.

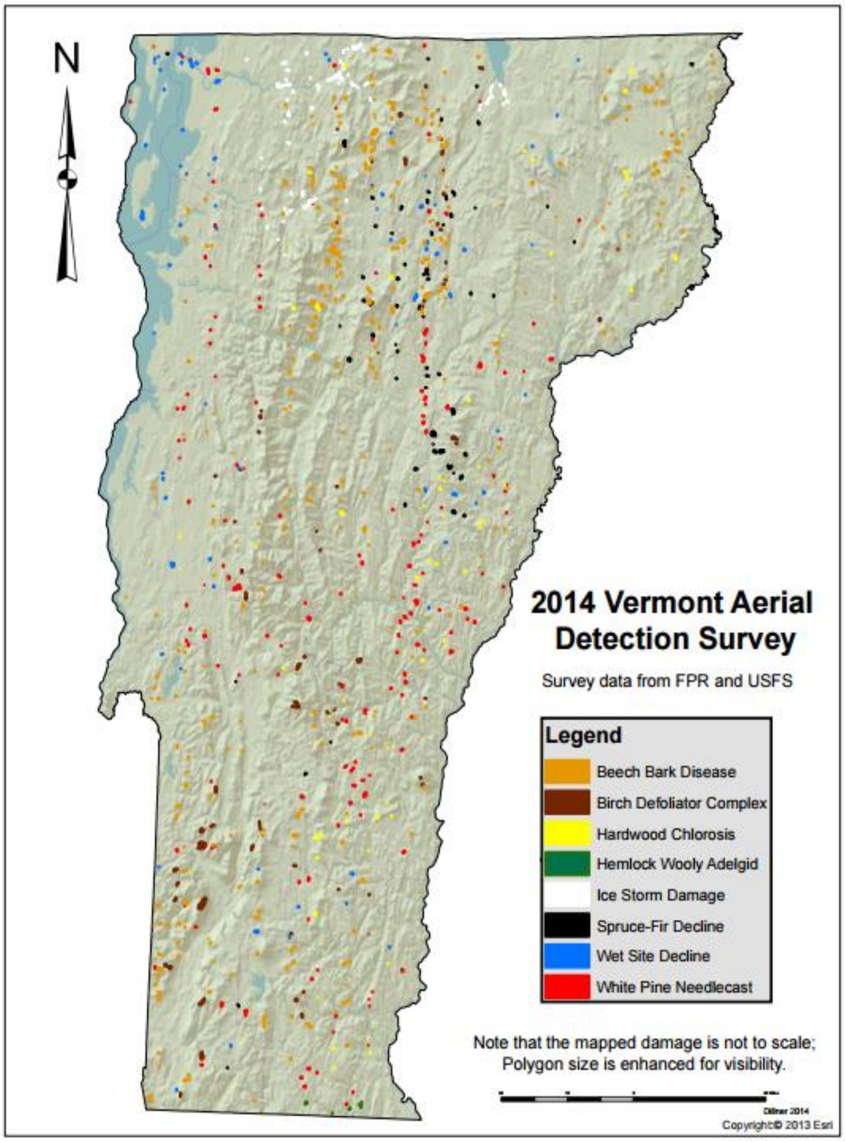

Figure 5. Locations of mapped forest damage by damage agent. Figure courtesy of VT FPR, Dillner 2014

Long Term Trends

While 2014 was a relatively healthy year for most species, the temporal data set allows us to look at long-term trends and to identify the most chronic stress conditions. Summing all damage types shows substantial year to year variability (Figure 6). Since 2005, total mapped damage area has generally declined, with 2014 reporting the smallest area mapped over the 20 year period. One factor this may reflect is ample growing season precipitation over most of the past ten years. However, if the extremely high 1998 ice storm damage year is excluded the yearly surveys show a more consistent trend over time.

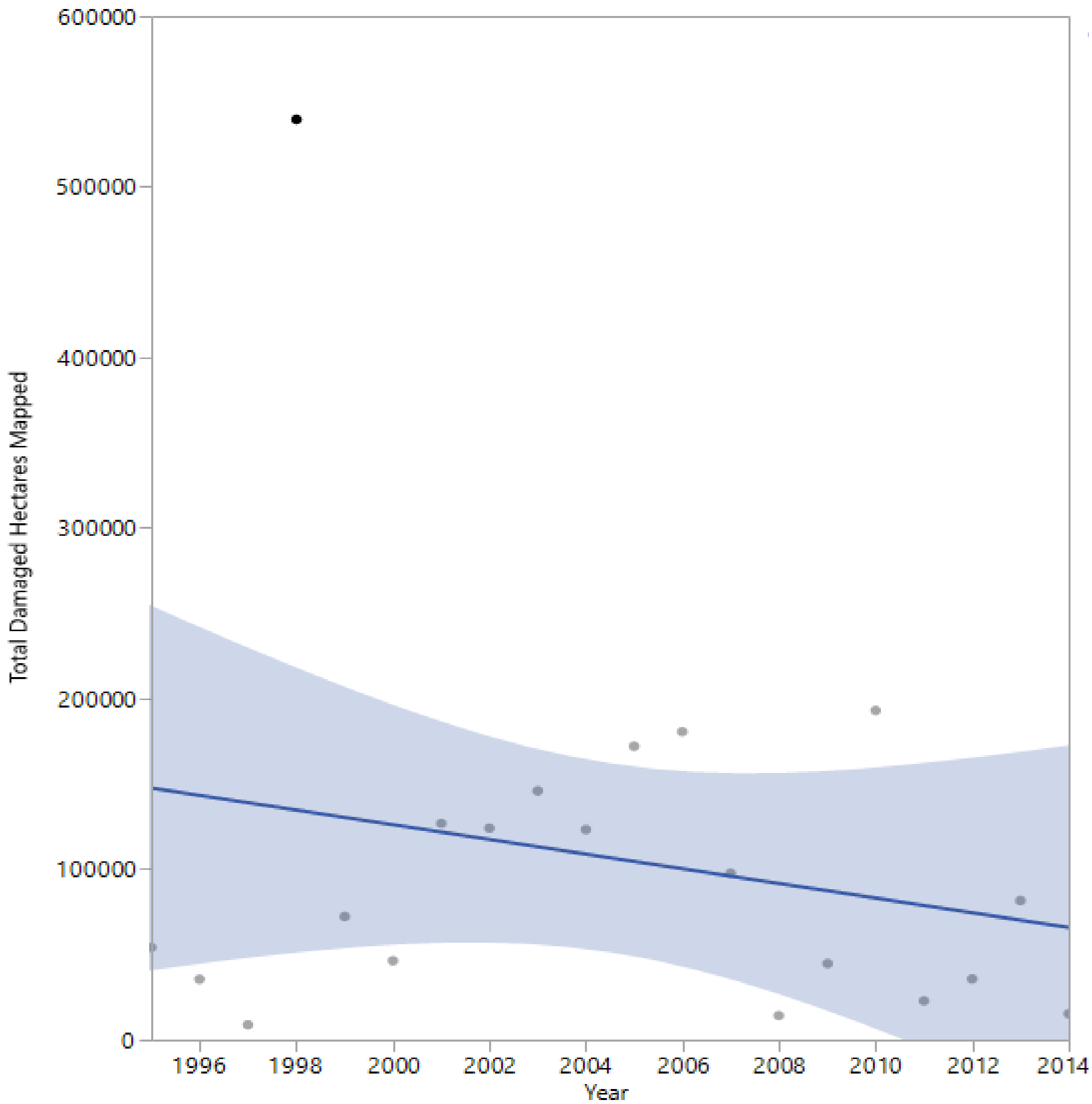

Figure 6. Total area (in hectares) of damage mapped during statewide aerial surveys between 1995 and 2014 with the 95% confidence intervals shaded in blue.

Long-term analyses of the five primary damage types recorded in the aerial survey data show that high year to year variability dominates (Figure 7). Branch breakage caused by the 1998 ice storm, was the most extensive damage type. In most other years, defoliation and discoloration were most widespread, but the agents that cause leaf damage have varied, including drought (2001), leaf fungi (2003 and 2013), forest tent caterpillar (2004-2006), and frost (2010). Dieback and mortality, the most severe damage types in terms of tree health, have been at low levels, particularly in the past five years, with dieback alone demonstrating a marginally significant decreasing trend in mapped area over the 20 year record (p = 0.07).

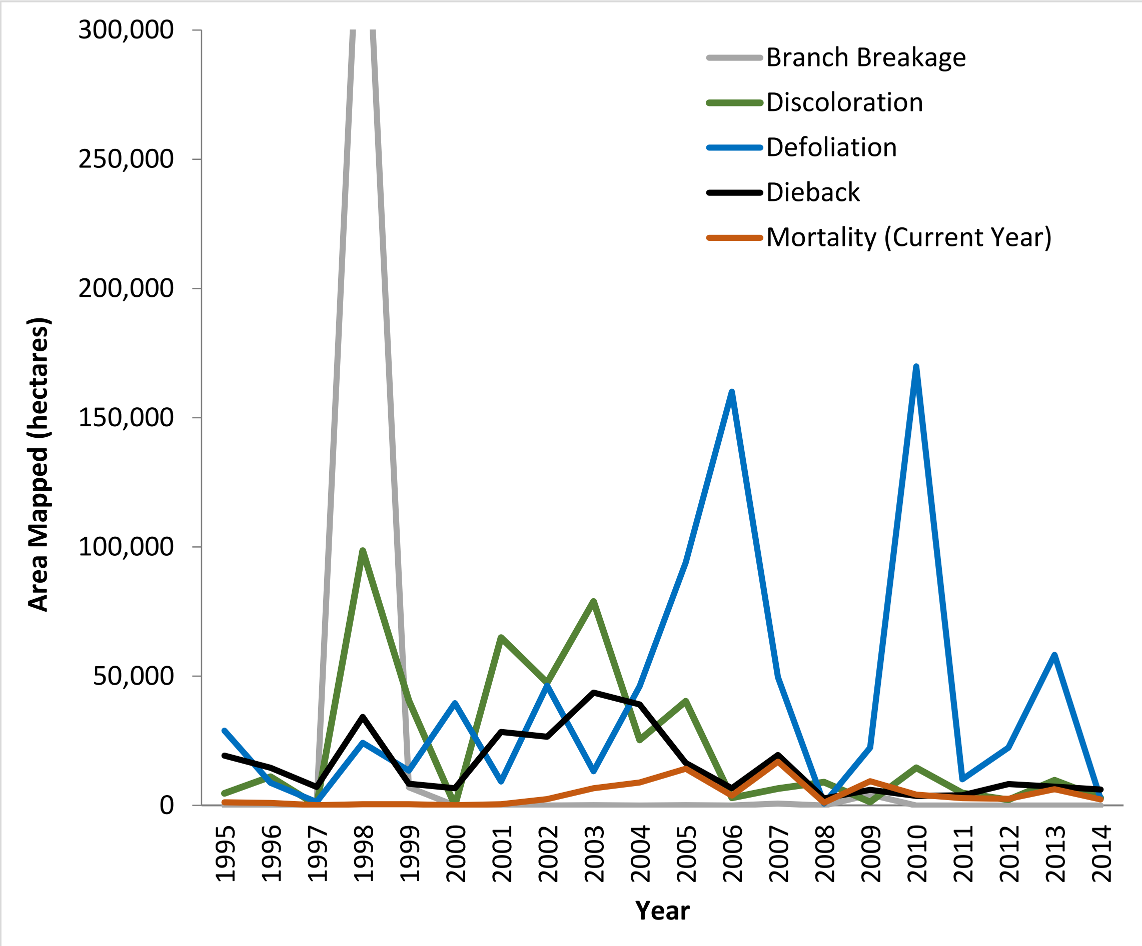

Figure 7. Temporal trends in key damage types mapped during statewide aerial surveys between 1995 and 2014.

Annual fluctuations of select damage agents are shown in Figure 8. The decrease in dieback after the early 2000's when there had been a period of dry years, coincides with a decrease in drought damage, hardwood decline and beech bark disease. The incidence of beech bark disease has dropped to almost a third of its peak levels. Anthracnose and forest tent caterpillar had peak years when they caused substantial damage, while birch defoliation has continued to fluctuate.

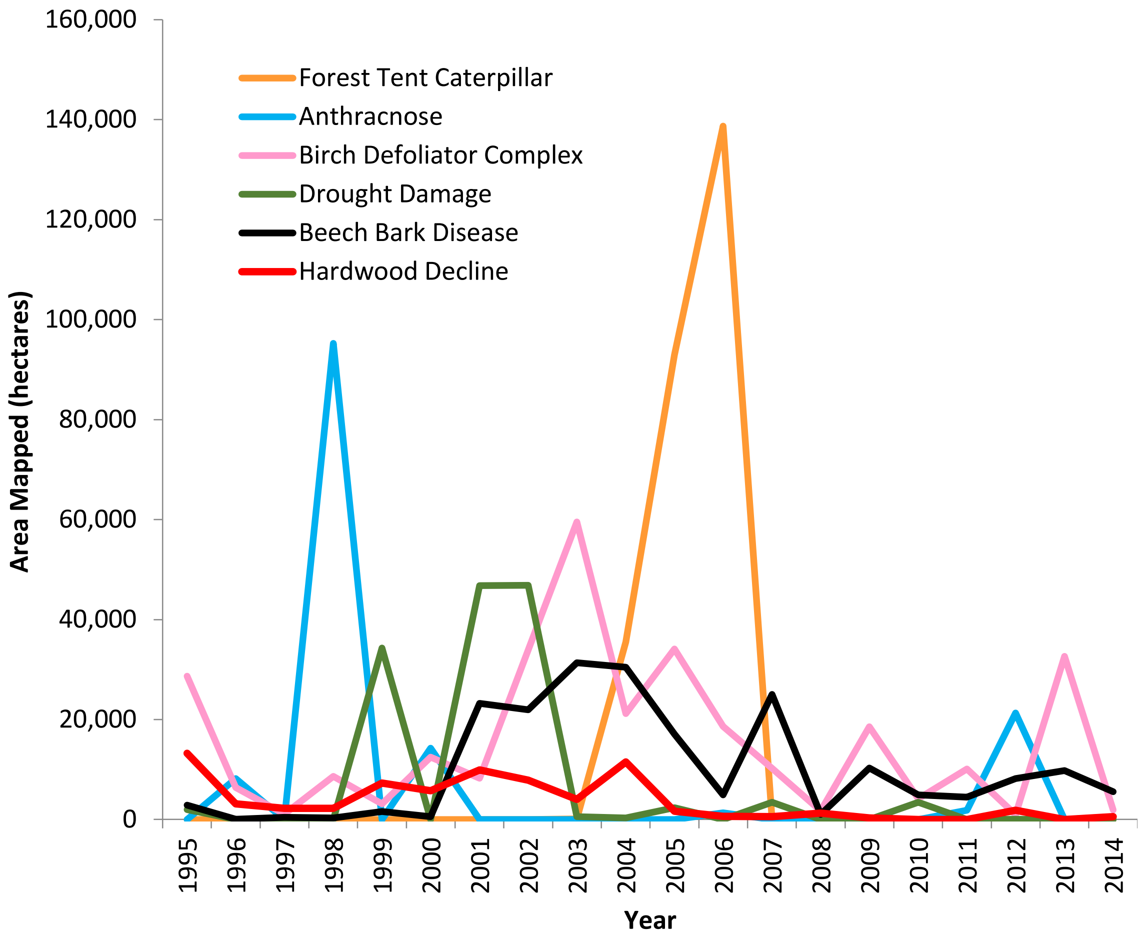

Figure 8. Temporal trends in select damage agents mapped during statewide aerial surveys between 1995 and 2014.

Fifty-eight different damage agents have been mapped since 1995. Table 2 shows only the 33 agents that were mapped in at least four different years during the 20 year study period. Birch defoliators, beech bark disease, and spruce-fir decline were mapped every year. Other commonly mapped damage agents include wet-site related decline, larch decline, logging-related decline, hardwood decline, and birch decline.

Table 2. Damage agents that were mapped in at least four different years between 1995 and 2014, including the number of years that the damage was detected and mapped, the total area mapped over the 20 year period, and the maximum number of hectares mapped in a single year.

Damage Agent Name	Number of Years Mapped (1995-2014)	Total Area Mapped (ha)	Maximum Area Mapped (ha)
Birch Defoliator Complex	20	316,356	59,519
Beech Bark Disease	20	204,201	31,346
Spruce-Fir Decline	20	33,842	6,753
Wet Site Related Decline	19	90,425	32,557
Larch Decline	19	7,311	1,586
Logging Related Decline	18	7,139	1,529
Hardwood Decline	17	74,259	13,263
Birch Decline	17	18,202	6,302
Wind Damage	16	5,382	2,464
White Pine Symptoms	14	2,041	815
Hardwood Chlorosis	13	24,354	7,760
Locust Leafminer	13	928	382
Fire	13	221	54
Drought Damage	12	140,256	46,864
Poplar Leaf Fungus	11	5,056	2,089
Willow Defoliation	11	1,176	802
Hardwood Defoliator Complex	10	50,058	41,503
Maple Leaf Cutter	10	31,062	11,908
Anthracnose	9	142,809	95,260
Balsam Woolly Adelgid Related Decline	9	13,323	3,637
Unknown	8	26,540	22,909
Pine Needlecast/Brown Spot Needle Blight	8	4,611	2,081
Hemlock Mortality	6	266	226
Ice/Snow Damage	5	394,785	381,843
Bruce Spanworm	5	1,465	1,304
Poplar Symptoms	5	354	197
Apple Scab	5	212	85
Forest Tent Caterpillar	4	267,376	138,734
Winter Injury	4	33,837	29,416
Arborvitae Leafminer Damage	4	1,051	442
Red Pine Symptoms	4	241	106
Ash Decline	4	96	39
Arborvitae Mortality	4	26	12

When the maximum extent of damage caused by specific damage agents is compared to number of years they were mapped, damage agents fall into three categories (Figure 9). Many cause only limited impacts; they occur infrequently and cause little damage (MINOR). Some have a locally important impact, occurring in many or most years, but rarely causing damage over a wide area (CHRONIC). Many chronic damages are related to site, as in drought, wet site, or many of the declines. Others are endemic pests, like birch defoliators and beech bark disease, that are host-specific, and cause repeated impacts only where their hosts are present and susceptible. The final group is infrequent but significant in extent of damage (EPISODIC). Some of these are directly related to weather events, like ice or frost damage. Others are biotic: insects with irruptive population cycles or fungal diseases that build up after repeated wet weather. These should be considered conceptual groups, as specific damage causing agents would be classified differently if another time period was examined.

No agents caused extensive damage on an annual basis. Several episodic stress events covering a broad area were mapped, affecting up to 20% of Vermont's forestland. Of the agents that were mapped frequently, none exceeded 3% of the state's forest in a single

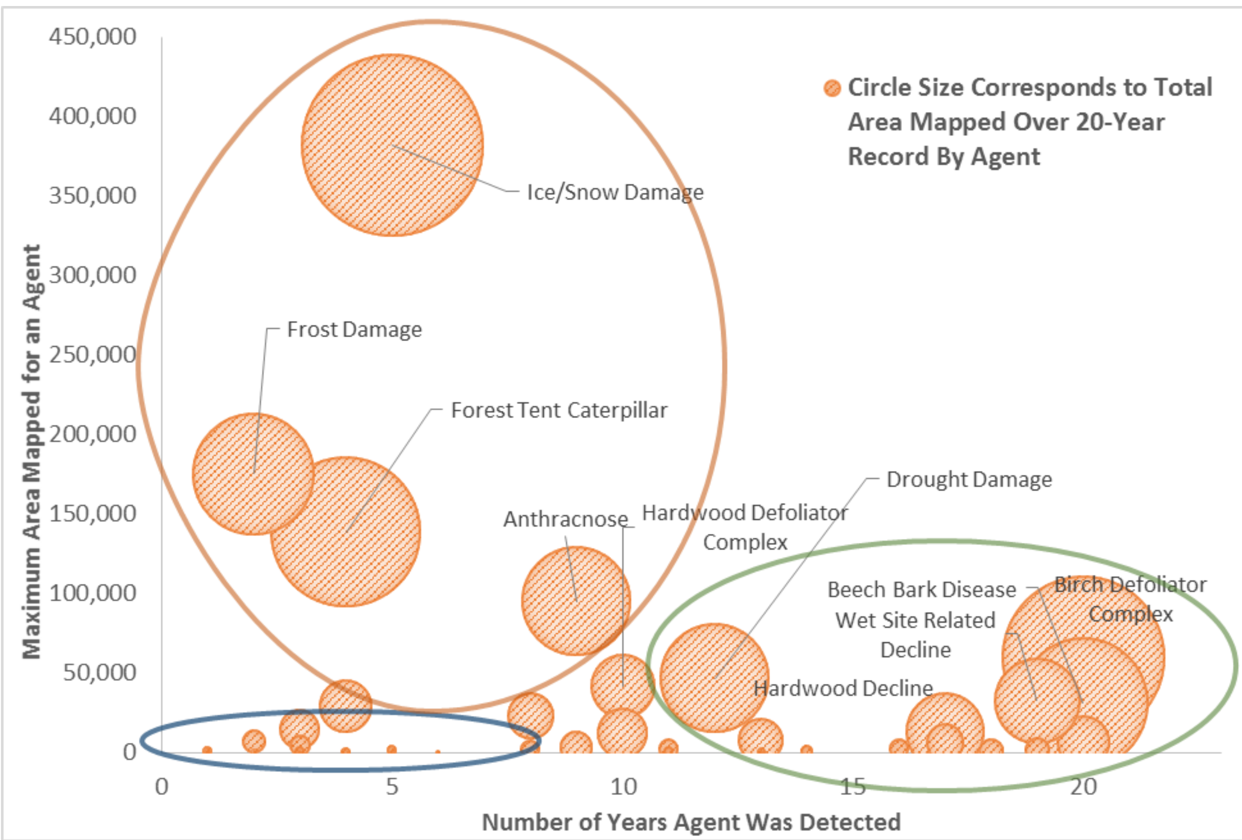

Figure 9. Mapped data points of the 58 different damage agents detected between 1995 and 2014. Damage agents are plotted by frequency of detection versus maximum extent mapped during aerial surveys, with point size corresponding to the total area recorded for that agent over the twenty-year period. The larger circles identify groupings of points into the minor (blue), chronic (green) and episodic (orange) categories described in the text.

year. However, some of the damages may be having a significant impact on individual hosts. For example birch defoliation was mapped during each of the twenty years, affecting nearly half the birch forest type in Vermont when at its peak.

Implications

Aerial surveys provide the longest statewide annual record of stressors faced by Vermont's forests. Over the past twenty years, only limited areas of dieback and mortality and relatively low levels of total damage have been mapped. This reflects a low occurrence of moderate or severe forest decline.

Agents that repeatedly cause extensive damage would be more likely to have significant impacts on ecosystem health, as has occurred recently in the western US, where an increase in bark beetles has caused substantial conifer mortality. In Vermont, several insect, disease, or weather-caused damages were mapped over a large area, but none were widespread for more than three years. However, annual damage to individual species, such as birch and beech, are cause for concern.

Fifty-eight different causes of damage were mapped, reflecting the complexity of Vermont's forests. Many pests and abiotic events are episodic, so a number of stressors which have historically occurred in Vermont were uncommon or not detected in this twenty year period. Many have the potential to cause widespread damage and leave the state's forests vulnerable to decline and mortality should they reemerge.

Moving forward, maintenance of long-term metrics will be essential. Several invasive insects and diseases have been detected close to Vermont's borders. Under a warming climate, increases are expected in extreme weather events, such as ice storms, wind, drought, and flooding, and in defoliator outbreaks. Annual aerial surveys will provide critical information about the impact of these stressors on the forest and help inform resource management.

Visible damage symptoms are mapped on approximately five percent of Vermont's forests each year. Mapped damage area in 2014 was relatively low, but the episodic nature of the most severe damage agents and increased intensity and frequency of disturbance predicted with climate change highlight the importance of ongoing monitoring.

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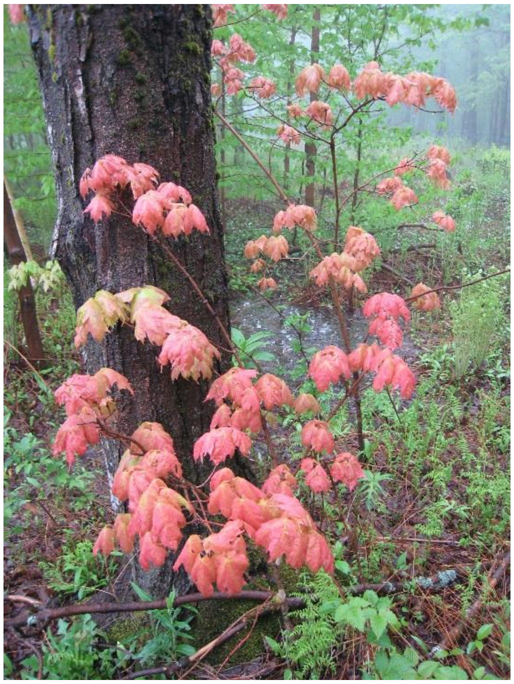
Additional Resources

VMC Project Database Links

Aerial Detection Surveys: http://www.uvm.edu/vmc/project/statewide-aerial-sketchmapping-tree-defoliation-mortality

Forest Health Monitoring: http://www.uvm.edu/vmc/project/forest-health-monitoring

Forest Phenology



Monitoring subtle changes in phenology can serve as an indicator of larger changes that can cascade through forest ecosystems.

Field Assessments of Sugar Maple Phenological Events

The timing of seasonal plant events, including springtime leaf expansion and fall senescence, has important implications for ecosystem processes. Long-term field assessments of tree phenology allow us to understand how changes in climate are impacting forested ecosystem. Subtle changes in the timing and duration of phenology may have widespread consequences throughout forest ecosystems. Current VMC data sets include visual assessments from 1991 to present of sugar maple (*Acer saccharum* Marsh.) bud break and fall senescence at two elevations on the western slopes of Mount Mansfield in the Green Mountains of Vermont.

The Data

Annual phenology assessments for sugar maple started each spring while buds were dormant and continued to full leaf expansion. Spring phenology was assessed twice weekly on five dominant sugar maple at the Proctor Maple Research Center, at an elevation of 415 m (1400 feet). At each date, ten tree buds per tree were assigned to one of 8 bud developmental stages (Skinner and Parker 1994). Average daily phenological stage was calculated from the mean of the five trees assessed.

Metrics of fall phenology included visual ratings of percent color and leaf drop, recorded weekly beginning in September on the same trees at the Proctor Maple Research Center. Additional sugar maple trees were also monitored at a site above the Underhill State Park at an elevation of 670 m (2200 feet). Percent color was assessed as the proportion of the current leaves exhibiting a color other than green. Percent leaf drop was estimated as the proportion of potential leaves missing. While these are subjective visual estimates, at important stages, such as full color or full leaf drop, the estimates are most reliable. After field data are collected, color estimates were recalculated as the proportion of initial fully foliated crown with color (actual color):

$$\text{Actual color (\%)} = 100 \times \left(\frac{\text{Percent field color}}{100} - \left(\frac{\text{Percent field color}}{100} \times \frac{\text{Percent leaf drop}}{100}\right)\right)$$

Tom Simmons of VT FPR retired in 2014 after collecting 23 years of phenology and many other forest health data sets.

The date of leaf drop can vary depending on weather events (e.g. rain and wind) and not necessarily when tree senescence begins. Our indicator dates of fall senescence were based on when trees had foliage that was all colored or dropped.

Temporal trends in spring phenology were assessed by examining the dates of two significant phenological events across 23 years of data: (1) first day of year (DOY) of bud break (phenological stage 4); and (2) first day of year of full leaf expansion (phenological stage 8).

Fall phenology was similarly examined by comparing the timing of two significant fall phenological events across time: (1) the day of year (DOY) with maximum fall color observed in the canopy; and (2) the day of year (DOY) on which all tree's leaves had either colored or fallen from the canopy. Yearly anomalies for all phenological events were calculated by comparing each year's data to the mean value for the entire measurement period. Linear regression was performed to assess the change in timing of each seasonal developmental event across the 23 year period.

2014 in Summary

The day of year of first bud break in 2014 for sugar maple (DOY 132) was considerably later than the long-term average (DOY 124). Green-up was more rapid than the long-term average of about 12 days – in 2014, there was just one week between bud break and full leaf-out. At lower elevation, maximum fall color occurred at the same time as in 2013, but full leaf drop came 9 days later than last year and nearly 4 days later than the long-term mean. At higher elevation both stages occurred later than last year and closer to the long term means, with fall color 2.3 days earlier and leaf drop 1 day later than the long-term means.

Long Term Trends

While 2014 was consistent with the long-term mean, a trend toward an earlier start of spring was observed in the long term dataset as evidenced by both earlier bud break and earlier full leaf expansion dates. The changes in fall development similarly showed trends which would lengthen the growing season by delaying fall senescence. The timing of maximum fall leaf drop had the strongest and most statistically significant response of all the phenological variables considered in this study, with an almost 9 day delay over the 23 year record at the lower elevation site.

High variability in our spring phenology data is likely the result of our low sample size (n=5) for each year. As such, it is difficult to make statistical inferences for bud burst ($p = 0.34$) or leaf out ($p = 0.25$). Nevertheless, there does appear to be a weak trend for earlier spring phenological measures since the beginning of our monitoring efforts (Figure 10).

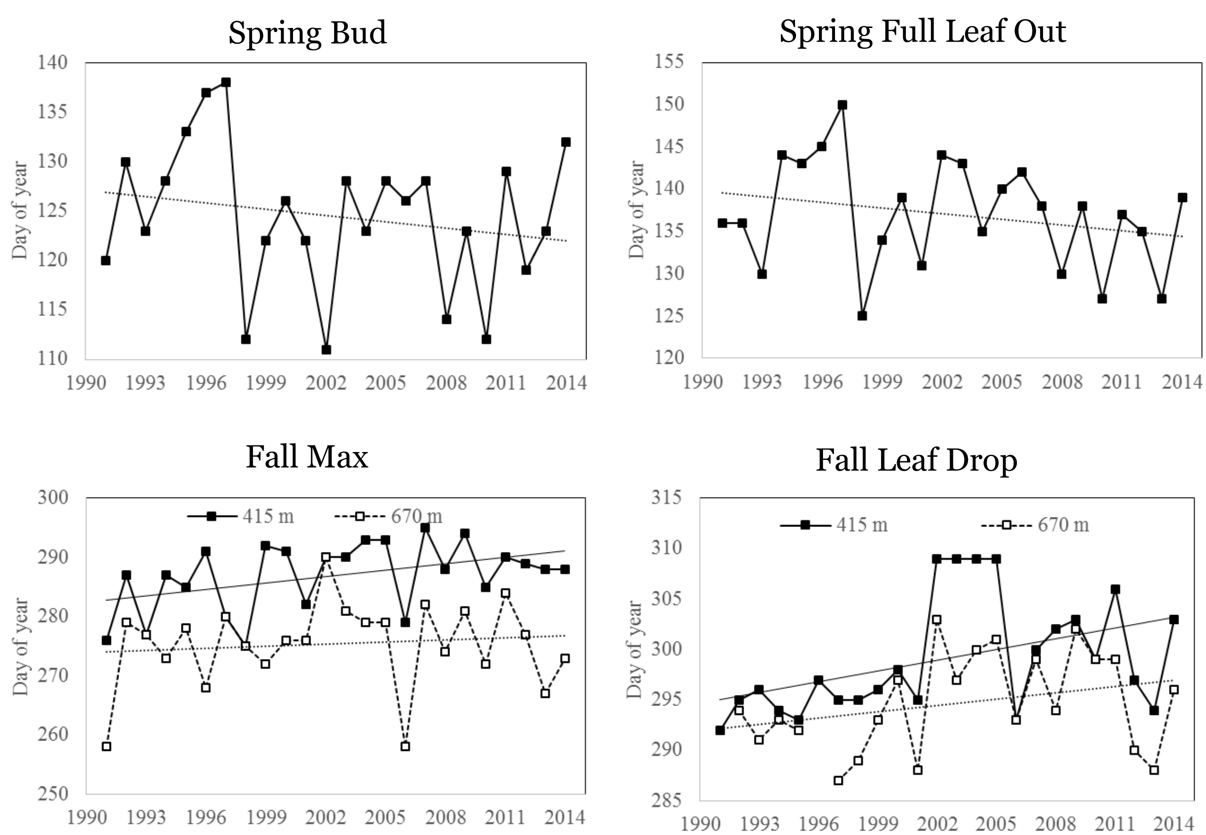


Figure 10. Long-term trends in the timing (mean day of year) of spring and fall phenological events for sugar maple from 1991 to 2014. Spring bud burst (top left) and full leaf out (top right) are assessed yearly at lower elevation (415m), with linear trend line shown. Fall maximum coloration (bottom left) and leaf drop (bottom right) yearly data are shown for sugar maple at two elevation (415m and 670 m) as well as a linear trend line in both.

Significant trends towards later fall color and leaf drop at lower elevations continue to be observed. The delay of maximum fall colors at low elevations showed significantly later peak foliage over time ($p = 0.03$), culminating in an average delay of 8.4 days across the data record. Fall leaf drop similarly had a statistically significant delay ($p= 0.03$) with a cumulative 8.2 day delay in drop at low elevation. Trees at upper elevation, on the other hand, did not show a trend of changing fall phenology for either of the fall metrics.

These trends toward earlier springs and later falls are consistent with trends reported in earlier analyses of the VMC data set (see http://www.uvm.edu/vmc/reports/SugarMapleSpringPhenology_Mansfield2010.pdf)

Implications

There is mounting global evidence for trends of changing vegetation phenology, including earlier spring leaf out and later leaf senescence in the fall. As found in the 2013 data, analysis of 2014 and the long-term trend continues to indicate that phenology of sugar maple trees may be changing in accordance with globally observed patterns. Once again, changes in fall phenology were not observed in sugar maples growing at upper elevations, which continues to be surprising given model data suggesting that warming due to climate would be more extreme at higher elevations (Giorgi et al. 1997), however these documented models relied on winter temperature cues. Exploring microclimatic differences at each elevation are necessary to tease apart the possible mechanisms behind differing phenological responses of trees at the two sites.

The changes we observed in the timing of foliar development carries important economic repercussions for Vermont's maple syrup and tourist industries. Vermont is the largest producer of maple syrup in the United States, accounting for 41% of the country's production and earning 50 million dollars in 2011 (Sawyer et al. 2013). Tapping schedules are generally determined by tradition (Frumhoff et al. 2007), but warmer winters and earlier springs are now shortening and advancing the sugaring season (Skinner et al. 2010). Maple syrup producers will need to employ new management techniques for the industry to adapt to the changing climate (Frumhoff et al. 2007, Skinner et al. 2010). Similarly, these changes are relevant to the state's tourism industry which relies on leaf peeping tourists in autumn. The tourism industry may include altered schedules and expectations for peak foliage.

These results carry implications for water cycling in forests, as earlier springs may escalate evapotranspiration resulting in increased periods of low stream flow during the peak growing season (Daley et al. 2007). Although a longer growing season typically increases forest productivity, carbon sequestration dynamics could be altered by water limitations in Northern hardwood forests. While growing seasons may initially create a carbon sink, productivity of the region's forests will likely be water and nutrient limited over the long term.

Indeed, climate change is accompanied by much uncertainty regarding the future of the region's forests. Increased pest outbreaks, range shifts leading to increased competition between species, and water limitations are some of the stressors that will face sugar maple trees in Vermont. Knowledge regarding the alteration of seasonal developmental events and the consequent lengthening of the growing season provides an ecologically and economically relevant backdrop to these environmental changes.

Despite a later-than-normal spring in 2014, sugar maples continue to show a trend towards earlier spring and later fall phenological events. Earlier springs may shorten the window for maple syrup production.

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Additional Resources

VMC Project Database Links

Bud Phenology: http://www.uvm.edu/vmc/project/tree-phenology-monitoring-bud-development.

Fall Color and Leaf Drop: http://www.uvm.edu/vmc/project/tree-phenology-monitoring-fall-color-leaf.

Acid Deposition

National Atmospheric Deposition Program/National Trends Network

Automated Precipitation Collector at the VMC Air Quality Site in Underhill. Sampling at this site started in 1984.

Atmospheric deposition monitoring programs provide an important foundation for environmental research. As atmospheric inputs accumulate on the landscape over time there have been numerous studies documenting the cascading impacts on ecosystems, such as the dieback of red spruce in the 1970s and 80s. Long-term atmospheric deposition monitoring has been a cornerstone of VMC monitoring and research, providing key information on the sources of pollution, trends in deposition rates and impacts on forested ecosystems. Today, this information is necessary to understand how air quality policies have ameliorated acid deposition across the region, and to inform future policy and management decisions to sustain the health of the region's forested ecosystems.

The Data

Atmospheric deposition monitoring has been conducted by the Vermont Monitoring Cooperative for over thirty years at the Proctor Maple Research Center and Lye Brook Wilderness Area in southern Vermont (monitoring station located in Bennington). These stations are part of several national (The National Atmospheric Deposition Program – NADP, National Trends Network – NTN, Atmospheric Integration Research Monitoring Network -AIRMoN) or statewide (Vermont Acid Precipitation Monitoring Program - VAPMP) networks, which enable the monitoring of spatial and temporal patterns of acidic deposition.

Here we examine the NADP/NTN datasets collected at the Proctor Maple Research Center on the western slopes of Mount Mansfield, Vermont. This record contains a 30-year record of pH, NO_3 and SO_4 measurements for weekly composite precipitation samples. These networks consists of over 200 sites in the continental U.S. allowing us to better understand trends in acid deposition in Vermont and how they compare to other regions.

2014 in Summary

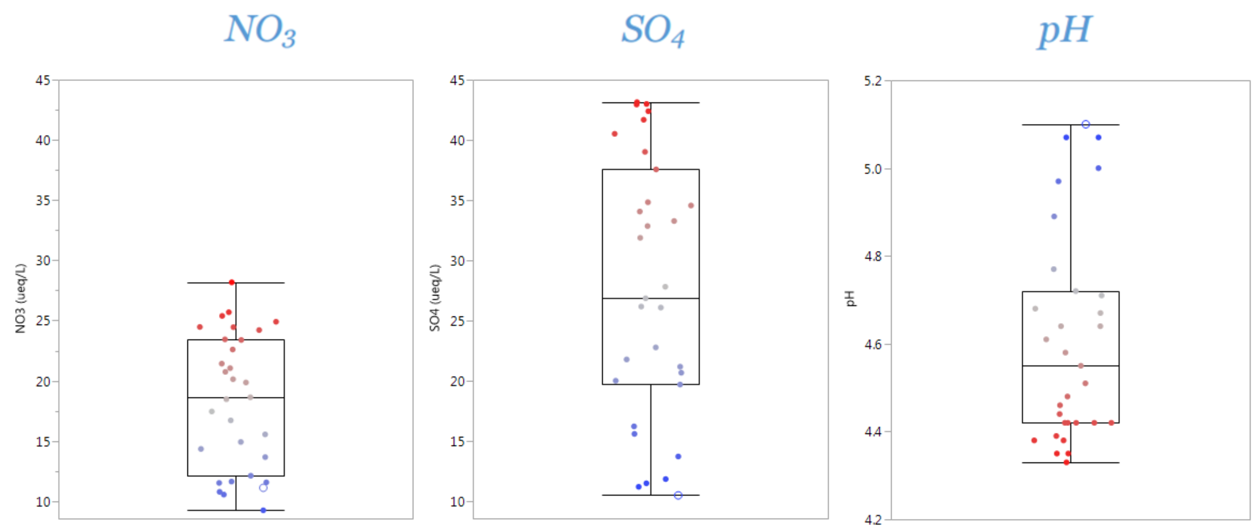

Figure 11. Quantile box plots show that 2014 (blue open circle) was a near outlier year, with the lowest mean SO_4 concentrations (middle) recorded and highest mean pH (right). NO_3 concentrations (left) were also in the lowest quartile, although not at record low values. Each dot represents a yearly mean value, with earlier dates in red and more recent dates in blue.

For all three deposition metrics (pH, SO_4 and NO_3), 2014 continued the trend of reduced pollution concentrations (Figure 11, Table 3). pH was the best year on record with a mean weekly composite over 5.0 ("unpolluted" rain typically has a pH of 5.6). When monitoring began in 1984, the pH of rain and snow samples was about 4.4. As pH is a logarithmic scale this represents a roughly fivefold improvement in acidity.

Similarly, SO_4 concentrations were at record lows in 2014. While NO_3 was also in the lowest quartile for the 30 year record, this marks the second year in a row where NO_3 deposition exceeded that of SO_4. In the early years of acid rain monitoring in Vermont, sulfates accounted for about 2/3 and nitrates 1/3 of the acidity in our precipitation. Over time, upwind emissions of both sulfur oxides (SO_X) and nitrogen

Table 3. Summary statistics for NO_3, SO_4 and pH for 2014 and the long-term record.

		NO_3 (ueq/L)	SO_4 (ueq/L)	pH
2014	*2014 Average*	11.11	10.48	5.07
Full Record (1984-2014)	*Long-term Average*	18.33	27.58	4.61
	Standard Deviation	5.60	10.89	0.24
	Minimum	9.24	10.48	4.33
	Maximum	28.18	43.14	5.10

oxides (NO_X) have declined. However, the reductions in SO_X have been proportionately greater than reductions in NO_X. Nitrogen deposition is expected to become a more important factor in the future, especially since emissions and deposition of reduced nitrogen (NH_X) have not yet declined.

Long-term Trends

The VMC record on acid precipitation dates back to the early 1980s. Over that time, acid deposition in Vermont reflects decreasing emissions resulting from the Clean Air Act amendments in 1977 and 1990. This includes decreases in both sulfate and nitrate pollution, and a corresponding increase in precipitation pH. However, the most significant reductions are witnessed in sulfate, with more modest changes in nitrate. These trends are consistent with those reported at other NADP sites in the Northeast.

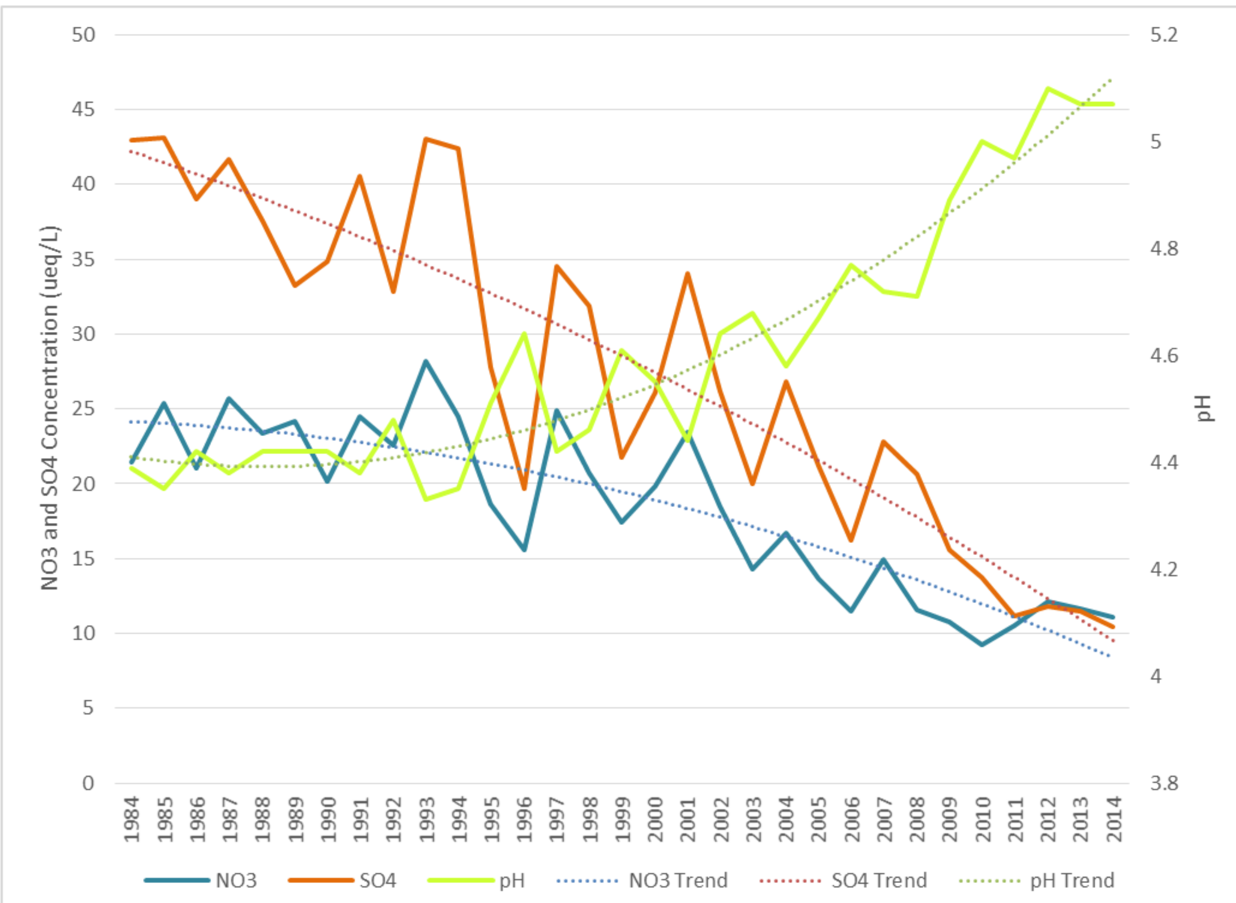

Figure 12. Long-term trends based on yearly mean concentrations (ueq/L) and pH highlight the success of the amendments to the 1990 Clean Air Act.

Nitrogen deposition is becoming a more significant driver of acid deposition as reductions in sulfur emissions continue (Figure 12). Nitrogen emissions are declining more slowly due to the difficulty of removing nitrogen compounds from flue gases and motor vehicle exhaust and from the diffuse sources of these compounds arising from agriculture. Although nitrogen "hotspots" can still be found near utility boilers, much of this type of pollution comes from fertilizer use and from confinement farming such as feedlots and poultry operations.

Vermont is in relatively good shape with respect to nitrogen pollution nationwide (Figure 13). However, the Green Mountains show the susceptibility of mountain ecosystems due to more frequent exposure to acid mist in clouds and higher levels of precipitation. As nitrogen becomes a more important constituent of acid deposition, monitoring networks and modelers are combining resources to better understand the spatial and temporal patterns of nitrogen deposition.

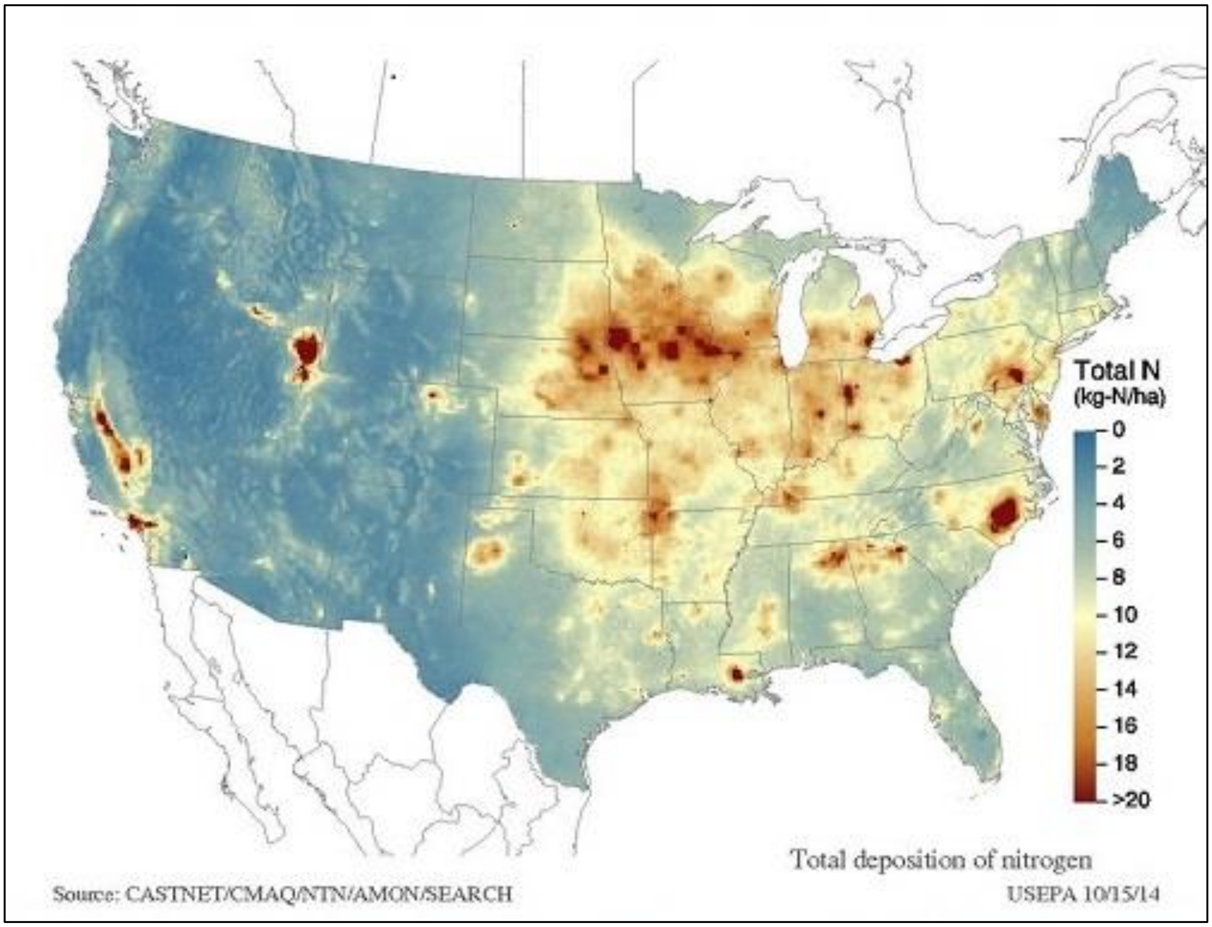

Figure 13. 2013 spatial distribution of total nitrogen deposition across the continental US. All three monitoring networks that collaborated to produce this map are represented at the VMC air quality site in Underhill.

Implications

Acid deposition is a regulatory success story, but high elevation forests remain sensitive to acid deposition due to thin soils with low buffering capacity and increased exposure to acid deposition from cloud cover and more frequent precipitation events.

Additional Resources

National Atmpospheric Deposition Program. http://nadp.sws.uiuc.edu/

EARTH: The Science Behind the Headlines. American Geosciences Institute. http://www.earthmagazine.org/

VMC Project Database Link

National Atmospheric Deposition Program/National Trends Network (NADP/NTN) http://www.uvm.edu/vmc/project/national-atmospheric-deposition-programnational-trends-network

Hg

Mercury Deposition

Mercury Deposition Network Monitoring at VT99

Long time site operator Mim Pendleton collecting a mercury sample at the Aerochemetrics collector.

Mercury is a persistent pollutant that can accumulate in organisms as it moves up the food chain, leading to neurological damage, lowered reproductive success, motor skill impairment and hormonal changes in humans and animals (Driscoll et al. 2007, Evers et al. 2004). Human activities such as fossil fuel burning and waste incineration elevate levels of atmospheric mercury, which is later transferred to forests and waterbodies through both dry and wet (in precipitation) deposition. Since 1992, VMC has been collecting data on both wet and dry mercury deposition and the mechanisms of mercury cycling, making it one of the longest records in the U.S. In 2004, the VMC joined the Mercury Deposition Network (MDN, part of the National Atmospheric Deposition Program) as one of over 120 sites in the US and Canada. The VMC air quality site serves as a sentinel site for the northeast coast of the continent – it is high enough in elevation to detect regional mercury transport events that are not detected by other stations. This very long record has provided context to many shorter-duration studies, including the way mercury cycles through the forest canopy[2], how mercury bio accumulates in birds[3] and amphibians[4], how mercury levels are influenced by elevation[5], and how falling leaves contribute to deposition[6]. VMC and its partners have committed to this long-term monitoring in order to document and better understand the input of mercury into Vermont's forested ecosystems and the inhabitants of those ecosystems, including birds, fish, bobcats and human beings.

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[2] Mercury Flux at PMRC - http://www.uvm.edu/vmc/project/mercury-flux-pmrc
[3] Bicknell's Thrush Population Demographics and Ecology: Assessing levels of methylmercury in montane forest bird community on Mount Mansfield - http://www.uvm.edu/vmc/project/bicknells-thrush-population-demographics-ecology-assessing
[4] Mercury Burdens in Amphibians - http://www.uvm.edu/vmc/project/mercury-burdens-amphibians
[5] Cloudwater Chemistry on Mount Mansfield - http://www.uvm.edu/vmc/project/cloudwater-chemistry-mount-mansfield
[6] Litterfall Mercury Dry Deposition in the Eastern USA - http://www.uvm.edu/vmc/project/litterfall-mercury-dry-deposition-eastern-usa

Hg

Mercury Deposition

The Data

VMC conducts year-round sampling of precipitation chemistry at the air quality monitoring site at the Proctor Maple Research Center in Underhill, Vermont. Weekly composites of precipitation are gathered in an automated wet-only precipitation collector at the site. The collector opens automatically when rain or snow is detected, capturing precipitation through a funnel and tube sampling train into a bottle charged with hydrochloric acid (to better preserve the sample). The collector is heated in the winter and vented in the summer as needed. Samples are collected every Tuesday and shipped to the Mercury Analytical Laboratory at Eurofins Frontier Global Science, Inc. in Bothell, WA for analysis of mercury content and cleaning of the sampling train. Data are submitted to NADP for quality control and posted on the NADP/MDN website (http://nadp.isws.illinois.edu/data/MDN/).

2014 in Summary

Mercury monitoring at VMC's air quality site (VT99) for 2014 shows lower deposition than on average for the 10 year record (Table 4). However, 2014 was still well above the lowest years on record (2009 and 2012). Over the entire record for VT99 total mercury deposition fluctuated from a high of 11,609 ng/m² in 2007 to a low of 6,127 ng/m² in 2012. Similarly, the precipitation-weighted mean mercury concentration and the maximum mercury concentrations measured at VT99 do not exhibit any clear trend, although for 2014, both were below the mean for the entire record. It is unlikely that a downward trend will appear until the hotly contested EPA rules concerning mercury are put in place.

Table 4. Precipitation-weighted mean yearly Hg concentration (ng/L), maximum Hg concentration (ng/L) and total Hg deposition (ng/m²) reported at the VT99 site. The color scale represents the lowest (green) and highest (red) years for a given metric. 2008 is excluded because an insufficient number of valid samples were collected.

Year	Precipitation-weighted Mean Hg Concentration	Max Hg Concentration	Total Hg Deposition
2005	5.58	33.9	7,416
2006	5.18	97.2	7,855
2007	8.74	131.6	11,609
2008			
2009	5.27	33.7	6,290
2010	5.55	48.0	8,369
2011	6.12	88.7	9,609
2012	4.73	63.9	6,127
2013	5.78	21.1	8,074
2014	5.25	11.5	7,231
Overall Mean	***5.80***	***58.8***	***8,064***

Comparison to the Regional MDN Network: Examining the total Hg deposition across the region (depicted in Figure 14), the VT99 site has reported some of the highest and lowest total deposition across the time series. This highlights the variable nature of Hg deposition and the need for continued monitoring. Perhaps more concerning is the reduction in the number of reporting sites as time has progressed. Because of funding shortfalls, four of the nine MDN sites across our region are no longer collecting data. This places additional emphasis on the remaining six sites to measure the trends in Hg deposition for our region. Also of concern is the lack of significant reductions in Hg deposition across the region.

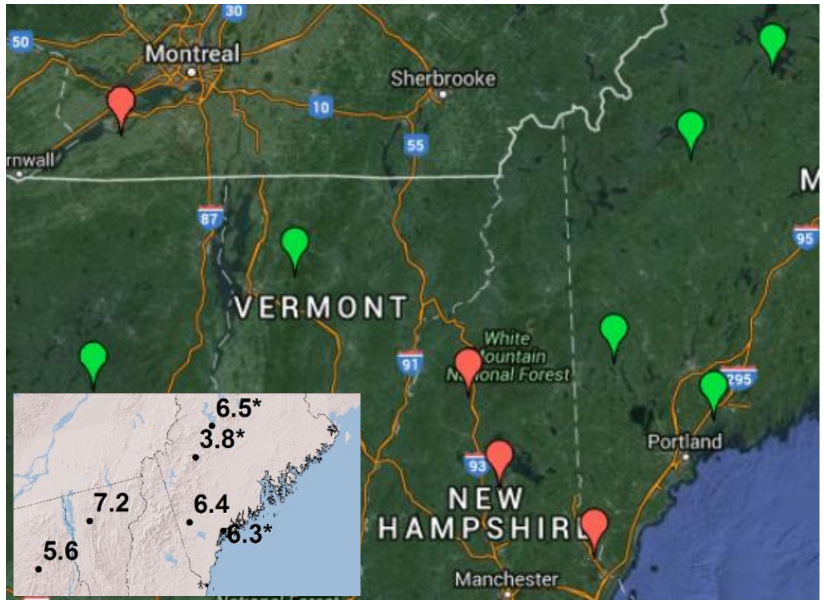

Figure 14. Of the 9 US Hg monitoring sites across the region from the Adirondacks to central Maine, only six remain in operation today (closed sites in red). Inset: Regional deposition totals for 2014 (NADP 2014, except those with asterisks which were calculated by VMC).

Long Term Trends

Examination of the full data record at VT99 suggests that Hg deposition has decreased from the peak deposition in the mid- 2000's, though variability remains quite high. Since Hg deposition and concentration measurements began at VT99 in 2004, there has been no statistically significant trend, either increasing or decreasing (Figure 15). While the severity of spikes in both Hg concentration and total Hg deposition are lower than measured in previous years, a higher baseline average for most precipitation events has the tendency of slightly (although not significantly) increasing deposition rates in recent years. The higher elevation of the VT99 site makes it more sensitive to regional transport events,

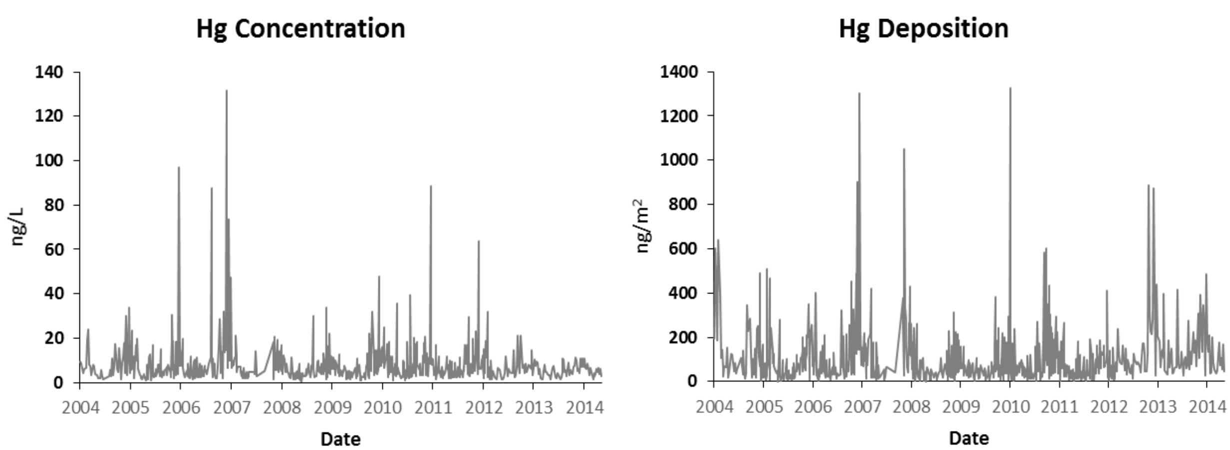

Figure 15. Long-term trends in Hg concentration and total Hg deposition for all precipitation events at the VT99 MDN site.

which may partially explain why the data is so highly variable – one week receiving a regional pulse, the next week not.

Table 5. Percentiles provide a comparison to the larger national MDN network. This percentile value represents the proportion of MDN sites reporting total Hg deposition values below VT99. Over the 10 year monitoring at VT99, mean annual deposition is higher than 57% of national MDN sites. 2014 was a relatively good year for VT99, with only about a third of MDN sites recording lower mean Hg deposition.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Overall Average
#reporting stations	95	104	112	116	125	133	115	113	116	120	184
National Average	8635	8463	7849	9024	7763	7637	9253	8685	8867	9111	7792
VT99 Average	7415	7856	11621	9195	6291	8370	9570	6128	8074	7233	7776
VT99 Percentile	39%	45%	86%	54%	43%	59%	54%	21%	51%	35%	57%

For a larger perspective, compared to the ***national*** network of MDN sites (Figure 16, Table 5), the VT99 monitoring station has fallen from the high end of measured values (2007, with higher total Hg deposition than 86% of other MDN sites) and away from low end of measured values (2012, with higher total Hg deposition than only 21% of other MDN sites). Over all the years of measurements, the VT99 site typically falls in the middle of reported Hg deposition values across the Mercury Deposition Network.

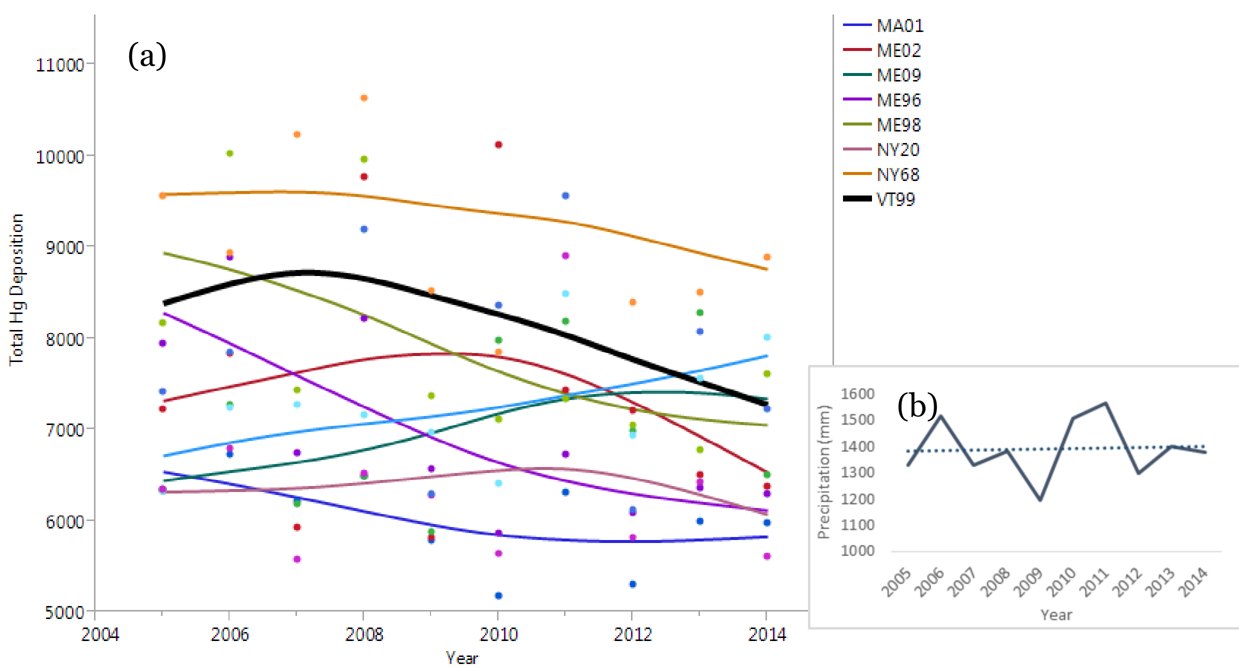

Figure 16. Total Hg deposition (a) in ng/L by year for northeastern MDN monitoring sites with comparable years of data collection. Note that in recent years Hg deposition has decreased in VT, but still remains among the highest deposition rates in the region. Inset (b) displays the precipitation record at the site, which shows no obvious trend over the same period.

Implications

In the long term, mercury deposition levels decreased dramatically with the enactment of clean air legislation in the late 20th century (Kamman and Engstrom 2002). However, the lack of reduction policies specifically targeting mercury has led to the leveling off of deposition rates in recent years. The absence of a trend in either direction is a good sign for the health of Vermont's forested ecosystems in that there is not an increasing rate of deposition. But because mercury persists in the environment and continues to be cycled through the various storage pools (soils, air, biota) until it is essentially buried under soil, the continued low-level input and occasional spikes will likely drive cumulative increases in mercury in Vermont's forests, which are particularly sensitive to these inputs (Driscoll et al. 2007).

Planetary warming caused by climate change can lead to further complications, among them increasing temperatures that may lead to higher rates of organic productivity in aquatic ecosystems, as well as higher rates of bacterial action which can increase methylmercury production. These events, combined with the thawing of huge areas of previously frozen northern peatlands, may move previously unavailable pools of mercury into global ecosystems, highlighting the pressing need for further limits on and monitoring of mercury emissions from anthropogenic sources (Figure 17) (AMAP/UNEP 2015). The persistence of mercury in the ecosystem and the global nature of mercury pollution make eliminating anthropogenic contributions crucial to lowering concentrations in Vermont and worldwide.

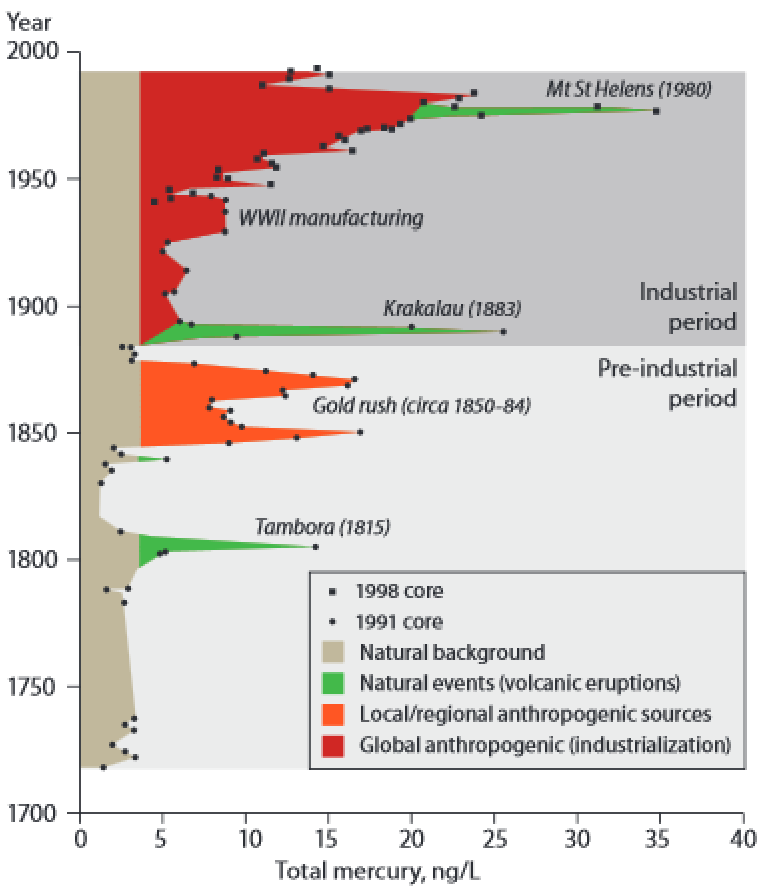

Figure 17. Ice core record of deposition from Wyoming, USA. The elevated levels associated with the 1850-84 gold rush probably reflect local/regional sources rather than a global signature. Increasing levels of environmental mercury associated with industrialization, however, are found in ice cores around the globe.

Mercury continues to arrive and build up in Vermont's forests. Several sport fish species accumulate mercury, and many states, including Vermont, have issued guidelines on the number of fish that may be safely eaten to limit mercury exposure in people.

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Additional Resources

Vermont Health Department Fish Consumption Recommendations: http://healthvermont.gov/enviro/fish_alert/documents/fish_alert.pdf

VMC Project Database Link

Wet Deposition of Mercury at Proctor Maple Research Center (Mercury Deposition Network-MDN): http://www.uvm.edu/vmc/project/wet-deposition-mercury-proctor-maple-research

O_3

Ozone

Ozone

Visible ozone injury to white ash.

Monitoring ozone pollution levels and foliar injury in Northern and Southern Vermont

Ozone is a colorless, odorless gas that occurs naturally in the stratosphere, where it helps protect us from harmful ultraviolet radiation. Closer to ground level, ozone pollution is formed from photochemical reactions of nitrogen oxides and hydrocarbons, and causes a range of adverse effects on human health and sensitive vegetation. The US EPA sets and periodically revises national ambient air quality standards for ozone and other commonly occurring air pollutants, including "primary standards" to protect human health, and "secondary standards" to protect the environment. The current primary ozone standard is based on the highest 8-hour concentration in a day. The form of the standard is based on the 4th highest daily 8-hour concentration in a year, averaged over a 3-year period. The level of the current primary standard was recently changed to 70 parts per billion (ppb), and no secondary standard was set.

EPA's Clean Air Scientific Advisory Committee has recommended that the primary ozone standard be lowered to into the range of 60 to 70 ppb. The Advisory Committee also recommended that EPA set a separate secondary ozone standard to protect sensitive vegetation, based on cumulative exposure over the summer growing season. Because exposure to high concentrations are more damaging than low concentrations, a weighting function – called the W126 – is applied to the hourly ozone data before summing concentrations over the highest 3 months of the "summer" season (April through September). Because most ozone damage to plants occurs when plants are photosynthetically active, the W126 is typically limited to the "daylight" hours (nominally defined as 8 AM through 8 PM). The range of the summer, daytime w126 secondary ozone standard recommended by EPA's Science Advisors was between 7 and 15 parts per million-hours (ppm-hrs.).

The Data

The Vermont DEC Air Quality and Climate Division measures hourly ozone concentrations, year round, at long-term monitoring sites in Bennington (generally

O_3

Ozone

representative of southern Vermont) and at the VMC site in Underhill (generally representative of Northern Vermont). The most recent 2014 and 3-year average data, expressed as both the 4th highest daily 8-hour maximum and the 3-month daytime W126 index are summarized in Table 6 below.

Table 6. 2014 and 3-year average ozone concentrations in Northern & Southern Vermont.

	2014 4th Highest 8-hr Maximum	2012-2014 Avg. 4th Highest 8-hr Maximum	2014 3-Month 12-hr Daytime W126	2012-2014 Avg. 3-Mo. 12 Hr. W126
Underhill	**59 ppb**	**62 ppb**	**3.9 ppm-hrs**	**4.3 ppm-hrs**
Bennington	**61 ppb**	**63 ppb**	**3.9 ppm-hrs**	**4.7 ppm-hrs**

2014 in Summary

The 2014 ozone season was a relatively clean one in the northeastern US. The 4th highest 8-hour concentrations at the Underhill and Bennington, VT sites were 59 and 61 ppb respectively. The 3-year averages of these 8-hour maximum values were 62 ppb and 63 ppb – below the 70 ppb level of the current primary health standard, but within the 60 to 70 ppb range recommended by EPA's science advisors. The 2014 seasonal daylight w126 ozone levels were 3.9 ppm-hours at both VT sites, and the 3-year average w126 ozone values were 4.3 ppm-hours at Underhill and 4.7 ppm-hours at Bennington –well below the 7 to 15 ppm-hours range recommended by EPA's science advisors.

Long-Term Trends

20-year trends in W126 ozone in northern (Underhill) and southern (Bennington) VT are plotted in Figure 18, as 3-year averages associated with the middle of each 3-year period. Also shown in Figure 18 are 3-year averages of percentages of observed ozone foliar injury symptoms on ozone sensitive plants aggregated across the Forest Service *Forest Inventory and Analysis* (FIA) plots in northern and southern VT. The FIA ozone foliar injury

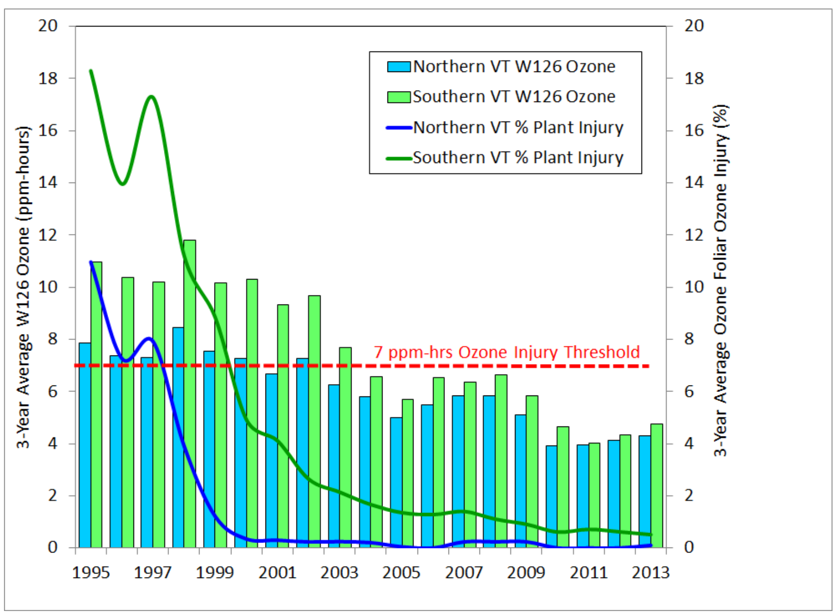

Figure 18. Long-term trends in W126 ozone levels and in foliar ozone injury in northern and southern Vermont

monitoring was terminated in 2010, but fortunately, the State of Vermont continued to collect this important parameter. It can be noted that declines of foliar injury have tracked the trends in W126 ozone levels, and that visible plant injury symptoms dropped to near zero as W126 concentrations dropped below about 7 ppm-hrs – the lower level of the range recommended by EPA's science advisors. Over the same 20-year period, peak 8-hour ozone has dropped from a range of 75-80 ppb to 65-60 ppb.

Implications

Substantial improvements have been observed in Vermont ozone concentrations over the past 20 years. These reductions reflect effective controls on emissions of hydrocarbons and nitrogen oxides from sources like power plants, and motor vehicles – both within Vermont and (more importantly) in upwind urban and industrial regions. Peak daily 8-hour concentrations - most relevant to human health effects – have declined from close to 80 ppb in the early 1990s to close to 60 ppb in the past few years. Vermont levels of the biologically-relevant summer seasonal W126 ozone index have experienced similar improvements, dropping from the range of 10 to 20 ppm-hrs in the early 1990s to 4 to 5 ppm-hrs in recent years. The frequency of visible foliar injury symptoms on ozone sensitive forest plants in Vermont has also declined during this 20-year period, with injury symptoms rarely observed over the past few years.

It should be noted that visible ozone injury symptoms are evidence of relatively extreme plant damage. Other effects - such as reduced photosynthesis, plant growth and carbon uptake, and increased susceptibility to disease and insect damage – can occur at ozone exposures lower than those which produce visible injury symptoms. In a similar way for both environmental and human health effects, no safe "threshold" concentration of ozone exposure has been identified below which no harmful effects are expected. So while the substantial progress achieved over the past few decades is good news for Vermont's citizens and our environment, we should work to continue this progress into the future, as current ground level ozone exposures remain well above natural conditions, and further reductions will yield further benefits to the health of Vermont's forest environment.

Vermont's ozone pollution has improved to levels where visible injury is rarely observed on our forest plants. However, plant health can still be affected at ozone exposures well below those which cause visible injury. Continued reductions are needed in the future.

Additional Resources

Forest Inventory and Analysis Ozone Biomonitoring Program (active 1994-2010): http://www.nrs.fs.fed.us/fia/topics/ozone/

VMC Project Database Link

Ambient Air Monitoring for Ozone: http://www.uvm.edu/vmc/project/ambient-air-monitoring-for-ozone

Climate

The VMC Meteorological Monitoring Network

The VMC takes meteorological measurements at 0.5, 7.5, 17, and 24 meters above the forest floor at 1300' at the canopy research tower at the Proctor Maple Research Center in Underhill, VT.

The Vermont Monitoring Cooperative (VMC) has been monitoring weather conditions in Vermont for over 20 years. VMC currently operates seven meteorological stations across a range of elevations and cover types, maintaining real-time data streams and archiving of long-term data. Weather and climate are related but very different phenomena, weather being the condition of the atmosphere (precipitation, temperature, cloud cover or humidity for example) over the short term, while climate refers to longer-term averages and expected seasonal patterns. Without long-term weather records it would be impossible to tease out yearly fluctuations from bigger climate trends, which makes this information critical to scientists and planners of all kinds. One of the complexities of climate analyses is the high degree of spatial variability. Multiple VMC stations allow for the assessment of climate trends and patterns across a broader region of VT than any single station could provide.

The Data

Meteorological observations are taken at seven VMC sites from Lake Champlain to Mt. Mansfield. Although the stations are not identical, variables collected include wind speed and direction, air temperature, relative humidity, barometric pressure, solar irradiance, precipitation, and at Lake Champlain stations, water temperature. These variables are logged as 15 minute data at most stations. The longest record comes from the Mt. Mansfield summit station operated by the WCAX transmitter crew and supervised by the National Weather Service, going back to 1954, predating the VMC! Other stations operated by the VMC began operation in the early to mid- 1990s, with the newest station added in 2010.

2014 in Summary

While the Mt. Mansfield West meteorological station was not operational during March and April, overall the remaining months in 2014 were only slightly above the average for temperature, compared to the long-term trends. This was primarily driven by warmer than normal temperatures in May, June, October and December, coupled with cooler than normal temperatures in February, August and November (Table 7). January temperatures were unusually dynamic with the largest daily deviations in both above and below average temperatures (Figure 19).

Perhaps more interesting was the increased variability in maximum wind speed over the winter and fall months of 2014. While the long-term average of maximum wind speeds is muted because not all high wind events occur on the same day each year, the increased variability and frequency of high wind events in 2014 is apparent (Figure 20).

Table 7. Monthly average deviations from long-term normal for mean, min and maximum temperatures at Mt. Mansfield West. Red indicates warmer than normal months and blue indicates colder than normal months. Note that data for March and April are absent due to station maintenance.

Month	Mean T	Min T	Max T
January	-1.74	-1.89	-1.36
February	-1.62	-1.12	-2.20
March			
April			
May	0.60	0.61	0.33
June	0.59	0.57	0.30
July	-0.37	-0.52	-0.63
August	-0.89	-0.48	-1.36
September	-0.60	-0.66	-0.56
October	1.53	1.57	1.31
November	-1.71	-1.58	-1.51
December	1.43	1.57	1.16

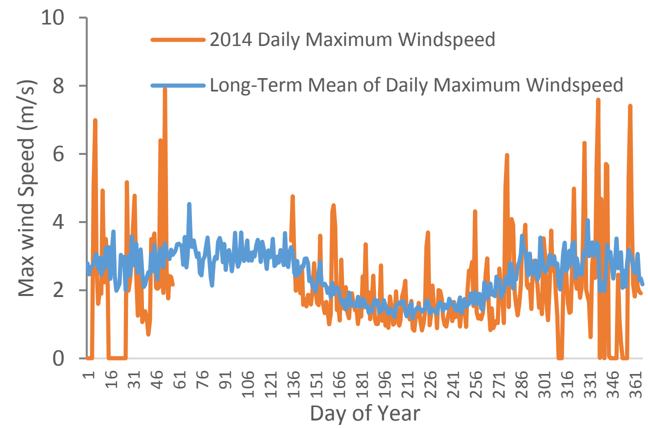

Figure 19. Daily maximum 2014 wind speeds compared to the long-term averages highlights the increased frequency of wind events in fall and winter.

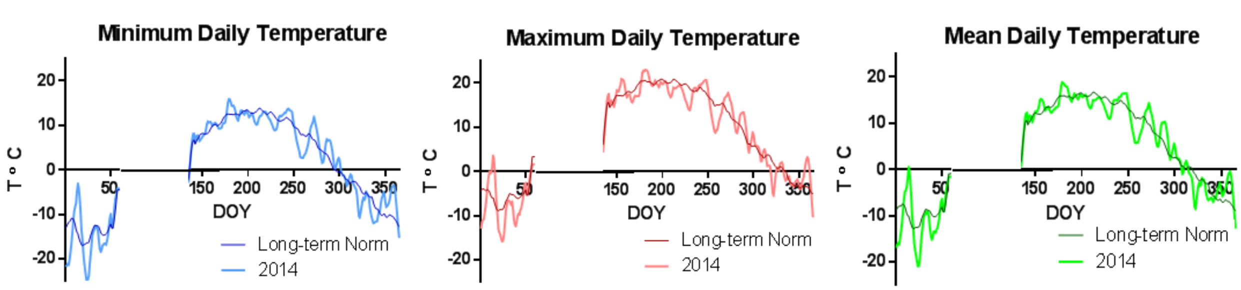

Figure 20. A two-week moving window smooth of daily temperature data for 2014 in comparison to the long-term mean.

Table 8. Precipitation totals recorded at the Mt. Mansfield West met station for 2013 in comparison with the 1997-2014 long-term mean (normal).

Month	Normal Total Monthly Precipitation	2014 Totally Monthly Precipitation	Percent Deviation from Normals
May	79	79	-1%
June	132	170	29%
July	117	121	4%
August	101	78	-23%
September	89	66	-27%
October	157	138	-12%

While June was a relatively wet month in 2014, it was followed by consecutive months of below average precipitation (Table 8). However, none of these deviations are significant enough for widespread forest health impacts.

Long-term Trends

Based on the daily data between 1997 and 2014, we have seen a consistent (although not significant) rise in mean, max and min daily temperatures (Figure 21). Despite the caveat that short term datasets may not reflect long term trends, this rise is congruent with regional and national trends (IPCC, 2014; EPA 2014). The most extreme change is in daily minimum temperatures, up 3 degrees on average over this data record. Most of this increase occurs in the spring and summer on Mansfield, with July reporting the strongest (and only significant monthly) long-term increase in mean temperature ($p = 0.03$). The addition of 2014 data did not alter these trends, although temperatures were closer to the long term average than in 2013.

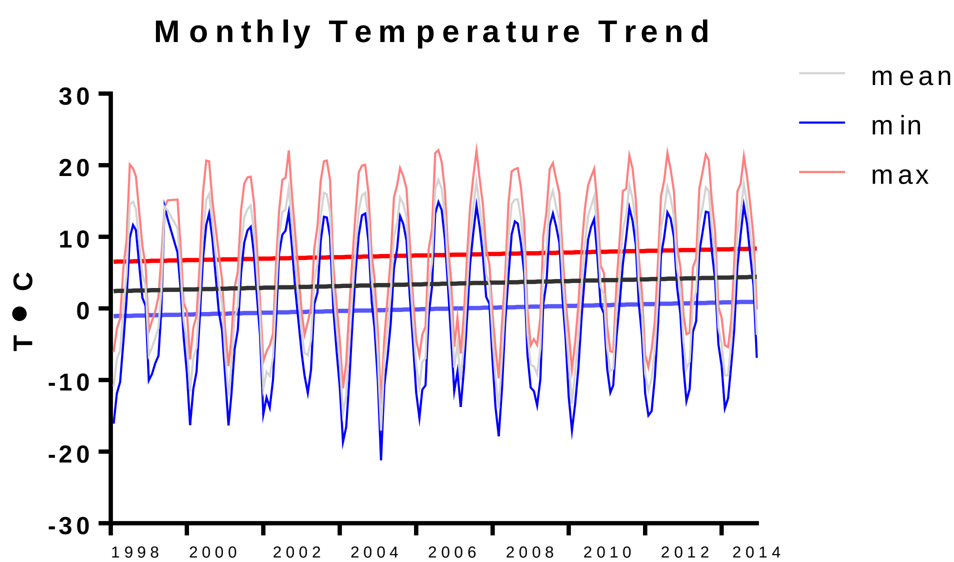

Figure 21. Long-term trends in mean monthly climate metrics show a steady but insignificant increase in mean, min and maximum temperatures on Mt. Mansfield.

Implications

Because climate variability is high, both temporally and spatially, conditions witnessed in 2014 and the longer term trend are not necessarily indicative of a new climate regime. However, the widespread warming witnessed across the VMC meteorological network are in agreement with regional and national assessments indicating that temperatures have increased over the past several decades (Betts, 2011; EPA, 2014; IPCC, 2014). Further, the dramatic variability in winter temperatures witnessed in 2014 could represent an additional stress for species adapted to cold weather dormancy. The variable spring temperatures may eventually affect phenological adaptations, potentially increasing vulnerability to insects, diseases and spring frost injury, and may have an adverse impact on major agricultural crops in Vermont such as apples and sugar maples (Figure 22; Grubinger, 2011; Rustad, 2012).

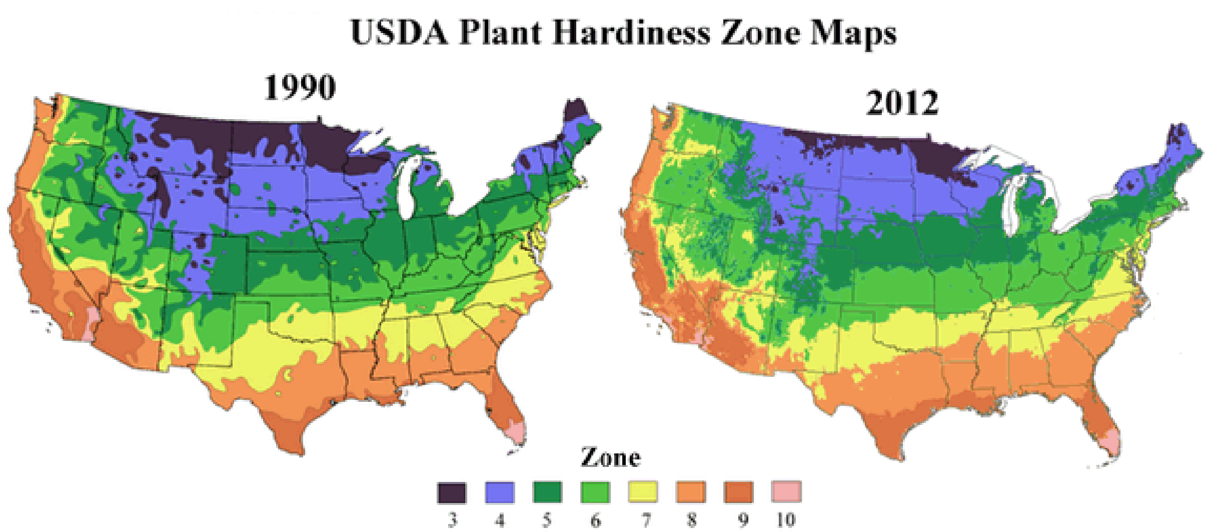

Figure 22. In 2012 the USDA released a new map of plant-hardiness zones to reflect more accurately the growing conditions on the ground. The USDA release was accompanied with a caveat that not all the changes in the map were due to climate change; new methods accounted for some of the difference.

If this trend continues, for species at either the far northern or southernmost portion of their range, climate instability could make survival challenging. Even when climate conditions remain within a species' natural tolerance, differences in competitive advantages among species due to phenological changes or erratic and unseasonable temperature fluctuations could alter ecosystem structure and function (Pucko, 2014).

While warming trends continue it is perhaps the increase in variability that may stress forested ecosystems the most.

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Additional Resources

Vermont State Climatologist: http://www.uvm.edu/~vtstclim/

VMC Project Database Links

Burton Island Meteorological Monitoring:
http://www.uvm.edu/vmc/project/burton-island-meteorological-monitoring

Colchester Reef Meteorological Monitoring:
http://www.uvm.edu/vmc/project/colchester-reef-meteorological-monitoring-38-m

Diamond Island Meteorological Monitoring:
http://www.uvm.edu/vmc/project/diamond-island-meteorological-monitoring

Mount Mansfield East Slope Mid Elevation Forest Meteorological Monitoring:
http://www.uvm.edu/vmc/project/mt-mansfield-east-slope-mid-elevation

Mount Mansfield Summit Meteorology:
http://www.uvm.edu/vmc/project/mount-mansfield-summit-meteorology

Mount Mansfield West Slope Mid Elevation Forest Meteorological Monitoring:
http://www.uvm.edu/vmc/project/mt-mansfield-west-slope-mid-elevation

Proctor Maple Research Center Meteorological Monitoring:
http://www.uvm.edu/vmc/project/proctor-maple-research-center-meteorological-monitoring

Forest Birds

Vermont Center for Ecostudies Director Chris Rimmer and Conservation Biologist Kent McFarland with an 11 year old tagged and recaptured Bicknell's thrush.

Breeding Bird Surveys

Since the 1960's Vermont has seen the conversion of nearly 7 percent of agricultural land and 14 percent of forest land to urban use (VMC, 2009). These changes in land use, along with associated parcelization and fragmentation of the landscape are recognized as major driving forces affecting species habitats, ranges and population numbers (Wilcove *et al*., 1998, VNRC, 2007). Anthropogenic perturbations caused by atmospheric pollutants (e.g. elevated mercury in blood and feathers of Bicknell's Thrush (Rimmer et al., 2005, 2009)) and changing environmental conditions add to the pressures on many forest bird species (Audubon, 2014). Species such as Bicknell's Thrush, which overwinter in wet broadleaf forests in the West Indies, are also being subjected to many human-induced perturbations on their overwintering grounds. Regular monitoring is essential to assess trends in species presence, species richness, population levels and demographics. Such information is critical to the conservation of sensitive species.

Methods

Breeding Bird Surveys were conducted at permanent study sites located on the Mt. Mansfield ridgeline and in Ranch Brook, in Underhill State Park and at the Lye Brook Wilderness Area (LBWA). These four study sites are part of VCE's long-term Forest Bird Monitoring Program (FBMP) which was initiated in 1989 with the primary goals of conducting habitat-specific monitoring of forest interior breeding bird populations in Vermont and tracking long-term changes (Faccio *et al*. 1998).

Each study site contains 5 point count stations. Survey methods include unlimited distance point counts, based on the approach described by Blondel et al. (1981) and used in Ontario (Welsh 1995). Counts begin shortly after dawn on days where weather conditions are unlikely to reduce count numbers. Observers record all birds seen and heard during a 10-min sampling period, divided into 2, 3, and 5-minute intervals. Montane fir-spruce sites on Mt. Mansfield were sampled once, while hardwood-dominated sites at LBWA and Underhill were sampled twice during the breeding season.

2014 in Summary

Both montane study sites on Mount Mansfield rebounded from the previous year's record or near-record lows for relative abundance and species richness. Although the number of individual birds detected at Underhill State Park in 2014 was slightly below average, species richness was the second lowest ever recorded (Figure 23). Similarly, both species richness and the number of individual birds detected at Lye Brook remained below average in 2014.

Overall, a combined total of 55 avian species have been detected during breeding bird surveys at three study sites on Mt. Mansfield from 1991-2014. Species richness was similar at both montane forest sites, with a total of 32 species detected at both the Mansfield ridgeline and Ranch Brook. Surveys at Ranch Brook continue to average a greater number of individuals and species per year than the higher elevation and more exposed Mansfield ridgeline site. Surveys at the mid-elevation, northern hardwood study sites at Underhill State Park and Lye Brook Wilderness showed similar species composition, with a total of 47 and 46 species, respectively.

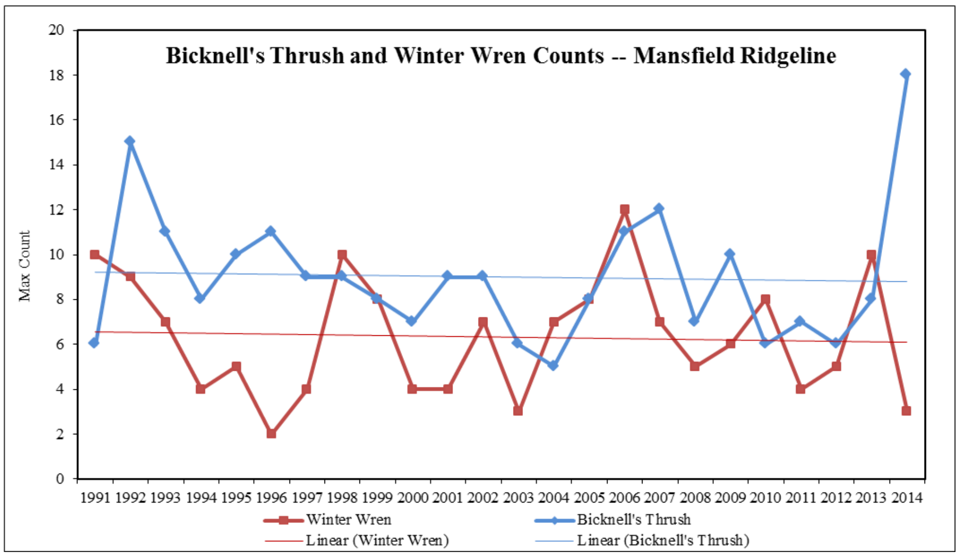

Figure 23. Twenty-four year data and trends for Bicknell's Thrush and Winter Wren from annual surveys conducted at the Mt. Mansfield Ridgeline site.

Long Term Trends

Mt. Mansfield Ridgeline – In 2014, the number of species detected (n=11) rebounded slightly from the previous year record low of just 8 species, while numerical abundance (n=86) jumped dramatically to the third highest in the survey's 24-year history. Of the eight most commonly recorded species, only Winter Wren and Yellow-rumped Warbler were below their 24-year average, and counts of all except Winter Wren increased from 2013, including a record high count of Bicknell's Thrush (n=18) (Figure 24).

Ranch Brook – Abundance (n=73) more than doubled from 2013's record low of 36 individuals, while species richness increased to the highest since 2008. This included a Black-throated Green Warbler, a new species for the Ranch Brook site, and three Blue-headed Vireos, a record high for this species, which has only been detected in two other years (2006 and 2013). Of the eight most abundant species, five species were above the long-term mean for Ranch Brook, including Bicknell's Thrush, which bounced back from zero detections in 2013 (Figure 24). However, over the 19-year survey period, Bicknell's Thrush exhibits a declining trend at an annual rate of -2.07%.

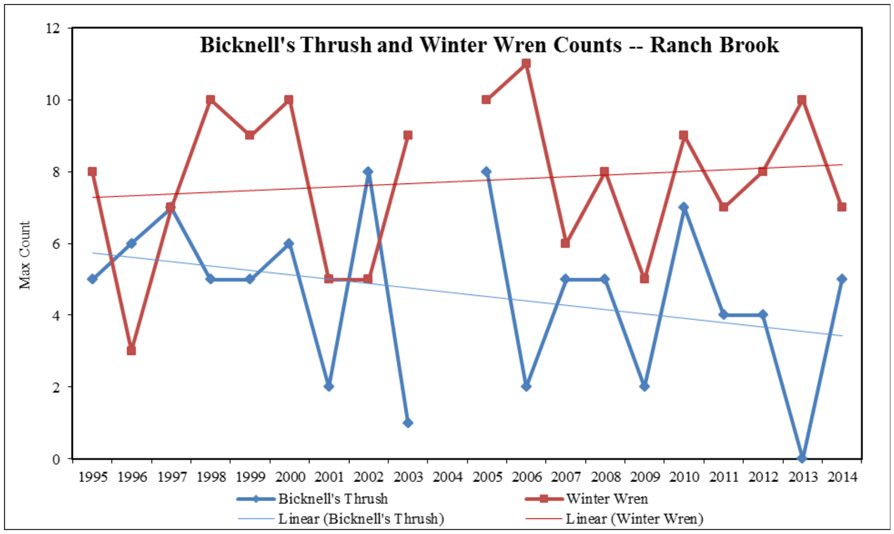

Figure 24. Nineteen year data and trends for Bicknell's Thrush and Winter Wren from annual surveys conducted at the Mt. Mansfield Ranch Brook site.

Underhill State Park – Total number of individuals and species richness remained below average for the site, with just 57 individuals of 13 species recorded, including a Barred Owl, the first for the count. Among the 8 most common species, five were above the 21-year mean, and three were below. Overall, counts of Ovenbird and Black-throated Green Warbler appeared to be increasing, while the long-term trend for Hermit Thrush, the Vermont State bird,

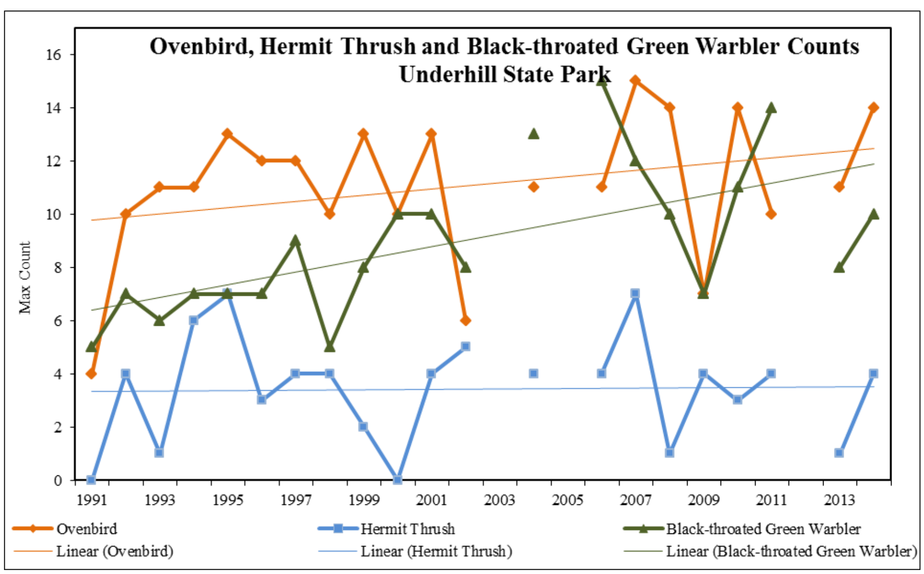

Figure 25. Twenty-one year data and trends for Ovenbird, Hermit Thrush, and Black-throated Green Warbler from annual surveys conducted at Underhill State Park.

remained relatively flat (Figure 25). As with the Mt. Mansfield montane sites, Winter Wren numbers dropped in 2014, with just a single bird detected at Underhill.

Lye Brook Wilderness Area – Both abundance (n=54) and species richness (n=15) were slightly below the 14-year mean. Among the eight most common species, only two (Red-eyed Vireo and Ovenbird) were above the 14-year average, and only Red-eyed Vireo and Yellow-bellied Sapsucker exhibited increasing population trends. Although Ovenbird numbers increased to the second highest in the count's 14-year history, the species continued a declining trend at an annual rate of -1.27% (Figure 26). While numbers of Black-throated Blue Warbler rebounded from a record low of just three individuals in 2013, their long-term trend shows a significant decline of -3.15% per year (r2 = 0.387; P = 0.036). Although no new species were encountered, a single Rose-breasted Grosbeak was the first detected since 2001, and only the third since surveys began in 2000.

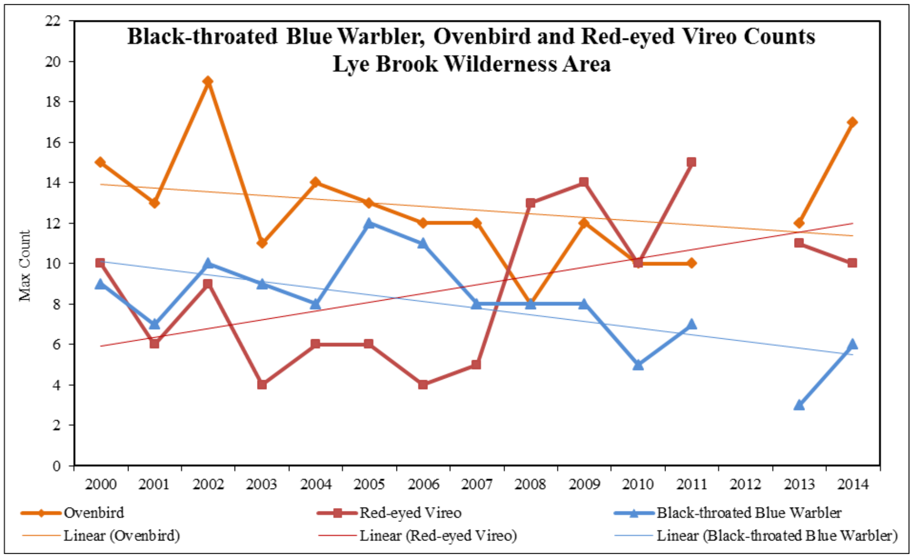

Figure 26. Fourteen year data and trends for Ovenbird, Red-eyed Vireo, and Black-throated Blue Warbler from annual surveys conducted at LBWA.

Implications

Long-term trends in count survey numbers over the past 24 years at Mt Mansfield strongly suggest that, on average, numbers of many bird species (e.g. Bicknell's Thrush, Blackpoll Warbler, Dark-eyed Junco, White-throated Sparrow) have declined at high-elevation sites since 1991. However, it should be noted that site-specific trend estimates must be interpreted carefully, as these data are from a limited geographic sample. Year to year changes in survey counts may simply reflect natural fluctuations in abundance, differences in detection rates, variability of singing rates due to nesting stage, and/or a variety of dynamic factors, such as predator or prey abundance, overwinter survival, and local habitat change.

It is difficult to know which of the many anthropogenic stressors (e.g., habitat degradation, land use change due to development, acidic precipitation and other atmospheric pollutants, or changing climatic conditions) may be contributing to these declines, but it is likely all have had impacts. As previously mentioned, Bicknell's Thrush is one species that is also being heavily impacted on its overwintering grounds due to forests under siege from illegal charcoal production, subsistence farming, logging and squatting (e.g., McFarland et al. 2013, Rimmer and McFarland 2013). Loss of winter habitat is of crucial concern because of the birds' restricted range and highly selective habitat requirements.

Trends in some anthropogenic stressors are being reversed (SO_4 reduced by ~50 %; pH in precipitation now above 5.0) in the northern hemisphere, but climate change has yet to be addressed in any meaningful ways. Reversing the effects of some of these stressors will take decades and it is still unclear if humans have the willpower or discipline to make changes necessary to slow or possibly reverse some of these effects (e.g. changing climate, meaningful reductions in pollutants). In the meantime, forest birds will likely need to rely on their innate abilities to adapt to changing conditions and environments to survive and continue to thrive. This will be more difficult for habitat specialists such as Bicknell's Thrush.

Not all the news is bad, however, as some species continue to hold their own or experience increasing numbers (e.g. Winter Wren, American Robin) at higher elevations on Mt. Mansfield and at the lower elevation Underhill State Park (Black-throated Blue Warbler, Black-throated Green Warbler, Ovenbird). Numbers of Red-eyed Vireo at LBWA also appear to be increasing. Continued data collection and comparison with survey data from other ecologically similar sites will be necessary to fully elucidate population trends of various species at these sites.

Significant changes to forest bird habitat and environment are occurring, forcing species to adapt to ensure their survival. Can they adapt quickly enough?

Ancillary Studies on Blackpoll Warbler Migration

During 2014, our long-term banding studies on the Mt. Mansfield ridgeline yielded remarkable findings on the fall migration patterns of Blackpoll Warblers. In June and July of 2013, we attached miniaturized light-level geolocators to 19 adult breeding males, using a backpack harness arrangement; we recovered units from 3 returning birds in 2014. Colleagues in a parallel study recovered an additional 2 geolocators from breeding male Blackpoll Warblers in Nova Scotia. Analysis of the 5 units confirmed a long-suspected non-stop autumn migration of this species over the western Atlantic

Figure 27. Flight trajectory of male Blackpoll Warbler #2540-59026, banded and fitted with a geolocator on Mt. Mansfield on 8 June 2013, recovered on 8 July 2014. Its geolocator data revealed that it left Mansfield and flew east to the Maine or New Brunswick coast, then struck out over the Atlantic Ocean on 13 October, making landfall on Hispaniola 2+ days later, resting and refueling on the island an additional 2 days, then arriving in either northern Colombia or Venezuela on 18 October. Its non-stop flight covered an estimated 2750 km in 64 hours (from DeLuca et al. 2015; Fig. 1a).

Ocean to either the Greater Antilles or the northeastern coast of South America. As reported by DeLuca et al. (2015), this transoceanic migration ranged from 2270 to 2770 km (mean $\pm$ s.d. = 2540 $\pm$ 257) and required up to 3 days (62 h $\pm$ 10) of non-stop flight (Figure 27). This represents one of the longest non-stop overwater flights recorded for a songbird and confirms what has long been believed to be one of the most extraordinary migratory feats on the planet.

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Additional Resources

VMC Project Database Link

Forest Bird Surveys: http://www.uvm.edu/vmc/project/forest-bird-surveys

Amphibians

Populations of the spring peeper (Pseudacris crucifer), the well known early spring caller, are declining on Mount Mansfield.

Amphibian Monitoring on Mt. Mansfield

Amphibians such as frogs and salamanders are ideal indicators of forest health and water quality because their survival depends on clean water and a narrow range of healthy soil and water conditions. Changes in amphibian populations over time may indicate changes in environmental quality that might otherwise only be discovered over a longer period of time and with more expensive detection methods. On-going monitoring of key indicator species will aid in the assessment of changes in their abundance over time.

The Data

The amphibian monitoring program was one of the original VMC projects and was described in the first (1991) annual report. Steve Trombulak and Jim Andrews initially chose seven frog and salamander species to follow over time as part of a larger effort to understand the dynamics of amphibian populations throughout the state. Jim Andrews ultimately developed this information into a statewide, citizen science inventory called the Vermont Reptile and Amphibian Atlas, online at VtHerpAtlas.org. The seven species were selected due to their local abundance, and their dependence on forest cover, soil, and water conditions. Two of them, the Green Frog and the American Toad, were chosen for their broad distribution and possible sensitivity to herbicides. Specimens are collected using drift fences that channel the animals to buckets which are opened and checked during rain events. Identification of changes in the abundance and distribution of these species may indicate changes in the environmental health of the forest and its waters.

This is the longest-running set of amphibian monitoring data in the state. We have drift-fence data from Mt. Mansfield from 1993 to the present, with the exceptions of only 2004 and 2009. For more detailed information on initial methods, locations of drift fences, and survey results, see the 1995 VForEM annual report at: http://www.uvm.edu/vmc/reports/1995_AmphibianMonitoring_Inventory_LyeBrook_Report.pdf. For a more recent update, go to http://www.uvm.edu/vmc/attachments/project/999/reports/2012_AmphibianMonitoring_MtMansfield_AnnualReport.pdf

2014 in Summary

Only one amphibian species, the Northern Dusky Salamander, (*Desmognathus fuscus*) saw an increase on numbers from 2013 to 2014. One species, the Eastern Newt (*Notophthalmus viridescens*), maintained 2013 levels, and the other nine species that are annually monitored saw slight or greater decreases in adult numbers. In 2014 all anuran young of the year were found except Pickerel Frogs (*Lithobates palustris*) and Spring Peepers (*Pseudacris crucifer*). Total numbers of frogs and salamanders are down from 2013 for both adults and young of the year (Table 9).

Table 9. Monitoring results from drift fences on Mt. Mansfield in 2014.

Common Name	Scientific Name	# of all ages	# young of the year	% young of the year
Caudates (Salamanders)				
Spotted salamander	*Ambystoma maculatum*	30	10	33%
N. Dusky Salamander	*Desmognathus fuscus*	17	0	0%
N. Two-lined Salamander	*Eurycea bislineata*	8	1	13%
Spring Salamander	*Gyrinophilus porphyriticus*	1	0	0%
Eastern Newt	*Notophthalmus viridescens*	14	4	29%
E. Red-backed Salamander	*Plethodon cinereus*	176	2	1%
Group totals	Group totals	246	17	7%
Anurans (frogs)				
American Toad	*Anaxyrus americanus*	31	5	16%
Green Frog	*Lithobates clamitans*	13	3	23%
Pickerel Frog	*Lithobates palustris*	1	0	0%
Wood Frog	*Lithobates sylvaticus*	95	16	17%
Spring Peeper	*Pseudacris crucifer*	6	0	0%
Group totals	Group totals	146	24	16%
Amphibian totals	Amphibian totals	392	41	10%

For some species, such as the American Toad (*Anaxyrus americanus*), the Wood Frog (*Lithobates sylvaticus*) or the Eastern Newt, there is great annual variability, so declines in these populations may be followed by a multi-year increase, and are not of concern, yet. Other species, such as the Pickerel Frog (*L. palustris*) and the Northern Two-lined Salamander (*Eurycea bislineata*), have too low sample sizes for accurate conclusions. The Spring Peeper counts have continued to be low and are of more concern. Possible sources of their decline may be loss of appropriate breeding habitat (open grassy temporary shallow water), an increase in Green Frogs (*L. clamitans*) that could be disturbing the eggs during their tadpole stage or possibly feeding on the adult peepers when the Green Frogs are also adults. Changes in the amount of, or depth of frost in, the leaf litter, where Spring Peepers overwinter could also bring about declines.

No abnormal anurans were collected in 2014. Since 1998, only 14 abnormal anurans have been captured at this site.

Long Term Trends

The most significant long term trends are the continued decline of the Spring Peeper and the continued increase of the Eastern Red-backed Salamander (Figure 28). Unlike Wood Frogs, Eastern Red-backed Salamanders overwinter below the frost line, and don't require wetlands for breeding, as Spring Peepers and Wood Frogs do. This species (Eastern Red-backed Salamander) is reported to do well in mature hardwood forests with abundant coarse woody debris and deep leaf litter. Its success may well be the result of maturing forests. Other species with increasing long term population trends are the American Toad and the Northern Two-lined Salamander.

Spotted Salamander (*Ambystoma maculatum*) populations are neither increasing nor decreasing. This species is long lived and should have less annual variability than some

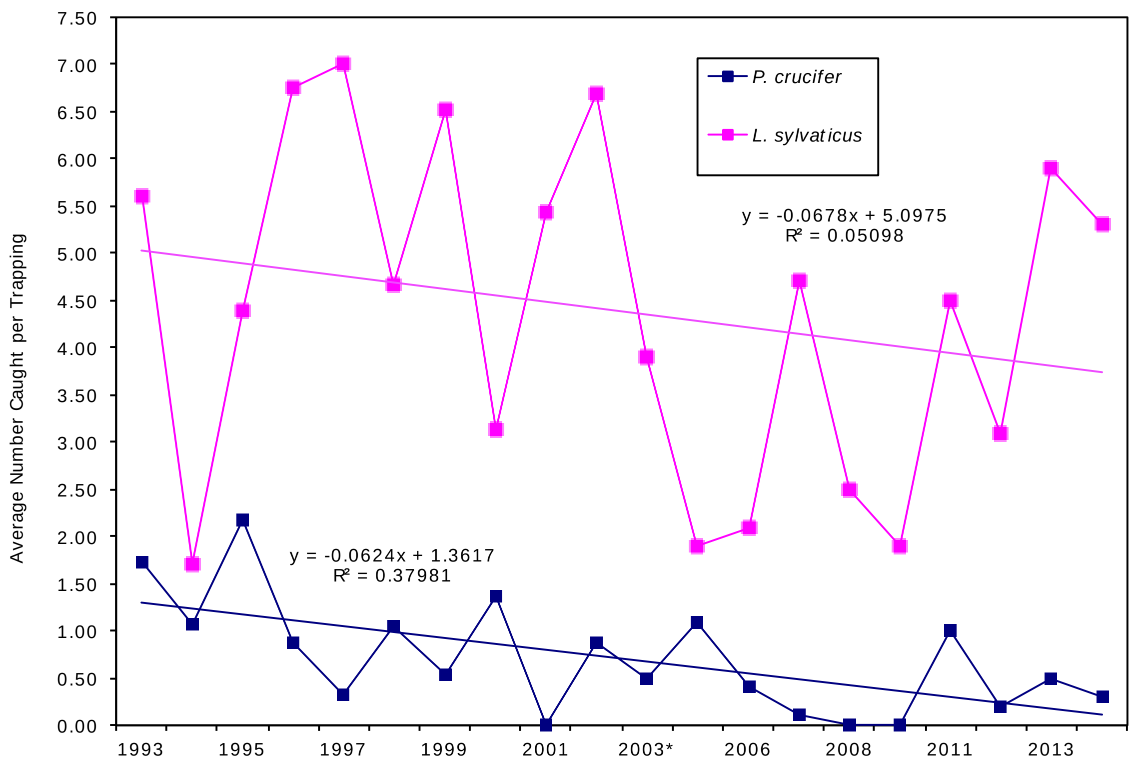


Figure 28. Wood Frog (Lithobates sylvaticus) and Spring Peeper (Pseudacris crucifer) indices from Mt. Mansfield, Underhill, Vermont, 1993-2014.

of the shorter lived species. It breeds in the same pools as Wood Frogs but is more resistant to mortality from predation, short term droughts, and the late season freezes that are becoming more common, because unlike Wood Frogs it overwinters below the frost line. An increase in annual variability was noticed in this species in 2002, the same year that Green Frogs numbers showed a large increase, and Wood Frog and Eastern Red-backed Salamander populations increased, too.

Erratic frosts at both shoulder seasons affect some species, like Wood Frogs, more than others. These types of life history comparisons between species will help us rule out some potential causes of these population trends and suggest others, but at this point, little is known about what is driving these changes.

The drift-fence array at Mt. Mansfield has facilitated the longest-running amphibian-monitoring program in the state. It is the only amphibian drift-fence location in Vermont that has been monitored almost continuously from 1993 through 2014. Due to budget cuts, 2014 may be the last year of monitoring at Mt. Mansfield. Long-term monitoring studies are very valuable. There are many questions that these data may answer including how numbers of young of year relate to adult population numbers, correlations and interactions between species, and how climate change effects local populations of amphibians.

Implications

The data collected about reptiles and amphibians from Mt. Mansfield, Lye Brook, and from the participants in the VT Reptile and Amphibian Atlas have been used to provide conservation information to private individuals, companies and organizations and governmental units. Biologists from GMNF asked for advice on reptile and amphibian management, private foresters consider herptiles in their management plans, citizens and the VT Department of Transportation assist in road crossings during spring migratory periods, and critical habitat for rare or threatened species has been purchased. All species benefit from these conservation measures. The continuing decline of several species of amphibians in Vermont should be cause for concern for all of us.

Only one amphibian species of the 11 that we monitor saw an increase in numbers at Mount Mansfield over the last 2.5 decades.

Additional Resources

Vermont Reptile and Amphibian Atlas VtHerpAtlas.org

VMC Project Database Link

Amphibian Monitoring At The Lye Brook Wilderness And Mount Mansfield:
http://www.uvm.edu/vmc/project/amphibian-monitoring-lye-brook-wilderness-mt

Sentinel Streams

Parapsyche apicalis, a filter-feeding caddisfly seen here in its larval stage, is an indicator of good water quality.

Sentinel Stream Monitoring at Ranch Brook

The Vermont Department of Environmental Conservation (VT DEC) is conducting long term monitoring of approximately ten "sentinel" streams in Vermont. Sentinel streams are widely variable in terms of size (4.6 -510 km^2), elevation (33 m – 585 m) and geographical separation. The one thing they have in common are relatively undeveloped watersheds that have not experienced heavy impact from anthropogenic activity. Five of these sites are currently gaged for stream discharge, either by VT DEC or by the USGS. All ten streams are currently being monitored on an annual basis, with the data that is being collected used to track trends in water quality, macroinvertebrate and fish communities, physical habitat, and water temperature. One of the longest running sentinel monitoring stations is at Ranch Brook near Stowe, VT. With a drainage area of 10 km^2 and an elevation of 378 m (1240 ft.), it is one of the smallest and most pristine reference streams. By focusing on these types of reference streams, VT DEC hopes to be able to observe long term impacts related to climate change, allowing eco-regional level alterations from localized watershed anthropogenic impacts to be factored into biological expectations on reference streams.

The Data

With a continuously operated USGS gage and annual monitoring by VT DEC since 2000, Ranch Brook has one of the best data sets in the state for pairing biological condition with stream hydrology. Continuous stream discharge data is available from the USGS gage, in addition to summary information, including daily mean and annual peak discharge. VT DEC collects macroinvertebrate community samples during an annual index period that runs from September 1st through mid-October. Samples are collected from riffle habitats, and sorted and identified in the laboratory. VT DEC biologists use a number of community variables (called metrics) to assess stream health. Metric values are compared to established thresholds determined from historical statewide data. Three of the metrics that VT DEC uses to assess biological condition are macroinvertebrate density, total richness, and Ephemeroptera-Plecoptera-Tricoptera (EPT) richness. Density is a general measure of community productivity, but can also provide information on water quality and habitat stability. Total species richness provides a measure of overall stream biodiversity, while the richness of the insect orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) indicates the diversity of macroinvertebrates that are particularly sensitive to water quality stressors.

2014 in Summary

Macroinvertebrate density at Ranch Brook in 2014 was 346 individuals per square meter, higher than VT DEC's minimum biological standard for a healthy Vermont stream, which is set at 300. Moderately low densities are indicative of a low productivity habitat (i.e. low nutrient concentrations and algae growth), and are typical in small, high gradient mountain streams. However the abundance at Ranch Brook is about two to three times lower than that found at similar sized streams sampled throughout Vermont over the last three years, including other small sentinel streams.

Total species richness (45.5) and EPT richness (26.5) at Ranch Brook were very high compared to the State's minimum biological criteria (27 and 16, respectively), and slightly higher than the average for other similarly sized streams over the last three years (Figure 29).

Long Term Trends

Annual peak discharge during each water year (October – September) at Ranch Brook shows a great deal of variability, and an interesting trend since 2010 when compared to earlier years of record (Figure 30). Four of the top five highest annual discharges have occurred since 2010.

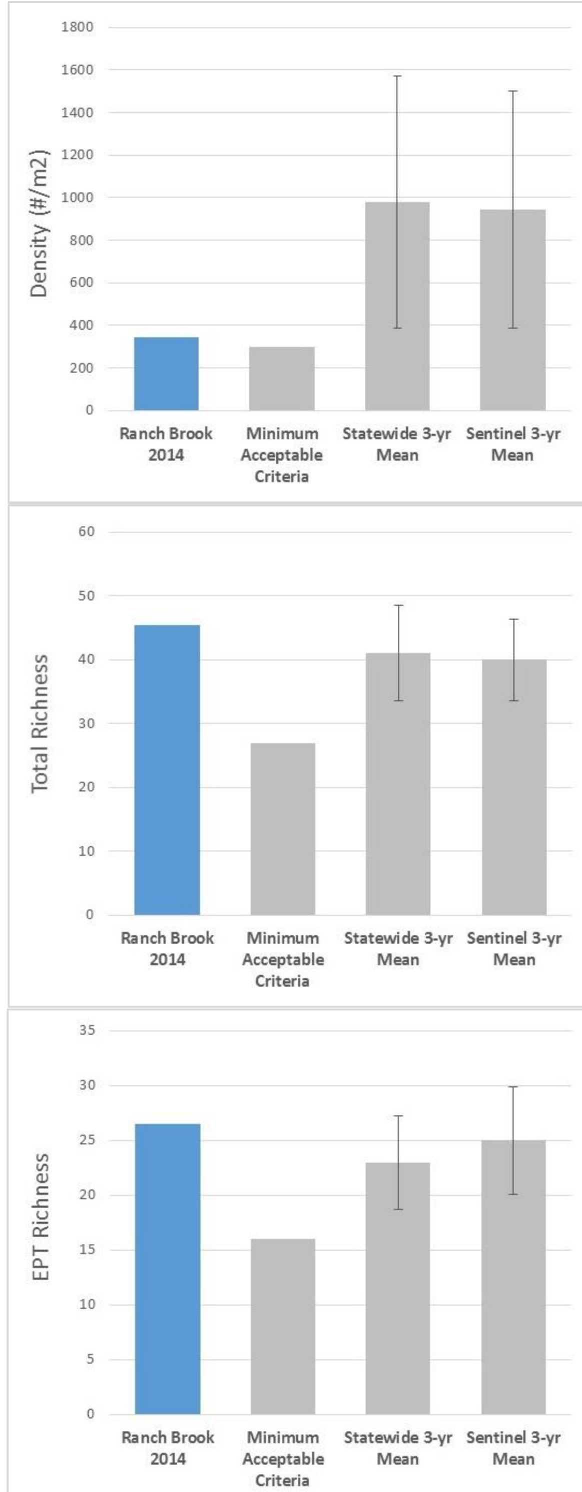


Figure 29. Macroinvertebrate density, total species richness and EPT richness from Ranch Brook in Stowe, VT, compared to minimal acceptable criteria and statewide and Sentinel stream 3 year means.

Figure 30. Comparison of annual peak flows at Ranch Brook in Stowe, VT with stream macroinvertebrate density (upper graph) and total species richness and EPT richness (lower graph).

Figure 31. Comparison of annual peak flows at Ranch Brook in Stowe, VT, with density of Baetidae (Ephemeroptera) populations. Baetidae are early colonizers that often increase in abundance after disturbance events.

When this hydrological variability is plotted against macroinvertebrate density, it seems apparent that organism abundance is responding to recent high peak flows (Figure 31). Most of the highest recorded densities were early in this period of record, with notable exceptions in 2004 and 2005. Beginning around 2008, we see that densities are generally depressed in years when sampling followed a high annual peak discharge. The highest densities during this time period were recorded in 2009 and 2012, years with low peak discharges. Trendlines plotted through this data also suggest an inverse relationship over time between these variables.

While density seems to respond dramatically to stream hydrology, total richness and EPT richness do not. Both of these community metrics show low variability, even during recent high flood years. Both measures of diversity are remarkably similar in 2014 compared to values seen up to 15 years ago.

Implications

High precipitation events like Tropical Storm Irene and other storms that have affected Ranch Brook in recent years are expected to become more common with our changing climate. These events will lead to more hydrological variability and higher annual peak flows, which in turn scours stream beds and decreases habitat stability.

This data suggests that small, low-productivity mountain streams like Ranch Brook may have a hard time recovering macroinvertebrate abundance in response to increased flood flows. This instability could also have negative effects on the fish community, either as a direct result of high flow events, or through food web dynamics resulting from lower invertebrate abundance.

Despite recent flow disturbances and lower densities of macroinvertebrates, biological diversity at Ranch Brook is being maintained at exceptional levels. Further research at Ranch Brook and other sentinel sites will provide insight as to whether this resilience in diversity can be maintained in the long term. VT DEC intends to look at how other aspects of the macroinvertebrate community may be changing, too. For example, some members of the mayfly family Baetidae are considered "early colonizers", and often respond to habitat disturbances by increasing their proportional abundance. Trends at Ranch Brook suggest that this population has followed the hydrological trends and grown more dominant in recent years. Further investigation will help determine which populations may be more tolerant or sensitive to climate-related changes in stream temperature and hydrology.

In sum, density is most responsive community metric to flow variation, while species richness and EPT are not altered, and Baetidae often rapidly recover compared to other taxa resulting in their dominance of a community following high peak flows. There will be more that we can add to this story in coming years.

Macroinvertebrates in small, low-productivity mountain streams may have a hard time recovering in response to increased flood flows.

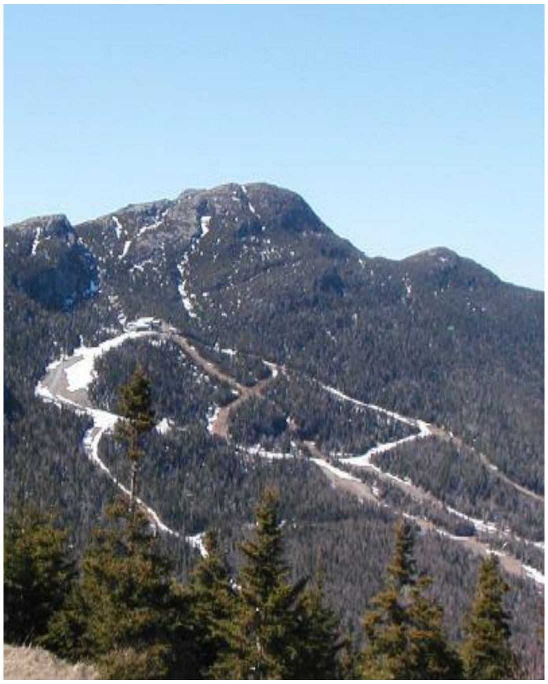
Additional Resources

VT DEC Biomonitoring and Aquatic Studies
http://www.watershedmanagement.vt.gov/bass/htm/bs_biomon.htm

VMC Project Database Link

Sentinel Stream Monitoring: http://www.uvm.edu/vmc/project/sentinel-stream-monitoring

Watershed Hydrology



View of Mt. Mansfield ski trails with winter snow receeding.

The Mt. Mansfield Paired Watersheds Study

Stream gages at Ranch Brook and West Branch near Stowe, Vermont have been operated continuously since their establishment in September 2000. The gaging was designed as a paired watershed study, with Ranch Brook (9.6 km^2) as a relatively pristine, undeveloped, forested control watershed, and West Branch (11.7 km^2) as the developed watershed. The basins are adjacent and similar in size, shape, aspect and drainage patterns. Elevation ranges from 415 to 1340 m in the West Branch basin and from 335 to 1173 m in Ranch Brook. West Branch contains nearly the entire expanse of Stowe Mountain Resort. Although the resort was well-established when the gaging began, it underwent a significant expansion during the course of the study. These sites provide needed information on mountain hydrology, and how mountain landscapes respond to development and extreme events.

The Data

Supported as a collaboration between the VMC and the US Geological Survey, stream gages on Ranch Brook and West Branch provide continuous monitoring of stream water heights (stage), which are related to discharge (flow) by an empirical rating based on frequent discharge measurements. This information informs the monitoring of long-term hydrology patterns and water quality trends including: baseline conditions, trends in stream acid/base status, cations (Ca, K, Mg, Na, Si), anions (Cl, NO_3, SO_4) suspended sediment output, snowpack and snowmelt and extreme climate events. These gaging stations provide a watershed framework for other VMC efforts including nutrient cycling, forest health assessments, forest fragmentation and biological monitoring.

2014 in Summary

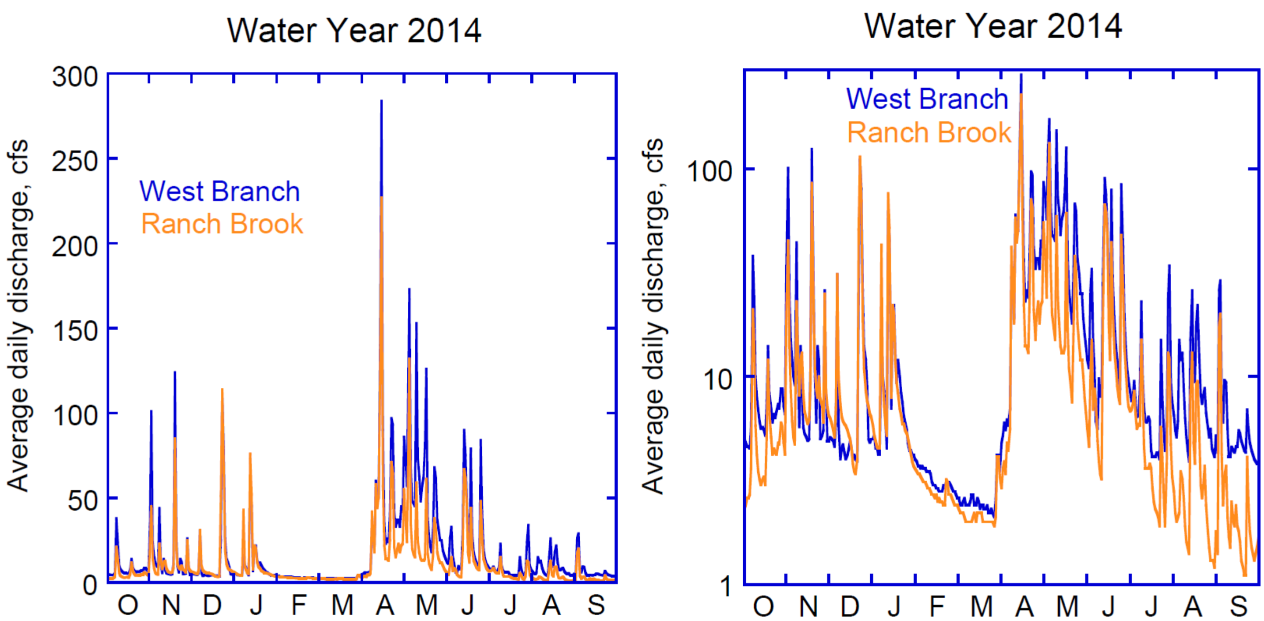


Figure 32. Streamflow at West Branch and Ranch Brook gages for Water Year 2014 (October 2013 through September 2014) in linear (left) and log (right) scales. The log scale plot illustrates the higher sustained base flow levels at West Branch.

Water year (WY) 2014 was a relatively tranquil year hydrologically, although there was one notable peak from a rain-on-snow event on April 15th (Figure 32). Overall, runoff was less than the long-term average (Figure 33).

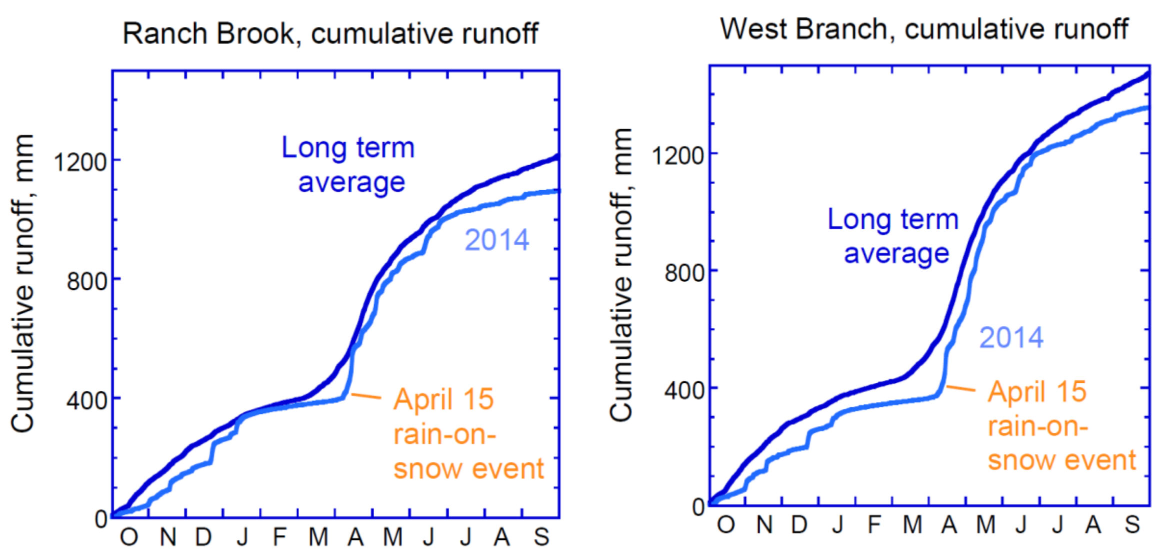


Figure 33. Cumulative runoff for Water Year 2014 at Ranch Brook (left) and West Branch (right) plotted on the long-term (2001-2014) average at each site (blue lines).

The WY started off with a dry fall and played "catch up" all year, but in the end fell below average for total runoff. West Branch fell further behind than Ranch Brook due to snowmaking withdrawals in the late fall and first part of winter. Rain and thaws in January brought both sites closer to average. A late snowmelt accompanied by a large rain-on-snow event on April 15th helped bring both sites to near average by the start of summer. But summer 2014 was dry in northern Vermont, leading to a steeper than average summer baseflow recession and an overall below-average flow year. The April 15th event was quite noteworthy as the 4th highest peak at Ranch Brook and 5th highest peak at West Branch over the 14 years of record.

Long Term Trends

Throughout the 14 years of streamflow monitoring, West Branch has consistently yielded higher runoff (flow normalized to watershed area) than Ranch Brook (Wemple et al., 2007) (Figure 34). Over the long-term, the average difference has been 21% greater runoff at West Branch. In Water Year 2014 the differential was slightly above average at 24% (Figure 34). Greater runoff at West Branch is what we would expect from the development; creation of impervious surfaces (parking lots, buildings), compacted soils (ski trail maintenance), and direct discharge of stormwater tend to increase surface runoff directly to streams at the expense of groundwater recharge, resulting in higher streamflow. Also, removal of trees for trails and development means less water demand by the forest, leaving more water available to run off. Because the ski resort was already in place when the gaging started, we cannot quantify its effect on hydrology. But the high magnitude of the differential suggests that some part of the difference may be natural. For example, there could be greater water input at West Branch due to different precipitation patterns in the two watersheds, snow redistribution, or groundwater input from outside the basin via bedrock fractures.

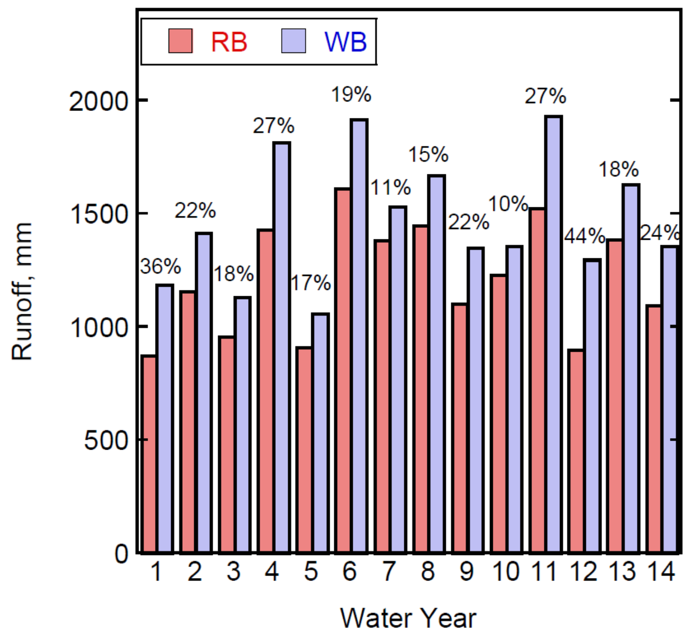


Figure 34. Annual runoff in mm at West Branch (WB) and Ranch Brook (RB) for the duration of study though the present report year. Percentage of greater runoff at WB relative to RB is given over each pair of bars.

Although annual runoff is consistently greater at West Branch, the relative difference varies greatly from year to year. The runoff differential is highest during the snowmelt period in April and May (Figure 35), partly as a consequence of the enhanced snowpack from machine-made snow, and the prolonged melt of skier- compacted snow. The low to negative differentials in late fall and early winter result from historic water extraction from West Branch for snowmaking. As yet, we have not been able to make a definitive assessment of the ski resort build-out on runoff. The assessment has been confounded by the construction of a large snowmaking storage pond, increased snowmaking, irrigation of the new golf course, and a new stormwater drainage system for the development.

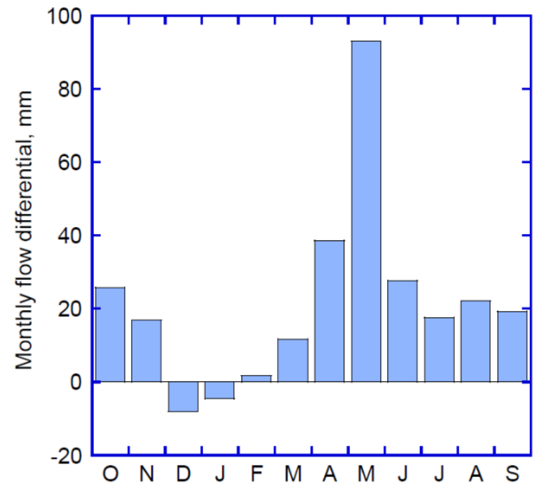


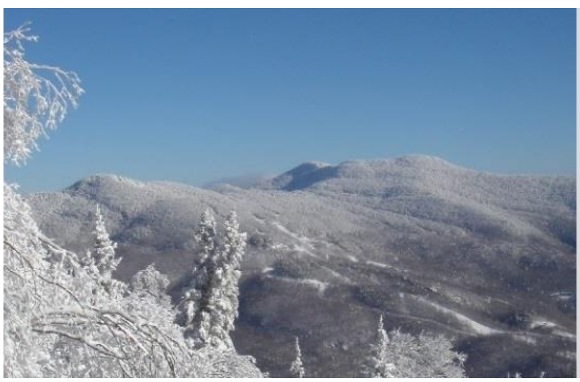
Figure 35. Long-term average, annual runoff differential in mm (WB – Ranch), by month (Water Years 2001 to 2014).

Implications

Mountain regions throughout the world face intense development pressures associated with recreational and tourism uses. Additionally, climate change scenarios have projected trends toward fewer, but more intense precipitation events and a greater proportion of winter precipitation arriving as rain rather than snow in the Northeast. Both of these results will have severe implications for high elevation sites, but diminishing snow amounts in particular will affect how commercial ski areas operate. Alpine ski resorts like Stowe Mountain Resort will need to rely more on snowmaking to keep trails covered and groomed, and are expanding and moving toward becoming four-season destination resorts through development of such things as golf courses, water parks, bicycle trails and other non-winter sporting activities. The result will be greater human presence, usage and impacts throughout the entire year which will place additional pressures on the landscape, many of which have not been experienced in the past. With this new development comes a greater percentage of the landscape covered by impervious surfaces; buildings, parking lots, tennis courts, walkways and other outdoor recreation facilities altering patterns, volume, velocity and chemical make-up of runoff.

Extremely intense rain events have the potential to temporarily overwhelm mountain streams leading to stream bank erosion, loss of stream bank cover and scouring of stream bottoms resulting in major disruptions to fish and macroinvertebrate habitat, increased sedimentation and water temperature (if cover is lost) and changes in essential stream nutrient and oxygen concentrations. Conversely, extended periods of low flows (droughty conditions), whether naturally-occurring or human induced (e.g. water removal from streams in late fall and early winter for snow making) can also adversely affect both aquatic and riparian animal and plant communities.

To our knowledge, this is still the only study of its kind, east of the Rocky Mountains, quantifying differences in overall streamflow volumes, peak flows, minimum flows, and timing and duration of each in both an undeveloped and a developed watershed at high elevation. This project has, and will continue, to produce real-world data needed by State regulatory agencies to make data-driven, environmentally sound decisions about development at Vermont's high elevation sites. Without proper regulatory oversight, safeguards and controls, alterations in streamflow (quantity, velocities, timing, and water quality) can potentially have devastating impacts on aquatic and riparian communities down-stream of highly developed sites.



Vermont's high elevation areas have the potential to be heavily impacted as the result of increased annual use and changing climatic conditions.

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Additional Resources

VMC Project Database Link

Paired Watershed Study on the East Slope of Mount Mansfield: http://www.uvm.edu/vmc/project/paired-watershed-study-east-slope-mount

Water Quality

Water Quality

Long Term Acid Sensitive Lake Monitoring at the Lye Brook Wilderness Area


Bourn Pond in the Lye Brook Wilderness Area, Green Mountain National Forest.

During the 1980s, the chemistry of lakes was surveyed throughout Vermont. Concern was mounting that remote, high-elevation lakes in geologically sensitive areas were either already acidified or risked acidification due to the long distance transport of atmospheric pollution. Initial monitoring within the southern Green Mountains indicated that this region of Vermont was especially sensitive to acidification and that a high proportion of the undeveloped lakes were notably acidic. In 1993, the VMC partnered with VT DEC to continue monitoring in the Lye Brook Wilderness on Branch and Bourn ponds. Acid lake monitoring in Vermont is funded by the US EPA's Long Term Monitoring Program (LTM), which supports VTDEC's work to sample 12 acidic lakes throughout Vermont, including Bourn and Branch ponds.

The Data

Long-term water chemistry monitoring has been carried out at two acid-sensitive lakes in the Lye Brook Wilderness area since the 1980s. The ponds, Bourn and Branch Ponds, are approximately 9.0 and 12.0 meters deep respectively, dark colored, with low pH and stratification in the spring and summer. Samples are collected three times a year in the spring, summer and fall, using a Kemmerer water sampler, at 1 m from the surface and 1-2 m from the bottom in the summer when the lake is stratified. Measurements include field pH, lab pH, secchi transparency, temperature, true color, apparent color, gran alkalinity, specific conductance, as well as concentrations of calcium, magnesium, sodium, potassium, aluminum (both speciated organic monomeric, and total dissolved), nitrate, sulfate, chloride and dissolved organic carbon (DOC). The methods of collection, processing and analysis have remained consistent for nearly 30 years, with one exception - the lab previously processing inorganic monomeric aluminum (IMAl) closed, and the new lab generated numbers that are not yet comparable to the previous assays. For this reason, we exclude discussion of IMAl this year. For this year's analysis, we focus specifically on measurements from the epilimnion, the uppermost layer in a thermally stratified lake, here defined as depths up to and including 1 meter.

2014 in Summary

Water quality at Bourn and Branch Ponds in 2014 largely follow the same patterns observed in 2013, and over the long-term record (Table 10). While slightly more acidic than 2013, both mean pH and dissolved organic carbon values remain some of the highest recorded over the near 30 year record. This is consistent with lake measurements made across the Northeast, all showing reduced acidity (higher pH) and increased DOC. Possible explanations for these changes range from increased organic matter solubility in soils (Monteith *et al*. 2007, SanClements *et al*. 2012) to increased CO_2 in the atmosphere and reduced atmospheric inputs. However, there is no conclusive cause identified thus far. Dissolved calcium concentrations in 2014 were slightly higher than 2013 but still among the lowest values recorded (11th percentile), continuing a long, steady decline in this critical base cation.

Table 10. Data from Bourn and Branch Ponds, epilimnion values only.

Year	Mean pH	Mean Dissolved Ca (mg/L)	Mean IMAl (ug/L)	Mean DOC (mg/L)
1986	4.98	1.042		
1987	4.97	0.875		
1988	4.97	0.807		
1989	4.87	0.840		
1990	5.06	0.743		
1991	5.03	0.922		
1992	5.37	0.790		
1993	5.13	0.722	81.75	4.62
1994	4.97	0.723	56.00	5.11
1995	5.24	0.773	56.33	4.58
1996	5.11	0.703		
1997	5.16	0.662		
1998	5.15	0.647	110.50	6.05
1999	5.21	0.661	108.17	5.83
2000	5.04	0.674	131.83	6.03
2001	5.16	0.591	120.92	4.71
2002	5.26	0.642	123.83	4.89
2003	5.17	0.651	148.83	5.91
2004	5.13	0.597	149.33	5.92
2005	5.22	0.577	151.60	5.58
2006	5.25	0.593	129.83	5.87
2007	5.33	0.577	98.83	4.64
2008	5.39	0.590	126.00	5.70
2009	5.51	0.560	122.17	5.65
2010	5.40	0.553	141.00	5.95
2011	5.38	0.603	123.18	6.79
2012	5.63	0.606	124.89	5.74
2013	5.49	0.552	111.67	6.49
2014	5.37	0.575	--	7.12
Long-term average	**5.23**	**0.671**	**119.55**	**5.74**
2014 percentile	**75%**	**11%**	**--**	**100%**

Long-Term Trends

There are several striking trends in Vermont's acid lakes, most notably an increase in the yearly mean pH from its low of 4.87 in 1989 on Branch Pond (Figure 36, top). This is consistent with lakes around the region which show steady increases in pH since the passage of the 1990 Clean Air Act Amendments. While this improvement continues to be strongly statistically significant ($p<0.001$), pH remains critically below levels necessary to expect a biological response (bench marks for healthy aquatic ecosystems are pH > 6.0). Limits on biological improvements are also likely due to the decline in available base cations, specifically calcium, a nutrient essential to the development and reproduction of fish and macroinvertebrates. At levels already below healthy benchmarks (calcium> 2.5 mg/L) availability of base cations remains a critical limitation to biological recovery in these systems (Figure 36, bottom). One bright note is that the decrease in calcium appears to have leveled off in Bourn Pond (since 2005) and Branch Ponds (since 2010).

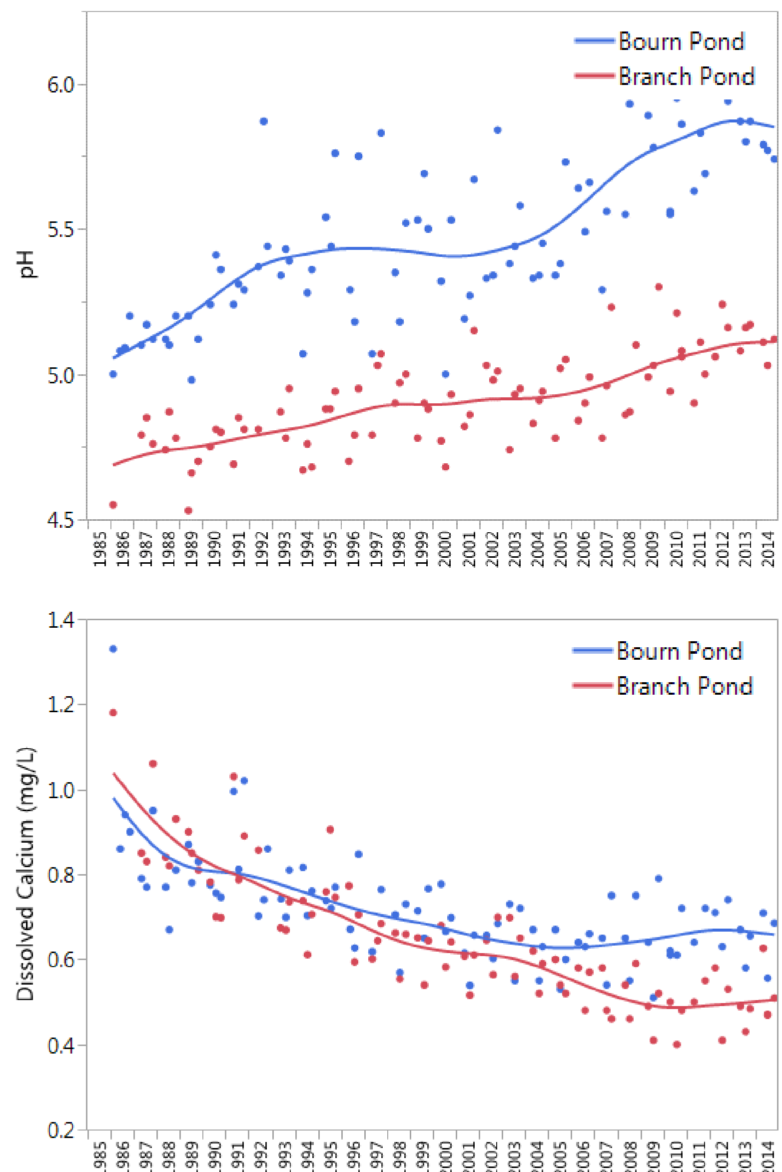

Figure 36. The ecological benefits of long-term increases in pH (top) are offset by decreases in dissolved calcium (bottom, mg/L) at the long-term acid lake monitoring sites.

Dissolved organic carbon levels have been increasing at both Bourn and Branch Ponds (Figure 37), which could aid in biological recovery through increased microbial food availability and reducing bioavailability of certain metals. Specifically, DOC mediates the impacts of the toxic inorganic monomeric aluminum to biota, and can speed conversion of toxic aluminum to organic forms beyond what is expected solely from decreased in acid deposition (Lawrence *et al.* 2013). However, while IMAl data was not available this year for addition to the trend analysis, findings from last year still hold - the rate of increase in IMAl has exceeded the rate of increase in DOC over the 20 year duration of monitoring efforts for those quantities. These disparate rates could present limitations to future biological recovery.

Implications

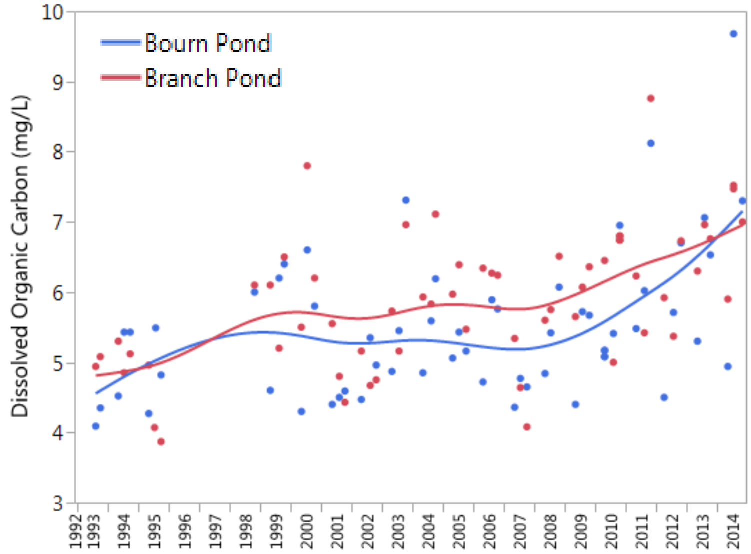

Figure 37. Long-term trends in dissolved organic carbon (DOC, mg/L) provide additional indicators of the health of high elevation surface waters.

Federal mandates under the Clean Air Act require Class I Wilderness Areas (like Lye Brook) to protect air-quality and related ecosystem values. The data collected at these water bodies provides one line of evidence with which to monitor and document the ecological impacts of both atmospheric pollution, and the policies meant to limit such impacts.

Acid-sensitive lakes have improved significantly since the 1990 Clean Air Act Amendments. But, because of the loss of calcium and magnesium throughout the watershed and in the lake itself, sensitive fish, snails, and insect species will not recover until further reductions in sulfur and nitrogen occur. Increases in dissolved organic carbon will aid in biological recovery as this weak organic acid binds with the toxic form of aluminum. In addition, time is needed to allow bedrock and soils to resupply calcium and magnesium to the lakes through the weathering process.

Analysis of air and water quality by means of chemical and biological inventories on these sensitive lakes will be maintained. Monitoring the lakes in Lye Brook Wilderness can be used to document trends resulting from emission reductions required by the Clean Air Act, but also to identify any potential new sources of stress or pollution, such as climate change. Such indicator trends are being used to inform management targeted towards the recovery of these water bodies.

While improvements in the acidity of high elevation surface waters are promising, a legacy of decreased base cations and increased toxic aluminum levels indicate that biological recovery remains uncertain.

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Lawrence, G.B, J.E. Dukett, N. Houck, P. Snyder, and S. Capone. 2013. Environmental Science and Technolology. 47 (13): 7095–7100

Additional Resources

Vermont Monitoring Programs for Acid Rain:
http://www.watershedmanagement.vt.gov/bass/htm/bs_acidrain-mon.htm

US Environmental Protection Agency Long Term Monitoring Program:
http://www2.epa.gov/airmarkets/monitoring-surface-water-chemistry

VMC Project Database Link

Biological And Chemical Survey Of Selected Surface Waters In Lye Brook Wilderness Area: Water Chemistry Of Water Bodies: http://www.uvm.edu/vmc/project/biological-chemical-survey-selected-surface-waters

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Aerial surveyor. Photo by the Vermont Department of Forests, Parks and Recreation.

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Stand of trees. Photo by Vermont Department of Forests, Parks and Recreation.

Dead alpine tree. Photo by the Vermont Monitoring Cooperative.

***Forest Phenology* Section**

Red maple leaf out. Photo by Brian Stowe.

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***Acid Deposition* Section**

N-Con Precipitation collector. Photo by Miriam Pendleton.

Acid damaged alpine trees. Photo by Vermont Monitoring Cooperative.

***Mercury Deposition* Section**

Mim Pendleton at ACM Collector. Photo by Judy Rosovsky.

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***Ozone* Section**

Ozone injury on white ash. Photo by Gretchen Smith.

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***Climate* Section**

Forest Environmental Monitoring Canopy Tower. Photo by Miriam Pendleton.

Sunset over Lake Champlain. Photo by Vermont Monitoring Cooperative.

***Forest Birds* Section**

Chris Rimmer, Kent McFarland and Bicknell's Thrush. Photo by Vermont Center for Ecostudies

Mount Mansfield. Photo by Vermont Center for Ecostudies

***Amphibians* Section**

Spring Peeper on finger. Photo by Erin Talmage, The Vermont Reptile and Amphibian Atlas.

Eastern Red Backed Salamander. Photo by Erin Talmage, The Vermont Reptile and Amphibian Atlas.

***Sentinel Stream* Section**

Parapsyche apicalis. Photo by Vermont Department of Environmental Conservation.

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***Watershed Hydrology* Section**

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***Water Quality* Section**

Bourn Pond. Photo by Flask Ehrlenmeyer http://mapcarta.com/22828132/Gallery

Lily pads in the water. Photo by Judy Rosovsky.

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