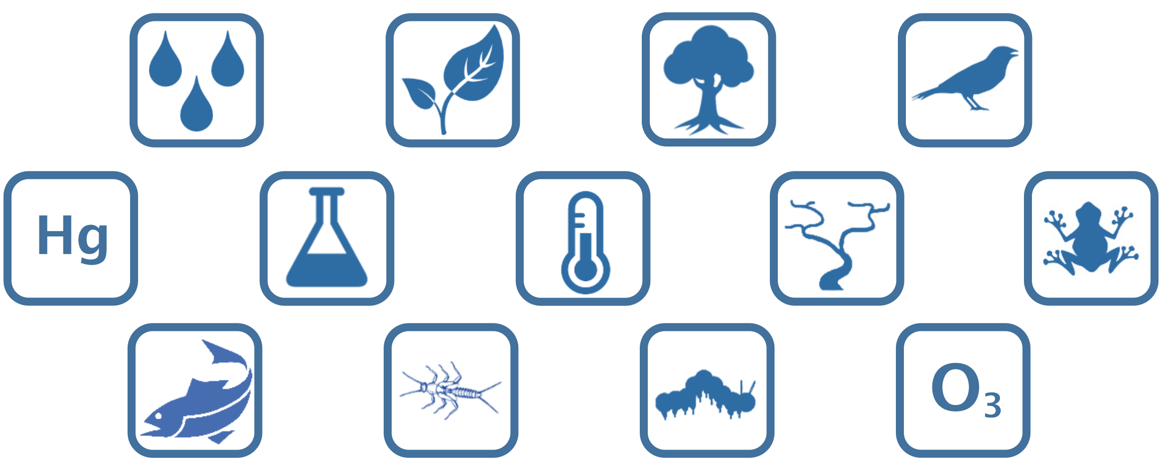
FEMC

Forest Ecosystem Monitoring Cooperative

Long-Term Monitoring Update 2016

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



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The Forest Ecosystem Monitoring Cooperative Long-Term Monitoring Update - 2016

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Forest Ecosystem Monitoring Cooperative, South Burlington, VT, USA

Contributing Editors: James Duncan, John Truong, Miriam Pendleton, Alexandra Kosiba, Jon Katz, and Jennifer Pontius.

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The Forest Ecosystem Monitoring Cooperative Editorial Staff

James Duncan – Director

Jon Katz – Analyst

Alexandra Kosiba – Project Coordinator

Miriam Pendleton – Site Operator

Jennifer Pontius – Principal Investigator

John Truong – Field and Project Coordinator

Project Leaders and Supporters Contributing to this Report:

James S. Andrews, Vermont Reptile and Amphibian Atlas Project

David Gay, National Atmospheric Deposition Program

Joshua Halman, Vermont Agency of Natural Resources

Bennet Leon, Vermont Agency of Natural Resources

Rebecca Harvey, Vermont Agency of Natural Resources

Jim Kellogg, Vermont Agency of Natural Resources

Rich Kirn, Vermont Agency of Natural Resources

Aaron Moore, Vermont Agency of Natural Resources

Chris Rimmer, Kent McFarland, Steve Faccio & John Lloyd, Vermont Center for Ecostudies

Barbara Schultz, Vermont Agency of Natural Resources

Jamie Shanley, U.S. Geological Survey

Sandra Wilmot, Vermont Agency of Natural Resources

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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 Forest Ecosystem Monitoring Cooperative (FEMC, formerly the Vermont Monitoring Cooperative) 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 FEMC network has completed nearly 250 individual research and monitoring projects conducted by over 215 collaborators over its 27-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 FEMC 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 2016 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, FEMC 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. Because of the FEMC's history of operations in Vermont, this update is focused on datasets related to that state, with a separate report detailing trends in regional datasets.

Forest Health

Long-Term Canopy Condition and Regeneration

Long-term trends in tree health provide information on the condition and vigor of Vermont's forests. Assessing tree crown condition and regeneration help us monitor the status of our forest, as well as detect change. Trees with healthier, denser foliage can sequester more carbon, add more wood annually, and better resist pests and pathogen outbreaks. Measuring regeneration gives us a sense of what our forest may look like in the future. While in any one year, crown health metrics may vary due to weather events and/or insect or disease outbreaks, the long-term species trends give us context for the annual observations. As our climate continues to change, monitoring forest health trends will be critical.

Forest health technicians measure canopy condition, seedling abundance, sapling survivorship, invasive species, and damage agents on a network of 48 long-term forest health monitoring plots.

The Data

In 1990, a national Forest Health Monitoring (FHM) program was established to measure forest health and detect emerging problems. Following this protocol, the Forest Ecosystem Monitoring Cooperative (formerly the Vermont Monitoring Cooperative) established 48 FHM plots in Vermont between 1991 and 2016. In addition to the original 19 plots measured from 1991-2014, 22 plots were added in 2015, and 7 more in 2016.

The 48 Vermont FHM plots contain 1,983 mature trees from 31 species, spanning 8 forest types and 8 biophysical regions. Annually, crews assess tree species, canopy condition, seedling abundance, sapling survivorship, invasive species, and damage agents. Crown health assessments include early symptoms of tree stress, such as changes in foliage transparency, crown dieback, and live crown ratio. Elevated crown transparency can suggest either short or long-term decline, while crown dieback is a metric for more serious decline symptoms. Live crown ratio measures the percentage of the tree height with live foliage.

Regeneration counts provide an estimate of the relative success of germination and initial survivorship across species from year to year. Saplings (1 to <5 inches in diameter) have been measured on the 19 original FEMC plots between 1997 and 2007, and then again starting in 2014. From 2008 to 2013, the plots were measured on a 3-year rotation. Seedlings (<1 inch and greater than 12 inches for hardwoods or 6 inches for softwoods) have been measured periodically during that time as well. In beginning in 2014, all seedlings of any height have been tallied yearly. Regeneration serves as a proxy for the future composition of the forest canopy. In total, the information obtained from this plot network provides a robust estimate of the current condition of Vermont's forests, providing early indications of potential problems that may affect forests across Vermont and beyond.

Hemispherical canopy photo at long-term plot LBA2300A (2016).

2016 in Summary

Crown Health

In 2016, for all selected key hardwood species, mean dieback was elevated compared to the long-term mean (Table 1). A few species showed no significant change in crown dieback, including white pine, balsam fir, and red spruce, however, mean was slightly elevated for these species too. White ash, in particular, showed increased dieback in 2016 (16.9%), compared to the long-term average (8.3%), as did red oak (13% and 4.6% respectively). Overall dieback across all species was 12.2%, compared to 9.4% in 2015, which represents an increase compared to the long-term average of 7.8%. Several weather-related stress factors in 2015 may have contributed to crown health in 2016. Late spring frost injury, drought, and localized wind storms were observed across Vermont in 2015. While any one year can have events that stress trees (e.g., drought, insects, disease), long-term trends of increased dieback can be cause for concern.

Foliage transparency showed little change in 2016 (Table 1). At 20.7%, transparency was lower in 2016 than in 2015 (21.4%), and very similar to the long-term average (20.0%). The only species to exhibit an increase in transparency was paper birch. 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.

Table 1. Crown health metrics (dieback, transparency, and live crown ratio) in 2016 and compared to the long-term mean. 'Dif' column indicates the difference, with red values showing a decline in health (one standard deviation), green shows an improvement, and no color indicates no change.

Species	Dieback (%)			Transparency (%)			Live crown ratio (%)		
	2016 mean	Long-term mean	Dif	2016 mean	Long-term mean	Dif	2016 mean	Long-term mean	Dif
American beech (*Fagus grandifolia*)	13.1	9.4	**3.7**	20.4	22.7	2.3	54.5	60.2	**5.7**
Balsam fir (*Abies balsamea*)	13.4	12.1	1.3	20.2	19.6	0.6	62.2	70.3	8.1
Eastern hemlock (*Tsuga canadensis*)	8.4	4.2	**4.2**	18.3	22.2	3.9	67.5	82.9	**15**
Eastern white pine (*Pinus strobus*)	10.6	8	2.6	21.6	23.1	1.5	49.9	48.2	1.7
Northern red oak (*Quercus rubra*)	13	4.6	**8.4**	20.1	17.2	2.9	49.8	33.5	**16**
Paper birch (*Betula papyrifera*)	17.1	11.1	**6**	27.7	23.6	**4.1**	43.5	44.9	1.4
Red maple (*Acer rubrum*)	11.3	7.1	**4.2**	20.1	20.3	0.2	49.1	48.8	0.3
Red spruce (*Picea rubens*)	8.9	6.7	2.2	18.9	17.4	1.5	48.4	51.3	2.9
Sugar maple (*Acer saccharum*)	10.5	6	**4.5**	18.5	17.5	1	53.1	56	**2.9**
White ash (*Fraxinus americana*)	16.9	8.3	**8.6**	22.2	19.4	2.8	47.1	37.3	**9.8**
Yellow birch (*Betula alleghaniensis*)	10.6	7.1	**3.5**	18.7	19.1	0.4	54.5	55.1	0.6

Live crown ratio of red oak and white ash increased in 2016 indicating expansion of branches with foliage, suggesting possible tree recovery. However, other species (American beech, eastern hemlock, and sugar maple) showed a decrease in live crown ratio. The average value in 2016 across all species was 52.7%, which is slightly lower than the 2015 value of 52.9% and the long term average of 54.3%. Rapid reduction of live crown ratio may be related to storm breakage or extensive top dieback.

Regeneration

Regeneration counts increased in 2016 relative to 2015 (Figure 1). reflecting fluctuations in heavier and lighter seed years. Since 2014, there has been a high density of red maple seedlings in the FHM plots, with a mean density of 19,516 seedlings per hectare (ha). Sugar maple also produced good seedling densities, at 3,858 seedlings/ha. Compared to the previous two years, yellow birch regeneration was slightly depressed and very few seedlings of paper birch were detected. American beech seedlings still constitute a considerable component of the understory, a result of beech bark disease, which often prompts mature beech to produce copious root sprouts. These sprouts can outcompete other seedlings (as they are attached to the 'mother' tree) and can lead to dense beech understories.

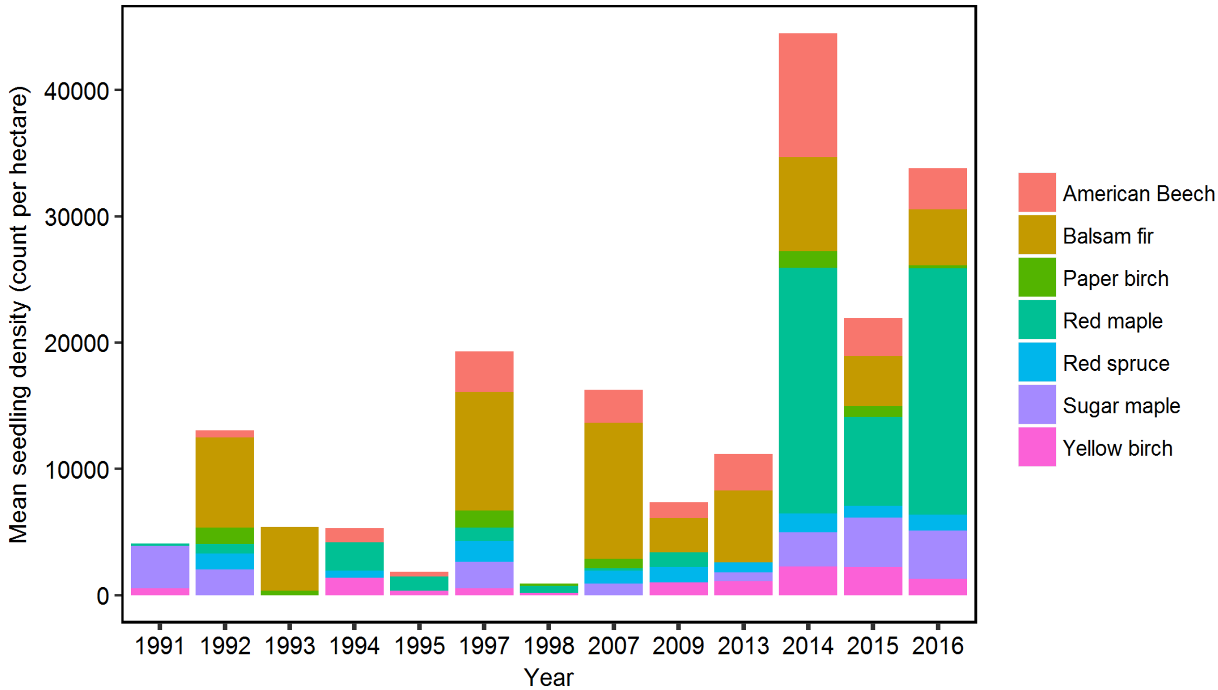

Figure 1. Mean seedling density (count per hectare) for selected species assessed at FEMC forest health monitoring plots. Note that seedling counts were not assessed each year. In 2014, seedling protocol changed, which accounts for the increase in total seedlings from 2013-2014.

For dominant and codominant trees measured in 2016, balsam fir dominated the plots (435 trees), followed by sugar maple (315) and red maple (208) (Figure 2). However, despite the large number of mature trees, balsam fir did not have the highest number of seedlings (2,143 seedlings counted) (Figure 2). By far, red maple had the most seedlings in 2016 (5,387). American beech had the third highest number of seedlings (1,942). There were many more species detected as seedlings (although this does include some woody species that remain shrubs or small trees) compared to mature trees. In 2016 there were some surprising species detected in the plots, including black gum.

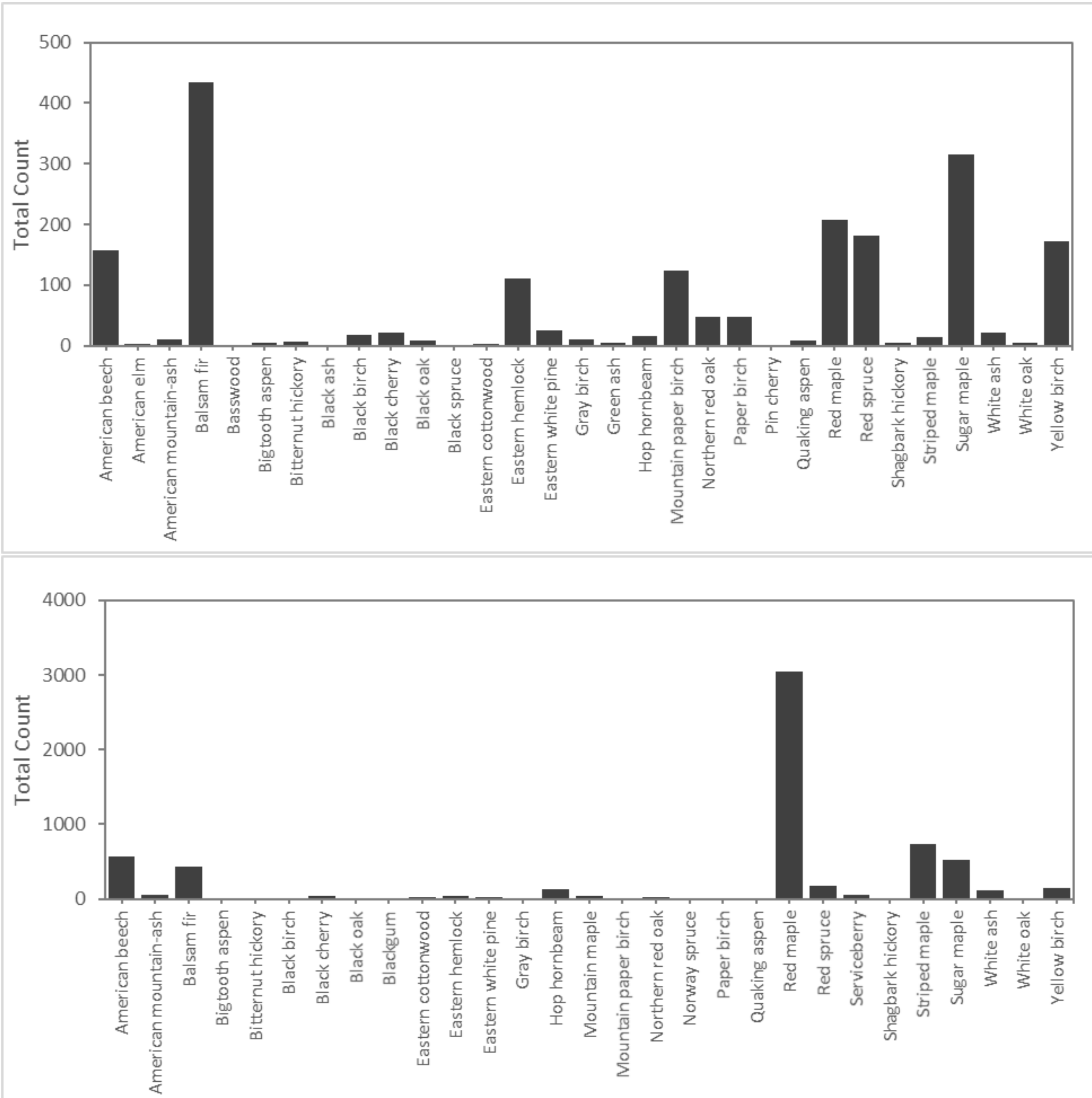

Figure 2. Species stem counts of all dominant and codominant trees 5 inches in diameter or greater (top) and seedlings (bottom) tallied across the 2016 FEMC Forest Health Monitoring plots.

Long Term Trends

An examination of the full temporal dataset allows us to look past the year-to-year variability to consider species-specific trends and identify more chronic stress conditions. It is evident that there is high annual variability in all three crown health metrics, and particularly for certain tree species. Mean crown dieback has remained consistent for most species over the measurement period (Figure 3). The exceptions are paper birch and white ash, which have both experienced increased dieback over recent years. Mean crown transparency values have steadily increased for many of the species examined, with white ash and paper birch showing the most dramatic increase. Steady increases in crown dieback are worrying; this could indicate broad spatial trends in elevated tree stress and decline. However, live crown ratio, which is the amount of foliage relative to total height, has remained steady or in some cases increased for some species (Figure 3). A few exceptions are beech, hemlock and sugar maple, which may be the result of increased dieback or the impact of storms. The FEMC will continue to monitor these species to understand how changing environmental conditions are altering forest health or competitive relationship.

In 2016, overall seedling density was similar to previous years on 19 plots with long-term records (Figure 2). It is important to note that a protocol change, implemented in 2014, expanded the definition of seedlings to capture current germinants. 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” diameter were counted. Thus, one explanation for the increase in 2014 overall seedling density may stem from the inclusion of seedlings that were previously

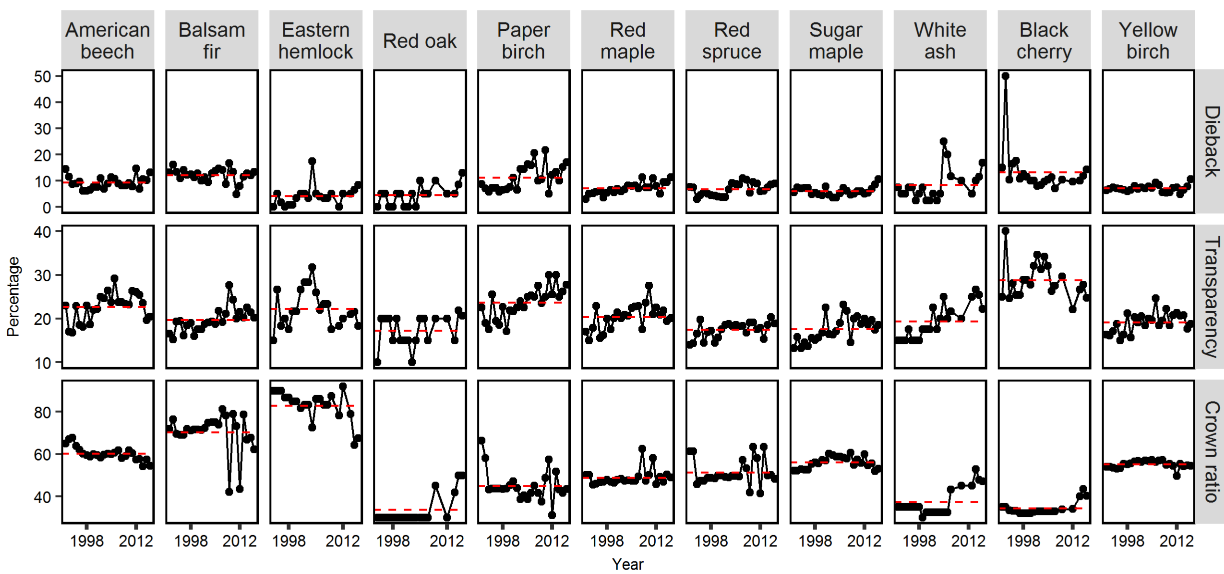

Figure 3. Tree crown health metrics: percent dieback, percent crown transparency, and live crown ratio (percentage of tree with foliage) for 11 dominant tree species in Vermont. Red dashed line shows the long-term mean (1993-2016) for that species and metric.

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, affected overall germination success and survivorship across species. In 2016, however, we saw an uptick from 2015, indicating that conditions were favorable for regeneration.

Seedling density across the 19 monitoring plots showed that red maple dominated the plots (Figure 1, Figure 2). Across all 41 plots, dominant species were balsam fir and red maple. 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-elevation shade tolerant species such as sugar maple and eastern hemlock is concerning. Considering that the species composition of mature trees across the FEMC long-term monitoring plots (Figure 2) is dominated by balsam fir at upper elevations and northern hardwoods (sugar maple, American beech, and yellow birch) at mid-lower elevations, this 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.

Regional Context & Implications

Long-term forest health monitoring has allowed us to detect subtle but steady changes in the condition of our forests. 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 over time, ongoing work to monitor tree health and regeneration will inform forest management decisions to maximize forest resiliency, productivity, and health of Vermont's forests.

Long-term suggest that certain species are showing greater dominance than should be expected, while others show continued declines. Tree crown health remained stable for some species, but white ash and paper birch continue to show signs of decline.

Acknowledgements:

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Additional Resources

VT Forests, Parks and Recreation Vermont Forest Health Highlights 2016 https://fhm.fs.fed.us/fhh/fhh_16/VT_FHH_2016.pdf

VT Forest Insects and Disease Conditions 2016 http://fpr.vermont.gov/sites/fpr/files/Forest_and_Forestry/Forest_Health/Library/2016%20Forest%20Insect%20%26%20Disease%20Conditions%20in%20Vermont.pdf

FEMC Project Database Links

Forest health monitoring: https://www.uvm.edu/femc/data/archive/project/forest-health-monitoring

Aerial Detection Surveys

Forest Disturbance

Damage to trees caused by insects, disease, animals, and weather, are a natural and common occurrence in the region's forests. Such disturbances can result in changes to biodiversity and species composition, and allow for cycling of nutrients from trees to soil, but can also negatively affect timber quality and other important ecosystem services. There is also concern that climate change and further introduction of non-native pests and pathogens may alter disturbance patterns.

The Data

Aerial detection surveys (ADS) have been used to map the cause and extent of forest disturbances in Vermont for nearly 50 years.

Statewide annual sketch-mapping surveys are collected by Vermont Department of Forests, Parks, and Recreation (VT FPR), and the US Forest Service over the Green Mountain National Forest and other federal lands. The US Forest Service Forest Health Monitoring Program sets survey methods and standards for ADS across the US.

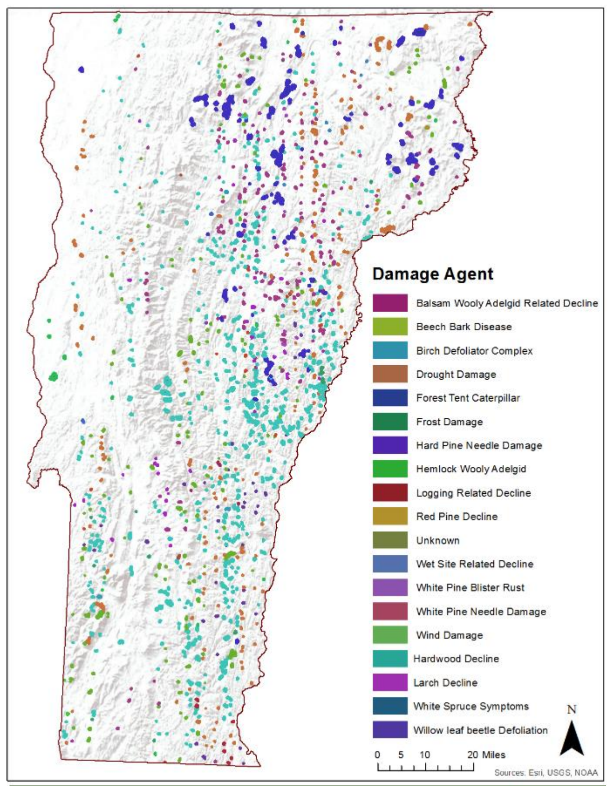

Figure 4. Locations of 2016 mapped forest disturbance from Vermont aerial detection surveys. Disturbance polygons were increased in size for visibility.

In most years, assessments cover the entire state (>2.5 million hectares). Mapped polygons include the disturbance cause, type, size, and severity which are confirmed with ground assessments. Causal agents of disturbance can range from insects and disease, to weather events (ice, wind, and frost), wild animals, and humans. Surveys are a cost-effective and vital tool for detecting emerging forest health issues and tracking trends, but are not comprehensive of all forest damage.

2016 in Summary

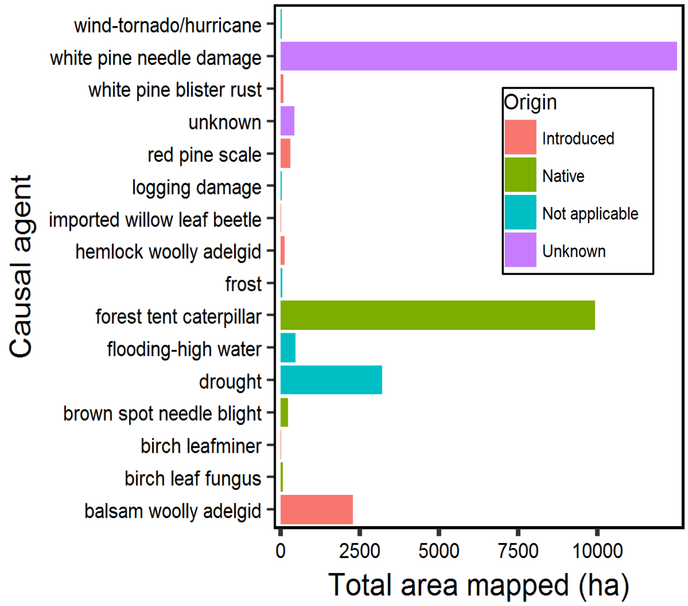

Figure 5. Area (in hectares) of mapped 2016 disturbance by causal agent according to Vermont aerial detection surveys. Color corresponds to the agent's origin.

In 2016, 32,737 hectares (80,897 acres) of forest disturbance were mapped in Vermont, which is less than 1% of Vermont's forestland. This is a decrease from 2015 when 46,425 ha were mapped, and is much lower than the long-term (1995-2016) average of 100,843 ha/year.

White pine needle damage was more widespread (Figure 4) and severe than in previous years. Due to the extent of damage and the earlier timing of aerial surveys in 2016, it accounted for the most area mapped (12,510 ha) for the first time in the record (Figure 5). Understanding the cause of this damage is ongoing. For more information, see the document from University of Massachusetts Extension (2016).

In 2016, we saw the first year of a forest tent caterpillar (*Malacosoma disstria*) outbreak, primarily in northern Vermont (Figure 4). Outbreaks result in defoliation of hardwood trees and usually last several years. It was the second most mapped agent (9,917 ha) (Figure 5), yet amounted to less than 1% of Vermont's hardwood forests.

A forest tent caterpillar found during 2016 in Vermont.

Symptoms attributed to drought accounted for 3,209 ha, amounting to 0.1% of Vermont's forestland (Figure 5). On-the-ground surveys found that stressed trees – such as those already affected by insects or diseases – showed more signs of drought stress. Dry conditions may also explain why fall foliage was earlier and showy (VT FPR 2016).

Some regionally destructive, non-native pests, like gypsy moth (*Lymantria dispar*), browntail moth (*Euproctis chrysorrhoea*), and emerald ash borer (*Agrilus planipennis*), were not detected in Vermont in 2016 although they caused damage elsewhere in the northern Forest region (MA, ME, NH, NY, and VT)

More complete results of the 2016 Vermont ADS effort can be found in the 2016 report, *Forest Insect and Disease Conditions in Vermont* (VT FPR, 2016).

Long Term Trends

Summing all disturbances per year (1997-2016) reveals substantial year to year variability (Figure 6). This is partially due to shifting monitoring and assessment priorities year to year, but also depends on the nature of the disturbance. Several disturbances are episodic, particularly abiotic weather events (e.g., late spring frost events, drought) and many insect outbreaks. The year of the highest disturbance area occurred in 1998 with a severe ice storm that caused widespread damage to trees (381,843 ha). Only two agents have been detected every year in the 22-year period: beech bark disease and birch defoliator complex (Figure 7).

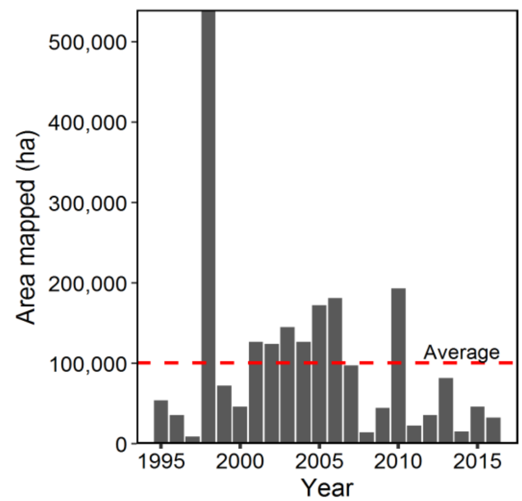

Figure 6. Annual area mapped as disturbed (grey bars; hectares) during statewide aerial detection surveys in Vermont. Red dashed line indicates the average disturbance (1995-2016).

In total, 66 different damage agents have been mapped in Vermont since 1995. When the maximum extent of damage caused by specific damage agents is compared to number of years they were mapped, agents have varying impacts in the landscape (Figure 7). In general, insects and abiotic agents have had the largest effect on the region's forests. The most damaging agents overall have been ice and snow damage (394,838 ha), birch defoliator complex (324,541 ha) and forest tent caterpillar (277,202 ha).

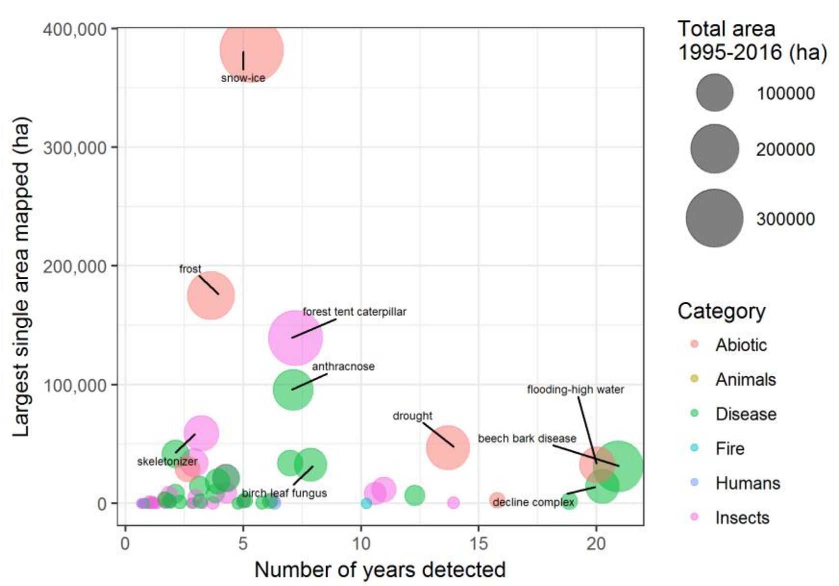

Figure 7. Mapped disturbance agents in aerial detection surveys from 1995-2016 plotted by the frequency (number of years detected) and largest single area mapped (ha; e.g., largest polygon) attributed to agent. Circle size corresponds to the total area recorded for that agent over the twenty-one-year period and color corresponds to the agent category. Only agents that have affected >50,000 ha are labeled for clarity.

Abiotic disturbance agents, like ice and frost events and drought, can indiscriminately affect trees regardless of species (although there can be reasons why specific species may be more harmed in abiotic events, due to branching structure, wood density, or habitat, for example) and as a result can cause widespread disturbance. Most other disturbance agents have only affected a small area of regional forestland. Only seven agents out of 66 have resulted in total damage greater than 100,000 ha in the 22-year period. Many tree diseases identified in the region have not caused large disturbance extents despite frequent occurrence (Figure 7). Of diseases, beech bark disease and anthracnose have resulted in the largest disturbance area. Forest fire is an infrequent event regionally, and when it does occur, the extent is small.

Regional Context & Implications

Aerial detection surveys data provides the longest statewide annual record of forest disturbances. Relatively low levels of total forest disturbance have been mapped. Most disturbances cause small damage extents and minor total damage.

The annual rate of disturbance in Vermont is comparable to the rest of northern Forest region (3% of forestland/year). Many, if not all, of the disturbances affecting Vermont's forests are regional issues. Disturbances do not know where state boundaries lie, and as a result pests and pathogens, as well as abiotic stressors, like hurricanes, ice, and drought can affect the whole northern Forest region.

As our climate continues to change, it is projected that extreme weather events will become more frequent, which may mean more storms, wind, ice, frost, or flood events. Elevated summer temperatures, along with changes to rainfall patterns, could lead to more severe and frequent droughts. Such abiotic events can cause large areas of damage to multiple tree species (Figure 7). It is only as we continue to monitor disturbances over time can we begin to understand the patterns of various types of events and how they may be changing.

Many invasive insects and diseases have been detected in Vermont, or in neighboring states. Overall, introduced pests and pathogens have caused much more disturbance to the region's forests than those of native origin, and we could see widespread declines of

In 2016, there was less disturbance than the Vermont average (1995-2016) and the regional average (1997-2016). The most damaging disturbance agents in 2016 were white pine needle damage, forest tent caterpillar, and drought.

specific species, such as ash (*Fraxinus* spp.) with the continued spread of emerald ash borer. The good news is that we are not seeing widespread outbreaks of introduced pests and pathogens in Vermont, nor are we seeing increases in total disturbance over time, in Vermont or regionally. The high species diversity in many of Vermont's forest stands and continued vigilant monitoring may be helping to mitigate widespread issues and to identify problems before they become widespread.

Additional Resources

UMass Extension, Plant Diagnosis Laboratory. 2016. Dramatic needle browning and canopy dieback of eastern white pine (Pinus strobus) in southern New England. Available online at https://ag.umass.edu/sites/ag.umass.edu/files/content-files/alerts-messages/2016whitepineupdate.pdf

Vermont Agency of Natural Resources. 2017. Climate Change in Vermont. Available online at http://climatechange.vermont.gov/vermonts-changing-climate

Vermont Forest Parks and Recreation (VT FPR). 2016. Forest Insect and Disease Conditions in Vermont: 2016. Report. Available online at: http://fpr.vermont.gov/sites/fpr/files/ForestandForestry/ForestHealth/Library/2016%20Forest%20Insect%20%26%20Disease%20Conditions%20in%20Vermont.pdf

FEMC Project Database Links

Aerial Sketchmapping: https://www.uvm.edu/femc/data/archive/project/statewide-aerial-sketchmapping-tree-defoliation-mortality

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, had better understand how changes in climate are affecting forested ecosystems.

The Data

Current FEMC 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 25-year period.

2016 in Summary

The day-of-year of first bud break in 2016 for sugar maple (DOY 129) was similar to the long-term average (DOY 125). Full leaf out (DOY 141) occurred 4 days later than the long-term mean, and was 9 days later than in 2015. The transition from bud break to full leaves was back to the long-term average of 12 days - a departure from the previous two years in which green-up occurred much more rapidly. At lower elevations, maximum fall color occurred the same day as in 2015, which is more than a week later than the long-term mean. Full leaf drop came 1 day later than last year and 7 days later than the long-term mean. At higher elevations, peak color was slightly more delayed (3 days later than 2015, but 13 days later than the long-term mean), and full leaf drop was 3 days later than the long-term mean.

Long Term Trends

While 2016 spring phenology timing was similar to the long-term mean, it still fits a long-term trend toward an earlier start of spring (Figure 8). 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 8).

In the fall, significant trends towards later fall color and leaf drop at lower elevations continued to be observed (Figure 8). The delay of maximum fall colors at low elevations showed consistently later peak foliage over time, culminating in an average delay of 7.3 days across the data record. Fall leaf drop showed a similar 10.1-day cumulative delay at low elevations. Interestingly, trees at upper elevations did not show a significant 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 FEMC data set (see https://www.uvm.edu/femc/attachments/project/999/reports/SugarMapleSpringPhenology_Mansfield2010.pdf)

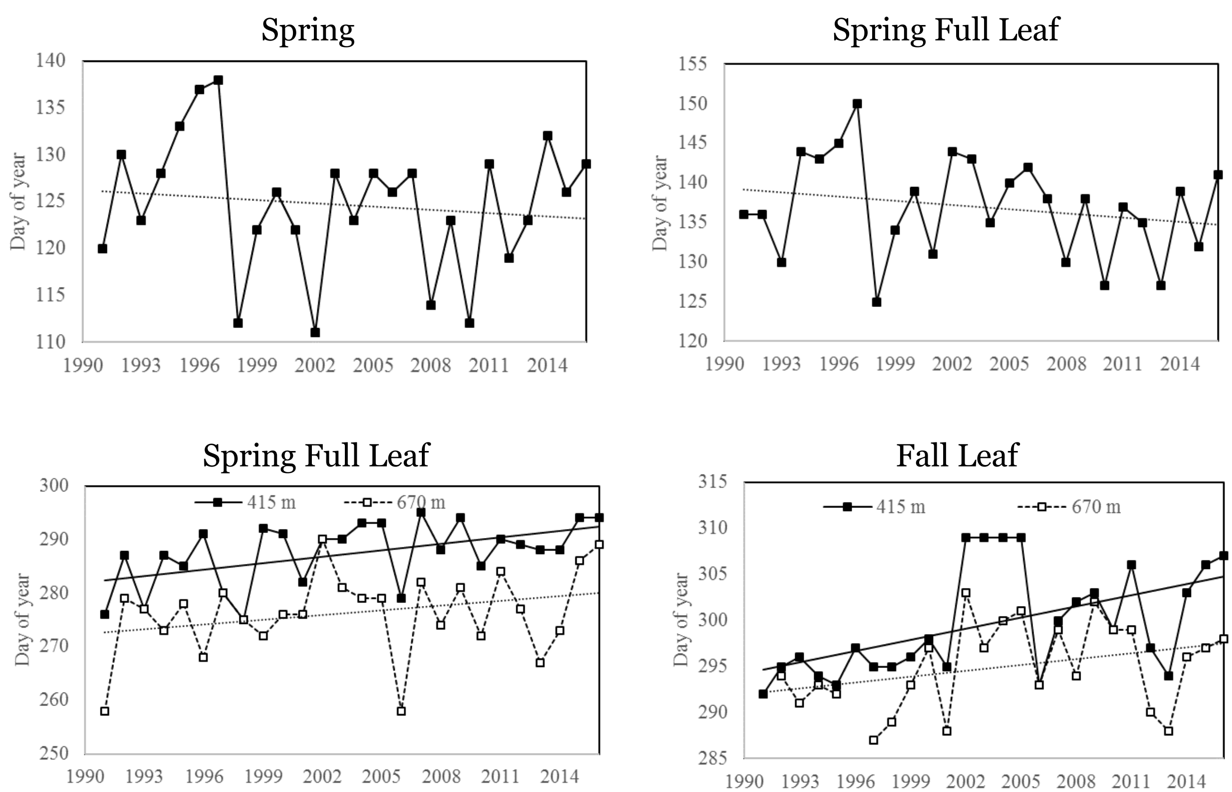

Figure 8. Long-term trends in the timing (mean day of year) of spring and fall phenological events for sugar maple from 1991 to 2016. Spring bud burst (top left) and full leaf out (top right) are assessed yearly at lower elevation (415m), with linear trend line shown. Fall maximum coloration (bottom 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.

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.

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Additional Resources

FEMC Project Database Links

Bud Phenology: https://www.uvm.edu/femc/data/archive/project/tree-phenology-monitoring-bud-development

Fall Color and Leaf Drop: https://www.uvm.edu/femc/data/archive/project/tree-phenology-monitoring-fall-color-leaf

Acid Deposition

National Atmospheric Deposition Program/National Trends Network

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

The ecological consequences of atmospheric acid deposition have been well studied in the Northeastern US. Through these investigations, acid rain has led to the decline of red spruce in the 1970s and 80s, the leaching loss of calcium and other cations from soil, and the acidification of lakes and streams. Two measures of acid deposition are sulfate (SO_4) and nitrate (NO_3); when emitted as air pollutants, these molecules can form acids through reactions with water in the atmosphere, creating what we know as 'acid rain'. Recognizing this serious environmental threat, regulations were enacted to control emissions of sulfur and nitrogen oxides, which react in the atmosphere to produce acidic compounds; as a result, acidic deposition has declined and ecosystem recovery is underway.

The Data

National Atmospheric Deposition Program (NADP) has been monitoring precipitation chemistry in the US since 1978 through the National Trends Network (NTN) program. The 250 national NTN sites collect data on the amounts, trends, and geographic distributions of acids, nutrients, and base cations in precipitation.

NTN sites are predominantly located away from urban areas and point sources of pollution. Each site is equipped with a precipitation chemistry collector and gage. The automated collector ensures that the sample is exposed only during precipitation (wet-only-sampling). Site operators follow standard operational procedures to help ensure NTN data is comparable. All samples are analyzed and verified by the Central Analytical Laboratory (CAL) at the Illinois State Water Survey (ISWS). Measurements include acidity (H^+ as pH), conductance, calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), sulfate (SO_4^{2-}), nitrate (NO_3^-), chloride (Cl^-), and ammonium (NH_4^+).

Deposition is expressed as a concentration of the pollutant, which reflects the amount of water in which it is transported.

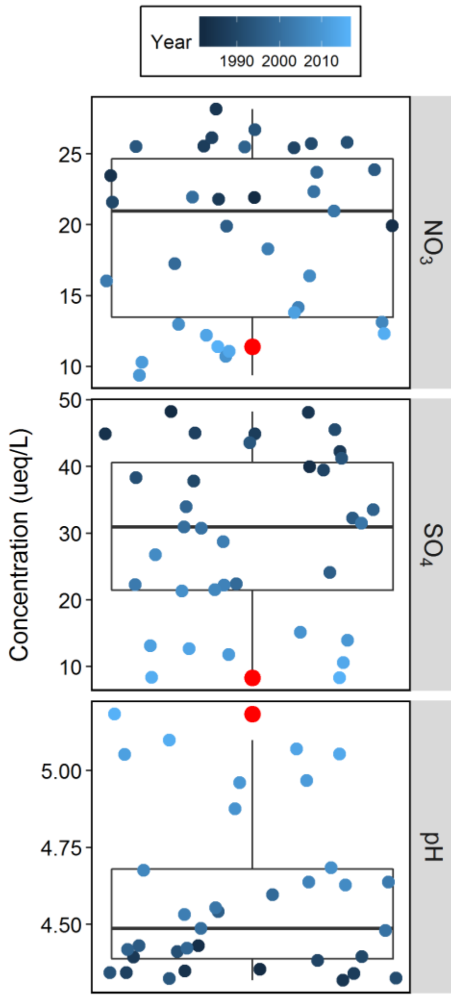

Figure 9. Mean annual deposition of nitrate (NO_3), sulfate (SO_4), and pH displayed with quantile box plots. The most recent year's measurements (2016) are indicated in red, and shades of blue correspond to the year, with lighter values corresponding to more recent data. Solid horizontal line indicates the long-term mean; any points outside vertical bars at top and bottom of boxes show values that are statistically outside of the range for that parameter.

The Forest Ecosystem Monitoring Cooperative has conducted atmospheric deposition monitoring for over thirty years at the Proctor Maple Research Center in Underhill and near Lye Brook Wilderness Area in southern Vermont. The Underhill NADP/NTN site has been a cornerstone of FEMC monitoring and research, providing key information on the sources of pollution, trends in deposition rates and how this influences forested ecosystems. The continental scale of NTN sites reveals spatial and temporal trends in acid deposition in Vermont and the Northeast and allows comparison with other regions of the U.S. 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.

2016 in Summary

For all three metrics of acid deposition (NO_3, SO_4, pH), 2016 continued the trend of reduced pollution concentrations over historical measurements (Figure 9).

While mean deposition of NO_3 in 2016 was not the lowest value observed in the record (Figure 9), it was the fifth lowest at 11.4 ueq/L, and was a considerable decline form the record high of 28.13 ueq/L in 1985. Further, for every year in the most recent decade (2006 on), precipitation contained the lowest measured concentrations of NO_3.

In 2016, we saw the lowest concentration of SO_4 in the record (8.33 ueq/L). This is a dramatic decline the historical high of 48.20 ueq/L in 1982. For the first time in the past five years, deposition of SO4 fell below that of NO3.

The average pH was the highest on record at 5.18, which indicates that precipitation in the form of rain, snow, or ice is less acidic than in 2015. While the pH has increased considerably from the record's low of 4.32 in 1989, "unpolluted" rain typically has a pH of 5.6. Therefore, there is still room for continued improvement in lowering the acidity of precipitation. As pH is a logarithmic scale, this increase represents a roughly fivefold improvement in precipitation acidity.

In the early years of acid rain monitoring in Vermont, sulfates accounted for about 66% of the acidity in precipitation, while nitrates contribute the other 33%. While upwind emissions of both sulfur oxides (SO_X) and nitrogen oxides (NO_X) have declined over time, reductions in SO_X have been greater than NO_X. While the stress imposed by SOx deposition has been greatly reduced, it is unclear how the continued deposition of NOx will impact forested ecosystems.

Long-term Trends

Since precipitation chemistry was first measured in Vermont, rain has become less acidified (Figure 10). These changes reflect declines in sulfur- and nitrogen-based emissions due to the Clean Air Act (1977) and subsequent amendments (1990). The most significant reductions have occurred for sulfate deposition, which has fallen from nearly 50 ueq/L to less than 10 ueq/L.

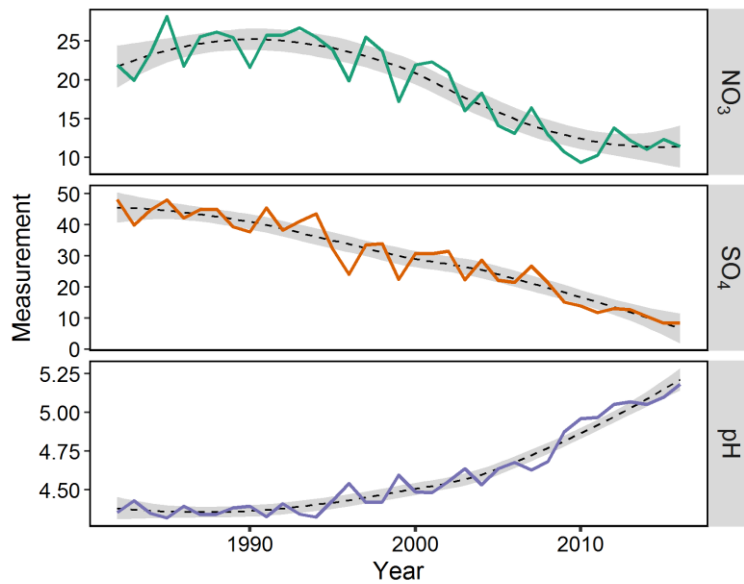

Figure 10. Long-term precipitation chemistry showing annual mean concentrations (ueq/L) of nitrate (NO3) and sulfate (SO4), and mean pH (solid colored lines). Black dotted line shows trend (LOESS function) with 95% confidence intervals (grey shading).

Changes that are more modest have been measured for nitrate deposition. This is primarily due to the relative difficulty of removing nitrogen compounds from flue gases and their diffuse pollution sources such as motor vehicle exhaust and agricultural activities. Sulfuric emissions have been easier to control through regulation of emissions from the burning of coal, natural gas, and other fossil fuels.

Concurrently, there has been a dramatic increase in precipitation pH (Figure 10). Since pH is on a logarithmic scale, increasing pH by a value of 1 signifies a substantial change in precipitation acidity.

Looking forward, it is likely that reductions in SO_4 may continue (Figure 10), along with resultant decreases in precipitation acidity. However, it appears that reductions in NO_3 concentrations may have plateaued. Because nitrogenous pollution primarily comes from diffuse sources such as automobile exhaust, fertilizer use, and confinement farming such as feedlots and poultry operations in agricultural regions, continued reductions may require additional legislative or regulatory action.

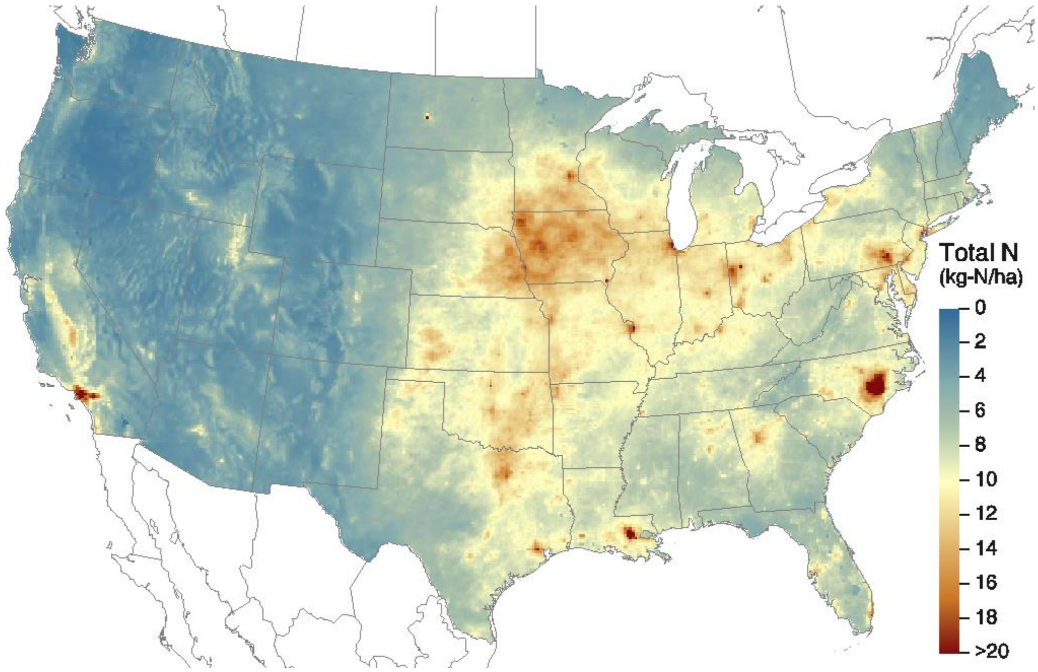

Figure 11. Spatial distribution of total nitrogen deposition (kg/ha) across the continental US in 2015. Source: US EPA.

Regional Context & Implications

Vermont is in relatively good shape compared to nitrogen pollution loads nationwide (Figure 11). However, forests along the spine of the Green Mountains continue to be at risk from additional acidic inputs due to more frequent exposure to acid mist in clouds, higher amounts of precipitation, and relatively shallow acidic soils. 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.

Similar trends in reduced acidity of precipitation has been seen elsewhere in the region, although western and southern portions of New York continue to receive elevated deposition (Figure 11). Many areas in the Midwest US have been experiencing very high levels of nitrogen deposition; these regions are characterized by developed manufacturing industries. As a result, continued declines in nitrate deposition may require additional regulations.

Acid deposition continued to decline in 2016, and the average pH of precipitation was 5.18, well above the historical low. Nitrate deposition may have plateaued and should continue to be monitored.

Additional Resources

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

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

FEMC Project Database Links

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

Hg

Mercury Deposition

Mercury Deposition Network Monitoring at VT99

Merury Deposition Network automated 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, FEMC 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 FEMC 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 FEMC 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[1], how mercury bioaccumulates in birds[2] and amphibians[3], how mercury levels are influenced by elevation[4], and how falling leaves contribute to deposition[5]. FEMC 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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[1] Mercury Flux at PMRC - https://www.uvm.edu/femc/data/archive/project/mercury-flux-pmrc

[2] Bicknell's Thrush Population Demographics and Ecology: Assessing levels of methylmercury in montane forest bird community on Mount Mansfield - https://www.uvm.edu/femc/data/archive/project/bicknells-thrush-population -demographics-ecology-ongoing

[3] Mercury Burdens in Amphibians - https://www.uvm.edu/femc/data/archive/project/mercury-burdens-amphibians

[4] Cloudwater Chemistry on Mount Mansfield - https://www.uvm.edu/femc/data/archive/project/cloudwater-chemistry-mount-mansfield

[5] Litterfall Mercury Dry Deposition in the Eastern USA - https://www.uvm.edu/femc/data/archive/project/litterfall-mercury-dry-deposition-eastern-usa

The Data

FEMC 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/).

2016 in Summary

Mercury monitoring at FEMC's air quality site (VT99) for 2016 shows slightly lower deposition than average for the 11-year record, higher than 2015 and roughly equal to 2014 (Table 2. 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.). 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. In 2016, precipitation-weighted mean concentration was roughly average for the record, while the maximum recorded concentration in a single sample was well below historical average. In 2016, Vermont registered lower concentration and deposition averages that most sites elsewhere in the United States (Figure 12).

Table 2. 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	5.6	33.9	7.4
2006	5.2	97.2	7.9
2007	8.7	131.6	11.6
2008			
2009	5.3	33.7	6.3
2010	5.6	48.0	8.4
2011	6.1	88.7	9.6
2012	4.7	63.9	6.1
2013	5.8	21.1	8.1
2014	5.2	11.5	7.2
2015	4.9	21.0	6.1
2016	5.8	21.3	7.3
Overall Mean	***5.7***	***52.0***	***7.8***

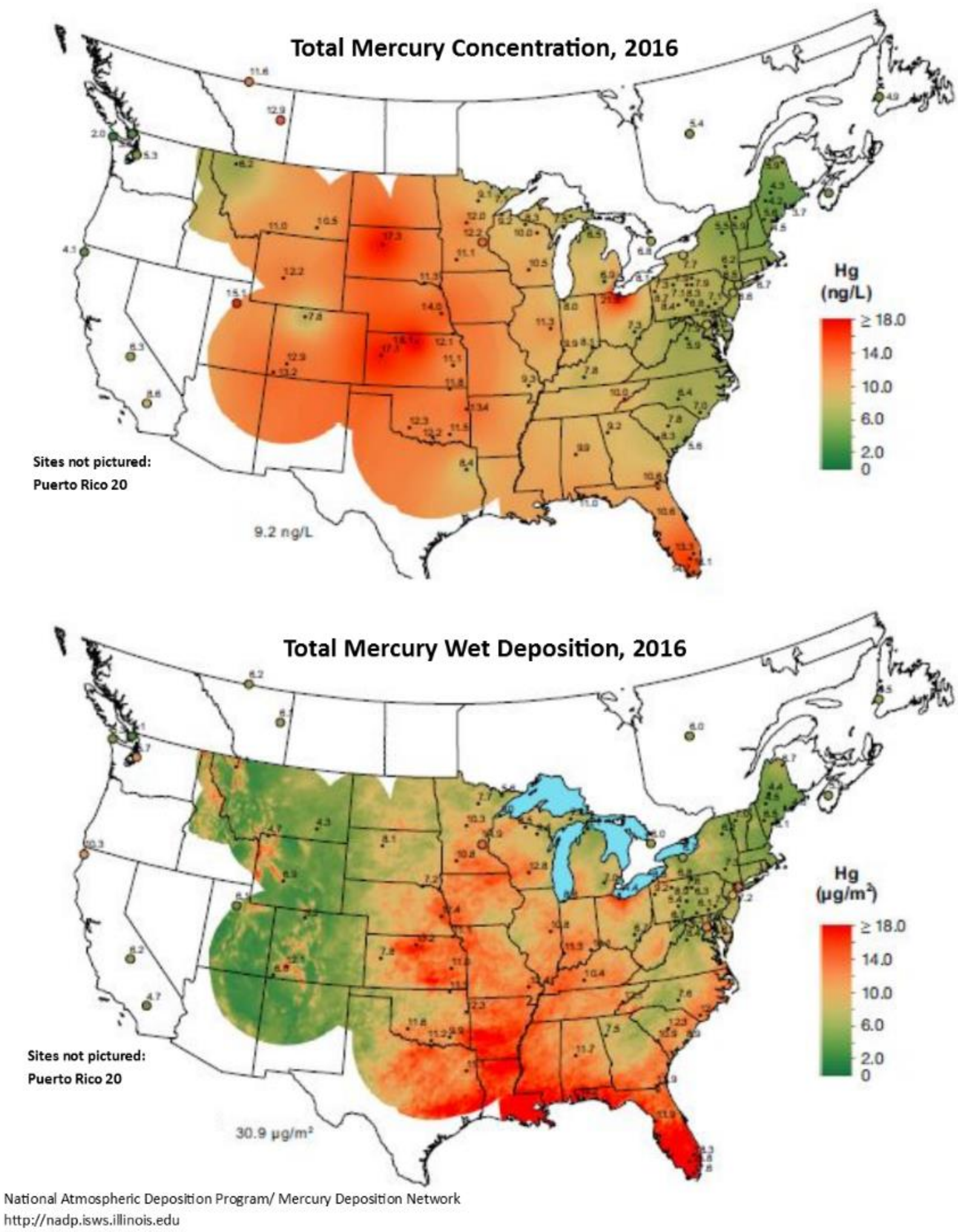

Figure 12. Estimated concentration and deposition of mercury in precipitation across the United States. Concentration varies with the amount of precipitation, and is used to determine pollution sources and other atmospheric possesses. Total deposition is the amount of chemical deposited from the atmosphere on the landscape, and is used to assess the consequences of specific pollutants on the ecosystem.

Hg

Mercury Deposition

Long Term Trends

Over 10 years of monitoring at VT99 prior to the current year, mean annual deposition was higher than 41% of national MDN sites (Table 3). The VT99 monitoring station has fallen from the high end of measured values (2007, with higher total Hg deposition than 85% of other MDN sites) and climbed from the low end of measured values (2012, with higher total Hg deposition than only 14% of other MDN sites). During most years of monitoring, the VT99 site typically falls in the middle of reported Hg deposition values across the Mercury Deposition Network.

Table 3. 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	2016	Overall Average
# of reporting stations	95	104	112	117	125	133	112	113	116	120	116	112	115
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	9.1	9.2
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	7.3	7.8
VT99 Deposition Percentile	34%	38%	85%	--	35%	49%	48%	14%	44%	31%	27%	41%	41%

Mercury deposition has decreased in VT in recent years, but still remains among the highest deposition rates in the region (Figure 13).

Hg

Mercury Deposition

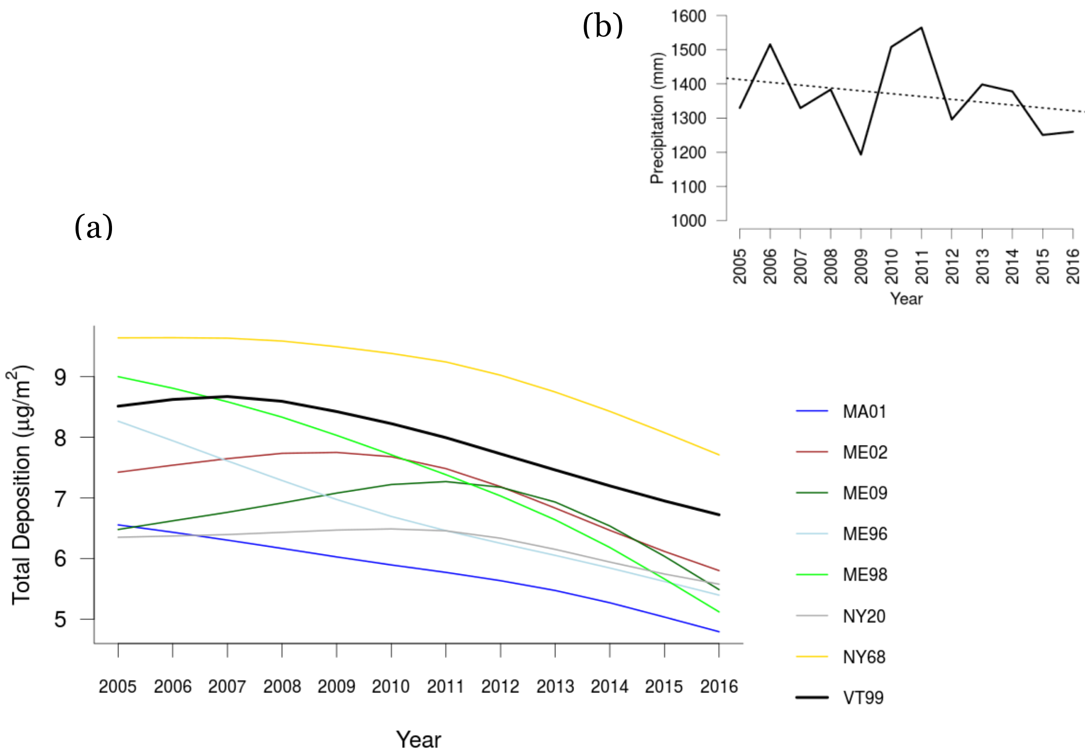

Figure 13. Total Hg deposition (a) in µg/m2 by year for northeastern MDN monitoring sites with comparable years of data collection, including spline smoothed lines. Inset (b) displays the precipitation record at the site, which shows little trend over the same period.

Indeed, a recent regional trends analysis using NADP MDN data (Figure 14) provides further signs of regional differences for VT99. Different periods were analyzed, including the years 1997-2013 as well as several shorter portions of the record. The shorter time period analyses were a way to incorporate the changing spatial pattern into the trends analysis as the MDN network expanded. This period from 2008 to 2013 shows VT99 having a statistically significant positive slope in increased mercury

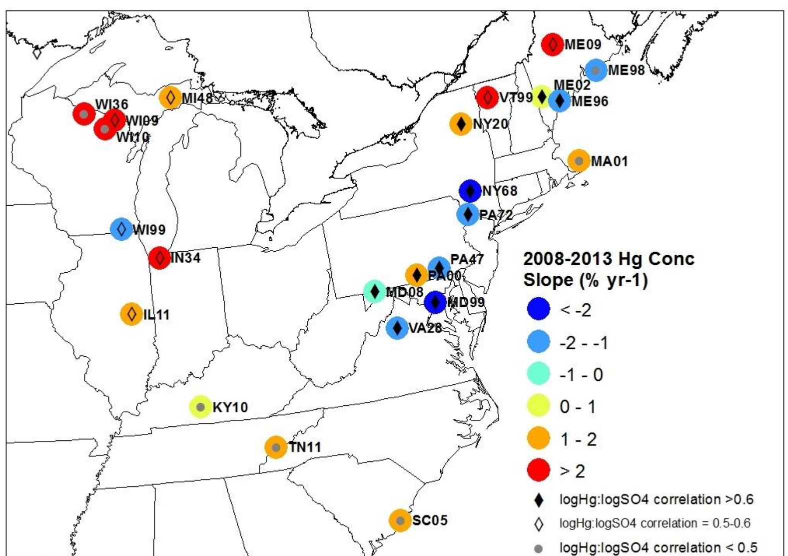

Figure 14. Annual rates of change in Precipitation Weighted Mean residual mercury concentration over the period 2008-2013 for co-located Mercury Deposition Network and National Trends Network sites in the northeastern U.S. Symbols indicate the site-specific linear correlation coefficients (R) obtained from a regression between weekly log Hg and weekly log SO4= concentrations (not residuals) over the 2008-2013 period.

concentrations. Five years is too short for a definitive trend, but it might suggest that VT99 is more influenced by global sources than are surrounding lower altitude MDN sites due to its relatively high altitude and the absence of nearby coal utility boilers (Weiss-Penzias et al. 2016).

Implications

In the long term, mercury deposition levels decreased dramatically with the enactment of clean air legislation in the late 20th century (Kamman and Engstrom 2002). The atmosphere is the main pathway for mercury into Vermont's ecosystems. It is estimated that more than half of this atmospheric deposition is dry. Dry deposition is difficult to measure but the NADP is committed to expanding its network of mercury dry deposition sites. Unfortunately, the FEMC had to terminate its Atmospheric Mercury Network (AMNet) site on Dec. 31, 2015 so dry deposition rates going forward will have to be inferred rather than measured.

Mercury persists in the environment and continues to be cycled through the various storage pools (soils, air, and biota). 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 2016, pers comm, 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. Mercury cycling is complex and not completely understood, also highlighting the need to track concentration and deposition rates.

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, sulfates are no longer well correlated. In the northeastern region mercury concentrations are up, suggesting that mercury measured here is not associated with regional S emissions. It is possible that the mercury falling on Vermont is from foreign or at least not from regional sources. As of March 2016, The U.S. Supreme Court denied a stay of the Environmental Protection Agency's Mercury and Air Toxics Standards ("MATS") which would implement emissions reductions of toxic air pollutants from existing and new coal and oil-fired power plants. Although the rule is under review by the EPA at the urging of the Trump administration, if it survives, we should 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 a global pollutant could mean more deposition for everyone, and potentially higher fish concentrations and therefore higher concentrations in VT humans. This underscores the need to curtail anthropogenic contributions 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's monitoring for identifying global patterns of mercury pollution.

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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

FEMC Project Database Links

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

O_3

Ozone

Monitoring ozone pollution levels and foliar injury in northern and southern Vermont

Ozone damage on Milkweed leaf

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 FEMC 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.

2016 in Summary

The most recent 2016 and 3-year average data for Bennington and Underhill are summarized in Table 4 below. The 4th highest 8-hour concentrations at the Underhill and Bennington sites were 60 and 67 ppb respectively. The 3-year averages of these 8-

hour maximum values were 61 and 63 ppb – below the 70 ppb level of the current primary health standard.

Table 4. 2016 and 3-Year Average ozone concentrations in northern & southern Vermont.

	2016 4th Highest 8-hr Maximum	2014-2016 Avg. 4th Highest 8-hr Maximum
Underhill	**60 ppb**	**61 ppb**
Bennington	**67 ppb**	**63 ppb**

Long-Term Trends

Long term trends in ozone in northern (Underhill) and southern (Bennington) Vermont are plotted in Figure 15 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 60-70 ppb more recently.

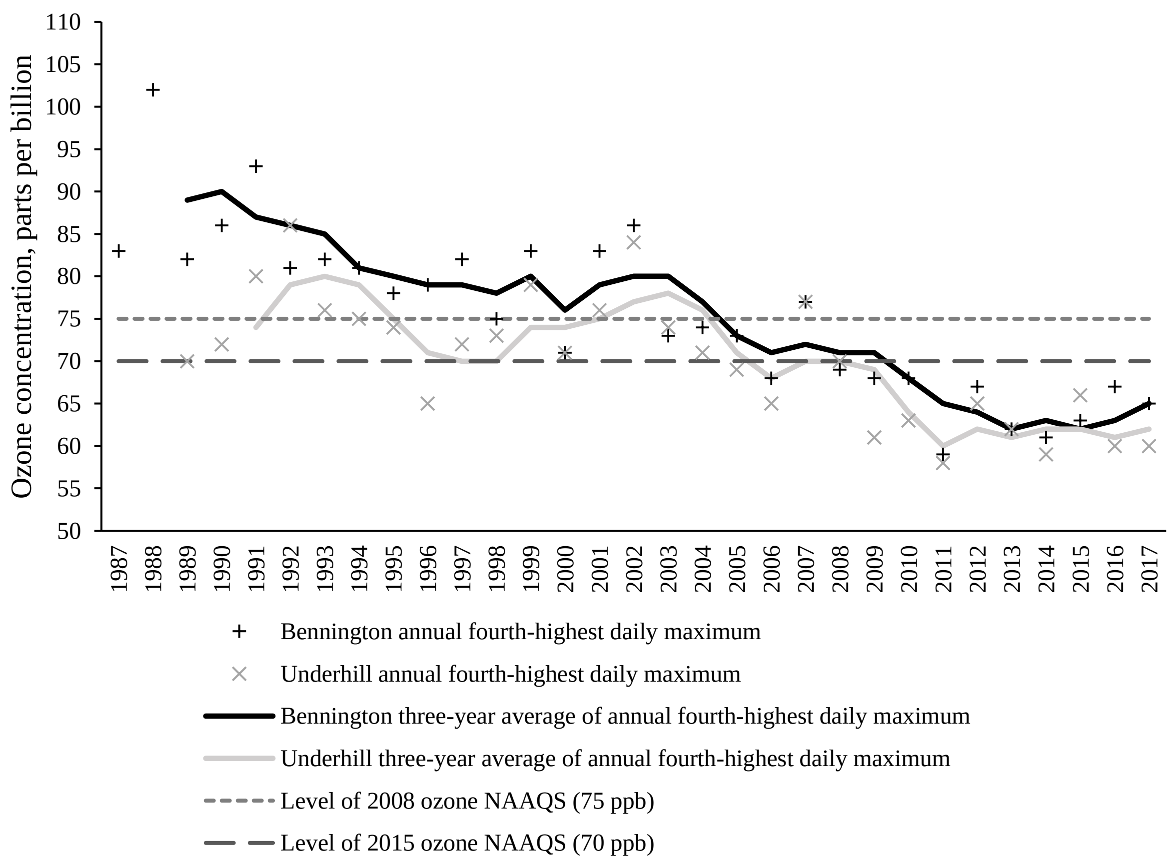

Figure 15. Vermont trends in ozone concentration. Data in the figure above are illustrated for the period 1987 to 2017 at the Bennington and Underhill ozone monitor locations. Points are plotted as rolling 3-year averages plotted on the last of the averaged years. Note that 2017 averages are preliminary 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 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 in other, upwind areas 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 forests. Therefore, 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

FEMC Project Database Links

Ambient Air Monitoring for Ozone:
https://www.uvm.edu/femc/data/archive/project/ambient-air-monitoring-for-ozone

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

Climate

The FEMC Meteorological Monitoring Network

The FEMC 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 Forest Ecosystem Monitoring Cooperative (FEMC) has been monitoring weather conditions in Vermont for over 20 years. FEMC 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. To add temporal and spatial depth to our summary FEMC expanded the climate summary for 2016 beyond the FEMC monitoring stations in Vermont to include trends from the surrounding 11 states (Maine, New Hampshire, New York, Massachusetts, Connecticut, Rhode Island, New Jersey, Pennsylvania, West Virginia, Delaware, and Maryland) using records from the Northeast Regional Climate Center (NRCC) at Cornell University. This regional summary provides a broader picture of emerging trends across a larger region. Much of the following regional summary is adapted from the NRCC annual summary with permission (link to NRCC summary in additional resources).

The Data

Continuous meteorological observations are taken at seven FEMC 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 FEMC began operation in the early to mid- 1990s.

2016 Vermont Summary

Overall, 2016 was the fifth warmest year on record for Vermont, with above-normal average temperatures recorded at the Mount Mansfield weather station in all months except April and December (Table 5).

Table 5. Monthly average deviations from long-term normal for mean, min and maximum temperatures at Mt. Mansfield in 2016. Red indicates warmer than normal months and blue indicates colder than normal months. Units are standard deviations from norms.

Month	Max Temp	Min Temp	Mean Temp
January	0.93	0.94	0.98
February	1.02	0.32	0.68
March	1.25	0.64	0.95
April	-0.22	-1.44	-0.83
May	0.48	0.28	0.38
June	0.40	0.29	0.39
July	1.18	0.61	0.94
August	1.91	1.92	1.90
September	1.39	1.11	1.32
October	0.63	0.67	0.68
November	1.20	0.72	0.98
December	-0.21	0.19	-0.02

The annual statewide average temperature was approximately 2°F above the average for the last 30 years, and slightly higher than the predicted value based on the last 30 years of record keeping (Figure 17).

The highest temperature recorded in 2016 was at the Passumpsic station, which saw 100°F on August 12, 2016. The Passumpsic station also observed the highest annual average temperature of 52.8°F. The lowest temperature in 2016 was recorded at the Mount Mansfield station, which saw -32°F on February 14, 2016. The lowest high (*i.e.* most temperate summer) temperature of 76°F and the lowest annual average of 37.3°F were also observed on Mount Mansfield, while the highest low (*i.e.* most temperate winter) temperature was in Waitsfield, which observed an annual low temperature of -8°F. Superlative temperatures across the state are mapped across Vermont in Figure 16.

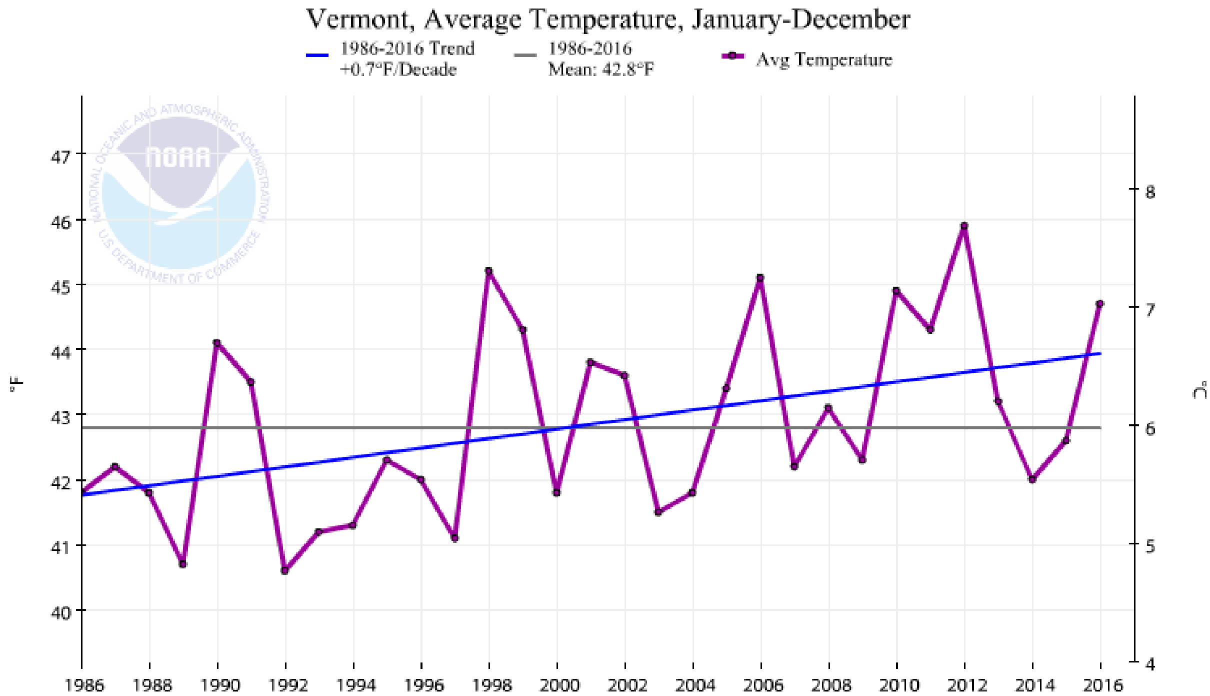

Figure 17. Annual average temperature history, with long-term average and 30-year trend. Figure credit: NOAA National Centers for Environmental information, Climate at a Glance: U.S. Time Series, Average Temperature, published November 2017 (http://www.ncdc.noaa).

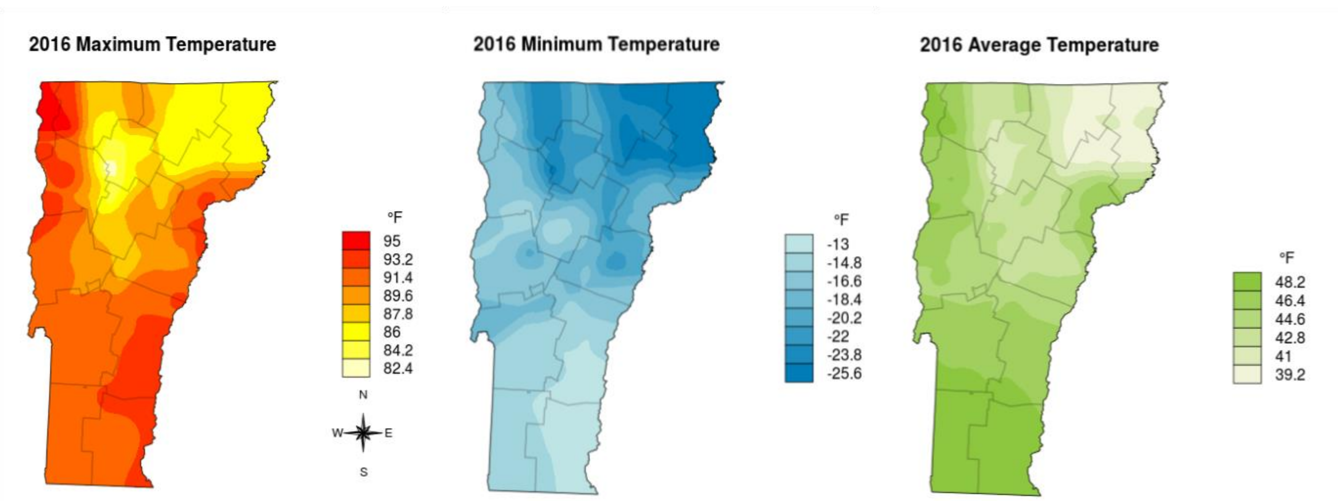

Figure 16. Annual maximum, minimum, and average temperature across the state based on data from 33 weather stations.

2016 Regional Summary

Temperature

The climate pattern in the Northeast during 2016 is generally one of warmer than normal temperatures with extreme local precipitation events. Most areas emerged from a warm winter to a hotter than normal summer; for many areas in the Northeast, this meant drought conditions, while for other areas in the Northeast there were periods of extreme flooding. The end of 2016 appeared to be another warmer than normal winter. Although there were local extreme snow events, the winter did not follow a single trajectory across the region.

The twelve states of the Northeast had their third warmest year on record in 2016. The region's average temperature was 49.3°F, which was 2.1°F above normal (Table 6). All twelve states ranked 2016 among their top seven warmest years on record.

Table 6. Average annual temperature in 2016 for the 12 states in the Northeast (°F). Table credit: NOAA, Northeast Regional Climate Center at Cornell University (http://www.nrcc.cornell.edu/regional/narrative/narrative.html)

State	Average	Departure	Rank	Coolest	Warmest
Connecticut	51.7	2.4	121	44.3 in 1904	52.5 in 2012
Delaware	57.2	1.8	118	50.9 in 1904	58.5 in 2012
Maine	43.2	1.9	117	36.5 in 1904	44.6 in 2010
Maryland	56.5	1.7	119	50.6 in 1904	57.5 in 2012
Massachusetts	50.3	2.2	119	43.3 in 1904	51.4 in 2012
New Hampshire	45.7	2.2	118	38.8 in 1904	46.6 in 2012
New Jersey	54.9	2.0	119	47.8 in 1904	55.9 in 2012
New York	47.6	2.1	120	41.1 in 1917	48.8 in 2012
Pennsylvania	50.9	2.0	120	45.2 in 1917	51.8 in 2012+
Rhode Island	52.2	2.2	121	44.8 in 1904	52.9 in 2012
Vermont	44.7	2.2	118	37.6 in 1904	45.9 in 2012
West Virginia	54.1	2.0	119	48.8 in 1917	54.3 in 2012+
Northeast	49.3	2.0	120	43.1 in 1917	50.2 in 2012

Rankings are for the 122 years between 1895 and 2016. 1=coolest; 122=warmest.
Departures are calculated using the 1981-2010 normals.
+ indicates extreme also occurred in one ore more previous years.

The year started with a warmer than normal winter: winter 2015-16 was the second warmest on record for the Northeast with an average temperature of 31.4°F, 5.4°F above normal. The six New England states each had a record warm winter, while New Jersey and New York both had their second warmest winters. East-central New York had record low snowfall, while deep snow from a single blizzard event fell along the southern New England coast in late January.

In the spring, arctic inputs led to frigid temperatures, particularly in New York and New England in early April. On April 4 and 5, temperatures were up to 30°F below normal, with a few sites having their all-time coldest April temperature on record. The cold spell significantly damaged some fruit crops that had budded early.

Warmer than normal temperatures returned for the summer months. The entire Northeast had its warmest August on record with an average temperature of 71.8°F, 3.7°F above normal. September was the third warmest on record with an average temperature of 64.5°F, 3.9°F above normal. The warm summer was followed by the third warmest autumn on record with an average temperature of 52.8°F, 2.9°F above normal. West Virginia had its second warmest autumn on record, while Delaware, Maine, Maryland, Pennsylvania, and Rhode Island had their third warmest.

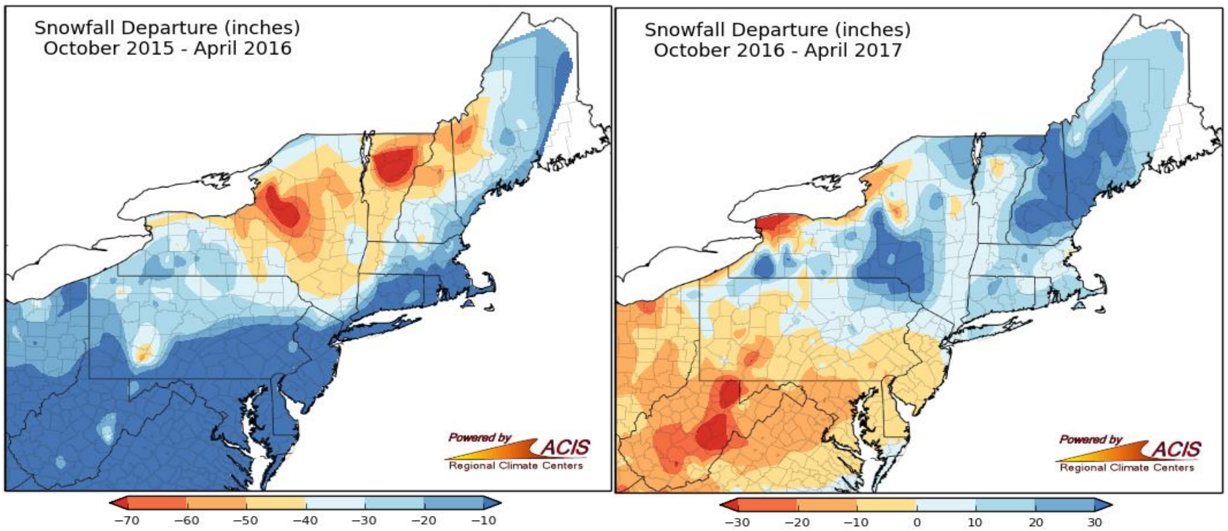

Figure 18. Regional snowfall departure from long-term normal for the winters at the beginning and end of 2016. The winter going into 2016 was short on snow across the region, while the winter at the end of 2016 saw more snow fall in the northeast and less snowfall in the southwest of the region. Note the different scales in the two maps. Figure credit: NOAA, Northeast Regional Climate Center at Cornell University (http://www.nrcc.cornell.edu/regional/monthly/monthly.html)

Rainfall

The Northeast wrapped up 2016 with 40.32 inches of precipitation, 91 percent of the long term normal (Figure 18). Ten states were drier than normal, while West Virginia and Delaware were at 101 percent and 106 percent of normal, respectively. It was the third wettest September on record for Delaware and portions of southern West Virginia and central Maryland had 1,000-year flooding events, meaning rainfall of that magnitude has a 0.1% chance of occurring in a given year.

Below-normal precipitation and above-normal temperatures contributed to intensifying drought conditions in 2016 (Figure 19). In August, extreme drought was introduced in parts of New York and New England for the first time since Drought Monitor data began in 2000. From mid-October through mid-December, more than half of the Northeast was in a drought. Seven Northeast states had drought advisories, watches, or warnings in place, some for the first time in more than a decade. Streamflow was also at record or near record low levels, increasing the rate of fish kills in some areas and causing some states to close portions of several waterways to fishing to protect stressed fish. The agriculture industry also suffered, with farmers in many drought-stricken counties becoming eligible for federal assistance. The dry conditions also contributed to increased fire activity and made wildfires more difficult to control.

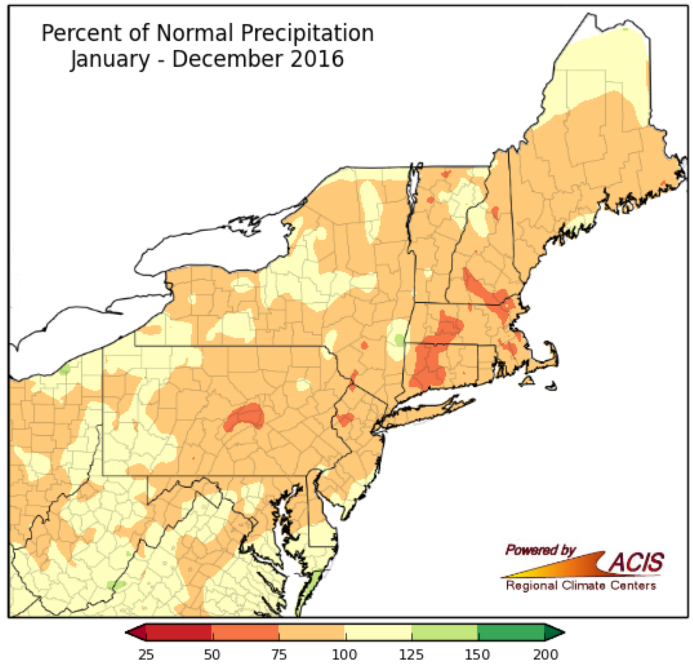

Figure 19. Across the 12 state region, the northeast saw below-average precipitation in 2016. Figure credit: NOAA, Northeast Regional Climate Center at Cornell University (http://www.nrcc.cornell.edu/regional/monthly/monthly.html)

Implications

While climate variability is high, both temporally and spatially, meteorological measurements witnessed across the Northeast are in agreement with local 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 will likely impact forested ecosystems the most in the near future. 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 2016 are 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).

Acknowledgements:
A special thank you to NOAA and the Northeast Regional Climate Center at Cornell University for the generous use of their regional data and their generous permission to adapt the regional climate summary.

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).

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Additional Resources

Vermont State Climatologist: http://www.uvm.edu/~vtstclim/
Northeast Regional Climate Center (NRCC): http://www.nrcc.cornell.edu/
NRCC Data Online: http://climod2.nrcc.cornell.edu/
NOAA Climate At A Glance: https://www.ncdc.noaa.gov/cag/time-series/

FEMC Project Database Links

Burton Island meteorological monitoring
https://www.uvm.edu/femc/data/archive/project/burton-island-meteorological-monitoring

Colchester Reef meteorological monitoring
https://www.uvm.edu/femc/data/archive/project/colchester-reef-meteorological-monitoring-38-m

Diamond Island meteorological monitoring
https://www.uvm.edu/femc/data/archive/project/diamond-island-meteorological-monitoring

Mount Mansfield east slope mid elevation forest meteorological monitoring
https://www.uvm.edu/femc/data/archive/project/mt-mansfield-east-slope-mid-elevation

Mount Mansfield summit meteorology
https://www.uvm.edu/femc/data/archive/project/mount-mansfield-summit-meteorology

Mount Mansfield west slope mid elevation forest meteorological monitoring
https://www.uvm.edu/femc/data/archive/project/mt-mansfield-west-slope-mid-elevation

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 2016 at three stations on the West Branch and two stations on Ranch Brook. Trout population surveys consisted of multiple run sampling with a 500-volt DC streamside 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 as one and yearling (1) and older fish (1++) combined as the other, 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 (Table 7).

Table 7. Population estimate of brook trout per each age class (YOY combined with yearling (1) and older fish (1++) per mile of each monitoring station.

Brook Trout	Ranch 1200'	Ranch 960'	West Branch 1550'	West Branch 1440'	West Branch 1410'
YOY/mile	1250	1309	600	1181	824
1++/mile	1660	987	780	1647	1690
Lbs/acre	18.3	10.6	19.9	20.4	24.5

2016 in Summary

Natural reproduction of brook trout continued to increase at the two Ranch Brook stations in 2016, but at the three stations in the West Branch reproduction declined relative to 2015. At the lower two West Branch stations the yoy counted per mile remained above the 2014 counts despite the decline, and at the highest elevation West Branch station the 2016 count was the lowest observed since 2006. Overall reproduction was down nearly 16% from 2015. (Figure 20). Yearling and older brook trout, however, increased at all five stations an average of 120% in 2016 (Figure 21). Population estimates for both yoy and yearling and older brook trout remained within the range observed over the 20 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

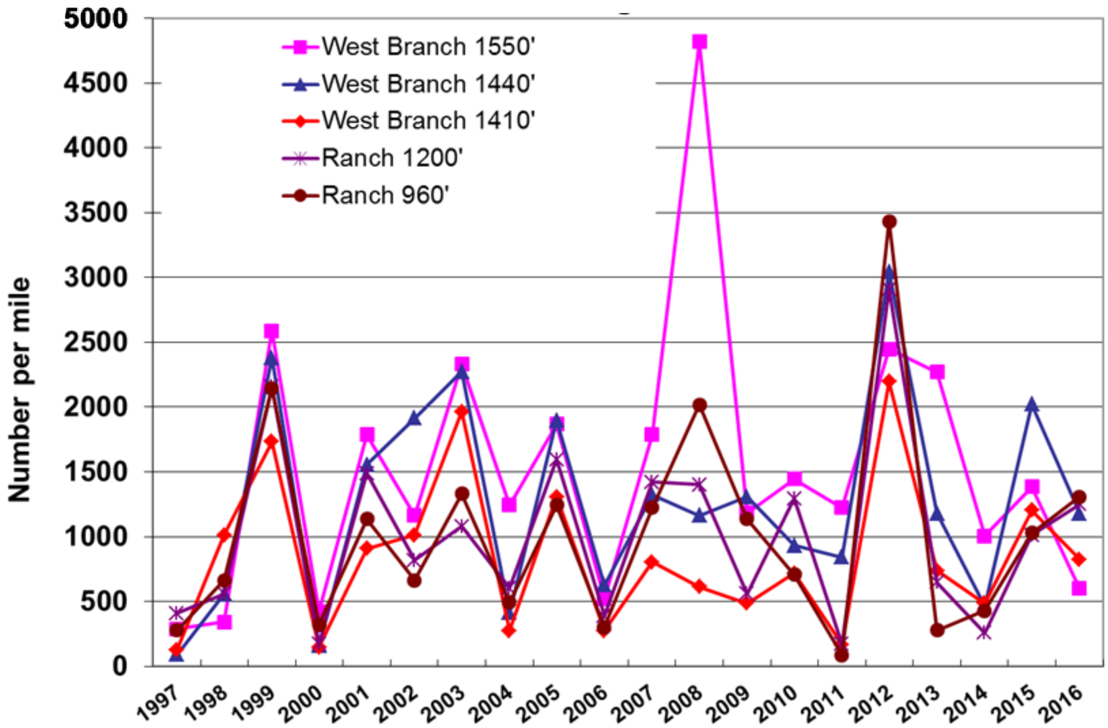

Figure 20. Vermont Department of Fish and Wildlife trout surveys: Young of year (yoy) expressed as number per mile, from 1997 through 2016.

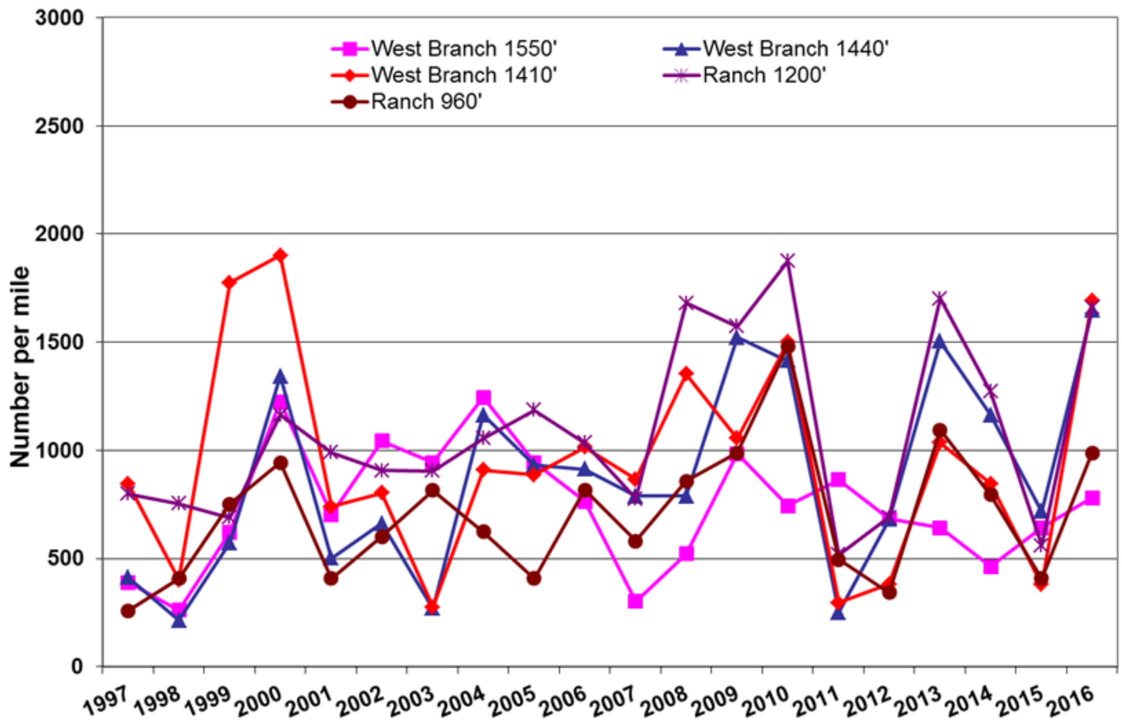

Figure 21. Vermont Department of Fish and Wildlife trout surveys: Yearlings and older fish, expressed as number per mile, from 1997 through 2016.

trout declines observed in some stations but these populations rebounded to above average levels by 2013.

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.

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Additional Resources

FEMC Project Database Links

Wild Brook Trout Monitoring in the West Branch of the Little River and Ranch Brook
https://www.uvm.edu/femc/data/archive/project/Wild-Brook-Trout-Monitoring-in-the-west-Branch-of-the-little-river-and-ranch-brook

Forest Birds

Breeding Bird Surveys

Vermont Center for Ecostudies volunteer checks for ectoparasites as part of the metrics gathered during banding.

In 2016, the Vermont Center for Ecostudies (VCE) continued demographic monitoring of Bicknell's Thrush *(Catharus bicknelli)*, Swainson's Thrush *(C. ustulatus)*, Blackpoll Warbler *(Setophaga striata)*, Yellow-rumped (Myrtle) Warbler *(S. coronata coronata)*, White-throated Sparrow *(Zonotrichia albicollis)*, and other songbirds, completing the 25th consecutive field season on the Mt. Mansfield ridgeline. VCE also continued long-term point counts of forest-interior breeding birds at two lower-elevation sites. This report presents a brief summary of data collected.

Also in 2016, VCE initiated a complementary study to monitor phenological mismatching between insectivorous songbirds and the arthropods upon which they feed. Birds, especially long-distance migrants, may be particularly vulnerable to this phenomenon. Their primary prey reach peak abundance earlier in warm years, but the annual cycle of birds is governed by photoperiod, which is unaffected by climate change. Birds may thus return from wintering grounds relatively late, miss the peak abundance of key prey species, and raise fewer young. Evidence that phenological mismatches are becoming widespread is meager. In 2016, VCE began to examine several key assumptions of this hypothesis on the Mount Mansfield ridgeline by monitoring the phenology of a mountain ecosystem at three trophic levels — plants, arthropods, and insectivorous birds — and to document how phenology is affected by local weather conditions, in order to provide insight into the link between climate and phenology.

Regular monitoring is essential to assess trends in species presence, species richness, population levels, and demographics. With the addition of phenological information, improved understanding can inform conservation strategies. Such information is critical to the protection of sensitive species, such as Bicknell's Thrush.

The Data

Mist-netting and banding were used to monitor breeding birds on an established study plot on the Mt. Mansfield ridgeline between c. 1155-1190 m elevation. On 20 days between 19 May and 14 September 2016, using 10-30 nylon mist nets (12 x 2.5-m and 6 x 2.5-m, 36-mm mesh) placed at sites that have been used annually since 1992. Nets were generally opened from late afternoon until dusk and from dawn until late morning on the following day. Individuals were fitted with U.S. Fish and Wildlife Service leg bands and data were recorded on age, sex, and breeding condition. VCE accumulated 2,172 net-hours in 2016, with a mean of 108.6 ±60 SD net-hours per day. A total of 512 captures included 392 individuals of 30 species, for a capture rate of 18 new birds/100 net-hours.

Breeding bird surveys were conducted at permanent study sites located on the west slope of Mt. Mansfield in Underhill State Park (UNSP) and at the Lye Brook Wilderness Area (LBWA), part of VCE's long-term Forest Bird Monitoring Program (FBMP) (Faccio et al. 1998, Faccio et al. 2017). Each 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. Both sites were sampled twice during the avian breeding season.

2016 in Summary

VCE recaptured 45 individuals that had been banded in a previous year. As usual, Bicknell's Thrush had the highest rate of return captures (37%), similar to that in previous years. Of the 52 Bicknell's Thrush captured, 16 were after second-year (ASY) males, 9 were second-year (SY, or yearling) males, 5 were ASY females, 6 were SY females, 1 was an adult bird of unknown sex, and 16 were hatching-year individuals of unknown sex. We collected blood samples from 59 Bicknell's Thrush and 30 Swainson's Thrush.

Point count surveys at the mid-elevation, northern hardwood study sites at Underhill State Park and Lye Brook Wilderness showed similar species composition, with a total of 50 and 48 species, respectively. The number of individual birds detected at UNSP in 2016 increased to above the 25-year average, and while species richness also increased, it remained slightly below average. At Lye Brook, both species richness and the number of individual birds detected increased to the second highest recorded in the count's 15-year history. Despite these increases, the long-term trends for both number of individuals and species richness have declined slightly at both sites (Figure 22).

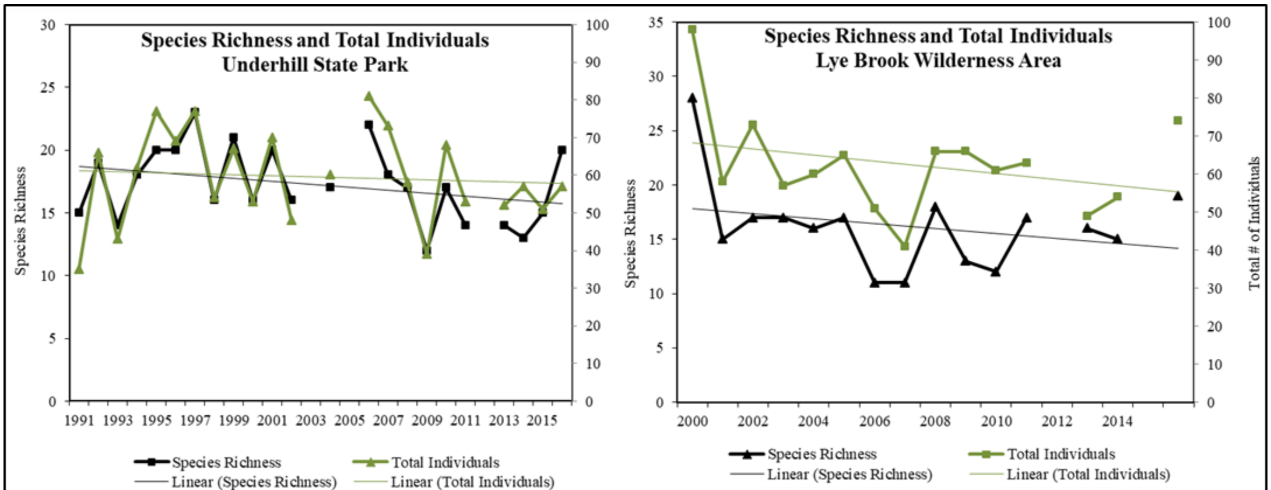

Figure 22. Annual totals and trends for species richness and total number of individuals detected at Underhill State Park, 1991 – 2016, and Lye Brook Wilderness Area, 2000-2016.

Long-term Trends

Mt. Mansfield Ridgeline – VCE has captured 316 adult Bicknell's Thrushes since 1992, 113 of these individuals in multiple years. The oldest known thrushes were a male and female, both aged as after-second-year when captured, making them at least 10 years old when last recaptured.

Underhill State Park – Total number of individuals and species richness increased from 2015, with 57 individuals of 20 species recorded, including a Ruby-crowned Kinglet and Yellow-bellied Flycatcher, both new for the survey. Among the nine most common species, only four were above the 25-year mean, and five were below. Overall, counts of Ovenbird and Black-throated Green Warbler increased; while the long-term trend for Hermit Thrush, the Vermont state bird, remained relatively flat (Figure 23). These results echo the broader, 25-year trends observed for these three species in the statewide Vermont FBMP dataset, in which both Black-throated Green

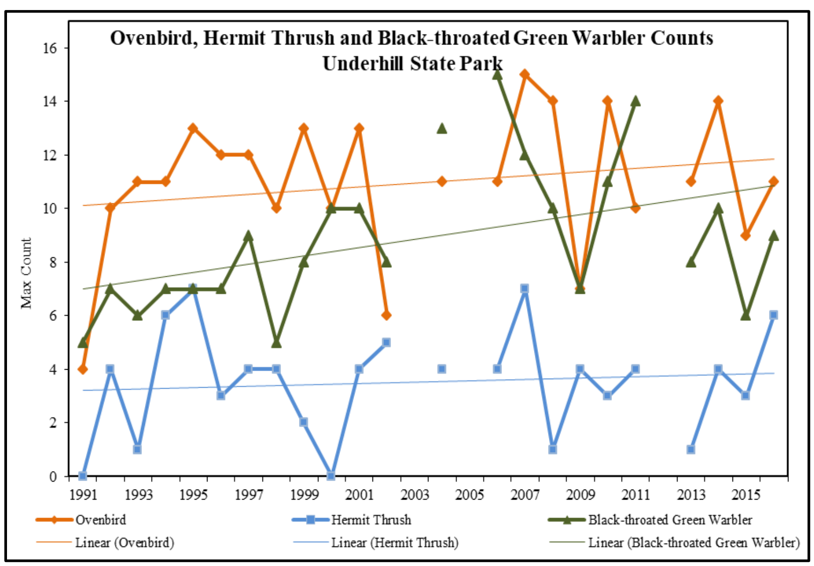

Figure 23. Twenty-five year data and trends for Ovenbird, Hermit Thrush, and Black-throated Green Warbler from annual surveys conducted at Underhill State Park, 1991-2016.

Warbler and Ovenbird significantly increased, while Hermit Thrush showed no trend (Faccio et al. 2017). A single Canada Warbler was detected in 2016, the first since 2013; this species is declining at a rate of 4.36% annually (r2=0.668), representing the sharpest decline among the nine most commonly detected species.

Lye Brook Wilderness Area – Both relative abundance (n=74) and species richness (n=19) increased to the second highest in the survey's history, and were both well above the 15-year means of 62.4 and 16.1, respectively. Among the eight most common species, all but Pileated Woodpecker were above the 15-year average; however, only Red-eyed Vireo, Yellow-bellied Sapsucker, and Black-throated Green Warbler exhibited increasing population trends. While numbers of Black-throated Blue Warbler increased for the second straight year from a record low of just three individuals in 2013, the species' long-term trend showed a moderate decline of -2.25% per year (r^2 = 0.227) (Figure 24). Counts of Red-eyed Vireo showed a strong upward trend (Figure 24), increasing by 8.76% annually (r^2 = 0.358), mirroring the significant statewide trend exhibited by VCE's 25-year study (Faccio et al. 2017).

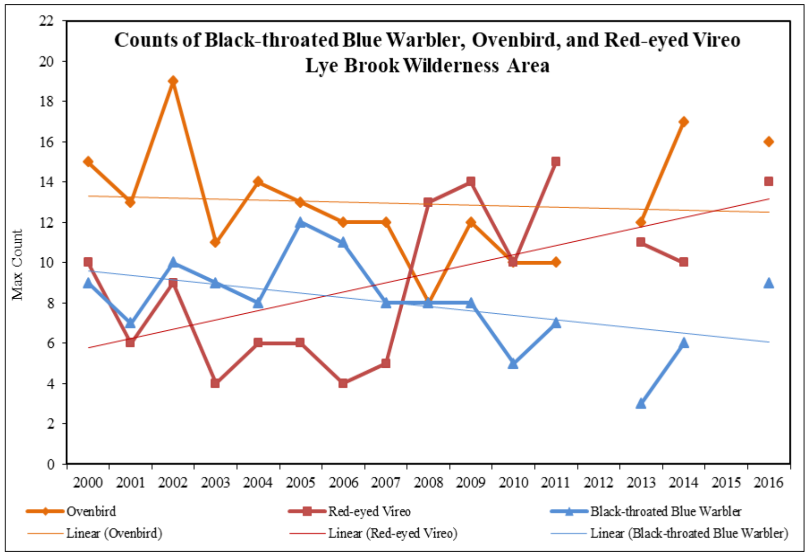

Figure 24. Twenty-five year data and trends for Black-throated Blue Warbler, Ovenbird, and Red-eyed Vireo from annual surveys conducted at Lye Brook Wilderness area, 2000-2016.

Implications

VCE's 2016 banding results reconfirmed the male-biased sex ratio of adult Bicknell's Thrush consistently documented over the 25 years of this study, with a 2.2:1 male: female ratio. Complementary research on the species' Hispaniolan winter range suggests that sexual habitat segregation may limit survivorship of females (Townsend et al. 2011), leading to VCE's focus on conserving female-dominated habitats on the wintering grounds. Analyses of VCE's Bicknell's Thrush banding data from Mt. Mansfield are currently underway to determine factors that drive annual survivorship in this species.

Long-term trends of forest birds at both UNSP and LBWA suggest that the relative abundance of the total number of birds detected has declined slightly over the survey period. However, it should be noted that site-specific trend estimates must be interpreted with caution, as these data are from a limited geographic sample and can be greatly influenced by years with extreme high or low counts.

Not surprisingly, most of the strongest population trends observed at both study sites—including the increasing trends of Black-throated Green Warbler at UNSP and Red-eyed Vireo at LBWA, and the declining trend of Canada Warbler at UNSP—reflect the broader state-wide trends for these species during the 25-year study of the Vermont Forest Bird Monitoring Program (Faccio et al. 2017).

The phenology study initiated by VCE in 2016 will shed light on the impact of climate change on migratory birds but they still face challenges from other anthropogenic stressors. Among these are habitat degradation and loss due to development, land use change, acid precipitation and other atmospheric pollutants. In addition, migratory species, whether short-distance or long-distance Neotropical migrants, have declined across Vermont forests, while year-round residents showed no trend (Faccio et al. 2017). This suggests that migratory species face additional limiting factors, both on their wintering grounds and during migratory stopover that could be impacting populations. Continued data collection and comparison with survey data from other ecologically similar sites will be necessary to fully elucidate population trends of various species at these sites.

Conservation groups are mobilizing knowledge to increase the Bicknell's Thrush population across its migratory range. Land management, local conservation of critical habitats, controls on pollution, and the recognition that this species is a bellwether of climate change lend hope of a brighter future for this intriguing, but globally vulnerable songbird.

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Additional Resources

For more information on Bicknell's Thrush and changing phenology, please visit: https://vtecostudies.org/blog/the-mount-mansfield-phenology-project

FEMC Project Database Links

Forest Bird Surveys: https://www.uvm.edu/femc/data/archive/project/forest-bird-surveys

Amphibians

Amphibian Monitoring on Mt. Mansfield

Populations of the American Toad (Anaxyrus americanus) exhibit great annual variability

After an initial amphibian survey and establishment of monitoring protocols, populations of amphibian species have been monitored almost annually on Mount Mansfield since 1993. This monitoring has established baseline information of abundance for the species caught in drift-fences from which trends in abundance over time can be discerned. The monitoring also records changes in number and type of obvious external abnormalities as well as gathering inventory data for the Vermont Reptile and Amphibian Atlas, along with basic natural history on the species present. Amphibians are targeted for this kind of study because their multiple habitat usage and permeable skin make them especially sensitive to changes in environmental conditions and land use patterns. This is the longest-running set of amphibian monitoring data in the state.

The Data

Currently, drift fences are located at two elevations on the west slope of Mt. Mansfield: two at 1200 feet and one at 2200 feet. Amphibians that encounter a fence must turn to one side and many eventually fall into a bucket. Lids are removed from the buckets in the late afternoon on rainy days, and the captured amphibians identified and counted the following morning

Due to an anticipated break in the funding the drift fences were removed from Mt. Mansfield during the summer of 2015. Luckily, funding was restored, the fences were reinstalled in May of 2016 and data collection restarted in June of 2016.

Because the re-installation of fences occurred in the summer of 2016, no data were collected in April and May 2016. In order to be able to continue comparing year-to-year results we needed to have a full year of results, including a spring migration in April and May. We chose to include the data collected during April and May 2017, as it was the closest chronologically to the 2016 field season and encompasses one full year. For the rest of this report, when we refer to amphibian data collected in 2016 in the figures and tables, we are including those two months of data from 2017.

2016 in Summary

Eastern Newt (*Notophthalmus viridescens*)

The big news from this data set is that adult Spring Peeper captures were way up from 2014 (the last year that comparable data were collected from Mt. Mansfield). Although the long-term trend has not turned around yet, the increased number of adult Spring Peepers caught during the 2016/17 monitoring (mostly in early 2017) may signal the beginning of a recovery.

In 2016/17, all the usual caudate (salamander) species were caught as adults, including Spring Salamanders (*Gyrinophilus porphyriticus*). Young of all of these salamander species except Northern Dusky (*Desmognathus fuscus*) and Spring Salamanders were also caught.

In 2016/17, all adult anurans (frogs) were found, but no young American Toads (*Anaxyrus americanus*), Pickerel Frogs (*Lithobates palustris*) or Gray Treefrogs (*Hyla versicolor*) were found. Only one juvenile Spring Peeper (*Pseudacris crucifer*) was detected, and none were detected during the 2014 field season.

Table 8. Monitoring results from drift fences on Mt. Mansfield in 2016-17.

Common name	Scientific name	#of all ages	#of young of the year	% young of the year
Caudates (Salamanders)				
Spotted salamander	*Ambystoma maculatum*	26	11	42%
N. Dusky Salamander	*Desmognathus fuscus*	11	0	0%
N. Two-lined Salamander	*Eurycea bislineata*	14	3	21%
Spring Salamander	*Gyrinophilus porphyriticus*	4	0	0%
Eastern Newt	*Notophthalmus viridescens*	34	11	32%
E. Red- backed Salamander	*Plethodon cinereus*	138	2	1%
Group totals		227	27	12%
Anurans (Frogs)				
American Toad	*Anaxyrus americanus*	35	0	0%
Green Frog	*Lithobates clamitans*	6	2	33%
Pickerel Frog	*Lithobates palustris*	4	0	0%
Wood Frog	*Lithobates sylvaticus*	86	10	12%
Spring Peeper	*Pseudacris crucifer*	26	1	4%
Group totals		157	13	8%
Amphibian totals		384	40	10%

The American Toad (*Anaxyrus americanus*), the Wood Frog (*Lithobates sylvaticus*) and the Eastern Newt (*Notophthalmus viridescens*) exhibit great annual variability in populations, so declines in these species may be followed by a multi-year increase, and are not of concern, unless the decreases continue. Other species, such as the Pickerel Frog (*L. palustris*) and the Northern Two-lined Salamander (*Eurycea bislineata*), have too low sample sizes for accurate conclusions.

Among the other species monitored, the Spring Salamander (*Gyrinophilus porphyriticus*) count was up from the previous season but the Northern Dusky Salamander (*Desmognathus fuscus*) count was down. Both the Green Frog (*Lithobates clamitans*) and Red-backed Salamander (*Plethodon cinereus*) counts were down but the long-term trends for these species are still increasing.

No abnormal anurans were collected in this most recent data set. Since 1998, only 14 abnormal anurans have been captured at this site.

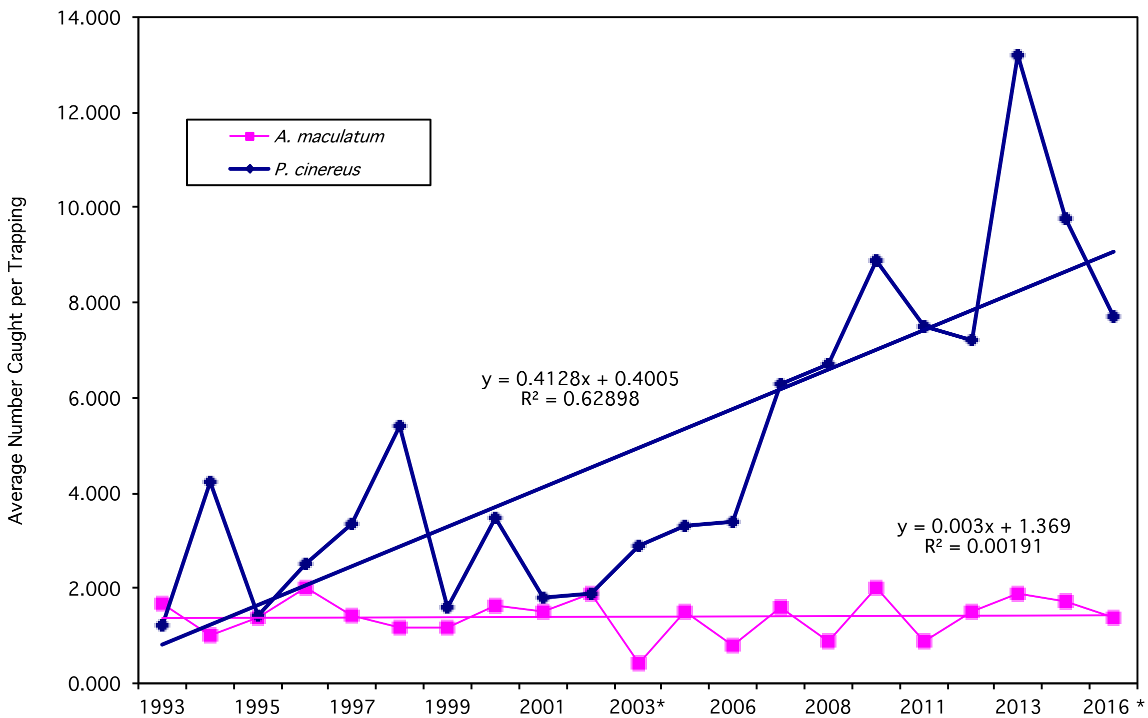


Figure 25. Spotted salamander (Ambystama maculatum) and Eastern Red-backed Salamander (Plethodon cinereus) population indices from Mt. Mansfield, Underhill, Vermont, 1993 – 2016.

Long Term Trends

Long-term trends in amphibian populations vary year to year and in protected habitat, amphibians can generally hold their own. The major threat to populations is habitat loss and fragmentation due to development. Climate change is also problematic causing annual cycles to be disrupted. A late frost or spring drought can significantly impair amphibian reproductive success. The Mt. Mansfield site is relatively undisturbed by development making it more useful for detecting changes caused by climate or other abiotic factors.

Over the length of the record, Wood Frog YOY showed a high in 2003 of 59% when Spotted Salamander YOY were also high at 50% during the same year. In contrast, Wood Frogs showed their lowest percentage of YOY in 2012 (4%) while Spotted Salamanders were at a high 40%. One possible difference is that Spotted Salamanders are more resistant than Wood Frogs to a variety of potentially threatening conditions such as predation, short-term draught, winterkill and late season freezes in their


Eastern Red-backed Salamander photographed on Mount Mansfield.

breeding ponds. The spring temperatures have varied a great deal in the past few years with some Wood Frogs moving at record early dates elsewhere in Vermont. This could result in fatal freezing temperatures after eggs were laid. Spotted Salamanders over-winter well below the frost line. In contrast, Wood Frogs freeze and thaw in the leaf litter and are very susceptible to winter kill if soil temperatures drop low enough. Another interesting correlation is that the increased annual variation of Spotted Salamanders began in 2002, the same year that Green Frog populations soared, Wood Frog populations peaked, and Eastern Red-backed Salamanders began their impressive increase. The different life histories of these species may provide some clues as to what is driving declines in Spring Peepers at the same time that we see long-term increases in other species such as Eastern Red-backed Salamanders.

The long-term monitoring studies of amphibians are very valuable due to their sensitivity to land use changes. These data may lead to answers of questions beyond amphibian natural history. In coming decades, newer challenges to the forest ecosystem may be identified by examining this record, which was originally started to assess the influence of certain pesticides on the environment.

Implications

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

Adult Spring Peeper captures in 2016/2017 surpassed those of 2014 showing potential recovery in light of long-term trends of decline.

Additional Resources

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

FEMC Project Database Link

Amphibian Monitoring at the Lye Brook Wilderness and Mount Mansfield https://www.uvm.edu/femc/data/archive/project/amphibian-monitoring-lye-brook-wilderness-mt

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 km²), elevation (33m – 585m) and geographical separation. Most 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 km² and an elevation of 378 m, it is one of the smallest and 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-tiered 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 (e.g. 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 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.

2016 in Summary

Figure 26 shows 2016 results for four of the eight metrics used to assess biological condition, as well as the overall assessment rating. Average macroinvertebrate density over two sampling events at Ranch Brook during the fall index period was 948 individuals per square meter, higher than Vermont DEC's minimum biological criteria for a healthy stream. This is within the range of other similarly sized reference streams, and comparable to the mean of other randomly sampled small high gradient streams throughout the state. This also shows a continued recovery in density for Ranch Brook, which has showed a depressed density for several years following flood flows in 2010 and 2011. Total taxa richness (41) was very high in 2016 compared to DEC's minimum criteria (27), and similar to reference and statewide averages. This pattern was also seen in the richness of pollution sensitive "EPT" (Ephemeroptera, Plecoptera, and Trichoptera) taxa.

A "functional feeding group" refers to one of several types of ecological feeding types to which a stream macroinvertebrate 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. A relatively high score (0.55) at Ranch Brook indicates similarity to a typical reference stream, and is well above DEC's minimum threshold of 0.40.

High values for these four metrics, as well as the other metrics evaluated by DEC, caused Ranch Brook to get a ratings of *"Very Good/Excellent"* and "*Excellent"* for the two sampling events in 2016, at and near the highest possible scores. 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.

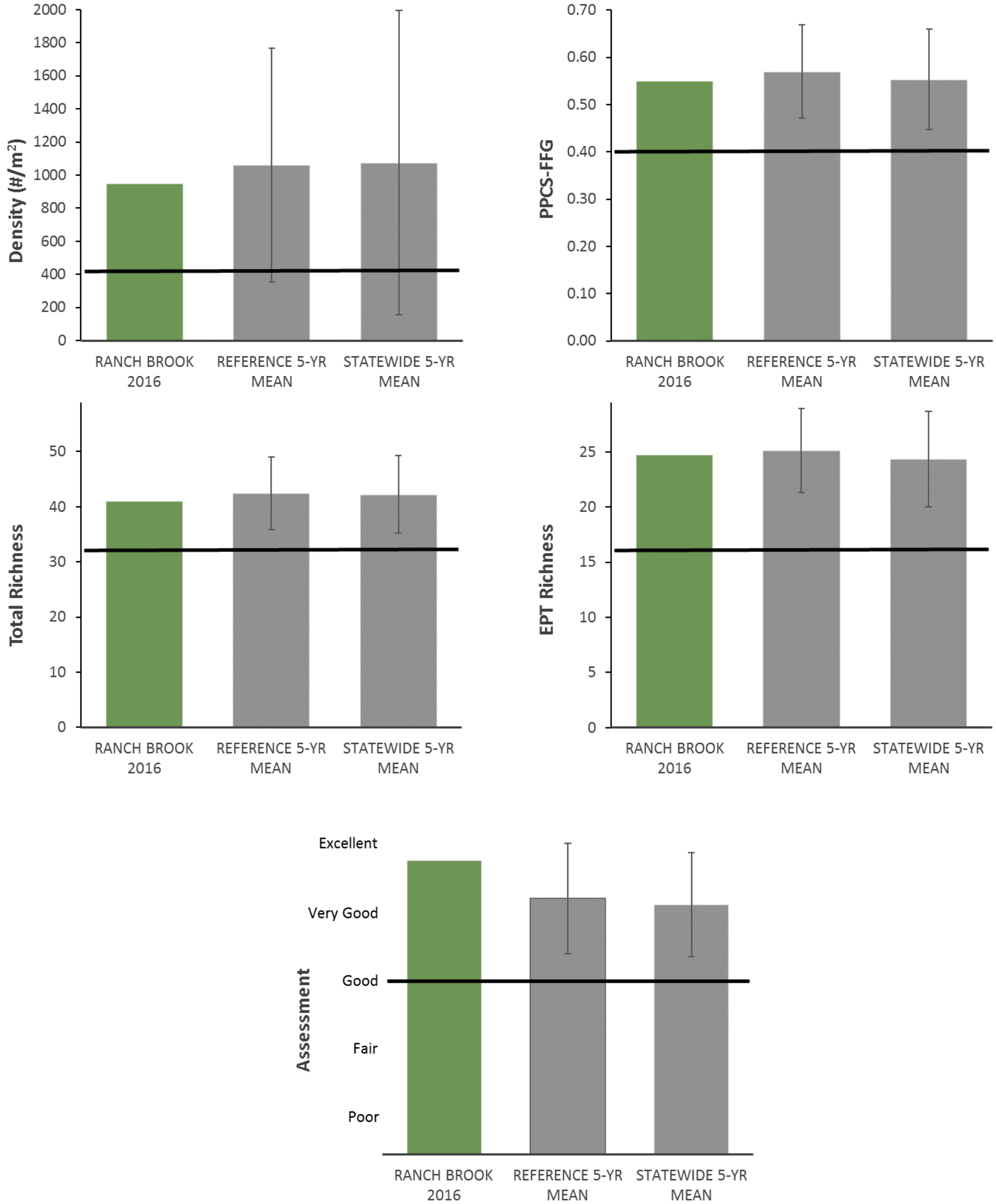


Figure 26. Scores for four biological metrics used to assess biological health, as well as overall assessment rating. Values at Ranch Brook are compared to averages at similarly sized streams from throughout the state, and at other reference sites (other sentinel and Green Mountain National Forest streams). The horizontal black bar represents DEC's minimum acceptable criteria.

Long Term Trends

Macroinvertebrate richness has remained very stable over time (Figure 27). 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.

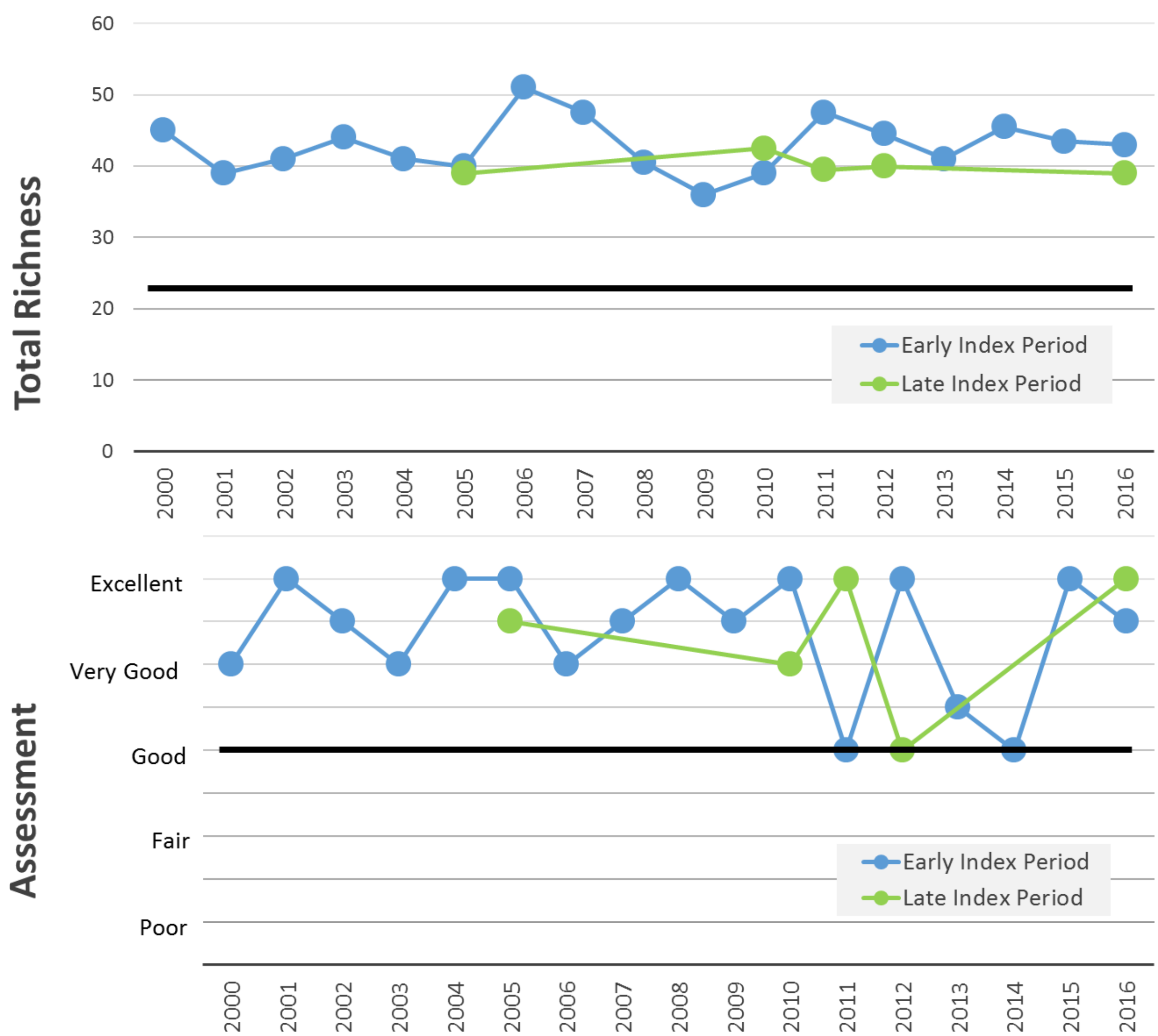


Figure 27. Long-term trends in macroinvertebrate richness and overall assessment rating. Two biological samples were collected in five different years, with these multiple sample collections typically separated by at least five weeks. The horizontal black bar represents DEC's minimum acceptable criteria.

In a previous 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 previous 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 in 2015 and 2016.

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 populations within the community change, it is necessary to analyze the raw data. Figure 28 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.

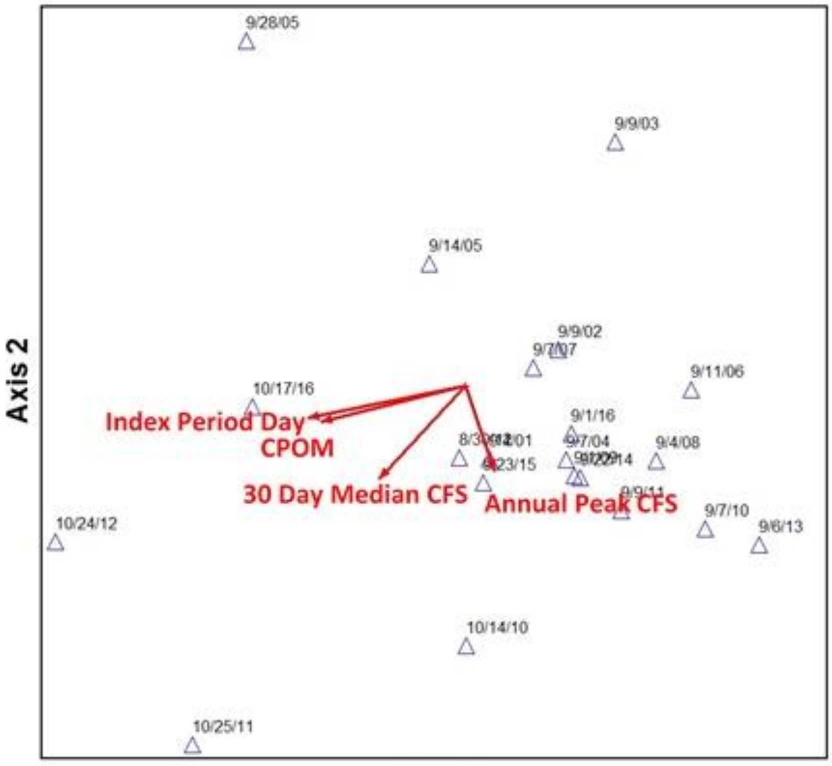


Figure 28. Canonical correspondence analysis (CCA) ordination plot. Biological samples are represented by triangles. Samples grouped near each other have more similar communities, and are shaped more strongly by the abiotic factors represented as red vectors.

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 of 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.

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.

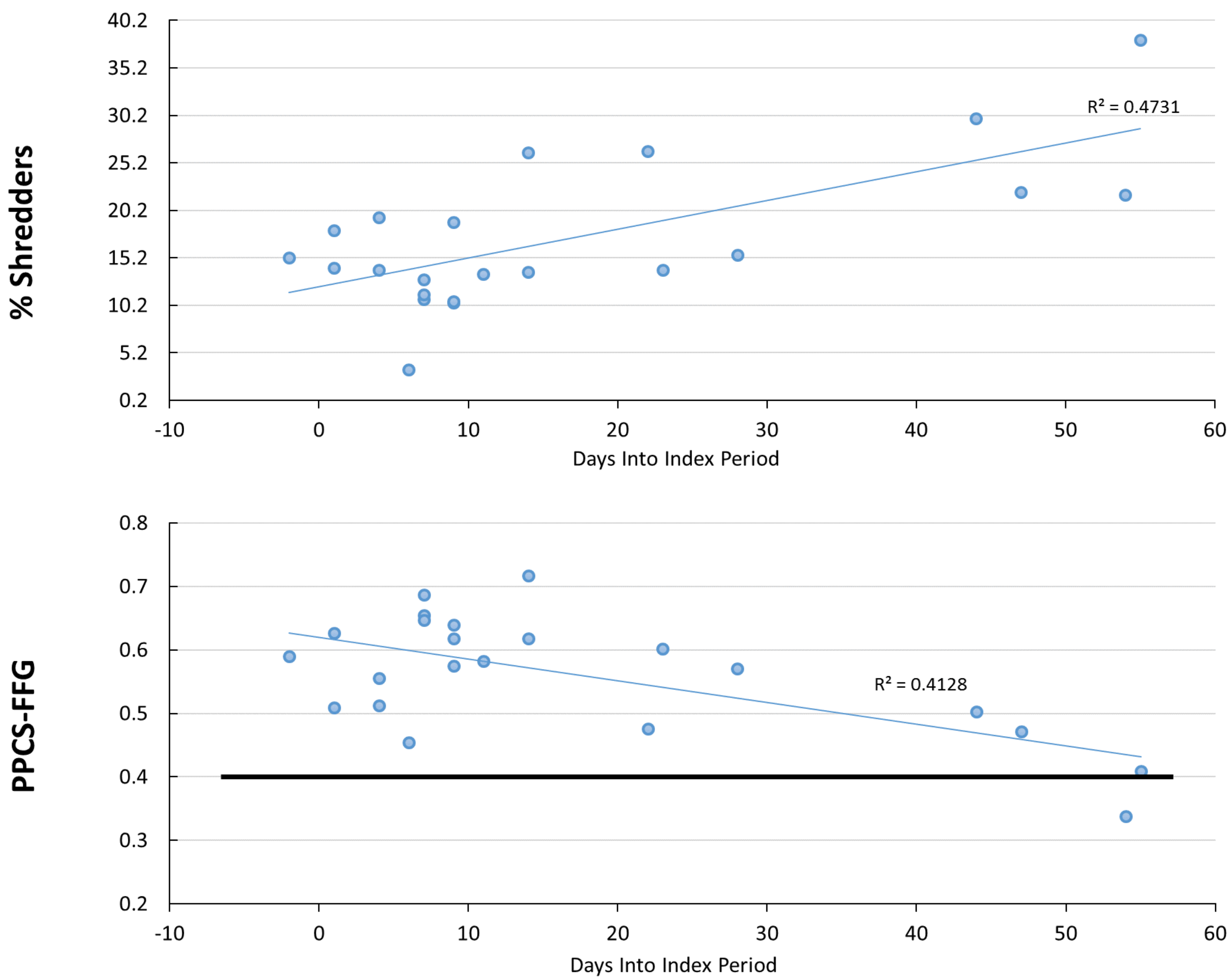


Figure 29. Relationship between functional feeding group variables and the number of days into DEC's fall index period that the biological sample was collected. PPCS-FFG is one of the eight metrics used to assess biological health, with the black line representing minimum acceptable criteria.

It 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 (Figure 29). This kind of seasonal community shift could confound our ability to fully understand how taxon populations are changing over longer periods because 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.

It appears that biological condition may have finally rebounded fully after relatively low flow years in 2015 and 2016.

Additional Resources

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

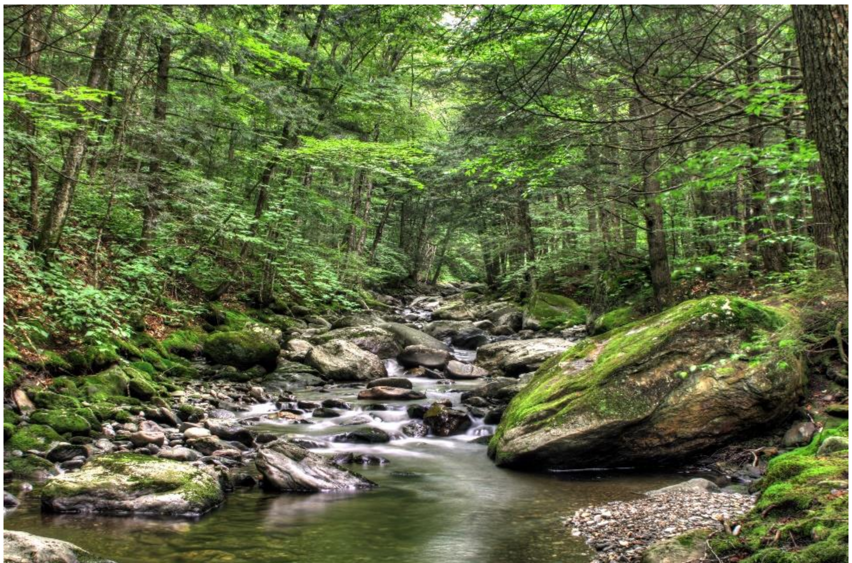
FEMC Project Database Link

Sentinel Stream Monitoring:
https://www.uvm.edu/femc/data/archive/project/sentinel-stream-monitoring

Watershed Hydrology

The Mt. Mansfield Paired Watersheds Study

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 km²) as the forested control watershed, and West Branch (11.7 km²) 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.


Ranch Brook near Stowe Mountain Resort has been monitored since 2000.

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) 2016 (October 2015 through September 2016). The report interprets the WY16 streamflow's in the context of the full 16-year record. Historic and near real-time flow data are available on the USGS website (links provided in Additional Resources).

In WY2016, the gages were jointly funded through a cooperative agreement between the USGS, the Vermont Department of Environmental Conservation and the Forest Ecosystem 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 the University of Vermont, Sterling College, Vermont Agency of Natural Resources, 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

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 provides a basis for monitoring of long-term hydrology patterns and water quality trends including: baseline conditions, trends in stream acid/base status, cations (Ca, K, Mg, Na, and 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 FEMC efforts including nutrient cycling, forest health assessments, forest fragmentation and biological monitoring.

Discharge vs. runoff

Streamflow, or discharge, is measured in volume per unit time – in the U.S., typically as cubic feet per second, or cfs (Figure 30). Throughout this report, we use 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 allowing runoff to 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.

2016 in Summary

Relative to the 16-year record, WY2016 had below average runoff for the third consecutive year. WY16 (start of water year is in October) featured a low runoff fall and winter, then an above normal spring due to a very steep warmup in March, then a very dry summer and early fall with droughty areas around the state by July and persisting into the fall. The dry conditions resulted in ground fires (where roots and organic matter catch fire) in Chittenden County, and in Lake Champlain, water levels were extremely low causing hazardous navigation in some areas.

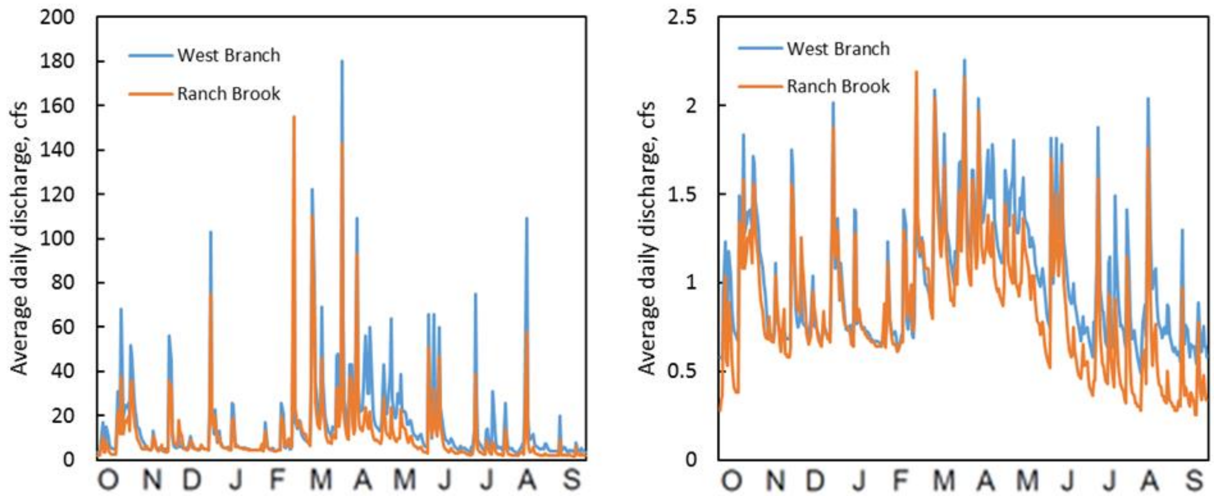


Figure 30. Streamflow at West Branch and Ranch Brook gages for Water Year 2016 (October 2015 through September 2016) in linear (left) and log (right) scales. The log scale plot highlights the higher sustained base flow levels at West Branch.

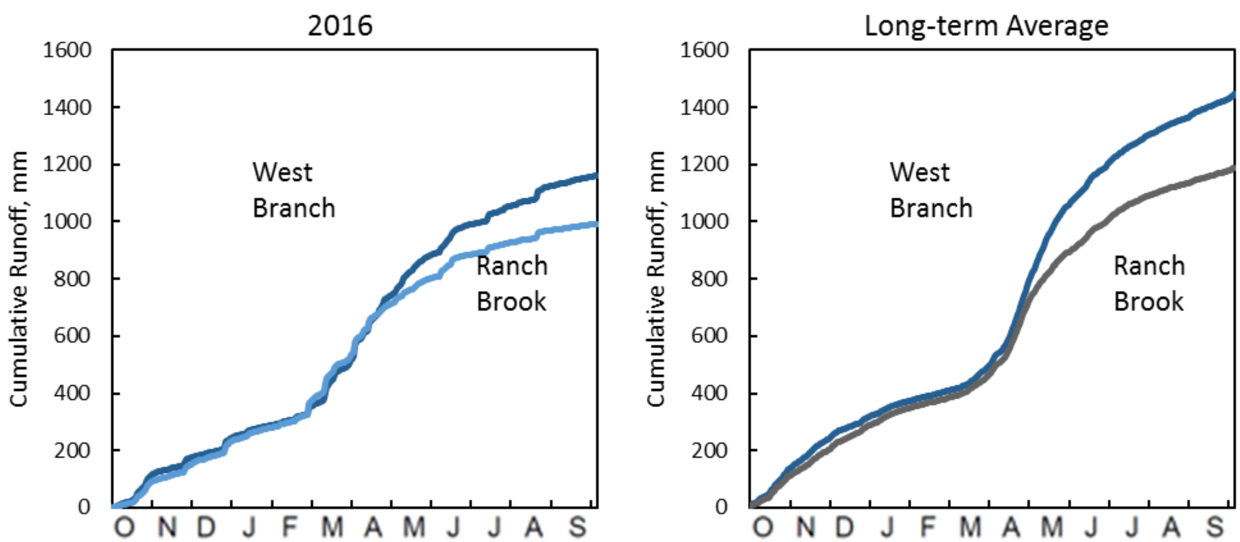


Figure 31. Cumulative runoff at both sites for Water Year 2016 (left) compared to long term (2000 -2016) averages at both sites (right).

Overall, runoff was less than the long-term average (Figure 32).

As in Water Year 2015, the cumulative runoff in Water Year 2016 ran below average for the most of the year except the spring when runoff was either at or slightly above the long-term (Figure 32). By May, both sites were well below the long-term average. Cumulative runoff at both sites continued to be well below average for the rest of the water year. The relative runoff patterns at the two sites in Water Year 2016 were similar to the long-term patterns (Figure 31), 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 comes 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 31).

The most notable aspect of WY 2016 at both sites was the lower cumulative runoff compared with the long term record. This time period also had consistently higer than normal temperatures (Burlington NWS data, link in additional resources) with the exception of October 2015, the start of the water year, and April 2016, where the monthly average temperatures were slightly below long-term normal temperature.

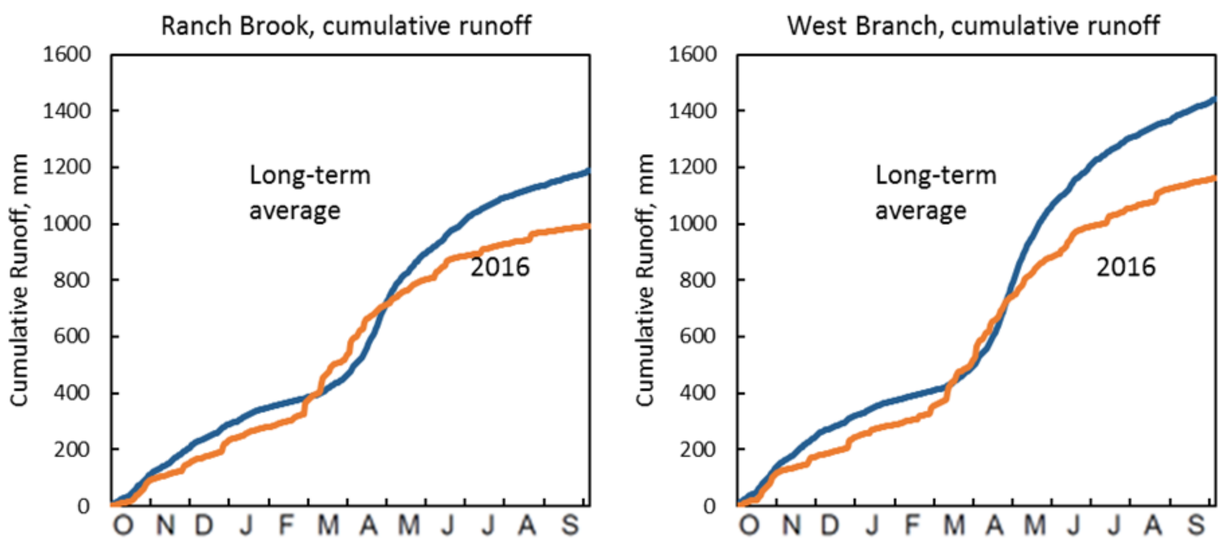


Figure 32. Cumulative runoff at West Branch and Ranch Brook based on the averages across the 16-year record (blue) and for Water Year 2016 only (orange).

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 33). Over the long-term, the average difference has been 21% greater runoff at West Branch. The Water Year 2015 differential was 17%, below the long-term average (Figure 33). 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 previous reports, we noted the extreme variability of large summer storms; these may preferentially impact West Branch. FEMC cooperators are currently investigating the role of local meteorology on the flow regimes.

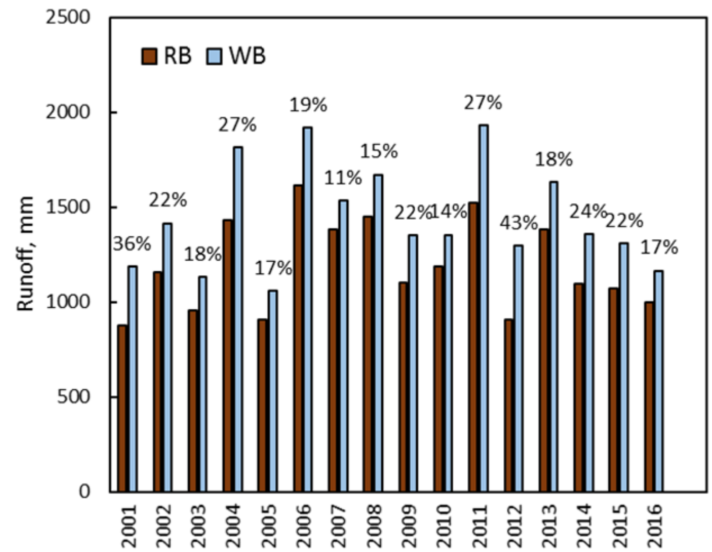


Figure 33. Annual runoff in millimeters at West Branch (WB) and Ranch Brook (RB) for the duration of study though the present report year. Percentage of greater runoff at WB relative to RB is given over each pair of bars.

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 34). 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.

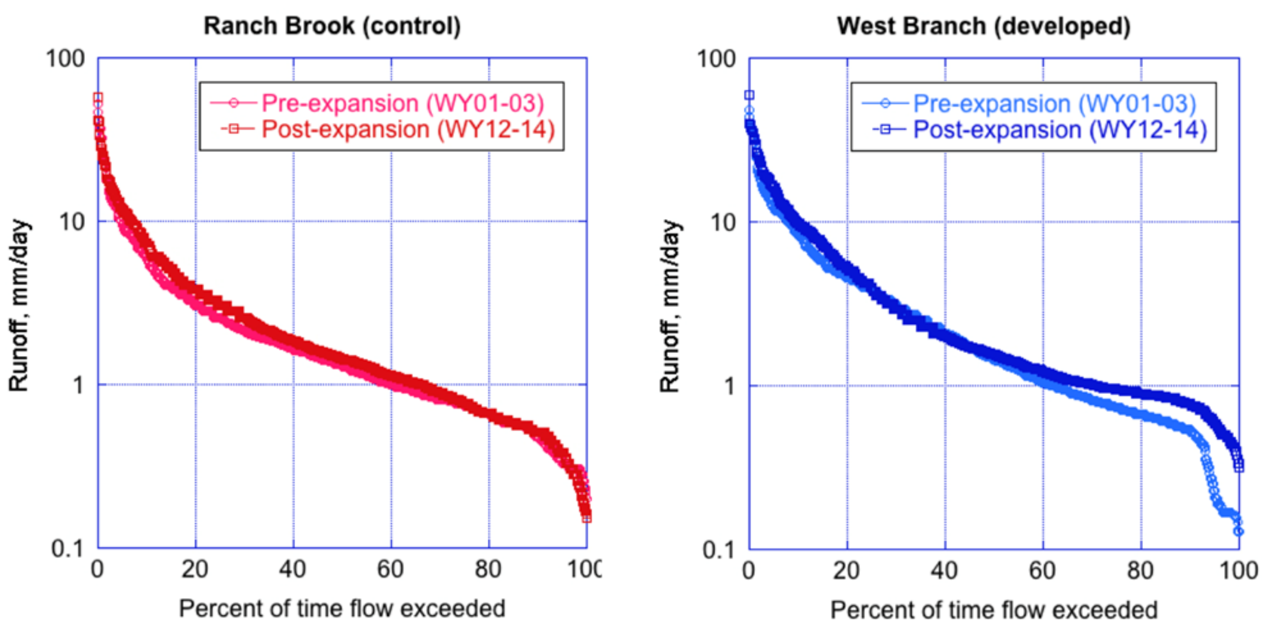


Figure 34. Flow duration curves for two three-year periods before and after the resort expansion, at Ranch Brook (left) and West Branch (right).

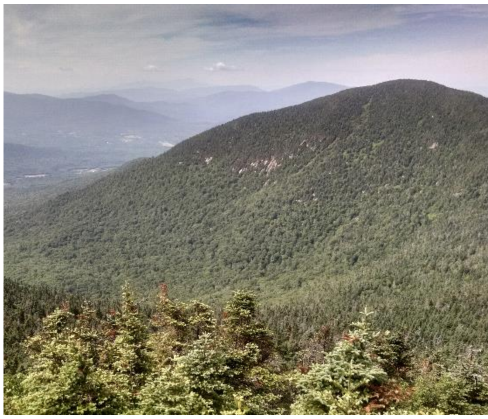
Implications

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 do not 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.

Mountain stream in Vermont, 2017

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 (drought conditions), whether naturally occurring or human induced (e.g. water for hotels and residences and snowmaking) 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 community's 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

Burlington National Weather Service data accessible at:

http://w2.weather.gov/climate/xmacis.php?wfo=btv

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.

FEMC Project Database Links

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

Water Quality

Water Quality from the Acid Lakes Monitoring Program

Acid rain was first detected as a serious environmental problem in the late 1960s. Emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_X) react with water, oxygen, and other chemicals in the atmosphere to form sulfuric and nitric acids. Resulting hydrogen ions in acid rain leach plant-necessary cations (e.g., calcium, magnesium, potassium, phosphorus) from the soil and into water bodies, and make toxic cations, like aluminum, more available. Such changes have been shown to negatively affect all levels of ecosystem health, from trees to soil microorganisms.

The Data

When high-elevation lakes in geologically sensitive areas were becoming acidified, the Environmental Protection Agency (EPA) enacted the Acid Lakes Monitoring Program, under the Long-Term Monitoring Program (LTM). In Vermont, collection is run by the Department of Environmental Conservation (DEC).

Water quality samples are collected three times a year (spring, summer, and fall). Measurements include pH, transparency, temperature, color, and concentrations of calcium, magnesium, sodium, potassium, aluminum, nitrate, sulfate, chloride and dissolved organic carbon (DOC). For most measurements, the methods of collection, processing, and analysis have remained consistent for nearly 30 years, providing long-term records water quality in VT and throughout the US.

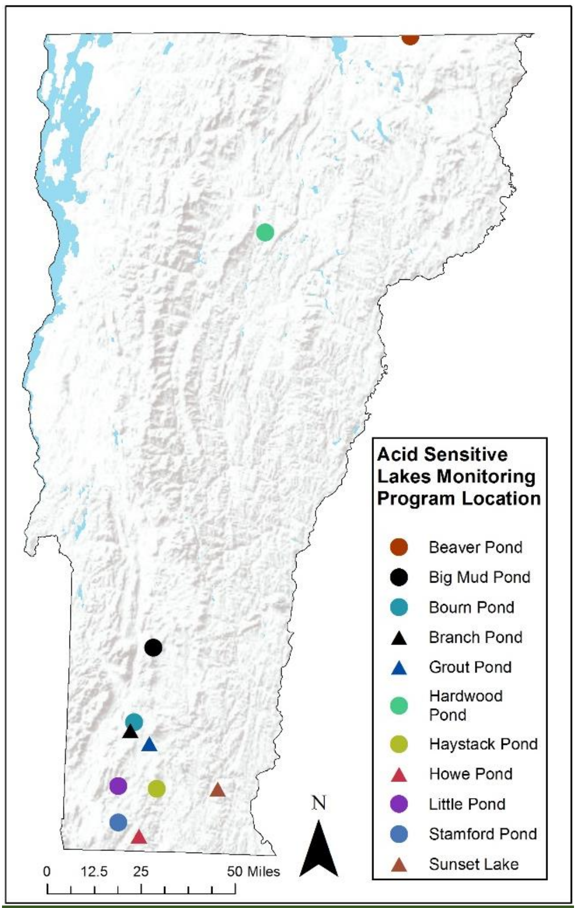


Figure 35. Locations of lakes/ponds in the Acid Lakes Monitoring program.

2016 in Summary

In 2016, we saw a range of values for water quality measurements in the 11 lakes and ponds in the Acid Lakes Monitoring Program (Figure 36) which reflects the variability in the different water bodies and in the parameters measured. For some, but not all, of the measured water quality parameters, average values among the 11 lakes improved from 2015.

Average pH was 5.94, which is slightly higher than the average value in 2015 (5.93), a sign of continued decreasing acidic inputs. Also a good indicator of improving water quality, dissolved aluminum decreased from 127.7 ug/L in 2015 to 93.5 ug/L in 2016 (Fig. 2).

Phosphorus concentration was about 12.6 ug/L, slightly lower than in 2015 when the average value was 13.5 ug/L. Dissolved organic carbon is a broad grouping of organic molecules resulting from decomposing organic matter. It is not only a food source for aquatic microorganisms, but is an indicator of terrestrial health. In 2016, the mean value (4.35 mg/L) declined from 2015 (4.76 mg/L).

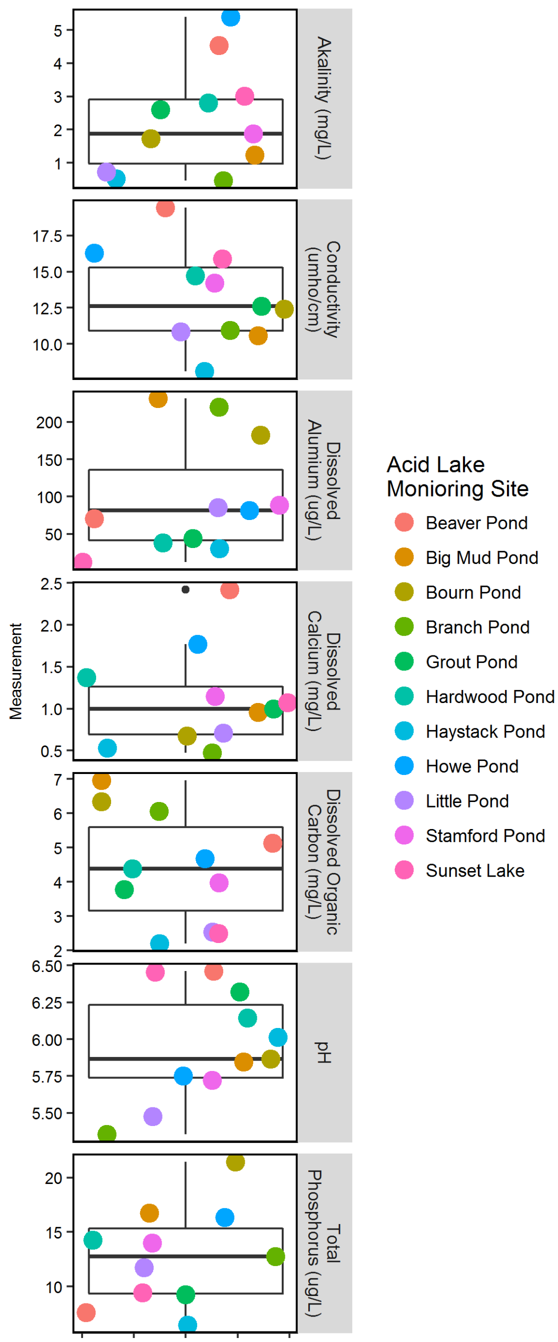


Figure 36. 2016 water quality measurements. Boxplot around points shows the mean (bold horizontal line) and extreme values (above or below horizontal lines on top/bottom of box). Colors correspond to the 11 acid lakes in the monitoring program.

Long-Term Trends

The data from the 11 lakes show evidence that acid accumulation and cation leaching has declined over the long-term record (1980-2016). Alkalinity and pH are both increasing over time (Figure 37). Concurrently, conductivity (a measure of the electrolyte concentration), dissolved aluminum, and dissolved calcium are decreasing.

Dissolved organic carbon has been increasing since it was first measured in the early 1990s, although there is more measurement variability among the 11 lakes for DOC compared to other measured variables, as indicated by the size of the confidence intervals around the average (Figure 37).

Phosphorus, which is easily transported in water, is an essential nutrient for all life; however, excessive concentrations can lead to algal blooms, as has been observed in Lake Champlain. Total phosphorus shows a varied pattern, but overall there is a decrease in concentration from a peak in 2008 (Figure 37).

Regional Context & Implications

Similar trends in pH and dissolved cations are evident across the region. These long-term data are proof of ecosystem recovery following the Clean Air Act and subsequent amendments, which have substantially reduced deposition of sulfur and nitrate – two components that react in the atmosphere to produce acid rain.

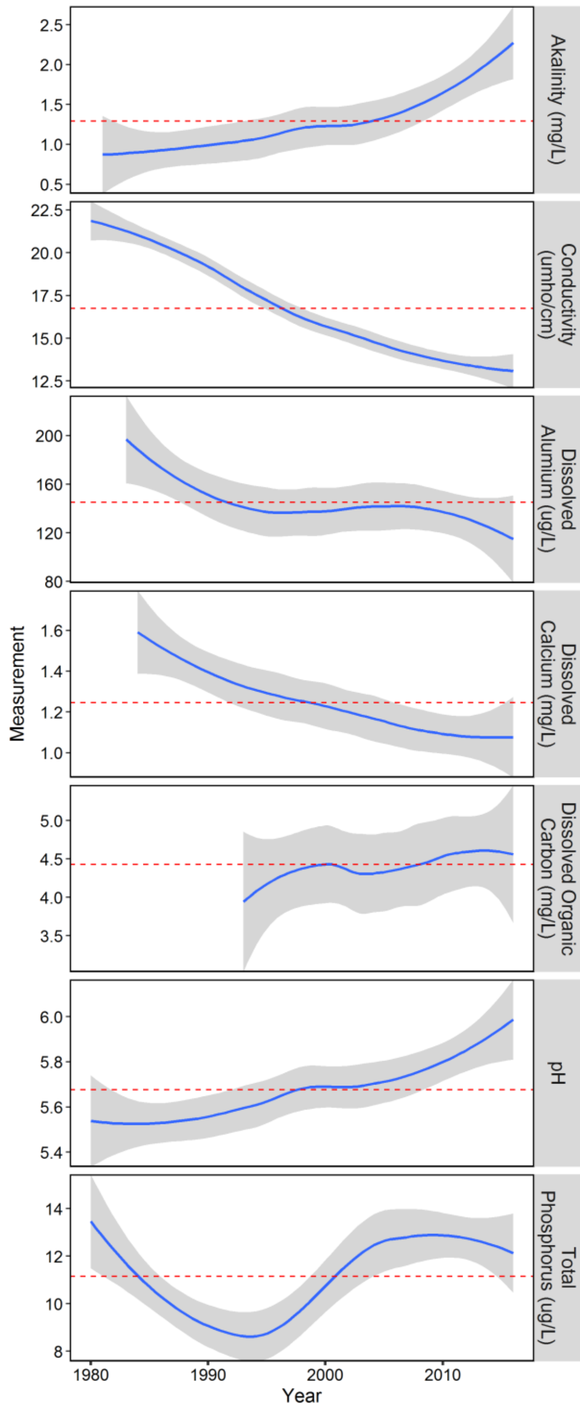


Figure 37. Average water quality measurements for 11 lakes/ponds in the VT Acid Lake Monitoring Program (blue line, smoothed with LOESS function), plus 95% confidence interval (grey shading). Red dashed line indicates the long-term average per measurement type.

As acid rain was first discovered in the mid-1960s, we lack records of water quality prior to acidification. As a result, it is uncertain what measurement values designate full ecosystem recovery. Further, acid rain has not completely vanished, as we are still seeing deposition of sulfur and nitrogen on the landscape. Despite this uncertainty, the relatively quick recovery of our lakes and ponds compared to values in the 1980s supports regulation to combat acidic pollutants and continued monitoring to help protect our valuable resources. Moving forward, as the threat of acid rain declines, other types of pollutants are becoming more problematic, such as phosphorus loading in our large water bodies.

Overall, the long-term data (1980-2016), provide support that vulnerable lakes and ponds in Vermont are recovering from decades of acid rain. Moving forward, phosphorus may become more problematic as acidic inputs decline

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Lawrence, G.B, J.E. Dukett, N. Houck, P. Snyder, and S. Capone. 2013. Increases in Dissolved Organic Carbon Accelerate Loss of Toxic Al in Adirondack Lakes

Recovering from Acidification. Environmental Science and Technolology. 47 (13): 7095–7100

Additional Resources

Vermont Department of Envrionmental Conservation. Vermont Integrated Watershed Information System. Accessible at https://anrweb.vt.gov/DEC/IWIS/

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

FEMC Project Database Links

Long Term Monitoring of Acid Sensitive Lakes https://www.uvm.edu/femc/data/archive/project/long-term-monitoring-acid-sensitive-lakes

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Intern Beth Romaker Measuring DBH. 2017. Photo by John Truong, FEMC.

LBA2300A Hemispherical Shot. 2016. Photo by FEMC.

Balsam fir forest. 2014. Photo by Alexandra Kosiba.

Aerial Detection Surveys Section

Forest Tent Caterpillar. 2016. Photo by John Truong, FEMC.

VT Forest Parks and Recreation. Aerial survey image.

Forest Phenology Section

Maple Leaves in the Fall. 2017. Photo by John Truong, FEMC.
Fall Colors. 2017. Photo by John Truong, FEMC.
Maple Leaf. 2017. Photo by John Truong, FEMC.

Acid Deposition Section

N-Con Precipitation collector. Photo by Miriam Pendleton, FEMC.

Dead alpine tree. Forest Ecosystem Monitoring Cooperative.

Mercury Deposition Section

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Rock Bass. 2016. Photo by John Truong, FEMC.

Ozone Section

Milkweed with ozone damage. Photo by Wisconsin Department of Natural Resources accessed from flickr (https://www.flickr.com/photos/widnr/6588144679/) and licensed under Creative Commons BY 4.0 license (http://creativecommons.org/licenses/by/4.0/).
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Climate Section

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A very cold wood frog, North Lincoln Street, Keene. Photo by Ashuelot Valley Environmental Observatory from flickr (https://www.flickr.com/photos/aveo/8552519499/) and licensed under Creative Commons BY 4.0 license (https://creativecommons.org/licenses/by-sa/4.0/).

Trout Section

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Eastern Brook Trout Held by Fly Fisherman Close-up 02. Photo by Chesapeake Bay Program accessed from Flickr (https://www.flickr.com/photos/29388462@N06/14649975757/) and licensed under Creative Commons BY 4.0 license (https://creativecommons.org/licenses/by-sa/4.0/).

Forest Birds Section

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Bicknell's Thrush Habitat. 2017. Photo by John Truong, FEMC.

Amphibians Section

American Toad. 2016. Photo by John Truong, FEMC.

Eastern Newt. 2017. Photo by Kelsey Hamm, FEMC.

Eastern Red-backed Salamander. 2017. Photo by Kelsey Hamm, FEMC.

Spring Peeper on finger. Photo by Erin Talmage, 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

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