Vermont Monitoring Cooperative

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

Long-Term Monitoring Update 2015

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The Vermont Monitoring Cooperative Long-Term Monitoring Update - 2015

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Vermont Monitoring Cooperative, South Burlington, VT, USA

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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) facilitates collaboration among federal, state, non-profit, professional and academic institutions for long-term monitoring of forested ecosystems across the region and an improved understanding of forest ecosystems in light of the many threats they face.

Forest ecosystems are complex entities supporting many organisms and providing a wealth of ecosystem services. Because a healthy forest system is also dynamic in response to natural climate variability, disturbances and succession, long-term monitoring is necessary in order to distinguish normal year to year variability from emergent forest health issues or subtle changes indicative of chronic stress.

Driven by its mission to aggregate the information necessary to monitor forest health, detect chronic or emergent forest health issues and assess their impacts on forested ecosystems, the VMC network has completed nearly 200 individual research and monitoring projects conducted by over 215 collaborators over its 26-year history. These projects, conducted across the state of Vermont and the larger northern temperate forest region, investigate a range of forest, soil, water, wildlife, pollutant and climate relationships. While the VMC data archive includes many individual investigations relevant to understanding and sustaining healthy forest ecosystems, this Long-Term Monitoring Update offers a sampling of key long-term data sets that represents the basic structure, condition and function of the forested ecosystem. 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. This allows us to quantify metrics collected in 2015 in the context of long-term monitoring datasets.

The information in this Long-Term Monitoring Update 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. 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

Forest monitoring plots, such as those measured across the VMC long-term forest health monitoring network, provide long-term data on forest health trends and responses to disturbance. Measurements include detailed assessments of decline symptoms, which provide information on subtle changes in forest condition that may not be apparent from broader surveys such as aerial detection surveys. Regeneration assessments provide a glimpse of the potential future composition of the region's forests. This type of long-term, field-based monitoring is essential to understanding the current condition of the forest resource, potential drivers of forest decline, and how to sustainably manage the region's forests.

Forest health technicians measure canopy condition, seedling abundance, sapling survivorship, invasive species, and damage agents on a network of 41 long-term forest health monitoring plots.

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. In 1991, the VMC started establishing a set of 19 long-term forest health monitoring plots, adopting key ecosystem measurement methods from the national FHM program. These include a full inventory of tree species, canopy characteristics, stress symptoms, damage agents, and regeneration success.

In 2015, the full network of VMC plots was measured, with an additional 22 plots established to better represent forests across the state. At the resulting 41 forest monitoring plots, field crews conducted detailed canopy assessments of 1,983 mature trees representing 16 different species, 8 different forest types, across 8 different biophysical regions. In total, the information obtained from this plot network provides a robust estimate of the current condition of the state's forests, providing early indications of potential problems that may affect the broader region.

2015 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 like crown dieback and live crown ratio. Our assessment of 2015 (Table 1) showed that while the mean dieback (11.4 percent) across all key species in 2015 was not excessive, it does represent an increase compared to the historical average (9.5) and 2014 levels (9.6). Overall percent transparency in 2015 (22.6 percent) was also slightly higher than historical (20.6 percent) or 2014 (21 percent) levels. Neither of these represent significant deviations from the norm based on the amount of variability inherent in year-to-year measurements.

Broken down by species, measurements of percent dieback, live crown ratio, and transparency were similar or improved compared to historical measurements for most species. Exceptions include paper birch with increased dieback and transparency, and white ash with increased transparency compared to historical norms. Changes in paper birch are consistent with reports of declines across the region, and may also be indicative of our maturing forests, of which paper birch is a minor component. Increases in white ash transparency could be due to frost injury that affected 24,000 acres across the state, from moisture deficits present during critical leaf expansion in April and May, and/or resulting from the increased incidence of ash yellows witnessed across the

Table 1. Indicators of tree condition for selected dominant and codominant stems. The long-term and 2015 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 (green) or below (red) the mean.

Species	% Dieback			Live Crown Ratio			% Transparency		
	2015 Mean	Long-Term Mean	*Dif*	2015 Mean	Long-Term Mean	*Dif*	2015 Mean	Long-Term Mean	*Dif*
Abies balsamea (Balsam fir)	13.4	13.0	0.4	67.9	70.9	-3.0	21.7	19.2	2.5
Acer rubrum (Red maple)	9.6	6.9	2.8	51.8	49.5	2.3	19.3	20.0	-0.7
Acer saccharum (Sugar maple)	8.7	5.8	2.9	52.5	56.7	-4.1	17.6	17.0	0.6
Betula alleghaniensis (Yellow birch)	8.2	6.8	1.4	54.0	55.2	-1.3	18.0	18.7	-0.7
Betula papyrifera (Paper or White birch)	22.4	11.6	10.8	40.1	44.1	-3.9	30.5	22.1	8.4
Fagus grandifolia (American Beech)	12.1	10.6	1.5	52.4	57.6	-5.2	20.6	23.2	-2.6
Fraxinus americana (White ash)	11.0	7.9	3.1	48.1	36.8	11.2	25.3	19.2	6.1
Picea rubens (Red spruce)	8.7	7.3	1.3	46.9	53.6	-6.7	19.5	16.7	2.8
Pinus strobus (Eastern white pine)	5.3	5.3	0.0	46.5	46.5	0.0	22.8	22.8	0.0
Quercus rubra (Northern red oak)	8.1	4.8	3.3	49.6	33.8	15.9	22.0	17.0	5.0
Tsuga canadensis (Eastern hemlock)	5.7	16.3	-10.6	59.8	72.9	-13.1	21.0	32.2	-11.2

region. Eastern hemlock also reported a reduced live crown ratio, but it is likely that this reflects the expanded plot network, capturing a broader range of stands, including those with hemlock understories or locations with sub-optimal conditions.

Long Term Trends

Forest Health Trends: An examination of the full temporal dataset allows us to look past the year-to-year variability to consider species recovery rates and identify more chronic stress conditions. Figure 1 fits a simple spline to the mean transparency and dieback for each species per year. While there is clearly a large amount of annual variability, the percent canopy dieback trend exhibits a nearly uniform peak in the mid-2000's. The 2001-2002 drought was likely involved in these widespread declines. Since that time, percent dieback has remained relatively stable across all species.

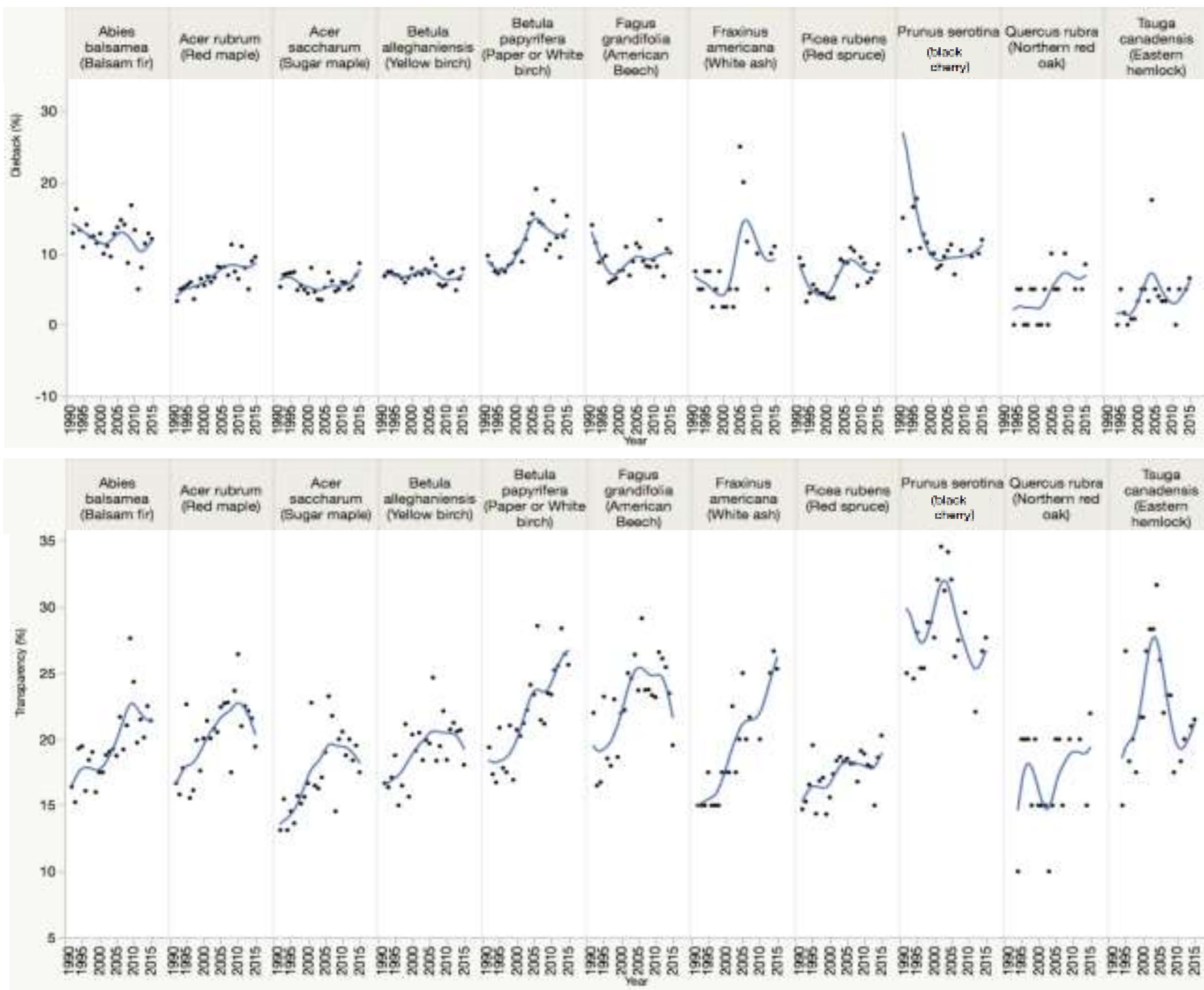

Figure 1. A simple spline fit to the plot mean dieback (top) and transparency (bottom) for each species per year. Note the high year-to-year variability, peak in dieback symptoms between 2007 and 2009, and peak transparency in 2010 for most species. In contrast, transparency continues on an upward trend for white ash and paper birch.

In contrast, mean transparency values over the past decade increased dramatically over those from the 1990's for almost all species. However, since 2010, there is evidence that this trend may be reversing for most species except for white ash and paper birch. The VMC will continue to monitor these species to understand how changing environmental conditions are altering forest health or competitive relationships.

Seedling Abundance: Seedling counts provide an estimate of the relative success of germination and initial survivorship across species from year to year. In 2015, overall seedling density was similar to previous years on 19 plots with long-term records (excluding 2014, which reported particularly high seedling counts)(Figure 2). However, it is important to note that a protocol change, implemented in 2014, expanded the definition of seedlings to capture current germinants and establishment patterns as well as longer term seedling survivorship. Prior to 2014, seedlings were only counted when they exceeded a certain height (6" for conifers, 12" for hardwoods, as per FIA protocol), and from 2014 on, all seedlings with true leaves and smaller than 1" DBH were counted. Thus, one explanation for the increase in 2014 overall seedling density may stem from the inclusion of seedlings that were previously ignored in counts. Yet this does not explain the significant drop in seedling density from 2014 to 2015. While different species cycle through different low and high mast years, the decrease is consistent across species. It is possible that the unusually dry spring, an official drought statewide and a moderate drought in southern Vermont in May, impacted overall germination success and survivorship across species.

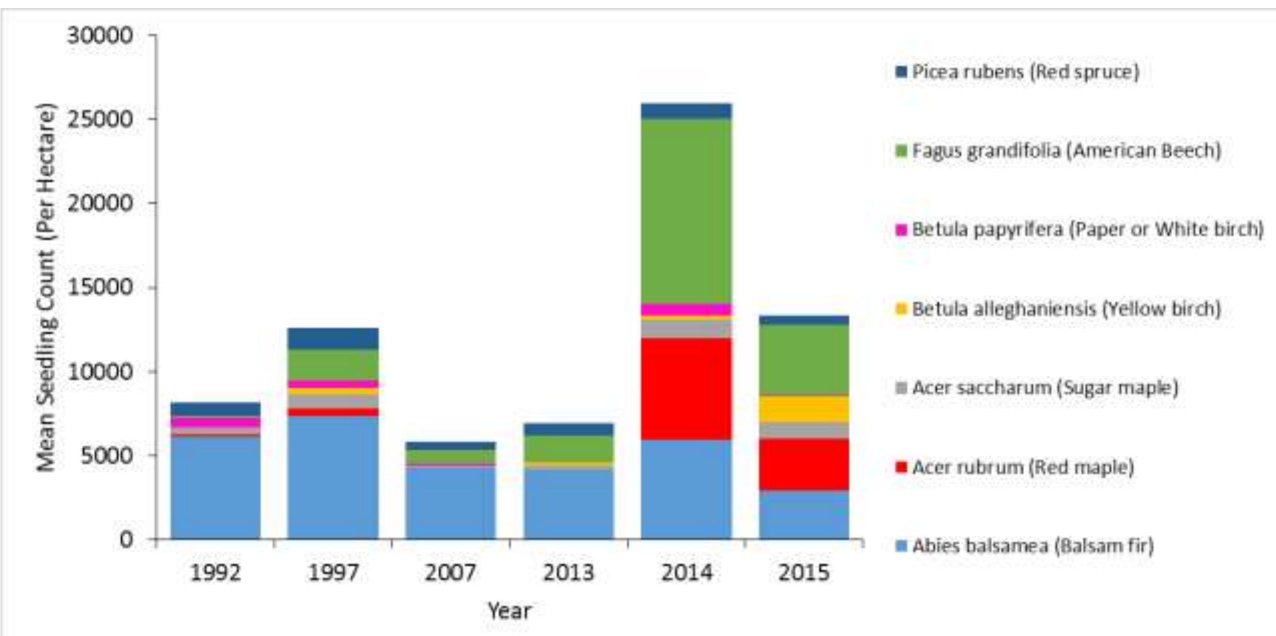

Figure 2. Mean number of seedlings per hectare (left axis) at the 19 consistently measured VMC forest health monitoring plots provide a picture of regeneration success and the potential composition of the future forest.

Seedling density across the 19 monitoring plots showed an increase in yellow birch seedlings in 2015 (Figure 2). Across all 41 plots, dominant species were American beech, red maple, and balsam fir (Figure 3). While these patterns vary dramatically across plots due to the broad geographic and elevational range of plots spanning many forest types, the lack of regeneration of low to mid-elevational shade tolerant species such as sugar maple and eastern hemlock is concerning. Considering that the species composition of mature trees across the VMC long-term monitoring plots (Figure 3) is dominated by balsam fir at upper elevations and northern hardwoods (sugar maple, American beech, and yellow birch) at mid-lower elevations, our data suggests that red maple regeneration is disproportionately high while sugar maple regeneration is disproportionately low. Given the regional economic and ecological importance of sugar maple, and apparent dominance of red maple regeneration in northern hardwood stands, further monitoring is warranted to understand the trends and patterns of sugar maple regeneration.

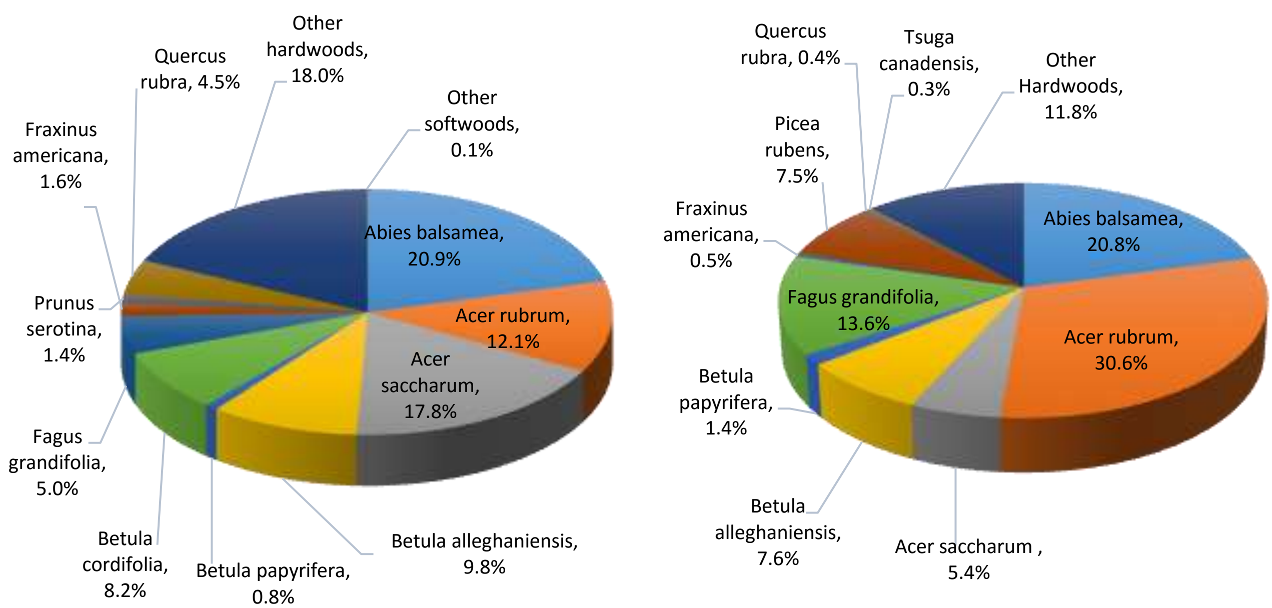

Figure 3. Species composition of all dominant and codominant trees greater than 12.7cm diameter (left) and all seedlings (right) tallied across the 2015 VMC monitoring plots.

Sapling Survivorship: Saplings (stems between 1 and 5 inches DBH) have been measured yearly on the 19 original VMC sub-plots between 1997 and 2007, and then again starting in 2014. This metric estimates the relative survivorship of seedlings and serves as a proxy for the future composition of the forest canopy. Our sapling assessments over this time period show a consistent drop in paper birch, yellow birch, and sugar maple. There are several ways that sapling counts can change: by growing out of the sapling class (and henceforth included in the full plot inventories of mature trees), through mortality of existing stems, and from a lack of recruitment of smaller stems into the sapling class. Based on this data we cannot determine which mechanism is primarily driving the decline in sapling numbers across the plot network. However, informed by the regeneration data, it is possible that reduced sugar maple seedling establishment and survivorship is contributing to its subsequent decline in the sapling class. Between the 2007 and more recent 2014 and 2015 sapling inventories, there were also dramatic increases in the density of both American beech and red spruce. Both are mid-late successional species that increase in dominance as forests mature. However, this dramatic rise (up almost 50% over 2007 levels for both species) may be a result of changes in site characteristics favoring these species. Low soil moisture may favor beech seedlings that originate from root sprouts. Reduced soil calcium from years of acid deposition would be better tolerated by species like beech and red maple.

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 be highly visible to the public. Long-term trends indicate that some species continue to fare better than others (e.g. increased dominance of American beech and red maple over sugar maple and birch species). Examination of metrics for other species indicates long-term trends that warrant ongoing monitoring of declining condition, particularly for paper birch and white ash. Regeneration data continues to indicate that the species currently dominating seedling classes may signal a shift in the composition of future forests in Vermont.

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 forest resiliency, productivity and health of the forested landscape into the future.

The region's forests are diverse and resilient, but shifting competitive relationships and regeneration patterns may lead to changes in forest composition over the coming decades.

Additional Resources

VT Forests, Parks and Recreation Vermont Forest Health Highlights 2015
http://fpr.vermont.gov/sites/fpr/files/Forest_and_Forestry/Forest_Health/Library/2015%20VT%20Forest%20Health%20Highlights.pdf

VT Forest Insects and Disease Conditions 2015
http://fpr.vermont.gov/sites/fpr/files/Forest_and_Forestry/Forest_Health/Library/2015%20I%26D%20Conditions%20Report%20final.pdf

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 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 complements plot-level field assessments of forest condition and has proven useful in detecting new health issues.

While more complete results of the 2015 Vermont sketch mapping effort can be found in the 2015 report on Forest Insect and Disease Conditions in Vermont (VT FPR, 2015), here we provide the long-term context for understanding the severity of forest injury in 2015 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 are 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 2015 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 more subtle decline symptoms.

2015 in Summary

In 2015, 46,425 hectares (114,718 acres[1]) of forest damage were mapped, accounting for less than 3% of Vermont's forestland. Beech bark disease and birch defoliation made up the majority of damage at 29% and 17%, respectively (Figure 4). This represented a marked increase from 2014, when 15,463 hectares (38,235 acres) were mapped.

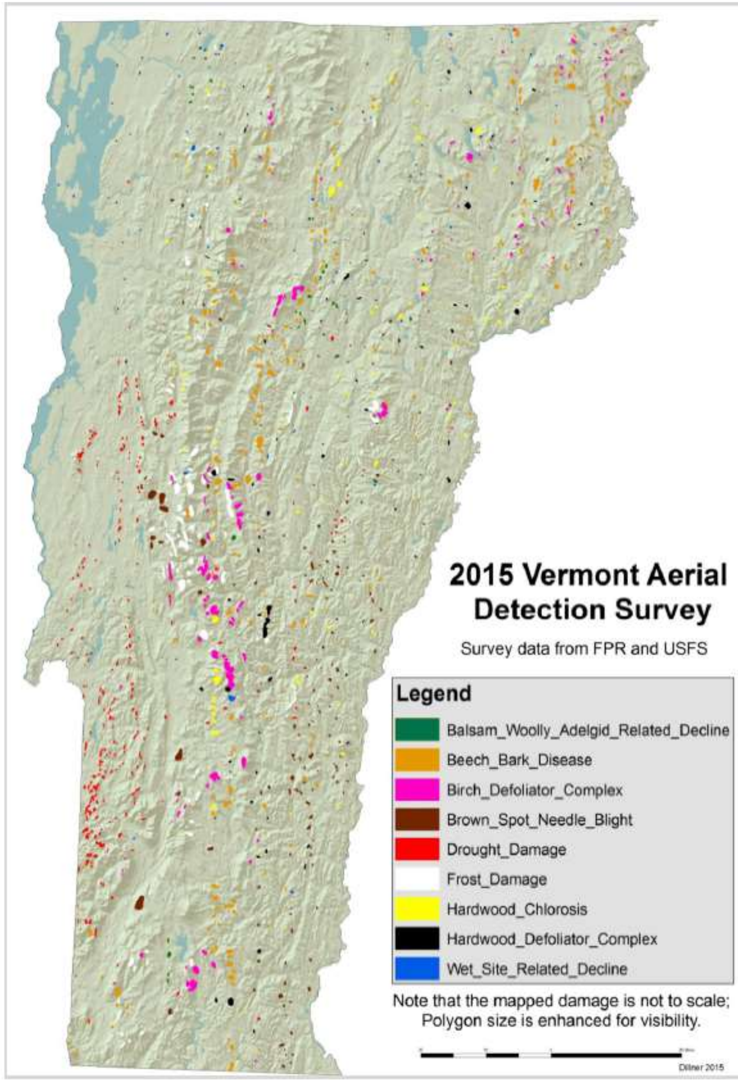

Figure 4. Locations of mapped forest damage by damage agent. Figure courtesy of VT FPR, Dillner 2015.

The non-native pest complex, beech bark disease, accounted for the largest mapped decline, with dieback attributable to the disease affecting more than twice as much area this year as compared to 2014. Weather was also a major driver of mapped damage, particularly impacts of a late frost on maples (7,964 hectares, 19,680 acres). Wetter conditions following a dry spring allowed *Septoria* on birch to establish, with 7,883 hectares (19,481 acres) of damage mapped.

Major defoliating insects did not reach outbreak levels, though an increase in light forest tent caterpillar defoliation was observed across the state. Red pine mortality increased significantly in 2015, and the red pine scale was detected for

[1] Due to minor corrections to earlier tabulations of polygon areas, the calculated areas reported here differ from those reported in FPR's 2015 Insect and Disease Conditions Report.

the first time in Vermont. White pine needle diseases increased again, with 4,544 hectares (11,229 acres) mapped as compared to 2014 (2,012 hectares, 4,972 acres). However, the extent of damage was likely much larger than the mapped area due to the difficulty of detecting damage in late summer.

Long Term Trends

While 2015 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 5). Since 2005, total mapped damage area has generally declined. Although more damage was mapped in 2015, it is still below the long-term norm for the dataset. This trend may reflect the influence of 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 more consistent damage over time with no clear decreasing trend.

Long-term analyses of the five primary damage types recorded in the aerial survey data show that high year to year variability dominates (Figure 6). 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. Performing a linear regression on dieback alone demonstrated a marginally significant decreasing trend in mapped area over the 21-year record (p = 0.08).

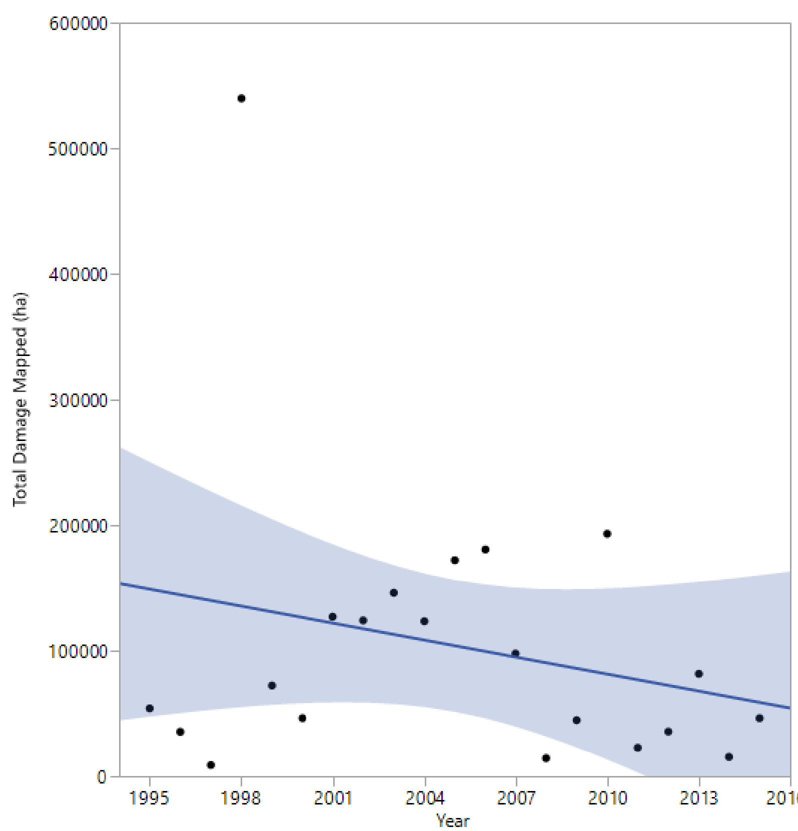

Figure 5. Total area (in hectares) of damage mapped during statewide aerial surveys between 1995 and 2015 with the 95% confidence intervals shaded in blue. The trend shown here of decreasing damage extent is driven largely by extensive ice storms in 1998.

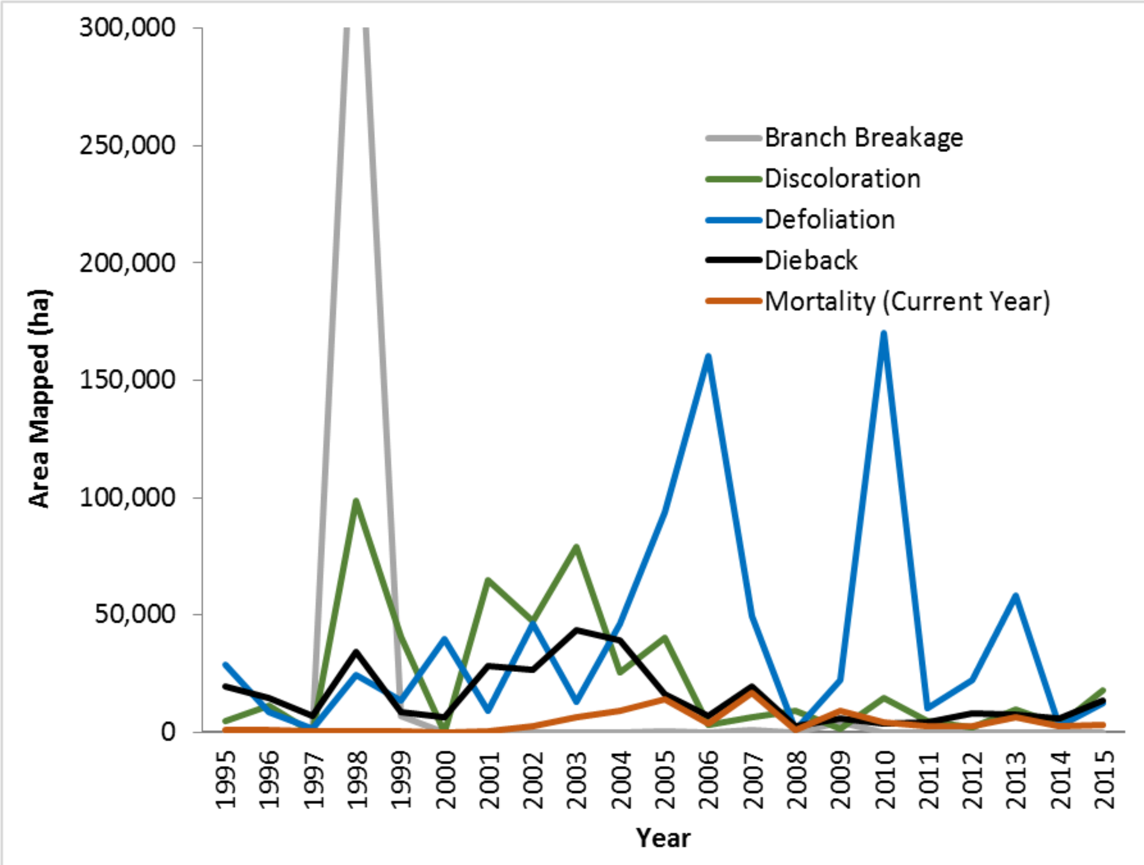

Figure 6. Temporal trends in key damage types mapped during statewide aerial surveys between 1995 and 2015.

Annual fluctuations of select damage agents are shown in Figure 7. 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.

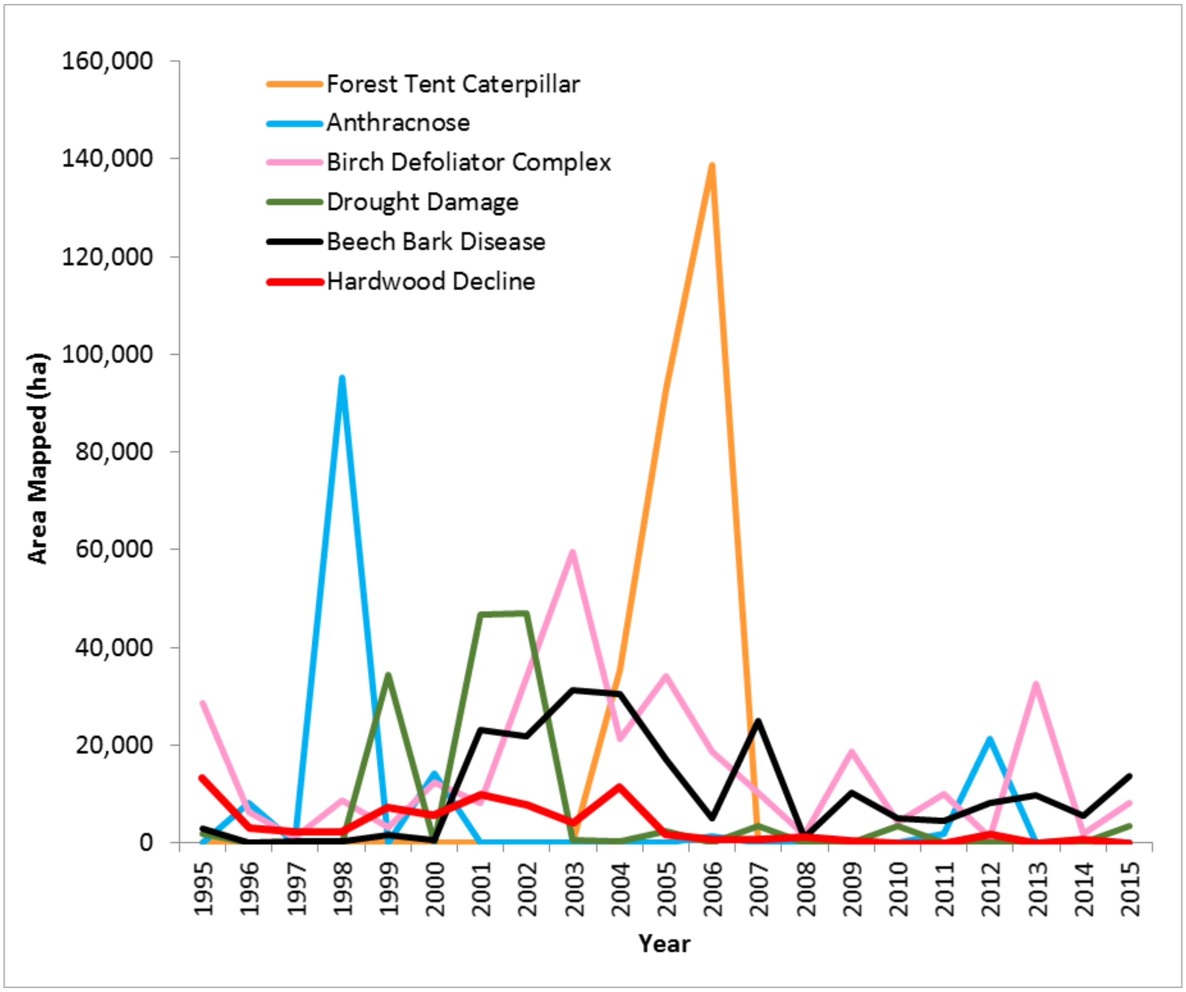

Figure 7. Temporal trends in select damage agents mapped during statewide aerial surveys between 1995 and 2015.

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 21-year period. Birch defoliators and beech bark disease 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 2015, including the number of years that the damage was detected and mapped, the total area mapped over the 21- year period, and the maximum number of hectares mapped in a single year.

Damage Agent Name	Number of Years Mapped (1995 - 2015)	Total Acres Mapped (ha)	Maximum Area Mapped (ha)
Birch Defoliator Complex	21	324,446	59,519
Beech Bark Disease	21	217,823	31,346
Wet Site Related Decline	20	91,168	32,557
Spruce-Fir Decline	20	33,842	6,753
Larch Decline	20	7,373	1,586
Logging Related Decline	19	7,177	1,529
Birch Decline	18	18,301	6,302
Hardwood Decline	17	74,259	13,263
Wind Damage	17	5,677	2,464
Hardwood Chlorosis	14	27,846	7,760
White Pine Symptoms	14	2,041	815
Locust Leafminer	14	936	382
Fire	14	223	54
Drought Damage	13	143,793	46,864
Poplar Leaf Fungus	12	5,110	2,089
Hardwood Defoliator Complex	11	52,335	41,503
Willow Defoliation	11	1,176	802
Maple Leaf Cutter	10	31,062	11,908
Balsam Woolly Adelgid Related Decline	10	14,185	3,637
Anthracnose	9	161,502	95,260
Unknown	9	27,006	22,909
Pine Needlecast/Brown Spot Needle Blight	9	9,155	4,544
Ice/Snow Damage	6	394,838	381,843
Hemlock Mortality	6	266	226
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 8). Many cause only limited impacts; they occur infrequently and cause little damage (MINOR, blue circle). Some have a locally important impact, occurring in many or most years, but rarely causing damage over a wide area (CHRONIC, green circle). Many chronic damages are related to site characteristics that may predispose them to decline, as in drought. 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 wide-extent damage agents (EPISODIC, orange circle). 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.

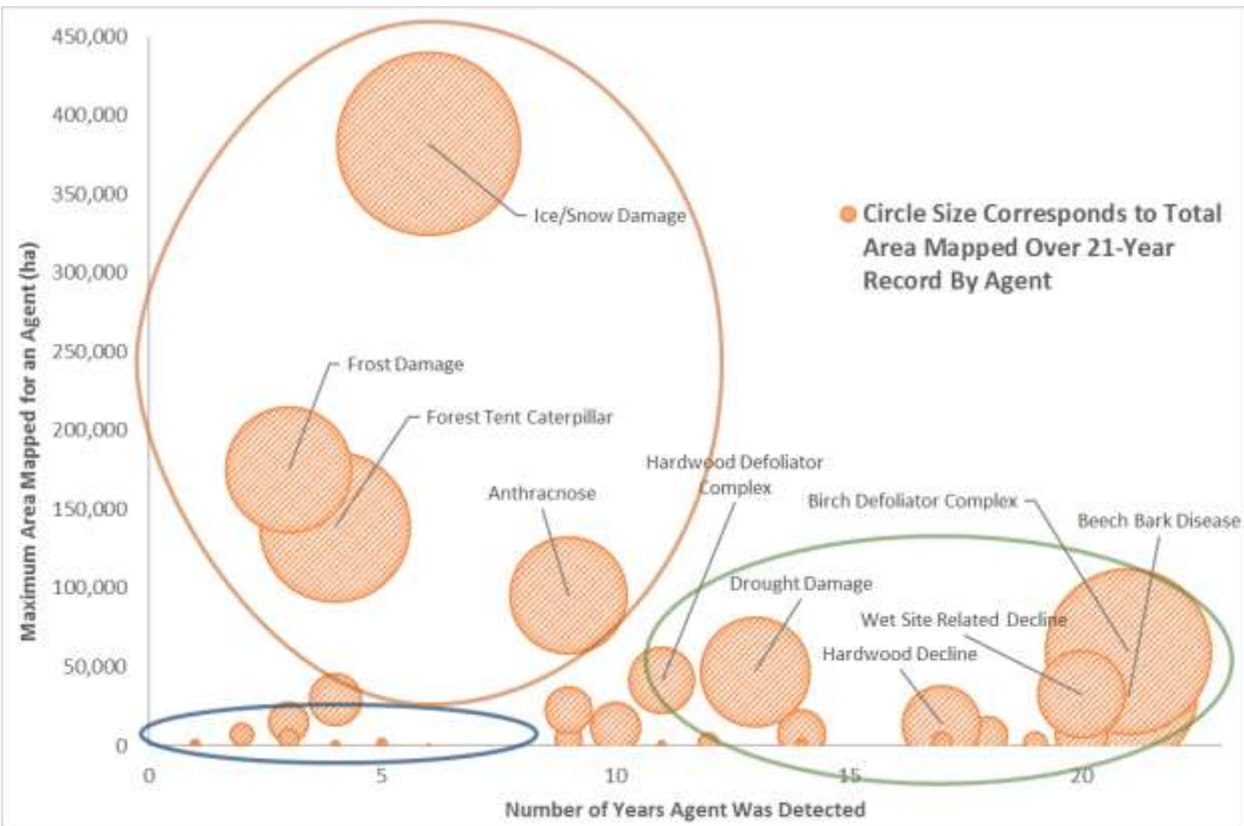

Figure 8. Mapped data points of the 58 different damage agents detected between 1995 and 2015. Damage agents are plotted by frequency of detection versus maximum extent mapped during aerial surveys, with point size corresponding to the total area recorded for that agent over the twenty-one-year period. The larger circles identify groupings of points into the MINOR (blue), CHRONIC (green) and EPISODIC (orange) categories described in the text.

No agents caused repeated, 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 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 21 years, affecting nearly half the birch forest type in Vermont at its peak.

Implications

Aerial surveys provide the longest statewide annual record of stressors faced by Vermont's forests. Over the past 21 years, only limited areas of dieback and mortality and relatively low levels of total damage have been mapped. This reflects a relatively 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 21-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 monitoring 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.

Mapped damage area in 2015 remained relatively low (< 3% of the state) but increased threefold over last year. 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.

References

Vermont Forest Parks and Recreation (VT FPR). 2015. Forest Insect and Disease Conditions in Vermont: 2015. Report. Available online at: http://fpr.vermont.gov/sites/fpr/files/Forest_and_Forestry/Forest_Health/Library/2015%20I%26D%20Conditions%20Report%20final.pdf

Additional Resources

VMC Project Database Links

Aerial Sketchmapping: 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 changes in vegetation, including springtime leaf expansion and fall senescence, has important implications for ecosystem processes. Long-term field assessments of tree phenology allow us to detect subtle changes in the timing and duration of phenology, which help us better understand how changes in climate are impacting forested ecosystems.

The Data

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. Annual phenology assessments start each spring while buds are dormant and continues until leaves are fully expanded. Spring phenology is assessed twice weekly on five dominant sugar maple at the Proctor Maple Research Center, at an elevation of 415 m (1400 feet). Trees are assigned to one of eight bud developmental stages based on an assessment of 10 random buds (Skinner and Parker, 1994) and then averaged to a plot-level mean.

Metrics of fall phenology include visual ratings of percent color and leaf drop, recorded weekly beginning in September on these same trees. Additional sugar maple trees were also monitored at a site above the Underhill State Park at an elevation of 670m (2200 feet). Percent color is assessed as the proportion of the current leaves exhibiting a color other than green. Percent leaf drop is 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 are recalculated to represent the proportion of the initial fully foliated crown with color as:

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

Timing of spring budbreak and fall color are informing us about the impacts of a changing climate here in Vermont.

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 trends in seasonal developmental events across the 23-year period.

2015 in Summary

The day-of-year of first bud break in 2015 for sugar maple (DOY 126) was similar to the long-term average (DOY 124). Full leaf out (DOY 132) occurred 5 days earlier than the long-term mean. This green-up duration was much more rapid than the long-term average of 12 days – in 2015, there were only 6 days between bud break and full leaf-out (1 day shorter than 2014). At lower elevations, maximum fall color occurred 6 days later than 2014– more than a week later than the long term mean. Full leaf drop came 3 days later than last year and nearly 7 days later than the long-term mean. At higher elevations, peak color was even more delayed (13 days later than 2014, and 11 days later than the long-term mean), although full leaf drop was only 2 days later than the long-term mean.

Long Term Trends

While 2015 spring phenology timing was similar to the long-term mean, it still fits a long-term trend toward an earlier start of spring (Figure 9). 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 or leaf out. Nevertheless, there does appear to be a weak but consistent trend for earlier spring phenological measures over the course of our monitoring efforts (Figure 9).

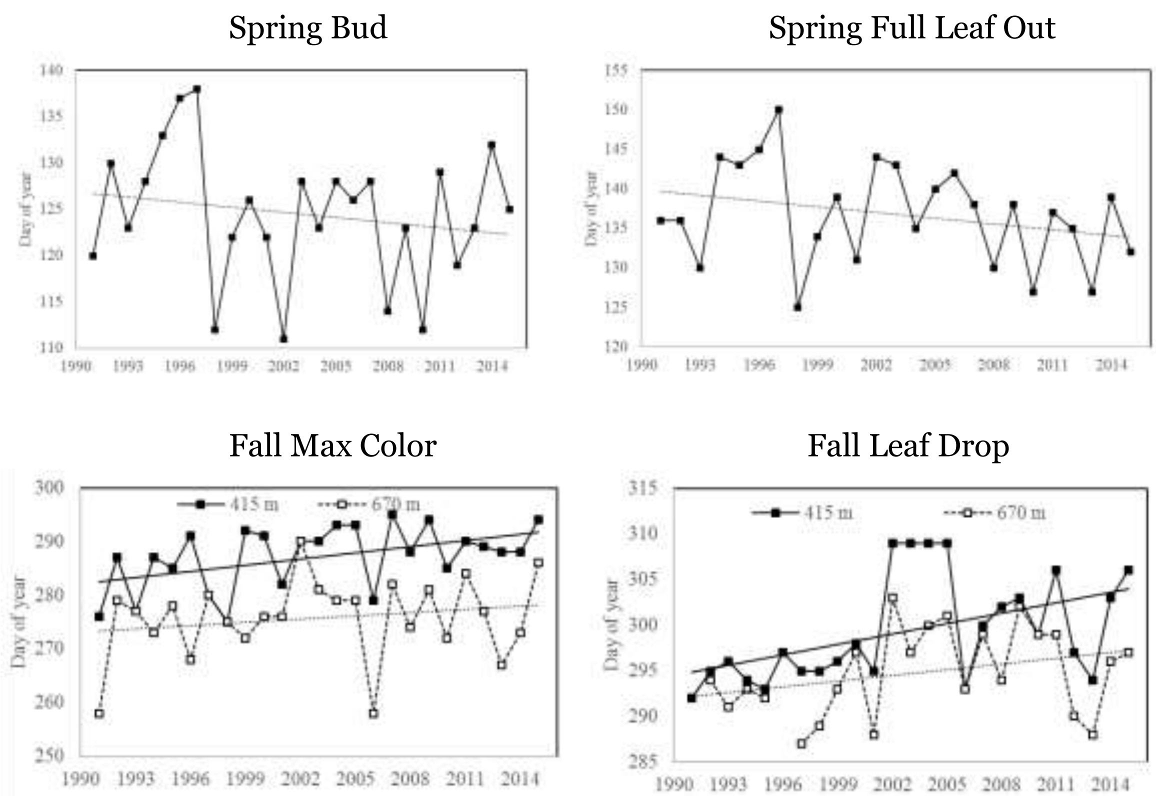

Figure 9. Long-term trends in the timing (mean day of year) of spring and fall phenological events for sugar maple from 1991 to 2015. Spring bud burst (top left) and full leaf out (top right) are assessed yearly at lower elevation (415m), with linear trend line shown. Fall maximum coloration (bottom left) and leaf drop (bottom right) yearly data are shown for sugar maple at two elevations (415m and 670 m) as well as a linear trend line in both.

In the fall, significant trends towards later fall color and leaf drop at lower elevations continued to be observed (Figure 9). The delay of maximum fall colors at low elevations showed consistently later peak foliage over time, culminating in an average delay of 7.1 days across the data record. Fall leaf drop showed a similar 6.9-day cumulative delay at low elevations. Interestingly, trees at upper elevations did not show a trend of changing fall phenology for either of the fall metrics. This continues to be surprising given model data suggesting that warming due to climate change may be more severe at higher elevations (Giorgi et al. 1997). Exploring microclimatic differences at each elevation are necessary to tease apart the possible mechanisms behind differing phenological responses of trees at the two sites. 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, supported by our data. The net effect of these long-term changes in phenology timing is a notable increase in growing season length. It is unclear how this may impact forested ecosystems. There are possible 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 and nutrient limitations in northern hardwood forests. While expanded growing seasons may benefit some species, it may leave others more vulnerable to climate extremes that occur more often in shoulder seasons. There may also be cascading impacts through forested ecosystems, including phenological asynchrony across taxonomic groups.

The changes we observed in the timing of foliar development carry 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). Warmer winters and earlier springs are now shortening and advancing the sugaring season (Skinner *et al.*, 2010), and 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).

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 ecologically and economically important information to sustainably manage our forests in the face of these environmental changes.

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.

References

Daley, M. J., N. G. Phillips, C. Pettijohn, and J. L. Hadley. 2007. Water use by eastern hemlock (*Tsuga canadensis*) and black birch (*Betula lenta*): Implications of effects of the hemlock woolly adelgid. Canadian Journal of Forest Research **37**:2031-2040.

Frumhoff, P. C., J. J. McCarthy, J. M. Melillo, S. C. Moser, and D. J. Wuebbles. 2007. Confronting climate change in the US Northeast. Union of Concerned Scientists. , Cambridge, MA.

Giorgi, F., J. W. Hurrell, M. R. Marinucci, and M. Beniston. 1997. Elevation dependency of the surface climate change signal: A model study. Journal of Climate **10**:288-296.

Sawyer, S., E. Kahler, and K. Perkins. 2013. 3.3 Food Production: Maple Syrup *in* Analysis of Vermont's Food System: Farm to Plate Strategic Plan. Vermont Sustainable Jobs Fund, Montpelier, VT.

Skinner, C. B., A. T. DeGaetano, and B. F. Chabot. 2010. Implications of twenty-first century climate change on Northeastern United States maple syrup production: Impacts and adaptations. Climatic Change **100**:685-702.

Skinner, M., and B. L. Parker. 1994. Field guide for monitoring sugar maple bud development. VMC Research Report #8. VT Agric. Exp. Sta. RR70. University of Vermont., Burlington, VT.

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 and its impacts on the forested landscape have been well documented over the past several decades. As atmospheric inputs have accumulated on the landscape there have been numerous studies documenting the cascading impacts on ecosystems, such as the dieback of red spruce in the 1970s and 80s, soil cation leaching and water quality impacts to name a few. These studies are made possible by the availability of long-term atmospheric deposition monitoring. The Underhill NADP/NTN site 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 both spatial and temporal patterns of acidic deposition. These networks consist 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.

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.

2015 in Summary

For all three deposition metrics (pH, SO_4 and NO_3), 2015 continued the trend of reduced pollution concentrations over historical measurements (Figure 10, Table 3). pH was the best year on record with a mean weekly composite of 5.1 . While this is up significantly from the historical low of 4.4, “unpolluted” rain typically has a pH of 5.6, indicating that there is still room for continued improvement. As pH is a logarithmic scale this represents a roughly fivefold improvement in acidity.

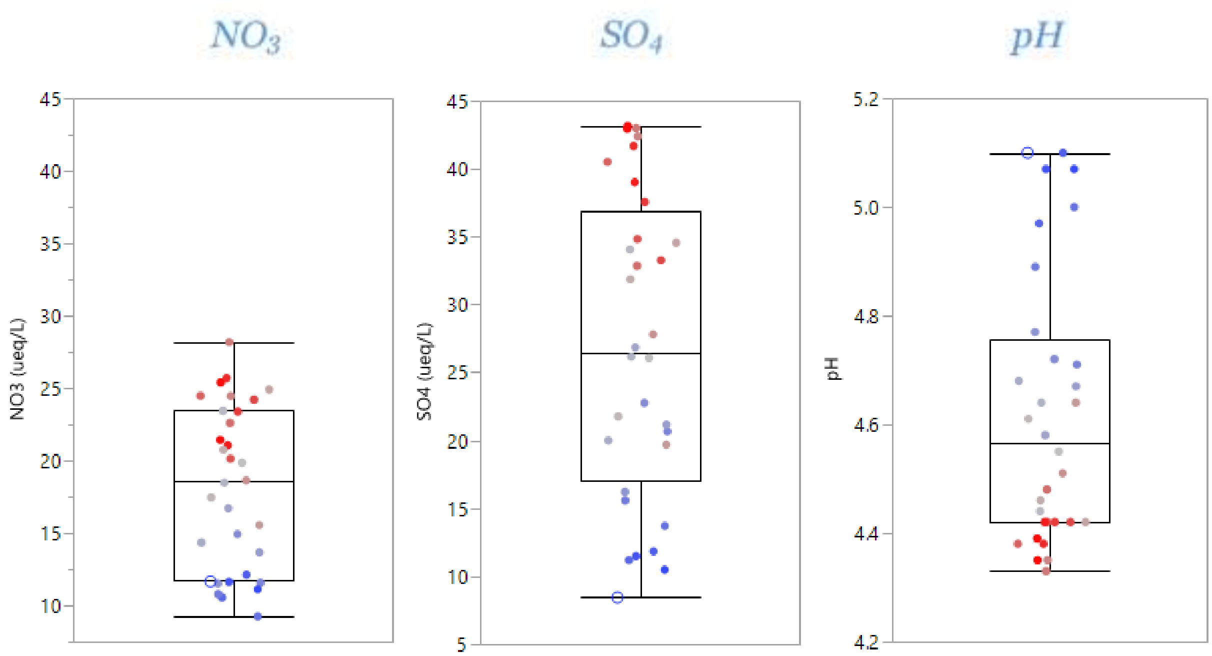

Figure 10. Quantile box plots show that 2015 (blue open circle) was a near outlier year, with the lowest mean SO4 concentrations (middle) and highest mean pH (right) on record. NO3 concentrations (left) were also in the lowest quartile, although not at record low values. Each dot represents a yearly mean value, with earlier dates in red and more recent dates in blue.

SO_4, a primary component of acid deposition, also set a new record in 2015 with the lowest concentrations on record. NO_3 concentrations in 2015 was in the lowest quartile of measurements for the 31-year record, and marks the fourth 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 oxides (NO_X) have declined. However, the reductions in SO_X have been proportionately greater than reductions in NOx. While the stress imposed by SOx deposition has been greatly reduced, it is unclear how the continued deposition of NOx will impact forested ecosystems, especially since emissions and deposition of reduced nitrogen (NHx) have not yet declined.

Table 3. Summary statistics for NO_3, SO_4 and pH for 2015 and the long-term record.

		NO_3 (ueq/L)	SO_4 (ueq/L)	pH
2015	*2015 Average*	11.66	8.44	5.10
Full Record (1984-2015)	*Long-term Average*	18.12	26.98	4.60
	Standard Deviation	5.63	11.24	0.25
	Minimum	9.24	8.44	4.33
	Maximum	28.18	43.14	5.10

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 and amendments in 1977 and 1990. This includes decreases in both sulfate and nitrate pollution, and a corresponding increase in precipitation pH (Figure 11). However, the most significant reductions are witnessed in sulfate, with more modest changes in nitrate. This primarily stems from the relative difficulty removing nitrogen compounds

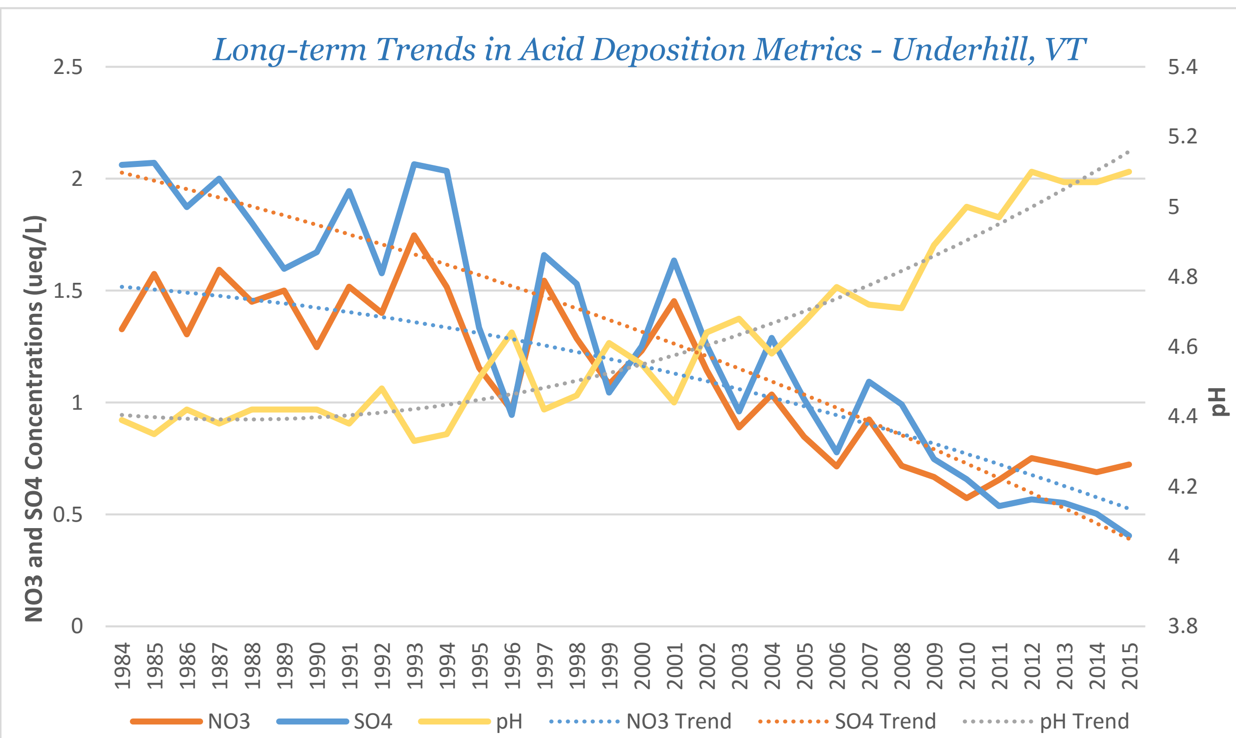

Figure 11. Long-term trends based on yearly mean concentrations (ueq/L) and pH highlight the success of the amendments to the 1990 Clean Air Act.

from flue gases and their diffuse pollution sources such as motor vehicle exhaust and agricultural activities.

Looking at the most recent trends (considering only the past several years), it is likely that reductions in SO4 may continue (Figure 11). However, it appears that reductions in NO3 concentrations have leveled off. Because NOx pollution primarily comes from diffuse sources such as automobile exhaust, fertilizer use and confinement farming such as feedlots and poultry operations in agricultural regions, it is likely that continued reductions may require additional legislative or regulatory action.

Implications

Vermont is in relatively good shape compared to nitrogen pollution loads nationwide (Figure 12). However, forests along the spine of the Green Mountains are still particularly susceptible due to more frequent exposure to acid mist in clouds, higher levels of precipitation and relatively shallow soils. This makes high elevation ecosystems particularly sensitive to secondary stress agents. 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 and its impacts on terrestrial and aquatic ecosystems.

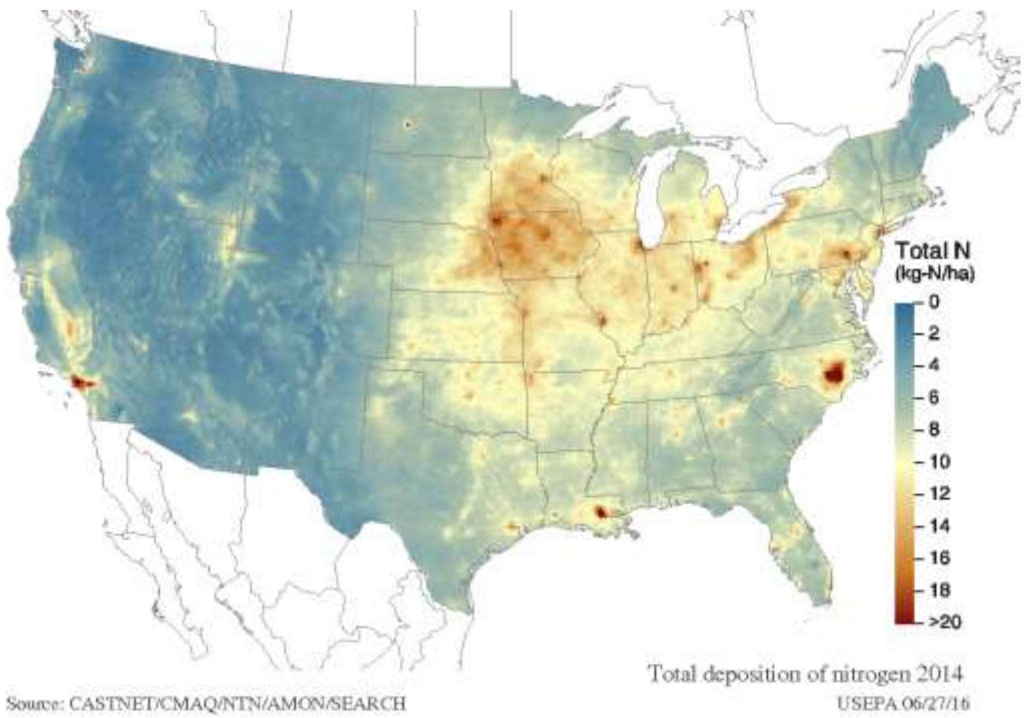

Figure 12. 2014 spatial distribution of total nitrogen deposition across the continental US. All three monitoring networks that collaborated to produce this map are represented at the VMC air quality site in Underhill.

Overall, acid deposition is a regulatory success story, but pH remains below "clean" levels and NOx deposition is no longer improving. Many sensitive ecosystems may still be susceptible to adverse impacts.

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 Links

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

Mercury Deposition

Mercury Deposition Network Monitoring at VT99

Long time site operator Mim Pendleton working on Merury Deposition Network sample 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 water bodies through both dry and wet (in precipitation) deposition. Since 1992, VMC has been collecting data on both wet and dry mercury deposition, 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 U.S. and Canada. The VMC air quality site serves as a sentinel site for the northeastern U.S. – 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 bioaccumulates 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

The Data

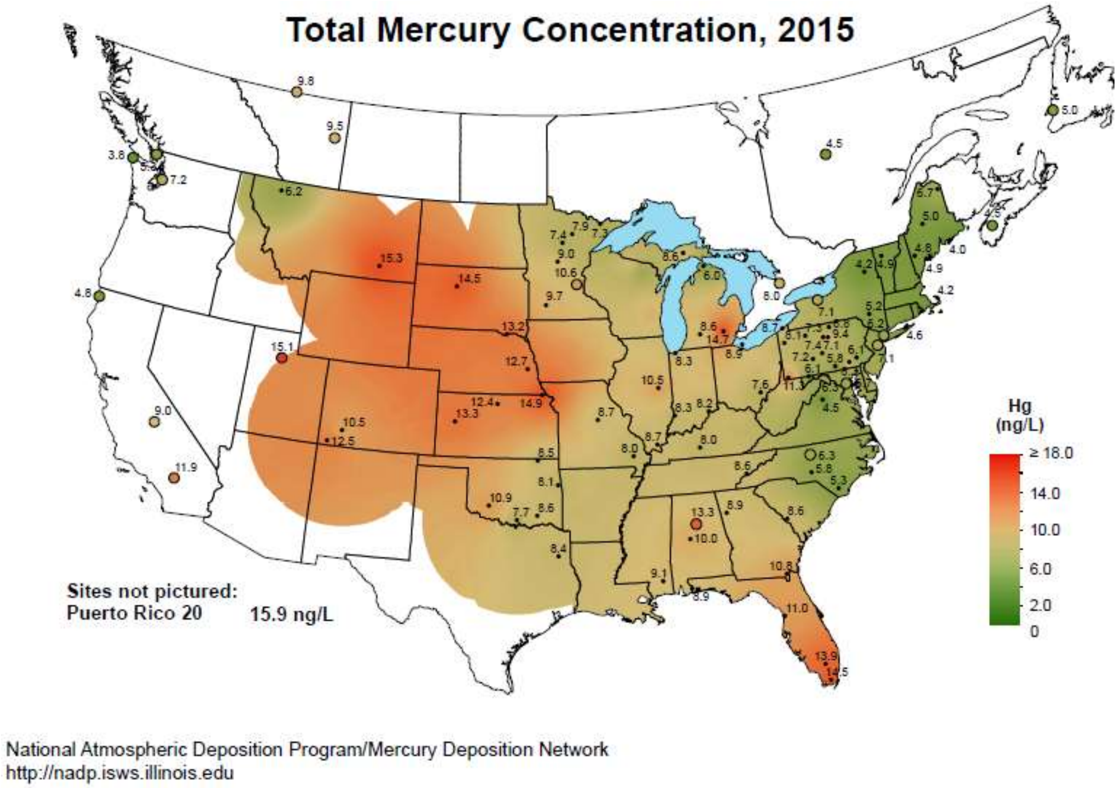
VMC conducts year-round sampling of precipitation chemistry at the air quality monitoring site at the Proctor Maple Research Center in Underhill, Vermont. Weekly composites of precipitation are gathered in an automated wet-only precipitation collector at the site. The collector opens automatically when rain or snow is detected, capturing precipitation through a funnel and tube sampling train into a bottle charged with hydrochloric acid (to 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 concentration 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/).

2015 in Summary

Mercury monitoring at VMC's air quality site (VT99) for 2015 shows lower deposition than on average for the 11-year record, being equal to 2012 and slightly lower than 2009, which makes 2015 one of the lowest years on record (Table 4). Over the entire record for VT99, total mercury deposition fluctuated from a high of 11.6 µg/m² in 2007 to a low of 6.1 µg/m² in 2012 and 2015. Similarly, the precipitation-weighted mean mercury concentration and the maximum mercury concentrations measured at VT99 are quite variable, and for 2015 both were below the mean for the entire record. Across the United States, Vermont registered lower concentration and deposition averages that most other sites (Figure 13).

Table 4. Annual mercury measurements from VT99. 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 ng/L	Max Hg Concentration ng/L	Total Hg Deposition µg/m2
2005	5.58	33.9	7.4
2006	5.18	97.2	7.9
2007	8.74	131.6	11.6
2008			
2009	5.27	33.7	6.3
2010	5.55	48.0	8.4
2011	6.12	88.7	9.6
2012	4.73	63.9	6.1
2013	5.78	21.1	8.1
2014	5.25	11.5	7.2
2015	4.90	21.0	6.1
Overall Mean	***5.71***	***55.1***	***7.9***



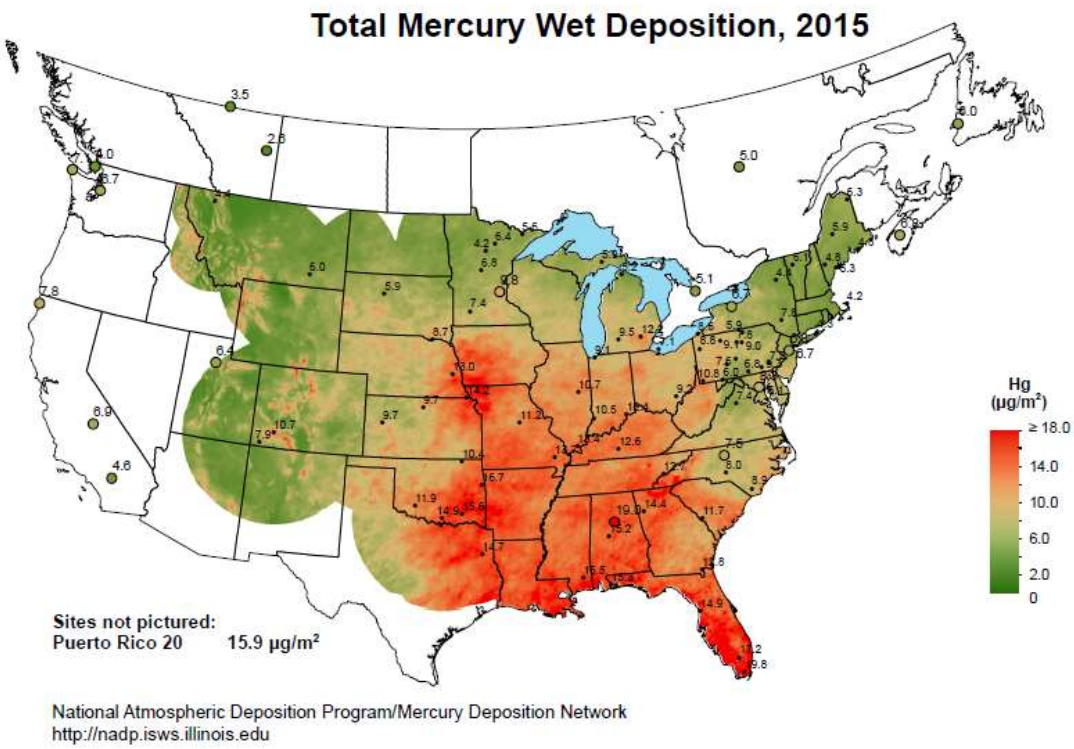


Figure 13. Estimated concentration and deposition of mercury in precipitation across the United States. Concentration varies with the amount of precipitation, and is used to determine pollution sources and other atmospheric possesses. Total deposition is the amount of chemical deposited from the atmosphere on the landscape, and is used to assess the consequences of specific pollutants on the ecosystem.

Long Term Trends

Over 10 years of monitoring at VT99, mean annual deposition is higher than 41% of national MDN sites. Thus 2015 was a relatively good year for VT99, with only roughly a quarter of national MDN sites recording lower mean deposition. Mercury deposition has decreased in VT in recent years, but still remains among the highest deposition rates in the region (Figure 14).

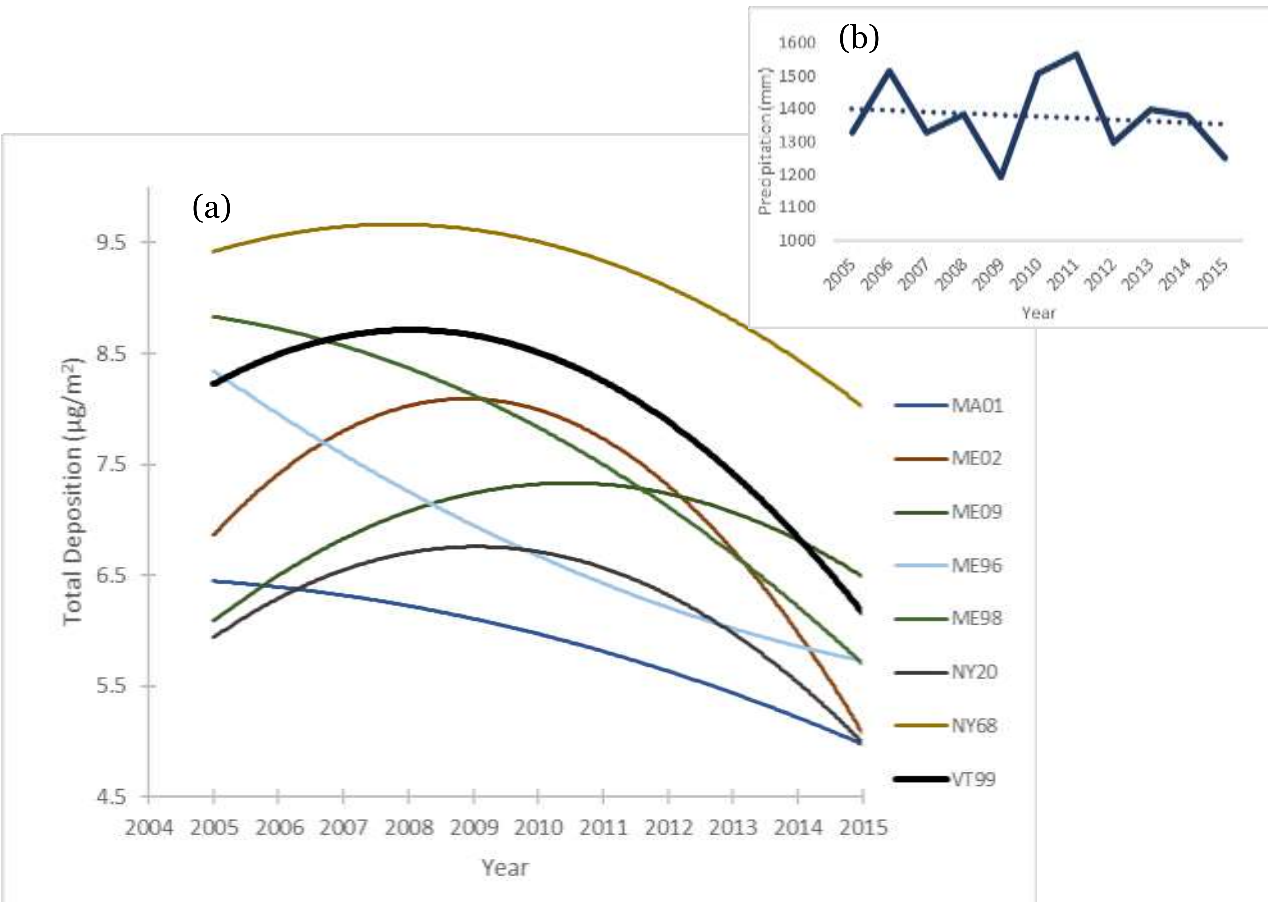


Figure 14. Total Hg deposition (a) in µg/m2 by year for northeastern MDN monitoring sites with comparable years of data collection, including binomial smoothed lines. Inset (b) displays the precipitation record at the site, which shows little trend over the same period.

Indeed, a recent regional trends analysis using NADP MDN data (Figure 15) provides further signs of regional differences for VT99 (NADP 2015). Different time periods were analyzed, including the entire record 1997-2013, and then several shorter portions of the record. As the MDN network was expanding the shorter time period analyses were a way to incorporate the changing spatial pattern into the trends analysis. This period from 2008 to 2013 shows VT99 having a statistically significant positive slope in increased mercury concentrations. Five years is too short for a definitive trend but might suggest, due to its relatively high altitude and the absence of nearby coal utility boilers, that VT99 is more influenced by global sources than are surrounding lower altitude MDN sites (Weiss-Penzias *et al.*, 2016).

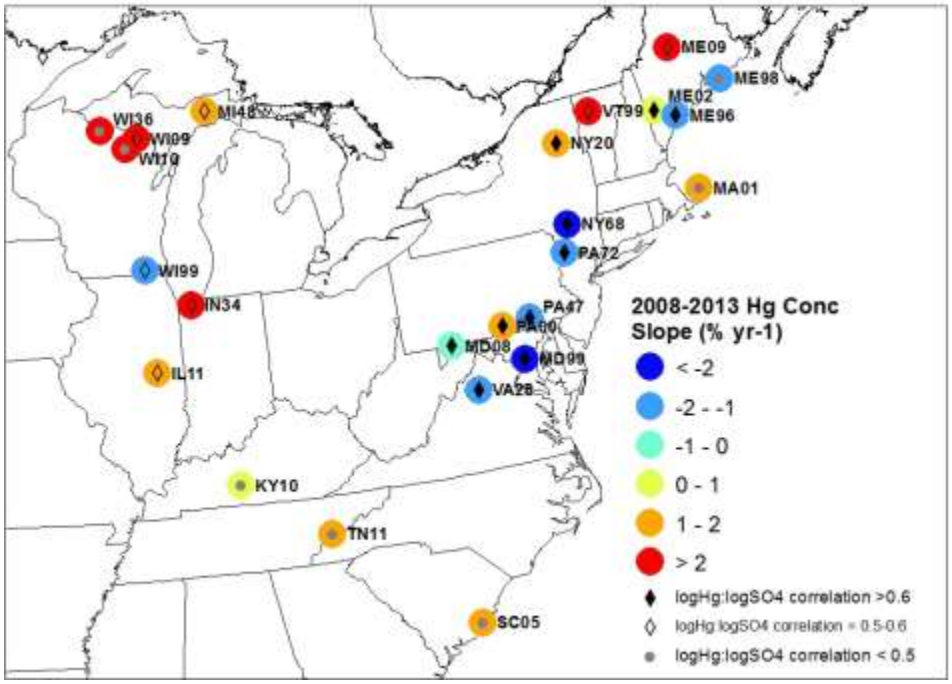


Figure 15. Annual rates of change in Precipitation Weighted Mean residual mercury concentration over the period 2008-2013 for co-located Mercury Deposition Network and National Trends Network sites in the northeastern U.S. Symbols indicate the site-specific linear correlation coefficients (R) obtained from a regression between weekly log Hg and weekly log $SO_4^{=}$ concentrations (not residuals) over the 2008-2013 period.

For a larger perspective, compared to the ***national*** network of MDN sites (Table 5), deposition at the VT99 monitoring station has ranged from the high end (85th percentile in 2007) to the low end (14th percentile in 2012) of measured values within the network. Over the period from 2005 to 2015, the VT99 site is in the 41st percentile for reported mercury deposition values across the Mercury Deposition Network.

Table 5. Percentiles comparing the number of national MDN network sites reporting total Hg deposition (µg/m2) values below VT99. Means are given for stations that met yearly quality criteria, while the number of reporting stations includes those stations that did not meet quality criteria.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Overall Average
# of reporting stations	95	104	112	117	125	133	112	113	116	120	116	176
National Mean Deposition (µg/m2)	9.2	9.3	8.7	9.7	8.6	9.0	10.2	8.8	9.9	9.5	8.9	9.0
VT99 Mean Deposition (µg/m2)	7.4	7.9	11.6	--	6.3	8.4	9.6	6.1	8.1	7.2	6.1	7.9
VT99 Deposition Percentile	34%	38%	85%	--	35%	49%	48%	14%	44%	31%	27%	41%

Implications

Mercury deposition levels have decreased dramatically with the enactment of clean air legislation in the late 20th century (Kamman and Engstrom, 2002). The atmosphere is the main pathway for mercury into Vermont's ecosystems, and it is estimated that more than half of this atmospheric deposition comes from dry deposition. While NADP is committed to increasing monitoring of dry mercury deposition, VMC unfortunately had to terminate its Atmospheric Mercury Network site on Dec. 31, 2015, so future dry deposition rates will have to be inferred rather than measured.

Mercury persists in the environment, cycling through various storage pools. 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; Gay personal communication, 2016; Weiss-Penzias *et al.,* 2016). Fish mercury burdens are one way to track these trends and in Vermont, fish advisories are still being issued (Chalmers *et al.*, 2014; Vijayaraghavan *et al.,* 2014). Until fish tissue sampling shows a long-term negative trend, the need to monitor mercury is critical.

Historically, sulfate emissions have been strongly correlated with mercury emissions because they shared the same primary source, coal-fired utility boilers, but with the impressive reduction in sulfates mandated by the Clean Air Act, this is no longer true. In the northeast, mercury concentrations are up, suggesting that mercury measured here is not associated with regional sulfur emissions. The Environmental Protection Agency's Mercury and Air Toxics Standards ("MATS"), which will implement emissions reductions of toxic air pollutants from existing and new coal and oil-fired power plants, has continued to progress. If it stays in place, we could see a downward trend in mercury deposition from regional sources in Vermont and the Northeast in the coming years.

More emission to the atmosphere from the globally occurring pollutant mercury could mean more deposition for everyone - higher concentrations in fish leading to higher concentrations in humans. This underscores the need to monitor and curtail anthropogenic contributions of mercury in Vermont and worldwide.

Regionally, Vermont's precipitation-borne mercury has not been decreasing as quickly as in neighboring states, highlighting the role of Vermont in monitoring and identifying global patterns of mercury pollution.

References

Chalmers, A.T., Krabbenhoft, D.P., Van Metre, P.C. and Nilles, M.A., 2014. Effects of urbanization on mercury deposition and accumulation in New England. *Environmental Pollution*, *192*, pp.104-112.

Driscoll, C. T., Han, Y. J., Chen, C. Y., Evers, D. C., Lambert, K. F., Holsen, T. M., and R.K. Munson. (2007). Mercury contamination in forest and freshwater ecosystems in the Northeastern United States. Bioscience, 57(1), 17-28. doi: 10.1641/b570106.

Gay, D. 2016. Pers comm.

Evers, D.C., Lane, O.P., Savoy, L. and W. Goodale. 2004. Assessing the Impacts of Methylmercury on Piscivorous Wildlife Using a Wildlife Criterion Value Based on the Common Loon, 1998–2003. Gorham (ME): Maine Department of Environmental Protection, BioDiversity Research Institute. Report no. BRI 2004-05.

Kamman, N.C., and D.R. Engstrom. 2002.Historical and present fluxes of mercury to Vermont and New Hampshire lakes inferred from 210Pb dated sediment cores. Atmospheric Environment 36: 1599–1609.

National Atmospheric Deposition Program (NADP). 2015. National Atmospheric Deposition Program 2014 Annual Summary. NADP Data Report 2015-01. Illinois State Water Survey, University of Illinois at Urbana-Champaign, IL.

Vijayaraghavan, K., Levin, L., Parker, L., Yarwood, G. and Streets, D., 2014. Response of fish tissue mercury in a freshwater lake to local, regional, and global changes in mercury emissions. *Environmental toxicology and chemistry*, *33*(6), pp.1238-1247.

Weiss-Penzias, P.S., Gay, D.A., Brigham, M.E., Parsons, M.T., Gustin, M.S. and ter Schure, A., 2016. Trends in mercury wet deposition and mercury air concentrations across the US and Canada. *Science of The Total Environment*. http://dx.doi.org/10.1016/j.scitotenv.2016.01.061

Additional Resources

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

Global Sources of Local Pollution: An Assessment of Long-Range Transport of Key Air Pollutants to and from the United States. 2009. National Academy of Sciences. Chapter 4, Mercury: Atmospheric Mercury Primer. https://www.nap.edu/read/12743/chapter/6#99

VMC Project Database Links

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

Project Lead: Bennet Leon Staff Editor: Judy Rosovsky

Ozone

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

Ozone damage on black cherry. Photo by John Skelly courtesy St. Louis Ozone Garden.

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 4^{th} highest daily 8-hour concentration in a year, averaged over a 3-year period. The level of the current primary standard is 70 parts per billion (ppb), and the secondary standard was set equal to the primary standard.

The Data

The Vermont Department of Environmental Conservation's Air Quality and Climate Division measures hourly ozone concentrations, year-round, at long-term monitoring sites in Bennington (generally representative of southern Vermont) and at the VMC site in Underhill (generally representative of Northern Vermont). While these two monitoring locations have effectively represented the northern and southern portions of the state for many years, another ozone monitor in the City of Rutland, in the central part of the state, began operation on April 1, 2016. It is too early to compare ozone design values from Rutland to the other sites, but preliminary data collected to date have averages within the range measured at Bennington and Underhill.

2015 in Summary

The most recent 2015 and 3-year average data for Bennington and Underhill are summarized in Table 6 below. The 2015 ozone season was relatively clean for Vermont. The 4th highest 8-hour concentrations at the Underhill and Bennington sites were 66

O_3

Ozone

and 63 ppb respectively. The 3-year averages of these 8-hour maximum values were 62 ppb at both sites – below the 70 ppb level of the current primary health standard.

Table 6. 2015 and 3-Year Average Ozone Concentrations in Northern & Southern Vermont.

	2015 4th Highest 8-hr Maximum	2013-2015 Avg. 4th Highest 8-hr Maximum
Underhill	**66 ppb**	**62 ppb**
Bennington	**63 ppb**	**62 ppb**

Long-Term Trends

Long term trends in ozone in northern (Underhill) and southern (Bennington) Vermont are plotted in Figure 16 as rolling 3-year averages plotted on the last of the averaged years. Peak daily 8-hour concentrations - most relevant to human health effects – have declined from a range of 85-90 ppb in the early 1990s to 60-65 ppb in more recent years.

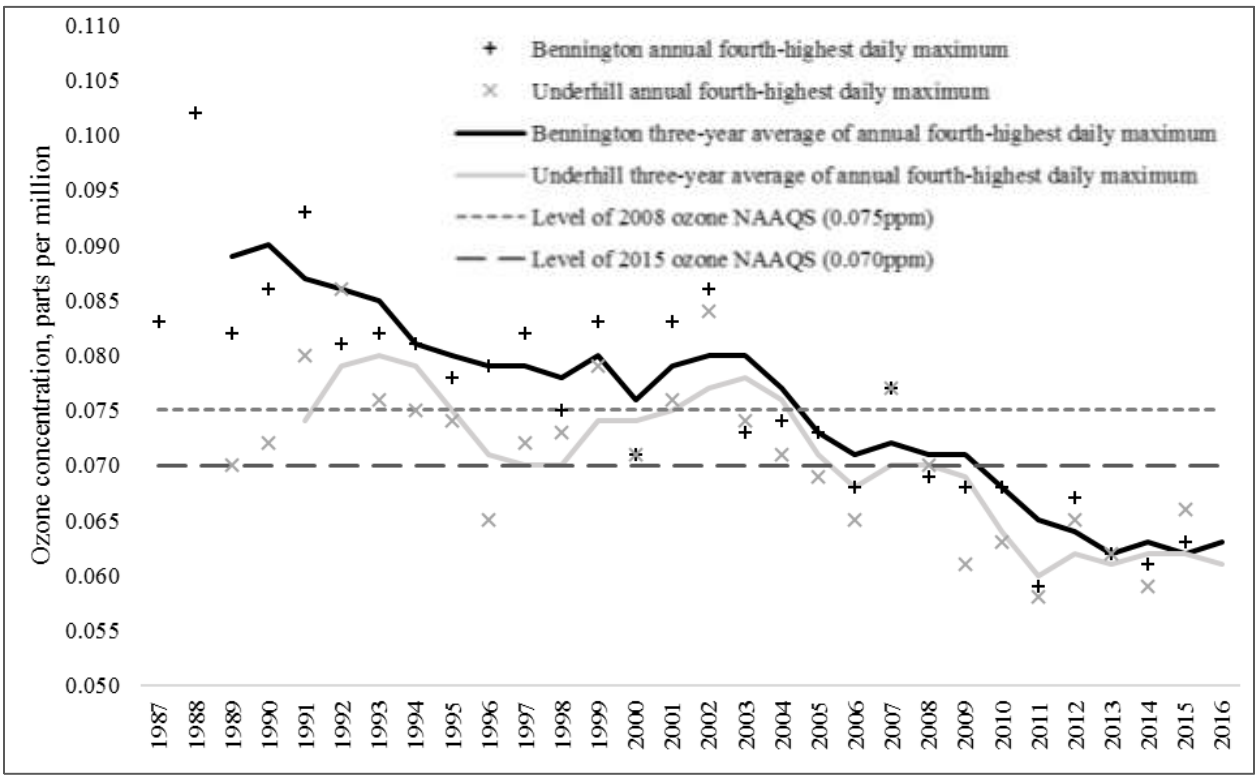


Figure 16. Vermont trends in ozone concentration. Data in the figure above are illustrated for the period 1987 to 2016 at the Bennington and Underhill ozone monitor locations. Note that 2016 averages are preliminary and subject to change.

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.

Despite attaining the current ozone standard, the regionally episodic nature and the transport of ozone precursors (volatile organic compounds and nitrogen oxides) from upwind regions remain a serious threat to meeting the standard. Implementation of control measures on sources of ozone-forming precursor emissions across the United States is critical to eliminate the current widespread non-attainment of ozone standards and the resulting atmospheric transport that impacts human health and the environment downwind.

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. No safe "threshold" concentration of ozone exposure has been identified below which no harmful environmental or human health effects are expected. 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. 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.

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

VMC Project Database Links

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

Forest Inventory and Analysis Ozone Biomonitoring Program (active 1994-2010): http://www.nrs.fs.fed.us/fia/topics/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, etc.) over the short term, while climate refers to longer-term trends and seasonal patterns. Without long-term weather records it would be impossible to tease out short term (i.e. yearly) anomalies from more ecologically significant 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 both temporal and spatial variability. Multiple VMC stations taking continuous measurements allow for the assessment of climate trends and patterns across the landscape.

The Data

Continuous meteorological observations are taken at seven VMC sites from the shores of Lake Champlain to slopes of Mt. Mansfield. 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 primarily logged as 15-minute averages. The longest record comes from the Mt. Mansfield summit station operated by the WCAX transmitter crew and supervised by the National Weather Service, dating back to 1954. Most of the other stations operated by the VMC began operation in the early to mid- 1990s.

Climate

2015 in Summary

Temperature measurements at the Mt. Mansfield West meteorological station show significantly colder than normal winters and significantly warmer temperatures in the fall (Table 7). This was of particular note for the month of February, with mean temperatures 7 degrees colder than normal (-6 °F on average). In contrast, December was the warmest on record, with mean temperatures 6 degrees warmer than normal (32 °F on average).

Table 7. Monthly average deviations from long-term normal for mean, min and maximum temperatures at Mt. Mansfield West in 2015. Red indicates warmer than normal months and blue indicates colder than normal months. Units are standard deviations from norms.

Month	Min Temp	Max Temp	Mean Temp
January	-1.05	-0.57	-0.79
February	-2.70	-2.34	-2.56
March	-1.55	-1.28	-1.41
April	-0.64	-0.74	-0.69
May	0.61	1.89	1.22
June	-1.00	-0.94	-1.03
July	0.01	0.07	0.06
August	0.84	0.31	0.54
September	2.15	2.07	2.06
October	-1.16	-0.74	-0.90
November	0.74	0.82	0.81
December	2.53	2.43	2.50

Climate scientists predict that record setting, extreme weather patterns like those witnessed in 2015 will become more common as the earth's atmosphere becomes more volatile in a changing climate. This trend toward increased variability is also evident in the daily temperature data, with days deviating more than 15 degrees from normal becoming common (Figure 17).

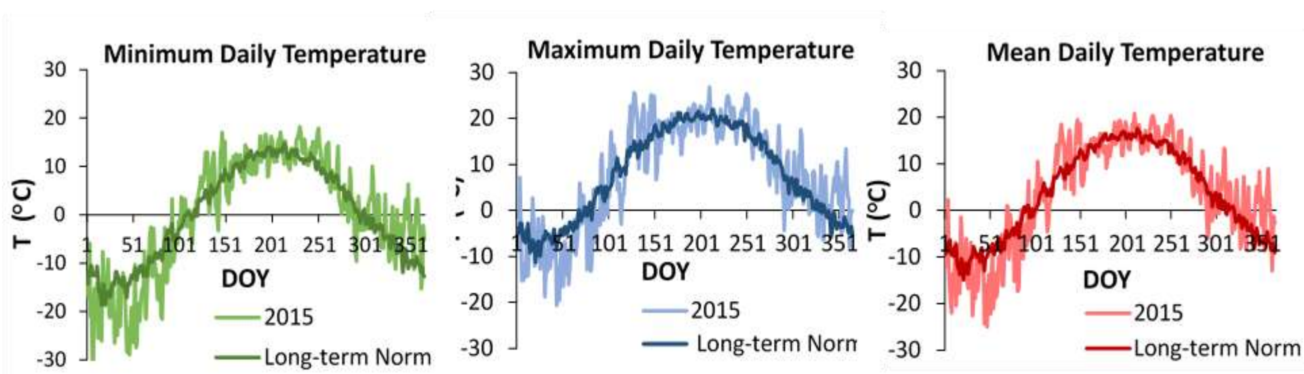


Figure 17. Daily minimum, maximum and mean temperature data for all of 2015 in comparison to the long-term mean (norm).

Long-term Trends

Based on the daily data between 1997 and 2015, we have seen a consistent (although not significant) rise in mean, max and min daily temperatures (Figure 18). 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 ($p = 0.03$). While 2015 winter temperatures were significantly colder than normal, this was not sufficient to alter these long-term warming trends over the full data record.

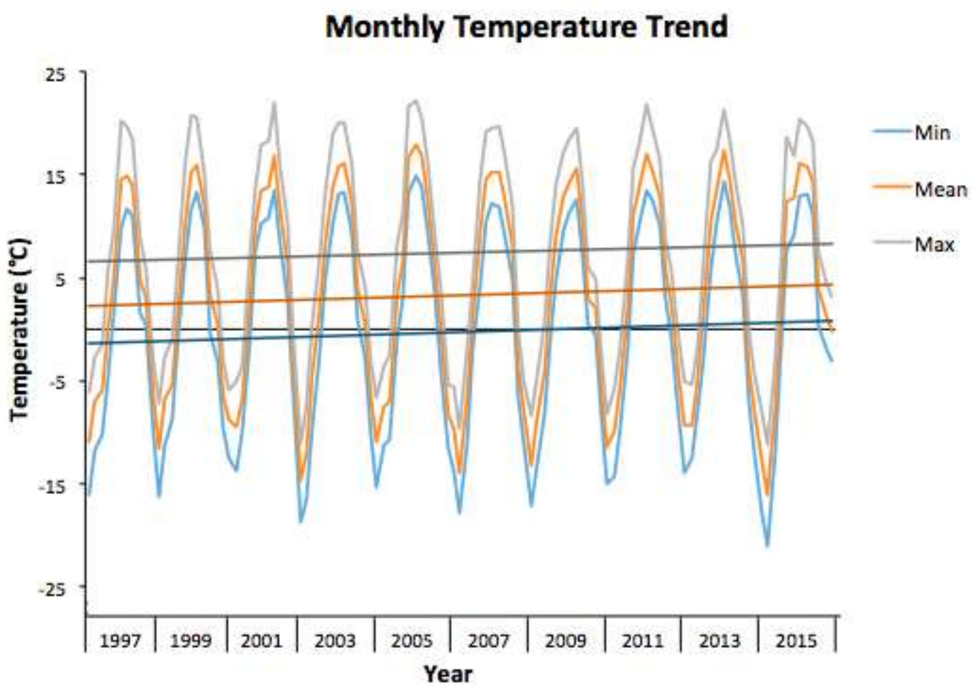


Figure 18. Long-term trends in mean monthly climate metrics show a steady but insignificant increase in mean, min and maximum temperatures on Mt. Mansfield.

Implications

While climate variability is high, both temporally and spatially, meteorological measurements 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). However, it is not the general warming trends that likely impact forested ecosystems the most. Instead, it is the increased frequency and severity of extreme climate events that are of concern to forest health professionals. The increase in extreme temperatures witnessed in 2015 may be an example of the increase in variability we will continue to see under a changing climate. These extremes represent an additional stress for species adapted to cold weather dormancy, increased risk of winter injury following winter warm spells, and frost damage during spring freeze events. 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). Variable temperatures may eventually affect phenological adaptations, potentially increasing vulnerability to insects, diseases, and may have an adverse impact on major agricultural crops in Vermont such as apples and sugar maples (Grubinger, 2011; Rustad, 2012).

Increased variability of temperatures and an increase in temperature extremes represent additional stress to New England flora and fauna.

References

Betts, A. K. 2011. Climate Change in Vermont (unpublished report). Available online: http://www.anr.state.vt.us/anr/climatechange/Pubs/VTCCAdaptClimateChangeVTBetts.pdf

EPA Climate Leaders Summit Report. Summit Date: Friday, November 8, 2013. Johnson & Wales University, Harborside Campus, Providence RI. Report Date: March 2014. Available online: http://www3.epa.gov/region1/climateleaderscollaboration/pdfs/ClimateLeadersSummitReport.pdf

Grubinger, V. 2011. Climate Change and Vermont Agriculture. University of Vermont Extension. Available online: http://www.uvm.edu/vtvegandberry/factsheets/climatechange.html

Intergovernmental Panel on Climate Change (IPCC) Climate Change 2014 Synthesis report Summary for Policymakers. IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp. Available online: http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf

Pucko, C. 2014. The Impacts of Multiple Anthropogenic Disturbances on the Montane Forests of the Green Mountains, Vermont, USA. University of Vermont, Department of Biology Ph.D. Thesis.

Rustad, L. *et al*. 2012. Changing Climate, Changing Forests: The Impacts of Climate Change on Forests of the Northeastern United States and Eastern Canada. Gen. Tech. Rep. NRS-99. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 48 p. Available online: http://www.fs.fed.us/nrs/pubs/gtr/gtr_nrs99.pdf

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

Trout

Wild Brook Trout Monitoring in the West Branch of the Little River and Ranch Brook

Brook Trout Monitoring on Ranch Brook, Stowe VT.

The brook trout *Salvelinus fontinalis* is native to Vermont and widely distributed in cold water streams throughout the state. These populations are often considered an indication of healthy ecosystems due to their stringent water quality and habitat requirements. In addition to their ecological value, brook trout are a favorite among Vermont anglers.

The Vermont Department of Fish and Wildlife has monitored wild brook trout populations in the West Branch of the Little River and Ranch Brook since 1997. While this evaluation initially focused on the potential effects of ski area development and snowmaking water withdrawals on brook trout populations, these data also provide valuable insights into the effects of broader environmental variables over the long term.

The Data

Trout population surveys were conducted annually from 1997 through 2015 at 3 stations on the West Branch and 2 stations on Ranch Brook. Trout population surveys consisted of multiple run sampling with a 500-volt DC stream-side electrofisher. Survey sections were generally 250 ft in length and were conducted during the summer months (July-early August) when stream flow had subsided and brook trout young-of-year (yoy) became large enough to effectively sample.

Trout captured during stream surveys were measured to the nearest millimeter and weighed to the nearest gram. Population estimates within each sampling station were based upon the removal method and determined by the maximum weighted likelihood method developed by Carle and Strub (1978). Population estimates were calculated for each of two age classes, yoy and yearling (1) and older fish (1++), distinguished by length distribution. The population estimates were standardized to represent number per mile (#/mi) for each age class and summed for the total brook trout population within each station.

2015 in Summary

Natural reproduction of brook trout rebounded in 2015 with all stations supporting greater than 1,000 yoy/mile, an average increase of 190% from the relatively low levels observed in 2014 (Figure 19). Yearling and older brook trout, however, declined an average of 32% in 2015 (Figure 20). Population estimates for both yoy and yearling and older brook trout remained within the range observed over the 19 years of study.

Long Term Trends

West Branch and Ranch Brook supported high quality brook trout populations maintained through natural reproduction. These populations consist of multiple age classes and average over 1500 trout per mile over the 19-year study. Wild brook trout populations vary considerably among and within streams due to differences in habitat conditions and localized land use effects while broad environmental variables may have significant temporal effects. While large fluctuations were observed for each age class both within and among the two study streams, no clear trends were evident.

Annual brook trout yoy production showed clear highs and lows, often consistent across the five stations and two study streams, suggesting the effect of broad environmental influences. Successful recruitment of yoy requires suitable habitat conditions over an extended period of time including fall spawning, overwinter incubation and spring emergence. In some years peak yoy production was followed by commensurate increases in the yearling and older population such as observed in 1999-2000 and 2012-2013. Yearling and older brook trout populations tend to be more stable and are able to quickly recover following extreme events. For example, very high flow events in the summer of 2010 and spring 2011 may have contributed to the yearling and older brook trout declines observed in some stations but these populations rebounded to above average levels by 2013.

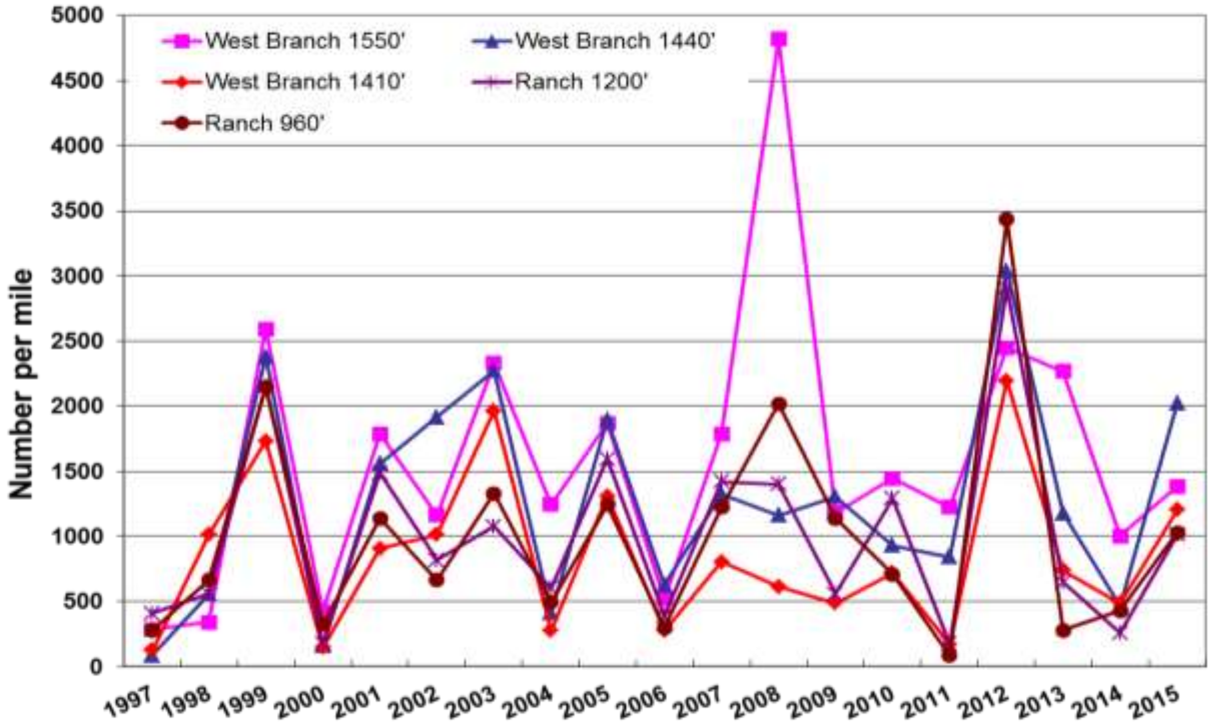


Figure 19. Vermont Department of Fish and Wildlife trout surveys: Young of year (yoy) expressed as number per mile, from 1997 through 2015.

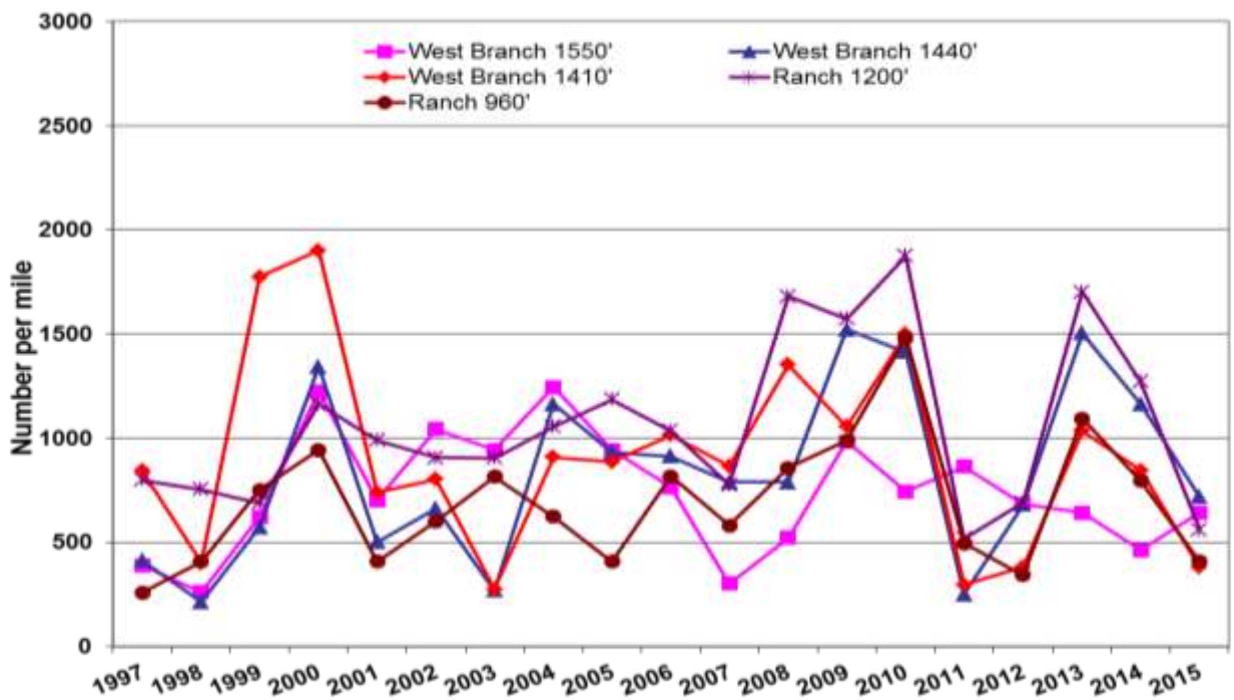


Figure 20. Vermont Department of Fish and Wildlife trout surveys: Yearlings and older fish, expressed as number per mile, from 1997 through 2015.

Implications

Global climate change predictions suggest a continued loss of brook trout populations throughout their range due to increases in stream temperature and flood frequency. Forested watersheds and riparian areas will be critical for the long term persistence of Vermont's wild brook trout populations as they serve to moderate water temperatures and streamflow, filter and retain sediments and nutrients, contribute and retain large wood and organic matter, stabilize streambanks and floodplains and provide for complex and diverse aquatic habitats. Improving aquatic passage through the elimination of manmade barriers (e.g. culverts, weirs and dams) will also help ensure brook trout are able to access critical habitats and recover from extreme natural events which reduce population levels.

The predicted climate change induced increase in flood frequency and stream temperatures do not bode well for brook trout populations.

References

Carle, F.L. and Strub, M.R., 1978. A new method for estimating population size from removal data. *Biometrics*, pp.621-630.

Forest Birds

Breeding Bird Surveys

The Bicknell's Thrush faces threats in both breeding and overwintering sites.

Bicknell's Thrush is one of several mid- and high-elevation songbird species from New England that migrates long distances to overwinter. The factors that affect neotropical migrant bird survivorship are many: demographics, inter-species competition, parental survival, migratory route conditions, etc. (eNature, 2007; Faaborg *et al.,* 2010). But land use changes in breeding grounds and overwintering areas clearly affect migratory species, and in the case of the Bicknell's Thrush may be reducing its already limited habitat (Rimmer *et al.,* 2005; VNRC, 2007). Only limited habitat is present in Massachusetts, where the Bicknell's thrush occurred prior to 1972 but is no longer found (Atwood *et al.*, 1996). While estimates of deforestation in some of the species' non-breeding grounds, such as Haiti, may vary, loss of forested habitat remains a serious threat (Alvarez-Berríos *et al.,* 2013).

Migratory passerines are subject to many human-induced and abiotic perturbations on their breeding areas and overwintering grounds. Hurricanes can have diverse effects on bird populations, from mass mortality of individual birds to the loss of trees for cavity-nesting birds to the creation of new and beneficial habitat (Brooks and Stouffer, 2010; Newton, 2007; Yaukey, 2008). Hurricanes can affect refueling locations on the migratory routes (Barrow *et al.*, 2005), though there is evidence that some migratory birds are plastic enough in their behavior to avoid some of the worst effects of storms and hurricanes (Boone, 2016; eNature, 2007). Nonetheless, Bicknell's thrush and other migratory passerines are vulnerable to habitat loss anywhere along their migratory routes.

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.

The Data

Breeding Bird Surveys were conducted at permanent study sites located in Underhill State Park (USP). This site is part of Vermont Center for Ecostudies (VCE) 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).

The study site contains five 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. The hardwood-dominated site at Underhill was sampled twice during the breeding season.

2015 in Summary

Funding shortfalls prevented bird surveys on Mount Mansfield and in the Lye Brook Wilderness in 2015, but VCE provided data collected through their Underhill State Park survey.

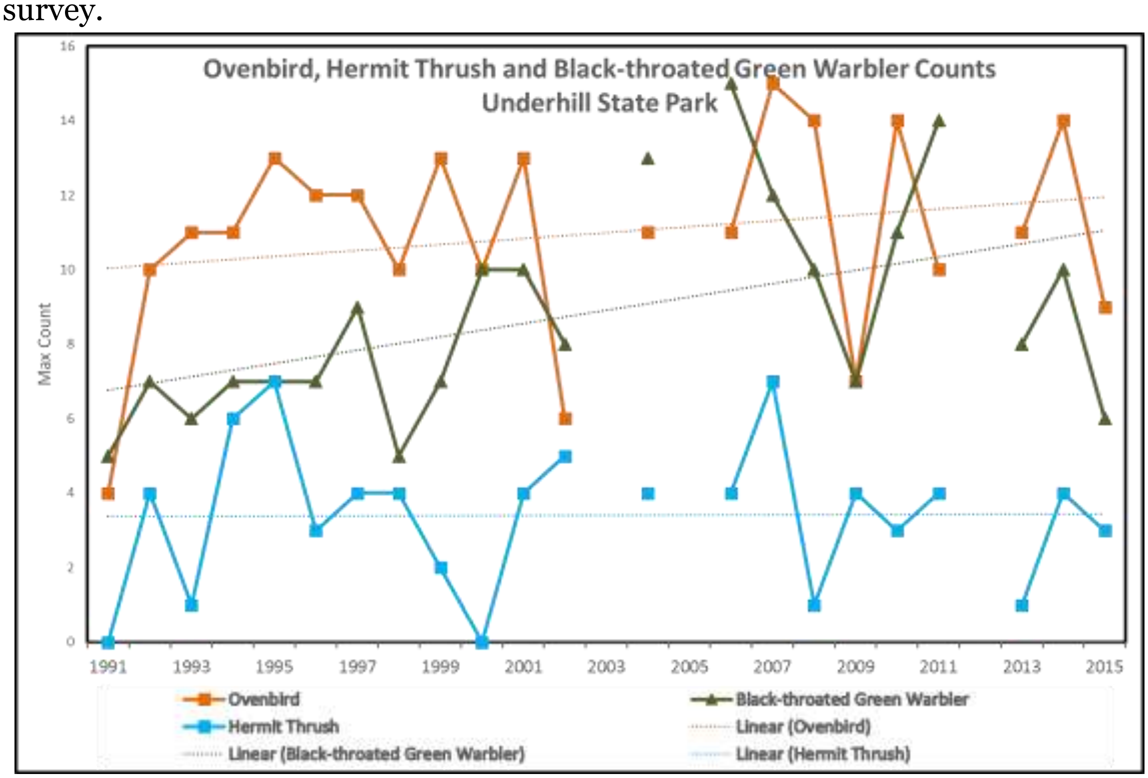


Figure 21. Data and trends over 25 years for Ovenbird, Hermit Thrush, and Black-throated Green Warbler from annual surveys conducted at Underhill State Park.

The number of individual birds detected at Underhill State Park was just above average. Species richness at Underhill State Park in 2014 was the second lowest ever recorded but in 2015 it was slightly higher, moving up from 14 to 15 species.

A total of at least 57 avian species have been detected during breeding bird surveys at three study sites on Mt. Mansfield from 1991-2015. Surveys from the mid-elevation, northern hardwood study sites at Underhill State Park had a species composition of 51 species over this time span.

Long Term Trends

The total number of individuals and species richness are low for at Underhill State Park, with 50 individuals of 15 species recorded. The Barred Owl, a new record for 2014, was not seen in 2015. The five most common species at Underhill State Park are Black-throated green and Black-throated Blue Warblers, Ovenbirds, Red-eyed Vireos and Hermit Thrushes. These five species were the most common in 2014, too. Overall, long term trends based on counts of Ovenbird and Black-throated Green Warbler still appear to be increasing, while the long-term trend for Hermit Thrush, the Vermont State bird, remained relatively flat (Figure 21). As with the Mt. Mansfield montane sites, Winter Wren numbers dropped in 2015, too, with none detected this year in Underhill (Figure 22). Data from another local site (Stowe, VT) shows a flat but not declining trend for Winter Wrens (Figure 22). Please note that the trends may be affected by data gaps during the time period covered.

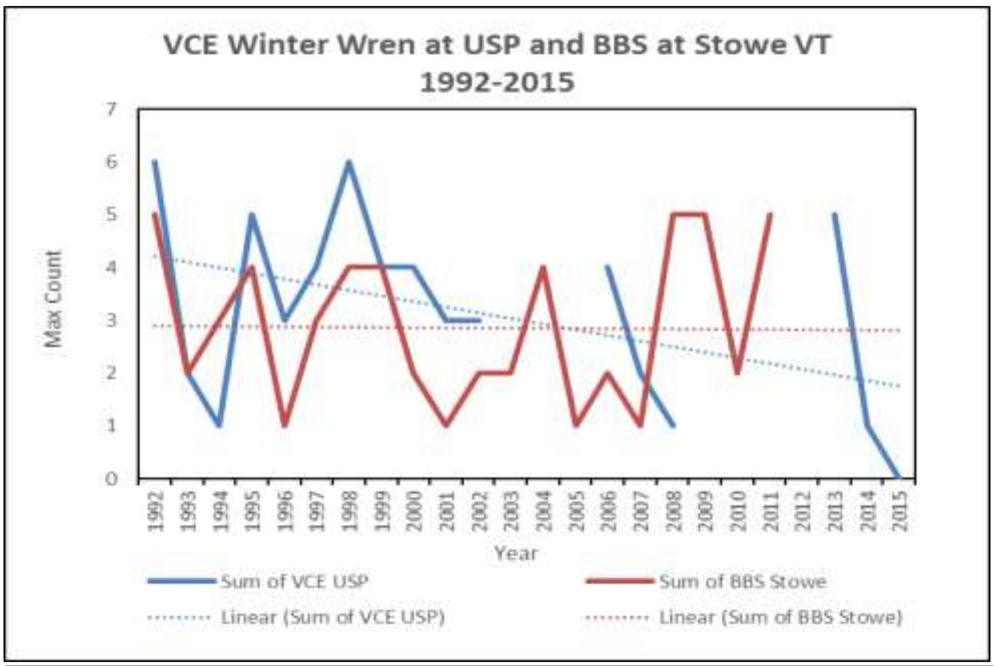


Figure 22 Twenty year data and trends for Winter Wren from annual surveys conducted at the Mt. Mansfield Ranch Brook site.

Implications

VCE has observed, based on their 25-year dataset, that many of the high-elevation bird species that they have been monitoring on and around Mt. Mansfield are declining. This includes Bicknell's Thrush, Blackpoll Warbler, Dark-eyed Junco and White-throated Sparrow. Interpretation of these trends must take into account the variability in point count survey results, from fluctuations in abundance, detection rates, nesting stage and other biotic factors. An additional caveat is that this set of data comes from a limited geographic area. Nonetheless, other similar surveys from this region show declines in songbird populations, particularly among those species engaged in long-distance migration (McNulty *et al.,* 2008; Eddy, 2008).

Many anthropogenic stressors may be contributing to these declines (e.g., habitat degradation, land use change due to development, acidic precipitation and other atmospheric pollutants, or changing climatic conditions). 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, but loss of habitat and resources anywhere along the migratory route can have an adverse effect (Boone, 2016).

There are efforts being made to compile bird data from multiple sources, such as the Avian Knowledge Network (U.S. NABCI, 2007). Comparison of surveys from ecologically comparable areas may help obviate the variability found from single geographic sources, and help ascertain the extent and consistency of the decline. By comparing different locations, it may be possible to identify or eliminate some sources of variation.

The role of climate change in the frequency and severity of tropical storms and hurricanes has not been clearly determined, but climate change in terms of rising temperatures alone will add an additional abiotic stressor. 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.

Neo-tropical migratory birds are vulnerable to biotic and abiotic changes and stressors all along their routes. It remains to be seen whether they are adaptable enough in behavior to surmount the increasing tide of change.

References

Alvarez-Berríos, N.L., D.J. Redo, T.M. Aide, M.L. Clark and R. Grau. 2013. Land Change in the Greater Antilles between 2001 and 2010. Land, 2 (2) (2013), pp. 81–107.

Atwood, J. L., C. C. Rimmer, K. P. McFarland, S. H. Tsai, and L. R. Nagy. 1996. Distribution of Bicknell's Thrush in New England and New York. Wilson Bulletin 108:650–661.

Barrow, W. J., J. J. Buler, R. H. Diehl, S. Faulkner, F. R. Moore, and L. Randall (2005). Broadscale Response of Landbird Migration to the Immediate Effects of Hurricane Katrina. In Science and the Storms: The USGS Response to the Hurrcanes of 2005 (G. . Farris, G. . Smith, M. . Crane, C. . Demas, L. . Robbins and D. . Lavoie, Editors). USGS, pp. 131–136.

Blondel, J., C. Ferry, and B. Frochot. 1981. Point counts with unlimited distance. Pp. 414-420, *In* C. John Ralph and J. Michael Scott (Eds.). Estimating numbers of terrestrial birds. Studies in Avian Biology 6: 630pp.

Boone, M. 2016. The effect of Hurricane Sandy on landbird migration in the northeastern United States. Diss. University of Delaware, 2016.

Brooks, M.E., and P.C. Stouffer. 2010. Effects of Hurricane Katrina and salvage logging on Bachman's Sparrow." *The Condor* 112.4 (2010): 744-753.

Eddy, G. and Emrick, J. 2008. Bird Population Declines in the Central Appalachian Mountains of West Virginia. The Redstart 75(2):48-98. http://www.brooksbirdclub.org/uploads/5/2/8/3/52832773/2008_redstart_vol_75-2.pdf

eNature. Nature Watch: Hurricanes and Birds. 2007. http://www.enature.com/articles/detail.asp?storyID=580

Faaborg, J., Holmes, R. T., Anders, A. D., Bildstein, K. L., Dugger, K. M., Gauthreaux, S. A., Heglund, P., Hobson, K. A., Jahn, A. E., Johnson, D. H., Latta, S. C., Levey, D. J., Marra, P. P., Merkord, C. L., Nol, E., Rothstein, S. I., Sherry, T. W., Sillett, T. S., Thompson, F. R. and Warnock, N. (2010), Conserving migratory land birds in the New World: Do we know enough?. Ecological Applications, 20: 398–418. doi:10.1890/09-0397.1

Faccio, S.D., C.C. Rimmer, and K.P. McFarland. 1998. Results of the Vermont Forest Bird Monitoring Program, 1989-1996. Northeastern Naturalist 5(4): 293-312.

McFarland K.P., C.C. Rimmer, J.E. Goetz, Y. Aubry, J.M. Wunderle, Jr., A. Sutton, J.M. Townsend, A. Llanes Sosa, and A. Kirkconnell. 2013. A winter distribution model for Bicknell's Thrush *(Catharus bicknelli)*, a conservation tool for a threatened migratory songbird. PLoS ONE 8(1): e53986. DOI:10.1371/journal.pone.0053986.

McNulty, S.A., S. Droege, R.D. Masters. 2008. Longterm trends in breeding birds in an old-growth Adirondack forest and the surrounding region. Wilson Journal of Ornithology 120:153–158.

Newton, I. (2007). Weather-related mass-mortality events in migrants. Ibis 149:453–467. doi: 10.1111/j.1474-919X.2007.00704.x

Rimmer, C.C. and K.P. McFarland. 2013. Bicknell's Thrush: a twenty-year retrospective on the Northeast's most vulnerable songbird. Bird Observer 41:9-16.

Rimmer, Christopher C., J.M. Townsend, A.K. Townsend, E.M. Fernández and J. Almonte. 2005. Avian diversity, abundance, and conservation status in the Macaya Biosphere Reserve of Haiti. *Ornitología Neotropical* 16 (2005): 219-230.

Vermont Natural Resource Council, 2007. Roundtable on Parcelization and Forest Fragmentation – Final Report. *Primary Author: Jamey Fidel, Forest and Biodiversity Program Director, Vermont Natural Resources Council.*

U.S. North American Bird Conservation Initiative Monitoring Subcommittee. 2007. Opportunities for Improving Avian Monitoring. U.S. North American Bird Conservation Initiative Report. 50 pp. Available from the Division of Migratory Bird Management, U.S. Fish and Wildlife Service, Arlington, VA; on-line at http://www.nabci-us.org/.

Welsh, D.A. 1995. An overview of the Forest Bird Monitoring Program in Ontario, Canada. Pp. 93-97, *In* C.J. Ralph, J.R. Sauer, and S. Droege, (Eds.). Monitoring bird populations by point counts. General Technical Report PSW-GTR-149. Pacific Southwest Research Station, Forest Service, U.S. Dept. of Agriculture, Albany, CA. 181pp.

Yaukey, Peter H. Effects of Hurricane Katrina on the urban resident landbirds of New Orleans, Louisiana. *The Condor* 110.1 (2008): 158-161.

Additional Resources

VMC Project Database Links

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

Amphibians

Amphibian Monitoring on Mt. Mansfield

The very rare Fowler's toad was recently found to have a breeding population near Vernon, VT. It is a state species of special concern.

Reptiles and amphibians (herps) in Vermont are excellent indicators of environmental change, because they are vulnerable to pollutants, habitat loss and other anthropogenic changes, and because they can only survive in a narrow range of temperature and climate conditions. Road construction is a major source of habitat fragmentation and loss, and roads present a lethal obstacle to migratory amphibians (Sorenson & Osborne, 2014). Changing temperature regimes may take a toll on local herp populations, by changing the abiotic cues on which they rely to prevent exposure to freezing temperatures, and through drought or other effects on hydroperiod (Olson, D.H. and D. Saenz., 2013). Vermont is host to eight species classified by the state as at high risk of extirpation due to rarity. On-going monitoring of both common and rare species will aid in the assessment of changes in their distribution and abundance over time.

The Data

In 2015, VMC was unable to sponsor amphibian population data collection. This year's section focuses on data collected as part of the statewide, citizen science inventory underpinning the Vermont Reptile and Amphibian Atlas[7]. Partial funding for the atlas in 2015 was provided by the Lintilhac Foundation and Vermont Department of Fish and Wildlife.

There are eight Vermont reptile and amphibian species classified as rare by state scientists. Sightings are reported by citizen scientists and from searches made regularly by Jim Andrews and other scientists. Identification of changes in the abundance and distribution of these species may indicate changes in the environmental health of the forest and its waters.

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[7] http://www.vtherpatlas.org

2015 in Summary

Winter herpetological activity: Some of the most interesting verified reports of 2015 have been the late season sightings of both reptiles and amphibians. In December of 2015 there were reports of eight species either actively moving or calling during December, and an American Toad was found moving in a yard in Huntington in January. This is the first report of toad activity in January since the beginning of the Atlas over 20 years ago. All of these reports occurred on warm days during an unseasonably warm fall and early winter.

Citizen reports of species are not necessarily consistent enough to use for population level monitoring, but they do tell us if those species are still present in the state. Figure 23 shows a decade of reports to the Atlas for the Eastern Musk turtle, which is a species at risk due to a limited range and few populations.

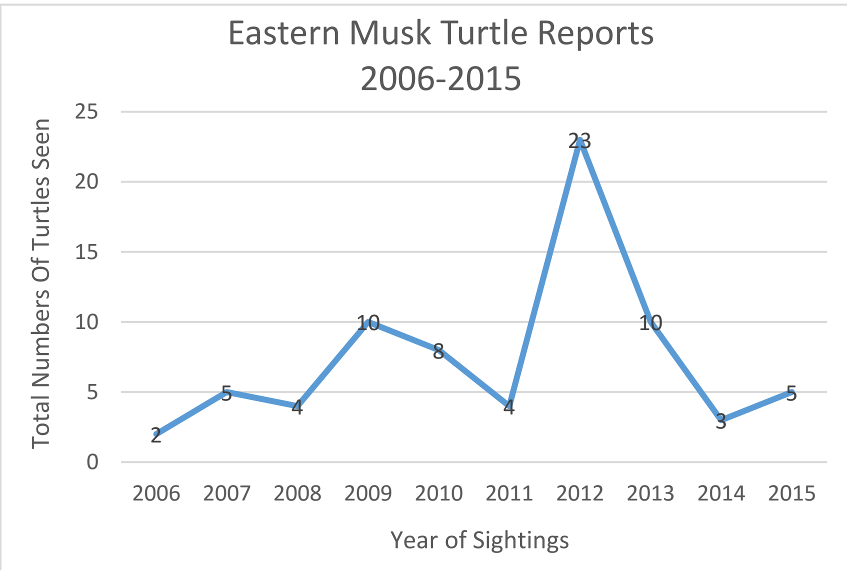

Figure 23. Vermont Eastern Musk turtle reports for the previous decade.

This represents an average of 7.4 reports/year, from an average of approximately 3 towns/year. If the 18 baby musk turtles sighted as a result of an unusually good nesting season are removed, the trend line is still positive, and the mean number of reports drops to 5.6/year.

Three native species were not reported this year: The state-endangered Fowler's Toad was last reported in Vermont in 2007, though reports of breeding on Stebbin's Island in New Hampshire near Vernon, VT have been confirmed. The Boreal Chorus Frog (state-endangered) was last heard in 1999. It has disappeared from the New York portion of the Champlain Valley and much of its habitat in Quebec and eastern Ontario. The North American Racer (state-threatened) was reported in 2008, then again in 2014, but not during 2015.

Table 8. Species with endangered (E) or threatened (T) status in Vermont, with years of previous and most recent sightings or callings reported. Endangered species are near extirpation and threatened are close to becoming endangered.

Name	State Status	Year of Previous Sighting	Year of Most Recent Sighting/Calling
Fowler's Toad *(Anaxyrus fowleri)*	E	2007	2007
Boreal Chorus Frog *(Pseudacris maculata)*	E	1999	1999
Five-lined Skink *(Plestiodon fasciatus)*	E	2014	2015
North American Racer *(Coluber constrictor)*	T	2008	2014
Eastern Ratsnake *(Pantherophis alleghaniensis)*	T	2014	2014
Timber Rattlesnake *(Crotalus horridus)*	E	2014	2015
Spiny Softshell Turtle *(Apalone spinifera)*	T	2014	2015
Spotted Turtle *(Clemmys guttata)*	E	2014	2015

Additional information on rare species: Fowler's Toad was officially listed as endangered on March 28, 2016. This would not have occurred without the Reptile and Amphibian Atlas data and support. The recovery plan for the state-endangered Timber Rattlesnake used Atlas data too.

Since 2000 we have had eight well-documented reports of Eastern Box Turtles in the Dover/Putney area of Vermont. The Reptile and Amphibian Scientific Advisory Group (RASAG) discussed the possibility that this might be a native breeding population.

Long Term Trends

There are several reptile and amphibian species whose populations in Vermont are precarious (see Table 8 above). None of these species are present on Mount Mansfield, where a more intensive population survey is conducted, consequently the statewide Atlas is the primary way data on these species are gathered.

Implications

Salamander chytrid is a newly discovered disease that was killing European salamanders and could potentially impact our salamanders (particularly newts) if the disease arrives in the US. The species list includes two common native Vermont species: the Eastern Newt and the Eastern Red-backed Salamander. The Reptile and Amphibian Atlas is the only source of data on those two species in Vermont and it will be this data that will allow us to see and report declines if this pathogen arrives in the U.S.

The disruptive effects of climate on reptiles and amphibians are manifold, as are the biotic perils they face. Monitoring and understanding the long term effects at the statewide population level would require geographically widespread species monitoring

(Hossack *et al.*, 2013). Citizen reports to the Vermont Reptile and Amphibian Atlas are an excellent and inexpensive source of data for the continued tracking of the presence and absence of species around the state, but they do not represent regular and scientific population surveys. Continued support of sustained and consistent data collections such as the Mt. Mansfield amphibian study and as many other similar projects as feasible would provide the minimum amount of information necessary to understand how and why these herp populations are changing.

Three of the eight state-listed rare herpetological species in Vermont were not seen in 2015.

References

Hossack, B.R., M.J. Adams, C.A. Pearl, K.W. Wilson, E.L. Bull, K. Lohr, D. Patla, D.S. Pilliod, J.M. Jones, K.K. Wheeler, S.P. McKay, and P.S. Corn. 2013. Roles of patch characteristics, drought frequency, and restoration in long-term trends of a widespread amphibian. Conservation Biology 27(6):1410-1420.

Olson, D.H. and D. Saenz. 2013. Climate Change and Amphibians. (March, 2013). U.S. Department of Agriculture, Forest Service, Climate Change Resource Center. http://www.fs.usda.gov/ccrc/topics/amphibians-and-climate-change

Sorenson, E., and J. Osborne. "Vermont Habitat Blocks and Habitat Connectivity: An Analysis using Geographic Information Systems." *Vermont Fish and* Wildlife *Department, Montpelier, Vermont* (2014). http://vtconservation.com/success/content/vermont-habitat-blocks-and-habitat-connectivity-analysis-using-geographic-information

Additional Resources

Vermont Reptile and Amphibian Atlas http://vtherpatlas.org/

Vermont Timber Rattlesnake Recovery Plan http://www.vtfishandwildlife.com/common/pages/DisplayFile.aspx?itemId=503500

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

Project Lead: Steve Fiske and Aaron Moore　　Staff Editor: Judy Rosovsky

Sentinel Streams

Biological Monitoring at Ranch Brook

Exuviae of a recently emerged stonefly, an indicator of good water quality.

The Vermont Department of Environmental Conservation (DEC) is conducting long term monitoring of twelve “sentinel” streams in Vermont. These reference streams are widely variable in terms of size (4.6 -510 km^2), elevation (33m – 585m) and geographical separation. They are in watersheds that have significant protection against impacts from anthropogenic activity. 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, it is one of the smallest and most pristine sentinel streams.

By focusing on reference streams with negligible prospects for development or land use change, DEC hopes to be able to isolate long term impacts related to climate change. All twelve streams are currently being monitored on an annual basis for water chemistry, physical habitat, water temperature, and biology (fish and macroinvertebrate communities). Several sites are also being gaged for stream discharge. Through this monitoring, we hope to be able to gain an understanding of how climate change is affecting stream habitat and water quality, and how changes in these abiotic variables may cause long-term alterations in biological communities.

The Data

Vermont 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. DEC biologists use population data, as well as a number of community variables (called metrics) to assess stream health. These metrics cover many aspects of community structure and function, including biodiversity, tolerance to pollution and ecological feeding habits. Metric values are compared to established thresholds determined from historical statewide data. These metric outcomes are then used to determine a narrative assessment for community health, using a five tier scale ranging from *Poor* to *Excellent*.

Abiotic data related to stream habitat is collected in conjunction with biology, and is used to explain what factors are shaping the biological communities. These habitat variables include water chemistry (including pH, alkalinity, sulfate, earth metals, turbidity, chloride, and nutrients), riparian canopy, substrate particle size, and periphyton cover. With a continuously operated USGS gage and annual monitoring by VTDEC since 2000, Ranch Brook also 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 daily mean and annual peak discharge values.

2015 in Summary

Figure 24 shows 2015 results for three of the eight metrics used to assess biological condition, as well as the overall assessment rating. Macroinvertebrate density at Ranch Brook was 659 individuals per square meter, higher than Vermont DEC's minimum biological criteria for a healthy stream. This is within the range of other reference streams, and similar to the average of other randomly chosen small high gradient streams throughout the state. This is a significant recovery for Ranch Brook, which has shown a depressed density for several years following flood flows in 2010 and 2011. Total species richness (44) was very high in 2015 compared to DEC's minimum criteria (27), and similar to reference and statewide averages.

A "functional feeding group" refers to one of several types of ecological feeding types to which a species has evolved; including predation, filtering suspended organic matter from the water, scraping algae from rock surfaces, and shredding fallen leaves and other detritus. Small forested streams like Ranch Brook typically have low algae growth and grazing, but high quantities of leaf detritus, and populations found at the site should reflect this. The *PPCS-FFG* score is based on a model that compares the distribution of functional feeding groups at a given site to what we would expect to find at a hypothetical site untouched by human activity. High scores at Ranch Brook indicate increased similarity to a typical reference stream, and this stream scores at or above reference and statewide averages.

High values for these three metrics, as well as the other metrics evaluated by DEC, caused Ranch Brook to get a rating of *Excellent* in 2015, the highest possible score. A score of *Good* (indicating a moderate change from the reference condition) is used as the benchmark for minimum acceptable biological health. In addition to acknowledging the high ecological condition of Ranch Brook, it should also be noted that other reference sites and randomly chosen streams throughout Vermont also score very highly. This is a good sign for the overall quality of headwater streams in Vermont.

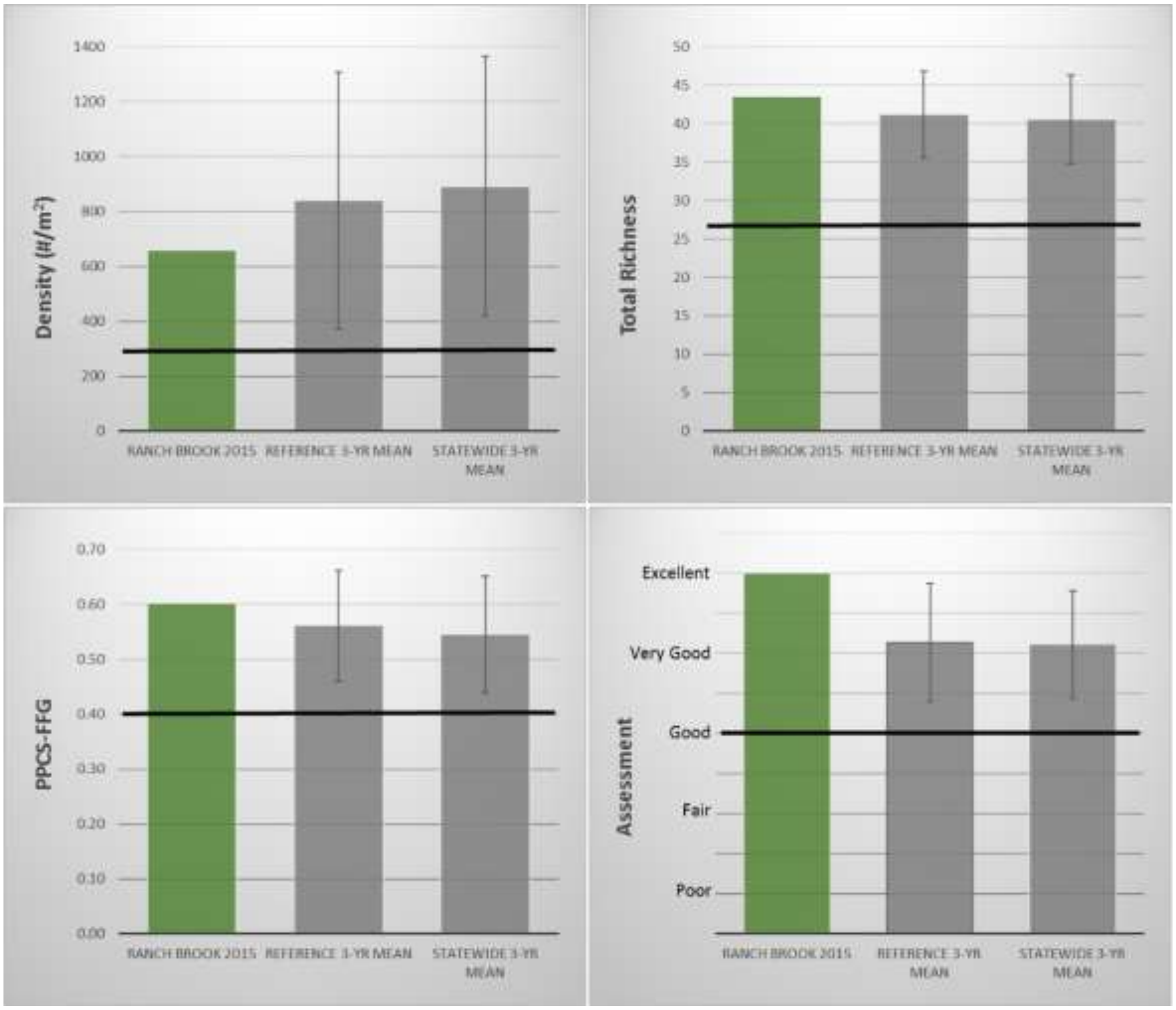

Figure 24. Scores for three biological metrics used to assess biological health, as well as overall assessment rating. Values at Ranch Brook are compared to averages at similarly sized streams from throughout the state, and at other reference sites (sentinel and Green Mountain National Forest streams). The horizontal black bar represents DEC's minimum acceptable criteria.

Long Term Trends

Macroinvertebrate richness has remained very stable over time (Figure 25). Ranch Brook is the only stream that DEC has frequently sampled twice during our index period; both in late summer/early autumn (before September 15th) and again in mid/late October. This consistency in richness holds regardless of what time the sample was collected.

In last year's annual report, we showed that density has been quite variable over time, and has an inverse relationship with peak discharge. The four highest annual peak discharges since 2000 have occurred over the last five years, and decreased densities have corresponded with lower than normal assessment ratings. It appears that biological condition may have finally rebounded fully after two relatively low flow years.

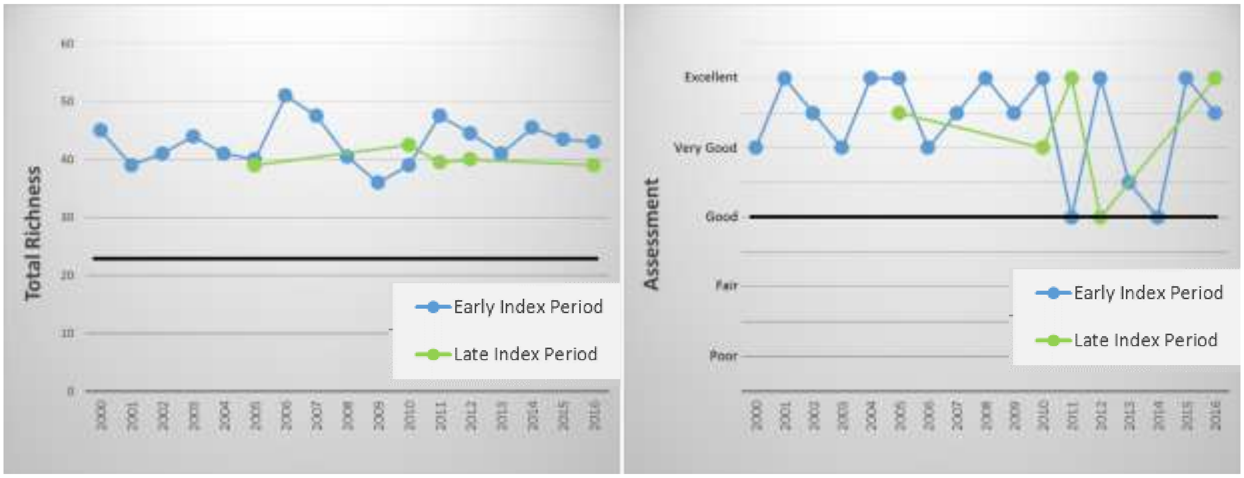

Figure 25. Long-term trends in macroinvertebrate richness and overall assessment rating. Two biological samples were collected in five different years, with these multiple sample collections typically separated by at least five weeks.

Metrics aggregate community data, and most tend to show little variability over time at reference sites like Ranch Brook. To get an understanding of how taxon populations within these communities change, it is necessary to analyze the raw data. Figure 26 shows a multivariate ordination plot using densities of individual taxon populations in each sample. The distance between samples shows the degree of basic community similarity (i.e. samples close together have similar populations of taxa). Axes represent inter-correlated combinations of 20 environmental variables, with red vectors showing which abiotic factors have the strongest relationship with these axes. These vectors “point” toward the community samples which are mostly strongly influenced by those habitat variables.

Of all the environmental variables analyzed, the strongest factors shaping stream communities in Ranch Brook were found to be the number of days into the biomonitoring index period the sample was collected, and the quantity coarse particulate organic matter (CPOM) present. CPOM quantity is highly indicative of the amount of fallen leaves dropped in the stream, which tends to increase dramatically by late autumn. Most samples taken in late October with high CPOM fall in the lower left side of the plot. Annual peak discharge and median discharge in the previous 30 days were also very important in influencing communities. Community samples shaped by high flows generally fall in the lower right portion of the plot.

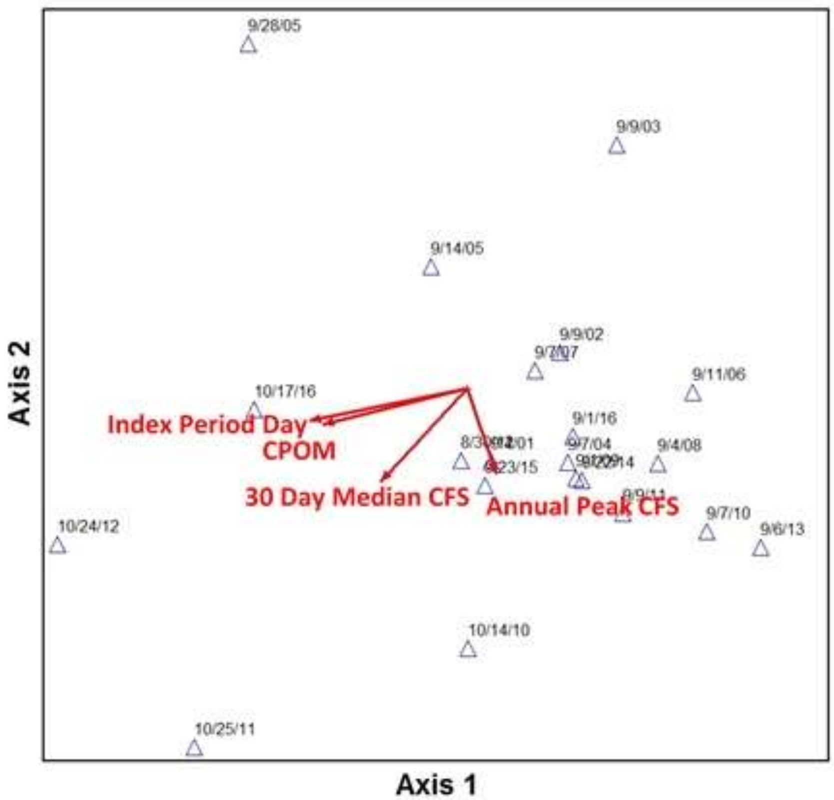

Figure 26. Canonical correspondence analysis (CCA) ordination plot. Biological samples are represented by triangles. Samples grouped near each other have more similar communities, and are shaped more strongly by the abiotic factors represented as red vectors.

Implications

Even though overall biological condition at Ranch Brook is consistently high over time, environmental and habitat factors are influencing what taxon populations are present in any given year. It makes sense that flow would be an important factor in shaping communities. In this type of reference stream, other variables related to water chemistry and substrate particle distribution may not be expected to change significantly over short time periods. Flow and temperature may respond more dramatically to climate change, though DEC has only been measuring temperature at Ranch Brook for the last 12 months.

It is an important finding that the timing of sampling is a major factor in the presence and abundance of taxa in these communities, though perhaps not surprising. The mid to late October samples were all likely collected after leaf fall. As autumn progresses, the resource base for macroinvertebrates shifts more heavily to a community based on breaking down leaf detritus. This is indeed what we see at Ranch Brook, with the leaf shredding insects increasing later in the season, and similarity to normal functional feeding group distribution in reference streams decreasing (Figure 27). This kind of seasonal community shift could confound our ability to fully understand how taxon populations are changing over longer periods of time as a result of climate change. These results suggest that it is important to consistently collect biological samples at sentinel sites at roughly the same time every year. Collecting biological samples at sentinel sites at both the beginning and end of DEC's fall index period might provide even more valuable data on how macroinvertebrate populations are affected by climate change variations in flow and temperature.

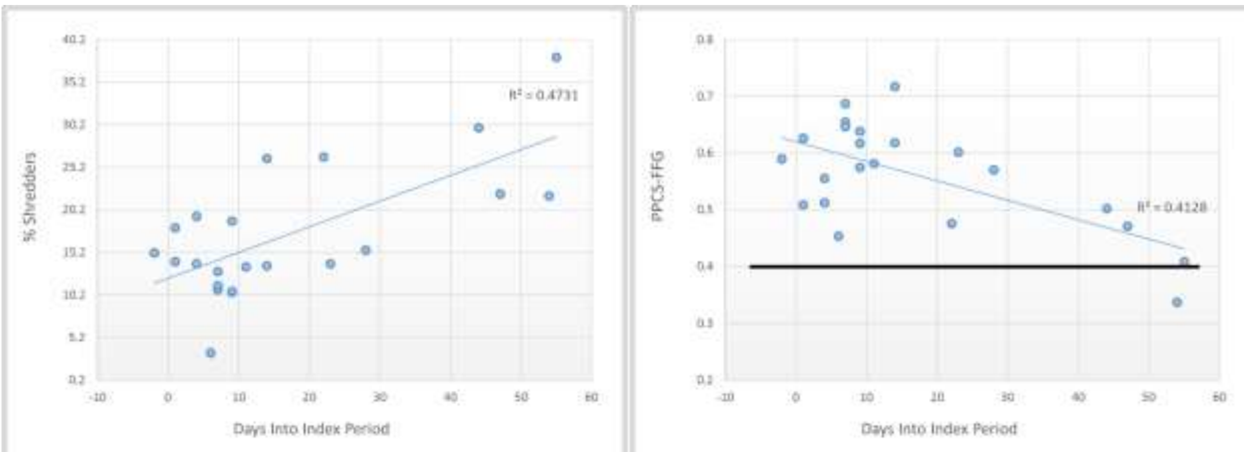

Figure 27. Relationship between functional feeding group variables and the number of days into DEC's fall index period that the biological sample was collected. PPCS-FFG is one of the eight metrics used to assess biological health, with the black line representing minimum acceptable criteria.

It appears that biological condition may have finally rebounded fully after two relatively low flow years.

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

The Mt. Mansfield Paired Watersheds Study

West Branch near Stowe Mountain Resort has been monitored since 2000.

Since September 2000, the U.S. Geological Survey has been continuously operating stream gages at Ranch Brook and West Branch near Stowe, Vermont (Wemple *et al.,* 2007). The gaging was designed as a paired watershed study, with Ranch Brook (9.6 km^2) as the forested control watershed, and West Branch (11.7 km^2) as the developed watershed. The West Branch watershed contains nearly the entire extent of the four-season Stowe Mountain Resort. In the classic paired watershed approach, monitoring would be conducted prior to any development, but the resort was established long before the study began.

However, the resort underwent a significant expansion during the course of the study, so the study design is appropriate to assess the effect of the expansion. This report on the Mt. Mansfield gaging is for Water Year (WY) 2015 (October 2014 through September 2015). The report interprets the WY15 streamflows in the context of the full 15-year record. Historic and near real-time flow data are available on the USGS website (addresses given at end of this report).

In WY2015, the gages were jointly funded through a cooperative agreement between the USGS and Vermont Monitoring Cooperative. The gages provide valuable information on mountain hydrology in Vermont, and how mountain landscapes respond to development and extreme events. To our knowledge these are still the only gaged watersheds at a ski resort. The gages have supported projects on snow hydrology and water quality by University of Vermont, Sterling College, Vermont ANR, and others. In particular, Beverley Wemple and students at University of Vermont have used the gages as a base for student projects and hands-on learning, and to attract additional funding for value-added research.

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.

Discharge vs. runoff

Streamflow, or discharge, is commonly reported as a volume per unit time – in the U.S., typically as cubic feet per second, or cfs (Figure 1). Throughout this report we typically refer to runoff rather than flow. Runoff is discharge divided by watershed area, and allows for direct comparison of flow in basins of different size. For example, if one basin is double the size of another and has double the flow, runoff would be the same. The dimensions of runoff are depth per unit time, i.e. the same as precipitation, thus runoff can be directly compared to precipitation. For example, if a watershed receives 1500 mm/yr of precipitation and has 1000 mm/yr of runoff, that means 500 mm/yr was lost to evapotranspiration plus or minus a change in the amount of water stored in the watershed, e.g. in soils.

2015 in Summary

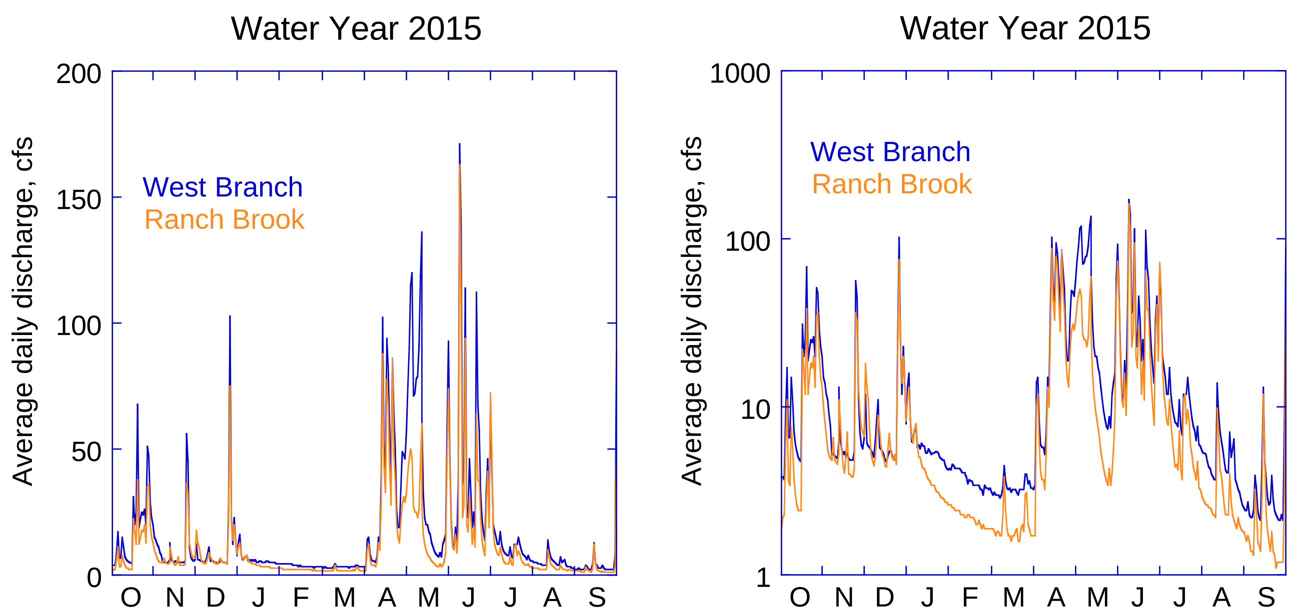

Figure 28. *Streamflow at West Branch and Ranch Brook gages for Water Year 2015 (October 2014 through September 2015) in linear (left) and log (right) scales. The log scale plot highlights the higher sustained base flow levels at West Branch.*

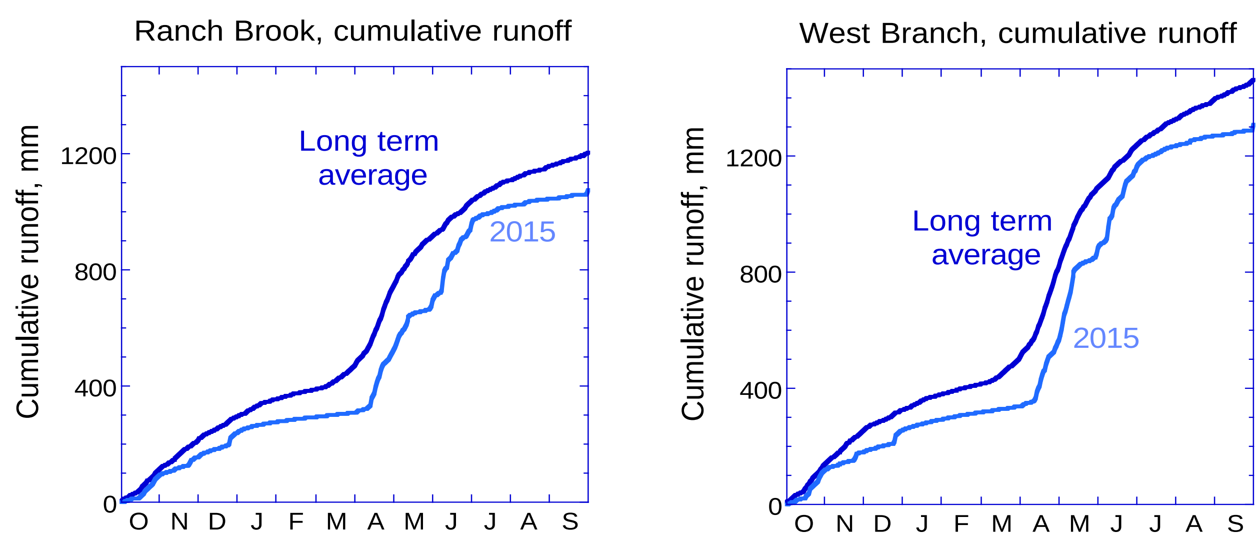

Figure 29. Cumulative runoff for Water Year 2015 (light blue lines) at Ranch Brook (left) and West Branch (right) plotted on the long-term (2001-2015) average at each site (dark blue lines).

Relative to the 15-year record, WY2015 had below average runoff for the second consecutive year. WY15 was notable for a fairly dry fall, and after large late December peak, a lack of mid-winter thaw events (Figure 28). Snowmelt was about average, and after a very wet June, the summer was fairly dry. Overall, runoff was less than the long-term average (Figure 29).

As in Water Year 2014, the cumulative runoff in Water Year 2015 ran below average for the entire year (Figure 29). The deficit began when fall rains were below average, and increased through the winter due to a lack of thaws. An unusually cold winter led to a later than average start to snowmelt (note the abrupt increase in cumulative flow at both sites in April). A very wet June brought both sites close to average cumulative runoff, but a dry summer restored much of the deficit. The relative runoff patterns at the two sites in Water Year 2015 were similar to the long-term patterns (Figure 30), with both streams generating similar runoff until part way into the spring snowmelt, when West Branch consistently generated greater runoff. Part of the greater snowmelt runoff was from melting of machine-made snow. (Water for snowmaking is withdrawn from West Branch upstream of the gage, so it is not double-counted). Runoff at West Branch continued to exceed that at Ranch Brook through the summer due to higher sustained base flow.

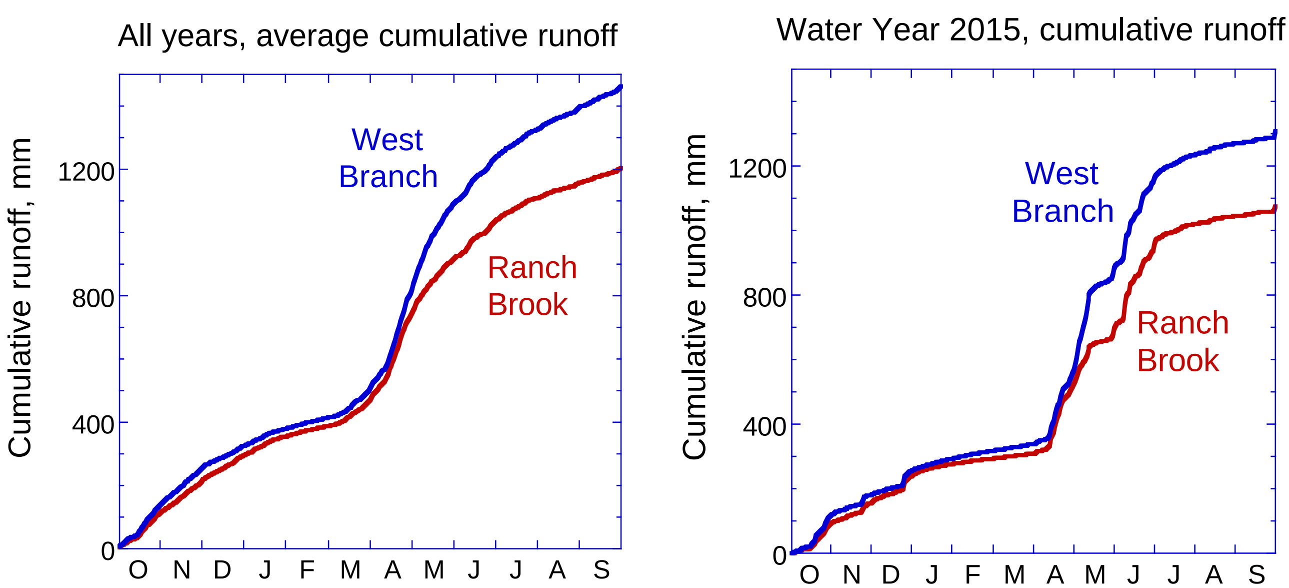

Figure 30. Cumulative runoff at West Branch and Ranch Brook based on the averages across the 15-year record (left) and for Water Year 2015 only (right).

Long Term Trends

As noted in previous reports, West Branch has consistently yielded higher runoff (flow normalized to watershed area) than Ranch Brook (Wemple *et al.*, 2007) (Figure 30 and Figure 31). Over the long-term, the average difference has been 21% greater runoff at West Branch. The Water Year 2015 differential was near average at 22% (Figure 31). We have repeatedly noted that greater runoff at West Branch is what we would expect from the creation of open land and development, but that the high magnitude of the differential suggests that some part of the difference may be natural. In last year's report we noted the extreme heterogeneity of large summer storms; these may preferentially impact West Branch. We are currently investigating the role of local meteorology on the flow regimes.

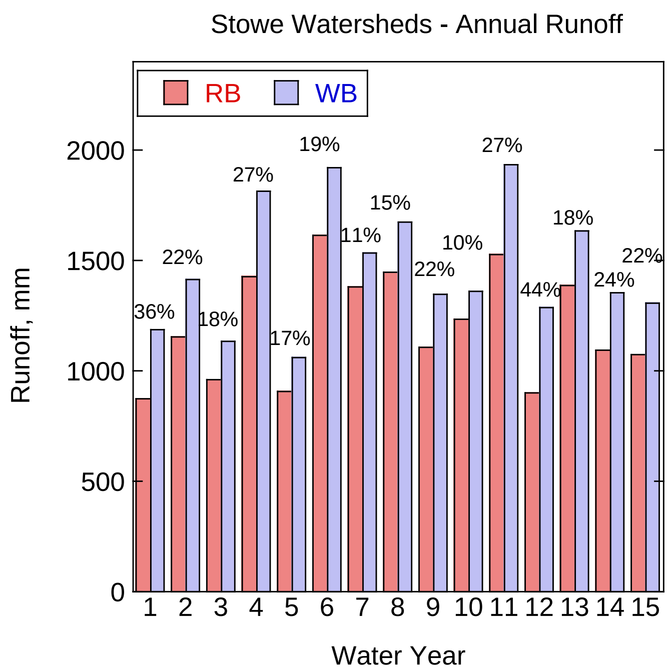

Figure 31. Annual runoff in mm at West Branch (WB) and Ranch Brook (RB) for the duration of study though the present report year. Percentage of greater runoff at WB relative to RB is given over each pair of bars.

In a first step to assess the hydrologic impact of the resort expansion, we constructed flow duration curves for two three-year periods of approximately equal precipitation, from before and after the construction period (Figure 32). Preliminary analysis suggests that the resort build-out had no clear impact on the hydrology, except for the low-flow regime. Construction of a new snowmaking pond with greater storage has lessened the need to draw water directly from the stream at low flows, thus enabling a higher sustained baseflow in late fall and winter.

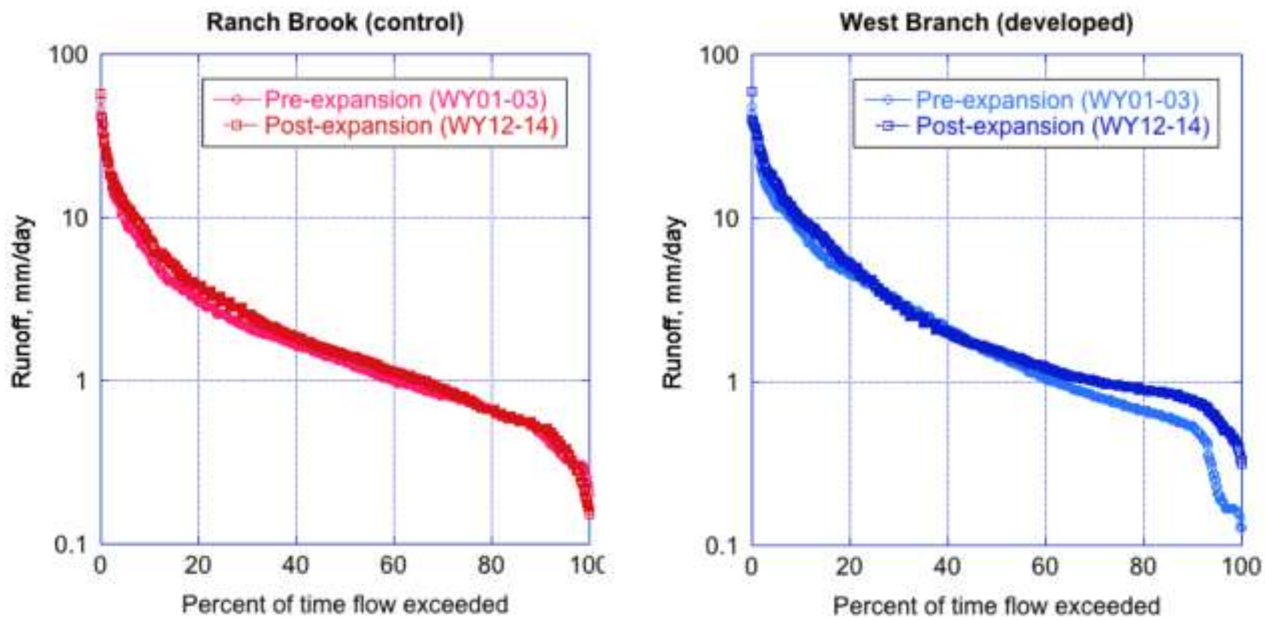

Figure 32. Flow duration curves for two three-year periods before and after the resort expansion, at Ranch Brook (left) and West Branch (right).

Implications

Mountain ecosystems worldwide are increasingly stressed by development of year-round recreational venues, tourism and other development such as communication towers and wind farms. Climate change disproportionally affects these ecosystems with warming temperatures and fewer more intense precipitation events which are increasingly in the form of rain rather than snow. Plants and animals adapted to live at high altitudes suffer. Ski areas with no snowmaking capacity are almost unheard of and certainly not viable and all areas are moving toward becoming year-round operations that rely on golf courses, waterparks, mountain bike trails and other recreational activities that don't require snow. As these build-outs progress there are more impervious surfaces – parking lots, condominiums, and tennis courts which will alter the patterns, volume, velocity and chemical make-up of runoff.

Climate models predict more extreme precipitation events (already evident) that can potentially flood mountain streams leading to erosion, loss of stream bank cover and scouring of stream bottoms causing 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 for hotels and residences and snow making) can also adversely affect both aquatic and riparian animal and plant communities.

This study provides valuable information 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.

References

Wemple, B., J. Shanley, J. Denner, D. Ross and K. Mills. 2007. Hydrology and water quality in two mountain basins of the northeastern US: assessing baseline conditions and effects of ski area development. Hydrological Processes 21(12): 1639-1650.

Additional Resources

VMC Project Database Links

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

West Branch data are accessible at: http://waterdata.usgs.gov/vt/nwis/uv?site_no=04288225.

Ranch Brook data are accessible at: http://waterdata.usgs.gov/vt/nwis/uv?site_no=04288230.

Water Quality

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

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

During the 1980s, initial chemical surveys were conducted on lakes throughout Vermont. Concern was mounting that remote, high-elevation lakes in geologically sensitive areas were 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 in color, with low pH and thermally stratify in the summer. Samples are collected three times a year in the spring, summer and fall using a Kemmerer water sampler. The samples are collected at 1 m below 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 monomeric, and total dissolved), nitrate, sulfate, chloride and dissolved organic carbon (DOC). Branch is more acidic than Bourn and is located just south of the Lye Brook Wilderness boundary. The methods of collection, processing and analysis have remained consistent for nearly 30 years. Last year's analysis focused on measurements from the epilimnion, the uppermost layer in a thermally stratified lake. This year, the focus will be on the deeper area of the lake, the hypolimnion, typically between 1-2 meters off the bottom at the deep hole.

2015 in Summary

Table 9. 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
2015	5.63	0.586	77.05	6.61
Long-term average	5.22	0.68	114.69	5.70
2015 percentile	97%	21%	11%	90%

In 2015, water quality trends in the epilimnion (top layer) of Bourn and Branch Ponds followed the same patterns observed in 2014, and over the long-term record. This includes low concentrations of both base cation (Ca, Mg, Na, K) and acid anions (SO_4, NO_3 and Cl). The decline in acid anion concentrations can be correlated to federally mandated reductions in national pollution emissions and deposition. Mean pH, alkalinity and dissolved organic carbon values continue to be some of the highest on record (Figure 33, Table 9). This is consistent with acid lake measurements made across the Northeast, showing reduced acidity (higher alkalinity), lower toxic inorganic monomeric aluminum (IMAL) and increased DOC.

Long-Term Trends

There are several notable trends in Vermont's acid lakes. First we'll discuss the top layer of the pond, the epilimnion. Alkalinity, a measure of a waterbodies' acid buffering capacity is now positive on both Bourn and Branch Ponds. This is most striking on the more acidic Branch Pond which has yielded positive alkalinities since 2011 (Figure 33, top). Calcium has declined by half since the 1980s but appears to be levelling off since the mid-2000s (Figure 34). The toxic form of aluminum, Inorganic Monomeric Aluminum (IMAL) is declining on both ponds. This is a beneficial trend for fish reproduction and survival. The phenomena of increased DOC is called lake browning and is occurring across the northeastern US, eastern Canada and northern Europe (Lawrence 2013). It has many possible ecological consequences including greater oxygen depletion and changes to the food web structure (Williamson et al, 2015). Some possible causes for brownification include increased organic matter solubility in soils (Monteith *et al*. 2007, SanClements *et al*. 2012), increased CO_2 in the atmosphere, increased precipitation and reduced atmospheric inputs. No conclusive cause has been identified thus far.

In the summer, samples collected from Bourn Pond's hypolimnion during stratification smell like "rotten eggs" due to the lack of oxygen (anoxia) and buildup of hydrogen sulfide (H2S) that's released from lake sediments. The anoxic conditions in the deepest area of the lake allow for oxidation or chemical reducing conditions to occur. This causes SO_4 to reduce to sulfide (as in hydrogen sulfide - H2S) near the lake sediments. When the hypolimnion sample is decanted at the surface the smell is strong. With thermal stratification, water chemistry in the hypolimnion can be dramatically different from spring to summer to fall. During the summer, anoxic conditions lead to the release of phosphorus, and temporary increases pH and alkalinity. This combined with the long-term reduction of sulfur and nitrogen oxides has resulted in a long-term improvement in the hypolimnion alkalinity (Figure 33, bottom). Phosphorus concentrations in the hypolimnion are nearly twice that of the epilimnion. This may be due to internal loading from sediments. Under certain conditions, phosphorus in sediments may be released due to warmer water, low dissolved oxygen, and changes in pH (Figure 35).

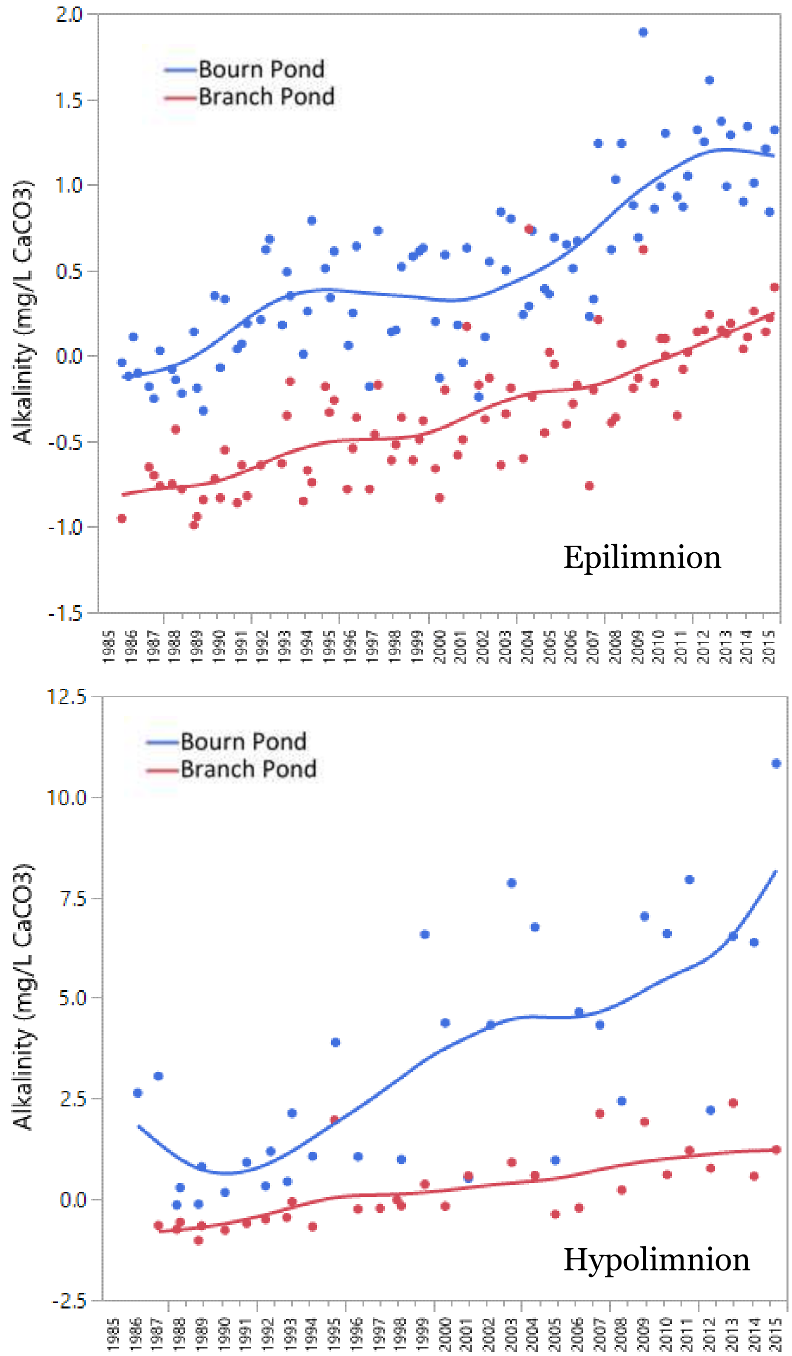

Figure 33. Long-term trends in Gran alkalinity (mg/L $CaCO_3$) in the epilimnion (top) and the hypolimnion (bottom) for Bourn and Branch Ponds.

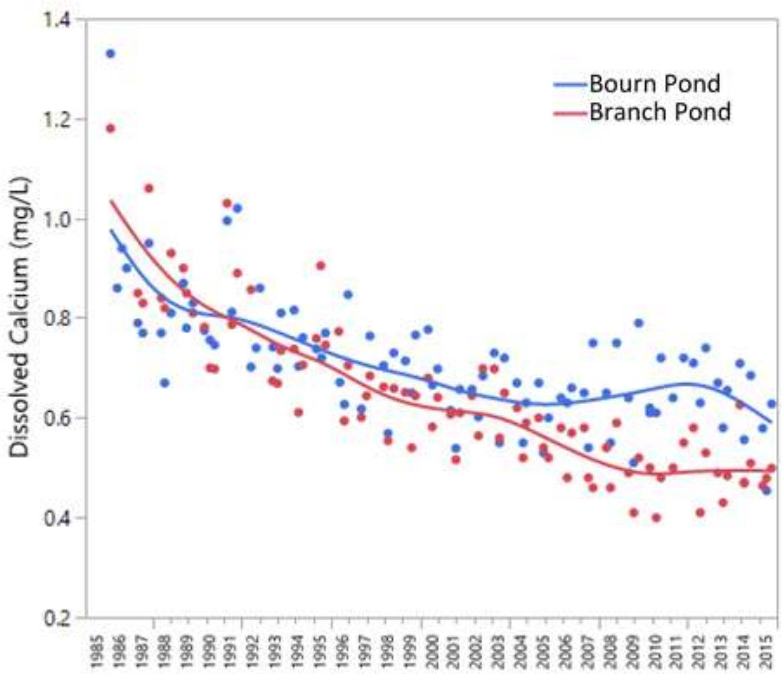

Figure 34. Long-term trends in dissolved calcium (mg/L) in Bourn and Branch Ponds provide indicators of the health of high elevation lakes.

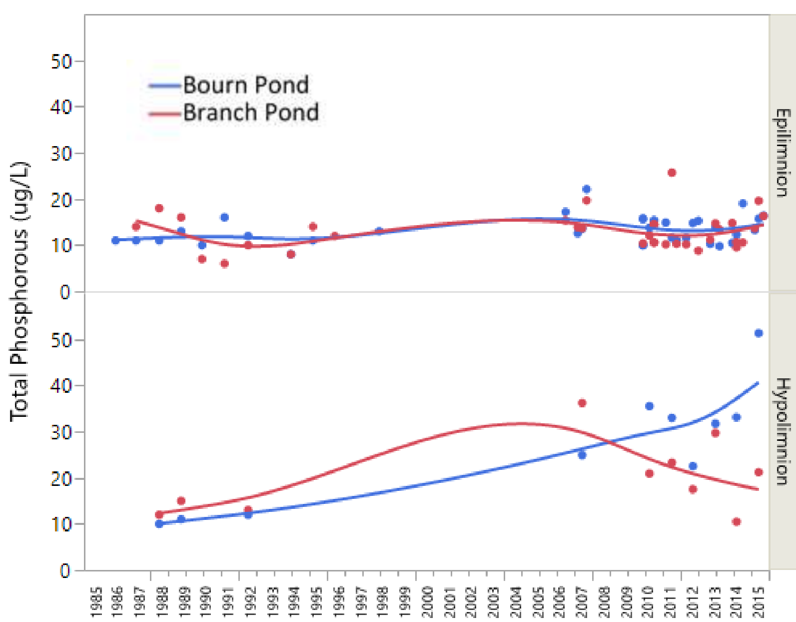

Figure 35. Long-term trends in total phosphorous (ug/L) in Bourn and Branch Ponds in the epilimnion (top) and hypolimnion (bottom).

Biological improvements are the bottom line for determining recovery in acid-impaired lakes. Some changes on Bourn and Branch Ponds are beneficial while others will hamper recovery. Recovery of biota will be limited by low concentrations of base cations, specifically calcium, a nutrient essential to the development and reproduction of fish and macroinvertebrates. Inorganic monomeric aluminum is declining, reducing the toxicity and harm to biota. Paired with improvements in pH and alkalinity, the waters are becoming less acidic and less toxic.

Ironically, the increases in pH and microbial activity may increase the phosphorus loading to these otherwise low nutrient lakes. Dissolved organic carbon levels have been increasing at both Bourn and Branch Ponds (Figure 36), 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 decreases in acid deposition (Lawrence *et al*. 2013). Ironically, the increases in pH and microbial activity may increase the phosphorus loading to these otherwise low nutrient lakes.

Implications

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 waterbodies 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.

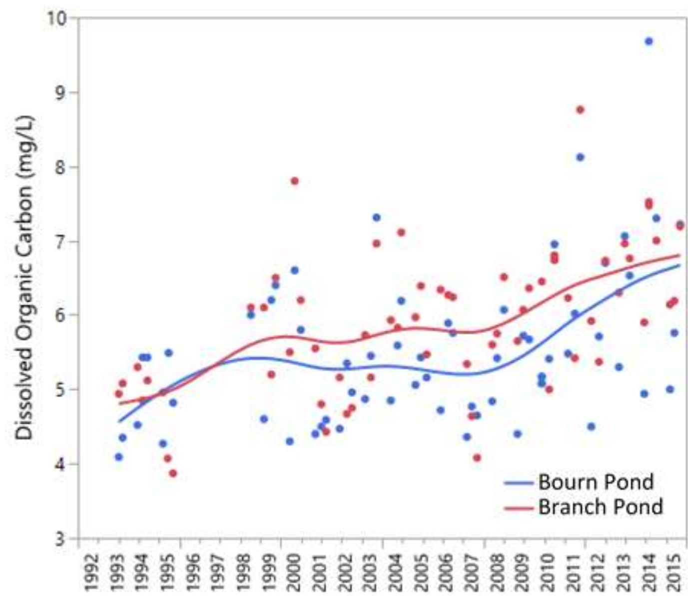

Figure 36. Long-term trends in dissolved organic carbon (DOC, mg/L) provide additional indicators of the health of high elevation surface waters.

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 lakes, 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. Bedrock and soils need time 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.

References

SanClements, M.D., G.P. Oelsner, D.M. McKnight, J.L. Stoddard and S.J. Nelson. 2012. New Insights into the Source of Decadal Increases of Dissolved Organic Matter in Acid Sensitive Lakes of the Northeastern United States. Environmental Science & Technology 46(6):3212-3219.

Williamson, C.E., Overholt, E.P., Pilla, R.M., Leach, T.H., Brentrup, J.A., Knoll, L.B, Mette, E.M and Moeller, R.E. 2015. Ecological consequences of longterm browning in lakes. Scientific Reports 5. 186666.

Monteith, D.T., J.L. Stoddard, C.D. Evans, H.A. de Wit, M. Forsius, T. Hogasen, A. Wilander, B. Skjelkvale, D.S. Jeffries, J. Vuorenmaa, B. Keller, J. Kopacek, and J. Vesely. 2007. Dissolved organic carbon trends resulting from changes in atmospheric deposition chemistry. Nature 450(7169): 537-540.

Lawrence, G.B, J.E. Dukett, N. Houck, P. Snyder, and S. Capone. 2013. Increases in Dissovled Orgnaic Carbon Accelerate Loss of Toxic Al in Adirondack Lakes Recovering from Acidification. 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 Links

Long-term Monitoring of Acid Lakes: http://www.uvm.edu/vmc/project/long-term-monitoring-acid-sensitive-lakes

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***Forest Health Monitoring* Section**

View from Warren Gap Long Trail. Photo by Judy Rosovsky, Vermont Monitoring Cooperative.

Aerial Detection Surveys Section

Aerial view of defoliation. Photo by Dan Dillner, Vermont Department of Forests, Parks and Recreation.

Defoliated hillside. Photo by Sandy Wilmot, Vermont Department of Forests, Parks and Recreation.

***Forest Phenology* Section**

Red maple leaf out. Photo by Brian Stowe, UVM Proctor Maple Research Center.

Fall foliage in the canopy. Photo by Josh Halman, VT Department of Forests, Parks and Recreation.

Sugar maple tapping. Photo courtesy of the Proctor Maple Research Center.

***Acid Deposition* Section**

N-Con Precipitation collector. Photo by Miriam Pendleton, Vermont Monitoring Cooperative.

Dead alpine tree. Photo by the Vermont Monitoring Cooperative.

***Mercury Deposition* Section**

Yellow Perch. Photo by Robert Colletta, USDA.

N-Con Collector. Photo by Judy Rosovsky, Vermont Monitoring Cooperative.

***Ozone* Section**

Black cherry with ozone damage. Photo by John Skelly courtesy of St. Louis Ozone Gardens.

***Climate* Section**

Forest Environmental Monitoring Canopy Tower. Photo by the Vermont Monitoring Cooperative.

Red Spruce Winter Injury. Photo by Gary Hawley, via EcoNewsVT http://www.econewsvt.org/news/winter-injury-carbon-loss-but-surprising-growth-resurgence

Trout **Section**

Brook trout at Ranch Brook, Stowe VT. Photo courtesy of Rich Kirn.

Brook trout sampling. Photo courtesy of Rich Kirn.

Forest Birds **Section**

Bicknell's Thrush. Photo courtesy of Steve Faccio, Vermont Center for Ecostudies.

Amphibians **Section**

Plethodon cinereus. Photo courtesy of Erin Talmadge, The Vermont Reptile and Amphibian Atlas.

Eastern Musk Turtle in Hand. Photo courtesy of Jim Andrews, The Vermont Reptile and Amphibian Atlas.

Sentinel Stream **Section**

Stonefly on rock. Photo courtesy of Vermont Department of Environmental Conservation.

In-stream sample collection. Photo courtesy of Vermont Department of Environmental Conservation.

Watershed Hydrology **Section**

West Branch, Stowe, VT. Photo courtesy of Jennifer Pontius.

Mountain view. Photo courtesy of Jennifer Pontius.

Water Quality **Section**

Bourn Pond. Photo by Heather Pembrook, Vermont Department of Environmental Conservation.

Lily pads in the water. Photo by Judy Rosovsky.

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